Process analysis and experimental verification of compact JT cryocooler at liquid helium temperature region

A compact 4He Joule-Thomson (JT) cryocooler using two-stage Gifford-McMahon (GM) cooler as pre-cooling stages has been successfully designed and developed. The GM refrigerator cools the incoming helium gas to 91K at the first stage and 14K at the second stage. The JT system consists of three tube-in-tube heat exchangers (HEX), two spiral heat exchangers and a JT orifice. Experiments discussed in this paper are carried out in the two styles of open loop and closed cycle. A new JT compressor with single cylinder and check valves is used in the closed cycle to provide high pressure gas. The curves of throttling are given and the cooling power is measured. In open loop the no-load temperature of 3.4K and the cooling power of 30mW@4.5K are obtained, while in closed cycle 4.27K and 5mW@4.5K are obtained respectively. The optimum operating frequency of JT compressor is also investigated. The heat exchanger is verified to be efficient when the temperature at second stage of GM refrigerator is changed to 20K.

Primary author: Mr ZHOU, Zhenjun (Key Laboratory of Space Energy Conversion Technologies, Technical Institute of Physics and Chemistry)

Presenter: Mr ZHOU, Zhenjun (Key Laboratory of Space Energy Conversion Technologies, Technical Institute of Physics and Chemistry)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Testing of EAST high-temperature superconducting current leads

In order to reduce the heat load to liquid helium, totally 13 pairs of HTS current leads were used in EAST facility. This paper is focused on testing of the current leads. A test facility was set up and used to test the HTS current leads. A 500W/4.5K refrigerator was used to cool down the test system. The top side of the HTS current leads was cooled by LN2 and bottom side cooled by 4.5K supercritical helium. The current was ramped up to 16kA and sustained about 20min. The test results showed that all HTS current leads fit the requirement of the EAST.

Primary author: LIU, Huajun (Chinese Academy of Sciences)
Presenter: LIU, Huajun (Chinese Academy of Sciences)
Track Classification: CEC-06 - Superconducting Magnet Systems
Material characterisation and preliminary mechanical design for the HL-LHC shielded beam screens operating at cryogenic temperatures.

Tuesday, 30 June 2015 09:00 (2 hours)

The High Luminosity LHC (HL-LHC) project aims at increasing the luminosity (rate of collisions) in the Large Hadron Collider (LHC) experiments by a factor of 10 beyond the original design value (from 300 to 3000 fb-1). It relies on new superconducting magnets, installed close to the interaction points, equipped with new beam screen. This component has to ensure the vacuum performance together with shielding the cold mass from physics debris and screening the cold bore cryogenic system from beam induced heating. The beam screen operates in the range 40–60 K whereas the magnet cold bore temperature is 1.9 K. A tungsten alloy is used to absorb the energy of particles. In this paper, the measurements, at room and cryogenic temperatures, of the mechanical and some physical properties of this tungsten alloy are shown. The strength of soldering with copper is also assessed at cryogenic temperatures. Then, the design and the thermal mechanical behaviour of the beam screen assembly are presented. It includes the heat transfer from the tungsten absorbers to the cooling pipes and through the supporting system that has to minimise the heat inleak to the cold mass. The behaviour during a quench is also presented.

Primary author: GARION, Cedric (CERN)
Co-author: Mr MRRONE, Marco (CERN)
Presenter: GARION, Cedric (CERN)

Session Classification: M2PoB - Cryogenic Materials III: Testing and Methods
Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
Dimensional changes of solids in varying external conditions such as temperature, pressure, magnetic and electric fields or even light play important role in material science, cryogenic and aerospace engineering. Often the measurements of dimensional changes require high precision combined with ease of use and absence of gravitational effects. We developed a dilatometer based on our miniature fiber based Fabry–Pérot interferometric sensor with a resolution down to 1pm. A differential measurement method provides simple data acquisition of linear dilation with high bandwidth ~10 MHz and use of telecom fibers allows flexibility in contactless measurement setup. First tests of the prototype have shown full compatibility of the dilatometer with cryogenic environment (down to 3.7K) and magnetic fields (at least up to 9T) as well as nanometer resolution on mm-sized sample (ppm) in non-optimized conditions. We present first data obtained with our dilatometer prototype and discuss its advantages and limitations.
RECENT PROGRESS OF CRYOGENIC SYSTEM FOR 40T HYBRID MAGNET

Wednesday, 1 July 2015 09:00 (2 hours)

The 40T hybrid magnet under construction at High Magnetic Field Laboratory of Chinese Academy Sciences (CHMFL) consists of resistive inserts and an 11T superconducting outsert with a clear bore of 800 mm. The outsert made of Nb3Sn CICC is cooled with forced flow supercritical helium at 4.5 K. The main cryogenic system includes a helium refrigerator (360W@4.5K) and a helium distribution system for the cooling of coils, structures, transfer line and current leads. The helium refrigerator was successfully commissioned and put into operation at 2012. The helium distribution system installation will be completed at July, 2015. This paper discusses the design of cryogenic system and recent progress in construction.

Primary author: Dr LI, JunJie (High Magnetic Field Laboratory, Chinese Academy Sciences)

Co-authors: Mr LI, Hong Qiang (High Magnetic Field Laboratory, Chinese Academy Sciences); Mr SHI, Lei (High Magnetic Field Laboratory, Chinese Academy Sciences); Mr FANG, Ming (High Magnetic Field Laboratory, Chinese Academy Sciences); Mrs MENG, Qiu Min (High Magnetic Field Laboratory, Chinese Academy Sciences); Mr AI, Xin (High Magnetic Field Laboratory, Chinese Academy Sciences); Mr CHEN, Xu Heng (High Magnetic Field Laboratory, Chinese Academy Sciences); Prof. OUYANG, Zheng Rong (High Magnetic Field Laboratory, Chinese Academy Sciences)

Presenters: Dr LI, JunJie (High Magnetic Field Laboratory, Chinese Academy Sciences); Prof. OUYANG, Zheng Rong (High Magnetic Field Laboratory, Chinese Academy Sciences)

Session Classification: C3PoD - Superconducting Magnets Cryogenic Systems I

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Tensile properties and conductivities of a precipitation hardened and cold-rolled Cu-0.3Cr-0.1Zr alloy at cryogenic temperature

Tuesday, 30 June 2015 17:30 (15 minutes)

The National Research Institute for Metals (NRIM: now NIMS) has accumulated physical and mechanical properties at cryogenic temperatures for structural alloys since 1980s. As a part of the work, electrical resistivity, magnetization, thermal conductivity and tensile properties were determined at cryogenic temperatures for precipitation hardened copper-based alloys as well as OFHC Cu in the cold-rolled condition (in: Handbook of Superconductivity and Cryogenics, Ohmsha, Tokyo, 1993), since few cryogenic data for those alloys were available. Cu-0.3%Cr-0.1%Zr alloy (CuCrZr) is one of typical precipitation hardened copper-based alloys, and exhibited an excellent combination of high strength and high electrical conductivity at the temperature range of 4 K to 300 K. The CuCrZr showed higher yield ratio (yield stress/tensile strength) at cryogenic temperature than oxygen free copper (OFC), but the ratio of yield stress to electrical resistivity was lower than. The thermal conductivity of CuCrZr was twice as high as that of phosphorous-deoxidized copper. The CuCrZr exhibited excellent non-magnetic stability and very low magnetic permeability at 4.2 K.

Primary author:  Prof. UMEZAWA, Osamu (Yokohama National University)
Presenter:  Prof. UMEZAWA, Osamu (Yokohama National University)
Session Classification:  M2OrD - Cryogenic Materials V: Structural Materials
Track Classification:  ICMC-11 - Metallic and Composite Materials
The Fermilab Muon Campus $g$-2 Cryogenic Distribution Remote Control System

Wednesday, 1 July 2015 09:00 (2 hours)

The Muon Campus (MC) is able to measure muon $g$-2 with high precision and comparing its value to the theoretical prediction. The MC has four 300 KW screw compressors, four liquid helium refrigerators. The centerpiece of the muon $g$-2 experiment at Fermilab is a large, 50-foot-diameter superconducting muon storage ring. This one-of-a-kind ring, made of steel, aluminum and superconducting wire, was built for the previous $g$-2 experiment at Brookhaven. Each subsystem has to be far away from each other and be placed in distant locations. Therefore choosing Siemens Process Control System PCS7-400, Automation Direct DL205 PLC, DL05 PLC, Synoptic and Fermilab ACNET HMI are the ideal choices as the Muon Campus $g$-2 cryogenic distribution real-time and on-Line remote control system.

This paper presents a method which has been successfully used by many Fermilab distribution cryogenic real-time and On-Line remote control systems.

Primary author: Mr PEI, Liujin (Fermi National Accelerator Laboratory)

Co-authors: Mr KLEBANER, Arkadiy (Fermi National Accelerator Laboratory); Mr THEILACKER, Jay (Fermi National Accelerator Laboratory); Mr BOSSERT, Richard (Fermi National Accelerator Laboratory); Mr SOYARS, William (Fermi National Accelerator Laboratory)

Presenter: Mr PEI, Liujin (Fermi National Accelerator Laboratory)

Session Classification: C3PoB - Cryo Controls

Track Classification: CEC-15 - Instrumentation and Controls
Occurrence of thermoacoustic phenomena at 0.8 K, 4 K and above

Thermoacoustics in cryogenics continues to be a very interesting phenomenon which is still poorly understood but often experienced unexpectedly in experiments where it causes unacceptable heat leaks. The authors report on the appearance and onset of this unwanted occurrence at temperatures below 1 K. Based on experiments, quantitative measurements of the heat leak caused by these pressure oscillations in bent tubes with 4.55 and 4.7 mm inner diameter with heat stationing links are presented. Parameters most likely affecting the magnitude of these thermoacoustic oscillations are studied and means of avoiding them are given.

Furthermore, we had the rare opportunity to record and analyze 4 K TAOs experienced on a test setup and present simple means of avoiding them.

Primary author: STAUTNER, Wolfgang (GE Global Research)

Co-authors: Dr ROCHFORD, James (GE Global Research); Dr XU, Minfeng (GE Global Research); Dr CHEN, Rui (GE Global Research)

Presenter: STAUTNER, Wolfgang (GE Global Research)

Session Classification: C1PoE - Thermal Fluids (Non-Aerospace)

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
A new 2 K superconducting half-wave cavity cryomodule for PIP-II

Argonne National Laboratory has developed and is implementing a novel 2 K superconducting cavity cryomodule operating at 162.5 MHz and designed for the acceleration of H-/proton beams from 2.1 to 10 MeV as part of the Fermilab Proton Improvement Project-II (PIP-II). The cryomodule supports operation of up to 2 mA average beam current and bunch population of up to 3.8x10^8 ppb. This work is an evolution of techniques recently implemented in two previous heavy-ion accelerator cryomodules now operating at Argonne National Laboratory [1, 2]. The 2 K cryomodule is based upon low-velocity superconducting half-wave cavity technology comprised of 8 half-wave cavities operated in the continuous wave mode with 8 superconducting magnets located in front of each cavity. All of the solenoids and cavities operate off of a single gravity fed 2 K helium cryogenic system expected to provide up to 50 W of 2 K cooling. Here we review the mechanical design of the cavities and cryomodule which were developed using methods similar to those required in the ASME Boiler and Pressure Vessel Code, overview the cryomodule layout and select subsystem design, and provide a status report on the cryomodule fabrication. Some of the subsystems to be discussed include the support and precision alignment of the cavity-solenoid assembly to within +/-0.5 mm at 2 K, the 5 and 70 K cooling of thermal intercepts and heat exchangers, and the 5 to 2 K cryogenic liquefaction system.

Primary author: CONWAY, Zachary (Argonne National Laboratory)

Co-authors: Mr BARCIKOWSKI, Albert (Argonne National Laboratory); Mr CHERRY, Glenn (Argonne National Laboratory); Mr KEDZIE, Mark (Argonne National Laboratory); Dr KELLY, Michael (Argonne National Laboratory); Dr OSTROUMOV, Peter (Argonne National Laboratory); Mr FISCHER, Richard (Argonne National Laboratory); Dr KIM, Sang-hoon (Argonne National Laboratory); Mr GEBICK, Scott (Argonne National Laboratory); Mr MACDONALD, Steven (Argonne National Laboratory); Mr NICOL, Thomas (Fermi National Accelerator Laboratory); Mr REID, Thomas (Argonne National Laboratory); Dr LEBEDEV, Valeri (Fermi National Accelerator Laboratory)

Presenter: CONWAY, Zachary (Argonne National Laboratory)

Session Classification: C1OrG - Superconducting RF Systems I

Track Classification: CEC-07 - Superconducting RF Systems
In-Flight Performance of the OCO-2 Cryocooler

Monday, 29 June 2015 16:15 (15 minutes)

The Orbiting Carbon Observatory-2 (OCO-2) will have completed its first year in space on July 2, 2015. The OCO-2 instrument incorporates three bore-sighted, high-resolution grating spectrometers, designed to measure the near-infrared absorption of reflected sunlight by carbon dioxide and molecular oxygen. OCO-2 currently flies in a sun-synchronous, near-polar orbit at an inclination of 98.1 degrees, mean altitude of 705 kilometers, 99 minute orbit period and 1:30 pm ascending node. The OCO-2 spacecraft forms part of a constellation of six Earth observing satellites known as the “A-Train” and leads this procession ahead of the JAXA GCOM-W1 spacecraft.

The cryocooler system design is coupled with the instrument’s thermal control design to maximize the instrument’s performance. A single-stage NGAS pulse tube cryocooler provides refrigeration to three focal plane arrays to 120 K via a high conductance flexible thermal strap. A variable conductance heat pipe (VCHP) based heat rejection system (HRS) transports waste heat from the instrument located inside the spacecraft to the space-viewing radiators. The HRS provides tight temperature control of the spectrometer to 267 K and maintains the cryocooler at 300 K.

Soon after entering the A-Train on August 3, 2014, the spectrometer and focal planes were cooled to their operating temperatures. Evidence of ice accumulation on the cryogenic surfaces was deduced from increased cryocooler loads and drove a need for two focal plane decontamination cycles on August 31, 2014 and October 23, 2014.

This paper provides a general overview of the cryogenic system design and reviews the in-flight cryogenic performance over the Observatory’s first year.

Primary author: NA-NAKORNPNANOM, Arthur (Jet Propulsion Laboratory)
Co-author: NAYLOR, Bret (Jet Propulsion Laboratory)
Presenter: NA-NAKORNPNANOM, Arthur (Jet Propulsion Laboratory)
Session Classification: C1OrH - Aerospace Cryocoolers
Track Classification: CEC-04 - Cryocoolers (Aerospace)
Design and tests of a new kind superconducting motor

In this paper an original topology of a superconducting motor is presented. The motor is based on the magnetic flux concentration principle when both superconducting wire and bulk are used. The superconducting wire creates a high homogeneous flux density when the superconducting bulk concentrates this flux density. The obtained flux density is variable in the air-gap of the motor. The inductor is stationary when the armature rotates to allow a stationary cryostat. All the inductor is immersed in liquid Nitrogen.

Primary author: Dr AILAM, El Hadj (Univ Khemis Miliana, LESI Lab.)

Co-authors: Dr HOCINE, Abdelfettah (Univ Khemis Miliana, LESI Lab.); Dr BENALLAL, Mohamed Nadjib (Univ Khemis Miliana, LESI Lab.)

Presenter: Dr AILAM, El Hadj (Univ Khemis Miliana, LESI Lab.)

Track Classification: ICMC-06 - HTS and MgB2 Bulk
Second-Law Analysis of a Cascade Joule-Thomson Microcooler

Tuesday, 30 June 2015 14:00 (2 hours)

Cascade Joule-Thomson Microcoolers have been proposed in literature in which different compressors with low values of pressure ratio of order four using different working fluids are anticipated to drive the microcooler. A cascade of five stages is expected to provide cooling at a load temperature of 150 K. In this study a second-law analysis of such a microcooler is performed to quantify the effect of important design parameters representing the basic components and processes of the microcooler on its performance. The effects of several important design parameters including the effectiveness of all heat exchangers as well as the effect of possible pressure drop in the recuperative heat exchanger on cooling power and the exergetic efficiency of the microcooler are obtained. The inefficiency of the compressors is included using an exergetic efficiency parameter for the compressors. The heat transfer from each stage to other stages is modelled using an effectiveness parameter for the heat exchangers that can be varied to investigate their influence on cooling power and the efficiency of the microcooler.

Primary author: Dr RAZANI, Arsalan (University of New Mexico)
Co-authors: Mr DODSON, Christopher (Air Force Research Labs); Mr MARTIN, Kyle (Applied Technology Associates); Mr FRASER, Tomas (Air Force Research Labs)
Presenters: Mr DODSON, Christopher (Air Force Research Labs); Mr MARTIN, Kyle (Applied Technology Associates); Mr FRASER, Tomas (Air Force Research Labs)
Session Classification: C2PoJ - Joule-Thomson Coolers
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
The helium recovery and purification system of the ADS-inject I

ADS-Injector I is one of the important parts in the Accelerator Driven Sub-critical project. In order to reduce the quantity of impurities in the helium and to recover the helium during superconducting cavities tests or maintenance, a helium purification and recovery system is implemented in the ADS-Injector I cryogenic plant.

It is composed by two high pressure recovery compressors, a helium booster and a helium cryogenic purifier. An atmospheric gas bag (100 m³), high pressure cylinder for impure gas helium (20 bottles at 20 MPa, 500N m³ each), high pressure cylinder for pure gas helium (20 bottles at 20 MPa, 500N m³ each), a liquid nitrogen tank (10,000 l) and dedicated transfer stainless steel pipe lines are provided for the vertical test stand and horizontal test stand.

The recovery and purification system can be operated automatically. The helium to be recovered is collected in the gas bag; if its pressure is too low to enter in the gas bag quickly, the low pressure helium is sent to a booster where its pressure is increased to the 1.05bara before entering the helium gas bag.

The helium coming from the gas bag is sent to the recovery compressor and stored in the high pressure (20 MPa) cylinder from which is delivered to the impure gas storage. The maximum rate of flow of each recovery compressors is 105Nm³/h. A cryogenic purifier which is cooled down to 77K with liquid nitrogen is used to trap impurities from gaseous helium. The output impurity of the helium can be decreased to less than 5 ppm and then it is stored in high pressure cylinder (up to 20 MPa) which is delivered to the pure gas storage.

**Primary author:** ZHANG, zhuo (IHEP)

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**Presenters:** Prof. LI, shaopeng (IHEP); ZHANG, zhuo (IHEP)

**Track Classification:** CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Lessons learned concerning the Cool-down of Superconducting Magnets using a Thermal Siphon Cooling-loop

Wednesday, 1 July 2015 14:45 (15 minutes)

The two cyclotron gas stopper superconducting solenoid coils were designed to be cooled down and to be kept cold in the range 4.25 K to 4.6 K using three pulse tube coolers per coil. These coolers are designed to produce from 1.4 to 1.7 W per cooler when the cooler first stage is at about 40 K. The cyclotron gas stopper coils are designed that they can be separated while cold, but unpowered. The magnet coils were cooled down separately in 2014. Room temperature helium gas from bottles was liquefied into the magnet cryostats. The magnet temperature at the end of the cool-down was 4.45 K for one coil and 4.6 K for the other at the end of the cool-down. The coil-down time for the coils was over three times longer than expected. The time to liquefy the helium is the magnet cryostats was also longer than expected. The reasons for the disparity between the calculated cool-down time and measured cool-down time are explained in the paper. Steps that could be taken to speed up the cool-down time are discussed.

Primary author:  GREEN, Michael (Michigan State University)
Co-authors:  Dr ZELLER, Al (Michigan State University); Dr CHOUHAN, Shailendra (Michigan State University)
Presenter:  GREEN, Michael (Michigan State University)
Session Classification:  C3OrF - Superconducting Magnets Cryogenic Systems II
Track Classification:  CEC-06 - Superconducting Magnet Systems
The Cost of Coolers for Cooling Superconducting Devices from 4.2 to 4.7 K, from 20 to 30 K, and from 65 to 80 K

Monday, 29 June 2015 11:00 (15 minutes)

This author and other authors have written papers concerning the cost of refrigeration at liquid helium temperature and higher temperature as a function of the refrigeration delivered. These papers have included small coolers as well. The lowest temperature range from 4.2 K to 4.7 K (the liquid helium temperature range) is covered using coolers that have two stages. The use of magnets and power equipment that use MgB2 conductors and HTS conductors have spurred the development of coolers that work well temperature ranges from 20 K to 30 K (for potential hydrogen temperature applications) and from 65 K to 80 K (for applications in the liquid nitrogen temperature range). This paper will present some cost data for a number of commercial two-stage and single-stage coolers. This data will be fitted to allow one to estimate the cost of coolers as a function of refrigeration for the three temperature ranges given above. The efficiency of several coolers over a range of temperatures will be discussed.

Primary author: GREEN, Michael (Lawrence Berkeley Laboratory)
Presenter: GREEN, Michael (Lawrence Berkeley Laboratory)
Session Classification: C1OrA - Cryocoolers for Superconducting Applications
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Second stage Cooling from a PT-415 Cooler at Second-stage Temperatures up to 125 K with Heat Loads on the First-stage from 0 to 60 W

Monday, 29 June 2015 11:15 (15 minutes)

The amount of cooling delivered to the second stage of a two stage cooler is dependent on the second stage temperature and the amount of refrigeration provided by the cooler first stage. The second stage cooling as a function of temperature for a Cryomech PT415 cooler (1.5 W at 4.2 K with 42 W on the first stage) has been estimated by scaling similar data that was measured for a Cryomech PT410 cooler (1.0 W at 4.2 K with 28 to 30 W on the first stage). In order to accurately calculate the cool-down time for a superconducting magnet using PT415 K coolers one must know how much cooling can be delivered by the cooler second-stage as a function of the second-stage temperature and the added cooling delivered to the cooler first-stage. There are applications where PT415 coolers are used in the temperature range from 15 to 22 K to cool and liquefy hydrogen. This report describes the method for measuring the cooler performance as well as the results of the measurements.

Primary author: GREEN, Michael (Michigan State University)

Co-authors: ZELLER, Al (Michigan State University); Dr CHOUHAN, Shailendra (Michigan State University)

Presenter: GREEN, Michael (Michigan State University)

Session Classification: C1OrA - Cryocoolers for Superconducting Applications

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Peak Current Limiting Properties of SFCL with Parallel Connected Coils using Two Magnetic Paths

Mon, 29 June 2015 09:00 (2 hours)

In this study, a superconducting fault current limiter (SFCL) with two magnetic paths using E-I iron core was proposed and its peak current limiting characteristics were analyzed. For the suggested SFCL to effectively perform the peak current limiting operation, the design of the SFCL considering its electrical equivalent circuit for E-I iron core was needed. In addition, the analysis on the influence of the magnetic flux on its peak current limiting characteristics was essential. Through the analyses for the fault current limiting experiments with this SFCL, two magnetic paths using E-I iron core were confirmed to be contributed to the peak fault current limiting operation of the SFCL.

Primary author: KO, Seok-Cheol (Kongju National University)
Co-author: Prof. LIM, Sung-Hun (Soongsil University)
Presenter: KO, Seok-Cheol (Kongju National University)
Session Classification: C1PoA - Cryogenics for Power Applications, Energy, Fuels and Transportation I
Track Classification: CEC-08 - Cryogenic Power Cables and Leads
High cooling power 4.2 K stage cryocoolers are in high demand, given their broad applications in such fields as magnetic resonance imaging (MRI) and low temperature superconductors. ARS has recently designed and developed a high cooling power 4.2 K stage pneumatic-drive G-M cryocooler which achieves a typical cooling power of 1.8 W/4.2 K. Steady input power of our newly developed helium compressor supplied to the cold head is 11.8 kW at 60 Hz. The operation speed of the cold head is 30 RPM, which is lower than other commercial 4.2 K stage cryocoolers, minimizing vibration of the cold head and extending its lifetime. The effects of geometry and operation conditions on the cooling performance of the 4.2 K stage G-M cryocooler are also numerically simulated and then compared with experimental test results.

**Primary author:** Dr HAO, Xihuan (Advanced Research Systems, Inc.)

**Presenter:** Dr HAO, Xihuan (Advanced Research Systems, Inc.)

**Session Classification:** C3OrD - 4K Cryocoolers

**Track Classification:** CEC-03 - Cryocoolers (Non-Aerospace)
Thermal load and assembly for QWR, HWR, SSR1 and SSR2

The heavy ion accelerator that will be built in Daejeon, Korea utilizes superconducting cavities operating in 2 K, 4.5K. The cryomodules are QWR (quarter wave resonator), HWR (half wave resonator), SSR1 (sing spoke resonator 1) and SSR2 (sing spoke resonator 2). The main role of the cryomodule is supplying thermal insulation for cryogenic operation of the cavities alignment. Thermal and structural consideration such as thermal load by heat leak and heat generation, cryogenic fluid management, thermal contraction. This paper describes detailed design considerations and current results have being done including thermal load estimation.

Primary author: Dr KIM, WooKang (IBS)

Co-authors: Dr PARK, Gunn-Tae (IBS); Dr KIM, Heetae (IBS); Dr CHA, Hyuk Jin (IBS); Dr KIM, Hyungjin (IBS); LEE, MinKi (Institute for Basic Science); Mr JO, YongWoo (IBS); Dr KIM, Youngkwon (IBS)

Presenter: Dr KIM, WooKang (IBS)

Track Classification: CEC-16 - Cryogenics for Medical, Food, Environmental, and Manufacturing
Cryogenic infrastructure supplied by Linde Kryotechnik AG for the Series Magnet Test Facility for FAIR

Tuesday, 30 June 2015 16:15 (15 minutes)

In order to test the fast-ramped superconducting magnets for FAIR (Facility for Antiproton and Ion Research), a cryogenic test facility with an equivalent overall capacity of 1.5 kW at 4.4 Kelvin was designed and commissioned at GSI Helmholtzzentrum für Schwerionenforschung GmbH. For efficient testing of the 108 dipole magnets the cryogenic infrastructure consists of a refrigeration system and four main test benches. Due to the different operating modes and load fluctuations a dedicated process and control concept was developed which allows an independent operation of each test bench and ensures highest efficiency over the whole operating range. The system is designed in a way that one magnet can be cooled down to its operating temperature while simultaneously another magnet is kept at cold state for the measurements. The third and fourth test benches serve for warming up and exchanging the magnets respectively. The high flexibility of the set-up moreover allows the testing of other FAIR magnets like the SIS100 quadrupole modules or the operation of a string configuration.

The project was executed in a close collaboration between GSI and Linde Kryotechnik AG. The presentation will show the key solutions of the refrigeration system and the test benches and highlight some commissioning results.

Primary author: Mr FISEL, Wolfgang (Linde Kryotechnik AG)

Co-authors: Mr SCHROEDER, Claus (GSI Helmholtzzentrum für Schwerionenforschung GmbH); Mr WILHELM, Hanspeter (Linde Kryotechnik AG); Mr KOLLMUS, Holger (Helmholtzzentrum für Schwerionenforschung GmbH); Mr HILDENBEUTEL, Jan (Linde Kryotechnik AG); Mr OHLIG, Klaus (Linde Kryotechnik AG)

Presenter: Mr HILDENBEUTEL, Jan (Linde Kryotechnik AG)

Session Classification: C2OrE - Cryogenic Systems II

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Experimental research on heat transfer coefficients for cryogenic internally finned heat exchanger

The aim of present experimental research is to find out the suitable correlations for designing the internally finned heat exchanger used in cryogenic applications. In order to conduct above experimental study, different size of internally finned heat exchangers were developed and tested in cryogenic environments. The experiments were conducted in the range of velocity varies from 0.001m/s to 0.14m/s. The effect of finned clearance on the prediction of overall heat transfer coefficient is also investigated experimentally. The results from present study were compared with these calculated from empirical equations. From the present experimental results, a more accurate new correlation has been formed using in cryogenic situations.

Primary author: LI, Xueliang
Co-authors: Prof. HONG, Guotong (Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences); Prof. YAN, Tao (Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences)
Presenter: Prof. YAN, Tao (Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences)
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
An Analytical Approach to Designing a Thermosiphon Cooling System for Large Scale Superconducting Magnets

Thermosiphon cooling scheme is a productive way of cooling large scale superconducting magnets. The absence of active pumping and the availability of the higher heat capacity parameter “latent heat” make this an attractive cooling method. Nevertheless, the design of such a system demands a well-organized study of the effect of various flow parameters, such as, mass flow rates, flow quality, etc., and also a robust mechanical design of the various components of the system. This paper presents an analytical approach to designing a thermosiphon cooling scheme based on homogeneous flow conditions as well as separated flow conditions. The design of the mechanical components such as the piping is also discussed. The design approach presented here has been applied to the reference design of two large superconducting solenoids, the Production Solenoid and the Detector Solenoid of the Mu2e experiment at Fermilab.

Primary author: Dhanaraj, Nandhini (Fermi National Accelerator Laboratory)
Co-authors: Schmitt, Richard (Fermilab); Peterson, Tommy (Fermilab)
Presenter: Dhanaraj, Nandhini (Fermi National Accelerator Laboratory)
Session Classification: C3PoD - Superconducting Magnets Cryogenic Systems I
Track Classification: CEC-06 - Superconducting Magnet Systems
Forced Two-Phase Helium Cooling Scheme for Mu2e Transport Solenoid

Wednesday, 1 July 2015 15:30 (15 minutes)

The Mu2e Transport Solenoid (TS) consists of two separate but similar solenoids, TS-u and TS-d. Each solenoid is in the shape of a quadrant with a centerline radius of approximately 3 m and has a helium cooling loop consisting of 25 vertically oriented rings with diameters ranging from 1 m to 1.25 m connected in series. This cooling loop configuration has been deemed adequate for cooling via forced single phase liquid helium; however it presents major challenges to forced two-phase flow such as "garden hose" pressure drop, concerns of flow separation from tube walls, difficulty of calculation, etc. Even with these disadvantages, forced two-phase flow has certain inherent advantages which make it a more attractive option than forced single phase flow. It is for this reason that the use of forced two-phase flow was studied for the TS magnets. This paper will describe the analysis using helium-specific pressure drop correlations, conservative engineering approach, helium properties calculated and updated at over fifty points, and how the results compared with those in literature. Based on the findings, the use of forced-two phase helium is determined to be feasible for steady-state cooling of the TS solenoids.

Primary author: TATKOWSKI, Grzegorz (Fermilab)

Co-author: SCHMITT, Richard (Fermilab)

Presenter: TATKOWSKI, Grzegorz (Fermilab)

Session Classification: C3OrF - Superconducting Magnets Cryogenic Systems II

Track Classification: CEC-06 - Superconducting Magnet Systems
Investigation on Joule-Thomson effect of the cryogenic propellants in thermodynamic vent system

Thermodynamic vent system technology is a widely used method to achieve efficient cryogenic propellants storage in aerospace fields, the Joule-Thomson effect of the cryogenic propellants, such as liquid nitrogen, liquid oxygen and liquid hydrogen, is analyzed and calculated based on the thermodynamic vent system, and this will lay a certain foundation for the efficient storage of cryogenic propellants using thermodynamic vent system.

Primary author: ZHOU, zhenjun
Presenter: ZHOU, zhenjun
Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Influence of thermophysical properties of working fluid on the design of cryogenic turboexpanders using ns-ds diagram

Wednesday, 1 July 2015 09:00 (2 hours)

Helium liquefaction and refrigeration plants are an essential part of nuclear fusion reactors, particle accelerators etc. The thermodynamic efficiency of these plants depends upon the performance of the turboexpander which is the main cold generating component and therefore they should be designed for higher thermodynamic efficiencies. Balje’s ns – ds chart, which is a contour of isentropic efficiencies plotted against specific speed and specific diameter is commonly used for the preliminary design of cryogenic turboexpanders. But, these charts were developed based on calculations for a specific heat ratio (γ) of 1.4, and studies show that care should be taken while implementing the same for gases like helium which has higher γ of 1.67. Hence there is a need to investigate the extent of applicability of ns-ds diagram in designing helium expansion turbines.

In this paper CFD analysis of two cryogenic turboexpanders, one designed for nitrogen and the other for helium were carried out using ANSYS CFX. The turboexpanders were designed based on the design methodologies prescribed by Kun and Sentz following ns-ds diagram of Balje and Hasselgruber’s technique for generating blade profile.

The computational results of the two cases were analysed to investigate the applicability of Balje’s ns-ds diagram for the design of turboexpanders for helium refrigeration and liquefaction cycles. It has been found that while CFD results of turbine performance match closely with the expected design data in case of nitrogen, for helium there is a noticeable difference. Efforts have also been made to discern the modifications that should be made in the existing design techniques following Balje’s chart so as to establish a streamlined design methodology for the development of helium turboexpanders with improved performance.

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Session Classification: C3PoE - Turbomachines and Helium Components

Track Classification: CEC-05 -Expanders, Pumps, Compressors, and Regenerators
Effective temperature of cryogenic liquid in arbitrary dimension

Compared to uniform temperature distribution, thermal radiation properties of nonuniform temperature distribution are different. The effective temperature of cryogenic liquid can be defined for the nonuniform temperature distribution. The effective temperature is defined in one-dimension, two-dimension and three-dimension. The properties of the effective temperature will be presented.

Primary author: KIM, Heetae (Institute for Basic Science)

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Presenter: KIM, Heetae (Institute for Basic Science)

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Modelling AC ripples in HTS coated conductors

DC transmission using high temperature superconducting (HTS) coated conductors offers a promising solution to the globally growing demand for effective, reliable and economic transmission of green energy up to GW level over very long distances. The credible estimation of the losses and thereby the heat dissipation involved is highly essential for the rational design of practical HTS DC transmission cables and corresponding cryogenic systems to fulfill this demand. In this respect, the evaluation of the dissipation caused by AC ripples (introduced in rectification / AC-DC conversion) is needed. Here we report a targeted modelling study into the AC losses in a HTS coated conductor subject to DC currents and AC ripples simultaneously, by solving Maxwell’s equations using the finite element method (FEM) in the commercial software package COMSOL. It is observed that the instantaneous loss exhibits only one peak per cycle in a HTS coated conductor subject to sinusoidal ripples and DC currents that are within our targeted conditions. This is a distinct contrast to the usual observation of two peaks per cycle in a HTS coated conductor subject to AC currents only. The unique mechanisms behind are also discussed. Finally, the magnitude of the AC ripple losses and their importance in the design of HTS DC transmission cables are estimated.

Primary author: Dr XU, Zhihan (Karlsruhe Institute of Technology)
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Presenter: GRILLI, Francesco (Karlsruhe Institute of Technology)
Session Classification: M1OrC - Superconductor Stability and AC Losses
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Experimental study of stability and transients in a horizontally heated boiling helium thermosyphon

Tuesday, 30 June 2015 11:00 (15 minutes)

Boiling helium natural circulation loops are being used as the cooling systems of large magnet systems because they provide inherent safety and maintenance advantages. It is the case of the CMS detector magnet at CERN (already in operation) or R3B-GLAD spectrometer at GSI (in installation phase). Such cooling systems are mainly composed by a top helium reservoir that provides the coolant by one or several descending feeding branches to the bottom of a hydraulic network in contact with the magnet to be cooled. The heat transferred to the fluid produces vapor in this element of the circuit, and the resulting buoyant force creates a flow. The behavior of such systems has been studied before for loops with a vertical heated branch, but only preliminary studies were conducted on loops with a horizontal heated section.

In this work experiments were conducted on a liquid helium thermosyphon facility with a 4 m length horizontal heated section. Wall temperatures on the heated section, mass flow rate and pressure drop were measured in steady and transient regimes and the stability limits of such a loop have been found. Also, different heating configurations were explored and their drawbacks and benefits were observed.

The result is that the loop is stable only above a non-zero low power and below a certain upper power limit for certain configurations. The distance from the heating to the vertical riser plays a very important role on stability. It has been found that even the low power instabilities can produce considerable temperature oscillations, potentially dangerous from the magnet protection point of view. The values of critical heat flux were found too for stable and instable cases.

Primary author: FURCI, Hernan (CEA Saclay)
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Presenter: FURCI, Hernan (CEA Saclay)
Session Classification: C2OrC - Pulsating Heat Pipes and Thermosyphons
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
In the past, cooling at 2K used to be an exotic application in large scale cryogenics. The required sub-atmospheric helium bath was established with the help of one of the following two technical approaches – rough vacuum pumping at ambient temperature or turbo compression at cryogenic temperature – or a combination of both. The aforementioned approaches are still being applied, but the optimum distribution between warm and cold stages is not always obvious.

In the last few years, 2K cooling became a new state-of-the-art in the fields of experimental and applied physics. Standardisation of the machinery and its controlling significantly reduced commissioning time which has clearly been demonstrated during start-up of refrigeration plants such as Fermilab and DESY. Thus, the technological readiness of cold compressors has successfully been proved.

This paper presents criteria for the optimisation of a cold compressor system under operational and economical aspects depending on the required 2K cooling capacity.

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**Presenter:** Mr DECKER, Lutz (Linde Kryotechnik AG)

**Session Classification:** C1OrC - Compressors & Expanders

**Track Classification:** CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Development of an oil-free compressor for GM and pulse tube cryocoolers

Pressure Wave Systems GmbH has developed an oil-free compressor for GM and pulse tube cryocoolers. The concept is based on hydraulically driven metall bellows which compress the Helium working gas. The system has 1kW of electrical input power and has been successfully tested with a SHI SRDK-101D GM cryocooler cold head. Set-up, performance and reliability of the compressor system will be discussed.

Primary author: Dr HÖHNE, Jens (Pressure Wave Systems GmbH)
Presenter: Dr HÖHNE, Jens (Pressure Wave Systems GmbH)
Session Classification: C1OrC - Compressors & Expanders
Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
The preparation of the vertical test of the beta=0.12 half-wave resonator at the Rare Isotope Science Project (RISP)

At Rare Isotope Science Project (RISP) in Korea, the accelerator system based on the superconducting cavities has been developed. The superconducting cavities made of bulk high purity niobium has a superconducting transition temperature around 9K and it needs to be cooled by liquid helium system. Since the operating RF bandwidth is very narrow around 80 Hz and sensitive to the deformation of the cavity, the pressure fluctuations of the LHe within the cryostat must be controlled tightly. The operation temperature ranges from 2K to 4K, which includes the superfluid regime. We report the progress we are making in the preparation of the vertical test of the superconducting cavity, half-wave resonator in terms of the temperature control system, leak check at cryogenic temperature, quench detecting system as well as RF system.

Primary author: PARK, Gunn-Tae (Institute for Basic Science)

Co-authors: KIM, Heetae (Institute for Basic Science); Dr KIM, WooKang (IBS)

Presenter: PARK, Gunn-Tae (Institute for Basic Science)

Track Classification: CEC-07 - Superconducting RF Systems
Theoretical research of helium pulsating heat pipe under steady state

Monday, 29 June 2015 14:00 (2 hours)

As a new-type heat pipe, pulsating heat pipe (PHP) has several outstanding features, such as great heat transport ability, strong adjustability, small in size and simple construction. PHP is a complex two-phase flow system associated with many physics subjects and parameters, which utilizes the pressure and temperature change in volume expansion and contraction during phase changes to excite the pulsation motion of liquid plugs and vapor bubbles in capillary tube between the evaporator and condenser. At the present time, some experimental investigation of helium PHP have been done. We developed a mechanical-thermal switch working as a novel pre-cooling system for the helium PHP, and the measured effective thermal conductivity of helium PHP was 16760 W/m·K with a heating power of 49.2 mW. However, theoretical research of helium PHP is rare. In this paper, the physical and mathematical models of operating mechanism for helium PHP under steady state are established based on the conservation of mass, momentum, and energy. Several important parameters are correlated and solved, including the filling ratio, advanced and receded contact angles of the liquid helium, flow velocity, and temperature etc. Based on the results, the operational driving force and flow resistances of helium PHP are analyzed, and the flow and heat transfer are further studied.

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Presenter: Dr LIU, Huiming (Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences)

Session Classification: C1PoJ - Novel Concepts and New Devices I

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
The experimental research and analysis about the influences of thermal coupling between the pulse tube and regenerator in PTCs

In order to have a more compact structure for the applications, for general design of the co-axial pulse tube cryocoolers (CPTCs), the pulse tube and regenerator share a thin stainless steel wall. In former theoretical analysis, this wall is considered to be adiabatic and few research pays attention to the thermal-coupling effect between the pulse tube and regenerator in CPTCs. In this research, the influence of the thermal-coupling is studied based on the experimental researches with a U-type pulse tube cryocooler firstly. In the experimental researches, the thermal link is considered to simulate the thermal-coupling between the pulse tube and regenerator. Based on our experimental researches, the thermal-coupling between the pulse tube and regenerator benefits for the performance of the PTCs. Furthermore, a simple analysis is introduced to explain the performance increase.

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**Presenter:** Dr HUANG, Taihe (Technical Institute of Physics and Chemistry, Chinese academy of science)

**Track Classification:** CEC-04 - Cryocoolers (Aerospace)
The researches of the thermodynamic cycle in the cold end of the UPTCs through CFD simulation

For U-type pulse tube cryocoolers (UPTCs), the design of the cold end is the key questions for the performance optimization. Some former experimental researches showed us several kinds of design of the cold end of UPTCs. The object of this paper is to compare the different design of cold end of UPTCs to explain the performance differences between them through the CFD simulations. Through CFD method, the thermodynamic cycles of the gas parcels in the cold end are displayed. According to the results, the cold end heat exchanger also has the heat-pumping effect. The coldest position is at the pulse tube near the cold end heat exchanger rather than exactly at the cold end. For UPTC with the design of double cold end heat exchangers, the two cold end heat exchangers acts as two heat resource. The PV power is used to pump heat from the second cold end heat exchangers to the first cold end heat exchanger. Based on these results, some important questions are discussed for the design of the UPTCs.

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Presenter: HUANG, Taihe (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Study on A Cascade Pulse Tube Cooler with Energy Recovery: New Method for Approaching Carnot

Thursday, 2 July 2015 09:00 (15 minutes)

A pulse tube cryocooler can not reach the Carnot efficiency basically because the expansion work must be dissipated at the warm end of the pulse tube, thus the ideal efficiency of a PTC is only $T_c/Th$, which is less than the Carnot efficiency $T_c/(Th-Tc)$. How to recover this amount of dissipated work is a key to improve the PTC efficiency. A cascade PTC is consisted of PTCs those are staged by transmission tubes in between, it can be a two-stages or even more stages, each stage is driven by the recovered work from the last stage by a well-designed long transmission tube. It’s shown that the more stages it has, the closer the efficiency will approach the Carnot efficiency. A two-stages cascade pulse tube cooler working at 233 K is designed, fabricated and tested in our lab, and experimental results show that the efficiency can be improved by 33%.

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Presenter: Mr WANG, Longyi (Institute of Refrigeration and Cryogenics, Zhejiang University)

Session Classification: C4OrB - Pulse Tube Configurations

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Heat Treatment Sensitivity of ITER Nb3Sn Wire for CS Magnets

Due to the potential spatial temperature variations during heat treatment of the large central solenoid (CS) coils, it is necessary to study the strand’s heat treatment sensitivity by characterizing the strands heat treated with slightly different temperature profiles. We present critical current (Ic) and residual resistivity ratio (RRR) results of ITER Nb3Sn strands made by two manufacturers for CS coils that were heat treated using varying temperatures and durations for the last stage of the heat treatment. Our results show that Ic is not very sensitive to the heat treatment for the range of temperature and time used, however, RRR did decrease with increasing heat treatment time and temperature. We will discuss the mechanisms responsible for the heat treatment sensitivity of Ic and RRR for the two strands. In particular, an expression of RRR as a function of heat treatment temperature and time is presented.

This work is funded by US-ITER under subcontract number 4000110684.

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Session Classification:  M2PoA - Superconductors Materials II: Nb3Sn, FeAs-based
Track Classification:  ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Testing and analytical modeling for purging process of a cryogenic line

Tuesday, 30 June 2015 14:00 (2 hours)

The purging operations for cryogenic main propulsion systems of upper stage are usually carried out for the following cases: 1) Purging of the Fill/Drain line after completion of propellant loading. This operation allows the removal of residual propellant mass; and 2) Purging of the Feed/Drain line if the mission is scrubbed. The lines would be purged by connections to a ground high-pressure gas storage source. The flowrate of purge gas should be regulated such that the pressure in the line will not exceed the required maximum allowable value. Exceeding the maximum allowable pressure may lead to structural damage in the line. To gain confidence in analytical models of the purge process, a test series was conducted. The test article, a 20-cm incline line, was filled with liquid hydrogen and then purged with gaseous helium (GHe). The influences of GHe flowrates and initial temperatures were evaluated. The Generalized Fluid System Simulation Program, an in-house general-purpose computer program for flow network analysis, was utilized to model and simulate the testing. The test procedures, modeling descriptions, and the results will be presented in the final paper.

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Presenter: HEDAYAT, Ali (NASA-MSFC)
Session Classification: C2PoL - Thermal Fluids (Aerospace Applications)
Track Classification: CEC-10 - Aerospace
Two-stage pulse tube refrigerator with step displacer as phase shifter

Thursday, 2 July 2015 09:15 (15 minutes)

Solid piston as phase shifter for the second stage of a two-stage pulse tube refrigerator is effective for getting higher performance. If a step displacer is used as the phase shifter, both stages can use higher performance phase shifter. In this paper, a gas separation type two-stage pulse tube refrigerator with the step displacer is discussed with numerical simulation. It is shown that the swept volume ratio of the displacer over the swept volume of the compressor, and phase angle difference between the displacer and the piston of the compressor is important for getting higher performance.

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Session Classification: C4OrB - Pulse Tube Configurations

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
A cryogenic tensile testing apparatus for micro-samples cooled by miniature pulse tube cryocooler

Tuesday, 30 June 2015 09:00 (2 hours)

This paper introduces a cryogenic tensile testing apparatus for micro-samples cooled by a miniature pulse tube cryocooler. At present, tensile tests are widely applied to measure the mechanical properties of materials; most of the cryogenic tensile testing apparatus are designed for samples with standard sizes, while for non-standard size samples, especially for micro-samples, the tensile testing cannot be conducted. The general approach to cool down the specimens for tensile testing is by using of liquid nitrogen or liquid helium, which is not convenient: it is difficult to keep the temperature of the specimens at an arbitrary set point precisely, besides, in some occasions, liquid nitrogen, especially liquid helium, is not easily available. To overcome these limitations, a cryogenic tensile testing apparatus cooled by a high frequency pulse tube cryocooler has been designed, built and tested. Samples with a diameter of as small as 3 mm and thickness less than 1 mm can be tensile tested. The operating temperatures of the developed tensile testing apparatus cover from 20 K to room temperature with a controlling precision of ±0.03 K and the whole deformation process of the specimen can be observed through a quartz window, which can be hardly realized by the way of liquid nitrogen or liquid helium cooling. The apparatus configurations, the methods of operation and some cooling performance will be described in this paper.

This research is supported by The National Natural Science Foundation of China (No. 51327806 and No. 51427806).

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Session Classification: M2PoB - Cryogenic Materials III: Testing and Methods

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
Numerical studies on the phase adjustment systems of high frequency pulse tube cryocooler with a gradient temperature distribution

Some single-stage high-frequency pulse tube cryocoolers (HPTCs) have been developed in recent years. At present, with an electric input power of 250 W and a frequency of 30 Hz, the lowest temperature achieved is around 15 K and the typical cooling capacity is about 350±50mW/20 K. Although single-stage is more attractive to customers compared with multi-stages because of its mechanical simplicity, it is difficult to achieve lower temperature, thus the employment of double-stage is a compromise approach. At the beginning of structure design, the liquid nitrogen (LN2) was employed as the pre-cooling stage to cool the hot end of the HPTC that has been developed in our lab. In the aspect of compactness and simplification, coaxial configuration has been adopted, and the inertance tube was arranged passing through the compressor internal space and wrapped in the reservoir, integrating the reservoir, pulse tube and compressor together. Therefore, a gradient temperature distribution from the liquid nitrogen temperature to room temperature is set up along the inertance tube. Furthermore, in order to reduce the adjustment difficulty, the double-inlet was also installed at the position of room temperature. Thus, for the gases, passing through the double inlet and then flowing into the pulse tube is also a process of temperature changes. Through some preliminary experiments, we discovered that the mechanism of the phase adjustment systems with a gradient temperature distribution is different from that with uniform temperature distribution. In this paper, the mechanism of the phase adjustment systems with temperature gradient will be numerical studied, and some preliminary experimental results will be presented.

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Session Classification: C1PoC - Vuilleumier Cryocoolers and Cooler Analyses

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Development of 1 kW Stirling cryocooler with using linear compressor

Tuesday, 30 June 2015 09:00 (2 hours)

Cryogenic cooling systems for HTS electric power devices require a reliable and efficient high-capacity cryocooler. A Stirling cryocooler with a linear compressor can be a good candidate. It has advantages of low vibration and long maintenance cycle compared with a kinematic-driven Stirling cryocooler. In this study, we developed dual-opposed linear compressor of 12 kW electric input power with two 6 kW linear motors. It is experimentally measured the electromagnetic parameters of fabricated linear motor such as thrust constant, effective resistance and inductance. The developed Stirling cryocooler has gamma-type configuration. Moving components of piston and displacer is supported with flexure spring. A slit-type heat exchange is used for cold and warm-end, and the generated heat is rejected by cooling water. In cooling performance test, electric heat is loaded to measure cooling capacity and spatial temperature distribution in cold-end heat exchanger surface. In addition, displacement of moving parts, dynamic pressure, input voltage and current are also measured during operation. With the measured experimental data, the dynamic behavior of linear compressor is discussed.

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Presenter: Dr KO, Junseok (Korea Institute of Machinery & Materials)
Session Classification: C2PoB - Stirling and Pulse Tube Cryocoolers
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
The European Spallation Source (ESS) is a neutron-scattering facility funded and supported in collaboration with 17 European countries in Lund, Sweden. Cryogenic cooling at ESS is vital particularly for the linear accelerator, the hydrogen target moderators, a test stand for cryomodules and the neutron instrument sample environments. The paper will focus on specific process design criteria, design decisions and their motivations for the cryoplants and auxiliary equipment. Key issues for all plants and their process concept are energy efficiency, reliability, smooth turn-down behavior and flexibility. The accelerator cryoplant (ACCP) and the target moderator cryoplant (TMCP) in particular, need to be prepared for a range of refrigeration capacities due to the intrinsic uncertainties regarding heat load definitions. Furthermore questions regarding process arrangement, 2K cooling methodology, LN2 pre-cooling, helium storage, helium purification and heat recovery will be addressed.

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**Presenter:** ARNOLD, Philipp (European Spallation Source ESS AB)

**Session Classification:** C1OrE - Refrigeration and Liquefaction - sponsored by TechSource, Inc.

**Track Classification:** CEC-01 - Large-Scale Refrigeration and Liquefaction
Hypervelocity impacts into laminates: experiments and multiphase SPH computations

Orbiting satellites or manned spacecraft experience hypervelocity impacts from micrometeoroids and space debris. Thin shields are used for their protection, and are typically made of monolithic metals. For better weight-to-strength ratio, the use of metal/epoxy laminates offers an alternative and is investigated in this study.

The Smoothed Particle Hydrodynamics (SPH) numerical method has proven to be a reliable tool for the study of hypervelocity impacts. Nevertheless, traditional SPH schemes produce large errors when inhomogeneous materials are treated. For this purpose an SPH multiphase compressible scheme has been developed and tested against numerical benchmarks.

A set of hypervelocity impact experiments was performed in order to validate the computational methodology and also to serve as a guide for the design of new shielding structures. These experiments refer to hypervelocity impacts at 4-5 km/s of mm-sized Aluminum projectiles onto glue bonded Aluminum 2024 laminate. In particular, the bonding layer consists of Stycast 2850FT glue, which is known for its good performance under cryogenic conditions as encountered in space.

The present study, examines the experimental results vis-à-vis the results obtained by means of the developed SPH algorithm. Furthermore, it discusses the observed material opening and breakup patterns, while it finally gives directions for further improvement of the algorithm.

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Presenter: Mr ZISIS, Iason (TU Eindhoven, The Netherlands)

Track Classification: CEC-10 - Aerospace
Conceptual Design and Thermal Analysis of a modular Cryostat for one single coil of a 10 MW Offshore Superconducting Wind Turbine

Tuesday, 30 June 2015 17:15 (15 minutes)

The needs for high power offshore wind turbine are increasing continuously together with the rapid development of the wind power market. Superconductivity may be the only technology to scale wind turbines up to 10 MW and beyond by reduction of the nacelle mass. Accordingly, a superconducting 10 MW wind turbine concept for offshore applications is currently under development within the SUPRAPOWER project supported by EU FP7. The objective of this work is to provide an important breakthrough in offshore wind industrial solutions by designing an innovative, lightweight, robust and reliable 10 MW class offshore wind turbine.

The superconducting coils based on MgB2 are supposed to work at about 20 K. Due to the requirements of handling, maintenance, reliability of long term and offshore operation, a concept of semi-modular cryostat was proposed. A cryogen-free cooling method was selected in the design of the cryostat using two stage Gifford-McMahon cryocoolers. The required low temperature difference between the coldest point at the cryocooler cold head and the warmest point at the coil part farthest from the cryocooler requires a special design for a support structure of the coil inside the cryostat and a very good thermal insulation.

The support structures of the cryostat were thermally optimized in aim of reducing the heat load. With careful consideration of AC loss, heat transfer by radiation and conduction through support structure together with current leads, the thermal performance of superconducting coil were analyzed analytical and for comparison by the use of AnsysTM. In this paper, the concept of the cryostat and thermal analysis results will be given in detail.

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Presenter: Dr SUN, Jiuce (Karlsruhe Institute of Technology)
Session Classification: C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II
Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Optical refrigeration is currently the only completely solid state cooling method capable of reaching cryogenic temperatures from room temperature. Optical cooling utilizing Yb:YLF as the refrigerant crystal has resulted in temperatures lower than 123K measured via a fluorescence thermometry technique. However, to be useful as a refrigerator this cooling crystal must be attached to a sensor or other payload. The phenomenology behind laser cooling, known as anti-Stokes fluorescence, has a relatively low efficiency which makes the system level optimization and limitation of parasitic losses imperative. We propose and model a variety of potential designs for a final optical refrigerator, enclosure and thermal link; calculate conductive and radiative losses, and estimate direct fluorescence reabsorption. We generate parasitic load-lines; these curves define temperature-dependent minimum heat lift thresholds that must be achieved to generate useful cooling.

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**Session Classification:** C1PoJ - Novel Concepts and New Devices I

**Track Classification:** CEC-17 - Novel Concepts and New Devices
Performance analysis of cryogenic system and cryomodules for the complete superconducting linear accelerator at IUAC, New Delhi.

Tuesday, 30 June 2015 16:30 (15 minutes)

The heavy ion superconducting linear accelerator as a booster of 15 UD pelletron accelerator is commissioned and operating for more than a year. The acceleration is achieved by a series of superconducting quarter wave bulk niobium cavities at 4.2 K. In the first phase, accelerator was partly commissioned with 8 cavities in first linac cryomodule along with superbuncher and rebuncher. In the second and final phase two more linac cryomodules with eight cavities each were installed in beam line. New helium refrigerator of Linde make LR 280 along with the additional section of liquid helium distribution line were integrated with existing CCI make helium refrigerator. The cooling philosophy for five beam line cryomodules with the new refrigerator was modified to have faster cooling rate of 20 – 25 K of the cavities against earlier 8- 10 K/hr in the critical zone of 150- - 70 K. Pressure fluctuation in the helium vessel of cavities was reduced significantly to avoid frequent breaking of RF locks. The paper will discuss in detail about the performance of new cryogenic system and the cryomodules during beam acceleration run. A detailed experimental analysis on thermal response of helium refrigerator with variable heat load from the cavities will be reported.

Primary author:  Dr DATTA, Tripti Sekhar (Inter- University Accelerator Centre. New Delhi. India)

Co-authors:  Mr CHOUDHURY, Anup (Inter- University Accelerator Centre. New Delhi. India); Mr CHACKO, Jacob (Inter-University Accelerator Centre. New Delhi. India); Mr ANTONY, Joby (Inter-University Accelerator Centre); Mr KUMAR, Manoj (Inter- University Accelerator Centre. New Delhi. India); Mr SAHU, Santosh (Inter- University Accelerator Centre. New Delhi. India); Mr KAR, Soumen (Inter- University Accelerator Centre. New Delhi. India); Mr BABU, Suresh (Inter-University Accelerator Centre. New Delhi. India)

Presenter:  Dr DATTA, Tripti Sekhar (Inter- University Accelerator Centre. New Delhi. India)

Session Classification:  C2OrE - Cryogenic Systems II

Track Classification:  CEC-02 - Large-Scale Systems, Facilities, and Testing
Theoretical analysis and experimental investigation on performance of the thermal shield of accelerator cryomodules by thermo-siphon cooling of liquid nitrogen.

Tuesday, 30 June 2015 11:15 (15 minutes)

Five beam line cryomodules with total 27 superconducting RF cavities are installed and commissioned at IUAC to enhance the energy of heavy ion from 15 UD Pelletron. To reduce the heat load at 4.2 K, liquid nitrogen cooled intermediate thermal shield is used for all these cryomodules. For three linac cryomodules, concept of forced flow LN2 cooling is used and for superbuncher and rebuncher, thermo-siphon cooling concept is incorporated. It is noticed that the shield temperature of superbuncher varies from 90 K to 110 K with respect to liquid nitrogen level. The temperature difference can’t be explained by using the basic concept of thermo-siphon with the heat load on upstream pipe. A simple thermo-siphon experimental set up is developed to simulate the thermal shield temperature profile. Mass flow rate of liquid nitrogen is measured with different heat load on upstream pipe for different liquid level. It is noticed that small amount of heat load on downstream pipe have a significant effect on mass flow rate. The present paper will be investigating the data generated from thermo-siphon experimental set up and a theoretical analysis will be presented here to validate the measured temperature profile of the cryomodule shield.

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Presenter: Dr DATTA, Tripti Sekhar (Inter- University Accelerator Centre. New Delhi. India)

Session Classification: C2OrC - Pulsating Heat Pipes and Thermosyphons

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Flow of nitrogen gas in a liquid helium cooled vacuum tube: Condensation heat transfer

Monday, 29 June 2015 12:00 (15 minutes)

Linear accelerators (LINACs) using superconducting radio frequency (SRF) technology comprise of a long string of SRF cavities housed in discreet cryomodules. This cavity string is operated immersed in liquid helium (LHe) with high vacuum on its inside. Sudden loss of this cold vacuum to surrounding atmosphere perceivably is the worst failure mode of the LINAC. An accidental rupture at any cryomodule interconnect will initiate an air in-flow, which will solidify on the inner wall of the cold cavity and transfer heat to the LHe bath. Here, we study such a condensing flow with an emphasis on the associated heat deposition onto the cold walls, and the subsequent heat transfer to LHe. The flow is generated by rapidly venting a large reservoir of nitrogen gas to a long vacuum tube immersed in 4.2 K LHe. Experiments are carried out with different mass in-flow rates of nitrogen, and the rise of the pressure and temperature of the tube are recorded at several locations along the flow. As the gas pressure in the tube rises we observe that the rate of heat deposition due to condensation initially increases, attains a maximum, and then sharply drops. Irrespective of the mass in-flow rate of the gas (severity of the loss of vacuum accident) the maximum rate of condensation heat transfer to the tube occurs when the tube temperature is in 22-26 K range, and the pressure in the tube typically below 1 kPa. These observations are discussed in context of the cryopumping theory. With increasing gas pressure the tube temperature continues to gradually rise and eventually attains a steady value. The estimate of the peak heat load to the LHe bath is deduced from the maximum temperature attained by the tube.

This work is supported by US Department of Energy grant DE-FG02-96ER40952.

Primary author: DHULEY, Ram (Florida State University)
Co-author: VAN SCIVER, Steven (Florida State University)
Presenter: DHULEY, Ram (Florida State University)
Session Classification: C1OrB - Cryogenic Heat Transfer
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Performance analysis of superconducting generator electromagnetic shielding

Monday, 29 June 2015 09:00 (2 hours)

The magnetic induction intensity of superconducting generator can reach a few Tesla, relative to the conventional generator, it has small volume and weight, compact structure, high power density and efficiency, big ultimate capacity, good stability, so superconducting generator is regarded as one of the attractive and novel generator with business competitiveness in the near future. Electromagnetic shielding is one of the unique special structure of superconducting generator. When superconducting windings work in an alternating magnetic field, AC losses are produced in the windings. The losses increase the low temperature medium dosage and refrigeration power consumption and cause temperature rise, so that the efficiency of the generator is reduced. When serious, temperature rise will lead to the quench of superconducting tapes. The electromagnetic shielding is used to shield the superconducting windings from the alternating magnetic field and reduce the effect of alternating magnetic field on the superconducting windings, in order to ensure the normal work of the superconductor in the superconducting state, improve the efficiency of generator. For the superconducting generator, the electromagnetic shielding is a very important key part.

Using Maxwell equation of electromagnetic field and the mechanical motion equation, it is established the steady state and transient finite element analysis model, which is suitable for the problem of thin wall cylinder of high temperature superconducting generator electromagnetic shielding. In different operation state of a high temperature superconducting generator, the magnetic field and eddy current distribution in the monolayer and multilayer shielding cylinder are calculated, shielding coefficients of the electromagnetic shielding are obtained, and the calculation results are analyzed and compared. The results provided in this paper are helpful to optimization design of superconducting generator electromagnetic shielding.

Primary author: XIA, dong (Chinese Academy of Sciences)
Co-author: Mr XIA, zheng (Shenyang University of Technology)
Presenter: XIA, dong (Chinese Academy of Sciences)
Session Classification: C1PoA - Cryogenics for Power Applications, Energy, Fuels and Transportation I
Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Study of He II Boiling Flow Field around a Heater

Boiling phenomena in He II were studied on the basis of the flow velocity field derived from flow field visualization and a PIV (Particle Image Velocimetry) measurement. Noisy and silent film boiling modes together with non-boiling state were generated on/around a horizontal planar and a cylindrical heaters. For PIV tracer particles, H2-D2 micro solid particles that were neutrally buoyant in He II were used. Video images showing the development and crush of vapor bubble or film and the motions of tracer particles dragged by the normal fluid component were used for visualization and PIV-analyzed. The PIV result of the boiling velocity field indicated that they were composed of AC and DC velocity components of the normal fluid. The AC component follows the dynamic behavior of vapor phase, and the DC results primarily from the thermal counter flow and secondarily is induced by the rising vapor bubbles due to buoyancy. In this study, unsteady velocity fields are investigated as well as the steady and the RMS velocity fields. It is the objective of the study that the characteristic features of flow field of He II film boiling modes and He I boiling mode in He II as well as of the non-boiling state, are compared with each other and the difference in the heat transfer performance of each boiling mode is made clear.

Primary author: Prof. MURAKAMI, Masahide (University of Tsukuba)
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Presenter: Prof. MURAKAMI, Masahide (University of Tsukuba)
Session Classification: C3OrJ - Special Session: Helium II Properties and Systems
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Investigation on the cold finger and compressor of a miniature pulse tube cryocooler

Pulse tube cryocoolers consist of compressors, cold fingers and phase shifting devices. The cooling performance of pulse tube cryocoolers mainly depend on the following two aspects, the dynamic behaviors of the compressors and the oscillating flow in the regenerators of the cold fingers, which are associated with the phase shifting performance of the phase shift devices.

In this paper, the influence of phase shifting devices on the performances of the compressor and cold finger of a miniature pulse tube cryocooler are investigated. A series of phase shifting devices are employed to adjust the working state of the compressor and cold finger. First, the phase shifting characteristics of the phase shifting devices are tested coupling with cold finger under different frequencies and working temperatures and cooling powers of the cold finger. Then, the performances of the compressor and cold finger are studied based on the experimental data. At last, a miniature pulse tube cryocooler is developed considering cooling performance, weight and reliability. The miniature pulse tube cryocooler can supply 1.5W@ 80K cooling power with an input power of 45W.

Primary author:  TANG, Qingjun
Co-author: Dr CHEN, Houlei (TIPC, Beijing China)
Presenter: Dr CHEN, Houlei (TIPC, Beijing China)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
The process design of the forced-flow cooled for CFETR CS model coil

Thursday, 2 July 2015 10:00 (15 minutes)

Superconducting magnet of Central Solenoid (CS) model coil of China Fusion Engineering Test Reactor (CFETR) is made of Nb3Sn/NbTi cable-in-conduit conductor (CICC), and operated by forced-flow cooling with a large amount of supercritical helium. The cryogenic circulation pump can be effective to achieve the supercritical helium (SHe) circulation to the forced-flow cooled (FFC) cable-in-conduit conductor (CICC) magnet. A distribution system will be constructed for cooling the CFETR CS model coil. This paper presents the design of FFC process for the CFETR CS model coil.

Primary author: Mr CHENG, Anyi (Institute of Plasma Physics, Chinese Academy of Sciences)

Co-authors: Mr FU, Bao (Institute of Plasma Physics, Chinese Academy of Sciences); Mr ZHANG, Qiyong (Institute of Plasma Physics, Chinese Academy of Sciences); Mr LU, Xiaofei (Institute of Plasma Physics, Chinese Academy of Sciences)

Presenter: Mr ZHANG, Qiyong (Institute of Plasma Physics, Chinese Academy of Sciences)

Session Classification: C4OrC - Cryogenic Systems and Facilities

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
The hydrogen circulation cold box of CSNS cryogenic system

Tuesday, 30 June 2015 14:00 (2 hours)

CSNS cryogenic system offers 1.5 MPa hydrogen as a neutron moderator at 18 ~ 22 K, and the para hydrogen concentration is higher than 99%. Two cold boxes were adopted, one is hydrogen circulation cold box and the other is accumulator cold box. The main equipments in the hydrogen circulation cold box are ortho-para convertor, H2-He heat exchanger, hydrogen circulators and hydrogen heater. And the accumulator was arranged in the accumulator cold box. Design proposal of the CSNS hydrogen circulation cold box was analyzed, and the structure of the cold box was determined. Double-cold boxes with external instrument control cabinet were selected. This paper introduced the engineering design, strength check, thermal loss analysis and the processing technology of the two cold boxes.

Primary author: Ms WANG, yaqiong (Institute of High Energy Physics)

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Presenters: Dr WANG, Guoping (Institute of High Energy Physics(IHEP)); Ms WANG, yaqiong (Institute of High Energy Physics)

Session Classification: C2PoH - Hydrogen Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Experimental Research of a Hybrid 4K J-T Cryocooler

Key Laboratory of Space Energy Conversion Technologies of TIPC, CAS has developed a 4.5K Joule-Thomson (J-T) refrigerator precooled by a three-stage pulse tube cooler. In this paper, special attention is paid to the characteristics of the J-T cycle, so a commercial two-stage GM cryocooler is used to provide precooling for the J-T cycle for the purpose of shorten experimental time. The analysis of the system performance results at different operating conditions are presented and discussed in detail. When only the power consumption of J-T compressors is considered, the COP (coefficient of performance) of the refrigerator is calculated to evaluate the performance of J-T cycle. Influence of charge pressure on cooling capacity is analyzed. Then experimental research is carried out to validate the theoretical result and cooling capacity of 12mW is gained at 4.5K. Orifice of different diameters is also studied to explore the effect of throttling resistance on the performance of J-T cooler. In order to increase pressure ratio, two compressors are used in J-T cryocooler, but experimental results of one stage compression is also demonstrated to confirm the necessity of the second stage compressor.

Primary author: Dr MA, Yuexue (Technical Institute of Physics and Chemistry CAS)

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Presenter: Dr LIU, Yanjie (Technical Institute of Physics and Chemistry CAS)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
The Designing and Testing of All Gas Bearing Helium Turbine of EAST Cryogenic System

The cryogenic system is one of the most important subsystems of EAST (Experimental Advanced Super-conducting Tokamak). Helium turbines is the core parts of cryogenic system. One of the four helium turbines is chose to be designed, manufactured and tested. Some analysis of the helium turbine structure, testing process and the testing results are given. The starting up process and the operational experience of gas bearing helium turbines are also present in this paper.

Primary author: Mr FU, Bao (Institute of Plasma Physics, China Academy of Sciences)
Co-author: Mr ZHANG, QiYong (Institute of Plasma Physics, China Academy of Sciences)
Presenter: Mr FU, Bao (Institute of Plasma Physics, China Academy of Sciences)

Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Proposed Thermodynamic Nomenclature of Cryogenic Refrigeration Cycles for Liquefaction of Natural Gas

Monday, 29 June 2015 14:00 (2 hours)

A new and systematic naming method is proposed as academic nomenclature of cryogenic refrigeration cycles for liquefaction of natural gas. Over decades, a large number of LNG processes have been designed and patented, even though only a few are operational in practice, including SMR (single mixed-refrigerant), C3-MR (propane-precooled mixed-refrigerant), cascade, or AP-X processes. These processes have been named and widely called by the refrigerants used in the cycles, by a technical term, or even by a proper noun (or a “product” name). In order to identify and reasonably compare the thermodynamic nature, it is necessary to name the closed refrigeration cycles more logically from an academic point of view. The nomenclature is composed of three components: (1) the refrigerant (methane, nitrogen, mixed-refrigerant, etc.) (2) the number of stages (1, 2, 3, etc.), and (3) the cycle type (JT, Brayton, Claude, etc.) In addition, the series or parallel combination of two or more cycles is denoted by symbols (+, //, etc.). Abbreviation (with “factorization” formula) is also presented for short and convenient notation.

This research is supported by a grant from the LNG Plant R&D Center funded by the Ministry of Land, Infrastructure and Transport (MOLIT) of Korean government.

Primary author: CHANG, Ho-Myung (Hong Ik University)
Co-authors: Ms LIM, Hye Su (Hong Ik University); Mr CHA, Kyu Sang (Korea Gas Corporation)
Presenter: Ms LIM, Hye Su (Hong Ik University)
Session Classification: C1PoG - Thermal Analysis and Design
Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Progress in Development of a 10 kW Brayton Cryocooler for HTS Cable in Korea

Recent progress in the development of a 10 kW Brayton cryocooler is presented for HTS cable systems under installation in Jeju Island, Korea. The role of this cryocooler is to continuously cool a liquid-nitrogen flow from 78 K to 67 K, and the liquid is pumped to three-phase 154 kV cable over a length of 1 km. The refrigerant of cryocooler is helium, whose operating pressure and flow rate was determined earlier from a thermodynamic study on reversed-Brayton cycle. As main components, heat exchangers and turbo-expanders are designed and fabricated by custom-orders. The heat exchangers are made of aluminum-brazed plate-fins, and the coldest part is arranged as two-pass cross-flow in accordance with our experimental study for preventing the freeze-out of liquid nitrogen. Two identical turbo-expanders are employed in parallel at the cold end, where the maximum rotating speed with gas bearings reaches 180,000 rpm and the output power is dissipated with eddy current brakes. The assembly is completed and the refrigeration capacity is measured with a dummy thermal load on the liquid-nitrogen stream. Details of thermal performance and short-term plans are reported towards an immediate application to the HTS cable systems.

This research is supported by a grant of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) for Power Generation & Electricity Delivery Program (No. 2014101050231B), funded by the Ministry of Trade, Industry and Energy of Korean Government.

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Presenter: CHANG, Ho-Myung (Hong Ik University)

Session Classification: C1PoB - Intermediate Temperature Systems

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
The Research of PID Control in a Large Scale Helium Refrigerator

In the development of a helium refrigerator, the control of load temperature stability is an important requirement. We usually use multistage control strategies to achieve the precise control of it. Each level has its strict control logic. PID controller is the core control module in the process. Therefore, a research of its principle and parameter settings occupies an important position in the development work. This paper detailed describes the PID control principle used in a large scale helium refrigerator of 10kW@20K at TIPC CAS, as well as several improvements on PID parameter settings, by using simulations and experiments in combination. The temperature is eventually controlled more precise.

**Primary author:**  Ms PAN, Wei (01082543662)  
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**Presenter:**  Ms PAN, Wei (01082543662)  

**Track Classification:**  CEC-01 - Large-Scale Refrigeration and Liquefaction
Continuous flow cryostats are used to cool samples to a variable temperature level by evaporating a cryogen, e.g. liquid helium (LHe). For this purpose LHe is usually stored outside the cryostat in a mobile dewar and supplied with a transfer line. In general, the complete setup has to be characterised by a low consumption of LHe. Additionally, a minimum sample temperature is favourable from an experimental point of view. The achievement of both requirements is determined by the respective cryostat design, as well as by the transfer line performance. Characteristic operating data, e.g. the LHe consumption during cool-down and steady state, the sample temperature and the outlet quality, are achieved with a test rig similar to a common continuous flow cryostat setup. In addition, an experimental transfer line with built-in pressure sensors has been commissioned to examine the frictional pressure drop of the LHe flow inside the transfer line. The presented operating data provide the basis for the development of an improved transfer line design as part of an ongoing research project. A decreased LHe consumption will reduce the operating costs of a continuous flow cryostat. Furthermore, decreased sample temperatures widen the field of application for continuous flow cryostats operated with LHe.

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**Presenter:** Mr DITTMAR, Nico (Technische Universitaet Dresden)  
**Session Classification:** C2PoC - Instrumentation and Controls I  
**Track Classification:** CEC-15 - Instrumentation and Controls
Evaporation Study for Integration of SOFI and MLI in Orbiting Liquid Oxygen Storage

As a cryogenic propellant of aircrafts, liquid oxygen has a low boiling point and can evaporate easily. It’s significant to conduct the research in the orbiting storage of liquid oxygen for deep space exploration. Spray-on foam insulation (SOFI) and Multilayer insulation (MLI) are combined in storage of liquid oxygen. In our research, we built the evaporation test-bed for liquid oxygen ellipsoidal tank, and tested the evaporation characteristics of different insulation processes in simulated orbiting conditions. The reflector layer and the separator layer are integrated together in the testment. The results show that daily evaporation rate of liquid oxygen reached less than 0.2% in high vacuum conditions, with boundary temperature of 90 K and 293K. Also, the meridional and zonal temperature distribution of different insulation layer is studied at steady-state. As the oxygen pressure rose from 0.1MPa to 0.6MPa, its saturation temperature (cold boundary temperature) increased from 90.06 K to 111.46K. The thermal performance of insulation system at different liquid oxygen pressures will be presented in this paper. And we predicted the direction of next exploration improvement.

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**Presenter:** Prof. WANG, Junjie (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

**Track Classification:** CEC-14 - Thermal Insulation Systems
Shift of the Fp-B curve peak of Nb3Sn conductors with very fine grain sizes

Tuesday, 30 June 2015 11:30 (15 minutes)

In an earlier work we demonstrated on a monofilament that the internal oxidation method can significantly refine the grain size and improve the high-field Jc of Nb3Sn strands. In that work we found that as the Nb3Sn grain size was reduced down to 20-50 nm (with an average of 36 nm), the peak of the Fp-B curve shifted from 0.2Birr to 0.34Birr. In this work we further reduce the grain size by using a lower reaction temperature and a higher-Zr Nb-Zr alloy, in order to find out how the Fp-B curve peak shifts as grain size decreases. A pinning theory is also developed to explain the shift of the Fp-B curve peak as grain size is reduced. In this work we also work towards implementing the internal oxidation method in practical multi-filamentary tube type Nb3Sn strands. Schemes to apply this method to rod-restack-process (RRP) and powder-in-tube (PIT) strands are also proposed.

Primary author:  XU, Xingchen (the Ohio State University)

Co-authors:  SUMPTION, Mike (The Ohio State University);  Dr COLLINGS, Ted (the Ohio State University);  Dr PENG, Xuan (Hyper Tech Research Inc.)

Presenter:  XU, Xingchen (the Ohio State University)

Session Classification:  M2OrA - Superconductor Materials III: Nb3Sn

Track Classification:  ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Suppression of persistent-current magnetization of Nb3Sn strands by transport current

Tuesday, 30 June 2015 09:00 (2 hours)

For Nb3Sn strands used in magnets, persistent-current magnetization must be carefully considered because it is an important contributor to field errors in magnets. Compared with the usual measurements by magnetometers, the true magnetizations of Nb3Sn strands used in magnets are in fact smaller because the transport currents they are carrying suppress their magnetizations. In an earlier work we investigated this influence on a cylindrical wire with constant Jc(B) by finite element modeling (FEM). In this work we experimentally measure the magnetization of a practical Nb3Sn strand with transport current using a lab-designed device equipped with two Hall probe magnetometers. This experiment yields a quantitative estimation of the dependences of the strand magnetization on transport current and magnetic field.

Primary author:  XU, Xingchen (the Ohio State University)

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Presenter:  XU, Xingchen (the Ohio State University)

Session Classification:  M2PoA - Superconductors Materials II: Nb3Sn, FeAs-based

Track Classification:  ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
ULTRA-FLEXIBLE THERMAL BUS FOR USE IN THE ASTRO-H ADIABATIC DEMAGNETIZATION REFRIGERATOR

Monday, 29 June 2015 11:00 (15 minutes)

The adiabatic demagnetization refrigerator (ADR) developed for the Astro-H Soft-Xray Spectrometer (SXS) is a multi-stage solid-state cooler. It is capable of holding the SXS detector array at 0.050 K for greater than 24 hours with a recycle time of less than one hour. This quick recycle time relies upon high-conductivity thermal straps to couple the individual stages to a pair of heat switches without imposing a lateral load on the paramagnetic salt pills. To accomplish this we construct thermal straps using a technique of diffusion bonding together the ends of high-purity copper straps leaving the length between as individual foils. A thermal bus created this way has a thermal conductivity comparable to a solid strap of the equivalent thickness but with much-increased flexibility. The technique for selecting the base material, machining, cleaning, forming into final shape, and finally bonding together individual foils will be discussed along with examples of complete straps in various geometries.

Primary author: Dr KIMBALL, Mark (NASA/Goddard Space Flight Center)
Co-author: SHIRRON, Peter (N)
Presenter: Dr KIMBALL, Mark (NASA/Goddard Space Flight Center)
Session Classification: C1OrB - Cryogenic Heat Transfer
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
A thermally-conductive electrical isolator for use at ultra-low temperatures in the Astro-H Adiabatic Demagnetization Refrigerator

Monday, 29 June 2015 11:15 (15 minutes)

The Soft X-ray Spectrometer (SXS) destined for the Japanese Astro-H mission contains a 6x6 array of microcalorimeters. To achieve ultimate resolution the array must be electrically isolated from the rest of the instrument as well as cooled to 0.050 K. The latter is achieved by directly coupling it to the coldest stage of a multi-stage Adiabatic Demagnetization Refrigerator (ADR). Thus, the electrical isolation is in-line with a portion of the cooling chain demanding the dielectric be thermally conductive at sub-Kelvin temperatures. We present here the design that balances electrical isolation with reasonable thermal conductance below 1-Kelvin.

Primary author: KIMBALL, Mark
Co-author: SHIRRON, Peter (N)
Presenter: KIMBALL, Mark
Session Classification: C1OrB - Cryogenic Heat Transfer
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Comparison of coil cooling techniques for a 25 MeV compact superconducting cyclotron

A compact superconducting cyclotron is being designed at Variable Energy Cyclotron Centre, Kolkata, India. This cyclotron shall be dedicated for medical applications specifically in the field of nuclear medicine and therapy. The cyclotron magnet will be made of NbTi superconducting coils wound on an Aluminium former. The coils will be segregated in two halves on either sides of the median plane. Each half will consist of four solenoid coils of different diameters and lengths. In addition, there will be four sectors each comprising of three sector coils of different sizes. These sector coils will provide the azimuthally varying component of magnetic field. This cyclotron is unique in its composition since it does not contain any iron. The average magnetic field calculated is 1.74 T and the maximum extraction energy will be 25 MeV which is sufficient for production of $^{99m}$Tc from Mo. The set of coils will be supported with glass-epoxy links attached to the former to reduce conduction heat load to the coils.

Two different methods of cooling have been proposed for the cyclotron. In the first method, the superconducting coils will be conduction cooled with the help of breaded Copper strips directly connecting the coil former walls with the cold head of cryocoolers. The second one is buoyancy induced recondensation cooling method. In this case liquid helium will pass through channels attached to the former surface to take the heat away from magnet and will get recondensed back in cryocoolers placed outside the cryostat. This paper presents the detailed design methodologies of both the cooling techniques and a comparison has been drawn in terms of temperature distribution in coils and rate of heat transfer achieved at steady state.

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Presenter: Mr GHOSH, Sundeep (Variable Energy Cyclotron Centre)

Track Classification: CEC-06 - Superconducting Magnet Systems
Recent development status of compact 2K GM cryocoolers

Wednesday, 1 July 2015 11:30 (15 minutes)

To meet the growing demand for compact cooling solution required by superconducting electronic devices, we developed a two-stage 2K GM cryocooler with cryostat system which can provide 0.1 W / 20 mW cooling power at 45 K / 2.3 K for first and second stage under no-load condition. Nevertheless, with several innovative technologies applied, the total length of expander cylinder is shortened to under 70% compared with the smallest conventional 4K GM cryocooler. In this paper we will present the design methods including material selection and structure design with detailed explanation which have been confirmed by both simulation and experimental results. The research results have been achieved by "Development of a Compact Superconducting Single Photon Detector System for Photon-Quantum Information and Communication", the National Institute of Information and Communications Technology (NICT), JAPAN.

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Presenter: BAO, Qian (Sumitomo Heavy Industries, Ltd.)
Session Classification: C3OrD - 4K Cryocoolers
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Experimental study of one-stage VM cryocooler operating below 8K

The Vuilleumier (VM) refrigerator, known as heat driven refrigerator, is one kind of closed-cycle Stirling type regenerative refrigerator. The VM refrigerator with power being supplied by liquid nitrogen was proposed by Hogen and developed by Y. Zhou, which shows great potential for development below 10K.

This paper describes the design and development of a VM cryocooler operating below 8K. The experimentation was achieved by using liquid nitrogen as a heat sink of middle cavity. The regenerator was optimized by using a part of ceramic magnetic regenerator material Er3Ni to replace the lead sphere. The arrangement of regenerative material in the regenerator was also optimized. Using He4, a temperature below 8K has been obtained with a pressure ratio near 1.6, working frequency of 0.8Hz, and charge pressure of 1.8 MPa. The cooling power at 10K is about 500mW.

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Presenter: Prof. JUNJIE, Wang (Technical Institute of Physics and Chemistry)

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Application of plate-fin heat exchangers with different UAs for mitigating the effects of pulsed heat load

The heat loads of the superconducting magnets in an international fusion device are pulsating with time, which will cause the variation of the return mass flow of the refrigerator. It is necessary to mitigate the fluctuation of the mass flow to avoid the performance degradation of turbines and compressors which designed to operate in a narrow range of mass flow. In this paper, a novel technical was suggested after thermodynamic analysis, where a traditional single heat exchanger was replaced by two plate-fin heat exchangers in cold end. Though reasonable selection of the UAs, the mass flow fluctuation could be decreased. The results of the dynamic simulation revealed that the fluctuation of mass flow only occurred in the short time, the average mitigation was greater than 95%.

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Presenter: Prof. LI, Lai Feng (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
CFD studies on heat transfer and pressure drop characteristics of an offset strip-fin heat exchanger in helium systems

The accuracy of correlations of colburn(j) and friction(f) factor have important effect on the accuracy of simulation results in the dynamic simulation of large scale helium systems. However, the most available correlations in the literatures and experimental results are used air as heat transfer medium. A steady-state three-dimensional numerical model was built to study the heat transfer and pressure drop characteristics of an offset strip-fin heat exchanger in helium systems. Then, the j and f factor were obtained under different Reynolds though numerical analysis. These results were compared with the existing results obtained by air to find the influence of different fluid medium. Further, the most suitable and convenient correlations for helium were developed by regression analysis. This work may be helpful to guide the selection of the general correlations of j and f in calculation of heat exchanger in dynamic simulation.

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Presenter: Prof. LI, Lai Feng (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Experimental and simulation study on a Vuilleumier cryocooler with larger pressure ratio

The pressure ratio of Vuilleumier(VM) cryocooler is generally smaller than GM cryocooler, which evidently affects its terminal temperature and refrigeration. In this paper, a detailed study on a VM cryocooler with larger pressure ratio is introduced. By increasing the hot displacer’s stroke distance and shortening its length on the original experimental system which could achieve a no-load temperature 9K, the pressure ratio raised from 1.4–1.8 to 1.7–2.1. Experimental results indicate that simply increasing the pressure ratio could not achieve a lower temperature and the cold end regenerator which has significant influence on the performance of VM cryocooler should be optimized in the energy storage capacity to adapt to the increased work mass. In addition, volume specific heat capacity, thermal penetration distance and flow resistance have to be comprehensive considered while selecting the regenerator materials. By optimizing the regenerator materials of the cold end regenerator, a no-load temperature at 9.2K was achieved so far. Finally, establish a simulation of the cryocooler using the software Sage. Comparing with the experimental results could verify the accuracy of the program and find the optimal way to improve the experimental system.

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Presenter: Prof. WANG, Junjie (Technical Institute of Physics and Chemistry, CAS)

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Expansion Vessel for Supercritical Hydrogen in a Spallation Neutron Source Moderator Circuit

High-energy neutrons are being decelerated by passing through supercritical parahydrogen circulated by pumps in a closed loop. Fluctuations in neutron heat load cause changes of the circuits’ local and average temperature and hence significant pressure variations if it is not taken care of the nearly incompressible behavior of hydrogen. Solutions by adding a variable volume in form of a helium gas-backed metal bellow to mitigate pressure deviations are already in use. This paper presents an alternative approach by introducing a vertical storage vessel for supercritical hydrogen in a side arm of the moderator loop, with cold incompressible high density hydrogen at the bottom and warmer compressible lower density hydrogen at the top. The engineering challenge is to keep the temperature profile in the vessel stable under all operating conditions.

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Presenter: KLAUS, Marcel (Technische Universitaet Dresden)

Session Classification: C1PoJ - Novel Concepts and New Devices I

Track Classification: CEC-17 - Novel Concepts and New Devices
An investigation on the Application of ErPr Packed Sphere Matrix in Stirling Type Pulse Tube Cryocooler

This paper introduces a new kind of packed sphere matrix made with ErPr, and analyzes the application in Stirling type pulse tube cryocooler. In pulse tube cryocoolers, ideal regenerator requires regenerator matrix high in specific heat, low in flow resistance and conductive heat loss. However, below the liquid hydrogen temperature the specific heat of stainless steel decreases significantly, while that of helium rises as the temperature decreases from 25 K to 10 K. This makes the regenerator low in efficiency. Due to the magnetic phase transition, the specific heat of ErPr rises at the temperature of 30 K as the temperature decreases, which makes it superior to other regenerator matrix materials in specific heat at low temperature. To understand the material better, experiments have been designed to test the thermal conductivity and flow resistance of porous media. Several kinds of regenerator matrix materials have been tested and compared in thermal conductivity. The flow resistance of packed sphere matrix in different sizes has been measured at both low and ambient temperature. To analyze the application of ErPr in Stirling type cryocooler, a co-axial multi-bypass Stirling type pulse tube with ErPr made regenerator has been modeled and analyzed in commercial software.

*This research is supported by The National Natural Science Foundation of China (No. 51327806 and No. 51427806).*

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**Presenter:** CHEN, Liubiao (Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, CAS)

**Track Classification:** CEC-05 - Expanders, Pumps, Compressors, and Regenerators
The X-IFU instrument for X-ray observation on ESA’s new ATHENA satellite will employ a complex cryogenic chain for detector-cooling down to 50 mK, similar to the one foreseen for the European SAFARI instrument onboard SPICA (JAXA). A problem that typically arises from the use of such systems is the existence of heat peaks during the recycling stages of some parts that can compromise the stability of the entire chain.

Like previously developed Energy Storage Units (ESU) [1, 2] a liquid hydrogen ESU is presented as a solution for absorbing the heat peaks released by the recycling of a 300 mK cooler, without significant temperature increase. This device is capable of storing 400 J of thermal energy between 15 and 16 K, by taking advantage of the liquid-to-vapor latent heat of hydrogen in a closed system. The ESU is composed by a low temperature liquid hydrogen reservoir, two interfaces for gas precooling and a hydrogen gas storage vessel at room temperature. This vessel can either be an expansion volume (for preliminary testing) or, at an advanced stage, a canister filled with a metal hydride, LaNi4.8Sn0.2, that chemically absorbs hydrogen. This largely reduces the volume of the vessel, since its storage density is higher than that of liquid hydrogen. Metal hydrides might also enable working at near-constant pressure and temperature in the cold cell, comparable to what would be achieved at a triple-point transition.

Along with preliminary results on ESU performance, challenges such as microgravity, mass/volume budgets and meeting specific ESA requirements that arise from working on space-ready systems are addressed and discussed.

[1] Afonso, J. et al., Cryogenics 51 (2011) 621

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**Session Classification:** C4OrD - Novel Concepts and New Devices III

**Track Classification:** CEC-17 - Novel Concepts and New Devices
Fast-response, active gas-gap heat switches for low temperature applications

Wednesday, 1 July 2015 15:00 (15 minutes)

Heat switches are critical to many low temperature applications, where control of heat flow and selective thermal isolation are required. Their designs tend to be driven by the need for the lowest possible off-state conductance, while meeting requirements for on-state conduction. As a result, heat switches tend to be designed as close as possible to the limits of material strength and machinability, using materials that have the lowest thermal conductivity to strength ratio. In addition, switching speed is important for many applications, and many designs and switch types require a compromise between the power used for actuation and on/off transition times. We present a design for an active gas-gap heat switch, developed for the Soft X-ray Spectrometer instrument on the Japanese Astro-H mission, that requires less than 0.5 mW of power to operate, has on/off transition times of <1 minute, and that achieves a conductance of >50 mW/k at 1 K with a heat leak of <0.5 µW from 1 K to very low temperature. Details of the design and performance will be presented.

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Co-author: KIMBALL, Mark
Presenter: SHIRRON, Peter (NASA/GSFC)
Session Classification: C3OrG - Cryogenic Instrumentation and Control Systems
Track Classification: CEC-15 - Instrumentation and Controls
Gas gap heat switch for a Cryogen-free magnet system

Wednesday, 1 July 2015 09:00 (2 hours)

Cryogen-free superconducting magnet systems (CFMS) have become popular over the last two decades for the simple reason that the use of liquid helium is rather cumbersome and that helium is a scarce resource. Some available CFMS use a mechanical cryocooler as the magnet’s cold source. However, the variable temperature inserts (VTI), for any CFMS, are not cryogen-free as they are still based on helium gas circulation through the sample space.

We designed a prototype of a gas gap heat switch (GGHS) that allows a thermal management of a completely cryogen-free magnet system, with no helium losses. The idea relies on a parallel cooling path to a variable temperature insert (VTI) of a magnetic properties measurement system under development at Inter-University Accelerator Centre. A Gifford-McMahon cryocooler (1.5 W @ 4.2 K) would serve primarily as the cold source of the superconducting magnet, dedicating 1 W to this cooling, under quite conservative safety factors. The remaining cooling power (0.5 W) is to be diverted towards a VTI through a controlled GGHS that was designed and built with a 100 µm gap length.

The built GGHS thermal performance was measured at 4 K, using helium as the exchange gas, and its conductance is compared both with a previously developed analytical model and a finite element analysis. Lessons learned lead to a new and more functional prototype yet to be reported. Modifications include an improved assembly and an upgraded cryopump actuator.

In order to achieve the optimization of the diverted heat flux we suggest using a temperature-controlled sorption pump to manage the pressure inside the GGHS, consequently varying the conductance all the way from the OFF to the ON state.

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Session Classification: C3PoD - Superconducting Magnets Cryogenic Systems I

Track Classification: CEC-17 - Novel Concepts and New Devices
First helium measurements with a new cryogenic flow meter

Tuesday, 30 June 2015 14:00 (2 hours)

A new method for flow measurement in cryogenic systems was published recently. The caloric measuring principle is based on two analytical and linearly independent evaluation functions for the mass flow rate, both using the same temperature and heater power measuring data as input parameters. This enables a complete compensation of systematic errors, as well as in situ calibration of the flow meter during operation. The remaining measurement uncertainty, constituting only of random errors, is typically less than 1% with regard to the actual flow rate.

The Karlsruhe Institute of Technology and WEKA AG, Switzerland, are presently developing a commercial flow meter for application in helium cryostats. The flow meter, which consists of a cryogenic sensor and room temperature electronics, is designed for operating temperatures between 300 K and 4 K, for pressures up to 5 MPa and for helium flow rates of 0.2 to 12 g/s. The sensor design is compact, which enables the installation in most helium cryostat and transfer systems.

This paper presents the results of first low-temperature experiments with supercritical helium, which were carried out in a control cryostat of the 2 kW helium refrigerator of the TOSKA test facility. The new flow meter was connected in series to an existing Venturi tube, which was used for reference measurements.

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Presenter: Mr JANZEN, Andreas (Karlsruhe Institute of Technology, Institute for Technical Thermodynamics and Refrigeration)

Session Classification: C2PoK - Instrumentation and Controls II

Track Classification: CEC-15 - Instrumentation and Controls
An Investigation on A New Structure of Stirling Type Two-stage Pulse Tube Cryocooler

This paper introduces a new structure of Stirling type two-stage cryocooler driven by a linear compressor with an input power of 250W at an operating frequency of 27 Hz. The cryocooler is compact in structure, for both of the two stages have a co-axial configuration and the reservoir of the second stage also works as the radiation shield. The warm end of the second stage is set at the cold end of the first stage. For both stages, the regenerator matrix consists of a stack of stainless steel screen. The second stage applied a capillary tube and a reservoir as phase shifters. At the operating frequency of 27 Hz the noload temperature 16.3 K has been achieved at the second stage and 47 K at the first stage. The influence of charge pressure, input power and cold phase shifter are also reported.

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Presenter: CHEN, Liubiao (Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, CAS)

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Development of a cooling system for 66/6.9kV-20MVA REBCO superconducting transformers with a Ne turbo-Brayton refrigerator and subcooled liquid nitrogen

Monday, 29 June 2015 09:00 (2 hours)

In Japan, we have developed 3φ-66/6.9kV-20MVA RE1Ba2Cu3O7-δ (RE: Rare Earth, Y, Gd and so on, REBCO) superconducting transformers with a current limiting function as a national project. First we made a basic research on the ac loss reduction and the enhancement of current capacity of REBCO superconducting tapes, the dielectric strength of liquid nitrogen, a current limiting function of REBCO superconducting windings and so on. The subcooling of liquid nitrogen was required from the viewpoint of dielectric strength. We have finished the design of a 20MVA transformer and fabricated a 1/10 model, i.e. 3φ-66/6.9kV-2MVA one. The superconducting windings were installed in a GFRP cryostat and cooled with subcooled liquid nitrogen at 65 to 77 K. The iron core was located at room temperature. For the sake of a long maintenance interval and a high cooling efficiency, we developed a turbo-Brayton refrigerator with neon gas as a working fluid. The cooling capacity was 2kW at 65K. Here an expansion turbine and a two-stage turbine compressor with non-contact magnetic bearings were adopted. In the 2MVA model, liquid nitrogen was forced-flowed between the GFRP cryostat and an additional cryostat in which a pumping system and a heat exchanger between the neon gas and the liquid nitrogen were installed. In addition, for the future system, we are making a research and development of a new cooling system in which a radiator-type heat exchanger was directly installed into the GFRP cryostat. In this paper we will report the progress of the research and development.

This work was supported in part by New Energy and Industrial Technology Development Organization (NEDO) as Technological Development of Yttrium-based Superconducting Power Equipment.

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Presenter: IWAKUMA, Masataka (Kyushu University)
Session Classification: C1PoA - Cryogenics for Power Applications, Energy, Fuels and Transportation I
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Fabrication of Biomedical Titanium Alloys with High Strength and Low Modulus by Spark Plasma Sintering

Monday, 29 June 2015 14:00 (2 hours)

Ti–24Nb–4Zr–8Sn, abbreviated as Ti2448 from its chemical composition in weight percent, is a multifunctional β type titanium alloy with body centered cubic (bcc) crystal structure, and its highly localized plastic deformation behavior contributes significantly to grain refinement during conventional cold processing. In the paper, in order to explore an effective method to fabricate biomedical Ti alloy with high strength and low modulus, Ti2448 alloy powders were synthesized via mechanical alloying and subsequently ultrafine-grained Ti alloy with high strength and low modulus were fabricated via the spark plasma sintering. The effects of sintering temperature on the microstructure of the synthesized Ti2448 were investigated using scanning electron microscope (SEM) and transmission electron microscope (TEM). Also the effects of ball milling and SPS conditions on the mechanical property in the low temperature of the Ti2448 alloy have been discussed. Such Ti alloys with noteworthy mechanical properties in low temperature region promote their potential applications for cryogenic and biomedical equipments.

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Session Classification: M1PoB - Cryogenic Materials II: Properties and Treatments

Track Classification: ICMC-11 - Metallic and Composite Materials
Multi-Layer Aerogel Insulation for Cryogenic Applications

Monday, 29 June 2015 14:00 (2 hours)

Aspen Aerogels, Inc. validated the key process step for a next generation aerogel manufacturing technology to enable the fabrication of thin, low density aerogel materials. When the thin aerogel is stacked with reflector layers to form an aerogel-based insulation system, called Multi-Layer Aerogel Insulation (MLAI), it provides thermal performance advantages compared to incumbent insulation systems. Thermal performance testing was performed on various aerogel-based systems at cryogenic temperatures across a vacuum range from 10^-5 to 760 torr by the Cryogenics Test Laboratory at NASA Kennedy Space Center to select the optimized aerogel insulation system for prototype development and testing. System-level cryogenic testing at Ball Aerospace & Technologies will also be presented. Like other aerogel systems, this breakthrough thermal insulation is also found to be much more durable and consistent than traditional multi-layer insulation, keeping costs down by minimizing/eliminating rework.

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Session Classification:  C1PoL - Thermal Insulation

Track Classification:  CEC-14 - Thermal Insulation Systems
Synthesis of Nanoscale Magnesium Diboride Powder

Wednesday, 1 July 2015 12:00 (15 minutes)

A procedure has been developed for the preparation of small grained magnesium diboride (MgB2) powder by reacting nanometer size boron powder in a magnesium vapor. Plasma synthesized boron powder that has particle sizes ranging from 20 to 300nm was mixed with millimeter size chunks of Mg by rolling stoichiometric amounts of the powders in a sealed cylindrical container under nitrogen gas. This mixture then was placed in a niobium reaction vessel, evacuated, and sealed by e-beam welding. The vessel was typically heated to approximately 830°C for several hours. The resulting MgB2 particles have a grain size in the 200 nm to 800 nm range. Agglomerates of loosely bound particles could be broken up by light grinding in a mortar and pestle. At 830°C, many particles are composed of several grains grown together so that the average particle size is about twice the average grain size. Experiments were conducted primarily with undoped boron powder, but carbon-doped boron powder showed very similar results.

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Session Classification: M3OrB - Superconductor Wires IV: MgB2 and Applications
Track Classification: ICMC-04 - MgB2 Processing and Properties
Numerical and Experimental Investigation of the Electromechanical Behavior of REBCO Tapes and Cables

Tuesday, 30 June 2015 14:00 (2 hours)

The Twisted Stacked-Tape Cable (TSTC) is one method for cabling flat REBCO tapes and may be a viable option for implementing high temperature superconductors in various applications including power transmission, fusion and high-energy physics. To fully characterize the electromechanical behavior TSTCs it is important to understand the performance of single REBCO tapes under various loading conditions. Tension and combined tension-torsion experiments on single REBCO tapes have been continued, from prior preliminary studies, to characterize three commercially available tapes of SuperPower, SuNAM and American Superconductor. To better understand how these loads affect the critical current of REBCO tapes a structural numerical finite element analysis was performed for single tapes and compared to the experimental data. In addition finite element analysis was also used to determine characteristic of a full scale TSTC after cabling.

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Co-authors: CHIESA, Luisa (Tufts University School of Engineering); TAKAYASU, Makoto (MIT)

Presenter: ALLEN, Nathaniel (Tufts University)

Session Classification: M2PoC - Superconductor Cables II: HTS

Track Classification: ICMC-09 - HTS Cables
Highly Formable Tantalum Barrier for Nb3Sn Conductors

Tuesday, 30 June 2015 09:00 (2 hours)

Ta diffusion barrier integrity is critical in the development of higher Nb ratios in internal-tin (IT) conductors. Current fabrication methodologies predominantly employ conventional wrapped Ta sheet, which deform non-uniformly during wire drawing. This leads to non-uniform Ta layers, with thickness varying between 10-2 microns as evident from IT cross-sectional images. The objective of this work is to present strategies to replace conventional Ta sheet material with severe plastic deformation (SPD)-processed, uniform, fine-grain material. Preliminary work has demonstrated that simply replacing the sheet with SPD-processed sheet improves the layer drawability in wrapped composite tubular components. Innovative SPD strategies have led to the development of “weld-healing” of electron beam (EB) welds in Ta tube. We will present ongoing work on the weld-healing path as well as development of seamless fine grained Ta capable of higher thickness reductions. Microstructural and mechanical test results will be discussed.

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Session Classification:  M2PoA - Superconductors Materials II: Nb3Sn, FeAs-based

Track Classification:  ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Quantifying MLI Thermal Conduction in Cryogenic Applications from Experimental Data

Monday, 29 June 2015 17:30 (15 minutes)

Multilayer Insulation (MLI) uses stacks of low-emittance metalized sheets combined with low-conduction spacer features to greatly reduce the heat transfer to cryogenic applications from higher temperature surrounds. However, as the hot-side temperature decreases from room temperature to cryogenic temperatures, the level of radiant heat transfer drops as the fourth power of the temperature, while the heat transfer by conduction only falls off linearly. This results in cryogenic MLI being dominated by conduction, a quantity that is extremely sensitive to MLI blanket construction and very poorly quantified in the literature.

To develop useful quantitative data on cryogenic blanket conduction, multilayer nonlinear heat transfer models were used to analyze extensive heat transfer data measured by Lockheed Palo Alto on their cryogenic dewar MLI and measured by JPL on their spacecraft MLI. The data-fitting aspect of the modeling allows the radiative and conductive thermal properties of the tested blankets to be explicitly quantified. Results are presented showing that MLI conductance varies by a factor of 1000 between spacecraft MLI and Lockheed’s best cryogenic MLI.

It is clear from the three-order-of-magnitude range of values that MLI conductance is a high-uncertainty parameter in MLI performance. The analysis also demonstrates that conductance governs the thermal performance of both high-temperature spacecraft MLI as well as low-temperature cryogenic MLI. For both of these temperature extremes, MLI emittance is found to play a secondary role to spacer conductance in establishing MLI thermal effectiveness. Thus, MLI performance is critically dependent on the achieved MLI conductance.

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Presenter: Dr ROSS, Ronald (Jet Propulsion Laboratory)
Session Classification: C1OrF - Thermal Insulation Applications and Measurements
Track Classification: CEC-14 - Thermal Insulation Systems
An overview of Ball cryogen storage and delivery dewar systems

Tuesday, 30 June 2015 16:45 (15 minutes)

Since the 1960s on the Gemini program, Beech Aircraft and now Ball Aerospace have been designing and manufacturing dewars for a variety of cryogens including liquid hydrogen and oxygen. These dewars flew on Gemini, Apollo, Skylab and Space Shuttle providing fuel cell reactants resulting in over 150 manned spaceflights. Since Space Shuttle, Ball has also built the liquid hydrogen fuel tanks for the Boeing Phantom Eye unmanned aerial vehicle. Returning back to its fuel cell days, Ball has designed, built and tested volume-constrained liquid hydrogen and oxygen tank system for reactant delivery to fuel cells on unmanned undersea vehicles (UUVs). Herein past history of Ball technology is described. Testing has been completed on the UUV specific design, which will be described.

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Session Classification:  C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II
Track Classification:  CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Calorimetrically Measured Interstrand Contact Resistances and Coupling Magnetizations in Cored QXF-Type Nb3Sn Rutherford Cables for the LHC Quadrupole Upgrade

When exposed to a ramping magnetic field the Rutherford cable is the seat of coupling magnetization produced by interstrand coupling currents passing through the interstrand contact resistances (ICR) – the strand crossover resistances, Rc, and the side-by-side (adjacent-strand) resistances, Ra. The coupling magnetization, is greatest when the applied field is normal to the cable’s surface in which case it is proportional to 1/Rc + 20/N^3Ra, which defines an effective reciprocal ICR, 1/Reff. For an uncored cable Reff is essentially Rperpc while the introduction of a fully insulating core raises it to (N^3/20)Ra. The transport-current ramping of LHC quadrupole magnets has been shown to produce field errors of about 2 units of b1 and less than 0.2 units of cn, consistent with Rcs of on-average 125 μΩ. Evidently such ICRs have contributed to the successful operation of the LHC quadrupoles to date and hence could be recommended as target values for the QXF cable after the appropriate values of N and the other the cable-design parameters, w/t (width/thickness), Lp (semi-transposition pitch), have been included. Since the Rc of a typical uncored Nb3Sn cable is 0.25 μΩ a core needs to be included to raise its Reff into the multi-100 μΩ range. In preparation for investigating the effect of core-insertion on Reff a series of five QXF-type Rutherford cables have been wound with cores of widths ranging from 11.9 to 15.9 mm, representing core coverages, W, of from 72 to 97%. Interstrand contact resistances, Reff, were extracted from the results of low-frequency calorimetric AC-loss measurements, presented in the format Reff versus W%, and compared with predictions derived from the fortran program CUDI©.
Persistent Magnetization and Decay in Bi:2212, YBCO, and Nb3Sn and influence on Accelerator Magnet Field Errors

Cable magnetization leads to field errors in precision beam-line accelerator magnets. These errors are particularly problematic at the injection field, both in their base value, as well as their temporal drift. Drift in NbTi cable magnetization is due to the influence on strand magnetization of the decay of long-range coupling currents. But with HTS cables and magnets, a new drift mechanism will come into play – flux creep. Negligible for LTS, creep will be significant for HTS even at low temperatures, at least in the context of high precision field requirements. We have measured the magnetization of HEP relevant Nb3Sn, Bi:2212, and YBCO conductors; these are compared and estimates made of their relative impact on error fields in accelerator magnets, as compared to NbTi. We have also measured the magnetization creep of these strands for a time span of ~1200 s (20 min)—the time of a typical injection plateau in the Large Hadron Collider. Short samples and small helical coils of Nb3Sn and Bi:2212, as well as short samples of YBCO, were measured in applied magnetic fields of 1 T ("injection") and 12 T ("collision"). From a persistent magnetization viewpoint, Bi:2212 is seen to be comparable to Nb3Sn once correcting for the flatness of the Jc vs B curve; YBCO magnetization contributions will be highly dependent on magnet and cable design. Creep led to magnetization changes of 15-20% for YBCO, and 20-30% for Bi:2212 over the 1200 s time span (20 min). This led to estimates of b3 drift in units for Bi:2212, and tens of units or (much) more, for YBCO (depending heavily on cable and magnet geometry). A YBCO striation target is suggested to reduce the large magnetization and drift.

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Session Classification: M1OrA - Superconductor Cables I: HTS and LTS

Track Classification: ICMC-09 - HTS Cables
The Development of Persistent joints for MgB2 Conductors

Two different routes have been developed for persistent joints in react and wind MgB2, relevant to MRI. The first uses superconducting solder, the second does not. The joints were developed using standard MgB2 multifilamentary in-situ type strand. Both joint types assumed a react and wind approach. Two types of tests were performed. The first type was a direct I-V (4-point) measurement of the joints. This measurement was made at 4.2 K in fields of up to 7 T, and also at self-field at temperatures up to 30 K. In the second, a persistent current was induced in a small coil and its decay measured. These measurements were performed at 4.2 K, but in some cases in the presence of a background field. Direct I-V measurements show R values of below 10-10 ohms, and an Ic above 100 A at 0.5 T and 4 K for the first joint type. The second joint type achieved 200 A at several Tesla and 4.2 K. Results of numerous direct I-V and several drift measurements are compared, and the utility for MRI systems is discussed.

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Session Classification: M2OrB - Superconductor Wires I: Testing and Characterization
Track Classification: CEC-06 - Superconducting Magnet Systems
Thermodynamic optimization of mixed refrigerant Joule Thomson systems constrained by heat transfer considerations

Wednesday, 1 July 2015 11:45 (15 minutes)

Mixed refrigerant (MR) working fluids can significantly increase the cooling capacity of a Joule Thomson (JT) cycle. The optimization of MRJT systems has been the subject of substantial research. However, most optimization techniques do not model the recuperator in sufficient detail. For example, the recuperator is usually assumed to have a heat transfer coefficient that does not vary with the mixture. Ongoing work at the University of Wisconsin-Madison has shown that the heat transfer coefficients for two-phase flow are approximately three times greater than for a single phase mixture when the mixture is between 15% and 85% quality. As a result, a system that specifies a MR without considering the impact of two phase flow may require an extremely large recuperator or not achieve the performance predicted by the model. To ensure optimal performance of the JT cycle, the MR should be selected such that it is entirely two-phase within the recuperator. To determine the optimal MR composition, a parametric study was conducted on a thermodynamically ideal cycle. The results of the parametric study are graphically presented on a contour plot in the parameter space consisting of the extremes of the qualities within the recuperator. The contours show constant values of the normalized refrigeration power. This 'map' of the JT cycle shows the effect of MR composition on the cycle performance and can be used to select the MR that provides a high cooling load while also constraining the recuperator to be two phase. The predicted best MR composition can be used as a starting point for experimentally determining the best MR. To confirm that the map is generally useful, similar studies are carried out in order to compare the effect of changing the number of components, the charge pressures, the temperature range, and using synthetic vs hydrocarbon mixtures.

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Session Classification: C3OrC - Mixed Gases
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Effect of Cryogenic Treatment on Wear Resistance of Gray Cast Iron

The cryogenic treatment can improve wear resistance and mechanical properties of many metallic materials and the improvement is largely affected by the cryogenic treatment condition. In this work, samples of gray cast iron were treated at various cryogenic treatment temperature and cryogenic holding time. The main objective of this work is to investigate the effect of the cryogenic treatment condition on wear resistance of the gray cast iron. All the cryogenic treatment processes were done in a SLX-80 program-controlled cryogenic container. Wear tests were performed using a MMU-10G friction and wear tester. Surface feature of the treated samples were characterized with scanning electron microscopy (SEM). It was showed that the wear resistance of the cryogenically treated samples was superior to those of non-cryogenically treated ones. The lower temperatures for cryogenic treatment were more effective in improving the wear resistance properties. The improvement in wear resistance by cryogenic treatment was attributed to the decrease of residual stress in gray cast iron.

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Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
Commercialisation of pulse tube cryocoolers to produce 330 W and 1000 W at 77 K for liquefaction.

Tuesday, 30 June 2015 11:15 (15 minutes)

Fabrum Solutions in collaboration with Callaghan Innovation has been developing large pulse tube cryocoolers based on Callaghan Innovation’s diaphragm pressure wave generators (DPWG). The pulse tube’s lack of moving parts in combination with the DPWG’s metal diaphragms produces a cost-effective, long life and robust cryocooler. The DPWG has had 10 years of development, resulting in a series of DPWGs ranging in input powers from 0.5 kW to 30 kW that have been coupled to a variety of in-line and coaxial pulse tubes. Two DPWGs have had in excess of 7000 hours running to date. The PT330 cryocooler is based on a new 330 cc DPWG and has produced over 400 W of cooling at 77 K during testing. The PT1000 combines three such pulse tubes on a single 1000 cc DPWG to produce over 1000 W at 77 K. This paper details the development of the PT330 and PT1000 cryocoolers from initial lab prototypes through to commercial products, integrated into liquefiers and ready for use in applications such as: Nitrogen liquefaction, re-liquefaction of boil-off from storage tanks, or cooling of cryostats for High Temperature Superconductor applications.

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Session Classification: C2OrB - Large Capacity Coolers

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Advances on a free piston Stirling cryocooler with a large cooling capacity at 80 K

With the advantages of high thermal efficiency, high reliability and compact structure, a free piston Stirling cryocooler with a large cooling capacity at 80 K is very attractive for applications such as natural gas re-condensation and power applications of superconductivity. This article introduces our recent progress on a free piston Stirling cryocooler which was designed based on thermoacoustic theory. To acquire a better understanding and optimize the system, the influence of the regenerator porosity, the cold head heat exchanger dimensions and the operating frequency were investigated in detail. In addition, pressure drop across the regenerator and heat exchangers was observed and its effect was analyzed. Compared with the results reported before, the performance has been improved.

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Track Classification:  CEC-03 - Cryocoolers (Non-Aerospace)
The effect of cryogenic treatment on the room and cryogenic properties of 9Ni steel

The 9Ni steel is widely used in cryogenic temperature due to its superior cryogenic properties. In the present paper, the tensile and impact properties of 9Ni steel at 20℃, -40℃, -70℃, -110℃, -140℃ and -196℃ were tested by the MTS-SANS CMT500 universal tensile testing machine. The result showed that the strength increased with the fall of temperature while the impact toughness decreased with the fall of temperature. However, the reduction of impact toughness is slightly, it still could keep 225 J at -196℃. Furthermore, the effects of cryogenic treatment on the room temperature properties and cryogenic properties at -140℃ and -196℃ were also investigated in this paper. The results showed that cryogenic treatment at -140℃ and -196℃ both could increase the impact toughness of 9Ni steel. However, the cryogenic treatment had no obvious influence on the cryogenic properties at -140℃ and -196℃.

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Track Classification: ICMC-11 - Metallic and Composite Materials
The Study of Flow Performance inside a High-speed Radial-axial Flow Cryogenic Turbo-expander Impeller

In this paper, an optimization design for whole performance of a high-speed radial-axial flow cryogenic turbo-expander is discussed. The main structural parameters of the expander blade are obtained through a design method based on one-dimension steady flow. The non-developable ruled parabolic shaping method is used to design the leaf type. Then numerical simulation and detailed analysis are carried out based on the designed turbine with its given working condition using CFD software. At last the temperature field, pressure field, streamlines and isentropic efficiency are obtained, and the optimization design including the geometry of impellers and boundary conditions for an efficient turbo-expander is achieved.

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Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Design, Development and Application of Automatic Control Strategies for a 500W@4.5K Helium Refrigerator/Liquefier

A 500W@4.5K helium refrigerator has been designed to provide forced flow cooling of 4.5K super-critical helium for the superconducting coils testing or as a helium liquefier with the capacity of 90L/hr liquefaction rate, and is now in built at the Institute of Plasma Physics, Chinese Academy of Sciences (CASIPP). Its control system is designed and developed based on a Programmable Logic Controller (PLC) to achieve automatic process control in each defined operational mode. Via the analysis of process flow and control requirements, all operational modes with their logic control such as start-up conditions and interlocks have been designed. Through the process modeling and dynamic simulation, the dynamic behaviors of cryogenic process were revealed and the process parameters control loops were designed and simulated for optimizing the cool-down operation. As the core machinery in the refrigerator, two turbines with fully static gas bearing in series, which adopted double-valve fan brake control loops for optimized rotation speed control, are designed and manufactured by ourselves and will be tested in the commissioning of the refrigerator. In this paper, the design of automatic control strategies for the refrigerator as well as its control programs development and application on PLC control system will be presented in detail. Also, the whole project progress of the refrigerator and its control system will be reported.

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Track Classification: CEC-15 - Instrumentation and Controls
Performance test of a 1 L liquid hydrogen fuel tank for unmanned aerial vehicles.

Wednesday, 1 July 2015 11:30 (15 minutes)

A 1 L liquid hydrogen fuel tank has been designed, fabricated and tested to optimize boil-off rate and minimize weight for a 200 W light weight fuel cell in an unmanned aerial vehicle (UAV). A 200 W fuel cell requires maximum flow rate of 2.6 SLPM or less of liquid hydrogen boil-off rate in the fuel tank. After looking at several different insulation schemes, the system was optimized as two concentric lightweight aluminum cylinders with high vacuum and multi-layer insulation in between. MLI thickness and support structures were designed to minimize the tank weight and maintain boil-off in appropriate range. A small heater was added to the inner vessel in order to control evaporation rate corresponding to flight conditions or power consumption of the fuel cell. For support, filling and feed gas to a fuel-cell, the system was designed with two G-10 CR tubes which connected the inner vessel to the outer shell. A secondary G10-CR support structure was also added to ensure stability and durability during a flight. After fabrication the fuel tank was filled with liquid hydrogen. A series of boil-off tests were performed in various operating conditions to confirm thermal performance of the fuel tank for a 200 W fuel cell.

This study was funded by the Korea Institute of Science and Technology.

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Session Classification: C3OrB - Aerospace Systems

Track Classification: CEC-10 - Aerospace
Status of ITER thermal shield development

Monday, 29 June 2015 14:00 (2 hours)

Thermal shield (TS) will be installed in the ITER Tokamak to protect the superconducting magnet from thermal radiation from cryostat and vacuum vessel. The TS is cooled by 80 K helium supplied from cryoplant. The emissivity of TS surface must be maintained below 0.05 by bath-type silver electroplating. The TS is to be fully procured by Korea and it will be assembled in the ITER Tokamak by ITER organization. This paper describes the overall status of the ITER TS procurement: the manufacturing design and the current manufacturing status of vacuum vessel thermal shield (VVTS). Some mock-ups were fabricated and tested to validate the TS design and manufacturing: in-pit joint assembly, 3D shape bending method of long cooling tube, specimen tests for silver coating and cooling tube welding. Prior to the manufacturing of the TS, full-scale prototype of VVTS 10 degree section was developed in order to assess the overall manufacturing procedure of the TS except silver coating. After the completion of manufacturing design, R&D and prototype fabrication, the VVTS manufacturing started in October 2014. The current status of VVTS manufacturing is summarized in this paper.

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Presenter: NAM, Kwanwoo
Session Classification: C1PoG - Thermal Analysis and Design
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Numerical investigation on the temperature control of a NIF cryogenic target

Numerical investigation was performed on the temperature control of NIF cryogenic target in order to get a temperature uniformity of 0.1mK on the surface of the target capsule. Heat transfer process was discussed to find out major factors in the temperature control, tamping gas heat transfer and natural convection of the tamping gas was calculated. Spherically symmetric temperature field is required due to energy released from the tritium decay within the capsule, auxiliary heating is set on the hohlraum to compensate the higher heat loss caused by the lower tamping gas thermal resistance on the mid plane. Natural convection effect of the tamping gas is reduced by separating the tamping gas with plastic films and independent temperature control of the cooling arms. This research may provide theoretical foundation and reference for temperature control on the cryogenic target.

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Track Classification:  CEC-15 - Instrumentation and Controls
The Measurement and Uncertainty Analysis of Thermal Resistance in Cryogenic Temperature Sensor Installation

The choice of the appropriate installation method plays an important role for accurate temperature measurement. In the cryogenic and high vacuum environment, due to poor contact between the cryogenic temperature sensor and the surroundings that the sensor is installed and intended to measure, the self-heating from sensor measuring current brings about temperature difference and creates a potential temperature measurement error. The self-heating temperature difference is directly proportional to the thermal resistance for a mounted sensor, which means that lower installation thermal resistance of sensors is advantageous to obtain better measurement results. In this paper, a measurement model for the installation thermal resistance of sensor is built in terms of two currents method which is always used to measure self-heating effect. A cryostat that can provide variable temperature in the accurate temperature measurement and control experiments is designed and manufactured. This cryostat can reach 3K in a few hours and the sample temperature can reach as high as 20 K. Based on the experimental results, the measurement uncertainty of the thermal resistance are also analyzed and calculated. To obtain the best measurement results in our cryostat, the thermal resistances of sensors with two installation methods are measured and compared.

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Track Classification: CEC-15 - Instrumentation and Controls
Natural convection effect on the temperature fluctuation in a cylinder enclosure with supercritical helium.docx

A numerical study is performed for time-varying natural convection of helium fluid at low temperatures in a bottom wall heated cylinder enclosure. The numerical results are analyzed in detail to show the damping of the temperature fluctuation amplitude from the cold up wall to the hot down wall, which is characterized by the ratio of the fluctuation amplitude of down wall and up wall. Fluid flow field, thermal field and heat transfer are analyzed for some particular situations through the streamlines and isotherms. Based on the simulation results, the effects of thermal conductivity of walls and inclined angles of the enclosure on the damping of temperature fluctuation amplitude are studied. Numerical computations provide methods of decaying the propagation of the fluctuation amplitude through the fluid and wall, which have great importance in high precision temperature control at low temperature system cooled by cryocooler.

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Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Experiment study for controlling and stabilizing the sample temperature using a cryocooler

A system for high precise control of the sample temperature using a 4K GM cryocooler is described. The maximum temperature fluctuations in a GM cryocooler without a high heat bath or thermal resistance are typically of the order of 400mK between 4K and 20K. It is particularly difficult to dramatically diminish the fluctuation of the sample cooled by the cryocooler at low temperatures. In this system, the temperature fluctuations of 0.5mK could be achieved when the temperature were controlled between 7K and 20mK using a PID temperature control system with supercritical helium and PTFE thermal resistance. In addition, shutting off the cryocooler significantly reduces sample motion that results from vibration and expansion/contraction of the cold head housing. Precise temperature control at 18.7K was attained when the cryocooler is shut off in present study, and the fluctuations of the sample temperature was less than 2mK even when the cryocooler is shut down for 30 minutes. This technique makes it possible to control and stabilize the temperature regardless of the cryocooler is on or off.

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Track Classification: CEC-15 - Instrumentation and Controls
Optimization of a small-scale thermoacoustic cooler

Based on the linear thermoacoustic theory, the influence of geometric parameters of regenerator and phase mechanical (PM) tube on thermoacoustic refrigerator’s cooling capacity is studied in this paper. Theoretical analysis results show that there exists an optimal phase and impedance values to make the cooling capacity maximum. On this basis, the experimental study of the relationship between the geometric parameters of regenerator and PM tube and thermoacoustic refrigerator’s cooling capacity is also carried out. The experimental results are consistent with the theoretical analysis results, which notably showing the reliability of analytical results. This will provides an effective guidance for the design and optimization of thermoacoustic refrigerator.

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Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Performance Test of the Cryogenic Cooling System for the Superconducting Fault Current Limiter

Monday, 29 June 2015 09:00 (2 hours)

The Superconducting Fault Current Limiter (SFCL) is an electric power device which limits the fault current immediately in a power grid. The SFCL must be cooled to below the critical temperature of HTS (High Temperature Superconductor) modules. In general, they are submerged in sub-cooled liquid nitrogen for their stable thermal characteristics of HTS modules. To cool and maintain the target temperature and pressure of the sub-cooled liquid nitrogen should be designed well with a cryocooler and circulation devices. The pressure of the cryostat for the SFCL should be pressurized to reduce the generation of nitrogen vapor in quench mode of the SFCL.

In this study, we tested the performance of the cooling system for the prototype 154 kV SFCL, which consist of a 4 kW stirling cryocooler, a subcooling cryostat, a pressure builder and a main cryostat for the SFCL module, to verify the design of the cooling method and the electric performance of the SFCL. The normal operation condition of the main cryostat is 71 K and 500 kPa. This paper present results of tests of the overall cooling system.

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Session Classification: C1PoB - Intermediate Temperature Systems

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Predicting performance of axial pump of lox booster turbopump of staged combustion cycle based rocket engine using CFD

For manned space mission and deep space probe, reusable launch vehicles are envisaged to be utilized with high fidelity. For low cost, high impulse, long endurance mission with high execution and high reliability, hence demand to be curtailed the inert weight and thereby increasing the delivered pay-load. Turbopump (TP) feed system for a liquid rocket engine has the highest power to weight ratio in the entire field of turbomachinery. Thus, for designing a turbopump for a new liquid propellant rocket engine (LPRE) demands optimization of geometry based on the off-design performance at different operating regime. In this paper, CFD analysis of liquid oxygen (LOX) axial pump (LPOT) used as a booster pump for oxygen rich staged combustion cycle based rocket engine has been presented using ANSYS CFX in order to evaluate performance of the turbomachinery at different operating conditions. An implicit finite volume approach has been adopted to obtain the three dimensional flow field variables for the LOX pump. The computation technique involves the mathematical solution of the discretized three-dimensional, Reynolds Averaged Navier-Stokes (RANS) based two-equation SST (Shear Stress Transport) k-ω turbulence model over an unstructured grid. The data generated has been used to predict the performance characteristic of the axial pump for the throttling range varying from 60% to 105 % of nominal thrust value. The results have been analyzed to test the functioning of the pump at steady state and the attempts have been made to suggest suitable changes in the existing geometry of the turbopump.

Key words: CFD, Turbopump, Staged Combustion cycle, Cryogenic, Pump performance characteristics.

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Session Classification: C3PoE - Turbomachines and Helium Components
Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
The European Spallation Source (ESS) is a neutron-scattering facility being built with extensive international collaboration at Lund, Sweden. The ESS accelerator will deliver protons with 5 MW of power to the target at 2.0 GeV, with a nominal current of 62.5 mA. The superconducting part of the accelerator is about 300 meters long and contains 43 cryomodules. The ESS accelerator cryoplant (ACCP) will provide the cooling for the cryomodules and the cryogenic distribution system that delivers the helium to the cryomodules. The cryoplant will cover three cryogenic circuits: Bath cooling for the cavities at 2 K, the thermal shields at around 40-50 K and the power couplers thermalisation with 4.5 K liquid helium.

The open call-for tender for the ACCP had taken place in 2014 with Linde Kryotechnik AG being selected as the cryoplant vendor. This paper summarizes the progress in the ACCP development and engineering. Current status including basic process design, system configuration, machine concept and layout, main parameters and features, solution for the acceptance tests and further optimization is presented.

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**Session Classification:** C1OrE - Refrigeration and Liquefaction - sponsored by TechSource, Inc.

**Track Classification:** CEC-01 - Large-Scale Refrigeration and Liquefaction
Vortex tube (VT) is a simple low refrigeration producing device having no moving part. However, the flow inside it is very complex. Recent studies show that the performance of VT improves with the increase in the divergence angle of a flared VT. To explore the temperature separation phenomenon in the VT, a three dimensional computational fluid dynamics (CFD) analysis of VT was carried out. For the present work, a VT having diameter of 12 mm, length of 120 mm, cold outlet diameter of 7 mm and hot outlet annulus of 0.4 mm with 6 straight rectangular nozzles having area of 0.5 sq. mm each is considered. The turbulence in the flow field of the VT is modeled by standard $k\varepsilon$ turbulence model with Redlich-Kwong real gas model. The effect of variation of divergence angle of hot tube in the VT is studied and compared with the experimental results available in the literature. The temperature separation between the hot outlet and cold outlet, in both straight and 2 degree divergent tube is studied. Analysis results indicate that for a hot mass fraction above 0.5, the divergent tube have better cold production capacity compared to the straight tube. Some parameters like temperature gradient, velocities (axial, radial and tangential), velocity gradients, effective thermal conductivity and viscosity of fluid etc., have been investigated for heat transfer and shear work transfer in the VT. To understand the temperature separation mechanism, heat transfer and work transfer along the axial direction have been evaluated in both straight and divergent tubes. The isentropic efficiency and COP as refrigerator as well as heat pump of straight tube and divergent tube have been computed.

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**Session Classification:** C2OrD - CFD and Numerical Modelling

**Track Classification:** CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Investigation of activated carbon adsorption process in helium adsorption refrigerator and its effect on adsorption performance

Adsorption refrigerators are widely used in various kinds of cryogenic systems in space science. The performance of cooler is directly affected by the adsorption process of activated carbon. We present one adsorption model to describe the whole adsorption process and conduct relevant experiments to improve and optimize the model. This paper also presents experiment results of potential refrigeration performance differences on account of adsorption parameters.

Primary author: Mr LI, Xin (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Presenter: Mr LI, Xin (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
The European Spallation Source (ESS) is an intergovernmental project building a multidisciplinary research laboratory based upon the world’s most powerful neutron source to be built in Lund, Sweden. The ESS will use a linear accelerator which will deliver protons with 5 MW of power to the target at 2.0 GeV with a nominal current of 62.5 mA. A cryomodule test stand will be supplied with helium for the site acceptance tests. The target will have two moderators using supercritical hydrogen to cool down the neutrons. The neutron instruments and the experiments’ sample environment will use liquid helium and liquid nitrogen to cool detectors and samples. The ESS cryogenic system is designed to deliver cryogenic cooling capacity to all four client systems.

A first concept of the ESS cryogenic system was developed in 2010 and 2011 with a limited amount of input from the clients as well as from site infrastructure (i.e. buildings and utilities). The design had to be flexible enough to accommodate future changes in scope, schedule and available infrastructure. Over the following years the design has evolved together with these parameters to achieve a maturity today which allowed us to order the accelerator cryoplant and to start procurement of many of the other parts of the ESS cryogenic system. This paper presents the evolution of the design throughout the years and the factors influencing certain design choices, focusing on external design aspects, such as requirements for buildings and utilities.

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**Presenter:** Mr HEES, Wolfgang (European Spallation Source ESS AB)

**Session Classification:** C2OrE - Cryogenic Systems II

**Track Classification:** CEC-01 - Large-Scale Refrigeration and Liquefaction
Air Liquide latest developments of turbomachines: from design to commissioning

Wednesday, 1 July 2015 09:00 (2 hours)

Strong of 60 years of innovation and design in the field of cryogenic turbomachines, Air Liquide Advanced Technologies is constantly developing new products. The first cryogenic helium pump of Air Liquide standard range of cryomachine was commissioned successfully in 2014. The compression map of the pump was measured and in very good accordance with the calculations. The same motor cartridge is used for cold compressor used on 2K refrigerators, enabling to cover a wide range of flow rates and cold powers. Reliability and efficiency being a key issue in cryogenics, the latest developments focus on oil-free turbomachines on magnetic bearings. 270 kW turbomachines are under manufacture, and will be able to cover existing needs in the 35 - 200K range. They will also address new markets like the LNG boil-off gases reliquefaction.

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Presenter: GONDRAND, Cecile (Air Liquide Advanced Technologies)
Session Classification: C3PoE - Turbomachines and Helium Components
Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
[Invited] Study of Temperature Wave Propagation in Superfluid Helium to Cool Radio-Frequency Cavities

Wednesday, 1 July 2015 16:45 (30 minutes)

Oscillating Superleak Transducers (OSTs) can be used to localize quenches in superconducting radio-frequency cavities. Local hot spots at the cavity surface initiate temperature waves in the surrounding superfluid helium that acts as cooling fluid at typical temperatures in the range of 1.6 K to 2 K. The temperature wave is characterised by the properties of superfluid helium as the second sound velocity. For high heat load densities second sound velocities greater than the standard literature values are observed. This fast propagation has been verified in dedicated small scale experiments. Resistors were used to simulate the quench spots under controlled conditions. The three dimensional propagation of second sound is linked to OST signals and is improving the understanding of the OST signal especially there incident angle dependency. The characterised OSTs are used as a tool for quench localisation on a real size cavity. Their sensitivity as well as the time resolution was proven to be superior to temperature sensors, which were glued to the surface of the cavity.

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Presenter:  KOETTIG, Torsten (CERN)

Session Classification:  C3OrJ - Special Session: Helium II Properties and Systems

Track Classification:  CEC-13 - Helium II Properties and Systems
Study for cryogenic testing the Super-FRS magnets of FAIR in a new test facility at CERN

Tuesday, 30 June 2015 09:00 (2 hours)

A new cryogenic test facility is currently under construction at CERN for future needs of the laboratory. This facility will be at first used for the cryogenic testing of the Super-FRS magnets of the International Facility for Antiproton and Ion Research (FAIR) being built at GSI in Germany. In total 57 magnets will be tested of which the largest magnets have a cold mass of 45'000 kg. The magnet test rate will be 27 magnets per year and each magnet test will take about 46 days.
To obtain the required test rate, the test facility has to consist of three test benches. The cryogenic system of the test facility needs to cool-down the magnets to their operating temperature of 4.5 K, maintain the required temperature during the tests and warm-up the magnets after the tests. Two pre-cooler and heater units with a power of 15 kW will be needed for pre-cooling the magnets to 80 K and for warming-up the magnets after the tests. These units need to provide a gaseous helium flow up to 50 g/s at about 10 bar at the required temperature. A Sulzer TCF200 cold box will produce liquid helium up to a flow rate of 6 g/s to cool down the magnets to 4.5 K and maintaining the operating temperature during the tests.
This paper will cover the cryogenic study of the main components of the test facility to match the needs for testing the Super-FRS magnets. The calculation results to define the main operational parameters for the various operating modes will be presented in detail. Also, flow schemes and the design of some of the main components will be discussed.

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Presenter: DERKING, Jan Hendrik (CERN)
Session Classification: C2PoF - Test Facilities
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
A cryocooler used for fixed point at 1.8K

An apparatus is developed to realize the lambda point of helium used as a temperature fixed point. A two-stage Gifford-McMahon (GM) mechanical refrigerator with the cooling power of 1.5W at 4.2K is employed. A closed-cycle of 4He is used to get the temperature of 1.8K. The helium gas with pressure of 1bar condenses at a pot located the second stage. Then the liquid helium flows into a pump-pot via a flow-resistance-tube and the temperature is down to about 1.8K. A technique of sealed cell was developed to allow a heat flows alone the capillary, within which normal and superfluid helium can co-exist and the temperature of the interface is the transition temperature of helium. As the temperature of the pump-pot could be maintained below 2.1K, the plateau of the lambda point of helium could exist for long duration. The temperature fluctuation at the plateau of lambda point of helium could be less than 0.1mK.

Primary author: Prof. LIN, Peng (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

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Presenter: Prof. LIN, Peng (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Track Classification: CEC-15 - Instrumentation and Controls
An Optimization Design of A 20 K Helium Cryoplant Based On the Genetic Algorithm

The first large scale helium cryoplant with the cooling capacity of 10kW@20K has been successfully developed recently. Considering the large power consumption of this system, energy saving is very important. In this paper, a model which is described with Genetic Algorithm (GA) program and written in VC++ is established to simulate the cryoplant process. In this model, the pressure ratio and expansion ratio are the parameters to be optimized, while the exergy efficiency is set as the evaluation criteria. The results show that it is feasible to adjust some of the thermal variables to improve the efficiency of the system. This method based on the GA is highly efficient in searching the optimal solution and at last the efficiency of the large scale refrigeration system is improved to a great extend.

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Presenters: Mr XIONG, Lianyou (Technical Institute of Physics and Chemistry, CAS); Mr LIU, Liqiang (Technical Institute of Physics and Chemistry, CAS)

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
High-temperature superconductors offer new perspectives for efficient transportation of electrical energy in urban and industrial power grids. The size of the components is in many cases limited by the available refrigeration technology. In the operating temperature range of 65 – 70 K, cooling is presently achieved by liquid nitrogen, turbo-Brayton plants or batteries of regenerative cryo-coolers. However, none of these options is practicable in applications requiring a few kilowatt of cooling power. Also a reduction of the temperature to below 60 K is desirable in order to increase the current density in the superconductors.

Two-stage mixed-refrigerant Joule-Thomson cascades can present a reliable and highly scalable refrigeration alternative in this temperature range. The first stage of the envisioned process consists of a classical mixed-refrigerant cycle for pre-cooling to 120 K. The second, low-temperature stage operates with a mixture of nitrogen, oxygen and neon at high pressure. In order to avoid combustible hydrocarbon refrigerants in the pre-cooling stage, this work examines the use of a new mixture with low flammability consisting of nitrogen, argon, R-14, R-23 and R-1234yf. The applicability of different equations of state for the prediction of the thermophysical behavior of the mixture by is discussed.

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**Presenter:** Mr KOCHENBURGER, Thomas M. (Karlsruhe Institute of Technology, Institute for Technical Thermodynamics and Refrigeration)

**Session Classification:** C1PoB - Intermediate Temperature Systems

**Track Classification:** CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Final Report on the Controlled Cold Helium Spill Test in the LHC Tunnel at CERN

Tuesday, 30 June 2015 14:00 (2 hours)

The 27-km circumference LHC underground tunnel is a confined space in which the helium-cooled LHC magnets are installed. The vacuum enclosures of the superconducting magnets are protected by over-pressure safety relief devices that open whenever cold helium escapes either from the magnet cold enclosure or from the helium supply headers, into this vacuum enclosure. A 3-m long no stay zone around these devices is defined, based on scale model studies, protecting the personnel against cold burns or asphyxia caused by such an eventual helium release. Recently several simulation studies have been carried out modelling the propagation of the helium/air mixture along the tunnel resulting from the opening of such a safety device, releasing a helium flow in the range between 1 kg/s and 0.1 kg/s. To validate these different simulation studies, real life mock-up tests have been performed inside the LHC confined space, releasing helium flow rates of 1 kg/s, 0.3 kg/s and 0.1 kg/s. For each test, up to 1000 liters of liquid helium were released under standard operational tunnel conditions. The data recorded include oxygen concentration, temperature and flow speed measurements, and video footage permit to assess qualitatively the visibility. These measurements were made in the up- and downstream directions, with respect to the ventilation flow, of the spill point in the LHC tunnel.

This paper presents the experimental set-up under which these release tests were made, the effects of these releases on the atmospheric tunnel condition as a function of the release flow rate, and will discuss the modification to the personnel access conditions to the LHC tunnel that are presently implemented as a result of these tests.

Primary author: Mrs DUFAY-CHANAT, Laetitia (CERN)

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Presenter: Mrs DUFAY-CHANAT, Laetitia (CERN)

Session Classification: C2PoQ - Safety, Reliability, and Standards

Track Classification: CEC-11 - Safety, Reliability, and Standards
Modelling and Testing of Fin-type Heat Exchangers for the ITER Current Leads

Tuesday, 30 June 2015 14:00 (2 hours)

The ITER current leads will transfer large currents of up to 68 kA into the biggest superconducting magnets ever built. Following the development of prototypes and targeted trials of specific manufacturing processes through mock-ups, China is preparing for the series fabrication in ASIPP (Chinese Institute of Plasma Physics). A key component of the ITER HTS current leads are the resistive heat exchangers. Special R&D was conducted for these components at CERN and ASIPP in support of their designs. In particular several mock-ups were built and tested in room temperature gas to measure the dynamic pressure drop and compare to 3D CFD models. The benchmarking of the models on experimental data has helped in defining the proper modelling parameters. Finally this paper will also report on the results obtained during operation under nominal conditions on the heat exchanger sections of the ITER current lead prototypes.

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Presenter: BAUER, Pierre (ITER Organization)

Session Classification: C2PoN - Cryogenic Power Cables and Leads II

Track Classification: CEC-08 - Cryogenic Power Cables and Leads
Study of a multi-strategy controller on a helium liquefier

Helium liquefier is widely used in the fields of superconducting, nuclear fusion energy and high-energy physics. However, the present PID controlling system of the liquefier is not well able to keep the compressor suction pressure, outlet pressure and turbine inlet pressure all in the expected range. Thus, a multi-strategy controller for a helium liquefier is proposed in this paper. A dynamic simulation model of this liquefier is also developed and shown. To study the control effect, an operation process including cool-down, steady-state and pulse of heat is described. The simulation result of this process is presented and compared with the result of the present PID controlling system.

**Primary author:** Mr LEI, Linglong (University of Chinese Academy of Sciences)

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**Presenter:** LIU, Liqiang (Technical Institute of Physics and Chemistry of CAS-Academia Si)

**Track Classification:** CEC-01 - Large-Scale Refrigeration and Liquefaction
Transient analysis of single stage GM type double inlet pulse tube cryocooler is carried out using a one dimensional numerical model based on real gas properties of helium. The model solves continuity, momentum and energy equation for gas and solid to analyse the physical process occurring inside of the pulse tube cryocooler. Finite volume method is applied to discretize the governing equations with realistic initial and boundary conditions. Input data required for solving the model are the design data and operating parameters viz. pressure waveform from the compressor, regenerator matrix data, and system geometry including pulse tube, regenerator size and operating frequency for pulse tube cryocooler. The model investigates the effect of orifice opening, double inlet opening, and pressure ratio, system geometry on no load temperature and refrigeration power at various temperatures for different charging pressure. The results are compared with experimental data and reasonable agreement is observed. The model can further be extended for designing two stage pulse tube cryocooler.

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**Presenter:** Prof. NAIK, HEMANT (S. V. National Institute of Technology)

**Session Classification:** C1PoC - Vuilleumier Cryocoolers and Cooler Analyses

**Track Classification:** CEC-03 - Cryocoolers (Non-Aerospace)
SuperOx manufactures and markets high current, low cost 2G HTS tapes for HTS devices. Our core manufacturing technology includes the IBAD-MgO texturing on strong, non-magnetic Hastelloy substrates to make buffer templates and the PLD growth of the GdBCO layer. At present we offer tapes with single lengths over 300 m and $I_c$ (77 K, s.f.) of 300-500 A/12 mm and 100-150 A/4 mm. SuperOx differentiates itself by providing deep customisation of the tape to meet specific application requirements, including any thickness of silver and/or copper coatings, surround polyimide insulation, low resistance soldered joints, solder plating, and lamination.

In addition to manufacturing 2G HTS tapes we provide further integration of the tapes into HTS device modules and ultimately into ready HTS devices by developing in-house capabilities and partnering with outside experts.

We have developed in-house capabilities for making basic modules of more complex HTS devices such as pancake and racetrack coils for magnets and rotating machines, soldered stacks of tapes for high current cables, HTS current leads, and tapes with proprietary protection against overcurrent for fault current limiters. Another development are solid 2D blocks of any size and shape consisting of multiple layers of 2G HTS tapes that represent an advanced and easily engineerable alternative to bulk HTS materials for applications that require trapping and/or shielding of magnetic field.

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Presenter: Dr MOLODYK, Alexander (SuperOx)

Session Classification: M2OrC - Superconductor Wires II: Coated Conductors and Applications

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
The sizing of cryogenic safety relief devices requires detailed knowledge on the evolution of the pressure increase in cryostats following hazardous incidents such as the venting of the insulating vacuum with atmospheric air. Based on typical design and operating conditions in liquid helium cryostats, the new test facility PICARD, which stands for Pressure Increase in Cryostats and Analysis of Relief Devices, has been constructed. The vacuum-insulated test stand has a cryogenic liquid volume of 100 liter and a nominal design pressure of 16 bar. This allows a broad range of experimental conditions with cryogenic fluids. In case of helium, mass flow rates through safety valves and rupture disks up to about 3.5 kg/s can be measured. Beside flow rate measurements under various conditions (venting diameter, insulation, working fluid, liquid level, set pressure), the test stand will be used for studies on the impact of two-phase flow and for the measurement of flow coefficients of safety devices at low temperature. This paper describes the layout and the design parameters of the test stand and presents first experimental data from the commissioning phase.

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Presenter:  Ms HEIDT, Carolin (Karlsruhe Institute of Technology (KIT))

Session Classification:  C3OrH - Cryogenic Safety

Track Classification:  CEC-11 - Safety, Reliability, and Standards
The study of metal-insulator transition at very low temperature in p-type 70Ge:Ga semiconductor by applying the scaling laws

We studied the metal-insulator transition (MIT) induced by the magnetic field, in barely metallic and compensated p-type 70Ge:Ga using the scaling laws, at low temperature in range (0.65 -0.048 K) and in magnetic field up to 5.3 T. We have determined the magnetic field for which the conductivity changes from the metallic behaviour to the insulator regime. On the metal side of the MIT, the electrical conductivity obeys the relation $\sigma = \sigma_0 + mT^{1/2}$ down 48 mK. The zero-temperature conductivity can be described by scaling laws. We reanalyzed experimental data already published in reference "Michio Watanabe, Kohei M. Itoh, Youiti Ootuka, and Eugene E. Haller, Phys. Rev. B. 60, 15 817-15 823 (1999).".

Primary author: Prof. EL KAAOUACHI, Abdelhamid (University Ibn Zorh Faculty of sciences, Agadir, Morocco)

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Presenter: Prof. EL KAAOUACHI, Abdelhamid (University Ibn Zorh Faculty of sciences, Agadir, Morocco)

Track Classification: ICMC-05 - Thin Films
Theoretical analysis of liquefaction for liquid air energy storage

As a promising large scale energy storage system, the liquid air energy storage (LAES) has advantages like high energy density and no geographical limitation. This paper describes the liquefaction process for LAES and conducts the theoretical analysis of thermodynamic characteristics to investigate the performance of LAES system. Comparative analysis of the liquefaction process is studied between the conventional air separation system and liquid air energy storage. The results can be used to improve and design the LAES cyclic process.

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Presenter: Prof. WANG, Junjie (Key Laboratory of Cryogenics, TIPC, Chinese Academy of Sciences)

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Finite-Time Thermodynamic optimization of a large-scale helium Brayton cryo-refrigerator with static gas bearing turboexpander

Large-scale helium cryo-refrigerator is widely used in superconducting systems, nuclear fusion engineering, and scientific researches etc., however, its energy efficiency is quite low. We built a 2kW at 20.0K helium Brayton cryo-refrigerator. As to the characteristics of the plant/cycle, we put forward a model of helium Brayton cryo-refrigerator/cycle according to finite-time thermodynamics. Analytical expressions of cooling capacity and COP are obtained, and we found that the expressions are piecewise functions. Further, comparison between the model and the experimental results for cooling capacity of the helium cryo-refrigerator shows that error is less than 7.6%. Effects of the pressure ratio, efficiency of turbine and compressor, etc. on cooling capacity and COP of the helium cryo-refrigerator are investigated. In a word, this study provides a better understanding of energy conversion and utilization of the cycle and helps to optimize it.

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Presenter: Dr LI, Qiang (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Safety related issues of the unexpected Argon release into the tunnel

Modern physics laboratories require very large amounts of cryogenics fluids. Often the fluid must be transported along the tunnels or stored in the underground cavities. Currently there is several ongoing projects where vary large amounts of liquid (LAr) or gaseous Argon (GAr) will be used. One of them is a part of LAGUNA-LBNO (Large Apparatus studying Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations) design study, where GLACIER neutrino detector is considered. For its proper operation it requires appropriate environment (It must be located in the deep underground cavity) and approximately 150000 tons of LAr. This huge amount of cryogen must be transported down the tunnel in cryogenic-tank trucks or using pipelines. In both cases there is a risk of uncontrolled LAr or GAr leak to the tunnel which can be dangerous for people and installation itself.

The presented work focuses on the risk analysis and the consequences of the Argon unexpected leak to the tunnel. It shows the mathematical model and numerical tools which can serve to model the Argon cloud propagation, temperature distribution and Oxygen deficiency. Results present series of numerical experiments of the Argon leak into the tunnel for different external conditions (e.g. different ventilation regimes).

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Presenter:  MALECHA, Ziemowit (Wroclaw Univ of Technology)
Session Classification:  C3OrH - Cryogenic Safety
Track Classification:  CEC-11 - Safety, Reliability, and Standards
Prediction of two-phase pressure drop in heat exchanger for mixed refrigerant Joule–Thomson cryocooler

The overall efficiency of mixed refrigerant Joule–Thomson (MR J–T) cryocooler is governed by the performance of recuperative heat exchanger which precools the refrigerant mixture prior to expansion in a J-T valve. In the heat exchanger, the hot stream of the mixed refrigerant undergoes condensation at high pressure while the cold stream gets evaporated at low pressure. The pressure drop in the low pressure stream is crucial since it directly influences the achievable refrigeration temperature. However, experimental and theoretical studies related to two-phase pressure drop in multi-component mixtures at cryogenic temperatures, are limited. Therefore, design of efficient MR J–T cryocooler is a challenging task due to lack of predictive tools.

In the present work, the existing empirical correlations, which are commonly used for prediction of pressure drop in the case of pure refrigerants, evaporating at near ambient conditions, are assessed for the mixed refrigerants. Experiments are carried out to measure the overall pressure drop in the evaporating cold stream of the heat exchanger. The various mixture compositions of nitrogen and hydrocarbons are used to study the pressure drop variations. Several tests are conducted on simple tube-in-tube and multi tubes-in-tube helically coiled heat exchangers for the same mixture compositions. The predicted overall pressure drop in the heat exchanger is compared with the experimental data for both the heat exchangers. The suggested empirical correlations can be used to predict the hydraulic performance of the heat exchanger.

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Session Classification: C2PoJ - Joule–Thomson Coolers
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Performance analysis of a miniature Joule-Thomson cryocooler with and without the distributed J-T effect

Wednesday, 1 July 2015 16:30 (15 minutes)

Cryogenic temperatures are required for proper functioning of infrared sensors and thermal cameras, space chamber simulations, preservation of biological samples, etc. Such temperatures can be produced by expanding a high pressure gas in a relatively easier way. This is popularly known as the Joule-Thomson (J-T) effect. A typical miniature J-T cryocooler consists of a storage reservoir/compressor providing the high pressure gas, a finned tube recuperative heat exchanger, an expansion valve/orifice, and the cold end heat exchanger. The recuperative heat exchanger is indispensable for attaining cryogenic temperatures. The geometrical parameters and the operating conditions of the heat exchanger drastically affect the cryocooler performance in terms of cooldown time and cooling effect.

In the literature, the numerical models for the finned tube recuperative heat exchanger have neglected the distributed J-T effect. The distributed J-T effect accounts for the changes in enthalpy due to changes of pressure in addition to those due to changes of temperature. As the pressure drop of the high pressure fluid in the finned tube is large (of the order of 80-100 bar), contribution of pressure variation to changes in enthalpy cannot be neglected. The objective of this work is to study the performance of a miniature J-T cryocooler with and without the distributed J-T effect to highlight its importance. A one dimensional transient model is employed for the numerical analysis of the cryocooler. Cases with different operating conditions and geometrical parameters are worked out with Argon and Nitrogen as working fluids. J-T expansion at the end of the finned tube is also considered to complete the cryogenic cycle. The mathematical model, method of resolution, and results of the study are presented in this paper.

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Session Classification: C3OrK - Special Session: JT Coolers

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Commissioning of the helium cryogenic system for the HIE-ISOLDE accelerator upgrade at CERN

Tuesday, 30 June 2015 09:00 (2 hours)

The High Intensity and Energy ISOLDE project is a major upgrade of the existing ISOLDE and REX-ISOLDE facilities at CERN. The most significant improvement will come from replacing most of the existing REX accelerating structure by a superconducting linear accelerator (SC linac) composed ultimately of six cryo-modules installed in series, each containing superconducting RF cavities and solenoids operated at 4.5 K.

In order to provide the cooling capacity at all temperature levels between 300 K and 4.5 K for the six cryo-modules, an existing helium refrigerator, manufactured in 1986 and previously used to cool the ALEPH magnet during LEP operation from 1989 to 2000, has been refurbished, reinstalled and recommissioned in a dedicated building located next to the HIE-ISOLDE experimental hall.

This helium refrigerator has been connected to a new cryogenic distribution system, consisting of a 30-meter long vacuum insulated transfer line, a 2000-liter storage dewar and six interconnecting valve boxes, one for each cryo-module.

This paper describes the whole cryogenic system and presents the commissioning results including the preliminary operation at 4.5 K of the first cryo-module in the final experimental hall.

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Session Classification: C2PoA - Cryogenic Systems I
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Test platform of thermal insulation performance of cryogenic transfer line

Cryogenic transfer line is the key component of the large-scale helium cryo-refrigerator or cryostat. Heat leakage of modern cryogenic transfer line is quite low, so it is difficult to determine the heat leakage rate of the transfer line. For this reason, we design and built a test platform of thermal insulation performance of cryogenic transfer line. The test platform consists of several subsystems: LN2/LHe dewar, ports of the test platform, fluid management system, air warmed heat exchangers, measurement subsystem, and data acquisition subsystem etc. In a word, the test platform is a powerful tool of research for thermal insulation performance of cryogenic transfer line.

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Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
High-entropy alloys consist of multiple elements with different crystal structures but can crystallize as a single phase. Recently, we developed a new technique to prepare high-entropy alloys, which is called high-gravity combustion synthesis. In the new technique, high-entropy alloys are produced by rapid solidification of hot melts from highly-exothermic aluminothermic reactions. High-gravity combustion synthesis may provide a fast and efficient way to produce high-entropy alloys with low energy consumption. Here, we report several high-entropy alloys by high-gravity combustion synthesis and investigate the cryogenic properties of the alloys.

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**Session Classification:** M2OrD - Cryogenic Materials V: Structural Materials

**Track Classification:** ICMC-11 - Metallic and Composite Materials
The Fe-based NaZn13-type compounds LaFe13-xMx (M=Si, Al) have attracted considerable attention because of their intriguing properties, such as magnetocaloric effect and abnormal thermal expansion. These unusual properties are of fundamental interest and have potential technical applications in cryogenic engineering when related materials operate in low temperature environment. The thermal expansion coefficient and spontaneous magnetization of rare earth intermetallic compounds LaFe13-xAlx (1.2≤x≤1.8) have been investigated and relationships between them were considered. Results indicate that LaFe11.6Al1.4 and LaFe11.4Al1.6 show near zero thermal expansion behavior from room temperature to liquid helium temperature. And it has been found that the spontaneous magnetostriction is proportional to the square of the spontaneous magnetization, which proves that the thermal expansion has a close relation with the spontaneous magnetization.

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**Session Classification:** M2PoD - Cryogenic Materials IV: Physical Properties

**Track Classification:** ICMC-11 - Metallic and Composite Materials
Low-temperature negative thermal expansion in Al doped La(Fe,Si)13 compounds

Tuesday, 30 June 2015 14:00 (2 hours)

Negative thermal expansion (NTE) materials, which contract rather than expand when heated, can be blended with materials showing positive thermal expansion to form composite for obtaining precisely tailored thermal expansion coefficient. Low-temperature NTE materials have wide potential applications in cryogenic engineering. The NaZn13-type La(Fe,Si)13-based compounds are recently developed as promising NTE materials, the NTE properties of which, in this study, were modified by doping minor Al element in order to make it more suitable for practical applications in cryogenic engineering. The results indicate that the NTE operation-temperature window shifts toward a lower temperature region due to the decrease of the Curie temperature (Tc) with increasing the amount of Al element in LaFe11.5Si1.5-xAlx compounds. Furthermore, the NTE operation-temperature window of LaFe11.5Si1.5-xAlx was broadened with increasing Al content. Such La(Fe,Al,Si)13 compounds with noteworthy NTE properties in low temperature region promote their potential applications for cryogenic equipments and precise instruments.

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Session Classification: M2PoD - Cryogenic Materials IV: Physical Properties

Track Classification: ICMC-11 - Metallic and Composite Materials
Low-temperature thermal conductivity of highly porous copper

Monday, 29 June 2015 11:30 (15 minutes)

The development and characterization of new materials is of extreme importance in the design of cryogenic apparatus. Recently the Versarien company developed a technique capable of producing copper foam with controlled porosity and pore size. Such porous materials could be interesting for cryogenic heat exchangers as well as of special interest in some cryogenic devices for micro-gravity environments. For instance, in our Energy Storage Units [1, 2] for potential use in space applications, a porous ceramic is used to retain a cryogenic liquid (N$_2$, Ne, H$_2$, He) by capillarity. However, due to the ceramic’s low thermal conductivity, a high thermal gradient builds up for low filling ratios. A high thermal conductivity material like copper with small pore size and high porosity (up to 80%) would combine the same capillary effect with a good thermal homogeneity in this type of devices with the possibility of easy soldering.

In the present work, a system was developed to measure the thermal conductivity of four Versarien samples of copper foam for a porosity between 50% and 80%, within the range of temperatures 20 – 260 K, using a 2 W @ 20 K cryocooler. The coherence of our measurements is validated using a copper control sample and by electrical resistivity measurements at room temperature, by the estimation of the Lorenz number. With these measurements, the purity (Resistivity Residual Ratio) and the tortuosity were obtained for all samples.


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Session Classification:  C1OrB - Cryogenic Heat Transfer

Track Classification:  CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Cryogenic system options for a superconducting aircraft propulsion system

Tuesday, 30 June 2015 16:00 (15 minutes)

Environmental and economic pressures lead to a need, in the aerospace industry, to develop ever more efficient passenger aircraft. Further progress in this regard may necessitate a move away from the conventional configurations seen today toward more radical designs. Aircraft with distributed propulsion may lead to fuel savings by allowing the exploitation of aerodynamic improvements. However, the transfer of propulsive power in the order of MW and 10s of MW poses significant challenges. A fully superconducting electrical system, from generators through distribution to fan motors, may be light and efficient enough to allow such a system to be economical in the future, but the provision of cryogenic temperatures in an aircraft is expected to be the greatest hurdle to its successful implementation. Losses at cryogenic temperatures in the order of kW must be expected.

A consortium consisting of Airbus Group Innovations, Rolls-Royce and Cranfield University are involved in the Distributed Electrical Aerospace Propulsion (DEAP) project. The use of a superconducting power architecture aboard a distributed propulsion aircraft is considered, to study the possible benefits and drawbacks such a system could bring about at an aircraft level. The inevitable increase in system weight and the cryogenic system’s power consumption must not be so high as to offset the aerodynamic and propulsive gains of the new aircraft configuration.

This paper will examine the cryocooling system choices that were considered in the DEAP project. Both a system with cryocoolers and a liquid methane heat sink, as well as a liquid hydrogen system will be compared and the advantages and challenges to their use in passenger aircraft will be discussed. The impact of the system’s efficiency and mass on the aircraft’s viability will be detailed. Technology targets for the successful implementation of superconducting aircraft will be presented to the community.
In this work, we have proposed, realized and analyzed trilayered Josephson junctions with a resonance-percolation charge transport (see [1] about this) consisting of two superconducting electrodes made of MoRe alloy with a critical temperature of about 10 K separated by a silicon layer of thicknesses up to 30 nm doped by tungsten with 4 - 12 at.%. We have studied low-temperature (T=4.2 K) current-voltage character of the junctions and revealed two novel important features, comparatively high characteristic voltages \( V_c = I_c R_n \) (\( I_c \) is the critical current and \( R_n \) is the normal-state resistance) up to 5 meV and even more which exceed theoretical estimates for a single Josephson junction and well-resolved Shapiro steps at voltage biases \( V_n = (h/2e)n f \) (\( n \) is an integer) in the presence of external microwave irradiation with the frequency \( f \) in the range from 0.5 to 20 GHz. Unusually high values of \( V_c \) and \( V_n \) in some samples can be explained by the presence of tens of junctions in series. We propose a simple theoretical formalism for charge transport across a set of resonance-percolating trajectories inside a nanometer-thick semiconducting films which is based on a distribution function of the transmission coefficient across a doped semiconducting interlayer.

The emergence of novel functionalities due to the disorder in doped nanometer-thick semiconducting films makes it possible to realize a trilayered junction with enhanced conductance properties and, at the same time, well separated metallic electrodes (see also [2]). We believe that it enables their use for various superconductive electronics applications including voltage standards.

Insulation system for high temperature superconductor cables

Wednesday, 1 July 2015 09:00 (2 hours)

Large-scale superconductor applications, like fusion magnets, require high-current capacity conductors to limit system inductance and peak operating voltage. Several cabling methods using high temperature superconductor (HTS) tape are presently under development so that the unique high-field, high-current-density, high operating temperature characteristics of 2nd generation ReBCO coated conductors can be utilized in next generation fusion devices. Large-scale magnets are generally epoxy impregnated to support and distribute electromagnetic stresses through the magnet volume. However, the present generation of ReBCO coated conductors are prone to delamination when tensile stresses, such as those that occur during epoxy cure or during cooldown, are applied to the broad surface of ReBCO tapes. We present the development of a conductor insulation system which effectively insulates HTS cabled conductors at high withstand voltage while simultaneously preventing the intrusion of the epoxy impregnant into the cable, thus eliminating degradation due to conductor delamination. We also describe a small-scale coil test program to demonstrate the effect of the cable insulation scheme and present preliminary test results.

Supported by the US Department of Energy, Office of Fusion Energy Science SBIR Award DE-SC0011862.

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Session Classification: M3PoB - Cryogenic Materials VI: Insulation

Track Classification: ICMC-12 - Insulation and Impregnation Materials
Numerical analysis on flow characteristics and performance of partial emission cryogenic liquid hydrogen pump with different impeller types

A partial emission cryogenic liquid hydrogen pump of radial-straight-blade was developed to meet an application requirement of small flow rate and high pump head. The exterior performance and flow characteristics of a partial emission cryogenic liquid hydrogen pump were simulated and studied in this paper. The external characteristic was predicted by using of sliding mesh method. The phenomenon of reverse and secondary flow was found in pump, in order to improve the internal flow, three kinds of impeller types were proposed. Based on the results, it can be concluded that the amount and extent of the vortex of backward inclined blade is fewer than radial-straight-blade. It was a good situation to improve inner flow that using the complex backward inclined blade (6+6). The prediction of external characteristics is accurately, by which the relative deviation of head was ±5%.

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**Track Classification:** CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Study of a percolation transition in a dilute two dimensional hole gas at low temperature in GaAs/AlGaAs

The study of the existence of a possible percolation transition in a dilute two dimensional hole gas in GaAs/AlGaAs within a parallel magnetic field, was the aim of our investigation in this work at a fixed low temperature $T=260$ mK. Following the evolution of the electrical conductivity as a function of magnetic field at high carrier densities, we have showed the creation of a density inhomogeneity beyond the critical percolation leading to metallic side. The results were proved in the present article by studying the exponent characterizing the type of transition and the variation of the critical percolation densities, which are considered good indicators to observe the percolation transition. In this investigation, we have reanalyzed the data obtained by Kumar et al published in the reference [M. Kumar et al, Solid State Communications Vol. 135. pp. 57-61 (2005)].

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Track Classification: ICMC-05 - Thin Films
Experimental investigation of a Hydrogen Pulsating Heat Pipe

Tuesday, 30 June 2015 11:45 (15 minutes)

The oscillating heat pipe (OHP) has been increasingly studied in cryogenic application, for its high transfer coefficient and quick response. Compared with Nb3Sn and NbTi, MgB2 whose critical transformation temperature is 39K, is expected to replace some high-temperature superconducting materials at 25K. In order to cool MgB2, this paper designs a Hydrogen Pulsating Heat Pipe, which allows to study how applied heat, filling ratio, and length of adiabatic section affect the thermal performance of the OHP, respectively. The thermal performance of the hydrogen OHP is investigated for filling ratios of 30%, 50% and 70% at different heat input, what’s more the starting power is received at these three filling ratios.

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Presenter: Mr DENG, Haoren (Zhejiang University)
Session Classification: C2OrC - Pulsating Heat Pipes and Thermosyphons
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
The regenerator is a critical component of all Stirling and Pulse Tube cryocoolers. It generally consists of a microporous metallic or rare-earth filler material contained within a cylindrical shell. The accurate modeling of the hydrodynamic and thermal behavior of different regenerator materials is crucial to the successful design of cryogenic systems. Previous investigations have used experimental measurements at steady and periodic flow conditions in conjunction with pore-level CFD analysis to determine the pertinent hydrodynamic parameters, namely the Darcy permeability and Forchheimer coefficients. Due to the difficulty associated with experimental measurement at cryogenic temperatures, past investigations where performed at ambient conditions. These results are assumed to be accurate for cryogenic temperatures since, for fully-developed flow, the Darcy and Forchheimer coefficients should depend only on the geometry of the porous medium. There is, however, a pressing need in the literature to determine the hydrodynamic parameters or ErPr under prototypical conditions and verify the validity of the foregoing assumption. In this analysis, a regenerator filled with spherical Er50Pr50 powder was assembled and tested under periodic helium flow at cryogenic temperatures. The mass flow and pressure drop data was correlated with a porous media CFD model to determine the Darcy Permeability and Forchheimer coefficients. These results are compared to the previous investigations at ambient temperature conditions, and the relevance of room-temperature models and correlations to cryogenic temperatures is critically assessed.

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Presenter: PERRELLA, Matthew (Georgia Institute of Technology)

Session Classification: C4OrA - System Issues and Regenerator Performance

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Input current ripple and vibration suppression in second generation control electronics

In collaboration with the Jet Propulsion Laboratory, Iris Technology is developing second generation cryocooler control electronics. The present development retains key features from the TRL 6 Low Cost Cryocooler Electronics (LCCE) design. Architected for cost sensitive missions, LCCE and this second generation “LCCE-2” are also extremely robust. Class S active electronic components and space grade discretes are used to achieve the required 300 krad Total Ionizing Dose (TID) and >0.97 reliability at three (3) years of mission life. The LCCE provides high efficiency (>92% typical) power conversion, precision temperature control, and is highly customizable through uploadable register values. An extensive data stream is provided to the ground station through the payload computer interface, including temperatures, voltages, and currents. LCCE-2 extends on this performance through the addition of two new features: input current ripple suppression and active vibration suppression. A linear cryocooler electronics module is essentially a programmable inverter, converting the DC input into an AC input at the commanded amplitude and frequency. This naturally results in a sinusoidal variation in the “DC” current draw into the electronics at twice the cryocooler drive frequency, on the order of several amps for the nominally 100W LCCE. This manifests as an unacceptable current ripple back onto the spacecraft bus. LCCE-2 incorporates a high efficiency (>93%) active input ripple filter (IRF) circuit to reduce the ripple by greater than 30 dB. Active vibration suppression is required to reduce the vibrations imparted by the driven linear cryocooler into the payload. LCCE-2, through the addition of an accelerometer circuit and additional firmware that modulates the drive signal of one of the two opposing compressor motors, reduces the exported vibration for the first three harmonics. The overall LCCE-2 design and performance is discussed herein with a focus on these new features.

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Presenter: KIRKCONNELL, Carl (Iris Technology)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Local Cryogenics for the SIS100 at FAIR

Tuesday, 30 June 2015 17:15 (15 minutes)

In the coming years a new international accelerator Facility for Antiproton and Ion Research (FAIR), one of the largest research projects worldwide, will be build close to Darmstadt in Germany. FAIR will provide antiproton and ion beams with unprecedented intensity and quality. One of its major accelerators will be the SIS100 having a circumference of about 1100 meters. The SIS100 tunnel will house a complex cryogenic system supplying up to 20 kW cooling capacity @ 4 K to about 300 superconducting magnet modules and further physics equipment. The SIS100 local cryogenic system can be principally divided into three sections each fed from a separate Feed Box. Each Feed Box supplies 4 K helium for magnet and bus-bar cooling as well as 50 K helium for the current lead and thermal shield cooling to the left and right part of such a section which comprises one sixth of the ring. Each sextant consists of a cold arc and a straight warm section. By-pass Lines circumvent the straight warm sections of SIS100 to supply helium and cold electrical connections to the superconducting quadrupole doublets within these sections. The purpose of such an infrastructure is to be able to separate the ring into six sections which can be independently cooled down, warmed up and serviced. The By-pass Lines are polish in-kind contribution, coordinated by the Jagiellonian University of Krakow and will be designed, manufactured and commissioned by the Wroclaw University of Technology. The design and the first manufactured components will be presented.

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Presenter: EISEL, Thomas (GSI)
Session Classification: C2OrE - Cryogenic Systems II
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
A study on intermediate buffer layer of a coated Fiber Bragg Grating cryogenic temperature Sensors.

Wednesday, 1 July 2015 14:15 (15 minutes)

The sensor characteristics of a coated Fiber Bragg grating (FBG) cryogenic temperature sensor depends mainly on the coating materials. The sensitivity of the coated FBG can be improved by enhancing the effective thermal strain transfer between the layers and the bare FBG. The dual coated FBG’s has a primary layer and the secondary coating layer. The primary coating layer acts as an intermediate buffer layer between the secondary coating layer and the bare FBG. The outer secondary coating layer is normally of higher thermal expansion sensitive metals. In this work, a detailed study is carried out on chromium and titanium intermediate buffer layers with various coating thickness and combinations. To improve the sensitivity, the secondary coating layer was tested with Mercury, Indium, Lead and Tin. The sensors were then calibrated in a cryogenic temperature calibration facility at Institute of Technical Physics (ITEP), Karlsruhe Institute of Technology. The sensors were subjected to several thermal cycles between 4.2 and 80K to study the sensor performance and its thermal characteristic. The sensor exhibits the Bragg wavelength shift of 14pm at 20K. The commercially available detection equipment with a resolution of 1pm can result into the temperature resolution of 0.071 K at 20K.

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Presenter: RAMALINGAM, Rajinikumar
Session Classification: C3OrG - Cryogenic Instrumentation and Control Systems
Track Classification: CEC-15 - Instrumentation and Controls
Electromagnetic behavior of striated coated conductors wound into pancake coils

Monday, 29 June 2015 16:30 (15 minutes)

Large magnetization of coated conductors is one of the most serious concerns of their applications to MRI or NMR magnets, because it deteriorate the uniformity and stability of the magnetic fields. As the counter measure against large magnetization, the striation of coated conductors was proposed, and its effect was demonstrated in small coils. Even if filaments (narrow conductor strips in a striated coated conductor) are insulated electrically, filaments are connected one another electrically at both ends of the coated conductors. Therefore, a current can circulate through both ends, and its decay time constant should be large. Of course, MRI or NMR magnets are not operated at 50 / 60 Hz, and, if the decay time constant of the circulating current is small enough as compared to the time scale of the operation of a magnet, the striation might be effective.

We study the electromagnetic behavior of striated coated conductors wound into pancake coils through numerical electromagnetic field analyses. The length of conductors, resistances between filaments at the ends, the magnetic field to which a conductor is exposed in a coil, the ramping up rate of the current and the magnetic field, etc. are varied to look at their influence on the decay time constant of the circulating current, in other words, the current imbalance between filaments. We also vary the resistance between filaments (not insulated completely). Based on the numerical results, the effect of striation is discussed.

This work is supported in part by the Ministry of Economy, Trade and Industry (METI) as Development of Fundamental Technologies for HTS Coils Project.

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Session Classification: M1OrC - Superconductor Stability and AC Losses
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Linear Resonance Compressor for Stirling-Type Cryocoolers Activated by Piezoelectric Stack-Type Elements

Tuesday, 30 June 2015 09:00 (2 hours)

A novel type of the PZT based compressor operating at mechanical resonance, suitable for pneumatically-driven Stirling-type cryocoolers was developed theoretically and built practically during this research. A resonance operation at relatively low frequency was achieved by incorporating the piezo ceramics into the moving part, and by reduction of the effective piezo stiffness using hydraulic amplification. The detailed concept, analytical model and the test results on the preliminary prototype were reported earlier and presented at ICC17. A fine agreement between the simulations and experiments spurred development of the actual compressor intending to drive a miniature Pulse Tube cryocooler, particularly our MTSa model, which operates at 103 Hz and requires an average PV power of 11 W, filling pressure of 40 Bar and a pressure ratio of 1.3.

The paper concentrates on design aspects and optimization of the governing parameters. The large diameter to stroke ratio (about 10:1) allows for the use of a composite diaphragm instead of a clearance-seal piston. The motivation is to create an adequate separation between the coolant and the buffer gas of the compressor, thus preventing possible contamination in the cryocooler. Providing a similar to conventional linear compressors efficiency and power density, the piezo compressor may serve as a good alternative for cryogenic applications requiring extreme reliability and absence of magnetic field interference.

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Session Classification: C2PoB - Stirling and Pulse Tube Cryocoolers
Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
A conceptual study on the use of a regenerator in a hybrid energy storage unit (LIQHYSMES)

Tuesday, 30 June 2015 17:00 (15 minutes)

Wind and FV parks raise the issue of a discontinuous electrical generation. The unavoidable demand for a buffering system that balances the grid is binding as is the need for new solutions. As energy carrier with its high volumetric energy density, liquid hydrogen is an inevitable choice for large-scale energy storage. But, since balancing loads or rapidly evolving fluctuations on the grid with just hydrogen is unrealistic, due to its slow response, it is necessary to integrate it with an electrical energy storage device that enables rapid response. This approach combines the use of a liquefaction plant for hydrogen, and a superconductive magnetic energy storage (SMES): the synergy obtained with a cryogenic infrastructure and a SMES, i.e. a compact LIQHYSMES storage unit, allows a steady operation mode of the hydrogen, buffering the unpredictable requests from the electrical grid and restraining costs. Besides, in this case, conventional liquefaction methods (e.g. Claude system) are not a viable solution, meaning that a substantial simplification of the process is possible where a regenerator/recuperator is employed and only if a temporary/intermediate storage is required. The use of a regenerator results in an advantageous solution allowing to recover at least partially the exergy stored in the form of liquid hydrogen, even though it does not represent a standard application in cryogenics. A study is conducted to develop a regenerator (among other parts) for a proof of concept small scale LIQHYSMES system. A 1D model of differential equations is implemented to investigate the regenerator performances, addressing parameters such as regenerator configuration, material and fluid properties, temperature profiles, etc. Results are then analysed and discussed. Moreover, given the advanced manufacturing phase of all components, the implementation of the Fiber Bragg Grating sensor for mapping temperature profiles within the regenerator is also addressed.

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Session Classification: C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Capillary cooling of superconducting coils

Wednesday, 1 July 2015 15:00 (15 minutes)

Superconducting coils in AC application have losses which tend to warm up the coil and so limit the performance. Good thermal contact between the coil and the cooling agent is very important. Cooling by heat conduction is no option since big metallic plates in close contact with the coil generate eddy-current heating. In this research we investigate the possibility of cooling the coil with a capillary through which a cryoliquid, e.g. liquid hydrogen or liquid neon, flows. The first results, using liquid nitrogen, will be reported.

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Session Classification: C3OrF - Superconducting Magnets Cryogenic Systems II
Track Classification: CEC-06 - Superconducting Magnet Systems
[Invited] The origin of strain sensitivity in Nb3Sn

Tuesday, 30 June 2015 11:00 (30 minutes)

Externally applied strain affects the superconducting properties of Nb3Sn in a detrimental way. This is an important design issue in high-magnetic-field applications utilizing Nb3Sn technology where distortion due to Lorentz forces and differential thermal contraction is unavoidable. An overview is given of how the critical current density of Nb3Sn is affected by temperature, magnetic field and strain. Subsequently, it is demonstrated that the large strain sensitivity in Nb3Sn is a direct result of a strain-induced distortion of the niobium chains. Ab-initio calculations are combined with microscopic theory to determine how this distortion affects the superconducting properties and normal state resistivity in quantitative terms, and the results are validated with experimental observations. The same model is then used to explain the different degrees of strain sensitivity between Nb3Sn, Nb3Al, Nb and NbTi. Understanding the underlying mechanisms that determine the (strain-dependent) superconducting properties of Nb3Sn is an important step forward in maximizing the performance of Nb3Sn technology in high field applications.

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Presenter: MENTINK, Matthias (CERN)

Session Classification: M2OrA - Superconductor Materials III: Nb3Sn

Track Classification: ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Experimental and CFD analyses of a thermal radiation shield dimple plate for cryogenic pump application

Tuesday, 30 June 2015 11:30 (15 minutes)

Large customized cryogenic pumps are used in fusion reactors to evacuate the plasma exhaust from the torus. They usually consist in an active pumping surface area cooled below 5 K and shielded from direct outer thermal radiation by plates cooled at about 80K. Cryopumps are exposed to excessively high heat fluxes during pumping operation and follow regeneration cycles with rapid warm-up and cool-down phases. Therefore, high cryogenic mass flows are required to operate the cryopumps and thus pressure drop and heat transfer characteristics become key issues in the design of the pump cryogenic circuits.

For optimal flow distribution and enhanced heat transfer, actively cooled dimple plates are a preferred design option for the thermal radiation shield. A test dimple plate of 2310 mm x 520 mm with a typical rhomb pattern of circular welding spots has been manufactured and tested against pressure drops with a dedicated test facility using a water loop. In the present work, computational fluid dynamics (CFD) simulations of the test dimple plate have been performed and pressure drops have been compared to experimental results. Despite the complexity of the geometry and the size of the model, a good agreement with the experimental results was found. Then, the tried and tested CFD approach has been applied for further calculations with relevant operation conditions, using gaseous helium at cryogenic temperature as working fluid. The resulting pressure drop and heat transfer characteristics are finally presented.

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Session Classification: C2OrD - CFD and Numerical Modelling
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Thermal Analysis of Superconducting Undulator (SCU) Cryomodules

Wednesday, 1 July 2015 09:00 (2 hours)

A cryocooler-cooled superconducting undulator (SCU0) has been operating in the Advanced Photon Source (APS) storage ring since January of 2013. Based on lessons learned from the construction and operation of SCU0, the 2nd superconducting undulator (SCU1) has been built and cold tested stand-alone. An excess cooling capacity measurement and static heat load analysis show a large improvement of cryogenic performance of SCU1 compared with SCU0. ANSYS-based thermal analysis of these cryomodules incorporating all the cooling circuits was completed. Comparisons between measured and calculated temperatures at the three operating conditions of the SCU0 cryomodule (static, beam heat only, beam heat and magnet current) will be presented.

Work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

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Presenter: SHIROYANAGI, Yuko (Argonne National Laboratory)

Session Classification: C3PoD - Superconducting Magnets Cryogenic Systems I

Track Classification: CEC-06 - Superconducting Magnet Systems
Computational and experimental investigation of hydroformed niobium tubes for superconducting RF cavities

Superconducting radio frequency (SRF) cavities are a well-established technology for imparting energy to the charged particles. Hydroforming technique has been researched to achieve higher accelerating fields and drastic reductions in resonator production time and costs. This study discussed the characterization of hydroformed niobium tubes to support for the subsequent hydro-forming of Nb tube into seamless cavities. The niobium tubes were heat treated and characterized by tensile strength, residual resistance ratio (RRR), and grain size. The optimally heat treated Nb tubes were subjected to hydraulic bulge testing. Finally, finite-element models (FEM) incorporating constitutive relationships analytically derived from the tensile and bulge tests, respectively, were constructed to replicate the bulge test. In addition, crystal plasticity model incorporating microstructure was investigated.

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Presenter: KIM, Hyun Sung (The Ohio State University)

Session Classification: C1OrG - Superconducting RF Systems I

Track Classification: CEC-07 - Superconducting RF Systems
Pulsed field stability and AC loss of Nb3Sn CICCs by quantitative modeling and experiments

Monday, 29 June 2015 17:00 (15 minutes)

The performance during an operating plasma scenario of Nb3Sn Cable-in-Conduit Conductors (CICCs) designs envisaged for the ITER Central Solenoid has been analyzed with the code JackPotACDC. At present there is no experimental facility available to test the stability of the conductors under relevant pulsed plasma operating conditions. Only limited experimental data is existing that is suitable for quantitative analysis but the time and magnetic field amplitude scales are different from the actual ITER operating conditions. Nevertheless, such tests are particularly useful for benchmarking of the code. To better assess the stability margins for the ITER magnets, the computed local electric field on the strands at most severe conditions during the plasma scenario is compared with the one obtained from the single harmonic pulse test performed in the SULTAN facility and DC transport current tests determining the current sharing temperature. The results of the stability test with the single harmonic magnetic field pulse is scaled to the ITER plasma operating conditions by using the numerical model. The first results are presented and discussed.

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Session Classification: M1OrC - Superconductor Stability and AC Losses

Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Transverse, axial and torsional strain tests on REBCO tapes as a basis for CORC modeling

Tuesday, 30 June 2015 17:15 (15 minutes)

For high current REBCO superconductors in high magnet fields with currents in the order of 50 kA, single coated conductors must be assembled in a cable. The geometry of such a cable is mostly such that combined torsion, axial and transverse loading states are anticipated in the tapes and tape joints. A set of experimental setups as well as a convenient and accurate method of stress-strain state modeling based on Finite Element Method (FEM) has been developed. Systematic measurements on single REBCO tapes are carried out combining axial tension and torsion as well as transverse loading. Then the behavior of a single tape subjected to the various applied loads is simulated in the model. This paper presents the results of experimental tests and detailed FE modeling of the 3D stress-strain state in a single REBCO tape under different loads, taking into account the temperature dependence and the elastic-plastic properties of the tape materials, starting from the initial tape processing conditions during its manufacture up to magnet operating conditions. Furthermore a comparison of the simulations with experiments is presented with special attention for the critical force, the threshold where the tape performance becomes irreversibly degraded. We verified the influence of tape surface profile non-uniformity and copper stabilizer thickness on the critical force. The FE models appear to describe the tape experiments adequately and can thus be used as a solid basis for optimization of various cabling concepts.

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Presenter: NIJHUIS, Arend (University of Twente)

Session Classification: M2OrC - Superconductor Wires II: Coated Conductors and Applications

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Cryostat design for the measurement of surface resistance of thin-film coated SRF Cavities

A liquid helium cryostat has been developed for the measurement of surface resistance of thin-film coated SRF cavities at high frequencies (7.8 GHz). The technique is based on the measurement of RF power absorbed in the coated film using calorimetry. The thin film substrate forms the lower end of a pillbox-like cavity, which is separated from the upper-half of the cavity by a vacuum gap. This gives good thermal isolation between the sample and the rest of the cavity body and facilitates quick and easy replacement of the samples mounted on a cradle which is assembled and prepared in a clean room environment. This paper describes the cryostat design in detail with some initial results.

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Presenter: PATTALWAR, Shrikant (STFC Daresbury Laboratory, UK)

Track Classification: CEC-07 - Superconducting RF Systems
Qualification of Electron-Beam Welded Joints between Copper and Stainless Steel for Cryogenic Application

Monday, 29 June 2015 14:00 (2 hours)

Joints between copper and stainless steel are commonly applied in cryogenic systems. A relatively new and increasingly important method to combine these materials is electron-beam (EB) welding. Typically, welds in cryogenic applications need to withstand a temperature range from 300 K down to 4 K and pressures of several MPa. However, very little data is available for classifying EB welds between OFH copper and 316L stainless steel.

Therefore, a broad test program has been conducted in order to qualify this kind of weld. The experiments started with destructive tensile tests at room temperature, at liquid nitrogen and at liquid helium temperatures, yielding information on the yield strength and the tensile strength of the welds at these temperatures. The tests were followed by nondestructive tensile tests up to yield strength, i.e. the range in which the weld can be stressed during the operation. To verify the leak-tightness of the joints, integral leak tests at operating pressures of 5 MPa were carried out before and after each tensile test, each at room and at liquid nitrogen temperature. Finally, the hardness of the EB weld was measured in the weld area. The results of the qualification indicate that EB welded joints between OFH copper and 316L stainless steel are reliable and present an interesting alternative to other technologies such as brazing or friction welding.

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Session Classification:  M1PoB - Cryogenic Materials II: Properties and Treatments
Track Classification:  ICMC-11 - Metallic and Composite Materials
Performance of the cold powered diodes and diode leads in the main magnets of the LHC

Tuesday, 30 June 2015 16:30 (15 minutes)

During quench tests in 2010 variations in resistance of an order of magnitude were found in the diode by-pass circuit of main LHC magnets. An investigation campaign was started to understand the source, the occurrence and the impact of the high resistances. Many tests were performed offline in the SM18 test facility with a focus on the contact resistance of the diode to heat sink contact and the diode wafer temperature. In 2014 the performance of the diodes and diode leads of the main dipole bypass systems in the LHC was assessed during the so-called CSCM test. In the test a current cycle similar to a magnet circuit discharge from 11 kA with a time constant of 100 s is performed. Resistances of up to 400 µΩ have been found in the diode leads at intermediate current, but in general the high resistances decrease at higher current levels and no signs of overheating of diodes have been seen and the bypass circuit passed the test. In this report the performance of the diodes and in particular the contact resistances in the diode lead are analysed with available data acquired over more than 10 years from acceptance test until the CSCM test in the LHC.

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Presenter: Dr WILLERING, Gerard (CERN)

Session Classification: C2OrF - Superconducting Magnets II

Track Classification: CEC-06 - Superconducting Magnet Systems
SOFI/Substrate Integrity Testing for Cryogenic Propellant Tanks

Monday, 29 June 2015 12:15 (15 minutes)

Liquid propellant tank insulation for space flight requires low weight as well as high insulation factors. Use of Spray-On Foam Insulation (SOFI) is an accepted, cost effective technique for insulating a single wall cryogenic propellant tank and has been used extensively throughout the aerospace industry. Determining the bond integrity and the SOFI’s ability to withstand the strains, both physical and thermal, applied during fill and drain cycles is critical to the longevity of the insulation. This determination has previously been performed using highly volatile, explosive cryogens, which increases the test costs enormously, as well as greatly increasing the risk to both equipment and personnel.

CTD has developed a new test system, based on previous NASA testing, that enables a relatively small SOFI/substrate test sample to be monitored for any deformations, delaminations, or disjunctions within during the cooling and mechanical straining process of the substrate, as well as enabling the concurrent application of thermal and physical strains to two specimens at the same time. The thermal strains are applied by cooling the substrate to the desired temperature (from 4 K to 250 K) while maintaining exposure to ambient conditions at the surface of the SOFI foam. Multiple temperature gaging points are exercised to ensure even cooling across the substrate, while surface temperatures of the SOFI can be monitored to determine the heat flow through the SOFI. The system also allows for direct measurement of the strains in the substrate during the test. The test system as well as test data from testing at 20 K for liquid Oxygen simulation testing will be discussed.

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Session Classification: M1OrB - Cryogenic Materials I: Testing and Methods
Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
In February 2014 CERN launched a design study for a future 100 TeV circular proton-proton collider with collision energy 7 more than in the present Large Hadron Collider. A new 100 km circular tunnel for the collider is foreseen as well as at least two new general purpose detectors. The study will materialize as a conceptual design report is to be issued in 2018 and eventually leading to operation earliest medio 2040.

The increase in collision energy from 7 to 100 TeV enforces a scaling up of the detector magnets in size and magnetic field for maintaining particle detection resolution. Options for the new detector magnet systems are being explored. Following the present largest detectors ATLAS and CMS, the study covers scaling up of the ATLAS magnet system layout based on using toroids for muon tracking and a solenoid for the inner detector. Also two dipole magnets are incorporated for covering the low angle forward directions. In a similar way the second option features a scaled-up CMS solenoid but also in combination with two dipole magnets.

The outer dimensions of the magnet systems show a diameter of 20-30 m and an overall length of 40 to 50 m. The magnetic field in the bores of the large toroid and solenoid will go up to some 2.5 and 6 tesla, respectively, with peak magnetic fields in the 7-8 tesla range, still possible with NbTi technology. The magnetic stored energies are in the record range of 40-70 GJ.

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**Session Classification:** C2OrF - Superconducting Magnets II

**Track Classification:** CEC-06 - Superconducting Magnet Systems
Comparison tests of cellular glass insulation for the development of cryogenic insulation standards

Monday, 29 June 2015 17:15 (15 minutes)

Standards for thermal insulation used in applications between ambient and low temperatures, below 100 K, require test data under relevant conditions and by different laboratories to develop data sets for the proper comparisons of materials. This critically important technology is needed to provide reliable data and methodologies for industrial energy efficiency and energy conservation. Under ASTM International’s Committee C16 on Thermal Insulation, two standards have been issued that including C1774 Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems and C740 Standard for Multilayer Insulation in Cryogenic Service. Thermal conductivity data sets have been taken using identical flat-plate boiloff calorimeter instruments independently operated at the Cryogenics Test Laboratory of NASA Kennedy Space Center (KSC) and the Thermal Energy Laboratory of LeTourneau University (LETU). Precision specimens of cellular glass insulation were produced for both laboratories to provide the necessary comparisons to validate the thermal measurements and test methodologies. Additional specimens of commercial cellular glass pipe insulation were tested at LETU to compare with the flat plate results. The test data are discussed in relation to the experimental approach, test methods, and manner of reporting the thermal performance data. This initial Inter-Laboratory Study (ILS) of insulation materials for sub-ambient temperature applications provides a foundation for further ILS work to produce standard data sets for several key commercial materials.

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Session Classification: C1OrF - Thermal Insulation Applications and Measurements
Track Classification: CEC-14 - Thermal Insulation Systems
Cryogenic Refrigeration System for Fermilab’s Muon Experimental Program

A new helium cryogenic refrigeration system for operating large superconducting solenoid magnets for two future muon experiments at Fermilab has been designed, installed, and operated for initial commissioning. This cryogenic system will support the Muon g-2 and Mu2e experiments at Fermilab’s Muon Campus. Much of the system consists of equipment reused from the Tevatron including gaseous helium and liquid nitrogen inventory storage, four 300 kW screw compressors, and four 600 W liquid helium satellite refrigerators. New piping and cryogenic transfer lines have been built and a new control system was installed. Two refrigerators with transfer line are independently available for each of the Muon g-2 and Mu2e experiments. This paper describes the Muon Campus cryogenic system, discusses the successful commissioning operation, and illustrates how existing cryogenic infrastructure is reused to meet new experimental needs.

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Presenter: SOYARS, William (Fermilab)

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Temperature dependence of critical current and transport current losses of 4 mm YBCO coated conductors manufactured using nonmagnetic substrate

AC losses in YBCO coated conductor tapes are one of the major heat load on the cryogenic systems in HTS cables, fault current limiters, and transformers. To reduce AC losses in tapes made using RABiTS process, a nonmagnetic substrate is being developed. Coated conductor tapes designed and manufactured using the new substrate have been characterized for critical current density and transport current losses at several temperatures between 63 and 77 K. Self-field critical current and transport current loss measurements were performed on several tape sections with the new nonmagnetic substrates and compared with regular RABiTS tapes. 4 mm wide tapes laminated by brass on both sides were measured. Temperatures below 77 K were achieved by pumping on liquid nitrogen and the temperature was controlled using a resistive heater and temperature controller. Loss measurements were performed at several frequencies in the 10 - 400 Hz interval. Critical current of the tape sections measured by standard four probe method was in 140 - 160 A range in the self-field at 77 K, and lowering of the temperature by 10 K the critical current increased by factor of two. Transport current losses were measured using a lock-in technique with compensation of inductive components. Measured transport current loss data were compared with Norris strip model. Results of the critical current and AC losses of the coated conductor samples with the new substrate will be discussed.

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Session Classification: M2OrB - Superconductor Wires I: Testing and Characterization
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Optimization of Cryogenic Chilldown and Loading Operation Using SINDA/FLUINT

Tuesday, 30 June 2015 14:00 (2 hours)

A cryogenic advanced propellant loading (APL) system is being developed at NASA. The APL will be employed in a wide range of applications including autonomous cryogenic loading operations. The number of applications and a variety of loading regimes call for development of computer assisted design and optimization methods that will reduce time and cost and improve reliability of APL. An aspect of this development is modeling and optimization of non-equilibrium two-phase cryogenic flow in the transfer line. Previously, we reported on modeling the cryogenic chilldown and loading of the NASA-KSC testbed using SINDA/FLUINT. The model is based on the solution of two-phase flow conservation equations in one dimension and a full set of correlations for flow patterns, losses, and heat transfer in the pipes, valves, and at t-junctions. It was shown that the pressure, fluid and wall temperatures, obtained during chilldown of the facility were well represented by the model.

For future cryogenic loading applications it is desired to optimize the entire chilldown process during system design. The objective of such an optimization could be multifold, including: (i) to attain system parameters that minimize chilldown time or (ii) minimize fluid loss. Many parameters may be varied during the optimization process. These include pipe sizing, valve opening and timing, for both flow valves as well as dump valves, pressure in the storage tank, etc.

Currently an optimization procedure is being implemented in the existing KSC model to study the feasibility of such an approach in SINDA/FLUINT. Results of this development will be reported as well as refinement to the model since our last report.

The optimization results will also be compared with those obtained using an unconstrained nonlinear optimization method applied to a homogeneous model of two-phase cryogenic flow.

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Session Classification: C2PoL - Thermal Fluids (Aerospace Applications)

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Thermal Performance Testing of Cryogenic Multilayer Insulation with Silk Net Spacers

Monday, 29 June 2015 17:45 (15 minutes)

Early comprehensive testing of cryogenic multilayer insulation (MLI) focused on the use of silk netting as a spacer material. Silk netting was used for multiple test campaigns designed to provide baseline thermal performance estimates for cryogenic insulation systems. As more focus was put on larger systems, the cost of silk netting became a deterrent and most aerospace insulation firms began using Dacron (or polyester) netting spacer material by the early 1970s. In the midst of the switch from silk netting there was no attempt to understand the difference between silk and polyester netting, though it was widely believed that the silk netting provided slightly better performance. Without any better reference for thermal performance data, the silk netting performance correlations continued to be used. In order to quantify the difference between the silk netting and polyester netting, a brief test program was developed. Silk netting was obtained from the remnants of legacy flight programs and was tested on the Cryostat-100 boil-off calorimeter in three different configurations. The data shows good agreement with the historical silk netting based correlations and indicates a performance improvement when compared to previous testing performed using polyester netting and aluminum foil/microfiberglass paper MLI systems. Additionally, the data further reinforce a recently observed trend that the heat flux is not directly proportional to the number of layers installed on an MLI system.

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Presenter: JOHNSON, Wesley
Session Classification: C1OrF - Thermal Insulation Applications and Measurements
Track Classification: CEC-14 - Thermal Insulation Systems
Demonstration of Hybrid Multilayer Insulation for Fixed Thickness Applications

Monday, 29 June 2015 16:45 (15 minutes)

Once on orbit, high performing insulation systems for cryogenic systems need just as good radiation (optical) properties as conduction properties. This requires the use of radiation shields with low conductivity spacers in between. By varying the height and cross-sectional area of the spacers between the radiation shields, the relative radiation and conduction heat transfers can be manipulated. However, in most systems, there is a fixed thickness or volume allocated to the insulation. In order to understand how various combinations of different multilayer insulation (MLI) systems work together and further validate thermal models of such a hybrid MLI set up, test data is needed. The MLI systems include combinations of Load Bearing MLI (LB-MLI) and traditional MLI. To further simulate the space launch vehicle case wherein both ambient pressure and vacuum environments are addressed, different cold-side thermal insulation substrates were included for select tests.

The basic hybrid construction consists of some number of layers of LB-MLI on the cold side of the insulation system followed by layers of traditional MLI on the warm side of the system. The advantages of LB-MLI on the cold side of the insulation blanket are that its low layer density (0.5 – 0.6 layer/mm) is better suited for lower temperature applications and is a structural component to support heat interception shields that may be placed within the blanket. The advantage of traditional MLI systems on the warm side is that radiation is more dominant than conduction at warmer temperatures, so that a higher layer density is desired (2 - 3 layer/mm) and less effort need be put into minimizing conduction heat transfer. Liquid nitrogen boil-off test data for a cylindrical calorimeter are presented along with analysis for spacecraft tank applications.

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Session Classification: C1OrF - Thermal Insulation Applications and Measurements
Track Classification: CEC-14 - Thermal Insulation Systems
Solid-cryogen-stabilized, cable-in-conduit superconductor cables

This paper considers the use of a solid cryogen as a means to stabilize, both mechanically and thermally, superconducting wires (MgB2, 2212 or 2G) within a dual channel cable-in-conduit (CIC) cable for use in AC applications, such as a generator stator winding. The cable consists of two separate channels; the outer channel contains the superconducting strands and is filled with a fluid (liquid or gas) that becomes solid at the device operating temperature. Several options for fluid will be presented, such as liquid nitrogen, hydrocarbons and other chlorofluorocarbons (CFCs) that have a range of melting temperatures and volumetric expansions (from solid at operating temperature to fixed volume at room temperature). Implications for the quench protection and conductor stability, enhanced through direct contact with the solid cryogen, which has high heat capacity, will be presented. We present options for filling and cooldown. For example, during cooldown, cold nitrogen gas could be pumped through the outer channel until the cable temperature reaches ~100 K. Liquid nitrogen would then be injected into the cable until the outer channel is filled with liquid, and cold helium gas would be pumped through the inner cooling channel (without the strands) until the cable reaches the target operating temperature, which may be in the range from 20K to 60 K. At this point, the cryogen in the stranded-channel will be solid, essentially locking the wires into the mechanical structure of the cable, preventing degradation due to mechanical deformation and providing enhanced thermal capacity for stability and protection. The relatively high heat capacity of solid cryogens at these lower temperatures (compared to gaseous helium) enhances the thermal stability of the winding. During operation, coolant flow through the open inner channel will minimize pressure drop.

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Session Classification: C2PoN - Cryogenic Power Cables and Leads II
Track Classification: CEC-08 - Cryogenic Power Cables and Leads
Hierarchy of Two-Phase Flow Models for Autonomous Control of Cryogenic Loading Operation

Tuesday, 30 June 2015 11:45 (15 minutes)

We report on the development of a hierarchy of models of two-phase flow in cryogenic transfer line. The work is motivated by NASA plans to develop and maturate technology of cryogenic propellant loading on the ground and in space. The solution of this problem requires two-phase cryogenic flow models that are fast and accurate enough to identify flow conditions, to detect deviations from the nominal regime, and to propose optimal recovery strategy online without human interaction. The hierarchy of models described in this presentation is ranging from incompressible isothermal single-phase flow to separated non-equilibrium two-phase cryogenic flow. It includes heat transfer and pressure loss correlations for boiling flows based on the flow pattern recognition. We provide details of two models: (i) homogeneous, quasi-steady moving front model and (ii) the separated two-phase cryogenic flow model. Both models are based on the integration of energy and mass conservation equations on a one-dimensional grid of control volumes and solution of the momentum conservation equations on the staggered grid. The models are used to predict pressure, temperature, and liquid holdup during chilldown and loading of liquid nitrogen in a large scale cryogenic testbed at NASA-KSC.

The heat transfer and pressure loss correlations are validated by comparison of the model predictions with chilldown test data obtained at the National Institute of Standards and Technology. The accuracy of the model predictions for cryogenic loading operation is validated by comparison with experimental data obtained from the cryogenic testbed at NASA-KSC. The speed and stability of the models is analyzed. The application of the models to the online fault detection and isolation during loading operation is discussed.

The models performance is compared with the baseline model developed using a commercial SINDA/FLUINT software.

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Session Classification: C2OrD - CFD and Numerical Modelling

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Josephson generation of coherent THz stimulated emission on Planar Multilayer Superconducting Lattice (PMSL)

The transmission fluxon waves and plasmon waves are considered on Planar Multilayer Superconducting Lattice (PMSL). These nonlinear solitary waves are presented in the form of pulses that can propagate without change of form and without the loss or acquisition of energy. The wave-resistant, that can store information, also moving in the right direction that leads to the interaction with electronic devices. Such waves can be transformed into a single pulse-fluxons. One unit of fluxons can be is transformed in other form of signal which is required for the electronic systems. In addition, the movement and vibrations of fluxons in Josephson junctions is accompanied by stimulated emission in the range up to 10 THz. This effect allows to use of PMSL in the generators and detectors for the wide of electromagnetic spectrum. The signal applied to the film transformed in the voltage, the amplitude of which is dependent from the layer number. So that PMSL is expected to use in applications such as proximity switches, current limiters, microlasers Infrared (IR) of range and also antenna with scanning beam, where the gap of superconducting film is synthesized with low impedance.

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Track Classification: ICMC-13 - Radiation and Other Degradation Effects
Correlation of critical current density of bulk MgB2 having high connectivity between SC grains with concentration and distribution of higher magnesium borides and oxygen-enriched inhomogeneities, the role of Ti additions

Wednesday, 1 July 2015 12:15 (15 minutes)

MgB2-based bulk materials synthesized under 30 MPa – 2 GPa pressure demonstrated an enhanced connectivity, AF ~50–98% compared to other reports (below 50%) and a shielding fraction of 75–100 %. The materials demonstrate high critical current densities, jc, but no strict correlation was found between AF and jc. On the other hand, we found correlations between jc and the distribution of nanostructural inhomogeneities like impurity oxygen as oxygen-enriched Mg–B–O nanolayers or nano-inclusions and its solution in the MgB2 matrix and with the amount and size of higher magnesium borides MgBx, x>4 inclusions. With increasing MgB2 manufacturing temperature from 600÷800°C to 1050÷1100°C the Mg–B–O nanolayers transform into separate dispersed Mg–B–O inclusions and the sizes of inclusions of higher magnesium borides are decreased. The tendency is observed in a wide range of synthesis pressure (0.1 MPa–2 GPa). The described structural transformations are accompanied by an increase of jc in low and medium magnetic fields and by transition from the grain boundary to the point pinning. The Ti addition results in a further increase in jc due to: Ti promotes the formation of MgBx inclusions and segregation of oxygen in a MgB2 matrix, thus shifting the formation of Mg–B–O separate nano-inclusions to lower synthesis temperatures and facilitates the formation of a homogeneous MgB2 matrix with lower oxygen content, but with an increased number of Mg–B–O and MgBx pinning centers. Ti-contained inclusions are rather big to be pinning centers by itself. Besides, Ti absorbs impurity hydrogen forming titanium hydrides, thus preventing material from cracking and formation of MgH2, especially at low synthesis temperatures. The results of the jc and AC loss study by transformer method and trapped magnetic field using rings from MgB2 are discussed.

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Session Classification: M3OrB - Superconductor Wires IV: MgB2 and Applications

Track Classification: ICMC-04 - MgB2 Processing and Properties
Structure and properties of oxygen-containing thin MgB2 films

Wednesday, 1 July 2015 12:00 (15 minutes)

The results of the investigations of crystal structure, phase composition, relief, and superconducting characteristics of the oxygen-containing thin films from magnesium diboride (MgB2), which are deposited on the dielectric wafers by a magnetron sputtering of the magnesium diboride targets, are presented. It has been demonstrated that depending on the parameters of the deposition and annealing processes the thin films with various degrees of the structure perfection and phase composition could be fabricated. The various combinations of the Abrikosov vortices pinning types could be realized in the films such as a pinning in the places of fluctuation of superconducting critical temperature (δTc-type) or a pinning in the places of fluctuation of the free path length (δl-type). The appearance and density of these fluctuations can be influenced by the synthesis conditions. We obtained the deposited superconducting thin films, the structure of which can be described as MgBxOy and is in fact a solid solution of oxygen in the magnesium diboride crystal lattice. The density of superconducting critical currents of these films attains 1.8•1011 – 8.2 • 1010 A/m² at 10 K and 8•1010 – 2.8 • 1010 A/m² at 20 K in the 0–1 T fields (if an external magnetic field is oriented in parallel to the wafer surface).

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Session Classification: M3OrA - Superconductor Wires III: Thin Films

Track Classification: ICMC-05 - Thin Films
Engineering, Manufacture and Preliminary Testing of the ITER Toroidal Field (TF) Magnet Helium Cold Circulator

Monday, 29 June 2015 12:00 (15 minutes)

The ITER cryodistribution system provides the supercritical Helium (SHe) forced flow cooling to the magnet system using cold circulators. The cold circulators are located in each of five separate auxiliary cold boxes planned for use in the facility. Barber-Nichols Inc. has been awarded a contract from ITER-India for engineering, manufacture and testing of the Toroidal Field (TF) Magnet Helium Cold Circulator. The cold circulator will be extensively tested at Barber-Nichols’ facility prior to delivery for qualification testing at the Japan Atomic Energy Agency’s (JAEA) test facility at Naka, Japan. The TF Cold Circulator integrates features and technical requirements which Barber-Nichols has utilized when supplying Helium cold circulators worldwide over a period of 35 years. Features include a vacuum jacketed hermetically sealed design with a very low Helium leak rate, a heat shield for use with both Nitrogen & Helium cold sources, a broad operating range with a guaranteed isentropic efficiency over 70%, and impeller design features for high efficiency. The cold circulator will be designed to meet MTBM of 17,500 hours and MTBF of 36,000 hours. Vibration and speed monitoring are integrated into a compact package on the rotating assembly with operation and health monitoring in a multi-drop PROFBUS communication environment using an electrical cabinet with critical features and full local and network PLC interface and control.

For the testing in Japan and eventual installation in Europe, the cold circulator will be certified to the Japanese High Pressure Gas Safety Act (JHPGSA) and CE marked in compliance with the European Pressure Equipment Directive (PED) including Essential Safety Requirements (ESR). The test methodology utilized at Barber-Nichols’ facility and the resulting test data, validating the high efficiency of the TF Cold Circulator across a broad operating range, are important features of this paper.

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Session Classification: C1OrC - Compressors & Expanders
Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Thermodynamic analysis of a intermediate cooled heat exchanger working in high temperature ratio for Joule-Thomson cooler

Heat exchangers of high efficiency are critical components in cryocoolers, whose performance influences the overall performance of the cryocoolers to a large extent. The entropy generation in heat exchangers primarily is a result of heat transfer across finite temperature difference. The traditional approach is to increase the heat transfer area and heat transfer coefficient so as to reduce the entropy generation. But it is limited by economic consideration and size restriction. Besides, entropy generation within heat exchangers increases owing to property variations at low temperature, and the enhancement of heat transfer has limited effects. A novel approach, based on the minimization of entropy generation, is adopted to optimize heat exchangers in the paper. The temperature difference is redistributed by intermediate cooling the hot stream. As a result, the entropy generation is reduced. The approach is especially applicable when the ratio of temperatures at two ends is high. A model is built to analyse the temperature difference distribution and entropy generation when the hot stream is cooled in different ways. The property variations including changes in specific heat capacity and heat transfer coefficients at low temperature, axial conduction, as well as parasitic heat loads, increase entropy generation greatly, which are considered in the model.

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Session Classification: C3OrK - Special Session: JT Coolers

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Design and performance of a 3D printed liquid hydrogen tank with vapor cooled shielding for use in unmanned aerial vehicles

Monday, 29 June 2015 14:00 (2 hours)

Liquid hydrogen storage systems utilize various insulation methods that have direct bearing on the mass and overall volume of the tank which can be inversely related. When utilizing liquid hydrogen as a fuel source for fuel cells, the vaporized fuel must be warmed to minimize ice build-up on fuel lines and to ensure compatible temperatures with fuel cell membranes. Advances in 3D printing technologies have enabled the incorporation of the traditionally external heat exchanger into the tank structure itself, thereby reducing mass and volume while providing vapor cooling for the stored liquid hydrogen. Integrating the heat exchanger creates a complex structure that conventional manufacturing methods (e.g. machining, injection molding) are not well suited for. We use selective laser sintering (SLS) of a low density engineering polymer to create the tank liner which is then overwrapped with carbon fiber (Type IV configuration) to carry the pressure loads. Estimated final mass of the tank system is 2.8 kg resulting in a gravimetric capacity of hydrogen to tank material mass of 13.3% and 55% volumetric efficiency, while energy density of the tank is 4.5 GJ/m^3 and specific energy is 15 MJ/kg. Thermodynamic modeling of the tank system indicates a mass flow rate of 1.05E-05 kg/s at steady state operating conditions. Initial comparisons between tank performance and modeling estimates are made. The resulting tank has improved performance for utilization in small portable power applications not previously amenable to cryogenic hydrogen.

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Session Classification: C1PoL - Thermal Insulation
Track Classification: CEC-14 - Thermal Insulation Systems
Recent Development Status of High-Capacity 4K Pulse Tube Cryocooler

Wednesday, 1 July 2015 12:00 (15 minutes)

A high-capacity 4K two-stage pulse tube cryocooler (PTC) with a remote valve unit that produces cooling capacity of 1.5 W at 4.2 K and 36 W at 45 K simultaneously has been under development at Sumitomo Heavy Industries, Ltd. (SHI). The PTC can be used for dilution cryocoolers, magnet cooling and other cryogenic devices. Compared to the SHI 1W commercial PTC Model RP-082B2S, the cooling capacity at the second stage is improved significantly by enlarging the volume of the second stage regenerator and pulse tube, and by optimizing the DC flow in the cold head of PTC. To achieve the increased cooling capacity, a large compressor unit has also been under development. The electrical power consumption of the new compressor is specified to be about 9.5 kW at 50 Hz. Experimental results of refrigeration performance, load curves, etc of the prototype units will be described in this paper.

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Session Classification:  C3OrD - 4K Cryocoolers
Track Classification:  CEC-03 - Cryocoolers (Non-Aerospace)
Many researchers have studied performance of cryogenic thermal insulation materials with various cryogenic liquids. However, there are not many cases under liquid hydrogen environment. KIST has been operating a 1 L/hr scale hydrogen liquefaction and storage facility since 2013. The KIST liquid hydrogen system can liquefy hydrogen gas to liquid, store and transfer to a dedicated storage tank.

In this study, KIST has built a cryogenic insulation material testing apparatus according to the ASTM C1774, and conducted insulation performance tests for selected materials at liquid hydrogen environment. A series of experiments were carried out under various cold vacuum pressures ranging from high vacuum to ambient pressure, and the results are compared for several cryogenic insulation materials such as aerogel and perlite powders under liquid hydrogen environment.

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Session Classification: C1OrF - Thermal Insulation Applications and Measurements

Track Classification: CEC-14 - Thermal Insulation Systems
The structural design of composite flywheel

Composite flywheel is a novel energy storage device which can realize energy conversion between mechanical energy and electric energy. It has many advantages including high energy storage, high power, no pollution, high storage efficiency, noise free, wide application, long cycle life, and so on. The subject studied in this paper is a 0.5MJ/10000r/min superconducting composite flywheel energy storage system. Use the ANSYS finite element analysis software to set up the composite flywheel rotor model, extract the radial stress along the radius direction, circumferential stress and shear stress under the condition in maximum rotation rate. The results show that composite material can be well used for the high-speed flywheel structural design.

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Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Tensile strengths of polyamide based 3D printed polymers in liquid nitrogen

Wednesday, 1 July 2015 09:00 (2 hours)

Advances in additive manufacturing technology have made 3D printing a viable solution for many industries, allowing for the manufacture of designs that could not be made through traditional subtractive methods. Applicability of additive manufacturing in cryogenic applications is hindered, however, by a lack of accurate material properties at cryogenic temperatures. Nylon, commonly used in cryogenic engineering applications, is available for printing using fused deposition modeling (FDM) and selective laser sintering (SLS). We selected 5 SLS (DuraForm® EX, DuraForm® HST, DuraForm® PA, PA 640-GSL, and PA 840-GSL) and 1 FDM (Nylon 12) nylon variants based on the bulk material properties and printed properties at room temperature. Tensile tests were performed on five samples of each material while immersed in liquid nitrogen at approximately 77 Kelvin. Samples were tested in XY and, where available, Z printing directions to determine influence on material properties. Results show typical SLS and FDM nylon ultimate strength retention at 77 K, when compared to (extruded or molded) nylon ultimate strength.

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**Session Classification:** M3PoB - Cryogenic Materials VI: Insulation

**Track Classification:** ICMC-14 - Cryogenic Materials Testing and Methods
Effect of operating frequency and phase angle on performance of Alpha Stirling cryocooler driven by a novel compact mechanism

Tuesday, 30 June 2015 14:00 (2 hours)

Literature suggests that Alpha configuration Stirling cryocooler shows better theoretical performance when compared with Gamma configuration cryocooler. However, this has not been confirmed experimentally due to non-availability of drive mechanism providing large stroke to diameter ratio for Alpha cryocooler. The concept of novel compact drive mechanism can be used to operate miniature Alpha Stirling cryocoolers. The drive mechanism allows the use of multi-cylinder system while converting rotary motion to reciprocating motion. A stroke to diameter ratio of three is chosen and the drive dimensions are calculated for four piston-cylinder arrangements with 90° phase difference between adjacent arrangements providing two Alpha Stirling cryocoolers working simultaneously. It is also possible to use the drive mechanism to drive two different configurations of Stirling cryocooler simultaneously viz., Alpha configuration and Gamma configuration with equal volume displacement for the compression space. Due to specific arrangement in this drive mechanism, the combined peak torque requirement falls by 26.81% below the peak torque needed when only one unit is considered separately, leading to use of a comparatively lower torque motor.

For the thermodynamic analysis, second order cyclic analysis provides a simple computational procedure. Losses leading to decrease in refrigerating effect and increase in power requirement are calculated using appropriate equations from available co-relations for the conditions prevailing in the present system. The effects of phase angle between compressor and expander pistons as one parameter and the operating frequency as the other parameter, keeping other parameters fixed are presented in this paper. The maximum net refrigeration effect as well as COP is available at phase angle of 81°. However, in order to have a symmetrical system, the phase angle is fixed at 90° for both, the Alpha as well as Gamma cryocoolers. The cryocooler performance enhances with increase in operating frequency.

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Session Classification: C2PoM - Novel Concepts and New Devices II

Track Classification: CEC-17 - Novel Concepts and New Devices
Visual investigation of solid-liquid phase equilibria for non-flammable mixed refrigerant

Tuesday, 30 June 2015 14:00 (2 hours)

Mixed refrigerant (MR) which efficiently resolve the limitations of pure refrigerant for Joule-Thomson (J-T) cooling, draws a lot of attention from numerous researchers. Although MR can possess desirable characteristics for wide temperature range of cooling with partial evaporation and condensation, it has a significant operating challenge. Unlike hydrocarbon MRs, a non-flammable MR may have a fundamentally serious clogging problem at the J-T expansion part. This is due to the high freezing temperature of a constituent in the selected non-flammable MR. In this paper, the solid-liquid phase equilibria (i.e., freezing point) of the non-flammable MR which is composed of Argon, R14 (CF4), and R218 (C3F8), has been experimentally investigated by a visualized apparatus. Argon, R14 and R218 mixtures are selected to be efficiently capable of reaching 97 K in the MR J-T refrigerator system. Solid-liquid phase equilibria of mixtures have been tested with the molar compositions from 0 to 0.8 for each pure refrigerant. Each test result is simultaneously acquired by a camcorder for visual inspection and temperature measurement during a warming process. Experimental results show that the certain mole fraction of Argon, R14, and R218 mixture can achieve remarkably low freezing temperature even below 77 K. This unusual freezing point depression characteristic of the MR can be a useful information for designing a cryogenic MR J-T refrigerator to reach further down to 77 K.

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**Session Classification:** C2PoP - Mixed-Gas Properties

**Track Classification:** CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Experimental comparison of Pressure ratio in Alpha and Gamma Stirling cryocoolers with identical compression space volumes and driven simultaneously by a solitary novel compact mechanism

Stirling cryocoolers are capable of satisfying the contemporary requirements of a low-capacity cooler. A compact mechanism that can drive Stirling cryocooler with larger stroke and thus enhance the cooler performance is the need at present. The increase in the stroke will lead to a higher volumetric efficiency. Hence, a cryocooler with larger stroke will experience higher mass flow rate of the working fluid, thereby increasing its ideal cooling capacity. The novel compact drive mechanism is capable of operating more than one cryocoolers of different Stirling configurations simultaneously. This arrangement makes it possible to compare different Stirling cryocoolers on the basis of pressure ratio obtained experimentally. The preliminary experimental results obtained in this regard are presented here.

The initial experimentation is carried out on two Alpha Stirling units driven simultaneously by the novel compact mechanism. The pressure ratio obtained during the initial stages is 1.3538, which is enhanced to 1.417 by connecting the rear volumes of the compressor pistons to each other. The fact that annular leak across the expander pistons due to high pressure ratio affects the cryocooler performance, generates the need to separate the expansion space from bounce space. This introduces a Gamma configuration that is operated simultaneously with one of the existing Alpha units by same drive mechanism and having identical compression space volume. The results obtained for pressure ratio in both these units prove the concept that cooling capacity of Alpha configuration exceeds that of Gamma under similar operating conditions. This has been observed at 14 bar and 20 bar charge pressures during the preliminary experimentation. These results are presented in this paper. Thus, the theoretical predictions regarding pressure ratio and hence the cooling capacity of Alpha and Gamma configurations for low-capacity units are confirmed experimentally in the present work.

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Session Classification: C4OrD - Novel Concepts and New Devices III

Track Classification: CEC-17 - Novel Concepts and New Devices
Exergy analysis of LNG boil-off gas reliquefaction systems

Boil-off gas (BOG) generation and its handling is an important issue in LNG value chain because of economic, energy and safety reasons. Absorption of BOG in high pressure subcooled LNG facilitates liquid pumping and avoids the necessity of high-energy gas-compression. Condensation of BOG by nitrogen refrigeration cycle ensures returning of condensed BOG back to storage tank. Reverse Brayton cycle with nitrogen as working fluid is a preferred refrigeration cycle for reliquefaction systems because it is compact, safe, easy to operate and has quick start-up capability when compared with mixed refrigerant cycles. During the last decade several variants of reliquefaction systems with different configurations have been proposed in literature. Thermodynamic analysis of these systems are required to understand their strengths and weaknesses in order to arrive at an informed decision regarding their possible adoption.

In the present work, reliquefaction systems having Reverse Brayton refrigeration cycle with nitrogen as working fluid is analysed using first and second law of thermodynamics. Exergy analysis on a simplified base-level reliquefaction system with minimum number of equipment has been performed and used as the yardstick for evaluating the modified systems. The base cycle is modified with precooling, stages of compression and arrangement of heat exchangers etc. Aspen Hysys 8.6®, a process simulator is used for simulating different configurations of reliquefaction systems. The results show that exergy destruction in components and the occurrence of pinch in the heat exchanger where BOG condenses are important factors and they affect reliquefaction capacity. The analysis of modified cycles shows that change of configuration coupled with addition of precoolers and intercoolers decreases the destruction of exergy and hence the operating cost of the system.

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Session Classification: C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Helium extraction and nitrogen removal from LNG boil-off gas

Helium is an invaluable rare gas as it has a lot of applications in industrial and research. At present, helium is produced mainly from helium-bearing natural gas which contains 1~8% helium. However, most of helium reserves dissolved in natural gas is located in only a few countries in the world, and the low concentration of helium in Chinese natural gas field makes extracting helium from the natural gas uneconomical. Accordingly, it is important to explore possible unconventional helium sources especially in China to mitigate the helium shortage. Therefore, the helium-bearing boil-off gas (BOG) from LNG storage tank in LNG plant, which has a helium concentration of about 1%, has attracted the attention in China as a new helium source. However, as the BOG is usually recondensed to recover methane, it is likely to cause continuous accumulation of nitrogen in the unit, thus a nitrogen removal process must be integrated. This paper describes a conceptual design on a cryogenic separation process of helium extraction and nitrogen removal from LNG boil-off gas. In this process, methane and other few hydrocarbons are firstly separated with N2, He and H2 through cryogenic distillation, and then N2 is separated with He and H2 through cryogenic condensation at a lower temperature, next the H2 content of mixture is removed in a dehydrogenation unit, and finally the helium is extracted and purified in a helium liquefier. As an example, a 3000000m3/day LNG plant in China will produce 4900NM3/h BOG stream with a volumetric concentration of 88.8% CH4, 9.9% N2, 1% He and 0.3% H2. With this method, the helium extracted and liquefied can reach 70 L/hr. Moreover, about 4400NM3/h CH4 and 400NM3/h N2 can be recovered with final purity of 99% and 99.5% respectively.

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Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Since 2007, the European X-ray Free Electron Laser (XFEL) is being constructed at DESY, Germany. 800 superconducting niobium 1.3 GHz nine cell cavities and 100 superconducting magnet packages will be operated in a liquid helium II bath at 2K. The static and dynamic heat loads at 2K result in a vapour mass flow up to 96 g/s at 3100 Pa. A four stage cold compressor system is used to return the vapour to the XFEL helium refrigerator. Relative pressure oscillations of the helium II bath should be kept below 1% for stable RF operation of the cavities. In addition, fast changes of vapour pressure and mass flow at the inlet of the cold compressors must be avoided during variation of RF load, e.g. due to switching on/off of RF power or due to cavity quenches. Electrical heaters in the helium II bath of the XFEL linac will be used to compensate the RF load changes. The concept and results of measurements performed at Cryo Module Test Bench (CMTB), Accelerator Module Test Facility (AMTF) and FLASH accelerator are reported.
Performance evaluation of a developed orifice type heater for thermal compensation control at J-PARC cryogenic hydrogen system

Tuesday, 30 June 2015 14:00 (2 hours)

The J-PARC cryogenic hydrogen system provides supercritical hydrogen with the para-hydrogen concentration of more than 99% and the temperature of less than 20 K to three moderators so as to provide cold pulsed neutron beams of a higher neutronic performance. The nuclear heating is estimated to be 3.75 kW at the moderators for a 1-MW proton beam operation. The temperature rise is estimated to be 2.4 K at a circulation flow rate of 0.19 kg/s. There was concerned that the slight temperature rise would lead to a large pressure increase in the hydrogen loop since the supercritical hydrogen behaves as an incompressible fluid. Furthermore, temperature fluctuation of the feed hydrogen stream should be also reduced below 0.25 K because the neutron performance is affected by a hydrogen density change. We prepared a heater for thermal compensation and an accumulator, with a bellows structure, for volume control, so as to mitigate the pressure fluctuation caused by the proton beam on and off. We have developed a compact orifice type high-power heater and perform its performance evaluation during off and on beam operation. It is clarified through the commissioning processes that the heater control would be applicable for the 1-MW proton beam operation by extrapolating from the experimental data.

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Session Classification: C2PoH - Hydrogen Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Pressure and temperature fluctuation simulation of J-PARC cryogenic hydrogen system

At the J-PARC spallation neutron source, high-energy MeV-order neutrons generated from a mercury target are reduced to the appropriate energy level (meV order) in three types of hydrogen moderators (coupled, decoupled, and poisoned). The J-PARC cryogenic hydrogen system provides supercritical cryogenic hydrogen to the moderators at a pressure of 1.5 MPa and temperature of 18 K and removes 3.8 kW of the nuclear heating for the 1 MW proton beam operation, when the nuclear heating is estimated to be 3.8 kW. The temperature rise is estimated to be 2.4 K at a circulation flow rate of 0.19 kg/s. We prepared a heater for thermal compensation and an accumulator, with a bellows structure, for volume control, so as to mitigate the pressure fluctuation caused by the proton beam on and off below the allowable pressure of 0.1 MPa because the slight temperature rise leads to a large pressure increase in the supercritical hydrogen loop because of its incompressibility. In this study, an 1-D simulation code has been developed to understand pressure and temperature propagation through the hydrogen loop when the proton beam is turned on and off. Pressure drop through each component was estimated using a CFD code, STAR-CD. Heat transfer of supercritical hydrogen was calculated using author’s correlation. It was confirmed that the simulation results agreed with the experimental data under the same condition.

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Session Classification: C2PoH - Hydrogen Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Computational Fluid Dynamic Investigation of Loss Mechanisms in a Pulse-Tube Refrigerator

Tuesday, 30 June 2015 09:00 (2 hours)

In predicting Pulse-Tube Refrigerator (PTR) performance, One-Dimensional design and analysis tools such as Gedeon Associates SAGE® typically include models for performance degradation due to thermodynamically irreversible processes. SAGE®, in particular, accounts for convective loss, turbulent conductive loss and numerical diffusion “loss” via correlation functions based on analysis and empirical testing.

While the simplicity of 1-D simulation tools facilitates PTR design and analysis, this convenience comes at the cost of modeling detail. An investigator wanting to drill-down into the constitutive relationships or governing principles can be shielded from low-level physical details that may otherwise lead to design insights. In these types of investigations, a higher-order Computational Fluid Dynamics (CFD) simulation complements a 1-D simulation. Whereas 1-D simulation is a sufficient starting point for PTR design, Two-Dimensional and Three-Dimensional CFD models enable an investigator to refine the design—to explore and visualize “real” physical heat-transfer and fluid flow behavior that has been condensed, simplified or omitted in 1-D modeling tools. In a 2-D or 3-D CFD model, the system dynamics and complexity between the input and output of a particular PTR component are not hidden. In this regard, higher order CFD is also a means of validating 1-D models, or of tuning lower-order design tools to new performance spaces before physical functional validation or prototyping.

In this study, we compare CFD and SAGE® estimates of PTR refrigeration performance for four distinct pulse-tube lengths. Performance predictions from PTR CFD models are compared to SAGE® predictions for all four cases, and also compared to select published analytical and empirical models. Then, to further demonstrate the benefits of higher-fidelity and multidimensional CFD simulation, the PTR loss mechanisms are characterized in terms of their spatial and temporal locations.

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Session Classification:  C2PoE - CFD Modelling and Measurements Techniques

Track Classification:  CEC-04 - Cryocoolers (Aerospace)
Operational Experiences of J-PARC cryogenic hydrogen system for a spallation neutron source

Tuesday, 30 June 2015 14:00 (2 hours)

At the J-PARC, the high-energy MeV-order neutrons, which are produced via a spallation reaction between 3-GeV protons and the mercury nucleus, are moderated to cold neutrons with MeV-order energy by passing them through a supercritical hydrogen moderator (1.5 MPa and around 20 K). The cryogenic hydrogen system, which provides it to three hydrogen moderators, has been completed in April 2008. We have encountered several troubles such as unstable operation of helium refrigerator due to some impurities, a leakage through a welded bellows of an accumulator, hydrogen pump impeller damage and so on until now. Furthermore, the Great East Japan Earthquake was occurred during the cryogenic hydrogen system operation in March 2011. The proton beam power has increased to 400 kW and stable long-lasting operation has been achieved for three months. A 530-kW proton beam operation has been completed on trial for a limited time of 60 s. In this paper, we describe the operation characteristics and experiences of the J-PARC cryogenic hydrogen system.

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Presenter: TATSUMOTO, HIDEKI (Japan Atomic Energy Agency)
Session Classification: C2PoH - Hydrogen Systems
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Determination of thermodynamic temperature between 4.2K and 24.5 K by a new constant pressure refractive index gas thermometer

A new constant pressure refractive index gas thermometer (CPRIT) is proposed that measures the thermodynamic temperatures T from 4.2 K to 24.5 K with a quasi-spherical microwave resonator. The pressure fluctuation plays the essential entry for the measurement uncertainty by traditional refractive index gas thermometers operating above the triple point of water and constant volume gas thermometers running from 4.2K to 24.5K. We present a new method with the proposed CPRIT for stabilizing gas pressures in the fractional differences within one part of million in the temperature from 4.2 K to 24.5 K. The gas pressure stabilization promote the stability of measurement temperature so to decrease the measurement uncertainty. In addition, we propose a new procedure to minimize the deformation of the quasi-spherical cavity, and a new feature of gas fill ducts to decrease their disturbance for microwave resonances in the cavity. We report in this paper the theoretical model for the CPRIT and the analyses for all the imperfection disturbances for microwave resonant measurements. The theoretical analysis shows that the proposed CPRIT is anticipated to achieve a temperature measurement fluctuation bound with 25μK with helium as the working gas.

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**Presenter:** Dr GAO, Bo (Technical Institute of Physics and Chemistry, Chinese Academy of Sciences)

**Track Classification:** CEC-11 - Safety, Reliability, and Standards
Experience with cryogenic operation of Accelerator Module Test Facility during testing of one third of XFEL cryomodules

Wednesday, 1 July 2015 14:15 (15 minutes)

The European X-ray Free Electron Laser (XFEL), which is under construction at DESY, will produce pulsed electron beam with energy of 17.5 GeV. 800 superconducting niobium 1.3 GHz nine cell cavities and 100 superconducting magnet packages will be installed in 100 cryomodules. Each cryomodule of 12 m total length includes the 2K cold mass and two radiation shields at ca. 5-8K and 40-80K temperatures. All cavities, magnet packages and assembled accelerator modules have to be tested at nominal operating conditions. The tests take place in the Accelerator Module Test Facility (AMTF). We report our experience on cryogenic operation of AMTF after two years of operation.

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Session Classification:  C3OrE - Operating Experience II

Track Classification:  CEC-02 - Large-Scale Systems, Facilities, and Testing
Load specification and embedded plate definition for the ITER cryoline system

Monday, 29 June 2015 09:00 (2 hours)

The ITER cryoline (CL) system is part of overall ITER cryogenic system involving the cryoplant and the cryodistribution. The CLs are complex network of vacuum-insulated multi and single process pipe lines, distributed in three different areas at ITER site. The conceptual design phase of the lines has been completed and the detailed design, fabrication and installation will be performed by contractors appointed by India, responsible for in-kind supply of CL system to the ITER project. The CLs will have to support different operating conditions during the machine life-time of 20 years; either considered as normal, occasional or exceptional and will be designed to withstand these scenarios. The major loads considered for the design are inertial, pressure, temperature, assembly, magnetic, snow and enforced relative displacement. All the loads cases and the various load combinations which forms the design basis are put together in Load Specification.

Based on the defined load combinations, conceptual estimations for the reaction loads, has been carried out for the lines located inside the Tokamak building. Adequate numbers of embedded plates (EPs) per line have been defined, integrated in the building design. The finalization of building EPs to support the lines, before detailed design, is one of the major design constraints as the usual logic of the design is altered and has made the cryoline project technically more challenging. At the ITER project level, it was important to finalize EPs to allow adequate design and timely availability of the Tokamak building.

After the brief description of CL system, the paper will describe single loads and load combinations considered in load specification. The paper will also describe the approach for conceptual load estimation and selection of EPs for Toroidal Field Cyoline as example by converting all load combinations in two main load categories; pressure and seismic.

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Session Classification: C1PoD - Cryogenic Distribution Systems

Track Classification: CEC-01 - Large Scale Refrigeration and Liquefaction
Dynamic simulations of the cryogenic system of a tokamak

Wednesday, 1 July 2015 15:15 (15 minutes)

Power generation in the next decades could be provided by thermo-nuclear fusion reactors like tokamaks. There inside, the fusion reaction takes place thanks to the generation of plasmas at hundreds of millions of degrees that must be confined magnetically with superconductive coils, cooled down to about 4.4K.

The plasma works cyclically and the coil system is subject to pulsed heat loads which have to be handled by the cryogenic refrigerator cooling the superconductive coils. By smoothing the variable loads, the refrigeration capacity can be set close to the average power; optimizing investment and operational costs.

In the framework of the Broader Approach for ITER, CEA is in charge of providing the cryogenic system for the Japanese tokamak (JT60-SA), which is currently under construction in Naka. The system has been designed to handle the pulsed heat loads.

To prepare the acceptance tests of this cryogenic system foreseen in 2016, both dynamic modeling and experimental tests on a scaled down mock-up are of high interest for assessing pulsed load smoothing control.

After explaining HELIOS test experiments, a dynamic modelling of the cryogenic system of the Auxiliary Cold Box (ACB) of the tokamak is presented, with results on the pulsed load scenarios. The model has been built up using ad hoc coded components starting from industrial data.

The final goal is to realize a complete simulator of the helium distribution system in order to get a predictive tool that can be used to test multiple scenarios and controls. The same tool could also be adapted to any tokamak and used throughout the study of future fusion reactors operation. All the simulations have been performed with EcosimPro® computational software and the associated cryogenic library: CRYOLIB.

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Session Classification: C3OrG - Cryogenic Instrumentation and Control Systems

Track Classification: CEC-15 - Instrumentation and Controls
The development of new generation superconducting magnets for fusion research, such as the ITER experiment, is largely based on coils wound with so-called ‘cable-in-conduit’ conductors. These cable-in-conduit conductors consist of various types of stainless steel jackets, densely filled with superconducting strands based on either Nb3Sn or NbTi, and subsequently compacted. The concept of the cable-in-conduit conductor is based on a direct cooling principle, by supercritical helium, flowing through the central region of the conductor, in close contact with the superconducting strands.

Originating from this principle is a direct connection between the electrically grounded helium coolant supply line and the highly energized magnet windings. Various insulated regions, constructed out of high-voltage insulation breaks, are put in place to isolate sectors with different electrical potential. These axial insulation breaks are essentially build up from stainless steel end fittings, hermetically connected via a glass-reinforced resin composite body, of sufficient length, to prevent electrical breakdown during magnet operation.

In addition to high voltages and significant internal helium pressure, the insulation breaks will experience various mechanical forces resulting from differential thermal contraction phenomena and electro-magnetic loads. Special test equipment was designed, prepared and employed to assess the insulator breaks’ mechanical reliability.

A binary test setup is proposed, where mechanical failure is assumed when permeability to gaseous helium exceeds $10^{-9}$ Pa·m$^3$/s. The test consists of a load-to-failure insulation break charging, in tension, while immersed in liquid nitrogen at the temperature of 77 K. Leak tightness during the test is monitored by measuring the permeability of gaseous helium directly surrounding the insulation break, with respect to the existing vacuum inside the insulation break. The experimental setup is proven effective, and various insulation breaks performed beyond expectations.
Cryogenic thermometry for refrigerant distribution system of JT-60SA

Tuesday, 30 June 2015 14:00 (2 hours)

JT-60SA is a fully superconducting fusion experimental device involving Japan and Europe. The cryoplant supplies supercritical or gaseous helium to superconducting coils through valve boxes (VBs) or coil terminal boxes (CTBs). There are 89 temperature measurement points at 4 K in VBs and CTBs. Resistance temperature sensors will be installed on cryogen pipes in vacuum. Two type of sensors and two installation methods were experimentally evaluated in terms of accuracy and manufacturability. The sensor in the well method is installed in a narrow stainless steel capillary which is inserted into a cryogen pipe. This method is relatively conventional and accurate measurement, but technical inspections have to be imposed because of machining and welding pipes. The sensor in the saddle method is installed in a copper block which is attached on a cryogen pipe by silver brazing. This method is easy to make and not necessary to conduct specific inspections, but relatively inaccurate measurement because of less thermal contact between the sensor and fluid.

Two sensors installed on the pipe by each method have been examined at same time and compared with one reference sensor directly immersed in liquid helium in the pipe. The temperature of helium changes in the range of 3.34-5.06 K as an experimental parameter. The measured temperature difference between attached one and reference one has been within about 30 mK even by the saddle method. It is satisfied the accuracy requirement within 0.1 K.

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Session Classification: C2PoK - Instrumentation and Controls II

Track Classification: CEC-15 - Instrumentation and Controls
Properties of two stage Adiabatic Demagnetization Refrigerator

Monday, 29 June 2015 14:00 (2 hours)

In recent years, many space missions using cryogenic temperatures are being planned. In particular, a high resolution sensor like Transition Edge Sensor needs very low temperatures below 100 mK. It is well known that Adiabatic Demagnetization Refrigerator (ADR) is one of most useful methods to produce ultra-low temperatures in space because of independence on the gravity. We have studied a continuous ADR system consisting of 4 stages and it demonstrated to provide continuous temperatures around 100 mK. But there were some amounts of heat leaks from power leads which resulted to reduce the cooling power. In this study, several efforts to upgrade our ADR system will be presented. First, we will show the effect of using the HTS power leads. Then, a cascaded Carnot cycle consisting of 2 ADR units will be discussed.

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Session Classification: C1PoH - Aerospace Cryocoolers Analysis and Experimentation

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Magnetic refrigeration uses solid magnetic materials as refrigerant without global warming gas and fluorocarbon. In addition, it is expected the higher efficiency than that of vapor refrigeration system. Active Magnetic Regenerative Refrigeration (AMRR) system has demonstrated as an environmentally attractive candidate in near room temperature. There are many studies for the magnetocaloric materials based on experimental results, however, few studies on the theoretical view, especially for the entropy property due to the magnetic interaction.

Mean field theory is commonly used to calculate the properties of magnetocaloric materials, however, it is not in good agreement with the experimental data near the magnetic transition temperature. This is one of the issues to analyze the AMRR cycle by the computer simulation.

In this study, we will take a different approach to estimate the magnetic properties more precisely by using the Monte Carlo method. We will compare the calculation results between classical mean field theory and Monte Carlo method for a typical magnetic material, and then, we will simulate the AMRR cycle by using this approach.

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**Session Classification:** C2PoM - Novel Concepts and New Devices II

**Track Classification:** CEC-17 - Novel Concepts and New Devices
Preliminary Design of Helium Refrigeration System for RAON

Tuesday, 30 June 2015 09:00 (2 hours)

A large-scale helium refrigeration system is under designing by Rare Isotope Science Project for a new superconducting Linac, RAON. Heat loads of cryogenic components including cryomodules for superconducting, LTS magnets for IF (In-flight) Separator, and helium distribution system are predicted. The coldbox will supply 4.5 K supercritical helium and 40 K gas helium to each cryomodule through the distribution system. The cavities will be cooled at sub-atmospheric temperature, 2.1 K which is generated by recuperating systems in each cryomodule. 40 K helium is also used for the cooling of HTS magnets which will be installed at the front section. This paper presents current status of the helium refrigeration system for RAON.

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Session Classification: C2PoA - Cryogenic Systems I

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Transient heat transfer from a wire to a forced flow of subcooled liquid hydrogen passing through a vertically-mounted pipe

Wednesday, 1 July 2015 09:00 (2 hours)

Liquid hydrogen has been used as a fuel for a rocket engine and moderator material for cold neutron source. Recently, it is expected as a coolant for high-Tc superconducting devices because of its excellent cooling properties. The knowledge of transient heat transfer in forced flow of liquid hydrogen is necessary for the cooling design. However, there have been no experimental data on the transient heat transfer in liquid hydrogen as far as we know. In this work, transient heat transfer from a wire inserted into a vertically-mounted pipe to forced flow of subcooled liquid hydrogen with a temperature of 21 K and pressures of 0.4 and 0.7 MPa was measured by exponentially increasing heat input, \( Q = Q_0 \exp(t/T) \) where \( t \) is time and \( T \) is period. The Pt-Co wire heater has a diameter of 1.2 mm and length of 60 mm and 120 mm and is inserted into the pipe with a diameter of 8.0 mm, which is made of Fiber reinforced plastic due to thermal insulation. With increase in the heat flux up to the onset of nucleate boiling, surface temperature increases along the curve predicted by Dittus-Boelter correlation for longer period, where it can be almost regarded as steady-state. For shorter period, the heat transfer becomes higher than Dittus-Boelter correlation. In nucleate boiling regime, the heat flux steeply increases up to the transient DNB (departure from nucleate boiling) heat flux, which becomes higher for shorter period. Effect of flow velocity, period and heated length on the transient DNB heat flux was clarified.

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**Presenter:** TATSUMOTO, HIDEKI (Japan Atomic Energy Agency)

**Session Classification:** C3PoC - Convective Heat Transfer

**Track Classification:** CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Feed and End caps are connection boxes between Helium transfer lines and Cryomodules of the European XFEL project at DESY. Feed and End caps are characterised extreme narrow dimensional tolerances at the Cryomodule interface, in order to keep the XFEL linac beam pipe aligned perfectly during cryogenic operation. The expected movements of the beam pipe and process pipes due to pressure loading and thermal contraction are of the same order of magnitude as the specified tolerances. The purpose of the test was to validate if the dimensional tolerance specifications at the Cryomodule interface are fulfilled and the position of the beam pipe can be guaranteed. The Demaco contribution will show the test method, some test results and the positive conclusions.

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**Session Classification:** C1PoD - Cryogenic Distribution Systems  
**Track Classification:** CEC-02 - Large-Scale Systems, Facilities, and Testing
Reduction in variation in refrigeration temperature for a sorption compressor based J-T cooler

Wednesday, 1 July 2015 17:15 (15 minutes)

The requirement of a cryocooler with practically zero vibration and no electromagnetic interference has led to development of sorption compressor based Joule-Thomson (J-T) coolers. The adsorption is carried out at near room temperature and desorption process at an elevated temperature. High pressure is generated due to accumulation of desorbed gases inside the adsorber cell on providing heat input. The rate of desorption depends on the adsorbent loading level, the heat input rate and the time before the flow from desorption cell is started. Therefore, the rate of gases desorbed varies during the discharge phase as gas is continuously discharged after opening of the discharge valve. This affects the flow rate of the desorbed gases through the throttling device and results in the variation in the cold temperature desired. At the beginning of the throttling process, the gas mass flow rate is maximum due to maximum pressure difference between desorption and the adsorption cells. The adsorption rate within the cell does not match with the gas flow rate entering the adsorption cell. This causes increase in the pressure in the adsorption cell. As the pressure increases, the lowering of the temperature is affected. The variation in refrigeration temperature can be reduced by allowing the large flow rate through the throttling valve but not allowing simultaneously, the same to enter the adsorption cell. To achieve this simple insertion of a buffer chamber has been tried. In the present work, activated carbon is used as the adsorbent, with a mixture of nitrogen, methane, ethane and R134a acting as adsorbate. A buffer chamber of volume 9.75 l is used while the heat input is 990 W for a cycle time of 1500 seconds. A maximum variation of 8 °C is observed by using a buffer chamber against 11 °C without it.

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Session Classification: C3OrK - Special Session: JT Coolers

Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Development of high efficiency Stirling cryocooler for high temperature superconducting motor

Monday, 29 June 2015 11:30 (15 minutes)

For the wide spread of high-temperature superconductor (HTS) devices, a cryocooler having COP of >0.1, compact size, light-weight, high efficiency and high reliability is required. For practical use of superconductive devices, especially HTS motor used for electric vehicle. We developed a high efficiency Stirling pulse-tube cryocooler (STP). STP has high reliability and low vibration. However its efficiency was not enough to meet the demands of HTS motor. To further improve the efficiency, we reconsidered the expander of cryocooler and developed a Stirling cryocooler. A cooling capacity of 151W at 70K and a minimum temperature of 33K have been achieved with compressor input power of 2.15kW. Accordingly, the COP was about 0.07. The detail of cryocooler and the experimental results will be reported in this paper.

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Session Classification: C1OrA - Cryocoolers for Superconducting Applications

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Experimental characterization of the ITER TF structure cooling in HELIOS test facility

Wednesday, 1 July 2015 14:00 (15 minutes)

During ITER plasma operation, large thermal loads are generated in the stainless steel Toroidal Field (TF) coil casing. To avoid the increase of the TF conductor temperature in Cable in Conducts (CICC), cooling channels are implemented in between conductors and casings inner side, in particular in the plasma facing wall where the most stringent operating conditions in term of magnetic field, temperature and strain are located.

The cooling pipes in stainless steel are inserted in rectangular grooves filled with a charged resin, characterized by a good thermal conductivity.

To assess the efficiency of the cooling pipes and its thermal coupling with the charged resin, experimental characterizations have been performed. First of all, thermal resistance variation with respect to the temperature has been measured on material samples in a cryogenic bench. Further characterizations of the TF cooling scheme at cryogenic temperature have been performed on a dedicated mock-up in HELIOS test facility at CEA Grenoble. The mock up consists of a TF casing heated uniformly on its surface, a cooling channel implemented in the grooved filled with the charged resin, the filler, the insulation, the radial plate and a CICC. Both the cooling pipe and the CICC are cooled by supercritical helium flow at 4.4K and 5 bar. Temperature, pressure and mass flow are measured in different locations to investigate the repartition of the heat flux in both cooling pipe and CICC. Stationary as well as transient operating modes have been tested to assess the thermal efficiency of the case cooling design. The knowledge of this heat flux repartition will help refining the thermal hydraulic models in order to be more realistic in the analyses of the plasma disruption for example. The experimental tests are presented and the results are discussed and analyzed.

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Presenters: ROUSSET, Bernard (CEA Grenoble); HOA, Christine (CEA SBT)
Session Classification: C3OrF - Superconducting Magnets Cryogenic Systems II
Track Classification: CEC-06 - Superconducting Magnet Systems
5-year operation experience with the 1.8 K refrigeration units of the LHC cryogenic system

Wednesday, 1 July 2015 14:45 (15 minutes)

Since 2009, the Large Hadron Collider (LHC) is in operation at CERN. The LHC superconducting magnets distributed over eight sectors of 3.3-km long are cooled at 1.9 K in pressurized superfluid helium. The nominal operating temperature of 1.9 K is produced by eight 1.8-K refrigeration units based on centrifugal cold compressors (3 or 4 stages depending to the vendor) combined with warm volumetric screw compressors with sub-atmospheric suction. After about 5 years of continuous operation, we will present the results concerning the availability for the final user of these refrigeration units and the impact of the design choice on the recovery time after a system trip. We will also present the individual results for each rotating machinery in terms of failure origin and of Mean Time between Failure (MTBF), as well as the consolidations and upgrades applied to these refrigeration units.

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Presenter: FERLIN, Gerard (CERN)

Session Classification: C3OrE - Operating Experience II

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Within the Physics Department of CERN the development of CORC (Conductor on Round Core) type HTS cables is pursued in view of possible application in future detector and fusion magnets. An important issue is the design and qualification of terminations that connect CORC cables mutually or to bus-bar systems. A termination design is envisaged which combines a simple manufacturing process with a lowest possible joint resistance in the few nano-ohm range at 4.2 K, first for a single CORC cable and subsequently for a six-around-one CORC based Cable-in-Conduit Conductor.

For the investigations a first 12 meter long single CORC cable of 38 tapes was manufactured at the company Advanced Conductor Technologies (ACT) in Boulder, Colorado that can carry 8 kA at 10 T and 4.2 K. Another 2 m long cable with 28 tapes was manufactured as well for testing joints. The investigation is on the effect of tapering the CORC cable within the joint to form a staircase like geometry on each end of the cable, which allows current to pass directly from the copper casing to the inner HTS tape layers within the CORC cable.

Simulations have shown a substantial decrease in joint resistance at operating current in the case both CORC cable and join casing are tapered. Joint manufacturing has to cope with typical problems as delamination of the ReBCO tapes and the formation of gas-bubbles inside the joint as both cause an increase of electrical resistance between layers of ReBCO tapes and between the CORC cable and the copper casing. Various soldering alloys and filling techniques have been evaluated.

The CORC cable samples and various terminations were tested at CERN. In this paper, various termination designs, the manufacturing process and experimental results are summarized.

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Session Classification: M2PoC - Superconductor Cables II: HTS

Track Classification: ICMC-09 - HTS Cables
CERN operates and maintains the world largest cryogenic infrastructure ranging from ageing installations feeding detectors, test facilities and general services, to the state-of-the-art cryogenic system serving the flagship LHC machine complex. After several years of exploitation of a wide range of cryogenic installations and in particular following the last two years major shutdown to maintain and consolidate the LHC machine, we have analysed and reviewed the maintenance activities to implement an efficient and reliable exploitation of the installations. We report the results, statistics and lessons learned on the maintenance activities performed and in particular the required consolidations and major overhauling, the organization, management and methodologies implemented.

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**Presenter:** Dr SERIO, Luigi (CERN)

**Session Classification:** C3OrE - Operating Experience II

**Track Classification:** CEC-02 - Large-Scale Systems, Facilities, and Testing
Development of linear compressor for compact 2K Gifford-McMahon cryocoolers

Wednesday, 1 July 2015 09:00 (2 hours)

The superconducting single photon detection (SSPD) system has been researched and developed the miniaturization of Gifford-McMahon (GM) cryocooler (SRDK-101D, Sumitomo Heavy Industries, LTD) that occupies many of system volume for using it in the vehicle. Total volume of the commercial cryocooler expander and the cryostat should be down about 2/3 and the compressor unit (CNA-11) should be about 50% volume down, and then the cryocooler performance is demanded needs the cooling capacity of 20mW at 2.3K in the cooling temperature. The major alteration is indispensable to decrease a present volume greatly though the optimization of an internal composition parts is one method to miniaturize the compressor unit volume. Because the adsorber and the oil separator that has almost the same volume as the main body of the compressor greatly occupy the space volume, it thinks the compressor unit to be an effective means that the development of a no lubrication compressor that excludes this part enables the miniaturization. In addition, a no lubrication compressor has the possibility that a new usage can be created.

The linear compressor was selected as a no lubrication compressor, the prototype has been designed and developed and preliminary experiments were conducted. The detailed experimental results will be discussed in this paper.

This work has supported by the research and development concerning the miniaturization technology of SSPD system for National Institute of Information and Communications Technology (NICT) of Japan.

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Session Classification: C3PoE - Turbomachines and Helium Components

Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Forced flow heat transfer from a round wire in a vertically-mounted pipe to supercritical hydrogen

The knowledge of forced flow heat transfer of low temperature hydrogen under supercritical pressure is important for designing superconducting magnets wound with cable in conduit conductor. Forced flow heat transfer of hydrogen from a round wire in a vertically-mounted pipe was measured at the pressure of 1.5 MPa and the temperature of 21 K by applying electrical current to give an exponential heat input ($Q=Q_0\exp(t/\tau), \tau=5 \text{ s}$) to the round wire. Two round wire heaters, which were made of Pt-Co alloy, with the diameter of 1.2 mm and the length of 54.5 and 120 mm were set in the central axis of a flow channel made of FRP with the inner diameter of 5.7 and 8.0 mm, respectively. The average temperature of the heater was obtained by a resistance thermometry by four-terminal method. Supercritical hydrogen flowed upward in the channel. Flow velocity was varied from 1 to 12.5 m/s. The heat transfer coefficients of supercritical hydrogen were compared with the conventional correlation presented by Shiotsu et al[1]. It was confirmed that the heat transfer coefficients for round wire were expressed by the correlation using the hydraulic equivalent diameter.


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Session Classification: C3PoC - Convective Heat Transfer

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Pumping speed studies of activated carbons at 4.2 K adhered to indigenously developed hydroformed cryopanels

Monday, 29 June 2015 14:00 (2 hours)

For the fabrication of a cryopump with large pumping speeds for use in tokamaks, in particular, for gases such as helium and hydrogen, different activated carbon sorbents (with surface areas ~ 2000 m²/g) in the form of granules, spheres and cloths have been developed. These sorbents are adhesively bonded on a small size hydroformed (in-house developed technology) cryopanel of size ~500mm x 100 mm, and this constituted a Small Scale Cryopump Facility (SSCF). The pumping speeds of this SSCF for various gases have been measured as per AVS standards which comprises of a dome mounted with pressure gauges, calibrated leak valve and gas analyser. The SSCF cryopanel was shielded by LN2 cooled radiation shields and chevron baffles to minimize the heat in leak. The measured average pumping speeds for SSCF with the surface area of ~1000 cm² for He and H2 at the constant panel temperature of 4.5 K, in the pressure range of 10⁻⁷ to 10⁻⁴ mbar, are ~2500 l/s and 2700 l/s respectively. The Pump performances for SSCF were also studied by using the test particle Monte Carlo simulation in Molflow⁺. The pumping speeds for different gases were analysed by varying the sticking coefficient and compared with the experimental results to find the sticking coefficients for helium and hydrogen. This paper describes the characterization and performances of different activated carbons, details of the SSCF experimental setup and the experimental results, the Monte Carlo simulation results and their comparison towards realizing the large scale cryopump.

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Session Classification: C1PoG - Thermal Analysis and Design

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
LNG systems for natural gas propelled ships

Tuesday, 30 June 2015 17:30 (15 minutes)

In order to reduce the atmosphere pollution generated by ships the International Marine Organization has established the Emission Controlled Areas. In this areas nitrogen oxides, sulphur oxides and particulates emission is strongly controlled. From beginning of 2015 the ECA covers waters 200 nautical miles from the coast of US and Canada, US Caribbean Sea area, the Baltic Sea, North Sea and English Channel. From beginning of 2020 strong emission restrictions will be also in force outside the ECA. This requires newly constructed ships to be equipped with exhaust gas cleaning devices or to be propelled with emission free fuels. In comparison to low sulphur Marine Diesel and Marine Gas Oil, LNG is a competitive fuel, both from technical and economical point of view. LNG can be stored in vacuum insulated tanks fulfilling difficult requirements resulting from marine regulations. LNG must be vaporized and pressurized to the pressure compatible with engine requirements (usually a few bar). The boil-off must be controlled to avoid occasional gas release to the atmosphere. The paper presents the LNG system designed and commissioned for a Baltic Sea ferry. The specific technical features and exploitation parameters of the system will be presented. The impact of marine strict regulations on the system thermo-mechanical construction and its performance will be discussed. The review of possible flow-schemes of LNG marine systems will be presented with respect to the system cost, maintenance and reliability.

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Session Classification: C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II
Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Permanent effect of a cryogenic spill on fracture properties of structural steels

Tuesday, 30 June 2015 17:00 (15 minutes)

Fracture analysis of a standard construction steel ship deck, which had been exposed to a liquid nitrogen spill, showed that the brittle fracture started at a flaw in the weld as a consequence of low-temperature embrittlement and thermal stresses experienced by the material. In the present study, the permanent effect of a cryogenic spill on the fracture properties of carbon steels has been investigated.

Charpy V-notch impact testing was carried out at 0°C using specimens, from the ship deck material. The average impact energy appeared to be below requirements only for transverse specimens. No pre-existing damage was found when examining the fracture surfaces and cross sections in the SEM.

Specimens of the ship deck material and a DOMEX S355 carbon steel were tensile tested in liquid nitrogen. Both steels showed a large increase in yield- and fracture strength and a large increase in the Lüders strain compared to the room temperature behavior. A cryogenic spill was simulated by applying a constant tensile force to the specimens for 10 min, at -196°C. Subsequent tensile tests at room temperature showed no significant effect on the tensile behavior of the specimens.

A small amount of microcracks were found after holding a DOMEX S355 specimen at a constant force below the yield point. In a ship deck material tensile tested to fracture in liquid nitrogen, cracks associated with elongated MnS inclusions were found through the whole test region. These cracks probably formed as a result of the inclusions having a higher thermal contraction rate than the steel, causing decohesion at the inclusion-matrix interface on cooling. Simultaneous deformation may have caused formation of cracks. Both the microcracks and sulphide related damage may give permanently reduced impact energy after a cryogenic exposure.

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Session Classification: M2OrD - Cryogenic Materials V: Structural Materials

Track Classification: ICMC-11 - Metallic and Composite Materials
Cryogenic System for Turkish Accelerator Center

Tuesday, 30 June 2015 17:00 (15 minutes)

The Turkish Accelerator and Radiation Laboratory in Ankara (TARLA) is proposed as the first facility of Turkish Accelerator Center (TAC) Project. It aims to be the first user laboratory in the region of Turkey in which both electromagnetic radiation and particles will be used. Main purpose of the facility is to use IR FEL for research in material science, nonlinear optics, semiconductors, biotechnology, medicine and photochemical processes. TARLA will use TESLA type superconducting linear accelerators operating at 1.3 GHz. Electrons will be after pre-acceleration by two normal conducting RF cavities, electron main acceleration system consists of two ELBE designed 20 MeV superconducting linear accelerator modules (cryo-modules) which can be operated in continuous mode.

AL-AT (Air Liquide Advanced Technologies) takes part to the project by supplying cryogenic plant for 2K sub atmospheric superconductive cavity operation. The plant includes the He refrigerator associated to its compressor station, a Dewar, a storage tank for helium gas and transfer lines. In addition, an in-house cold compressor associated to ambient temperature helium vacuum pumps was designed to generate 2K Helium flows. Customized HELIAL MF has been designed and manufactured by AL-AT to match the refrigeration power need for the TARLA project which is around 200 W at 2 K.

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Session Classification: C2OrE - Cryogenic Systems II

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
To establish hydrogen worldwide storage and marine transportation, it is important to develop liquid hydrogen tanks/carriers like liquefied natural gas tanks/carriers as well as a long level sensor such as a superconducting magnesium diboride (MgB2) level sensor. In the case of lengthening the MgB2 level sensor, a whole MgB2 wire needs uniform superconducting characteristics. Long MgB2 wires 1.7 m long and 0.32 mm in diameter, which were fabricated by in-situ method and reinforced by a CuNi (7:3) sheath, were taken as an object of study. To suppress the critical temperature of the wires, impurities (10% SiC) were added to the MgB2 core. A characteristic Difference among all the individuals of the same 20 mm-long MgB2 short wires were discussed.

This work was supported in part by a Grant-in Aid for Scientific Research, JSPS KAKENHI Grant Number 24246143, Japan.

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Presenter: Prof. TAKEDA, Minoru (Kobe University)

Session Classification: C3OrG - Cryogenic Instrumentation and Control Systems

Track Classification: CEC-15 - Instrumentation and Controls
Among the various families of Fe-based superconductors, iron chalcogenides, while present a transition temperature not particularly high, show great advantages for potential applications in high field, albeit at liquid helium temperature. In thin films, the strain can push the critical temperature up to 21K, the critical field up to more than 50 T and the irreversibility field close to this value. The critical current and its anisotropy heavily depend on the type of substrate used for the deposition. It is possible to reach values up to 1 MA/cm² at liquid helium temperatures and self-field with weak magnetic field dependence and without appreciable anisotropy. In this study, we will show what are the defects acting as pinning centers for different substrates and how the shape of the pinning centers determines the anisotropic observed currents.

Finally, in the case of STO, we present the first measurements on FeSeTe thin films deposited on bi-crystals showing that, differently from HTS, the high angle grain boundary is less limiting the supercurrent. Experiments indicate that the current is not appreciably depressed up to a misorientation angle of 10 degrees.

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**Session Classification:** M3OrA - Superconductor Wires III: Thin Films

**Track Classification:** ICMC-07 - Pnictides and New Superconducting Materials
Cryogenic Supply for the Facility for Antiproton and Ion Research

Tuesday, 30 June 2015 16:45 (15 minutes)

At the site of the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt (Germany) the international accelerator Facility for Antiproton and Ion Research (FAIR) is currently under construction. FAIR is going to be one of the largest research facilities worldwide. In its accelerator chain there will be two large machines with superconducting magnets, the heavy-ion synchrotron SIS100 and the isotope separator SuperFRS, with a total helium cooling inventory of more than 8 tons, as well as several experiments and small users of liquid helium. Altogether 108 dipole magnets for the SIS100 have to be tested in advance in the recently commissioned Series Test Facility (STF) at GSI.

The liquid helium supply for FAIR will be provided by one large refrigerator with a capacity of 25 kW (4.3 K equivalent), a cool-down and warm-up unit (CWU) with a capacity of 80 kW (at 80 K), and by several small refrigerators and liquefiers located over the FAIR campus, combined with approximately 1.6 km of transfer lines.

In this presentation the progress of the cryogenic infrastructure at FAIR will be presented with a focus on the magnet testing, the distribution systems, and the large cryo plants.

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Session Classification: C2OrE - Cryogenic Systems II

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
CFD study on the effects of viscous shear in a hot cascade Ranque-Hilsch vortex tube

Tuesday, 30 June 2015 11:00 (15 minutes)

Ranque-Hilsch vortex tube is a device that is capable of splitting the highly compressed inlet gas into two streams of lower pressure gases, namely, central zone of cold fluid generated near the axis and peripheral zone of hot fluid around the inner wall of the tube. Though, vortex tube has many benefits over the conventional heating and cooling devices, low efficiency is the biggest drawback of it. Therefore, the method of hot cascading is an endeavor to make the use of the cold gas for cooling purposes while improving the heating capacity of the hot gas. Thus, the method of hot cascading enhances the overall efficiency of the whole system. The hot cascade vortex tube consists of two vortex tubes connected in series in such a way that, the hot gas emerging out of the first stage of vortex tube serves as the inlet fluid for the second stage vortex tube.

This paper presents two predominant parameters which are utmost concern in the process of thermal separation, namely heat transfer and work transfer due to viscous shear along the radial, axial and tangential directions per unit length are studied. The Computational Fluid Dynamics (CFD) study has been carried out using RANS standard k-epsilon turbulence model with a two dimensional axi-symmetric structure mesh geometrical domain and air as working fluid. The CFD results reveal that the work transfer due to the action of viscous shear along the tangential direction increases considerably with hot cascading. However, the work transfer due to viscous shear along the axial direction degrades the performance of the device, as the heat transfer takes place from cold zone to the hot zone. The effect of radial shear stress is negligible due to low value of radial velocity gradient.

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Session Classification: C2OrD - CFD and Numerical Modelling

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Astro-particle shielding superconducting magnet
cryogenic design for space travel missions

For long term missions in deep space, a large superconducting toroid magnet to protect astronauts from ionizing radiations coming from Galactic Cosmic Ray is under studied in the frame work of the Space Radiation Superconducting Shield (SR2S) European project. This magnet is made of Titanium clad MgB2 superconductor to afford a bending power greater than 5 T.m at a cryogenic temperature of 10 K. A specific cryogenic system, combining both space and terrestrial technologies, is designed to cool down this 10 m long and 12 m diameter magnet.

Two different types of cooling have been studied to maintain the superconducting magnet at 10 K. A V-groove sunshield is considered around the external side of the magnet to reduce the heat fluxes coming from the sun or planets. To optimized V-groove sunshield, several numerical simulations have been performed using surface-to-surface radiation solver from Fluent® CFD. The following parameters have been considered: number of layers, angle between multi-layer Insulation...

To complete this design, pulse tube cryocoolers will be used to absorb the heat fluxes coming from the human habitat attached to the magnet. They will be linked on their first stage to the magnet and on their second stage to the surface of an 80 K thermal shield. Long cryogenic Pulsating Heat Pipe (PHP), using nitrogen as a working fluid, are pursued to be used as thermal link at the surface of the 80 K thermal shield. The cool down of the entire magnet, as a function of weight and possible material, is also presented when assembled in orbit or in case of quench in deep space.

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Session Classification: C2PoL - Thermal Fluids (Aerospace Applications)
Track Classification: CEC-10 - Aerospace
The Mechanical and material properties of 316LN austenitic stainless steel for the fusion application in cryogenic temperatures

Tuesday, 30 June 2015 16:30 (15 minutes)

Due to the increasing demand on performance for all materials used in superconducting magnet systems possibilities of increasing the mechanical performance of austenitic stainless steel is investigated. Especially at cryogenic conditions e.g. at liquid Helium temperature a variety of superconducting applications are realized.
The aim of this work is to investigate the mechanical properties of the steel grade 316LN before and after processing for superconducting cable jackets.
Here, cold working and especially heat treatment are crucial steps taken to build the cable in conduit changing the values of yield strength, ultimate tensile strength and total elongation.
The mechanical properties were evaluated using static tension tests at 4.2 K. Additionally structural changes were evaluated by light optical microscopy and EBSD (Electron Backscatter Diffraction). Two 316LN steels are compared, showing the impact of slight variations in the chemical composition.

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Session Classification: M2OrD - Cryogenic Materials V: Structural Materials
Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
Implementation of the thermodynamic and phase transition equations of superfluid helium in a CFD software

Wednesday, 1 July 2015 17:30 (15 minutes)

The cryogenic design of the next generation of superconducting accelerator magnets depends on our ability to simulate the helium heat and mass transfer in the internal structure of these magnets. For that matter accurate tools must be developed such as numerical codes integrating the thermodynamic behavior and phase transition in superfluid helium. Moreover it would also help to understand the fundamental behavior of superfluid helium in confined geometries as the ones created by the structure of the magnet, i.e. electrical insulation, space between the collars...

We have implemented in 2D and 3D the He II conservation equations in Fluent© CFD software corresponding to a simplified two-fluid model. It consists of a conventional continuity equation, a modified momentum equation for the total fluid and an energy equation including the Gorter-Mellink internal convection term modeling the turbulence regime. The code is mainly suited to simulate transient and steady-state flow configurations. At the walls, heat transfers are conjugated with Kapitza resistance. In addition, a new method has been developed to simulate the He II / He I transition in 2D based on a modified Volume Of Fluid method (VOF). The interface between the two states of liquid helium has been locally recreated in the corresponding cells to properly mimic the second order phase transition (no latent heat).

Both steady and unsteady numerical simulation have been performed and compared with different experimental results.

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Session Classification: C3OrJ - Special Session: Helium II Properties and Systems
Track Classification: CEC-13 - Helium II Properties and Systems
Design of the control system for the cryogenic distribution systems of the European XFEL project

Wednesday, 1 July 2015 09:00 (2 hours)

The European XFEL project launched on June 5, 2007 will require four large cryogenic distribution boxes, two smaller cryogenic boxes, five feed- and end caps and six string connection boxes for the cryogenic system. For operating and diagnostic all cryogenic instrumentation is connected to Profibus. The cryogenic boxes are manufactured by several companies inside and outside of Europe. All instrumentations like temperature sensors, flow-transmitters, valve-controllers and so on are checked before assembly. All instrumentation is prepared in such a way that it can be easily integrated into the process control system.

The process control system EPICS (for Experimental Physics and Industrial Control System) is used to control and operate the cryogenic plant and all its subcomponents. A complementary component of EPICS is the Open Source software suit CSS (for Control System Studio). CSS is an integrated engineering, maintenance and operating tool for EPICS. CSS enables local and remote operating and monitoring of the complete system and thus represents the human machine interface.

More than 300 PROFIBUS nodes are foreseen to operate in the XFEL cryogenic facility. DESY will install an elaborate diagnostic and condition monitoring system. With these diagnostic tools it will be possible to examine the correct installation and configuration of all PROFIBUS nodes in real time. The condition monitoring system based on FDT/DTM technology shows the state of the PROFIBUS devices at a glance. This information will be used for preventive maintenance which is mandatory for continuous operation of the XFEL facility.

This paper will describe all steps form engineering to the facility acceptance tests and the first commissioning.

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Session Classification: C3PoB - Cryo Controls

Track Classification: CEC-15 - Instrumentation and Controls
Conceptual Design of the Cryogenic System for the HL-2M System

Medium-sized tokamak HL-2A has been operated for nearly ten years. In order to increase plasma parameters and extend experimental research space under the condition of higher power auxiliary heating, the HL-2A tokamak has been approved to be modified into HL-2M as the second step for HL-2A project. Cooling power of 300 W at 4.5 K is required to maintain operation of the cryogenic system of HL-2M. The cryogenic system used to cool the toroidal cryopump, neutral beam cryopump and other small superconducting magnets. To cope with different operation schedule, the cryogenic system has several operation modes, which are cool-down mode, warm up mode, two-phase helium cooling mode and cryopump regeneration mode. Considering the long-term planning, this cryogenic system which has some additional interfaces can also work under forced flow cooling mode. This paper describes the conceptual design of this cryogenic system, which includes the design of the flow scheme, the estimation of the heat load, the thermodynamic analysis of the system and the design of the operation modes.

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Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Development of cryogenic installations for large liquid argon based neutrino detectors

A proposal for a very large liquid argon (40 kt) based neutrino detector is being studied. To validate the design principles and detector technology, and to gain experience in the development of the cryostats and the cryogenic systems needed for such large experiments, several smaller scale installations will be developed and implemented, at Fermilab and CERN.

A small-scale prototype (35 t) is already operational at Fermilab, while two larger-scale experiments (500 t each) will be developed, built and tested at CERN. In parallel, two other detectors will be developed, built and installed on a neutrino beam line at Fermilab: a Near Detector (260 t) at about 110 meter and a Far Detector (760 t) at about 600 meter from the target. The final experiment (ELBNF) will receive a neutrino beam from Fermilab and will be installed at the Surf Underground Research Facility in Lead, SD, situated at about 1300 km from Fermilab at about 1.5 km below ground level.

The cryogenic systems for these installations will be developed, constructed, installed and commissioned by an international engineering team. These installations shall bring the required cooling power under specific conditions to the experiments for the initial cool-down and the long term operation, and shall also guarantee the correct distribution of the cooling power within the cryostats to ensure a homogeneous temperature distribution within the cryostat itself. The cryogenic systems shall also include gaseous and liquid phase argon purification devices to be used to reach and maintain the very stringent purity requirements needed for these installations (parts per trillion of oxygen equivalent contamination).

This paper gives an overview of the installations involved in this cryogenic project, describes the functional demands made to these cryogenic systems and presents the initial studies on which these future cryogenic systems will be based.

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Session Classification: C1PoB - Intermediate Temperature Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Quench Characteristics of Conduction-cooled 6T NbTi Magnet System

Tuesday, 30 June 2015 17:30 (15 minutes)

One of the important features of any conduction-cooled LTS coil is to achieve thermal stability against any thermal disturbances as the minimum quench energy of a NbTi coil is very minimal. The thermal stability of the conduction-cooled magnet system will be governed by the energy balance at the NbTi coil. The cryogen-free magnets are cooled using cryocooler alone through the conductive thermal links which makes more prone to quench and limits the sweep rates. We have developed a 6T NbTi cryogen-free magnet system (CFMS) with warm bore. The maximum sweep rate for the 6T CFMS is found to be 6 A/min. The dynamic heat generation (e.g AC loss) of coil limits the sweep rate. The maximum temperature of coil went to 53.25K when quench at 101.1A during training of the coil. The temperature of the 2nd stage cold head of the cryocooler went to 15.87K. We have done some intentional quench at higher sweep rate of 8 A/min and 20 A/min to study the quench characteristics. Quench of the 6T NbTi coil due to the cooling failure has also been experimentally studied. This paper briefly discusses the different types of quench characteristics for the conduction-cooled 6T NbTi magnet system. We have done FEA analysis of the 6T NbTi coil to simulate the maximum hot-spot temperature and its resistance growth during a quench. The experimental measurement has been compared with the FEM analysis. This paper also discusses the post-quench distribution of the dumped energy in different components of the magnet system.

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Session Classification: C2OrF - Superconducting Magnets II

Track Classification: CEC-06 - Superconducting Magnet Systems
New developments in Joule Thomson microcooling at the University of Twente

Thursday, 2 July 2015 09:45 (15 minutes)

The aim of the Joule Thomson microcooling research at the University of Twente is to develop small and fully integrated cryogenic cooling systems for cooling small electronic devices. In the previous project, we have successfully developed 100 K single-stage microcoolers and 30 K two-stage microcoolers using standard micromachining technology. In the paper, we now present three new developments: microcoolers with double-expansion aiming at lower operating temperatures or higher efficiency; microcoolers with thermoelectric precooling aiming at lower operating pressures or higher efficiency; and microcoolers with different support pillar matrices in the counter flow heat exchangers aiming at higher efficiency.

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Presenter: Dr CAO, Haishan (University of Twente)

Session Classification: C4OrD - Novel Concepts and New Devices III

Track Classification: CEC-17 - Novel Concepts and New Devices
Materials for damping the PTC-induced thermal fluctuations of the cold-head

Tuesday, 30 June 2015 09:00 (2 hours)

The cold head on mechanical Pulse Tube Cryocoolers (PTCs) are subject to substantially less mechanical vibration and electromagnetic interference compared to that typically found in Gifford MacMahon coolers. However, thermal fluctuations at the PTC frequency are still present at the cold-head, typically at a level of 200 mK peak-to-peak at 1.4 Hz for a Cryomech Model PT405 cooler running at 4 K. It is highly desirable to damp out these fluctuations if PTCs are to be used successfully for running systems sensitive to such thermal fluctuations, for example, bolometric detectors.

We report here the characterization over the temperature range 2.5 K to 9 K of two materials, GOS and GAP, for use as low-pass thermal filters. These materials have antiferromagnetic transitions at around 4 K giving rise to an enhanced heat capacity and have a high thermal conductance when fired as ceramic discs. These are two highly desirable properties for thermal dampers in this application. Thermal filter assemblies with discs of diameter 75 mm and thickness 2.5 mm and 1.5 mm (GOS and GAP, respectively) mounted in a Cryomech Model PT405 cooler show thermal attenuation levels of x0.12 (GOS) and x0.11 (GAP) at 0.01Hz with a clean-side temperature of 4 K; the PTC induced fluctuations at 1.48 Hz are damped completely to within the noise limits (0.2 mK) of the thermometers. Experimentally determined thermal conductance and heat capacity data is reported. For this system, with a PTC cold-head (dirty-side) temperature of 2.5 K, a clean-side power dissipation of up to 30 mW before its temperature rises above 4.2 K.

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Session Classification: M2PoB - Cryogenic Materials III: Testing and Methods

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
CFD Simulation of the Gas Flow in a Pulse Tube Cooler with two Pulse Tubes

Tuesday, 30 June 2015 09:00 (2 hours)

In order to realize larger and heavier mass supporting without additional supporting components, a new structural pulse tube cooler based on traditional U-shape pulse tube cooler and with one regenerator and two parallel pulse tubes has been proposed. In previous works, two prototypes of U-shape two-pulse-tube paralleled cooler have been designed and tested. In this paper, to help characterize the gas flow in the new structural pulse tube cooler, a two-dimensional axisymmetric Computational Fluid Dynamics (CFD) model is also developed to simulate oscillating fluid flow and heat transfer in the cooler. Results obtained from experiments and CFD simulations are presented and discussed in this paper.

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Session Classification: C2PoE - CFD Modelling and Measurements Techniques
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Effect of DC flow on a three-stage Stirling pulse tube cryocooler working at liquid helium temperatures

Monday, 29 June 2015 14:00 (2 hours)

Multi-stage Stirling pulse tube cryocoolers (SPTC) have great potentials in liquid helium temperatures applications with advantages of high reliability, low vibration, and convenience of stage coupling for lacking cold moving parts. Studies have shown that performance of GM type pulse tubes working at liquid helium temperatures can be improved by introducing DC flow, which decreases regenerator loss at liquid helium temperatures and increases cooling capacity. However, few study of DC flow in multi-stage Stirling pulse tube has been reported.

In this study, we report the calculation results on a numerical model built on a home-made three-stage SPTC working at 4.2K, and its hot end of the third-stage pulse tube and third-stage regenerator are connected by a capillary tube to introduce DC flow. The results indicated that a suitable DC flow can significantly improve the performance of the pulse tube cryocoolers. Several capillary tubes with different diameters and lengths were tested. Temperature distributions along the pulse tube were measured and DC flow was monitored in our experiments. Also parameters of the capillary tube were optimized for different operation conditions and the performance of STPC was improved.

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Session Classification: C1PoH - Aerospace Cryocoolers Analysis and Experimentation

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Modeling the Adsorption of Mixed-Gases Based on Pure Gas Adsorption Properties

Sorption-based Joule-Thomson (JT) cryocoolers often operate with pure gases. A sorption-based compressor has many benefits; however, it is limited by the pressure ratios it can provide. Using a mixed-refrigerant (MR) instead of a pure refrigerant in JT cryocoolers allows working at much lower pressures. Therefore, it is desired to use MRs in sorption-based cryocoolers in order to reduce one of its main limitations.

The adsorption of mixed gases is usually investigated under steady conditions, mainly for storage and separation processes. However, the process in a sorption compressor goes through various temperatures, pressures and adsorption concentrations; therefore, it differs from the common mixed gases adsorption applications. In order to simulate the sorption process in a compressor a numerical analysis for mixed gases is developed, based on pure gas adsorption characteristics. The pure gas adsorption properties have been measured for four gases (nitrogen, methane, ethane, and propane) with Norit-RB2 activated carbon. A single adsorption model is desired to describe the adsorption of all 4 gases. This model is further developed to a mixed-gas adsorption model. In future work more adsorbents will be tested with these four gases and the adsorption model will be verified against experimental results of mixed-gas adsorption measurements.

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Session Classification: C3OrK - Special Session: JT Coolers
Track Classification: CEC-04 - Cryocoolers (Aerospace)
Hydrogen environment embrittlement (HEE) on austenitic stainless steels SUS304, 304L, and 316L in the high pressure hydrogen gas was evaluated from ambient temperature to 20 K using a very simple mechanical properties testing procedure. In the method, the high-pressure hydrogen environment is produced just inside the hole in the specimen and the specimen is cooled in a cooled-alcohol dewar and a cryostat with a GM refrigerator. The effect of HEE was observed in tensile properties, especially at lower temperatures, and fatigue properties at higher stress level but almost no effect around the stress level of yield strength where almost no strain-induced martensite was produced. So, no effect of HEE on austenitic stainless steels unless the amount of the ferrite phase is small.

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**Session Classification:** M2OrD - Cryogenic Materials V: Structural Materials

**Track Classification:** ICMC-11 - Metallic and Composite Materials
Development of Integrated Submerged Liquid Hydrogen Pump

Integrated submerged liquid hydrogen pump was developed. The whole pump with its driving motor runs in liquid hydrogen. There is no dynamic seal between motor and pump. Only electric wire contacts environment air. The characteristics of pump, experimental device, and results are described in this paper. The speed of the pump can be adjusted from 300 rpm to 1300 rpm. The pressure head can be from 0.05 MPa to 0.7 MPa, and the flow rate can be from 1.4 to 6.3 liter/min with the increasing of pump speed.

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**Track Classification:** CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Parametric Investigation of multi-mesh Regenerator of a Miniature Stirling Cryocooler

Stirling cryocoolers find applications in various military, commercial and scientific projects which require cooling of infrared (IR) sensors, imaging cameras and optical elements. They are used to produce cryogenic cooling in the range of 60-80 K with the cooling power ranging from mW to a few watts. The performance of the cooler largely depends on the effectiveness of the regenerative heat exchanger used in the system. An attempt was made to optimize a 3-mesh regenerator for a Stirling cryocooler operating between a hot end temperature of 300 K and cold end temperature of 80 K using REGEN 3.3. Three mesh regenerators made up of different combinations of #200, #250, #300, #400 and #450 Stainless Steel wire meshes were considered. The study was carried out by varying the average pressure from 10 to 30 bar and the operating frequency from 20 to 80 Hz. The output given by REGEN 3.3 includes the gross and net cooling power, thermal losses, and associated pV work at the cold and warm ends of the regenerator. The optimization of regenerator is defined for a regenerator design that minimizes the required work supplied at the warm end to achieve a desired cooling power at the cold end. Thus the optimization is achieved by maximizing the COP, which is calculated from the net cooling power and pV work at the warm end of the regenerator. The COP is a function of length of each subsection of 3- mesh regenerator, mass flow and the phase between the cold end mass flow and pressure. After the analysis the optimum geometric and operating parameters of the 3-mesh regenerator was obtained. The results obtained from the analysis are helpful for the complete design and development of a miniature Stirling cryocooler.

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Track Classification: CEC-04 - Cryocoolers (Aerospace)
A dynamic optical measurement system for cryogenic fluids using laser interferometry

Thursday, 2 July 2015 09:30 (15 minutes)

Dynamic visualization is of great significance in the research of flow conditions and mass transfer process of cryogenic fluids. At present, spot sampling is commonly used in concentration analysis of cryogenic fluids. However, it cannot provide two-dimensional information for large area and will disturb the fluid. In this paper, a non-contact dynamic optical measurement system using laser interferometry was designed, which is sensitive to subtle changes of fluid concentration so a precise and dynamic interference pattern can be obtained. Ulteriorly, two-dimensional concentration distribution of the fluid can be calculated from the interference pattern. Detailed calculation process is presented in the paper. Influence of gradient magnetic field on the concentration distribution of liquid oxygen-nitrogen mixture was studied with this measurement system, and concentration profiles corresponding to different magnetic structures were measured. It is shown that oxygen enrichment in liquid mixture can be induced by the gradient magnetic field and the increment of oxygen concentration rises when magnetic gradient increases. Gas chromatography was utilized to verify the optical measurement results. The results from these two methods agree well.

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Session Classification: C4OrD - Novel Concepts and New Devices III
Track Classification: CEC-17 - Novel Concepts and New Devices
The new compressor system at Jefferson Lab (JLab) for the 12 GeV upgrade was commissioned in the spring of 2013 and incorporates many design changes, discussed in previous publications, to improve the efficiency, reliability and maintainability as compared to previous compressor skids used for this application. The 12 GeV helium compression system has five compressors configured with four pressure levels supporting three pressure levels in the new cold box. During compressor commissioning the compressors were operated independent of the cold box over a wide range of process conditions to verify proper performance including adequate cooling and oil removal. Isothermal and volumetric efficiencies over these process conditions for several built-in-volume ratios were obtained. This paper will briefly discuss the minor modifications/improvements incorporated into the skids and will summarize the analysis of the test data obtained.
Cryogenic turbulence test facilities at CEA/SBT

Thursday, 2 July 2015 09:30 (15 minutes)

Recently, CEA Grenoble SBT has designed, built and tested three liquid helium facilities dedicated to turbulence studies.

All these experiments are able to operate either in HeI or HeII within the same cooldown. Another common technical specificity of these three facilities is the use of moving parts inside liquid helium. The SHREK experiment is a von Karman swirling flow between 72cm diameter counterrotating disks equipped with blades. The HeJet facility is used to produce a liquid helium free jet inside a 20cm I.D., 47cm length stainless steel cylindrical testing chamber. Finally the OGRES experiment consists of an optical cryostat equipped with a particle injection device and an oscillating grid. It will be used either to study particle clustering or to visualize the flow produced by the oscillating grid.

We first detail specific techniques employed to accommodate with these stringent specifications. In particular, the so called Claudet bath is used to subcool the von Karman flow and free jet flow, allowing a pressurization above the critical point when necessary (e.g. it is needed to perform our home made Wollaston hot wire measurements). Another solution consisting in refilling with helium gas the upper part of the bath after pumping down is chosen for the oscillating grid as hot wires will not be employed (no mean velocity prohibits their use). Furthermore, the complexity of the Claudet bath leads to additional complexity for visualization (it would have required multiple viewports and complex particle seeding system).

Then control parameters as well as Re number and temperature ranges are detailed and results illustrating the possibilities of each experiment are presented.

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Session Classification: C4OrC - Cryogenic Systems and Facilities

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Thermal Design and Performance results of the first High Beta Cryomodule for HIE-ISOLDE at CERN

Monday, 29 June 2015 14:00 (2 hours)

The High Energy and Intensity HIE-ISOLDE is a facility under construction at CERN whose target is ultimately to produce radioactive ion beams at 10MeV/u maximum energy in order to significantly expand the nuclear physics programme carried out by REX-ISOLDE. In its final stage the new upgrade will be composed of two low-β and four high-β superconducting cryomodules. The first high-β cryomodule, currently being assembled at CERN, presents an optimum vacuum and cryogenics environment aimed at offering the highest beam quality output to the scientific community for a first physics run starting from 2015.

Since thermal control is essential to the performance of the whole cryomodule, a combination of a passive (materials, coatings, and surface finishes) and active (cryogenic loops, heaters) control has been implemented to keep the cryostat operating within the allowable thermal budget. Moreover in order to preserve the cavities from the risk of surface contamination, a thermal insulating system without multilayer insulation has been adopted with consequent effect on the global strategy of heat loads optimization.

A numerical model based on Finite Elements has been developed in order to generate a faithful global mapping of temperatures and heat fluxes inside the cryomodule. This simulation tool has as primary aim to reproduce as precisely as possible the most significant heat exchange phenomena, but it also represents a validation and diagnostic tool for interpreting the experimental data obtained from numerous temperature sensors located inside the cryostat. The numerical model, combined with the experimental results of the first test campaign, will serve as an optimization tool for the future cryomodules in terms of improvements in the global and specific heat loads management.

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Session Classification: C1PoG - Thermal Analysis and Design

Track Classification: CEC-07 - Superconducting RF Systems
The new 4.5 K refrigerator system at the Jefferson Lab (JLab) Central Helium Liquefier (CHL-2) for the 12 GeV upgrade was commissioned in late spring of 2013, following the commissioning of the new compressor system, and has been supporting 12 GeV LINAC commissioning since that time. The six design modes were tested during commissioning, consisting of a maximum capacity condition, nominal capacity, maximum liquefaction, maximum refrigeration, maximum fill and a stand-by/reduced load condition. The maximum capacity was designed to support a 238 g/s 30 K 1.16 bar cold compressor return flow, a 15 g/s 4.5 K liquefaction load and a 12.6 kW 35-55 K shield load. The other modes were selected to ensure proper component sizing and selection to allow the cold box to operate over a wide range of conditions and capacities. The cold box system is comprised of a two cold box sections with a large interconnecting transfer-line. The outside (upper) 300-60 K vertical cold box has no turbines and incorporates a liquid nitrogen pre-cooler. The inside (lower) 60-4.5 K horizontal cold box houses seven turbines that are configured in four expansion stages including one Joule-Thompson expander. The helium compression system has five compressors to support three pressure levels in the cold box. This paper will summarize the analysis of the test data obtained over the wide range of conditions and capacities which were tested.

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Session Classification: C3OrA - Operating Experience I
Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Development of integrated superconducting Quadrupole Doublet Modules for operation in the SIS100 Accelerator

Tuesday, 30 June 2015 17:45 (15 minutes)

The FAIR project evolves and builds an international accelerator and experimental facility for basic research activities in various fields of modern physics. Within the course of this project, integrated Quadrupole Doublet Modules (QDMs) are in development. The QDMs provide two superconducting main quadrupoles (focusing and defocusing), corrector magnets, cryogenic collimators and beam position monitors as integrated sets of ion-optical components. Furthermore LHe cooled beam pipes and vacuum cold warm transitions are used as ultra-high vacuum components for beam transportation. Supercon-ducting bus bars are used for the 13 kA current supply of the main quadrupole magnets. All components are integrated as one common cold mass in one cryostat. HTSC local current leads will be applied for the low current supply of the corrector magnets. The QDMs will be operated in the SIS100 heavy ion accelerator, the core component of the FAIR project. First versions of corrector magnets are already manufactured at JINR in Dubna / Russia and are now ready for testing. The ion-optical lattice structure of SIS100 requires multiple configurations of named components. Eleven different configurations, organized in four families, provide the required QDM setups. The high integration level of multiple ion-optical, mechanical and cryogenic functions, based on the requirements on operation safety, is leading towards sophisticated mechanical structures and cooling solutions, to satisfy the demanding requirements on position preservation during thermal cycling. The cryogenic and mechanical design solutions will be discussed and the planning for the complex manufacturing and testing processes will be presented.

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Session Classification: C2OrF - Superconducting Magnets II

Track Classification: CEC-06 - Superconducting Magnet Systems
[Invited] Heat transfer during bubble shrinking in saturated He II under microgravity condition

Wednesday, 1 July 2015 16:15 (30 minutes)

Microgravity experiments of He II boiling using a drop tower were carried out. The small cryostat equipped with optical windows and whole the equipment was dropped more than 100 times. Time duration of microgravity environment less than 1 m-g is about 1.2 sec. The process of bubble shrinking in He II in microgravity was observed by a high speed camera with a telecentric lens under the illumination of an LED light. First, large spherical bubble of about 10 mm was created by a short wire heater (Diameter 0.05 x Length 2.2 mm) for a heating time of 0.4 sec. And then the bubble shrinking was visualized after the heater switched off. The time variation of volume of bubble is estimated by image analysis. The shrinking speed of bubble was calculated from the time variation data. Shrinking speed must be subject to the heat flux across liquid-vapor interface. The calculation result of heat flux across the interface in terms of the latent heat and vapor density of saturated He II is roughly in agreement with the kinetic theory that takes into account of the effect of mass flux caused by vapor-liquid interface motion. It is found that the heat flux across the interface in microgravity is dominantly determined by the pressure difference due to surface tension.

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Presenter: TAKADA, Suguru (National Institute for Fusion Science)

Session Classification: C3OrJ - Special Session: Helium II Properties and Systems

Track Classification: CEC-13 - Helium II Properties and Systems
Liquid Nitrogen Historical and Current Usage of the Central Helium Liquefier at SNS

Tuesday, 30 June 2015 09:00 (2 hours)

The main cryogenic system for the Spallation Neutron Source (SNS) is comprised of a 4 K cold box, a 2 K cold box, six warm compressors, and ancillary support equipment. This system has been cold and operating with little disruption since 2006. Design and operation of Liquid Nitrogen (LN2) supplied from a single 20,000 gallon supply dewar will be discussed. LN2 used to precool the 4 K cold box heat exchanger started to increase around 2011. Consumption during 2012 and 2013 was almost double the nominal usage rate. Studies of this data, plant parameter changes to respond to this information, and current interpretations are detailed in this paper. The usage rate of LN2 returned to normal in late 2013 and has since remained there. Future study plans to understand potential causes of this including contamination migration within the 4 K cold box will also be addressed.

Primary author: DEGRAFF, Brian (ORNL)
Co-authors: Mr HOWELL, Matt (ORNL); KIM, Sang-ho (SNS/ORNL); Mr NEUSTADT, Thomas (ORNL)
Presenter: DEGRAFF, Brian (ORNL)
Session Classification: C2PoA - Cryogenic Systems I
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Testing of a 4 K to 2 K Heat Exchanger with an Intermediate Pressure Drop

Tuesday, 30 June 2015 14:00 (2 hours)

Most large sub-atmospheric helium refrigeration systems incorporate a heat exchanger at the load, or in the distribution system in some cases, to counter-flow the sub-atmospheric return with the super-critical or liquid supply. A significant process improvement is theoretically obtainable by handling the exergy loss across the Joule-Thompson throttling valve supplying the flow to the load in a simple but different manner. As briefly outline in previous publications, the exergy loss can be minimized by allowing the supply flow pressure to decrease to a sub-atmospheric pressure concurrent with heat exchange with the flow from the load. One practical implementation is to sub-divide the supply flow pressure drop between two heat exchanger sections, incorporating an intermediate pressure drop. Such a test is being performed at Jefferson Lab’s Cryogenic Test Facility (CTF). This paper will briefly discuss the theory, practical implementation and test results and analysis obtained to date.

Primary author: KNUDSEN, Peter (Jefferson Lab)
Co-author: Dr GANNI, Rao (JLAB)
Presenter: KNUDSEN, Peter (Jefferson Lab)
Session Classification: C2PoG - Heat Exchangers
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Commissioning and Operation of the Horizontal Test Apparatus at SNS

Monday, 29 June 2015 16:30 (15 minutes)

The Spallation Neutron Source (SNS) at Oak Ridge National Lab (ORNL) has built and commissioned an independent Cryogenic Test Facility (CTF) in part to support 4.5 K operation of a Horizontal Test Apparatus (HTA) vessel in the Radiofrequency Test Facility (RFTF) test cave. The HTA provides the functionality for testing a single dressed SNS medium or high beta Superconducting Radiofrequency (SCRF) cavity. The vessel’s capability to provide for in-situ plasma processing of the cavity’s inner niobium surface will be discussed. The design and commissioning of the HTA at 4.5 K will be presented as well as results from operating the HTA including cool-down, warm-up and steady state operations. Result from plasma processing a warm SCRF cavity in-between cold HTA tests will also be addressed.

Primary author: DEGRAFF, Brian (ORNL)

Co-authors: Mr HANNAH, Brian (ORNL); Mr SAUNDERS, Jeffery (ORNL); Mr DOLEANS, Marc (ORNL); Mr HOWELL, Matt (ORNL); KIM, Sang-ho (SNS/ORNL); Mr NEUSTADT, Thomas (ORNL)

Presenter: DEGRAFF, Brian (ORNL)

Session Classification: C1OrG - Superconducting RF Systems I

Track Classification: CEC-07 - Superconducting RF Systems
2K Pump Down Studies at SNS

Wednesday, 1 July 2015 12:00 (15 minutes)

The Spallation Neutron Source (SNS) linear accelerator consists of 81 superconducting radio frequency (SCRF) cavities cooled to 2.1K by a cryogenic refrigeration system. The 2.1 K cold box consists of four stages of cold compressors with LN2 cooled variable speed motors. Transitioning from 4K operation to 2.1K operation in the cryomodules involves pumping the cryomodules down from approximately 1 atm to 0.040 atm. This effort is conducted by use of several sequences developed as a collaborative effort between Jefferson Laboratory (JLab) and SNS personnel during the original commissioning of the SNS cryogenic system. Over the last ten years, multiple lessons have been learned since then about VFD behavior, thermal stability, procedural development and refining the sequence. In 2014, there were multiple pump down iterations that were not successful. Studies have been conducted to determine the cause of these unsuccessful iterations. The results of these studies including components replaced and aspects that have not yet been solved are presented in this paper. Future plans to refine the sequence and determine the cause of unsuccessful pump downs will also be presented.

Primary author: HOWELL, Matthew (UT Battelle/ORNL)

Co-authors: DEGRAFF, Brian (ORNL); Dr GANNI, Rao (JLAB); KIM, Sang-ho (SNS/ORNL); NEUSTADT, Thomas (ORNL)

Presenter: HOWELL, Matthew (UT Battelle/ORNL)

Session Classification: C3OrA - Operating Experience I

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Cryogenic System Operating Experience at SNS

Wednesday, 1 July 2015 11:45 (15 minutes)

The helium cryogenic system at Spallation Neutron Source (SNS) provides cooling to 81 superconducting radio frequency cavities. During the first ten years of operation, much operational experience and lessons learned have been gained. The lessons learned include integrated system issues as well as component failures in the areas of mechanical, electrical and controls. Several single point failure scenarios have also been identified and engineering efforts have begun to mitigate those possibilities. Past issues that have been corrected as well as current issues in the system will be detailed in this paper. In 2009, a Process Failure Modes and Effects Analysis (PFMEA) was completed as a way to identify high risk items and prioritize efforts. Since 2009, the progress on mitigating the identified high risk items has been tracked. The results of the PFMEA and the progress made in reducing risk to the cryogenic system operation will be detailed in this paper.

Primary author: HOWELL, Matthew (UT Battelle/ORNL)

Co-authors: DEGRAFF, Brian (ORNL); HANNAH, Brian (ORNL); MCMANAN, Chris (ORNL); VANDY-GRIFF, David (ORNL); BARNHART, Debra (ORNL); AFANADOR, Ralph (ORNL); KIM, Sang-ho (SNS/ORNL); NEUSTADT, Thomas (ORNL)

Presenter: HOWELL, Matthew (UT Battelle/ORNL)

Session Classification: C3OrA - Operating Experience I

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Helium Sourcing ... Calmer seas ahead?

Tuesday, 30 June 2015 17:30 (15 minutes)

What was the last year Helium market figure?
How has changed the worldwide Helium sourcing balance and “center of gravity”?
Do we have to expect a continuous shortage period for the next 10 years or, on the contrary, will
the market be over-supplied by the next coming large scale production units?
Facts will be presented on all these questions, view is given by Air Liquide, one of the world major
Helium suppliers.
Market repartition regarding Helium uses focused on cryogenic & scientific applications will also
be given to illustrate how this domain can play a role on Helium projected needs.

Primary author: Mr GRILLOT, David (Air liquide)
Co-author: Mr PRADES, Eric (Air liquide)
Presenter: Mr GRILLOT, David (Air liquide)
Session Classification: C2OrE - Cryogenic Systems II
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
A new cryogenic test facility for large superconducting devices at CERN

Thursday, 2 July 2015 09:00 (15 minutes)

To expand CERN testing capability to superconducting devices that cannot be installed in existing test facilities because of their size and/or mass, CERN is building a new cryogenic test facility for large and heavy devices. The first devices to be tested in the facility will be the S-FRS superconducting magnets for the FAIR project that is currently under construction at the GSI Research Center in Darmstadt, Germany. The facility will include a renovated cold box with 1.2 kW at 4.5 K equivalent power with its compression system, two independent 15 kW liquid nitrogen precooling and warmup units, as well as a dedicated cryogenic distribution system providing cooling power to three independent test benches. The article presents the main input parameters and constraints used to define the cryogenic system and its infrastructure. The chosen layout and configuration of the facility is presented and the characteristics of the main components are described.

Primary author: Dr PERIN, Antonio (CERN)

Co-authors: DERKING, Jan Hendrik (CERN); BREMER, Johan (CERN); Dr SERIO, Luigi (CERN); PIROTTE, Olivier (CERN); BENDA, Vladislav (CERN)

Presenter: Dr PERIN, Antonio (CERN)

Session Classification: C4OrC - Cryogenic Systems and Facilities

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
SAFARI (SpicA FAR-infrared Instrument) is an infrared instrument planned to be part of the SPICA (SPace Infrared telescope for Cosmology and Astrophysics) Satellite. It will offer high spectral resolution in the 30 – 210 µm frequency range. SAFARI will benefit from the cold telescope of SPICA and to obtain the required detectors sensitivity, a temperature of 50 mK is required. This temperature is reached thanks to the use of a hybrid sorption – ADR (Adiabatic Demagnetization Refrigerator) cooler presented here. This cooler provides respectively 14 µW and 0.4 µW of cooling power at 300 mK and 50 mK. The cooler is planned to advantageously use two thermal interfaces of the instrument at 1.8 and 4.9 K. One of the challenges that will be discussed is the low power available at each intercept. A dedicated laboratory electronic is being designed based on previous development with a particular focus on the 50 mK readout. Temperature regulation at 50 mK will also be discussed.

This cooler has been designed following flight constraints and will reaches a high TRL, including mechanical and environmental tests at the end of the on going qualification campaign.
Development of membrane cryostats for large liquid argon neutrino detectors

Monday, 29 June 2015 14:00 (2 hours)

A new collaboration is being formed to develop a multi-kton long baseline neutrino experiment that will be located at the Surf Underground Research Facility (SURF) in Lead, SD. In the present design, the detector will be located inside a cryostat filled with 40 kton of ultra pure liquid argon (less than 200 parts per trillion of oxygen equivalent contamination).

To qualify membrane technology for future very large-scale and underground implementations, a strong prototyping effort is ongoing: several smaller detectors of growing size with associated cryostats and cryogenic systems will be designed and built at Fermilab and CERN. They will take physics data and test detector elements in different configurations, filtration systems for liquid argon, design options, tank configurations and installation procedures.

A 35 ton prototype is already operational at Fermilab and will take data with single-phase detector in the spring. A similar size prototype with dual-phase detector is being constructed at CERN and will be operational next year. In the coming years a 260 ton prototype with single-phase detector will be constructed and exposed to a neutrino beam at Fermilab. The refurbished ICARUS T600 (760 ton) will be on the same beam line at 600 m.

In parallel two larger cryostats will be constructed at CERN and exposed to beams of particles, 500 ton with single-phase, 800 ton with dual-phase detectors. After the prototyping phase, the multi-kton detector will be constructed. After commissioning, it will detect and study neutrinos from a new beam from Fermilab.

These cryostats will be engineered, constructed, commissioned, qualified by an international engineering team.

This contribution will present the ongoing effort on development of the cryostats, and detail requirements, current status of design and construction and how we plan to go from 35 ton to multi-kton device.

Primary author: MONTANARI, David (Fermi National Accelerator Laboratory)

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Presenter: MONTANARI, David (Fermi National Accelerator Laboratory)

Session Classification: C1PoJ - Novel Concepts and New Devices I

Track Classification: CEC-17 - Novel Concepts and New Devices
Continuous Improvement at SuperPower of 2G HTS Wire for Demanding Applications

Tuesday, 30 June 2015 17:00 (15 minutes)

Advancements in 2G HTS conductor performance continue to drive the operating limits for a broad range of demanding applications. The design, testing and fabrication technology of 2G HTS (RE)BCO conductors is presented, highlighting the ability of 2G HTS wire to function under a wide range of operating conditions. SuperPower continues to address 2G HTS conductor development and production methods to improve characteristics and performance of the wire and provide technical support in its use. In particular, extensive studies on wire properties have been carried out and processing upgrades implemented to improve both the base performance of the conductor, as well as its functionality by enhancing key characteristics such as piece length, mechanical properties and uniformity of critical current and lift factor. Updated measurements on recent production material are presented and plans for future performance targets discussed.

Primary author: HAZELTON, Drew (SuperPower Inc.)
Co-authors: Mr KNOLL, Allan (SuperPower Inc.); Mr SAKAMOTO, Hisaki (SuperPower Inc.); Mr MCCLURE, Ross (SuperPower Inc.); Dr ZHANG, Yifei (SuperPower Inc.)
Presenter: HAZELTON, Drew (SuperPower Inc.)
Session Classification: M2OrC - Superconductor Wires II: Coated Conductors and Applications
Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Helium conservation is becoming increasingly important as helium availability is on the decline and prices are on the rise. The Florida State University National High Magnetic Field Laboratory has taken several steps over the past five years to increase the percentage of helium recovered. These include the installation of a standalone purifier, recovery flow meters, contamination meters, and a new piping system. The improvements to the recovery system have reduced the amount of helium purchased by the Mag Lab by 50% while helium usage has increased by roughly 30%. This article will provide details about the recovery system as a whole and describe some of the main components. There will also be some examples of the problems we've had to overcome, and some that we are still working on. Finally, there will be an update on the current status of the recovery system and a description of our plans for the future.

**Primary author:** BARRIOS, Matt

**Co-authors:**
- BAI, Hongyu (National High Magnetic Field Laboratory - FSU);
- KYNOCH, John (National High Magnetic Field Laboratory - FSU)

**Presenter:** BARRIOS, Matt

**Session Classification:** C2PoF - Test Facilities

**Track Classification:** CEC-02 - Large-Scale Systems, Facilities, and Testing
Theoretical and experimental investigations on impedance of pulse tube cold fingers to match with linear compressors

Monday, 29 June 2015 14:00 (2 hours)

The impedance match between the cold finger and the linear compressor of the Stirling-type pulse tube cryocooler (SPTC) is significant to optimize the compressor efficiency and to improve the cold finger cooling performance. Several researches ever studied the impedance match and concluded that there existed the optimal acoustic impedance of the cold finger to acquire the highest compressor efficiency. However, few researches have been done to design the cold finger with the optimal impedance. In this paper, an electrical circuit analogy model has been developed according to continuity equation and momentum equation. The model is used to design the specific dimensions of the cold finger. And furthermore, through the calculation of the pressure and the volume flow rate with the model, the impedance of each component of the cold finger such as regenerator, pulse tube, heat exchanger, phase shifter and reservoir can be achieved, respectively. The total impedance is the sum of every component. For a series of linear compressors developed in the authors’ laboratory, their respective mechanical parameters such as linear motor force factor, piston damp, coil resistance etc. have been tested and then the optimal acoustic impedances to match each compressor have been acquired. According to the model, specific cold fingers with optimal acoustic impedances have been worked out. Experimental investigations on acoustic impedance of these cold fingers have been made through measurements of pressure and mass flow rate at several positions of the cold finger, to compare with the theoretical values in the model. The actual performance of a series of SPTCs based on the theoretical and experimental investigations have been measured, the motor efficiencies of the compressors reach 74.2%–83.6% and the relative Carnot efficiency of the cold fingers achieve 3.0%@40 K, 9.6%@60 K, 16.2%@80 K, etc.

Primary author: Mr TAN, Jun (Shanghai Institute of Technical Physics)

Co-authors: Prof. DANG, Haizheng (Shanghai Institute of Technical Physics); Mr ZHANG, Lei (Shanghai Institute of Technical Physics)

Presenter: Mr TAN, Jun (Shanghai Institute of Technical Physics)

Session Classification: C1PoH - Aerospace Cryocoolers Analysis and Experimentation

Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Various dopants have been investigated for increasing Bc2 in MgB2. Most of these have not been beneficial, with the exception of C or C-bearing materials (increasing 4 K Bc2) and Dy2O3 (at higher temperatures). While Bc2 approximately doubled with C additions at 4.2 K, the high Bc2 results of the thin films have not been replicated in wires. Hence we re-investigate oxygen additions, with a focus on controlled oxygen addition for Bc2 increase. By diffusing O into PLD-made MgB2 thin films, we have successfully prepared a series of O-doped MgB2 thin films with different O concentrations. XRD shows a peak shift with the increase of O doping levels. The oxygen doping is controllable, generating a reproducible peak shift which is correlated with a significant increase in Bc2. The temperature at which Bc2 = 14 T is pushed up from 14 K to 21 K. Indeed, Bc2 is increased over the whole temperature range from 15 K to 30 K, and presumably is increased at lower temperatures as well. We also describe our efforts to realize oxygen doping in wires and the results of these measurements.

Primary author: LI, Guangze (The Ohio State University)
Co-authors: COLLINGS, Edward (The Ohio State University); SUMPTION, Mike (The Ohio State University)
Presenter: LI, Guangze (The Ohio State University)
Session Classification: M3OrA - Superconductor Wires III: Thin Films
Track Classification: ICMC-05 - Thin Films
Irreversible tensile stress of 2G HTS wires made by IBAD-MOCVD on Hastelloy substrates

Tuesday, 30 June 2015 11:15 (15 minutes)

Irreversible tensile stress was experimentally studied at 77K self field for 2G HTS wires fabricated using the IBAD-MOCVD processes on Hastelloy substrates. The irreversible stress is a critical stress above which the critical current (Ic) retention of a wire is less than 99% of its original Ic after the complete release of the stress. As a characteristic electromechanical property, the irreversible stress defines a critical stress condition at which an unrecoverable mechanical damage to the superconductor starts. Irreversible stress as well as the corresponding irreversible strain was determined for different types of 2G HTS wires with variations in structure, specifically in the thickness of the substrate and/or stabilizer. The effect of the stabilizer to substrate thickness ratio on the irreversible tensile stress was analyzed, in combination with the basic tensile stress-strain relationships of the wires. It was found that the irreversible stress was dependent on a chord elastic modulus determined from the stress-strain curve. The measurement methodology of the electromechanical properties of 2G HTS wires under tension was also discussed.

Primary author: Dr ZHANG, Yifei (SuperPower Inc.)
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Presenter: Dr ZHANG, Yifei (SuperPower Inc.)
Session Classification: M2OrB - Superconductor Wires I: Testing and Characterization
Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Thermal analysis of the cold mass of the 2 T solenoid for the PANDA detector at FAIR

Wednesday, 1 July 2015 15:15 (15 minutes)

The superconducting solenoid of the PANDA experiment at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany, is designed to provide a magnetic field of 2 T over a length of about 4 m in a bore of 1.9 m. To allow a warm target feed pipe oriented transversely to the solenoid axis and penetrating through the cryostat and solenoid, the magnet is split into 3 inter-connected coils fitted in a common support cylinder.

During normal operation, cooling of the cold mass to the working temperature of 4.5 K will be achieved through the circulation by natural convection of two-phase helium in cooling pipes attached to the Al-alloy support cylinder. Pure aluminum strips glued to the inner surface of the three coils and thermally bonded to the cooling pipes allow minimizing the temperature gradient across the 6-layers coils.

The thermal design of the cold mass during normal operation and current ramps up and down is validated using analytical approximations and numerical simulation.

Primary author: ROLANDO, Gabriella (CERN)

Co-authors: VODOPYANOV, Alexander (Joint Inst. for Nuclear Research (RU)); DUDAREV, Alexey (CERN); TEN KATE, Herman (CERN); Dr SCHMITT, Lars (GSI Darmstadt)

Presenter: ROLANDO, Gabriella (CERN)

Session Classification: C3OrF - Superconducting Magnets Cryogenic Systems II

Track Classification: CEC-06 - Superconducting Magnet Systems
Impact of Varying Acceleration to the Performance of Stirling-Type Pulse Tube Cryocooler

Stirling-Type Pulse Tube Cryocooler is widely used in Aerocrafts which are often faced with changing acceleration. While the performance of the cryocooler will decay at the circumstance. Experiments find that both the cryogen’s temperature field in the cold finger and the Compressor’s piston gap are affected by variable acceleration. A model is made for analyzing the changing of their performance whose result matches the experiment. The experiments is a reference to future cryocooler design and give a way to control the performance by adding a certain power of compressor.

Primary author: Dr LI, Jinze (Beijing TIPC)
Presenter: Dr LI, Jinze (Beijing TIPC)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Significantly enhanced critical current density (Jc) for MgB2 superconducting wires can be obtained following the advanced internal Mg infiltration (AIMI) route. But unless suitable precautions are taken, the AIMI-processed MgB2 wires will exhibit incomplete MgB2 layer formation, i.e. reduced superconductor core size and hence suppressed current-carrying capability. Therefore, it is crucial to investigate the mechanism of MgB2 layer formation in AIMI processed wires. Microstructural characterization of AIMI MgB2 wires before and after the heat treatment reveals that the reaction mechanism changes from a “Mg infiltration-reaction” at the beginning of the heat treatment to a “Mg diffusion-reaction” once a dense MgB2 layer is formed. A drastic drop in the Mg transport rate from infiltration to diffusion causes the termination of the MgB2 core growth. To quantify this process, a two-stage kinetic model is built to describe the MgB2 layer formation and growth. The derived kinetic model indicate that fully reacted AIMI-processed MgB2 wires can be achieved following the optimization of B particle size, B powder packing density, MgB2 reaction activation energy and its response to the additions of dopants. This kinetic model is used to explain the experimental observations in AIMI wires, including the sudden stop of MgB2 layer formation, optimal choice of B precursor type, and the effects of heat treatment temperature as well as C or Dy2O3 dopants on AIMI wires. Finally, suggestions are given for preparing full reacted, well performance AIMI wires according to the above kinetic analysis.

Primary author: LI, Guangze (The Ohio State University)
Co-authors: COLLINGS, Edward (The Ohio State University); SUMPTION, Mike (The Ohio State University)
Presenter: LI, Guangze (The Ohio State University)
Session Classification: M3OrB - Superconductor Wires IV: MgB2 and Applications
Track Classification: ICMC-04 - MgB2 Processing and Properties
Theoretical and experimental investigations on the performance characteristics of the linear compressor for the pulse tube cryocooler

The linear compressor providing powers for the Stirling-type pulse tube Cryocooler (SPTC) is endowed with remarkable merits such as high reliability and long life which have a strong appeal to aerospace applications. The pulse tube cold finger (PTCF) exerts evident and complicated influences on the compressor’s performance. However, there is seldom systematic investigation on the influences, which often leads to a poor cooler performance when a linear compressor is developed and then coupled to the PTCF.

In this paper, theoretical and experimental investigations on the linear compressor’s performance characteristics and the PTCF’s influences have been made. The compressor and the PTCF are assumed as a one-dimensional thermodynamic model. The governing equations of the working gas’ operating characteristics are summarized, such as the dynamic pressure, the mass flow rate, and the phase angle between them. The cooling performance’s effects on the characteristics of the working gas in the compression space are determined. Based on the characteristics of the working gas in the compression space, the governing equations of the compressor’s performance characteristics are deduced, such as the input electric power, the PV power, and conversion efficiencies of powers. The principles for achieving the compressor’s optimal performance are discussed in detail.

The experimental investigations are conducted on a series of linear compressors which drive SPTCs operating at 25-200 K. Varying with cooling capacities and operating temperatures, the linear compressors’ input electric powers, conversion efficiencies, and the working gas’ operating characteristics in the compression space are measured to verify the model. The SPTCs achieve input compressor capacities of 0-500 W with motor efficiencies of 74.2-83.6%, and 2.9%, 9.6%, 16.2% of Carnot efficiency at 40 K, 60 K, 80 K, respectively.

Primary author: Mr ZHANG, Lei (Shanghai Institute of Technical Physics, Chinese Academy of Sciences)

Co-authors: Mr BAO, DIngli (Shanghai Institute of Technical Physics, Chinese Academy of Sciences); Prof. DANG, Haizheng (Shanghai Institute of Technical Physics, Chinese Academy of Sciences); Mr TAN, Jun (Shanghai Institute of Technical Physics, Chinese Academy of Sciences)

Presenter: Mr ZHANG, Lei (Shanghai Institute of Technical Physics, Chinese Academy of Sciences)

Session Classification: C2PoB - Stirling and Pulse Tube Cryocoolers

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Design challenges of a 20kW liquid hydrogen cooling system for The European Spallation Source cold moderators.

Tuesday, 30 June 2015 14:00 (2 hours)

A key feature of the target system at ESS will be the cold moderators. With the use of supercritical hydrogen at 17 K and 1.5 MPa, the energy of the neutrons is reduced before they reach the instrument lines. The neutrons will deposit significant amounts of energy into the hydrogen that must be removed to maintain the hydrogen at its nominal operating temperature. The cooling for the hydrogen will be provided by the target moderator cryoplant (TMCP). This is the story behind the development of the world’s largest LH2 cooling for a neutron source.

Primary author: RINGNÉR, Jesper (ESS)

Co-authors: QUACK, Hans (TU Dresden); JURNS, John (European Spallation Source ESS AB); Mr KICKULIES, Marc (European Spallation Source); KLAUS, Marcel (Technische Universitaet Dresden); ARNOLD, Philipp (European Spallation Source ESS AB)

Presenters: RINGNÉR, Jesper (ESS); JURNS, John (European Spallation Source ESS AB)

Session Classification: C2PoH - Hydrogen Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Neon Helium Mixtures as a Refrigerant for the FCC Beam Screen Cooling: Comparison of Cycle Design Options

Monday, 29 June 2015 14:00 (2 hours)

In the course of the studies for the next generation particle accelerators, in this case the FCC-hh, different aspects are being investigated. One of these is the heat load on the beam tube, which results mainly from the synchrotron radiation. In case of the FCC-hh, a heat load of 500 kW is expected. The heat has to be absorbed at 40 to 60 K due to vacuum restrictions. In this range, refrigeration is possible with both helium and neon. Our investigations are focused on a mixed refrigerant of these two components, which combines the advantages of both. Especially promising is the possible substitution of the oil flooded screw compressors by more efficient turbo compressors. This paper investigates different flow schemes and mixtures compositions with respect to complexity and efficiency. Furthermore, thermodynamic aspects, e.g. whether to use cold or warm secondary cycle compressors are discussed.

Primary author: KLOEPPEL, Steffen (TU Dresden)

Co-authors: Dr HABERSTROH, Christoph (TU Dresden); HOLDENER, Fridolin (WEKA AG); QUACK, Hans (TU Dresden)

Presenter: KLOEPPEL, Steffen (TU Dresden)

Session Classification: C1PoG - Thermal Analysis and Design

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Combined Heat Transfer Analysis for all Solid State Cryocooler

Attaining cooling effect by using laser induced anti-Stokes fluorescence in solids appears to have several advantages over conventional mechanical systems and has been the topic of recent analysis and experimental work. Using anti-Stokes fluorescence phenomenon to remove heat from a glass by pumping it with laser light, stands as a pronouncing physical basis for solid state cooling. Cryocooling by fluorescence is a feasible solution for obtaining compactness and reliability. It has a distinct niche in the family of small capacity cryocoolers and is undergoing a revolutionary advance. In pursuit of developing laser induced anti-Stokes fluorescent cryocooler, it was required to develop numerical tools that support the thermal design and therefore a thorough understanding and analysis of combined heat transfer mechanism within the cryocooler was necessary. The paper presents the details of numerical model developed for the cryocooler and the subsequent development of a computer program. The program has been used for the understanding of various heat transfer mechanisms and is being used for thermal design of components for an anti-Stokes fluorescent cryocooler. The results are presented in tabular and graphical forms.

Primary author: Dr KUZHIVELI, Biju (National Institute of Technology Calicut)
Presenter: Dr KUZHIVELI, Biju (National Institute of Technology Calicut)

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Design details of the current lead test facility Karlsruhe (CuLTKa)

The new current lead test facility CuLTKa was successfully commissioned in 2014 at the Karlsruhe Institute of Technology (KIT), Germany. Towards the end of the year the first pair of current leads for the Japanese fusion experimental reactor JT-60 SA was tested. These current leads have to carry currents of up to 26 kA and are cooled with helium at two different temperature levels, 4.5 K and 50 K, respectively. After commissioning and test of the first pair of the HTS-current leads another 24 current leads will be tested within the next 2.5 years.

The facility consists of two valve boxes, one control box, which houses a 400 l liquid helium reservoir and two test cryostats. All cryostats are connected by cryogenic transfer lines. Two helium mass flows at 4.5 K and 20 to 70 K at overcritical pressures are provided by the 2 kW refrigerator. This publication will describe the way of designing the facility starting from the basic demands. The overall setup is derived and particular details are explained. Some design calculations will be opposed to measured data from its real performance. In addition the design of safety aspects is discussed.

Primary author: RICHTER, Thomas (Karlsruhe Institute of Technology (KIT))
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Presenter: RICHTER, Thomas (Karlsruhe Institute of Technology (KIT))
Session Classification: C2PoF - Test Facilities
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Influence of tailored MLI for complex surface geometries on heat transfer

Monday, 29 June 2015 16:15 (15 minutes)

Complex, non-developable surfaces require a tailored multi-layer insulation (MLI) for lowest heat loads. The most experiments showing the heat transfer through MLI are performed under quasi-ideal conditions determining the principle insulation quality. But the surface to be insulated in real cryostats implies feed-throughs and other non-developable surface parts. The thermal performance of MLI is degraded significantly at cutting points.
To investigate this degrading effect a LN2– filled cylinder with a diameter of 219 mm and a length of 1820 mm was insulated with MLI and the heat load was measured calorimetrically. In addition the heat load to an insulated cylinder with eighteen branches was measured. Both the cylinders have the same surface of 1.37 m² for a comparison of the results.
This article describes the experiments with different ways of tailoring the MLI for the cylinder with branches and discusses their results.
It was shown that the cutting points at the branches have a significant degrading influence on the thermal performance of MLI.

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Presenter: RICHTER, Thomas (Karlsruhe Institute of Technology (KIT))
Session Classification: C1OrF - Thermal Insulation Applications and Measurements
Track Classification: CEC-14 - Thermal Insulation Systems
A sorption-based helium-3 pump is developed to be incorporated in a closed-cycle dilution refrigerator (CCDR) that is realized by the Néel institute in Grenoble. This CCDR is to be used for future long-lifetime space missions requiring a cooling power of the order of 1 microWatt at typically 50 mK for at least 5 years. A crucial component in this zero-gravity dilution refrigerator is a pump to circulate helium-3 between 5 and 200 mbar. For this purpose, we designed a sorption-based pump that consists of a single sorption-compressor cell of which the sorber container measures 1 cm in diameter and 10 cm in length. It uses passive inlet and outlet valves and is thermally linked to a 15-K platform. Gas buffers are applied for stabilizing the low pressure and for storing the gas at 300 K thus reducing the filling pressure to below 20 bar. The pump is manufactured and tested. A compressor-cell input of 60 mW is required to establish a flow of 20 micromol/s between 5 and 200 mbar. The pressure fluctuation in that case at the low-pressure side is about 1.5 mbar. If needed, this fluctuation can be reduced to about 0.5 mbar by controlling the temperature of the low-pressure buffer (requiring an additional power input of 60 mW). Compared to mechanical pumps the main advantages are lower mass and less complex interfacing. Both advantages result from the fact that the pump is fully integrated with the cold part of the CCDR, whereas the alternative mechanical pumps need to be operated at the 300 K level. The construction of the sorption-based pump and test set-up will be presented as well as the test results.

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**Session Classification:** C1OrD - Low Temperature Aerospace Cryocoolers

**Track Classification:** CEC-04 - Cryocoolers (Aerospace)
Using In-situ Cryogenic Radiometers to Measure the Performance of a Large Thermal Vacuum Chamber

The James Webb Space Telescope will operate in space at temperatures lower than 50 K. To test the major parts of the telescope and instruments on the ground requires a very large thermal vacuum chamber with a helium-cooled shroud operating below 20 K. This chamber and shroud are being subjected to a series of 4 preliminary tests to characterize the chamber and the ground support equipment before the telescope and instruments are tested. We have made measurements in the first of these preliminary tests using simple radiometers, which are located in the chamber and are pointed at various locations and items of interest within the chamber. The radiometers, which have been previously described[1], consist of a Cernox thermometer attached to an absorber suspended behind a Winston cone with an acceptance half-angle of 11 degrees. 9 of these radiometers were anchored to the chamber at temperatures between 17 and 25 K and were able to resolve 10 nanowatts over an area of 2 cm². This level of sensitivity corresponds to a 60 K blackbody, which spans the radiometer field of view, changing in temperature by 0.04 K. The results of this test, and plans for future tests will be described.


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Session Classification: C3OrB - Aerospace Systems
Track Classification: CEC-10 - Aerospace
Adaptation of refrigeration compressors for Joule-Thomson cryocoolers fed with gas mixtures

Monday, 29 June 2015 11:30 (15 minutes)

Closed cycle Joule-Thomson (J-T) refrigerators supplied with gas mixtures are perspective coolers in many applications requiring low-cost and reliable sources of cooling power below 100 K. They are characterized by relatively simple construction and lack of moving parts working at low temperatures. The refrigerants are composed of nitrogen and hydrocarbons. Working pressure can as low as about 2 MPa, and thanks to its solubility in hydrocarbons, some fraction of compressor lubricating oil can circulate in the system. The main advantage of the J-T refrigerator using gas mixtures is the possibility of use of commercially available hermetic refrigeration compressors. The limiting factor is temperature increase of the mixture during compression. The paper is focused on the problems of adaptation of hermetic compressors to J-T cryocoolers requirements. Temperature limits as well as possible technical solutions to improve the compressor cooling and lubrication have been analyzed and discussed. Working parameters of the J-T refrigerator fed with gas mixture and will be presented together with the influence of compressor adaptation means.

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Presenter: Dr PIOTROWSKA, Agnieszka (Wroclaw University of Technology)
Session Classification: C1OrC - Compressors & Expanders
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
New measurements of multilayer insulation at variable cold temperature and elevated residual gas pressures

New MLI measurements at the TU Dresden flow type calorimeter have been carried out. Specimens of 10 and 20 layer double side aluminized polyester film were tested. A cylindrical cold surface of 0.9 m² is held at the desired cold boundary temperature between approximately 30 K and 300 K. The heat transfer through the MLI is measured by recording the mass flow as well as the inlet and the outlet temperature of the cooling fluid. Measurements at varied cold boundary temperatures have been performed. Moreover the effect of an additional vacuum degradation – as it might occur by decreasing getter material performance in real systems at elevated temperatures – is studied by a controlled inlet of nitrogen gas. Thus the vacuum pressure was varied over a range of 10⁻⁷ mbar to 10⁻² mbar. Different cold boundary temperatures between 35 K and 110 K were investigated. Test results of the bare test cylinder as well as 10 and 20 layer MLI are presented.

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Session Classification: C1PoL - Thermal Insulation
Track Classification: CEC-14 - Thermal Insulation Systems
Preliminary design of the beam screen cooling for the Future Circular Collider of hadron beams

Monday, 29 June 2015 14:00 (2 hours)

Following recommendations of the recent update of the European strategy in particle physics, CERN has undertaken an international study of possible future circular colliders beyond the LHC. This study considers an option for a very high energy (100 TeV) hadron-hadron collider located in a quasi-circular underground tunnel having a circumference of 80 to 100 km. The synchrotron radiation emitted by the high-energy hadron beam increases of more than two orders of magnitude compared to the LHC. To reduce the entropic load on the superconducting magnets’ refrigeration system, beam screens are indispensable to extract the heat load at a higher temperature level. After illustrating the decisive constraints of the beam screen’s refrigeration design, this paper presents a preliminary designing of the length of a continuous cooling loop comparing helium and neon, for different cooling channel geometries with emphasis on the cooling length limitations and the exergetic efficiency.

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Session Classification: C1PoG - Thermal Analysis and Design
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Comparative Study and Electromagnetic Analysis of Linear Drive System for a Stirling Cryocooler

Stirling cryocoolers are becoming more popular in the area of remote sensing and space applications because of their inherent characteristics viz., long life, high reliability, less weight etc. In order to have a good on-board performance, the selection of the compressor drive system is critical. Linear motors are simple in operation by avoiding side forces and the required axial force is generated by current flowing in a magnetic field. The recent trend is to replace the moving coil with moving magnet type motors. This paper explores the possibility of employing a range of components and materials for the development of a linear drive system. The analysis includes material selection, electromagnetic design using electro-mechanical energy conversion method and comparison of different configurations in order to meet the stringent operating requirements of the cooler. The compact size, available permanent magnet sizes and overall volume and weight reduction are quite a few constraints for the design. A number of material combinations are tried during the study before finalizing the geometry of the motor. The finite element analysis (FEA) and simulation are carried out using Maxwell software. Parametric study is carried out for different magnet and coil combinations, geometrical structures, and material combinations. The effect of magnet displacement on thrust force developed is analyzed in detail for different combinations under consideration. The air gap flux density was to be maintained at a minimum level to obtain the required force to operate the piston. The dimensions of the core are finalized after determining the saturation flux produced while the motor in operation. The effect of varying the inner and outer core thickness and their geometry on the air-gap flux density and saturation limits are also studied and compared with. The results are presented in the graphical and tabular forms.

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Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Non-destructive characterization of local Ic variation in a long length Bi-2223 tape

Spatial homogeneity of critical current, Ic, is one of the most important performances of practical HTS tapes. Such Ic homogeneity is typically characterized by the reel-to-reel transport measurement with a tap distance of several tens cm to several m. However, the spatial resolution is not enough in the conventional method to detect local Ic drop, especially in the case of Bi-2223 tape because of a small shunt resistance of the Ag sheath. In this study, we have succeeded in measuring in-plane Ic distribution in a commercial 100-m-class Bi-2223 tape with non-contact and non-destructive manner by using reel-to-reel high speed scanning Hall probe microscopy. This allows us to measure high resolution remanent flux image on the tape surface in liquid nitrogen bath with a spatial resolution of 34 um in width and 830 um in length. Traveling speed of the tape during the measurement was 36 m/h at maximum. By solving the inversion problem, we obtained in-plane Ic distribution in the tape. We have succeeded in analyzing Ic fluctuation over multi-scale length more than 5 decades. To check the validity of the Ic value, we also carried out site-specified four-probe measurements, then confirmed that these two measurements showed good agreement each other. Statistical behavior of the Ic fluctuation and the correlation with microstructure will be discussed.

This study was supported by the "JST: S-Innovation" and "JSPS: KAKENHI (24760235)".

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Session Classification: M2OrB - Superconductor Wires I: Testing and Characterization

Track Classification: ICMC-03 - BSCCO Processing and Properties
[Invited] Development of MgB2 superconductors and coils for practical applications

Wednesday, 1 July 2015 11:15 (30 minutes)

Hyper Tech Research will report on progress that has been made on developing magnesium diboride superconductor wires for research and commercialization efforts, with a specific emphasis on relating superconductor properties to the requirements of the application. The status of Hyper Tech Research’s current demonstration projects for fabricating MgB2 wire and coils for MRI, FCL, motors, and other applications will be presented.

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Presenter: Mr TOMSIC, Mike (Hyper Tech Research)

Session Classification: M3OrB - Superconductor Wires IV: MgB2 and Applications

Track Classification: ICMC-04 - MgB2 Processing and Properties
Film Boiling Heat Transfer from a Wire to Upward Flow of Liquid Hydrogen and Liquid Nitrogen

Wednesday, 1 July 2015 09:00 (2 hours)

Knowledge of film boiling heat transfer from a heated wire to forced flow of liquid hydrogen or liquid nitrogen in a narrow gap is important for conductor design and quench analysis of superconducting magnets wound with high-Tc cable in conduit conductor (CICC). However there have been few experimental data as far as we know.

Film boiling heat transfer coefficients in liquid hydrogen were measured for the heater surface superheats up to 400 K under pressures from 0.4 to 1.1 MPa, liquid subcoolings from 0 to 11 K and flow velocities up to 8 m/s. Two test wires used were both 1.2 mm in diameter, 120 mm and 200 mm in lengths made of PtCo (0.5 at. %) alloy. The former wire was located at the center of 8 mm diameter conduit and the latter was at the center of 5 mm conduit made of FRP (Fiber Reinforced Plastics). Film boiling heat transfer coefficients in liquid nitrogen were measured only for the 200 mm long wire. Temperature of the test wires were measured by resistance thermometry. The film boiling heat transfer coefficients are higher for higher pressure, higher subcooling, and higher flow velocity. The experimental data were compared with Shiotsu-Hama equation [1] for forced flow film boiling in a wide channel based on numerical analysis and experimental data. The data for 8 mm diameter conduit were about 1.7 times and those for 5 mm conduit were about 1.9 times higher than the predicted values by the equation. A new equation was presented modifying the Shiotsu-Hama equation based on the liquid hydrogen and liquid nitrogen data. The experimental data were expressed well by the equation.

Molecular dynamics for homogeneous nucleation of water and carbon dioxide in different carrier gases

Wednesday, 1 July 2015 12:00 (15 minutes)

We evaluate the feasibility of the natural gas liquefaction process with very limited gas treatment or heavy carbons removal. Such reduction in system processing would significantly reduce treatment steps and thus also maintenance costs. Phase transitions in a binary gas mixture of carbon dioxide and methane need be determined. In order to do so, we first focus on homogeneous nucleation phenomena constituting the fundamental process in phase transitions from vapour to liquid. Molecular Dynamics (MD) is a promising technique to study this. It was previously successfully used for single component systems like Argon [1]. We first compare and validate cluster dynamics and nucleation rates from a mixture of water (as condensate) and argon (as carrier gas) with existing results available in literature [2]. Promising results were already found. The applied methodology allows us to investigate also other mixture systems such as with helium as a carrier gas. In this case nucleation rates are compared with experimental data found from shock-tube measurements as well [3] in order to demonstrate the versatility of the method. Moreover, preliminary results based on homogeneous nucleation simulations in carbon dioxide are presented and directly compared with experiments from our laboratory expansion cloud chamber set-up.

Institut Néel - CNRS and Air Liquide are presently developing a Closed-Cycle Dilution Refrigerator for Space. Recent sub-system level tests have demonstrated the operation of the low temperature components: the mixing chamber can provide close to 1µW at 50mK, the Still (in which the phase separation between liquid and gas occurs) can confine the liquid against gravity, and 4He can be efficiently re-circulated by means of a superfluid fountain pump. Yet, one of the major components for the system is the 3He compressor to re-circulate the 3He pumped at still level. In the tests at sub-system level, this compressor would be a commercial pump not adapted for space use. JAXA and SHI have been developing 3He compressors for use in a JT cooler (the so-called “1K class cooler”). Through recent developments, the minimum inlet pressure could be lowered towards CCDR requirements. A common program between JAXA and CNES has been set up to issue a coupled test of the CCDR with the modified 3He compressor. We present both subsystems and recent results obtained when coupling these 2 subsystems. We discuss potential next steps.
Anisotropic fracture toughness properties of a Nitronic 50 forging at 4.2 K

Tuesday, 30 June 2015 16:45 (15 minutes)

Fracture toughness of a forging material Nitronic 50 (ASTM A182 F XM-19) was investigated at 4.2 K. The L-T and L-S specimens were used in this study. The expected directions of crack propagation for these specimens are parallel to the width (long transverse) direction and the thickness (short transverse) direction, respectively. In the fatigue pre-cracking for both specimens and J-tests of the L-T specimens, the crack extension followed the expected direction without diverting. In J-tests of the L-S specimens, however, the crack path changed to almost 90° with respect to general crack propagation plane inside the compact tension specimen, meaning that the L-S specimens show a strong anisotropy.

The evaluation of the J-integral test using the ASTM standard E1820 could be therefore not applied, as the unloading slopes of the determined load versus displacement record relies on the standard compliance function of a compact tension specimen where the crack extension is at the 0° plane, not at 90° plane. For this reason, a new consistent compliance function was determined by modeling anisotropic specimens by a FEM approach. In addition, the FEM procedure was verified nearly in a perfect manner by using several compact tension specimens which have similarly-shaped mechanical notches and measuring experimentally their stiffness at room temperature. Using the new compliance function and inserting this fit equation into the evaluation software, the fracture toughness of the anisotropic material could be estimated.

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Session Classification: M2OrD - Cryogenic Materials V: Structural Materials
Track Classification: ICMC-11 - Metallic and Composite Materials
Cryogenic System for the Cryomodule Test Stand at Fermilab

Tuesday, 30 June 2015 09:00 (2 hours)

This paper describes the cryogenic system for the Cryomodule Test Stand (CMTS) at the new Cryomodule Test Facility (CMTF) located at Fermilab. CMTS is designed for production testing of the 1.3 GHz and 3.9 GHz cryomodules to be used in the Linac Coherent Light Source II (LCLSII), which is an upgrade to an existing accelerator at Stanford Linear Accelerator Laboratory (SLAC). This paper begins with a description of the design and installation progress of the CMTS cryogenic distribution system. Next, the key cryomodule interface and operational requirements will be listed, followed by an overview of the installation and cooldown plans. The paper will conclude with a description of the heat load measurement plan.

Fermilab is operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.

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Session Classification: C2PoD - Superconducting RF Systems II
Track Classification: CEC-07 - Superconducting RF Systems
Performance Testing of a 15K Pulse Tube Cooler for Space Applications

Monday, 29 June 2015 11:00 (15 minutes)

Air Liquide has been working with ESA, CEA and Thales Cryogenics since 2010 to design, manufacture and test a 15K Pulse Tube Cooler system. This cooler is particularly adapted to the pre-cooling needs of cryogenic chains designed to reach 0.1-0.05K for focal plane cooling on scientific space missions such as ATHENA. The cooler is designed to provide cooling power $>0.3W$ at temperatures from 15 to 18K with an electrical power budget less than 300W (excluding electronics) and a 288K rejection temperature. Significant cooling power at an intermediate temperature (typically 80-100K) is also available. The design includes two cold fingers mounted on a common warm flange driven by a single high power compressor (240W PV power) specially developed for this application. The first cold finger is used to pre-cool the second, low temperature stage. An Engineering Model has been manufactured and the design and test results will be presented in this paper.

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Presenter: BUTTERWORTH, James (Air Liquide Advanced Technologies)

Session Classification: C1OrD - Low Temperature Aerospace Cryocoolers

Track Classification: CEC-04 - Cryocoolers (Aerospace)
ITER: Test protocol to demonstrate the Cryogenic Helium plant performances

Monday, 29 June 2015 16:45 (15 minutes)

The ITER Tokamak requires an average 75kW of refrigeration power to maintain the nominal operation condition of the ITER superconducting magnets and cryopumps. This is produced by three identical liquid helium (LHe) Plants.

Air Liquide Advanced technologies, as the supplier of the entire ITER liquid Helium plant, should demonstrate through various running conditions, that the expected functionalities and performances will be achieved.

In particular, a high power test cryostat will simulate the 75 kW isothermal loads in a liquid Helium bath.

This proceeding will present the tests phases as well as the main functionalities and equipments implemented to allow the cryogenic Helium plant acceptance by ITER.

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Session Classification: C1OrE - Refrigeration and Liquefaction - sponsored by TechSource, Inc.

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Measurement of heat capacity of yttrium silicide (Y5Si3) in the ultra-low temperature range

Most chemical processes to extract the Ho-163 isotope and insert it into a detector absorber involve yttrium based compounds. Rather than using yttrium as an intermediate step in the isotope extraction procedure, the metal yttrium silicide (Y5Si3) was a possible candidate to use directly as absorber material. We measured the heat capacity of small Yttrium Silicide (Y5Si3) sample in the temperature range 90mK -300mK using bolometric technique, to confirm if it could be used as an absorber in the fabrication of microcalorimeters. We also measured its resistivity from room temperature to 90 mK four wire measurement technique. Our result indicated that the heat capacity of Y5Si3 is larger than gold (often used as absorber material) by more than a factor of five in the working temperature range of TES microcalorimeters.

This work was supported by NSF funding.

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Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
A Simulink Library of cryogenic components to automatically generate control schemes for large Cryorefrigerators.

Wednesday, 1 July 2015 09:00 (2 hours)

In this article, we present a new Simulink library of cryogenics components (such as valve, phase separator, mixer, heat exchanger…) to assemble to generate model-based control schemes. Every component is described by its algebraic or differential equation and can be assembled with others to build the dynamical model of a complete refrigerator or the model of a subpart of it. The obtained model can be used to automatically design advanced model based control scheme. It also can be used to design a model based PI controller.

Advanced control schemes aim to replace classical user experience designed approaches usually based on many independent PI controllers. This is particularly useful in the case where cryoplants are submitted to large pulsed thermal loads, expected to take place in future fusion reactors such as those expected in the cryogenic cooling systems of the International Thermonuclear Experimental Reactor (ITER) or the Japan Torus-60 Super Advanced Fusion Experiment (JT-60SA).

The paper gives the example of the generation of the dynamical model of the 400W@1.8K refrigerator and shows how to build a Constrained Model Predictive Control for it. Based on the scheme, experimental results will be given.

This work is being supported by the French national research agency (ANR) through the ANR-13-SEED-0005 CRYOGREEN program.

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Presenter: Dr BONNE, François (CEA/SBT)

Session Classification: C3PoA - Controls and Simulation

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
[Invited] DESIGN AND FABRICATION OF A CRYOSTAT FOR LOW TEMPERATURE MECHANICAL TESTING FOR THE MECHANICAL AND MATERIAL’S ENGINEERING GROUP AT CERN

Monday, 29 June 2015 11:00 (30 minutes)

Mechanical testing of materials at low temperatures is one of the cornerstones of the Mechanical and Material’s Engineering (MME) group at CERN. A long tradition of more than 20 years and a unique know-how of such tests has been developed with a 18 kN double-walled cryostat. Large campaigns of material qualification have been carried out and the mechanical behavior of materials at 4 K has been vastly studied in sub-size samples for projects like LEP, LHC and its experiments. With the aim of assessing the mechanical properties of materials when submitted to higher loads, a new 100 kN cryostat capable of hosting different shapes of normalized samples has been carefully designed and fabricated in-house together with the associated tooling and measurement instrumentation. It has been conceived to be able to adapt to different test frames both dynamic and static, what will be of paramount importance for future studies of fracture mechanics at low temperatures.

The cryostat features of a double-walled vessel consisting of a central cylindrical section with a convex lower end and a flat top end closure. The transmission of the load is guaranteed by a 4 column system and its precise monitoring is assured by an internal load cell positioned next to the sample in the load train. This innovative approach will be discussed together with other unconventional instrumentation solutions such as optical fiber extensometry.

A validation of the whole system has been carried out at both room and cryogenic temperature. Bending efforts have been measured and dedicated tooling fabricated for the device’s optimization. The results obtained confirm an excellent performance of the system and enhance the analysis of materials under extreme conditions with state of the art instrumentation.

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Session Classification: M1OrB - Cryogenic Materials I: Testing and Methods

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
Experimental verification of cylindrical adjustable inertance tube for pulse tube refrigerators

Thursday, 2 July 2015 09:30 (15 minutes)

The performance of the Stirling type pulse tube cryocooler increases significantly with optimal use of an inertance tube. The phase angle produced by the inertance tube is very sensitive to its diameter(s) and length(s). Recent developments are reported here regarding an adjustable inertance tube whose length and diameter can be adjusted in real time during the operation of the cryocooler. The length will increase from 1.372m to 3.088 m and the diameter will increase from 6.9 mm to 8.7mm while the outer screw of the inertance tube turns from bottommost to the topmost position. A fluid impedance measurement has been carried out to verify the performance of this adjustable inertance tube. From the fluid impedance calculation, with an air mass flow rate of 0.77 kg/s and a pressure supply of 1532 Pa (gauge) at the inlet, the fluid resistance increases from 1.874e7 1/s-m to 2.559e7 1/s-m, the fluid compliance increases from 2.303e-11 [m^3-kg/J] to 2.702e-11 [m^3-kg/J], and the fluid inertance increases from 37243 [1/m] to 62242 [1/m], while rotating the outer screw from the bottommost to the topmost position. This particular adjustable inertance tube has the potential to change the phase angle at the cold end of Stirling pulse tube cryocooler by almost 30° at a working frequency of 27Hz.

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Presenter: Prof. PFOTENHAUER, John (Adviser, second author)

Session Classification: C4OrB - Pulse Tube Configurations

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Subsea Superconducting Power Cables for Offshore Renewable Energy Integration

Monday, 29 June 2015 11:45 (15 minutes)

Offshore renewable energy, such as wind, tidal and wave energy, represents a potential solution to the future energy demand, while the world’s energy consumption continues to grow rapidly and the production of both oil and gas is waning. Serious consideration has been given to the development of offshore wind farms, particularly in Europe, North America and Asia. Many projects have been approved and several farms are already under construction. To integrate these offshore farms and transfer power from them to shore-based power networks, efficient subsea power cables are urgently required, since conventional cables cannot play this irreplaceable role with very limited power capacity and considerable loss. Superconductors, which are only being utilized for developing land power cables so far, are a perfect solution.

Prof. Li, on behalf of the Applied Superconductivity Centre in the University of Edinburgh, will for the first time present their research work on applying superconductors to develop subsea superconducting power (SSP) cables. Such SSP cables are expected to entirely upgrade the present power network.

Both advantages and potential risks of SSP cables will be presented, followed by analysis of their reliability. An SSP cable with suitable configuration for subsea power transmission is proposed. Based on numerical modelling, its electrical and magnetic properties are studied and its loss characteristics are analysed. Results show that the SSP cables can greatly benefit subsea power networks with ultimate power capability and extremely low loss. However, efficient cooling is essential along with the protection of physical damage and fault current. All results will be presented and relevant discussion will be carried out.

Primary author: Prof. Li, QUAN (University of Edinburgh)
Co-author: Prof. MUELLER, Markus (University of Edinburgh)
Presenter: Prof. Li, QUAN (University of Edinburgh)
Session Classification: M1OrA - Superconductor Cables I: HTS and LTS
Track Classification: ICMC-09 - HTS Cables
Cryogenic parallel, single phase flows: an analytical approach

Managing the cryogenic flows inside a state-of-the-art accelerator cryomodule has become a demanding endeavor: In order to build highly efficient modules, all heat transfers are usually intercepted at various temperatures. For a multi-cavity module, operated at 2 K, this requires intercepts at 5 K and at 80 K at different locations with sometimes strongly varying heat loads which for simplicity reasons are operated in parallel. This contribution will analytically investigate the characteristics of these parallel flows, derive stability criterions and provide design suggestions.

Primary author: EICHHORN, Ralf (Cornell University)
Presenter: EICHHORN, Ralf (Cornell University)

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Time resolved cryogenic cooling analysis of the Cornell Injector Cryomodule

Managing parallel cryogenic flows has become a key challenge in designing efficient and smart cryo-modules for particle accelerators. In analyzing the heating dynamics of the Cornell high current injector module a power-full computational tool has been set-up allowing time resolved analysis and optimization. We will describe the computational methods and data sets we have used, report the results and compare them to measured data from the module being in good agreement. Mitigation strategies developed on basis of this model have helped pushing the operational limitations.

Primary author: EICHHORN, Ralf (Cornell University)

Co-authors: Dr SMITH, Eric (Cornell University); Mr QUIGLEY, Peter (Cornell University); Mr MARKHAM, Stephen (Cornell University)

Presenter: EICHHORN, Ralf (Cornell University)

Session Classification: C1PoE - Thermal Fluids (Non-Aerospace)

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
PIT and RRP® Nb3Sn strands are being studied as potential candidates for high field accelerator magnet upgrades for the LHC. It is well known that maintaining diffusion barrier integrity in these strands is vital to retaining adequate RRR for magnet stability. Here we report a quantitative study of the shape and position of filaments or sub-elements after rolling lengths of unreacted PIT and RRP® round wires to simulate cabling deformation. In the as-drawn condition shape deformation occurs preferentially in the outer ring filaments, increasing progressively with radial position, but rolling induces non-uniform shear bands that induce greater distortion of inner ring filaments. By making a full digitization of the shapes of all filaments, and by taking measurements of RRR, we find that a critical distortion occurs for thickness reductions between 10 and 20%. In this deformation range, the filament shapes transition from higher aspect ratio in outer filament rings to much larger aspect ratios in inner filament rings, especially in the vicinity of the strong 45° shear bands imposed by the rolling. We have benchmarked the deformation to determine a limit past which unacceptable damage has occurred, and will discuss how to best limit this damage, which inevitably leads to Sn leakage and RRR degradation when uncontrolled. Progress is currently being made toward an approach for accurate modeling and prediction of wire deformation in hopes of limiting degradation, thereby enhancing wire performance.

Primary author:  BROWN, Michael (Florida State University)

Co-authors:  TARANTINI, Chiara (FSU); LARBALESTIER, David (National High Magnetic Field Laboratory); LEE, Peter (Florida State University); Dr OATES, William (FSU); STARCH, William (ASC)

Presenter:  BROWN, Michael (Florida State University)

Session Classification:  M2OrA - Superconductor Materials III: Nb3Sn

Track Classification:  ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Cooling topology options for HTS rotating superconducting machinery

Monday, 29 June 2015 09:00 (2 hours)

Cryogenic system complexity presents a major challenge to the implementation of superconducting technologies. At MIT, we have developed concepts to simplify the cryogenic environment for superconducting rotating machinery, such as HTS motors and generators. We present cooling schemes for the rotor of a high-speed rotating machine that avoid the use of rotating cryogenic seals, which are particularly difficult to implement at high rotating speeds. We describe passive cooling methods, using a variety of gases, mixtures and pressures, to indirectly remove, at temperatures in the range from 30K to 50K, the relatively small cryogenic load (tens of Watts) originating in the rotor. Computational fluid dynamics models of the thermal performance of the system, and windage due to the finite gas pressure, are presented. The impact of the indirect rotor cooling scheme on cryostat design is presented. We have developed complementary cooling schemes for superconducting stators. Forced flow cooling of the stator is needed because of its significantly higher heat load, either distributed within the winding (for coils wound from cable-in conduit conductor) or indirectly through the use of conduction cooling plates (for potted monolithic coils). We show characteristics of the stator cooling system for different cooling fluids, and cable geometries for both direct and indirect cooling. We describe the design of a cooling system manifold to address electrical isolation requirement both within and between the stator’s phase group windings. We discuss the applicability of the proposed cooling schemes to stationary systems.

Primary author: Dr BROMBERG, Leslie (MIT - Plasma Science and Fusion Center)

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Presenters: Dr BROMBERG, Leslie (MIT - Plasma Science and Fusion Center); Dr MICHAEL, Philip (MIT - Plasma Science and Fusion Center)

Session Classification: C1PoA - Cryogenics for Power Applications, Energy, Fuels and Transportation I

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Design and Operation of a Cryogenic Nitrogen Pulsating Heat Pipe

Tuesday, 30 June 2015 11:30 (15 minutes)

We report test results using an innovative passive cooling system called a “Pulsating Heat Pipe” (PHP) operating at temperatures ranging from 77 K to 80 K and using nitrogen as the working fluid. PHPs, which transfer heat by two phase flow mechanisms through a closed loop tubing have the main advantage that no electrical pumps are needed to drive the fluid flow. In addition, PHPs have an advantage over copper straps and thermal conductors since they are lighter in weight, exhibit lower temperature gradients and have higher heat transfer rates. PHPs consist of an evaporator section, thermally anchored to a solid, where heat is received at the saturation temperature where the liquid portion of the two-phase flow evaporates, and a condenser where heat is rejected at the saturation temperature where the vapor is condensed. The condenser section has been thermally interfaced to a CT cryocooler from SunPower, with a cooling capacity of 10 W at 77 K. Alternating regions of liquid slugs and small vapor plugs fill the capillary tubing, with the vapor regions contracting in the condenser section and expanding in the evaporator section due to an electric heater that will generate heat loads up to 10 W. This volumetric expansion and contraction provides the oscillatory flow of the fluid throughout the capillary tubing thereby transferring heat from one end to the other. The thermal performance and temperature characteristics of the PHP will be correlated as a function of average condenser temperature, PHP fill liquid ratio, and evaporator heat load. The experiment is also operated at different inclination angles in order to investigate whether Earth’s gravitational force has a significant effect on its efficiency.

Primary author: Mr FONSECA, Luis (University of Wisconsin Madison)
Co-authors: Mr MILLER, Franklin (Professor University of Wisconsin Madison); Mr PFOTENHAUER, John (Professor University of Wisconsin Madison)
Presenter: Mr FONSECA, Luis (University of Wisconsin Madison)
Session Classification: C2OrC - Pulsating Heat Pipes and Thermosyphons
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
First results from the Cornell high Q cw full linac cryo-module

Monday, 29 June 2015 16:15 (15 minutes)

Cornell University has finished building a 10 m long superconducting accelerator module as a prototype of the main linac of a proposed ERL facility. This module houses 6 superconducting cavities- operated at 1.8 K in continuous wave (CW) mode - with individual HOM absorbers and one magnet/ BPM section. In pushing the limits, a high quality factor of the cavities (2•10^10) and high beam currents (100 mA accelerated plus 100 mA decelerated) were targeted. We will review the design shortly and present the results of the components tested before the assembly. The main focus of the paper will be on preparation of the first cool-down, being scheduled by the time of the conference.

Primary author: EICHHORN, Ralf (Cornell University)

Co-authors: SABOL, Dan (Cornell University); Dr SMITH, Eric (Cornell University); HOFFSTAETER, Georg (Cornell University); SEARS, James (Cornell University); QUIGLEY, Peter (Cornell University); O’CONNEL, Tim (Cornell University)

Presenter: EICHHORN, Ralf (Cornell University)

Session Classification: C1OrG - Superconducting RF Systems I

Track Classification: CEC-07 - Superconducting RF Systems
Recent NASA/GSFC Cryogenic Measurements of the Total Hemispheric Emissivity of Black Surface Preparations

Tuesday, 30 June 2015 09:00 (2 hours)

High-emissivity (black) surfaces are commonly used on deep-space radiators and thermal radiation absorbers in test chambers. Since 2011 NASA Goddard Space Flight Center has been measuring the total hemispheric emissivity of such surfaces from room temperature down to 20 Kelvin using a test apparatus that fits inside a small laboratory cryostat. We report the latest data from these measurements, including Chemglaze Z307 paint, Black KaptonTM, and a configuration of painted aluminum honeycomb that was not previously tested. We also present the results of studies of batch-to-batch reproducibility in Ball Infrared BlackTM and painted aluminum honeycomb. This work was performed to support the development and testing of the James Webb Space Telescope.

Primary author: TUTTLE, James (NASA/GSFC)

Co-authors: CANAVAN, Edgar (NASA–Goddard Space Flight Center); DIPIRRO, Michael (NASA/Goddard Space Flight Center); LI, Xiaoyi (NASA/GSFC)

Presenter: TUTTLE, James (NASA/GSFC)

Session Classification: M2PoB - Cryogenic Materials III: Testing and Methods

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
Design of a symmetric coupler for superconducting elliptical cavities.

Tuesday, 30 June 2015 09:00 (2 hours)

As kicks from fundamental power couplers become a concern for low emittance future accelerators, a design for a symmetric coupler for superconducting accelerating cavities has been started. In this coupler, a rectangular waveguide transforms into a coaxial line inside the beam pipe to feed the cavity. So far the RF design revealed an extremely low transversal kick on which we will elaborate. We will also address concerns about cooling and the thermal stability of the coaxial transition line. Therefore, we will calculate the heat, heat transfer and thermal stability of this coupler and evaluate the risk of quenching due to particle losses on the coupler.

Primary author: EICHHORN, Ralf (Cornell University)

Co-authors: EGERER, Collin (Cornell University); ROBINS, Joshua (Cornell University); VESHCHEREVICH, Vadim (Cornell University)

Presenter: EICHHORN, Ralf (Cornell University)

Session Classification: C2PoD - Superconducting RF Systems II

Track Classification: CEC-07 - Superconducting RF Systems
Test stand for routine thermal conductivity measurements of SRF cavity material.

*Tuesday, 30 June 2015 09:00 (2 hours)*

Thermal conductivity of SRF cavity material influences Q factor in many different ways. RRR and grain size are insufficient to characterize quality of the material and additional control of thermal conductivity is required. We have developed a test stand to perform regular thermal conductivity measurements of samples from cavity material sheets from 1.6 to \(\approx 10\) K. Thermal conductivity of C101 copper measured with the test stand is consistent with NIST model. We report thermal conductivity of fine grain and single grain samples and comparison with results obtained by other authors.

**Primary author:** Dr KOSHELEV, Sergey (Fermilab)

**Co-author:** Prof. ARKHAROV, Ivan (Bauman Moscow State Technical University)

**Presenter:** Dr KOSHELEV, Sergey (Fermilab)

**Session Classification:** C2PoD - Superconducting RF Systems II

**Track Classification:** CEC-07 - Superconducting RF Systems
Measurements of YBCO pancake coils: thermal conductivity, quench, and NZP at 4.2 K and 10 T.

Monday, 29 June 2015 09:00 (2 hours)

High energy physics (HEP) magnets require high magnetic fields, demanding the use of new superconducting materials. YBCO coated conductors are of interest in a number of possible HEP applications, including high field solenoids for muon colliders. The temperature distribution, quench, the normal zone propagation, and conductor protection are highly important in these applications. In the present work we have measured thermal conductivity, stability, and normal zone propagation in a YBCO pancake coil at 4.2 K in liquid helium bath. The experiments have been done in applied magnetic fields up to 10 T at transport currents of a certain percentage of the coil critical current. A pancake coil with 27 mm ID and 37 mm OD was measured. It was instrumented for voltage and temperature measurements at several places around the winding, such that both radial and azimuthal quench propagation could be measured. Several heaters were placed on the inner-most part of the winding. Thermal conductivity was measured by applying a steady heater power and measuring the temperature gradient. Heat pulses of various powers and durations were generated to measure quench and NZP. This work was performed on a “dry” winding; these results are baselines for comparisons of several different epoxy and insulation winding modes.

Primary author: Dr MAJOROS, Milan (The Ohio State University)
Co-authors: Dr KOVACS, Christopher (The Ohio State University); Prof. COLLINGS, Edward (The Ohio State University); Prof. SUMPTION, Michael (The Ohio State University)
Presenter: Dr MAJOROS, Milan (The Ohio State University)
Session Classification: M1PoA - Superconducting Materials and Applications
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Design of a REBCO HTS Superconducting Undulator

Monday, 29 June 2015 14:00 (2 hours)

Undulators are very important insertion devices for storage ring and free electron laser based light sources to produce high-brilliance hard X-ray photon beams. NbTi based superconductive undulators (SCUs) have been recently developed and shown to reach higher on-axis peak fields compared to the field values achieved with conventional undulators. However, cooling NbTi coils to 4.2 K requires complicated and expensive cryogenic equipment. High temperature superconductors (HTSs) have larger temperature stability margin; therefore, they can be operated at higher temperatures than NbTi greatly simplifying the cryogenic design. The engineering current densities of REBCO HTS wires have been also enhanced drastically during the past years. Because of these reasons, HTS undulators have recently become very attractive. Here, we discuss a design for a second-generation (2G) HTS undulator and address some of the problems related to resistive joints and winding schemes of the coils. In addition, the achievable on-axis peak field at 4.2 K has been calculated and shown to surpass that reached in NbTi-undulators.

Primary author:  Dr KESGIN, Ibrahim (Argonne National Laboratory)

Co-authors:  Dr DOOSE, Charless L. (Argonne National Laboratory); Mr KASA, Matthew T. (Argonne National Laboratory); Dr WELP, Ulrich (Argonne National Laboratory); Dr IVANYUSHENKOV, Yury (Argonne National Laboratory)

Presenter:  Dr KESGIN, Ibrahim (Argonne National Laboratory)

Session Classification:  C1PoK - Superconducting Magnets I

Track Classification:  CEC-06 - Superconducting Magnet Systems
Progress and Status of Cryogenic Refrigeration System for Project Hydra

Thursday, 2 July 2015 09:15 (15 minutes)

In the last decade, significant advances in the performance of second generation (2G) high temperature superconducting wire have made it suitable for commercially viable applications such as electric power cables and fault current limiters. Currently, the U.S. Department of Homeland Security is co-funding the design, development and demonstration of an inherently fault current limiting HTS cable under the Hydra project with American Superconductor and Consolidated Edison Company of New York, Inc. The cable will be approximately 200m long and is being designed to carry 96 MVA at a distribution level voltage of 13.8kV. The cable will be installed and energized near New York City. The project is led by American Superconductor teamed with Con Edison, Ultera (Southwire and nkt cables joint venture), Altran Solutions, and DH Industries. This paper describes the progress and status of the cryogenic refrigeration system designed and manufactured for the project. The refrigeration system successfully passed factory acceptance testing in November 2014. Details of the test results will be provided.

Primary author: Dr YUAN, Jie (AMSC)

Co-authors: CATSEMAN, Fred (DH Industries); HENDERSON, Nancy (AMSC); HENK, Tilleman (DH Industries)

Presenter: Dr YUAN, Jie (AMSC)

Session Classification: C4OrC - Cryogenic Systems and Facilities

Track Classification: CEC-08 - Cryogenic Power Cables and Leads
Measurements of magnetization of YBCO CORC and Roebel Cables at 4.2 K

Tuesday, 30 June 2015 14:00 (2 hours)

Coated conductor YBCO cables are of interest for (among other applications) use in high energy physics accelerator magnets. In dipole and quadrupole magnets (where coated conductor YBCO cable may be used for a high field insert) field quality, especially at injection, is a key parameter, and limits the amount of acceptable magnetization in a cable. In this presentation a superconducting 3 Tesla cosine-theta racetrack dipole magnet was used to measure magnetization of coated conductor YBCO CORC and Roebel cables at 4.2 K and at low ramp rates of the applied magnetic field (< 1 Hz). A magnetometer consisting of a saddle-like pick-up coil and a nominally matched compensation coil (both wound using an insulated copper wire 0.1 mm OD) was used for magnetization measurements. The magnetometer allowed sample rotation with respect to the applied magnetic field direction. A calibration was made using calibration coils, of known magnetic moments, which mimic the current flow in the cables. Samples of 15 cm length were measured for a two layer CORC cable with six strands and a cable pitch of 34 mm and for a 30 cm twist pitch Roebel cable. The magnetization of CORC and Roebel cables are compared to each other and to the YBCO tape used in their manufacture. Hysteric losses were dominant over coupling losses for these cables.

Primary author: MAJOROS, Milan (The Ohio State University)

Co-authors: Dr KOVACS, Christopher (The Ohio State University); Prof. COLLINGS, Edward (The Ohio State University); SUMPTION, Mike (The Ohio State University)

Presenter: MAJOROS, Milan (The Ohio State University)

Session Classification: M2PoC - Superconductor Cables II: HTS

Track Classification: ICMC-09 - HTS Cables
Spallation Target Cryogenic Cooling Design Challenges at The European Spallation Source

Tuesday, 30 June 2015 16:45 (15 minutes)

The European Spallation Source (ESS) project is a neutron spallation source research facility currently being designed and built outside of Lund, Sweden. A linear accelerator delivers a 5 MW, 2.0 GeV, 62.5 mA proton beam to a spallation target to generate fast neutrons. Supercritical hydrogen circulates through two moderators surrounding the target, and transforms the fast neutrons emitted into slow neutrons, which are the final form of useful radiation. The supercritical hydrogen is in turn cooled from a helium cryogenic plant operating at 17-20 K.

The supercritical cryogenic hydrogen circuit is a dynamic system, subject to significant changes in heat load. Proper pressure control of this system is critical to assure safe operation. The interaction between the hydrogen system and helium cryoplant poses unique challenges. This paper will investigate the impact of the hydrogen system constraints on operation and control of the helium cryoplant, and suggest design options for the helium circuit.

Primary author: JURNS, John (European Spallation Source ESS AB)

Co-authors: LYNGH, D (European Spallation Source ESS); QUACK, Hans (TU Dresden); RINGNÉR, Jesper (ESS); Dr WEISEND, John (European Spallation Source); ARNOLD, Philipp (European Spallation Source ESS AB)

Presenter: JURNS, John (European Spallation Source ESS AB)

Session Classification: C2OrG - Hydrogen and Other Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Current sharing, quench, and normal zone propagation in YBCO CORC and Roebel cables

Tuesday, 30 June 2015 14:00 (2 hours)

A two layer CORC (Cable on Round Conductor) cable, 156 cm long, was tested for stability and normal zone propagation at 77 K in liquid nitrogen bath. The cable was instrumented with potential taps and wires on each strand covering its central portion (i.e. excluding the end connections of the cable with the outside world). A heater was placed on top of the cable which allowed pulses of various powers and durations to be generated. DC transport currents of some percentage of the cable critical current were applied. During and after the heat pulse NZP was measured by a high speed data acquisition card (DAQ) controlled via LabView software. Shrinking as well as expanding normal zones have been detected. The cable showed a high degree of stability. It was able to carry a current of 0.58Ic with maximum temperature of 250 K for nearly 6 minutes and 0.635Ic with maximum temperature of 300 K for 1 minute without damage. The cable had relatively low current sharing, even with uninsulated strands. These results were compared to a Roebel cable measured for quench at 4.2 K in liquid helium and 10 T. It was mounted on a u-shaped holder and instrumented with voltage taps and a heater. This cable had intentional solder connections between the strands.

Primary author: MAJOROS, Milan (The Ohio State University)

Co-authors: VAN DER LAAN, Danko (Advanced Conductor Technologies); Prof. COLLINGS, Edward (The Ohio State University); Prof. SUMPTION, Michael (The Ohio State University)

Presenter: MAJOROS, Milan (The Ohio State University)

Session Classification: M2PoC - Superconductor Cables II: HTS

Track Classification: ICMC-09 - HTS Cables
The progress of the Robotic Resupply Mission III (RRM III) Cryogen Demonstration System (CDS), an on-orbit experiment to store, transfer and solidify a cryogen, is described. This experiment would demonstrate techniques for resupplying science missions that use liquid or solid cryogens. RRM III has progressed through System Requirements Review, and is moving towards Preliminary Design Review. This paper describes the driving requirements, operations, and an overview of the design status of the RRM-III CDS. Since 2012, the cryogen has been changed from liquid argon to liquid methane, an additional robotic transfer operation has been added, and progress has been made on the design and selection of key components for transfer operations. This paper also provides an overview of critical subcomponents of the cryogen demonstration system.

**Primary author:** Mr BOYLE, Robert (NASA)

**Co-authors:** Mr DELEE, C. Hudson (NASA GSFC); TUTTLE, James (NASA/GSFC); Mr FRANCIS, John (NASA GSFC); Ms JILL, McGuire (NASA GSFC); DIPIRRO, Michael (NASA/Goddard Space Flight Center); Mr WHITEHOUSE, Paul (NASA GSFC); Mr BARFKNECHT, Peter (NASA GSFC); Mr MUSTAFI, Shuvo (NASA GSFC); Ms LI, Xiaoyi (NASA GSFC)

**Presenters:** Mr DELEE, C. Hudson (NASA GSFC); Mr BOYLE, Robert (NASA)

**Session Classification:** C3OrB - Aerospace Systems

**Track Classification:** CEC-10 - Aerospace
Analytical Investigation in Bending Characteristic of Twisted Stacked-Tape Cable Conductor

Tuesday, 30 June 2015 14:00 (2 hours)

The second generation High Temperature Superconductor (HTS) REBCO tapes are very attractive to various applications of transmission power cables and high field magnets. Cabling methods for the HTS tapes cabling such as Roebel Assembled Coated Conductor (RACC), Conductor-On-Round Core (CORC), Twisted Stacked-Tape Cable (TSTC) and a few other alternates have been proposed and are being investigated for high current, high field applications. We have been developing TSTC cabling method, which consists of stacking flat tapes and twisting them along the stack axis. This compact cabling technique using REBCO tapes is very useful for both power transmission and high field magnet conductors. TSTC conductors has been fabricated by several methods, including sheathing the tape stack with a copper tube and embedding the stack in single and multiple helical grooves formed in a circular rod. In the latter configuration, an untwisted stacked-tape cable or a twisted stacked-tape cable can be embedded in each groove. In real applications of a REBCO tape cable its bendability is very important to fabricate, transport a long cable and wind a magnet. We have experimentally examined bendability of a TSTC conductor. A TSTC conductor is bendable since it is twisted. In this paper bending characteristics of various TSTC conductors, such as a single stack 40-tape cable, double-channel and three-channel cables in a rod will be investigated by an analytical calculation method. Critical current degradation due to bending will be discussed.

This work supported by the U. S. Department of Energy, Office of Fusion Energy Science under Grants: DE-FC02-93ER54186.

Primary author: TAKAYASU, Makoto (MIT)
Presenter: TAKAYASU, Makoto (MIT)
Session Classification: M2PoC - Superconductor Cables II: HTS
Track Classification: ICMC-09 - HTS Cables
Thermo-physical performance prediction of the KSC Ground Operation Demonstration Unit for liquid hydrogen

Tuesday, 30 June 2015 14:00 (2 hours)

The NASA Kennedy Space Center researchers have been working on enhanced and modernized cryogenic liquid propellant handling techniques to reduce life cycle costs of propellant management system for the unique KSC application. The KSC Ground Operation Demonstration Unit (GODU) for liquid hydrogen plans to demonstrate integrated refrigeration, zero-loss flexible term storage of liquid hydrogen, and densified hydrogen handling techniques. The Florida Solar Energy Center has partnered with the KSC researchers to develop thermal performance prediction model of the GODU for LH2. The model includes integrated refrigeration cooling performance, thermal losses in the tank and distribution lines, transient system characteristics during chilling and loading, and long term steady-state propellant storage. This paper will discuss recent experimental data of the GODU LH2 system and modeling results.

Primary author: BAIK, JONG (FLORIDA SOLAR ENERGY CENTER)

Co-authors: NOTARDONATO, Bill (N); Dr OH, In-Hwan (Korea Institute of Science and Technology); KARNG, Sarng Woo (Korea Institute of Science and Technology); Dr KIM, Seo Young (Korea Institute of Science and Technology)

Presenter: BAIK, JONG (FLORIDA SOLAR ENERGY CENTER)

Session Classification: C2PoH - Hydrogen Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Mechanical Robustness of Cryogenic Temperature Sensors Packaged in a Flat, Hermetically-Sealed Package

Wednesday, 1 July 2015 14:00 (15 minutes)

Much of the work to develop internationally recognized temperature scales over the past 50 years was performed with thermometers whose sensing elements were constructed from platinum wire, rhodium-iron wire, or doped germanium elements. For high stability the best results were obtained when the sensing element was strain-free mounted which reduced the effects of temperature-induced mechanical stress and deformation. Unfortunately, the devices were still highly susceptible to mechanical damage, and, barring a catastrophic mechanical shock, damage to the temperature sensors could go unnoticed as it could continue to operate with degraded accuracy. While not at the same level of stability as standards grade thermometers, many of the most commonly used cryogenic thermometers today are far more resistant to mechanical handling. This work examines the calibration offsets on six models of cryogenic temperature sensors resulting from mechanical shock and vibration. The models tested in this work were all obtained from Lake Shore Cryotronics, Inc., and included Cernox™ resistance thermometer models CX-1050-SD and CX-1050-AA, diode temperature sensor model DT-670-SD, platinum resistance thermometer models PT-103 and PT-111, and germanium resistance thermometer model GR-1400-AA. Mechanical treatments were performed via a simple drop test (heights 20 cm, 50 cm, 1 m, and 4 m), random vibration per MIL-STD-202, Method 214, Table 2, Condition H, and mechanical shock per MIL-STD-883, Method 2002, Condition B. Each sensor was calibrated pre- and post-mechanical treatment and the effect of the treatment on each test sensor was quantified in terms of the equivalent temperature calibration shift. This work details the calibration shift of each sensor type following each treatment type over the sensor type’s appropriate temperature range. Sensors packaged in the -SD package, a flat, hermetically sealed package, demonstrated the highest robustness.

Primary author: COURTS, Scott (Lake Shore Cryotronics, Inc.)
Presenter: COURTS, Scott (Lake Shore Cryotronics, Inc.)
Session Classification: C3OrG - Cryogenic Instrumentation and Control Systems
Track Classification: CEC-15 - Instrumentation and Controls
Helium–Hydrogen PVT-x Measurements and Equation of State

Wednesday, 1 July 2015 11:00 (15 minutes)

Although cryogenic helium-hydrogen mixture properties remain essential to modeling long-duration propellant storage, the property measurements and models have not been extensively studied in nearly 50 years. The majority of the available measurements are vapor-liquid-equilibrium (VLE) with little or no pressure-volume-temperature-composition (PVT-x) measurements which are important for predictive equation of state development. This paper presents the results of initial liquid hydrogen density measurements obtained in a Rubotherm IsoSORP in the single-sinker configuration and provides a comparison to the equation of state. Additionally, PVT-x measurements of helium-hydrogen mixtures are presented from 15 K to 32 K for pressure up to 100 psia. These measurements are combined with existing VLE data to regress an excess Helmholtz function for binary helium–hydrogen mixtures.

Primary author: RICHARDSON, Ian (Washington State University)

Co-authors: Prof. LEACHMAN, Jacob (Washington State University); Mr BLACKHAM, Thomas (Washington State University)

Presenter: RICHARDSON, Ian (Washington State University)

Session Classification: C3OrC - Mixed Gases

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Thermal and mechanical properties of selected 3D printed thermoplastics in the cryogenic temperature regime

Wednesday, 1 July 2015 09:00 (2 hours)

Insulating materials for use in cryogenic boundary conditions are still limited to a proved selection as Polyamid, Glasfiber reinforced resins, PEEK, Vespel etc. These materials are usually formed to parts by mechanical machining or sometimes by cast methods. Shaping complex geometries in one piece is limited. Innovative 3D printing is now an upcoming revolutionary technology to construct functional parts from a couple of thermoplastic materials as ABS, Nylon and others which possess quite good mechanical stability and allow realizing very complex shapes with very subtle details. Even a wide range of material mixtures are an option and thermal treatments can be used to finish the material structure for higher performance. The use of such materials in cryogenic environment is very attractive but so far poor experience exists. In this paper first investigations of the thermal conductivity, expansion and mechanical strength are presented for a few selected commercial 3D material samples to evaluate their application prospects in the cryogenic temperature regime.

Primary author: Dr WEISS, Klaus-Peter (KIT, Institute for Technical Physics)

Co-authors: BAGRETS, Nadezda (Karlsruhe Institute of Technology – KIT); Dr GOLDACKER, Wilfried (KIT, Institute for Technical Physics)

Presenter: Dr WEISS, Klaus-Peter (KIT, Institute for Technical Physics)

Session Classification: M3PoB - Cryogenic Materials VI: Insulation

Track Classification: ICMC-12 - Insulation and Impregnation Materials
Improvement of tube type Nb3Sn conductor in Hyper Tech

Tuesday, 30 June 2015 12:00 (15 minutes)

Tube type Nb3Sn conductor has been being explored by Hyper Tech Research Inc. Our standard conductor with 217 filament arrays have been generated with 12 T non-Cu Jc values of about 2400-2500 A/mm2 with filament size of 40 micros at the 0.85 mm strand. Recently we made 547 filament conductor which has filament size of 25 micros at the 0.85 mm strand without any drawing issue. We are working to improve the non-Cu Jc further. In this paper, creating artificial pinning centers has been used to increase flux pinning in order to raise the Jc overall in the 12-20T range within the tube type Nb3Sn strands. As a result, the artificial pinning centers refine the grain size by at least half, thereby increasing the layer Jc by at least 20%. Round Nb filament has been made to improve the filament array in the restack conductor to increase the reacted Nb3Sn area thereby increasing the Jc in the strand.

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Presenter:  PENG, Xuan (Hyper Tech Research Inc.)

Session Classification:  M2OrA - Superconductor Materials III: Nb3Sn

Track Classification:  ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Thermal and mechanical properties of impregnation materials for HTS cables and coils

Wednesday, 1 July 2015 09:00 (2 hours)

In the growing field of HTS applications, finding an appropriate impregnation material for cables and coils remains a challenging task. In HTS cables and coils, tapes have to be able to withstand mechanical loads during operation. Impregnation is playing a role of mechanical stabilization. However, material properties usually change significantly when going to low temperatures that can decrease performance of superconducting devices. For example, a large mismatch in thermal expansion between a conductor and impregnation material at low temperatures can lead to delamination and to degradation of critical current of the tapes. Impregnation materials can insulate tapes thermally that can lead to a damage of superconducting device in case of quench. Thus, thermal conductivity is an important property which is responsible for the temperature distribution in a superconducting cable or in a coil. Due to Lorenz forces acting on structural materials in a superconducting device, the mechanical properties of these materials should be investigated at operating temperatures of this device. Therefore, it is important to identify an impregnation material meeting all specific requirements. In this report, thermal and mechanical properties of the impregnation material candidates are presented in a temperature range from 300 K to 4 K.

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Session Classification: M3PoB - Cryogenic Materials VI: Insulation

Track Classification: ICMC-12 - Insulation and Impregnation Materials
Applications of Ortho-Para Hydrogen Catalyst

*Tuesday, 30 June 2015 16:00 (15 minutes)*

The underlying theory of hydrogen Ortho-Para conversion has long been known, but the specifics of non-linear heat of conversion from normal to para hydrogen have not been widely disseminated in the cryogenic literature. These factors are reviewed and thermally efficient applications in liquefiers and back conversion cooling systems are illustrated.

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**Presenter:** MCINTOSH, GLEN (MCINTOSH CRYOGENICS LLC)

**Session Classification:** C2OrG - Hydrogen and Other Systems

**Track Classification:** CEC-01 - Large-Scale Refrigeration and Liquefaction
After practical changes were approved to the initial conceptual design of the cryogenic system for the MSU FRIB and an agreement was made with JLab in 2012 to lead the design effort of the cryogenic plant and later the cryo-distribution system, many activities are in place leading toward a cool-down of the linacs prior to 2018. This is mostly due to using similar equipment used at CHLII for the 12 GeV upgrade at JLab and an aggressive schedule maintained by the MSU Conventional Facilities department. This paper provides an updated status of the cryogenic plant, including the equipment procurement status plant layout, facility equipment and project schedule.
MOI study of grain boundary transparencies in [001] tilt (Yb0.7Ca0.3)Ba2Cu3O7-d 6 and 9 degree bi-crystal thin films.

Wednesday, 1 July 2015 11:30 (15 minutes)

Low angle grain boundaries (GB) are still the most important current-limiting mechanism operating in rare earth barium copper oxide (REBCO) coated conductors. While Ca-doping is found to improve the transparency of low angle GBs in weak fields at high temperatures, the growing interest of building high field magnets using REBCO coated conductors requires evaluating the effectiveness of Ca-doping more broadly. In this study, we used Magneto-Optical-Imaging (MOI) to quantitatively study the GB transparency ($r_{GB}=J_{GB}/J_{grain}$) in several (Yb0.7Ca0.3)Ba2Cu3O7 PLD thin films grown on SrTiO3 6 and 9 degree bi-crystals in the broad temperature range 5 to 77 K. $J_{GB}$ and $J_{grain}$ and their ratio $r_{GB}$ in various doping states obtained by varying the post-growth annealing conditions were independently determined by analyzing the MO images. We found that post-growth annealing affects $J_{GB}$ and $J_{grain}$ differently. In 1 bar oxygen annealing, $J_{GB}$ stabilizes faster than $J_{grain}$. On the other hand, $J_{GB}$ is less affected by annealing in reduced oxygen atmosphere. As a result, higher $r_{GB}$ is achieved when the sample is oxygen-deficient. Another major finding is that $r_{GB}$ of Ca-doped and pure GBs have different temperature dependence. Starting from $T=0.6T_c$, $r_{GB}$ of Ca-doped GB increases much faster with temperature than that of pure GBs. We found that on the other hand, the benefit of Ca-doping is very limited at the low temperature end. This is speculated to be a result of non-uniform Ca-segregation at the GBs. Overall, our results suggest that Ca-doping is not very valuable for low temperature application of REBCO.

This work was performed at the National High Magnetic Field Laboratory, which is supported by the National Science Foundation Cooperative Agreement No. DMR-1157490.

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Presenter:  Dr POLYANSKII, Anatolii (FSU, NHMFL, ASC)

Session Classification:  M3OrA - Superconductor Wires III: Thin Films

Track Classification:  ICMC-05 - Thin Films
FRIB Cryogenic Distribution System

Monday, 29 June 2015 09:00 (2 hours)

The MSU-FRIB cryogenic distribution system supports the 2 K, 4 K, and 35 K operation of more than 70 loads in the accelerator and the experimental areas. It is based on JLab and SNS experience with bayonet-type disconnects between the loads and the distribution system for phased commissioning and cryomodule maintenance. The linac transfer line, which features three separate transfer line segments for additional independence during phased commissioning at 4 K and 2 K, connects the folded arrangement of 49 cryomodules and 4 superconducting dipole magnets. The pressure reliefs for the transfer line process lines, located in the refrigeration room outside the tunnel/accelerator area, are piped to be vented outdoors. The transfer line designs integrate supply and return flow paths into a combined vacuum space. The main linac distribution segments are produced in a small number of standard configurations; a prototype of one such configuration has been fabricated at Jefferson Lab and has been installed at MSU to support testing of a prototype FRIB cryomodule.

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Presenter:  Mr LAVERDURE, Nathaniel (Jefferson Lab)

Session Classification:  C1PoD - Cryogenic Distribution Systems

Track Classification:  CEC-02 - Large-Scale Systems, Facilities, and Testing
Conductance Degradation in HTS Coated Conductor Solder Joints

Tuesday, 30 June 2015 17:30 (15 minutes)

Solder joints between YBCO coated conductors and normal metal traces have been analyzed as part of an effort to develop a robust HTS lead assembly for a spaceflight mission. Measurements included critical current and current transfer profiles. X-ray micrographs were used to verify proper solder flow and to determine the extent of voiding. SEM of cross-sections with XDS analysis were crucial in understanding the diffusion of the protective silver layer over the YBCO into the solder for different solder processes. The assembly must be stored for an extended period of time prior to final cool-down and operation. Measurements of joint resistance over the course of months show a significant increase with time. Understanding the interface condition suggests an explanation for the change.

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Session Classification: M2OrC - Superconductor Wires II: Coated Conductors and Applications

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Requirements for quadrupole magnet conductor for the United States contribution to the high-luminosity upgrade of the Large Hadron Collider

Tuesday, 30 June 2015 11:45 (15 minutes)

The LHC will undergo a replacement of the inner triplets at the two main interaction regions between 2020 and 2023. Leading up to this activity will be the production of approximately 90 quadrupole magnets starting in 2018, for which approximately 10 tons of Nb3Sn conductor will be procured. The lead time for this conductor requires orders to be placed starting in 2016. This presentation will outline the proposed production specification, its relationship to magnet functional requirements, and its evolution from previous “baseline” conductor designs supported by the LHC Accelerator R&D Program and the U.S. Conductor Development Program. In particular, we describe how certain design trade-offs and pre-production statistics were evaluated, and how these considerations were propagated through a change in the final conductor diameter to 0.85 mm and its cascading effect on sub-element number, copper fraction, and so on. The present specification strives to achieve a nexus of property distributions that guarantees ample production margin, high yield, and low cost.

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Presenter: COOLEY, Lance (Fermilab)
Session Classification: M2OrA - Superconductor Materials III: Nb3Sn
Track Classification: ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Rocket propulsion testing depends, to a large extent, on the quality of liquid oxygen to ensure reliable system performance. Impurities within liquid oxygen may not only degrade test article combustion performance, but in sufficiently high concentrations could react with oxygen or cause an ignition in facility systems. Combustible contaminants in liquid oxygen can be classified as "total hydrocarbons," or THCs. Minimizing the concentration of these THCs, measured as methane, is important in delivering consistent quality liquid oxygen and minimizing the potential for contaminant ignition. Discussed are various methods of THC analysis, mechanisms that can potentially lead to accumulation of THCs in liquid oxygen systems, and methods for mitigating the rise of THCs in liquid oxygen systems. A case study of liquid oxygen systems at Stennis Space Center (SSC) will be discussed. THC levels have recently varied widely in liquid oxygen systems at SSC as well as in the commodity received from the supplier. The measured THC levels in the storage tanks generally increased over time and often exceeded the specified requirement limits. A comprehensive study of THC accumulation was commissioned to 1) assess the differences between the vendor and the SSC liquid oxygen sampling techniques, analytical instrumentation, and sampling procedures; and 2) review historical THC data coupled with a greater frequency of THC monitoring and analysis of trends. A campaign is currently underway using a specially instrumented 49,000 liter tank to monitor THC distribution within the tank, variation over time, and potential mitigation methods.

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**Session Classification:** C2OrG - Hydrogen and Other Systems

**Track Classification:** CEC-02 - Large-Scale Systems, Facilities, and Testing
Modification of liquid hydrogen tank for integrated refrigeration and storage

Tuesday, 30 June 2015 16:15 (15 minutes)

The modification and outfitting of a 125,000-liter liquid hydrogen tank was performed to provide integrated refrigeration and storage capability. These functions include zero boiloff, liquefaction, and densification and therefore requires provisions for sub-atmospheric tank pressures within the vacuum-jacketed, multilayer insulated tank. The primary structural modification was to add stiffening rings inside the inner vessel. The internal stiffening rings were designed, built, and installed per the ASME Boiler and Pressure Vessel Code, Section VIII, to prevent collapse in the case of vacuum jacket failure in combination with sub-atmospheric pressure within the tank. For the integrated refrigeration loop, a modular, skeleton-type heat exchanger, with refrigerant temperature instrumentation, was constructed using the stiffening rings as supports. To support the system thermal performance testing, three custom temperature rakes were designed and installed along the 21-meter length of the tank, once again using rings as supports. The temperature rakes included a total of 24 silicon diode temperature sensors mounted both vertically and radially to map the bulk liquid temperature within the tank. The tank modifications were successful and the system is now operational for the research and development of integrated refrigeration technology.

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Presenter: SWANGER, Adam (NASA Kennedy Space Center)

Session Classification: C2OrG - Hydrogen and Other Systems

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
An apparatus and method for the low-temperature mechanical training of shape memory alloys has been developed. The shape memory alloy (SMA) materials are prototypes being developed for novel thermal management systems in future cryogenic applications. Alloys providing two-way actuation at cryogenic temperatures are the chief target. The mechanical training regime was focused on the controlled movement of rectangular strips, with S-bend configurations, at temperatures as low as 30 K. The custom holding fixture included temperature sensors and a low heat-leak linear actuator with a magnetic coupling. The fixture was mounted to a Gifford-McMahon cryocooler providing up to 35 W of cooling power at 20 K and housed within a custom vacuum chamber. Operations included both training cycles and verification of shape memory movement. The system design and operation are discussed. Results of the training for select prototype alloys are presented.

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Presenter: SWANGER, Adam (NASA Kennedy Space Center)
Session Classification: M1OrB - Cryogenic Materials I: Testing and Methods
Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
A Study on the CryoTel® DS 1.5 Cryocooler for Higher Cooling Capacity

Tuesday, 30 June 2015 09:00 (2 hours)

The CryoTel® DS 1.5 is a split type Stirling cryocooler which was developed by Sunpower for systems requiring compact size, high efficiency, and high reliability. The DS 1.5 has a lift of about 1.4 watts at 77 K with 30 watts of input power. The cooler design includes gas bearings on the pistons and displacer for non-contact operation, and achieves low vibration by using dual opposed pistons inside the wave generator and a passive balancer on the cold head to offset the displacer motion. The efficiency of the DS 1.5 is ranked highly compared to other cryocoolers at 16% Carnot efficiency, but there are many customers who want more lift with the same size and reliability. Therefore, Sunpower performed a feasibility study of the DS 1.5 to maximize the lift without increasing the size. This paper describes the analysis and test results of increasing the cooler power density by using a higher operating frequency and charge pressure. Prototype testing showed good agreement with the model. Testing performed at various frequencies and charge pressures with a few internal component changes resulted in a maximum lift of 2.4 watts with an input power of 43 watts, achieving 15.9 % of Carnot. The prototype high capacity DS 1.5 achieved 0.7 watts more lift with only one percentage point lower efficiency, and with negligible cooler mass increase. The impact on the cool-down time on a thermal mass system was simulated and the cool-down time was 40% faster while consuming less input energy overall. Sunpower plans to build more units to gain a broader range of performance data and will then decide whether to proceed with a commercial product.

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Presenter:  Mr KIM, Yongsu (Ametek Sunpower Inc)
Session Classification:  C2PoB - Stirling and Pulse Tube Cryocoolers
Track Classification:  CEC-03 - Cryocoolers (Non-Aerospace)
Numerical and experimental verification of physical blast thermodynamic model

Wednesday, 1 July 2015 15:00 (15 minutes)

Helium inventory in big cryogenic systems may be of the order of hundred tons. During the warm up of the machine the helium has to be stored in warm pressurized tanks. A potential rupture of the tank may create a danger to adjacent objects. In order to formulate recommendations concerning storage of compressed gases in close vicinity of nuclear installations, like tokamaks, a thermodynamic model of physical blast has been formulated [1]. The model has been experimentally verified in laboratory scale test rig. To simulate rupture of compressed gas storage tanks, plastic tanks have been used. Scaling of the results to real cases like ITER compressed gas inventory requires good understanding of potential rupture of high volume gas storage tanks. Numerical model of tanks rupture have been elaborated and verified against experimental results. The model allows scaling of thermodynamic simplified description to real gas storage installations.

[1] M. Grabowski et al. Modelling and experimental verification of pressure wave following gaseous helium storage tank rupture, ICEC-25, Twente

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Session Classification: C3OrH - Cryogenic Safety
Track Classification: CEC-11 - Safety, Reliability, and Standards
Status and commissioning results of the helium refrigerator plant for the European XFEL

Wednesday, 1 July 2015 14:00 (15 minutes)

The European XFEL project is under construction at DESY in Germany. The superconducting XFEL linac is supplied by the XFEL helium refrigerator plant. This plant consists of two existing refrigerators, which were in service for the HERA storage ring until 2007. Since the XFEL linear accelerator requires cryogenic cooling at 2K, the existing cryogenic infrastructure had to be modified.

Two of the three existing HERA helium refrigerators were required to cover the design heat load of the XFEL-linac. The refrigerator infrastructure was extended by a 2 K cooling loop, whose main component consists of a string of four cold compressors generating approximately 1.7 kW isothermal cooling capacity at 2K. The step by step commissioning and extension of the accelerator as well as the future upgrade option of the heat load demanded an extremely high turn down ability, a particular challenge for 2K cold compressor strings.

The commissioning of the helium refrigerator infrastructure is underway and should be completed soon. The current status of this project, commissioning results and particular challenges are presented.

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Presenter: BLUM, Lars (Linde Kryotechnik AG)
Session Classification: C3OrE - Operating Experience II
Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Dynamics of liquid nitrogen cooling process of solid surface at wetting contact surface.

Monday, 29 June 2015 09:00 (2 hours)

Liquid cryogens cooling by direct contact with cooled surface is very often use as a method to drop the temperature of the devices or equipment i.e. HTS cables. Somehow, cool down process conducting in that way could not be optimized, because of cryogen pool boiling characteristic and low heat transfer coefficient. One of the possibility of increase the efficiency of heat transfer, as well the efficiency of cooling itself, is to use the spray cooling method. The paper shows dynamics analysis of liquid nitrogen cooling solid surface process. The model of heat transfer for the single drop of liquid nitrogen, which impact the flat and smooth surface with respect to the different Weber numbers, is shown. The temperature profiles in the solid are presented, as well, the required cooling time of solid. The numerical calculations are perform for different initial and boundary conditions such as: droplet size, initial velocity, temperature of surface etc., to study how the wetting contact surface is change, and how it contributed to heat transfer between solid and liquid cryogen.

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Session Classification: C1PoE - Thermal Fluids (Non-Aerospace)
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Contribution to the study of neon-nitrogen mixtures at low temperatures

*Tuesday, 30 June 2015 14:00 (2 hours)*

Theoretical studies show that neon can influence the nitrogen phase diagram, lowering its triple-point temperature. The use of a neon-nitrogen mixture that could remain liquid at temperatures below the nitrogen triple-point (63.15 K) could solve some problems in the cryogenics field, namely to obtain a stable cryogenic fluid in the temperature range from 44 to 54 K, where no pure cryogenics liquids exist at all.

This work consists of a contribution to the study of mixtures of neon and nitrogen at various compositions at low temperatures, in order to assess how far beyond 63.15 K can the temperature at which nitrogen solidifies be lowered. For this purpose, a thermosyphon-like pressure vessel was built, able to withstand pressures up to 25 bars and in which some experiments were performed. Indications that there may be a process of neon dilution in solid and liquid nitrogen are shown, as well as evidence of changes in the nitrogen phase diagram due to the introduction of neon, in comparison to a model that supposes no interaction between the two substances. Evidences of a change in the nitrogen triple-point temperature from 63.15 to 62.5 K are presented and discussed.

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**Session Classification:** C2PoP - Mixed-Gas Properties

**Track Classification:** CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Single-phase ambient and cryogenic temperature heat transfer coefficients in microchannels

Monday, 29 June 2015 11:45 (15 minutes)

Micro-scaling cryogenic refrigerators, in particular the Joule-Thomson (JT) variety requires very good information about heat transfer characteristics of the refrigerants flowing in the microchannel for optimal design and performance. There are numerous studies regarding heat transfer coefficient measurements of liquid flow in microchannels at/near ambient temperature and high Reynolds flow (Re>2000), that well agree with the conventional correlations. However, results from these studies of gaseous flow in microchannels at low Reynolds flow (Re<1000) disagree with conventional theory. Moreover, the studies performed at cryogenic temperatures are quite limited in number. Because extremely low Reynolds flow is present when micro-scaling a cryogenic JT refrigerator to MEMS fabrication levels, due to low pressure ratios provided by a single stage MEMS compressor the heat transfer characteristics at these conditions require investigation. In this paper, the single-phase heat transfer coefficients and friction factors for nitrogen are measured at ambient and cryogenic temperatures. The hydraulic diameters for this study are 60, 110 and 180 μm for circular microchannels. The Reynolds numbers varied from a very low value of 10 to 3000. The measured friction factors are comparable to those in macro-scale tubes. The experimental results of the heat transfer indicate that Nusselt numbers derived from measurements are significantly affected by axial conduction at low Reynolds flow (Re<500). The Nusselt numbers at high Reynolds flow (Re>1000) follow conventional theory. The detailed experiment, procedure, and measured results are presented in this paper and discussed regarding deviation from ideal theory at low Reynolds flow.

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Session Classification: C1OrB - Cryogenic Heat Transfer
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
[Invited] Record engineering current density of 246 A/mm² at 17 T in HTS Conductor on Round Core (CORC) cables made at Advanced Conductor Technologies

Advanced high-energy physics magnets, high-field research magnets and fusion reactors require the development of high-temperature superconducting cables for magnetic fields exceeding 20 T, or allow for operating temperatures above the boiling point of liquid helium. Using ReBCO coated conductors, Advanced Conductor Technologies is developing Conductor on Round Core (CORC) cables that will enable this next generation of magnets. We will discuss some of the latest results of CORC magnet cable development at Advanced Conductor Technologies, which have reached a critical current of close to 7 kA in a 6 mm diameter CORC cable at 4.2 K and a background field of 17 T. This is a record engineering current density of 246 A/mm² at 17 T, or about 213 A/mm² at 20 T, making CORC cables a viable candidate for use in the next generation of accelerator magnets. This record current density was reached by winding the cable from a new generation of SuperPower tapes with 38 μm thin substrate. A new type of CORC cable termination was used for injecting the high currents into the cable. The tapes with thinner substrates not only reduce the cable thickness, but also limit the bending strain of the superconducting layer, minimizing the performance degradation of the tapes during cabling. The new terminals and the availability of tapes with even thinner substrates will allow us to raise the current density in CORC cables towards 400 A/mm² at 20 T before the end of 2015.

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Session Classification: M1OrA - Superconductor Cables I: HTS and LTS

Track Classification: ICMC-09 - HTS Cables
To mitigate the results of potential failures of cryogenic systems a risk analysis should be performed during the system design phase. The risk analysis output is sensitive to input parameters reflecting failure rates of the system elements like welds, pipes, valves, bellows and others. Big helium cryogenic systems are relatively rare and they do not allow to create a data base allowing estimation of the probability of the system elements failure. It is necessary to transfer the data from other domains, like nuclear industry, chemical industry, power engineering and LNG installations. Paper provides review of available data bases containing probabilities of the system elements failures. Exemplary calculations of cryogenic systems cumulative failure rates are given. The results are compared with the experience gathered during the LHC accelerator up to now exploitation. The recommendations concerning input parameters to risk and reliability analysis of helium cryogenic systems are formulated.

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**Presenter:** Dr PIOTROWSKA, Agnieszka (Wroclaw University of Technology)

**Session Classification:** C3OrH - Cryogenic Safety

**Track Classification:** CEC-11 - Safety, Reliability, and Standards
Simulated Propellant Loading System: Testbed for Cryogenic Component and Control Systems Research & Development

Tuesday, 30 June 2015 17:15 (15 minutes)

Technologies in the fields of cryogenic components and control systems is constantly evolving to advance the state of current cryogenic operations that will support future space exploration missions. To meet new demanding requirements, these missions will increasingly rely upon research and development in energy-efficient storage, transfer and use of cryogens and cryogenic propellants on Earth and in space. The capability to test these technologies is sometimes limited to isolated subsystems with a narrow application spectrum. The motivation for the Simulated Propellant Loading System (SPLS) is to provide an integrated multipurpose generic testbed to allow dedicated test and evaluation of new technologies in a field environment on a scale that is relevant to launch facility propellant systems. The Cryogenic Test Laboratory (CTL) at the Kennedy Space Center has more than two years of operational experience of using the SPLS to support independent and integrated technology maturation. This paper presents the development of a highly repeatable automated cold flow test sequence that was used in the evaluation and advancement of autonomous control system technologies. A range of other recent applications and capabilities of the SPLS will also be presented.

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Presenter: TORO MEDINA, Jaime (NASA Kennedy Space Center)

Session Classification: C2OrG - Hydrogen and Other Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Magnetic and Structural Design of a 15 T Nb3Sn Accelerator Dipole Model

Monday, 29 June 2015 14:00 (2 hours)

Hadron Colliders (HC) are the most powerful discovery tools in modern high energy physics. A 100 TeV scale HC with a nominal operation field of at least 15 T is being considered for the post-LHC era. The choice of a 15 T nominal field requires using the Nb3Sn technology. Practical demonstration of this field level in an accelerator-quality magnet and substantial reduction of the magnet costs are the key conditions for realization of such a machine. FNAL has started the development of a 15 T Nb3Sn dipole demonstrator for a 100 TeV scale HC. The magnet design is based on 4-layer shell type coils, graded between the inner and outer layers to maximize the performance. The experience gained during the 11-T dipole R&D campaign is applied to different aspects of the magnet design. This paper describes the magnetic and structural designs and parameters of the 15 T Nb3Sn dipole and the steps towards the demonstration model.

Work is supported by Fermi Research Alliance, LLC, under contract No. DE-AC02-07CH11359 with the U.S. Department of Energy.

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Session Classification: C1PoK - Superconducting Magnets I

Track Classification: CEC-06 - Superconducting Magnet Systems
THE SAFE REMOVAL OF FROZEN AIR FROM THE ANNULUS OF AN LH2 STORAGE TANK

Monday, 29 June 2015 09:00 (2 hours)

Large Liquid Hydrogen (LH2) storage tanks are vital infrastructure for NASA. Eventually, air may leak into the evacuated and perlite filled annular region of these tanks. Although the vacuum level is monitored in this region, the extremely cold temperature causes all but the helium and neon constituents of air to freeze. A small, often unnoticeable pressure rise is the result. As the leak persists, the quantity of frozen air increases, as does the thermal conductivity of the insulation system. Consequently, a notable increase in commodity boil-off is often the first indicator of an air leak. Severe damage can result from normal draining of the tank. The warming air will sublimate which will cause a pressure rise in the annulus. When the pressure increases above the triple point, the frozen air will begin to melt and migrate downward. Collection of liquid air on the carbon steel outer shell may chill it below its ductility range, resulting in fracture.

In order to avoid a structural failure, as described above, a method for the safe removal of frozen air is needed. A thermal model of the storage tank has been created using SINDA/FLUINT modeling software. Experimental work is progressing in an attempt to characterize the thermal conductivity of a perlite/frozen nitrogen mixture. A statistical mechanics model is being developed in parallel for comparison to experimental work. The thermal model will be updated using the experimental/statistical mechanical data, and used to simulate potential removal scenarios. This paper will address methodologies and analysis techniques for evaluation of two proposed air removal methods.

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Presenter: KRENN, Angela (NASA)

Session Classification: C1PoB - Intermediate Temperature Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Dielectric Properties of Cryogenic Gas Mixtures Containing Helium, Neon, and Hydrogen

Monday, 29 June 2015 12:00 (15 minutes)

Past efforts of cooling high temperature superconducting (HTS) power cables by gaseous cryogens focused exclusively on helium [1]. We are working on exploring the benefits of gas mixtures containing helium with small amounts of hydrogen and neon gas to mitigate the limited dielectric strength of pure helium gas. This could potentially improve dielectric characteristics while maintaining the thermal, non-flammable and non-corrosive properties of pure helium gas.

From the dielectric point of view, hydrogen gas is far superior to helium and neon. Hydrogen gas has approximately 50% of the dielectric strength of nitrogen gas at room temperature [2]. The noble gases helium and neon exhibit dielectric strength 15% and 25% respectively that of nitrogen gas at room temperature. It is known from other gas mixtures studies that even a small amount of a superior gas can considerably improve the dielectric strength of the mixture more than the ratio would suggest [3].

The dielectric properties of pure helium gas at temperatures in the range of 50 K to 77 K have been studied in past HTS cable projects at Florida State University. The challenges with low breakdown voltage have led to the investigation of potential alternative cooling gases. The dielectric strength of helium gas mixtures containing 2% and 4% of neon and hydrogen have been measured and compared to that of pure helium. The limit of 4% of hydrogen was to ensure to keep the gas mixture non-flammable in air. All experiments were performed at 77 K at pressures between 0.1 and 2.0 MPa.


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Presenter: GRABER, Lukas (Florida State University)
Session Classification: M1OrA - Superconductor Cables I: HTS and LTS
Track Classification: ICMC-09 - HTS Cables
Fabrum Solutions in association with Callaghan Innovation and Absolut System has developed a 330 W pulse tube cryocooler based on Callaghan Innovation’s diaphragm pressure wave generators (DPWG). A cost-effective, long life and robust cryocooler has been achieved due to the pulse tube’s lack of moving parts and the DPWG’s metal diaphragms separating the working gas from the oil lubricated drive mechanism. A 330 cc DPWG was designed and manufactured to run with an inline pulse tube. Absolut System carried out the pulse tube design, manufacture by Fabrum Solutions with integration and testing by Callaghan Innovation. Over 400 W of cooling power at 77 K was achieved (target was 330 W at 77 K) from the cryocooler, which is now being run in a commercial application. A sealed condensation chamber was added to the cold-head and connected to a Dewar via vacuum insulated lines for liquefaction of Nitrogen. Three of the 330 W pulse tubes have been mounted to a single 1000 cc DPWG to produce > 1 kW of cooling power at 77 K, which is one of the topics presented in another paper at this conference. Details of the design, development, testing and integration are presented.

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Presenter: Mr EMERY, Nick (Callaghan Innovation)

Session Classification: C2OrB - Large Capacity Coolers

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Various high temperature superconducting (HTS) power system components have been demonstrated using liquid nitrogen as the cryogen. Gaseous helium is being explored as a viable option for cooling HTS power devices. One of the major advantages of using helium is the versatility of operating temperature of HTS systems that provides adaptable and compact power distribution networks. However, challenges in using helium gas as a cryogen exist due its weak dielectric strength and low thermal capacity compared to that of liquid nitrogen. Gaseous helium mixed with small volume fractions of hydrogen and neon are being explored as a means of enhancing the dielectric strength. In order to provide HTS power system with required cooling power, high pressure helium at a pressure of around 1 MPa is essential and the additives for helium gas need to preserve the thermal characteristics of pure helium gas. Data on cryogenic thermal properties of helium gas mixtures with the additives at high pressures are not available. Theoretical evaluation using mixing theory has not been verified experimentally at cryogenic temperatures and high pressures. In this study, heat capacity and thermal conductivity were measured experimentally for helium mixtures with up to 4 % volume fraction of hydrogen and neon at pressures higher than 1 MPa and temperature lower than 77 K. These thermal properties would be useful for identifying a gas mixture with optimal dielectric and thermal characteristics essential for using the mixtures as cooling media for HTS power applications. Results of both theoretical and experimental studies on thermal characteristics of gaseous helium mixtures are presented.

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**Session Classification:** C3OrC - Mixed Gases

**Track Classification:** CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Cylindrical Boiloff Calorimeters for Testing of Thermal Insulation Systems

Monday, 29 June 2015 14:00 (2 hours)

Several cryostat instruments for the testing of thermal insulation systems in a cylindrical configuration have been developed and standardized for laboratory operation. The measurement principal is boiloff calorimetry for the determination of the effective thermal conductivity ($k_e$) and heat flux ($q$) of a test specimen at a fixed environmental condition (boundary temperatures, cold vacuum pressure, and residual gas composition). Liquid nitrogen is the energy meter through heat of vaporization properties, but the design is adaptable for different cryogens. The main instrument, Cryostat-100, in guarded on top and bottom and provides directly measured absolute thermal performance data. A cold mass assembly, including the upper and lower guard chambers and a middle test vessel, is suspended from a lid of the vacuum canister. Each of the three chambers is filled and vented through a single feedthrough for minimum overall heat leak and simplified operation. The cold mass design provides thermal isolation by precluding direct solid conduction heat transfer from one liquid volume to another. Such isolation is critical for the very low heat measurement capability to be achieved as small variations in liquid temperatures between chambers can easily lead to dramatic errors in the results. All fluid and instrumentation feedthroughs are mounted and suspended from a top-domed lid to allow easy removal of the cold mass. A lift mechanism allows manipulation of the cold mass assembly and insulation test specimen. The cryostat system design details and laboratory standard test methods are discussed. Results for select thermal insulation materials including multilayer insulation, powders, foams, and aerogel blankets are presented. Additional cylindrical boiloff calorimeters including the comparative apparatus, Cryostat-200, and progress toward a liquid hydrogen apparatus are also discussed.

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Presenter:  FESMIRE, James (NASA)

Session Classification:  C1PoL - Thermal Insulation

Track Classification:  CEC-14 - Thermal Insulation Systems
Flat Plate Boiloff Calorimeters for Testing of Thermal Insulation Systems

Monday, 29 June 2015 14:00 (2 hours)

Several cryostat instruments for the testing of thermal insulation systems in a flat plate configuration have been developed and standardized for laboratory operation. The measurement principal is boiloff calorimetry for the determination of the effective thermal conductivity (ke) and heat flux (q) of a test specimen under a wide range of real-world conditions. The main instrument, Cryostat-500, is thermally guarded to provide absolute thermal performance data when properly calibrated with a known reference material. An adjustable edge guard ring enables calibration. Using liquid nitrogen as the energy meter, the cold boundary temperature can be adjusted to any temperature between 77 K and approximately 300 K by interposing a thermal resistance layer between the cold mass and the specimen being tested. The cold mass assembly, comprised of the heat measurement vessel and thermal guard vessel, is suspended from the vacuum chamber lid. A low thermal conductivity suspension system includes adjustable compliance rod assemblies for a given test specimen thickness and for amount of compression force. Different materials and varied test objectives require an appropriate combination of apparatus and method. Material type, thickness, density, flatness, compliance, outgassing, and temperature sensor placement are important considerations. Edge effects and calibration techniques for the flat plate apparatus are crucial in design and test operation. Over the full vacuum pressure range, the thermal performance capability is shown to be nearly four orders of magnitude. Compared to vertical cylindrical cryostats, the horizontal flat plate configuration provides key advantages for testing at ambient pressure conditions. The Cryostat-500 design details and laboratory standard test methods are discussed. Results for select thermal insulation materials including composites, foams, and aerogels are presented. Additional flat plate boiloff calorimeters including comparative instruments Cryostat-400 and Macroflash (Cup Cryostat) are also addressed.

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Presenter: FESMIRE, James (NASA)

Session Classification: C1PoL - Thermal Insulation

Track Classification: CEC-14 - Thermal Insulation Systems
Testing of a sub-scale HTS coil for wind turbine generator

Tuesday, 30 June 2015 17:15 (15 minutes)

Large power direct drive superconducting generators for off-shore wind turbines show promise for competitive cost of energy and would enable the deployment of wind turbine outputting 10 MW or more. As part of an ARPA-e project, a 10 MW generator was optimized based on YBCO excitation coils. The rotor is using an iron core in order to reduce the amount of HTS required and lead to an acceptable cost of energy. A subscale HTS coil was fabricated using off-the-shelf YBCO tapes as a demonstrator. This paper deals with the testing of the HTS coil between 77 K and 25 K. The coil is 0.65 meter long and 0.32 meter wide. It is composed of about 100 m of YBCO tape from Superpower. The coil is conduction cooled using an AL325 cryocooler; the experimental setup will be described in detailed as well as the electromagnetic and thermal analysis of the coil. The experimental results consist in Ic measurements at different temperature and voltage monitoring of the 4 sections of the coil to identify and potential conductor motion or mechanical structure degradation.

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Presenter: MASSON, Philippe (University of Houston)
Session Classification: C2OrF - Superconducting Magnets II
Track Classification: CEC-06 - Superconducting Magnet Systems
Interfilamentary bridging in Bi2212 conductors influences magnetization levels that are important for accelerator magnet applications. Specifically, bridging-induced magnetization is a linear function of sample length (L) and twist pitch (Lp). Magnetization measurements were made on state of the art Bi2212 strands with an 37 x 18 filament configuration (both as short straight samples and small helical samples). These results, when compared to a mathematical model, allowed us to extract an L- and Lp-independent connectivity parameter. These results were correlated to quantitative SEM studies made on cross sectional and longitudinal sample mounts. In addition to the magnetization, the magnetic relaxation rate (or flux creep rate) is important for accelerator applications. In this work, we show that not only the magnetization, but also the magnetic relaxation rates of Bi2212 strands are L and Lp dependent. The magnetic relaxation rate was measured as a function of L and Lp in transverse applied magnetic fields of 0-12 T. The magnetic relaxation rate was observed to increase by about 50% for samples with the largest L or Lp as compared to the samples with the smallest L and Lp. These results are interpreted in terms of weak bridging current induced anisotropy.

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**Presenter:** MYERS, Cory (Ohio State University)

**Session Classification:** M3OrC - Superconductor Wires V: BSCCO Processing and Properties

**Track Classification:** ICMC-03 - BSCCO Processing and Properties
Magnetization losses in MgB2 wire matrix material

Monday, 29 June 2015 17:30 (15 minutes)

Magnesium diboride conductors are considered for use on fully superconducting wind turbine generators and, as a result, being able to quantify the AC losses in MgB2 wound stators is paramount. AC losses were measured on several MgB2 conductors based on NiCu matrix material. The measurements were done calorimetrically at about 15 K and at applied magnetic fields up to 100 mT and frequencies up to 400 Hz. The AC losses measured are consistent with magnetization losses in magnetic materials and not with classic AC losses (magnetization, coupling and eddy). As previously reported in literature, the matrix material composed of NiCu alloys, while non-magnetic at room temperature, might present magnetic properties at cryogenic temperature. This paper deals with the characterization of the matrix material of several MgB2 conductors from different manufacturers through the measurement of the susceptibility with respect to temperature and the measurement of the major hysteresis loop showing the saturation field and the maximum energy dissipated per cycle. The results are then used to correlate the AC losses measurements.

Primary author: MASSON, Philippe (University of Houston)
Co-author: Dr LECLERC, Julien (University of Houston)
Presenter: MASSON, Philippe (University of Houston)
Session Classification: M1OrC - Superconductor Stability and AC Losses
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Cryogenic Considerations for Superconducting Magnet Design for the Material Plasma Exposure eXperiment

Wednesday, 1 July 2015 09:00 (2 hours)

In order to determine long term performance of plasma facing components such as diverters and first walls for fusion devices, next generation plasma generators are needed. A Material Plasma Exposure eXperiment (MPEX) has been proposed to address this need through the generation of plasmas in front of the target with electron temperatures of 1-15 eV and electron densities of 10^{20} to 10^{21} m^{-3} [1]. Heat fluxes on target diverters could reach 20 MW/m^2. In order generate this plasma, a unique radio frequency helicon source and heating of electrons and ions through Electron Bernstein Wave (EBW) and Ion Cyclotron Resonance Heating (ICRH) has been proposed. In support of this plasma generation, a series of magnets are needed with non-uniform central fields up to 2 T over a 5-m length in the heating and transport region and 2 T uniform central field over a 1-m length on a diameter of 1.3 m. Given the field requirements, superconducting magnets are under consideration for MPEX. In order to determine the best constructions for the magnets, the cryogenic refrigeration has been analyzed in comparison with commercially available magnet constructions to determine most economical method for MPEX operation with respect to cooldown and operation performance criteria. The current state of the MPEX magnet design including details on possible superconducting magnet configurations will be presented.


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Progress on fabricating seamless RRR Nb tubes for SRF applications

Tuesday, 30 June 2015 09:00 (2 hours)

The objective of the work reported is to demonstrate a fabrication method for developing reproducible uniform fine-grained microstructures in seamless RRR Nb tube. The target application is the inexpensive manufacture of RRR Nb superconducting radio frequency (SRF) cavities. Present methods to manufacture seamless Nb tubing from rolled Nb sheet by deep drawing, spinning, and flow forming indicate inconsistencies in microstructure along the through thickness of the tube. To tackle these problems and obtain seamless tubes that hydroform well, we have been developing a severe plastic deformation (SPD) process in combination with traditional tube extrusion by forward and backward extrusion. Forward extruded tubes in combination with SPD have indicated tremendous promise with similar mechanical characteristics, hardening exponents of 0.2 along the major tube axes, and ductilities greater than 40%. In order to increase process yield, a multi-step fabrication process involving an initial back extrusion and subsequent forward extrusion has been developed. Preliminary results on the effect of process path changes will be presented. Microstructure variations in terms of grain size, grain size distribution, and formation of novel textures along the tube circumference will be compared to previously fabricated Nb tubes by forward extrusion. Measurements of concentricity and thickness variations of the seamless Nb tubing will also be reported.

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Presenter: BALACHANDRAN, Shreyas (Texas A&M University)

Session Classification: C2PoD - Superconducting RF Systems II

Track Classification: ICMC-11 - Metallic and Composite Materials
High temperature superconductors (HTS) are an enabling technology for superconducting magnets generating magnetic fields greater than 25 T. The development of high field HTS magnets requires not only a conductor capable of carrying sufficient critical current density ($J_c$) at high magnetic field, but also one that is sufficiently strong to withstand the very large Lorentz forces and other stresses during fabrication, handling, and thermal cycling. Bi$_2$Sr$_2$CaCu$_2$O$_{8+x}$ (Bi-2212) is the only HTS material available as round wire. Recently, significant progresses have been made to improve the $J_c$ of Bi-2212 wire by use of over-pressure (OP) processing of the wire during heat treatment. This method has resulted in a more than doubling of the $J_c$ of the wire to 640 A/mm$^2$ at 4.2 K and 20 T. However, since Bi-2212 is a brittle material, the effect of these heat treatment changes on the mechanical properties of the material are not well understood.

In this study, a double-restack Bi-2212/AgMg wire was heat treated using a partial melt processing in both pure O$_2$ and Ar/O$_2$ atmosphere at various pressures including 1 bar, 50 and 100 bar (OP). The wires then experienced various amount of mechanical strains in both tension and compression. The Bi-2212 wire properties are investigated in various conditions, including green wire, 1 bar and OP-heat treated wires pre- and post-applying mechanical strains. A detailed and efficient polishing procedure is developed to prepare scratch-free specimens and to prohibit introducing filament damages caused during preparation method. The relationships between sample preparation techniques and the filament microstructure, distribution of secondary phases including AEC and Cu-free, and various filament damages are studied using optical, scanning electron and confocal microscopy.

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**Presenter:** Dr KAJBAFVALA, Amir (Materials Science Center, University of Wisconsin-Eau Claire)

**Session Classification:** M2OrB - Superconductor Wires I: Testing and Characterization

**Track Classification:** ICMC-03 - BSCCO Processing and Properties
To pump the ITER torus exhaust gas from the regenerating torus cryopumps, which will be a mixture of deuterium, tritium, and helium with trace impurities, a prototype cryoviscous compressor (CVC) has been designed, fabricated, and is under test. This prototype, which was based on successful demonstration of a sub-scale version, consists of a set of 24 5-cm diameter, 1.27-m long stainless steel tubes with embedded static mixer flow enhancements that is cooled with supercritical helium (SCHe) to cryopump the hydrogenic species while allowing helium to be exhausted through the CVC. In order to test the CVC, flow controls and vacuum jacketed piping were installed at a connection to the Cryogenic Test Facility (CTF) at the Spallation Neutron Source to cool the CVC with SCHe supplied at 4.5K and 3 bar. Helium heated to 20-30 K is used to regenerate the CVC. The CVC is designed to pump up to 20,000 Pa-m³ of deuterium that is mixed with 100 Pa-m³ helium gas with a flow rate of 200 Pa-m³/s. The integrated operation of the CVC with the CTF will be presented along with the performance test results of the CVC.

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Presenter: DUCKWORTH, Robert (Oak Ridge National Laboratory)

Session Classification: C1OrC - Compressors & Expanders

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Calorimetric Measurements of AC losses in HTS coils and tapes in a Stator Environment

Monday, 29 June 2015 16:45 (15 minutes)

Long HTS tapes have been fabricated in a variety of formats for the purpose of reducing the sensitivity to AC magnetic fields, from both conducted AC and external fields. Some of the conductors have been made more resistant to AC losses by HTS film composition and many others have been based on geometric arrangements of the conductors, such as different filament patterns in striated tapes, and helical twist shapes that do not exceed the minimum bend radius of the HTS films. Characterization by applying variable frequency AC and variable frequency strong magnetic fields, both synchronous and asynchronous, to samples of these conductors provides insight into their utility without the time and expense of building a complete motor or generator.

The measurements are taken using a modified previously reported calorimeter system that measures the total power losses in smaller high temperature superconducting coils or wire. The calorimeter measures self-field losses with the sample mounted in the stator environment of a generator/motor where a 0.6 Tesla alternating magnetic field is produced by an eight pole rotor designed to provide frequencies up to 400 Hz. The systems allow samples to carry direct or alternating current with the ability to concurrently expose them to a variable frequency alternating magnetic field. For this paper we will discuss differences in results from combination of synchronous and asynchronous losses on several conductor geometries.

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Presenters: MURPHY, John (University of dayton Research Institute); Dr HAUGAN, Timothy (USAF)
Session Classification: M1OrC - Superconductor Stability and AC Losses
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Quench induced critical current degradation in REBCO coated conductor and Bi2223 tape

Monday, 29 June 2015 09:00 (2 hours)

One of the remaining challenges for high temperature superconducting magnets is quench protection. To develop an effective quench protection system, it is important to understand the conditions that must be avoided during a quench so that the conductor is not degraded. Our previous study on Ag/Bi2212 round wires has shown that the quench degradation is a strain-driven effect and strongly depends on the hotspot temperature, $T_{\text{quench}}$, during the quench; critical current $I_{\text{c}}$ of Bi-2212 wires gradually degraded irreversibly when $T_{\text{quench}}$ exceeds 350-500 K, above which $I_{\text{c}}$ of Bi-2212 dropped quickly to zero. Here, similar quench experiments are performed on commercial REBCO coated conductors from Superpower and CT-OP Bi2223 tapes from Sumitomo. REBCO coated conductor has a Hastelloy substrate whereas Bi-2223 tapes include bare tapes, tapes reinforced with stainless steel and Ni-Cr. The dependence of their $I_{\text{c}}$ on $T_{\text{quench}}$ will be determined for various test setups, for example with or without epoxy impregnation. Microstructure of the degraded samples will be investigated using optical and electron microscopy to further reveal the degradation mechanism at microscopic level.

This work is supported by the U.S. Department of Energy, Office of High Energy Physics through a FY12 early career award.

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Presenter: YE, Liyang (Fermi National Accelerator Laboratory)

Session Classification: M1PoA - Superconducting Materials and Applications

Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Several years ago, we reported on a 50-gallon-per-day oxygen liquefier that uses Stirling-type pulse-tube coldheads driven by a large flexure-bearing pressure wave generator (PWG), in development for the new generation of U.S. Navy aircraft carriers. The first of these liquefiers is about to be deployed on the USS Gerald R. Ford. This presentation describes the completion and performance testing of the core cryocooler, and some of the balance-of-systems challenges encountered.
Stainless Steel to Titanium Bimetallic Transitions

Monday, 29 June 2015 17:00 (15 minutes)

In order to use stainless steel piping in an LCLS-II cryomodule, stainless steel to titanium bimetallic transitions are needed to connect the stainless steel piping to the titanium cavity helium vessel. Explosion bonded stainless steel to titanium transition pieces and bimetallic transition material samples have been tested. A sample transition tube was subjected to tests and x-ray examinations between tests. Samples of the bonded joint material were impact and tensile tested at room temperature as well as liquid helium temperature. The joint has been used successfully in horizontal tests of LCLS-II cavity helium vessels and is planned to be used in LCLS-II cryomodules. Results of material sample and transition tube tests will be presented.

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Presenter: KALUZNY, Joshua (Fermilab)
Session Classification: C1OrG - Superconducting RF Systems I
Track Classification: CEC-07 - Superconducting RF Systems
Mechanical problems for a Ni-alloy reinforced Bi-2223/Ag conductor -Towards a super-high field compact magnet-

Monday, 29 June 2015 14:00 (2 hours)

Recently, tensile stress tolerance of a Bi-2223 conductor has been drastically improved. Conventional Bi-2223 conductors with copper-alloy reinforcements or stainless steel reinforcements show tensile stress tolerance of ~250 MPa. The stress tolerance has been improved to 400-500 MPa with Ni-alloy reinforcements in combination with a pre-compression of Bi-2223 filaments/Ag-matrix [1]. This type of high mechanical strength Bi-2223 conductors are promising for developments of super high field magnets as they tolerate high hoop stress, resulting from high current density and a high magnetic field beyond 23.5 T.

However, it is probable that this type of composite conductor is easily damaged by a release of strain energy inside the conductor; note that the Bi-2223/Ag conductor has a compressive strain, while the reinforcement tensile strain. In fact, a notable fracture of a conductor after a thermal runaway was observed [2]. From the standpoint of coil protection, mechanism and a method to prevent this phenomenon are important. In this work, these are systematically investigated with a model experiment.

A piece of a high-mechanical strength Bi-2223 conductor was heated on a hot plate. Temperature and strain along the conductor longitudinal direction on a surface of the conductor were measured with a thermocouple and a strain gauge, respectively. The strain gauge showed a drastic change in strain at a temperature of ~200 ℃. After the experiment, the Bi-2223/Ag conductor shows a curve among the delaminated Ni-alloy reinforcements; i.e. the Bi-2223/Ag conductor was buckled. The result shows that strain energy was released by a melting of a solder which bonds the conductor and the reinforcements, resulting in a collapse of the composite conductor. The method to prevent the phenomenon will be investigated.

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Presenter: Mr NAWA, Masato (Graduate School of Engineering, Chiba University)

Session Classification: C1PoK - Superconducting Magnets I

Track Classification: CEC-06 - Superconducting Magnet Systems
Effect of heat treatment and test barrel materials on critical current measurements of Ag/Bi2212 round wires using ITER barrel configurations

Wednesday, 1 July 2015 09:00 (2 hours)

Critical current measurement for Ag/Bi-2212 wires has been typically performed by mounting a short sample (4-10 cm long) heat treated standalone at ~830 °C on a room temperature G-10 sample holder and cooling them down to cryogenic temperatures. During this process samples experience a huge temperature and strain change. This strain effect has not been carefully considered for critical current measurement, despite that critical current of Ag/Bi-2212 wires is well known to depend on strain. At Fermilab and BNL we began to use a new protocol by reacting meter long samples on 96% pure Al2O3 ITER barrels and transferring them to test barrels made from Ti-6Al-4V alloy. We are extending the study to include tests on barrels made from 304 stainless steel, Inconel 600, and G-10. Samples that will be investigated include wires heat-treated using 1 bar partial melt processing and an overpressure partial melt processing. Initial measurements showed that samples tested on the G-10 barrel reproduce Ic for short witness samples, while the Ti-alloy barrel results in a 10% Ic reduction. Fitting these Ic measurement results into the Ic-strain curves from previous research, the thermal pre-strain for the samples measured on the Ti-alloy, Stainless Steel, and G-10 will be evaluated.

This work is supported by the U.S. Department of Energy, Office of High Energy Physics through a FY12 early career award.

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Presenter: SHEN, Tengming (Fermilab)

Session Classification: M3PoA - Superconductor Materials IV: Properties and Applications

Track Classification: ICMC-03 - BSCCO Processing and Properties
OPERATIONAL HISTORY OF LIQUID HYDROGEN TANK WITH GLASS BUBBLES INSULATION

Monday, 29 June 2015 17:00 (15 minutes)

Culminating years of extensive research and development, field demonstrations have proven glass bubbles to be a superior insulation material for spherical liquid hydrogen storage tanks. Six years of operational history has been accumulated on a spherical 218,000-liter liquid hydrogen (LH2) storage tank with glass bubbles insulation in the evacuated annulus. Over this period of time the tank has been subjected to two complete LH2 fillings and thermal cycles. Each load of LH2 took approximately two years to boil away, representing an approximate 100% performance improvement over the original perlite powder insulation. No special maintenance was necessary and the tank sustained normal vacuum levels. Infrared imagery showed the outer surface temperatures to be uniform. The full-scale field application of glass bubbles insulation builds upon years of laboratory testing (compatibility, vacuum, vibration, structural, thermal performance) and custom 1000-liter tank testing with both liquid nitrogen and LH2. To extend application of the technology to tanks of non-spherical geometry, analysis of a targeted application of glass bubbles insulation to a horizontal 830,000-liter LH2 storage tank is presented. Also discussed is a survey of other vacuum-jacketed cryogenic tanks operating around the world with glass bubbles insulation.

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Presenter:  SASS, Jared (NASA Kennedy Space Center)
Session Classification:  C1OrF - Thermal Insulation Applications and Measurements
Track Classification:  CEC-02 - Large-Scale Systems, Facilities, and Testing
Performance of a 10 kJ SMES Model Cooled by Liquid Hydrogen Thermo-Siphon Flow for ASPCS Study

Monday, 29 June 2015 09:00 (2 hours)

From the point of view of environment and energy problems, the renewable energies have been attracting attention. However, fluctuating power generation by the renewable energies affects the stability of the power network. Thus, we propose a new electric power storage and stabilization system, Advanced Superconducting Power Conditioning System (ASPCS), which consists of a Superconducting Magnetic Energy Storage (SMES) and a hydrogen - energy - storage converge on a liquid hydrogen station for fuel cell vehicles. A 10 kJ small SMES system, in which Di-BSCCO coil cooled by liquid hydrogen is installed, has been developed to compose an experimental model of the ASPCS. The SMES coil is conductively cooled by liquid hydrogen flow through a thermo-siphon line under a liquid hydrogen buffer tank. A fabrication of the cryogenic system has been completed, and then it was cooled down by liquid hydrogen. The SMES coil has been successfully charged up to a nominal current of 200 A DC. Then Eddy current loss, which is mainly induced in pure aluminum plates pasted onto each pancake coils for conduction cooling, was also measured. Experimental results will be reported.

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Presenter: Dr SHINTOMI, Takakazu (KEK)

Session Classification: C1PoA - Cryogenics for Power Applications, Energy, Fuels and Transportation I

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
RE-Ba-Cu-O (REBCO, RE=rare earth) coated conductors are being produced today by at least six companies world wide in lengths over 500 meters. REBCO coated conductors are being tailored specifically to the requirements in high magnetic field applications as well as AC applications. We have developed heavily-doped REBCO conductors with 15 – 25 mol% Zr addition with excellent properties in magnetic fields of 2 – 30 T over a temperature range of 4.2 K to 77 K. Critical current densities exceeding 20 MA/cm² have been achieved at 30 K, 3 T (B||c) and pinning forces over 1000 GN/m³ have been attained at 20 K. In 20% Zr-added REBCO tapes with 2.2 µm thick films, critical currents of 4000 A/12 mm have been demonstrated at 30 K, 3 T (B||c). For AC applications, we have developed a laser striation and selective electroplating process to fabricate fully-stabilized, 12-filament low AC loss REBCO coated conductors in lengths of 20 meters. 24-filament and 48-filament REBCO conductors have also been demonstrated in 10 m and 1 m lengths respectively. The latest progress in our program on high performance REBCO coated conductors for high field and AC applications will be presented.

This work was supported the Advanced Research Projects Agency-Energy, Office of Naval Research and the Army Research Laboratory.

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Presenter: SELVAMANICKAM, Venkat (University of Houston)

Session Classification: M2OrC - Superconductor Wires II: Coated Conductors and Applications

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Investigation of structural and critical parameters changings after heat treatment of thin NbTi cold-rolled foil with anisotropic pinning

It is well known that in NbTi alloys the α-Ti nanostructure demonstrates pinning force anisotropy regarding magnetic field and Lorentz force directions. The investigation of such anisotropy is more appreciable using thin foil than round wires due to the absence of axial averaging. Earlier [1] we described the results of detailed study and developed the model of the critical current anisotropy in cold-rolled Nb50wt%Ti foil with the thickness of 10 μm where the main pinning appears due to the grain boundaries structure of elongated flat grains. Now we present the results of the correlations between the structure changes, corresponding pinning force anisotropy and critical parameters in cold-rolled Nb50%wtTi thin foil after heat treatment of 385ºC during 25 hours. Detailed TEM and SEM investigation were performed on the scanning/transmission electron microscope Titan 80-300 and EDX energy dispersive X-ray microanalysis system. The phase and texture analysis were performed using Bruker D8 Discover diffractometer and high resolution diffraction measurements on the beamline of Kurchatov synchrotron radiation source in transmission geometry where 2D detector is used.

Texture analysis demonstrated complicated combined texture of β-phase with FWHM of 5º along foil rolling direction. Texture does not change after heat treatment. The lattice parameter increases from 3.289A to 3.295A, the lattice micro-distortion decreases from 0.74% to 0.60%. The critical temperature increases from 8.86K to 9.00K. The content of α-Ti increases from 1.5%wt to 8%wt. The α-Ti particles are quite large (up to 300 nm) and located mainly on β-phase grain boundaries. The variations of the pinning force anisotropy are discussed in frames of abovementioned changings of pinning system caused by heat treatment.

ARIEL E-linac Cryogenic System: Commissioning and First Operational Experience

Wednesday, 1 July 2015 11:00 (15 minutes)

The Advanced Rare IsotopE Laboratory (ARIEL) is a major expansion of the Isotope Separator and Accelerator (ISAC) facility at TRIUMF. A key part of the ARIEL project is a 10 mA 50 MeV continuous-wave superconducting radiofrequency (SRF) electron linear accelerator (e-linac). The 1.3 GHz SRF cavities are operated at 2 K. HELIAL LL helium liquefier by Air Liquide Advanced Technologies (ALAT) with a tunable liquid helium production [1] was installed and commissioned in Q4'2013. It provides 4 K liquid helium to one injector and one accelerator cryomodules that were installed and tested in 2014 [2]. The 4 K to 2 K liquid helium transition is achieved onboard of each cryomodule. The cryoplant, LHe and LN2 distributions, sub-atmospheric (S/A) system and cryomodules were successfully commissioned and integrated into the e-linac cryogenic system. Required pressure regulation for both: 4 K cryoplant in the Dewar and 2 K with the S/A system was achieved under simulated load. Final integration tests confirmed overall stable performance of the cryogenic system with two cryomodules installed. The paper presents details of the cryogenic system commissioning tests as well as highlights of the initial operational experience.

References

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Presenter: KOVESHNIKOV, Alexey (TRIUMF)
Session Classification: C3OrA - Operating Experience I
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Progress towards commercial 2212 by the integrated development of powder and wire processes

Wednesday, 1 July 2015 15:00 (15 minutes)

This paper describes the development of a flexible approach for producing high-purity 2212 powder by low cost, single step aerosol spray pyrolysis (ASP) that also allows for the immediate packing and sealing of the powder into the silver billet, thereby avoiding contamination and agglomeration. Together these vital components form the superconducting filaments in the wire. The impurity content of the ASP powder is at less than half the levels specified in standard available powder, with carbon at 40 ppm or lower. Process conditions have been developed for producing a range of well controlled phase compositions and the solution make up procedure controls composition to a less than 1% deviation from the target level for each cation. A capability has also been developed for the low cost, rapid production of high quality, small scale 2212 multifilament wire that is needed to help develop upstream wire attributes and identify superior powder types. 2212 critical current density in small scale wire is comparable to higher filament count, higher fill factor long length standard wire made with similar powder. These two methods in combination are being applied to develop 1) powder with superior Jc potential and 2) wire with lower defect rates, as well as more optimal architectures and silver matrix chemistries.

This work was supported by Phase 1 SBIR DE-0011334 and the National High Magnetic Field Laboratory.

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Co-author: Dr CARTER, William (Solid Material Solutions, LLC)
Presenter: Dr OTTO, Alexander (Solid Material Solutions, LLC)
Session Classification: M3OrC - Superconductor Wires V: BSCCO Processing and Properties
Track Classification: ICMC-03 - BSCCO Processing and Properties
Overpressure (OP) processing Bi-2212 round wire increases $J_c$ and $J_e$ in long-length wire to values needed for practical applications in high-field magnets. In the past, OP processing of Bi-2212 coils was limited to small coils ~45 mm OD and ~25 cm long that could fit in the small, horizontal OP furnaces available at ASC and Fermi National Accelerator Laboratory. We worked with a furnace company to build a larger, vertical OP furnace to process larger coils designed to be insert coils in high-field, all superconducting magnets. The new furnace is designed with a working hot-zone that is 150 mm in diameter and 50 cm long, and for an OP pressure of 100 atm. The challenges and lessons learned bringing this large OP furnace on line and results from larger diameter Bi-2212 coils OP processed in it will be discussed.
Field Laboratory, Florida State University); Mr OZ, Yavuz (Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University); Dr KIM, Youngjae (Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University)

Presenter: Prof. HELSTROM, Eric (Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University)

Session Classification: M3OrC - Superconductor Wires V: BSCCO Processing and Properties

Track Classification: ICMC-03 - BSCCO Processing and Properties
Cryogenics on the Stratospheric TeraHertz Observatory

Wednesday, 1 July 2015 11:45 (15 minutes)

The Stratospheric TeraHertz Observatory (STO) is a NASA funded, Long Duration Balloon experiment designed to address a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium. STO surveys a section of the Galactic plane in the dominant interstellar cooling line at 1.9 THz and the important star formation tracer at 1.46 THz, at ~1 arc minute angular resolution, sufficient to spatially resolve atomic, ionic and molecular clouds at 10 kpc. The STO instrument package uses a liquid helium cryostat to maintain the THz receiver to less than 9 K and to cool the low noise amplifiers to less than 20 K. The first STO mission flew in January of 2012 and the second mission is planned for December 2015. The second STO mission will add two cryocoolers to the cryostat to enhance and extend the mission life. This paper discusses the integration of the STO instrument into an existing cryostat and the cryogenic aspects of the launch and operation of the STO balloon mission in the challenging Antarctic environment.

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Presenter: MILLS, Gary (Ball Aerospace)

Session Classification: C3OrB - Aerospace Systems

Track Classification: CEC-10 - Aerospace
High resolution NMR measurements by using a 400 MHz (9.39 T) LTS/REBCO NMR magnet with a best mix use of various field correction methods ~Towards a super-high field/compact type of NMR magnet~

Monday, 29 June 2015 14:00 (2 hours)

We have started a project to develop a high field compact NMR magnet using high-temperature superconducting (HTS) inner coils. As a first step towards such a magnet, a LTS/REBCO NMR magnet was developed and operated at 400 MHz (9.39 T) in a previous work [1]. However, a homogeneous magnetic field required for high-resolution NMR measurements could not be obtained using conventional field correction methods, due to an effect of a screening current induced in the inner REBCO coil. The REBCO coil had large field error harmonics; performance of a superconducting shim (SC) coils were remarkably reduced due to the diamagnetic effect of the REBCO coil, resulting in a residual field error harmonics.

In the present work, we operated the magnet with the best mix of field correction methods including a newly installed inner-SC shim coil and ferromagnetic shims in combination with conventional SC shim coils and room temperature (RT) shim coils. Major field error harmonics, which could not be corrected in the previous experiment, were successfully corrected; then higher-order field error harmonics generated by the ferromagnetic shims as a side effect, and lower-order harmonics due to a magnetization of the NMR probe and a sample were fully corrected using the RT shim coils. Eventually, a high-resolution 2D-NOESY NMR measurement for a protein solution sample, which is inevitable for structural biology, was successfully achieved. The field correction method achieved here is promising for a super-high field compact NMR magnet with HTS coils operated beyond 1 GHz (23.5 T).


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Presenter: Mr PIAO, Renzhong (Graduate School of Engineering, Chiba University)

Session Classification: C1PoK - Superconducting Magnets I

Track Classification: CEC-06 - Superconducting Magnet Systems
DESIGN REALIZATION TOWARDS THE QUALIFICATION TEST OF ITER COLD CIRCULATOR

Monday, 29 June 2015 14:00 (2 hours)

Cold circulators, part of ITER Cryo-distribution system, have now reached to a stage of final qualification to demonstrate the design to cater the maximum mass flow and operational demands of the toroidal field (TF) superconducting magnet of ITER with a very high isentropic efficiency. The design of the TF cold circulators are now complete, gratifying additionally the operational requirements of poloidal field & central solenoid superconducting magnet as well as the cryopumps towards the fulfillment of standardization aspects.

Management of physical and functional interfaces has been identified as one the most critical aspect towards the final performance of ITER cold circulator. Mechanical, instrumentation and control as well as utilities are recognized as physical interfaces; whereas, operating modes of the cold circulator as an integrated component in the Test Auxiliary Cold Box (TACB) is the functional interface. All the interfaces of cold circulators have been analyzed with the help of optimized interfacing parameters of TACB and test facility at JAEA, Naka, Japan during the course of design finalization of two numbers of TF cold circulators as well as a TACB.

Testing at the warm conditions after completion of precise manufacturing of cold circulators will be performed before final integration into the TACB in order to fulfill the Japanese as well as European regulatory requirement simultaneously. Components forming the pressure boundaries, such as the in-cryostat casing as well as on-cryostat mounting flange of cold circulators have been separately manufactured, tested and certified in order to mitigate the envisaged risk during the manufacturing processes. The paper will elaborate the methodology of interface management and control, analysis performed towards the interface management and preliminary test results towards the qualification test of the ITER cold circulator.

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Session Classification: C1PoF - Circulators, Pumps and Regenerators

Track Classification: CEC-05 - Expanders, Pumps, Compressors, and Regenerators
Physical properties of material useful for predicting stability and quench propagation in high-field Bi-2212 magnets

Monday, 29 June 2015 09:00 (2 hours)

Quench initiation and growth in high-field Bi-2212 magnets can be described by 3-D heat diffusion equations and well simulated using modern finite element modeling tools. However, the usefulness of this simulation is often limited by the lack of good physical properties of important components, such as the magneto-resistivity of silver and silver alloys in a heat-treated commercial wire, which may or may not suffer from reduction of residual resistivity ratio due to Cu loss from the Bi-2212 filaments into the silver matrix. Further uncertainty arises from the fact the Cu loss depending on heat treatment parameters and Cu has different solubility in different silver alloy wires, and the fact that heat treated Bi-2212 wires have a Tc of up to 92 K, making difficult measurement of resistivity of silver at 4.2-90 K. In this study, we measure the temperature dependence of the resistivity of Ag, Ag-0.2wt%Mg, AgAl, and several commercial Ag/Bi-2212 wires, in magnetic field up to 9 T from 300 K down to 4.2 K. Wires to be measured include a wire with pure silver sheath, a wire with Ag and Ag-0.2wt%Mg sheathes, and a wire with Ag and AgAl sheathes. Critical current temperature and critical fields of these wires will also be determined. We also measured the thermal conductivity of silver and epoxy (CTD101k). These data will be fed into a finite elemental model (COMSOL), developed here at Fermilab and bench marked with experimental data at 0-7 T, to study the high-field quench behavior of Bi-2212/Ag conductors in fields up to 30 T.

This work is supported by the U.S. Department of Energy, Office of High Energy Physics through a FY12 early career award.

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Session Classification: M1PoA - Superconducting Materials and Applications
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Performance of conduction-cooled HTS Magnet in radio blackout mitigation experiment

Wednesday, 1 July 2015 09:00 (2 hours)

In the framework of the Helmholtz-Russia Joint Research Group "COMBIT" a conduction-cooled HTS magnet has been designed and built for a radio blackout mitigation experiment. Radio blackout phases often occur during hypersonic or re-entry flight of space vehicles. A dense plasma layer created during hypersonic or re-entry flight leads to attenuation or reflection of radio waves and therefore to interruption of communication with ground stations or satellites including GPS signals, data telemetry, and voice communication. To prevent attenuation or reflection of radio waves transmitters and antennas can be placed in regions with lower plasma number density. The aim of "COMBIT" is to demonstrate that the plasma density can locally be reduced with crossed electric and magnetic fields which deflect charged particles and reduce the plasma number density in the vicinity of transmitters or antennas.

Numerical simulation of the plasma flow in crossed electric and magnetic fields was performed at Ioffe Institute. Ground experiments have been performed in an arc-heated wind tunnel (L2K facility) at the German Aerospace Center in Cologne. The magnetic field was produced by a conduction cooled HTS magnet consisting of 5 coated conductor double pancakes. The main challenge for design and construction of the magnet and cryostat was to realize a high stray field in the plasma beam outside the cryostat with a small coil diameter. In the 2014 measurement campaign magnetic fields up to 2 T in the plasma beam could be achieved, corresponding to a maximum field of 5.16 T at the winding. After a revision of magnet and cryostat a new measurement campaign will be started in 2015. Details about magnet and cryostat design and performance during the measurement campaigns at the German Aerospace Center will be presented together with first results related to the Radio blackout mitigation Experiment.

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Session Classification: C3PoD - Superconducting Magnets Cryogenic Systems I

Track Classification: CEC-06 - Superconducting Magnet Systems
Critical Current Properties of HTS Twisted Stacked-Tape Cable in Subcooled Liquid Nitrogen

Tuesday, 30 June 2015 14:00 (2 hours)

Railway Technical Research Institute has developed superconducting cable applications for railway systems in Japan. Railway feeders of superconducting cables could significantly reduce the voltage decay. Therefore, DC HTS Electrification has various advantages, such as the reduction of transmission losses, the improvement of the regeneration factor, and the reduction of substations. From a practical application perspective in a railway system, a Twisted Stacked-Tape Cable (TSTC) has been focused on with its compact size and bendability. A 2 m long, 32-YBCO-tape (4 mm width) TSTC conductor with a 200 mm twist pitch was investigated at various temperatures near 77 K using subcooled liquid nitrogen. The measured critical current of the straight cable was 1.45 kA at 77 K which agrees with the expected values estimated from the self-field. By controlling the equilibrium vapor pressure, the temperature was changed from 64 K to 85 K. The critical currents of the TSTC conductor were varied from 3.65 kA at 64 K to 0.42 kA at 85 K by the vapor pressure of nitrogen bath. Temperature dependence agrees with that of 4 mm YBCO tape. These results encourage a compact Twisted Stacked-Tape Cable application in railway systems.

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Presenter: TOMITA, Masaru (Railway Technical Research Institute)

Session Classification: M2PoC - Superconductor Cables II: HTS

Track Classification: ICMC-09 - HTS Cables
High-cycle fatigue properties of Alloy 718 plates were investigated at 77 K in this study. Two plates were used and had a normal-grained and a bimodal-grained (BG) microstructure, respectively. Regarding the normal-grained plate, we prepared two specimens that had different grain sizes by controlling solution-treatment conditions. One had a fine-grained (FG) microstructure and its mean grain size was 40 μm. The other had a coarse-grained (CG) microstructure and its mean grain size was 100 μm. On the other hand, the BG specimens were obtained after the same heat treatment as that of the FG specimens. However, it consisted of the FG and the CG regions. Mean grain size of each region was 30 μm and 100 μm, respectively.

High-cycle fatigue strength of the FG specimens was higher than that of the CG specimens. High-cycle fatigue strength of the BG specimens was almost the same as that of the CG specimens. In the observation of fracture surface, flat area (facet) was found at fatigue crack initiation site in all specimens. Each facet size was similar to the grain size of each specimen and about 100 μm in the CG and BG specimens. Observations of the microstructure beneath the fatigue crack initiation site of the BG specimens revealed that the facet corresponds to transgranular cracking in the coarse grain, meaning that fatigue crack initiated at the coarse grain in the BG specimens. Thus, it is surmised that the high-cycle fatigue strength of Alloy 718 with the BG microstructure is strongly affected by that of the CG region in that material.

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Presenter: ONO, Yoshinori (National Institute for Materials Science)
Session Classification: M2OrD - Cryogenic Materials V: Structural Materials
Track Classification: ICMC-11 - Metallic and Composite Materials
Development of tools for advanced quench diagnostics at LBNL Magnet Test Facility

Monday, 29 June 2015 14:00 (2 hours)

Testing of high-field superconducting accelerator magnets aims at identifying potential causes of quenching, localizing quench origins and measuring quench propagation velocity along the coil winding. This information is essential for establishing protection limits and providing useful feedback to the magnet designers. Traditionally, quench studies are conducted using voltage taps. However, for the long or complex magnets this approach becomes impractical due to large number of taps required to track quench propagation and difficulty of incorporating them without jeopardizing magnet integrity. At LBNL, we develop and implement alternative methods of quench diagnostics based on time-correlated multi-point sensing of magnetic and mechanical disturbances. We have built a novel inductive quench antenna comprising a pc-board array of dipole-buckled coils interfaced to a cryogenic 16:1 multiplexed amplifier, capable of input scanning at rates up to 1 MHz. Spatial resolution of the antenna for quench localization is approx. 1 cm, and multiple pc-board arrays can be stacked together to cover full length of the magnet. A six-channel cryogenic acoustic detection system is implemented and operated simultaneously with the quench antenna. Such combined acquisition setup allows for a high-accuracy quench localization. In addition, it enables separation of mechanical and electromagnetic events, spatial mapping of mechanically-unstable areas in the magnet, and estimation of an instantly released mechanical energy during magnet ramping. Quench diagnostics examples derived from recent testing of high-field block-type Nb3Sn dipole HD3b and Canted Cosine Theta NbTi dipole will be shown. A future upgrade path for the MTF diagnostic capabilities will be presented.

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Presenter: MARCHEVSKY, Maxim (Lawrence Berkeley National Laboratory)

Session Classification: C1PoK - Superconducting Magnets I

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Raytheon Advanced Miniature Cryocooler Characterization Testing

Monday, 29 June 2015 16:00 (15 minutes)

The Raytheon Advanced Miniature (RAM-100) cryocooler is a flight packaged, high frequency pulse tube cooler with an integrated surge volume and inertance tube. Its design has been fully optimized to make use of the Raytheon Advanced Regenerator, resulting in improved efficiency relative to previous Raytheon pulse tube coolers. In this paper, thermodynamic characterization data for the RAM-100 cryocooler is presented along with details of its design specifications.

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Presenter: CONRAD, Ted (Raytheon)
Session Classification: C1OrH - Aerospace Cryocoolers
Track Classification: CEC-04 - Cryocoolers (Aerospace)
Influence of neutron irradiation on conduction cooling superconducting magnets

Monday, 29 June 2015 14:00 (2 hours)

The conduction cooling superconducting magnets are now widely used in various application because of their minimum usage of helium. In the accelerator science field, they are also widely used for particle detector solenoids because they can minimize the materials needed for the magnet such that they can be more transparent against irradiated particles. For the same reason they are now used at irradiation environments because they can reduce the heat load due to the irradiation. However, the hadronic irradiation, such as neutron irradiation, can degrade thermal conductivity of pure aluminum that are used as thermal conductor. This leads to a pure cooling condition of the magnets. At J-PARC, there are two conduction cooling superconducting magnets; one is already built and under operation, the other is now under construction. The paper reports the influence of the neutron irradiation on those magnets, and discuss the possibilities of HTS based conduction cooling magnets under high irradiation environments.

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Presenter: OGITSU, Toru

Session Classification: C1PoK - Superconducting Magnets I

Track Classification: CEC-06 - Superconducting Magnet Systems
Numerical simulation and experimental investigation of a novel Scotch yoke for a Gifford-McMahon cryocooler

Wednesday, 1 July 2015 11:00 (15 minutes)

A novel GM cycle, called as asymmetric GM cycle is proposed. In an asymmetric GM cycle, the displacer moves slowly when it is close to the upper dead point, but moves rapidly when it is close to the lower dead point. Therefore, the expansion process is longer, while the discharging process is shorter than that in a conventional GM cycle. Meanwhile, the duration of the charging process can be kept the same as that in a conventional GM cycle. Accordingly, the phase shift between the pressure and the displacement can be improved, and the mass flow rate into the expansion space can also be increased. Therefore, the P-V work and the cooling capacity can be increased. In order to realize the novel GM cycle, a novel Scotch yoke is invented. In the novel Scotch yoke, there is a concave part at the upper center of the slide groove and a convex part at the lower center of the slide groove. The effect of the novel Scotch yoke has been confirmed by numerical simulation and experimental investigation. With a conventional Scotch yoke, the cooling capacity is 44 W at 37.4 K at the first stage and 1.0 W at 3.94 K at the second stage. With a novel Scotch yoke, the cooling capacity is 44 W at 35.9 K at the first stage and 1.0 W at 3.96 K at the second stage. The cooling capacity at the first stage at 40 K is improved by about 10%, from 51.5 W to 57.3 W.

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**Session Classification:** C3OrD - 4K Cryocoolers

**Track Classification:** CEC-03 - Cryocoolers (Non-Aerospace)
Value Engineering in System of Cryoline and Cryodistribution for ITER: In-kind Contribution from India

Monday, 29 June 2015 09:00 (2 hours)

System of cryoline and cryodistribution for ITER has matured to a stage of preliminary design phase with the advent of industrial associates. Starting from the cold power source, the system of cryoline and cryodistribution transfers the controlled cold power through a large network to the superconducting magnets and cryopumps. The functional responsibility also includes very high reliability and availability with respect to the operation of the ITER machine.

Following the completion of conceptual design, it was necessary to perform a detailed engineering study of the complete network of distribution system in totality, before entering into the industrial phase. This is to ensure the functional responsibility of the system. Industrial contracts have been established for the system of cryoline and cryodistribution with the objective to enter into the detailed design and construction phase of the overall systems. Value engineering in the area of distribution boxes including interfacing cryolines has been performed in order to access the integrated reliable performance with respect to the overall cryogenic system, reducing the risk transferred to the industrial partners. These include technical risk assessment, analysis, mitigation plan and implementation with the industrial partners. The paper will describe the methodology of technical risk management, value engineering performed to ensure fulfilment of licensing and regulatory obligations, functional reliability as well as testing and manufacturability by standard industrial processes, so that highly reliable integrated distribution system is delivered for the project.

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Session Classification: C1PoD - Cryogenic Distribution Systems

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Test procedures and functional verification of cryogenic valves considering operating conditions

Tuesday, 30 June 2015 09:00 (2 hours)

Cryogenic and high-pressure control valves have to meet topmost requirements as a result of extreme operating conditions. Of prime importance are accuracy and high reproducibility of the control performance and further maximised reliability and service life time. To verify these requirements several procedures are implemented which are partially defined with general standards. Furthermore long-time experiences by user and manufacturer are of great importance. The poster presentation describes already established routines as well as specific test procedures for particular applications. The interpretation of these procedures, their relevance and limits are clearly described. Examination of leakage and welding seams under ambient and cryogenic conditions; endurance and reliability tests; measurement of valve specific characteristics such as kv-values as well as material specific inspection are in focus of our approach.

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Presenters:  BOERSCH, Michael (WEKA AG);  ERNI, Pascal (WEKA AG)

Session Classification:  C2PoC - Instrumentation and Controls I

Track Classification:  CEC-15 - Instrumentation and Controls
Lockheed Martin Joule-Thomson Compressor Development

Monday, 29 June 2015 11:30 (15 minutes)

This paper describes the development and testing of a space-quality compressor capable of delivering closed-loop gas flow with a high pressure ratio, suitable for driving a Joule-Thomson cryocooler. The compressor is based on a traditional “Oxford style” dual-opposed piston compressor with linear drive motors and flexure-bearing clearance-seal technology for high reliability and long life. This J-T compressor retains the approximate size, weight, and cost of the ultra-compact, 200 gram Lockheed Martin Pulse Tube Micro Compressor, despite the addition of a flow-rectifying system to convert the pressure wave into a steady flow.

Key to this program was the development of a custom miniature check valve, small enough to be incorporated into the compressor without affecting overall size and with fast enough response time to capture the pressure pulses. One of the major challenges of working at this small scale is that components must be conceived within the confines of a plausible manufacturing process to be viable and cost effective.

Incorporating the micro check valves into the compressor body was done with a goal of minimizing dead volumes in order to maximize pressure ratio output. The result is a system of bores and passages that comprise an efficient two-stage, four-valve circuit integrated into a single-piece compressor hub.

The size, weight, and manufacturing costs of this J-T compressor are nearly the same as our Pulse Tube Micro compressor. And since it uses many of the same parts and processes, it can be readily adapted to the same high-volume, low cost manufacturing. Other uses for this compressor include long-life low power pumping of circulating systems, such as ambient or cryogenic remote cooling loops.

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Presenter: CHAMPAGNE, Patrick (Lockheed Martin)

Session Classification: C1OrD - Low Temperature Aerospace Cryocoolers

Track Classification: CEC-04 - Cryocoolers (Aerospace)
Effect of Discontinuities and Penetrations on the Shielding Efficacy of High Temperature Superconducting Magnetic Shields

Tuesday, 30 June 2015 09:00 (2 hours)

High Temperature Superconducting (HTS) materials have been demonstrated to be suitable for applications in shielding of both DC and AC magnetic fields. Magnetic shielding is required for protecting sensitive instrumentation from external magnetic fields and for preventing the stray magnetic fields produced by high power density equipment from effecting neighboring devices. HTS shields have high current densities at relatively high operating temperatures (40-77 K) and easily be fabricated using commercial HTS conductor. High current densities in HTS materials allow design and fabrication of magnetic shields that are lighter and can be incorporated into the body and skin of high power density devices. HTS shields are particularly attractive for HTS devices because a single cryogenic system can be used for cooling the device and the associated shield. Typical power devices need penetrations for power and signal cabling and the penetrations create discontinuities in HTS shields. Hence it is important to assess the effect of the necessary discontinuities on the efficacy of the shields and the design modifications necessary to accommodate the penetrations. This paper presents the details of the experimental and modelling efforts. Results of the experimental studies at variable amplitude and frequency of the magnetic field and a comparison of the results with those of the models are presented.

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Presenter: HATWAR, Rajeev (Florida State University)

Session Classification: M2PoB - Cryogenic Materials III: Testing and Methods

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
An hybride liquid nitrogen system for the cooling of focal plane detector

For the optimal trade-off between dark current, sensitivity, and cosmetics, these detectors need to be operated at a temperature of about 155 K. The detectors mosaic with a total area of 630 cm² directly facing the Dewar entrance window, is exposed to a considerable radiation heat load. This can only be achieved with a very performing cooling system.

After a short explanation of the LN2 solution versus mechanical cryo-coolers, the paper describes the cooling system, which is build such that it makes the most efficient use of the cooling power of the liquid nitrogen. This is obtained by forcing the nitrogen through a series of well designed and strategically distributed heat exchangers. The paper address also the specific problem caused by the change of direction associated to the telescope pointing.

In a conclusion we report about the performance of the system recorded during the laboratory system testing and the first months of operation at the telescope.

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Presenter:  LIZON, Jean Louis (ESO)

Track Classification:  CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Lockheed Martin Space Systems Company has built and delivered an engineering model microcryocooler to the Jet Propulsion Laboratory for use with instruments for deep space and earth science missions. Funding for this cryocooler was through JPL’s Maturation of Instruments for Solar System Exploration (MatISSE). This cooler is nearly identical to the compact coaxial microcryocooler presented at the 2014 International Cryocooler Conference. The cryocooler mass is just 320 grams for the entire thermal mechanical unit, and is compact enough to be packaged in a CubeSat. This paper describes the measured performance of the MatISSE cryocooler, including the performance at the very cold heat rejection temperatures expected for JPL deep space missions.

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**Presenter:** OLSON, Jeff (Lockheed Martin Space Systems Company)

**Session Classification:** C1OrH - Aerospace Cryocoolers

**Track Classification:** CEC-04 - Cryocoolers (Aerospace)
A wide bore superconducting solenoid is the core of the NAFASSY (NAtional FAcility for Super-conducting SYstems) test facility, which is under construction at the University of Salerno. The NAFASSY laboratory is a joint program among University of Salerno, ENEA, CRdC and INFN under the financial support of the Italian Ministry for University and Research. The facility, hosted in a new building, includes a 250 W supercritical He refrigerator, a 20kA two quadrants (-20V, +25V) power converter for feeding the solenoid or INFN fast ramped accelerator magnets, and a 50kA/+12V power supply for the testing sample. The completion and the commissioning of the facility is foreseen within 2016. The NAFASSY magnet is a large-bore Nb3Sn solenoid, able to provide a peak field of 8 T close to the insert inner radius. Having a warm bore diameter of 1144 mm and a height of 1276 mm, the solenoid will allow to perform tests relevant for long size NbTi or medium-field Nb3Sn Cable-In-Conduit Conductors (CICCs), as well as small magnets, at variable temperature (ranging from 4.2 K to 10 K) in the presence of a transverse magnetic field. In fact, the warm bore makes the sample under test to be independent of the background solenoid. The design of the magnet is based on a rectangular CICC, cooled by forced flow supercritical He at 4.5 K and fed at a maximum current of 20 kA through a pair of high temperature superconductors current leads. The detailed design of the 8T solenoid, including the electro-magnetic, structural and thermo-hydraulic analysis, will be reported, as well as the production status.
Description and validation of the Little correlation for boiling zeotropic mixtures in horizontal tubes from cryogenic to room temperature

Wednesday, 1 July 2015 11:30 (15 minutes)

The use of mixed gas working fluids has become common in Joule–Thomson (JT) type cryocoolers for a variety of applications in the cooling temperature range from 80 to 230 K. The thermal efficiency of mixed gas JT cryocoolers is dependent on the optimization of the gas mixture composition. Most optimization methodologies focus on thermodynamic criteria of the cycle because there are very little data or theory currently available regarding the heat transfer coefficient associated with these two-phase, multi-component mixtures at cryogenic temperatures. There is not a general and accurate correlation to predict the local heat transfer coefficient (htc) for mixtures during the boiling process. Little (2008) proposed a correlation to be used on horizontal tubes that shows good agreement with Nellis (2004) experimental data of nitrogen-hydrocarbon mixtures. However, it is not clearly shown how the correlation is obtained and how it should be applied. This paper provides a more complete description of the Little correlation and also expands its validation using the experimental data provided by Barraza et al. (2015). The new experimental data include local heat transfer coefficient for 2 components (binary) up to 5 components mixtures in the temperature range between 100 K and room temperature. These mixtures are formed from nitrogen-hydrocarbon and argon-fluorocarbon mixtures and evaporate in horizontal tubes with diameters from 0.5 to 3.0 mm for different heat flux, mass flux, evaporating pressure, and composition.

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Presenter: BARRAZA, Rodrigo (University of Wisconsin-Madison)
Session Classification: C3OrC - Mixed Gases
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Construction of the Cryogenic System for IHEP-ADS Injector I

Tuesday, 30 June 2015 09:00 (2 hours)

Accelerator driven sub-critical system in China is a kind of transmutation machine to minimize the nuclear wastes. As one of the important parts in ADS, Injector I will be built in IHEP, CAS which needs two cryomodules operating at 2K cryogenic environment to realize 10MeV Proton beam energy. Each cryomodule contains seven Spoke cavities and seven superconducting magnets. This paper describes the design of the cryogenic system, which include flow chart analysis, key equipment, heat loads analysis, infrastructure and the progress.

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Session Classification: C2PoA - Cryogenic Systems I

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Experimental investigation of 20 K two-stage layered active magnetic regenerative refrigerator

*Tuesday, 30 June 2015 14:00 (2 hours)*

An active magnetic regenerative refrigerator (AMRR) is one of the useful technologies to improve the efficiency of hydrogen liquefaction process. The AMRR utilizes magnetocaloric effect to reduce the cold end temperature of the active magnetic regenerator (AMR). Since the magnetocaloric effect is a reversible process, it facilitates high thermodynamic efficiency of AMRR. However, the magnetocaloric effect only appears near the transition temperature. Therefore, in order to achieve a wide temperature span of the AMR, the layered AMR with four kinds of magnetic refrigerants (GdNi2, Gd0.1Dy0.9Ni2, Dy0.85Er0.15Al2, Dy0.5Er0.5Al2) has been considered. Because each magnetic refrigerant has different heat capacity, it is very important to determine the proper mass flow rate of the helium gas which is used as a heat transfer medium. In this paper, the performance of the two-stage layered AMRR is experimentally investigated. The test apparatus includes two-stage layered AMRs, low temperature superconducting (LTS) magnet which generates maximum magnetic field of 4 T, and the helium gas oscillating flow system. The mass flow rate of working fluid is controlled separately at the first and second stages of the AMR. Each mass flow rate at the cold end is measured by two hot-film sensors (1260A-10, TSI) calibrated at the cryogenic temperature (20 K - 80 K). The temperature span of the AMR is recorded 60 K and the performance of the AMR with the variation of the mass flow rate is analyzed. The results show that the mass flow rate of working fluid is a crucial factor in the AMR performance.

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**Presenter:** PARK, Inmyong (KAIST)

**Session Classification:** C2PoH - Hydrogen Systems

**Track Classification:** CEC-06 - Superconducting Magnet Systems
Metal Insulator Transition due to Density inhomogeneity at very low temperature and evidence for the correlated hopping mechanism in absence of magnetic field in p-GaAs

In this work, we present a study of the temperature and carriers density dependence of the electrical transport of high mobility two dimensional hole system grown on the (311) surface of GaAs. At low temperatures, the analysis of the variation of conductivity data shows that a density inhomogeneity in the metallic phase leading to percolation-type transition to an insulating state at a critical density. Secondly, we investigated the temperature dependence of resistivity in the absence of the magnetic field near the metal-insulator transition of a high mobility of holes system in two dimensions grown on the (311) surface GaAs. We provide evidence of correlated hopping by observing the low Coulomb energy TES and the concomitantly smaller than predicted CES in single electron hopping picture. Even in the presence of multi-electron hopping, single-particle scaling form is maintained. Hence, we use the scaling form to manifest the crossover between Coulomb hopping and screened Mott hopping.

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**Track Classification:** ICMC-05 - Thin Films
Influence of ZnO and Dy2O3 on MgB2 Bulks Fabricated by High Temperature and Pressure Reaction

Monday, 29 June 2015 17:00 (15 minutes)

Recently, ZnO and Dy2O3 have been considered as dopants for the improvement of superconducting properties in MgB2 bulks. However, the effect of these dopants is still unclear: some studies reported these metal oxides worked as new pinning centers and others was attributed the effects to Mg site substitution. In addition, low temperature reactions may explore limited solubility regimes for these dopants. In order to study the intrinsic effect of ZnO and Dy2O3 in MgB2, a high temperature sintering method has been used to fabricate dense and homogeneous MgB2 bulks. To do this we used an induction furnace built inside of a high pressure vessel which allowed us to reach 1700°C and 1500 Psi. A slow cooling rate (2°C/min) was used in an attempt to obtain a homogeneous nucleation and phase distribution. A series of MgB2 bulk samples with ZnO and Dy2O3 additives were synthesized through this high pressure and temperature procedures. The resulting microstructures of these bulk samples were revealed by SEM and TEM. Atomic substitution were evaluated by high resolution XRD. The upper critical field Bc2, irreversible field Birr and Tc were obtained from both magnetic and resistivity measurements. The roles of substitution vs precipitate induced strain on Bc2 enhancements with adding ZnO and Dy2O3 were discussed.

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Presenter: YANG, Yuan (OSU)
Session Classification: M1OrD - Superconductor Materials I: Bulk and New Materials
Track Classification: ICMC-06 - HTS and MgB2 Bulk
High Strain and Twisting Tolerance in AIMI and PIT MgB2 Strands

Wednesday, 1 July 2015 09:00 (2 hours)

The influence of strand bending and twisting on the critical current density, Jc, and n-value of MgB2 multifilamentary strands were evaluated, and the field and temperature dependence of the transport properties was evaluated for MgB2 strands. Two types of MgB2 strands were fabricated; (i) advanced internal magnesium infiltration method (AIMI) strands, and (ii) powder in tube method (PIT) type strands. The bending strain tolerance of MgB2 strands was studied by applying a series of bending strains (0.0% to 0.8%) at room temperature, and then measuring transport properties at cryogenic temperatures. In order to study the effect of twisting, six twist pitch levels (10 mm to 100 mm) were applied on PIT MgB2 strand with 54 sub-filaments. Critical current densities of all samples in this study were measured on 5 cm long samples at 4.2 K in fields of up to 12 T. The n-values (or index number) were extracted from the V-I curve at all measured fields. The bending strain tolerances on the transport properties of both AIMI and PIT strands were measured and discussed. The influence of twisting on multifilamentary PIT strand was studied. Transport measurements were performed on the AIMI strand as a function of T from 4.2 K to 30 K. For AIMI strands, the strain dependence of Jc and n–value were undegraded out to 0.4%, with a reduction of only 10% at 0.6% bending strain. For PIT strands, both Jc and n–value were independent with bending strain up to 0.4%. Twisting down to Lt = 10 mm did not degrade the 4.2K transport properties of the MgB2 multifilamentary PIT strand (sub-filament size of ~ 20 µm).

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Presenter: YANG, Yuan (OSU)

Session Classification: M3PoA - Superconductor Materials IV: Properties and Applications

Track Classification: ICMC-04 - MgB2 Processing and Properties
Thermal Contraction of Electrical Insulators

Monday, 29 June 2015 11:30 (15 minutes)

The thermal contraction from room temperature to 4 K of electrical insulation materials has been measured using a modified Invar 36 rod-in-tube dilatometer. The test assembly permitted independent measurement, simultaneously, of two samples. This permitted the use of a reference and an insulation sample for each thermal run. Materials that were measured included a conventional epoxy resin, Kapton film, and a series of glass/epoxy resin, glass/polyimide resin, and glass/epoxy resin/Kapton laminates. The glass contents of the glass/epoxy resin laminates were varied to obtain the dependency of thermal contraction on volume percent glass. Data are compared to previous measurements and the laminate data are presented as a function of temperature and volume percent glass.

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Presenter: Dr REED, Richard (Cryogenic Materials, Inc.)

Session Classification: M1OrB - Cryogenic Materials I: Testing and Methods

Track Classification: ICMC-12 - Insulation and Impregnation Materials
Numerical Simulation of Heat Transfer for Wall-type and Fin-type Heat Exchanger

Wednesday, 1 July 2015 09:00 (2 hours)

Wall-type heat exchanger (WTHX) and Fin-type heat exchanger (FTHX) are attached to the first and second stage cold head of two G-M crycoolers respectively in the simulating experimental platform of the internal purifier (SEPEIP). WTHX and FTHX play a significant role in SEPEIP. WTHX is designed to remove heat from helium and freeze-out extremely few impurities, FTHX is for further cooling the helium. In this paper, numerical simulation and theoretical calculation for WTHX and FTHX are carried out. However, Numerical results are not so well consistent with the theoretical results. The cause of error is also investigated.

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Session Classification: C3PoC - Convective Heat Transfer

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Numerical and Experimental Investigations of composite materials in cryogenic environment

Composite materials are being used extensively in different realms of science and technology for various applications. Testing of these composite materials is of substantial importance, as the composite materials might be susceptible to failure due to the variation in the operating temperature ranges and the cryogenic temperatures at which the material have to endure.

In the present work, the mechanical characterization of composite materials is investigated using double walled vacuum insulated chamber which is designed as an attachment to the Universal Testing Machine (UTM). The chamber with two walls separated by vacuum, is made up of SS316LN. The chamber is designed to accommodate a moving shaft of the lower part of UTM which applies tensile load on the specimen (composite) while the upper shaft connected to the chamber is fixed. One end of both shafts from the cryogenic chamber are fixed to the jaws of the UTM and has a chuck fitted on the other end to hold the specimen during the test. The chamber provide a cryogenic environment for the testing of the composite materials. The cryogenic temperature in the chamber is obtained by purging of LN2 into the chamber. A vacuum pump of capacity 10-3 mbar is used to create vacuum between the walls of the chamber to create an isolated environment. Two thermocouples are fitted in the chamber to collect data pertaining to temperature distribution. The high resolution camera installed inside the chamber gives an insight on how and when the fracture occurs. A numerical simulation is done using a commercial software ABAQUS to predict the stress concentration zones in the composite material. Further, crack analysis is also done using extended finite element method (XFEM). The results show that cryogenic temperatures significantly influence the mechanical behaviour of composite materials.

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Presenter: Mr SUNIL, Karthik (School of mechanical engineering)

Track Classification: ICMC-14 - Cryogenic Materials Testing and Methods
The simulation of the heat and mass transfer performance in 1st heat exchanger of the inner purifier

As we know, the performance of the inner purifier plays an important role in the operation of the helium liquefier. In inner purifier, contaminated helium gas goes into the first stage heat exchanger (1st HEX) and is cooled down to nearly 65K, parts of impurity turn to liquid, which are subsequently removed when passing through liquid separate pot. Thus the heat and mass transfer performance of the condensation of the impurity in 1st HEX should be investigated, with high concentration of the non-condensable gas helium. In this paper, a simulation is presented and the results fit well with the experimental data.

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Presenter: Mr XU, Peng (The Technical Institute of Physics and Chemistry of the Chinese Academy of Sciences)

Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Dynamic simulation of mixed refrigerant process for small-scale LNG plant

With the increase demand of energy, natural gas has remained the fastest increasing fossil energy resource in the world recently. Since the gap between natural gas consumption and production is very large, more and more attentions have been shifted to some isolate small natural gas reservoirs which were previously considered to be too remote and costly to develop. Due to the small flow rate of natural gas, it is a good option to build small-scale LNG plant to liquefy the natural gas. Most of optimization studies concentrated on designing mixed refrigerant liquefaction process with lower energy consumption at steady-state simulation. Only a few studies have addressed dynamic simulation of natural gas liquefaction process. The main aim of this study was to conduct a dynamic simulation of mixed refrigerant liquefaction process for small-scale LNG plant and to investigate the dynamic responses of disturbances. The purpose of the small-scale LNG plant was to produce LNG at specified LNG temperature. Meanwhile, the process could tolerate several kinds of disturbances. Thus, the variations of natural gas composition, temperature, pressure, flow rate and environment temperature were adapted as disturbances. Then, these different kinds of disturbances were added to the process to test its stability and dynamic responses. The dynamic responses of LNG temperature and total energy consumption were the criteria to investigate the influences of disturbances on the process. In addition, the dynamic simulation results were compared with steady-state simulation results to verify the accuracy of dynamic model. Finally, the dynamic responses of disturbances were obtained and discussed. The results showed that LNG temperature could go back to its specified value and compressor duty varied with the disturbances. It indicated that the mixed refrigerant liquefaction process for small-scale LNG plant could overcome the disturbances and operate at stable state.

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Session Classification: C3PoA - Controls and Simulation

Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Series Supply of Cryogenic Venturi Tube Flowmeters for the ITER Project

Wednesday, 1 July 2015 14:30 (15 minutes)

In the framework of the ITER project, the CEA-SBT has been contracted to supply 277 venturi tube flowmeters to measure the distribution of helium in the superconducting magnets of the ITER tokamak. Six sizes of Venturi tube have been designed so as to span a measurable helium flowrate range from 0.1 g/s to 400 g/s. They operate, in nominal conditions, either at 4K or at 300K, and in a nuclear and magnetic environment.

Due to the cryogenic conditions and the large number of venturi tubes to be supplied, an individual calibration of each venturi tube would be too expensive and time consuming. Studies have been performed to produce a design which will offer high repeatability in manufacture, reduce the geometrical uncertainties and improve the final helium flowrate measurement accuracy. On the instrumentation side, technologies for differential and absolute pressure transducers able to operate in applied magnetic fields need to be identified and validated.

The complete helium mass flow measurement chain will be qualified in four test benches:
- A helium loop at room temperature to insure the qualification of a statistically relevant number of venturi tubes operating at 300 K.
- A supercritical helium loop for the qualification of venturi tubes operating at cryogenic temperature (a modification to the HELIOS test bench).
- A dedicated vacuum vessel to check the helium leak tightness of all venturi tubes.
- A magnetic test bench to qualify different technologies of pressure transducer in applied magnetic fields up to 100mT.

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Session Classification: C3OrG - Cryogenic Instrumentation and Control Systems

Track Classification: CEC-15 - Instrumentation and Controls
Liquid hydrogen Moderator optimization for Neutron Sources with high brilliance

Tuesday, 30 June 2015 14:00 (2 hours)

Neutron scattering experiments benefit from an increasing brilliance of the neutrons supplied. In addition to more powerful neutron sources, the efficiency providing those neutrons is becoming more important. Focus of the report presented here is therefore the optimization of one of the key components, the cold moderator. A cold moderator is usually a pressure vessel, which is filled with liquid hydrogen. So far, only the pressure and the temperature as well as the vessel geometry have been optimized. However, the nuclear spin of the hydrogen molecules was not considered yet. Novel theoretical studies suggest that the nuclear spin of the hydrogen molecule strongly affects the efficiency of moderation process. Therefore, a concept is presented which allows the characterization of such liquid hydrogen moderators for the full range of ortho-to-para ratios.

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Presenter: BESSLER, Yannick (Forschungszentrum Jülich)

Session Classification: C2PoM - Novel Concepts and New Devices II

Track Classification: CEC-17 - Novel Concepts and New Devices
Ground Operations Demonstration Unit for Liquid Hydrogen Initial Test Results

Tuesday, 30 June 2015 16:30 (15 minutes)

NASA operations for handling cryogens in ground support equipment have not changed substantially in 50 years, despite major technology advances in the field of cryogenics. NASA loses approximately 50% of the hydrogen purchased because of a continuous heat leak into ground and flight vessels, transient chill down of warm cryogenic equipment, liquid bleeds, and vent losses. NASA Kennedy Space Center (KSC) needs to develop energy-efficient cryogenic ground systems to minimize propellant losses, simplify operations, and reduce cost associated with hydrogen usage. The GODU LH2 project has designed, assembled, and started testing of a prototype storage and distribution system for liquid hydrogen that represents an advanced end-to-end cryogenic propellant system for a ground launch complex. The project has multiple objectives including zero loss storage and transfer, liquefaction of gaseous hydrogen, and densification of liquid hydrogen. The system is unique because it uses an integrated refrigeration and storage system (IRAS) to control the state of the fluid. This paper will discuss present the results of the initial phase of testing of the GODU LH2 system.

Primary author: NOTARDONATO, Bill (NASA Kennedy Space Center)
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Presenter: NOTARDONATO, Bill (NASA Kennedy Space Center)
Session Classification: C2OrG - Hydrogen and Other Systems
Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Cool-down acceleration for G-M cryocoolers with thermal oscillations passively damped by helium

Wednesday, 1 July 2015 11:45 (15 minutes)

4 K Gifford-McMahon cryocoolers suffer from inherent temperature oscillations which can be a problem for certain attached electronic instrumentation; Sumitomo Heavy Industries has exploited the high volumetric specific heat of super-critical He to quell these oscillations (approx. 10 dB) by strongly thermally linking a separate vessel of He to the second stage; no significant thermal resistance is added between the payload and the working gas of the cryocooler. A noticeable effect of the helium damper is to increase the cool-down time of the second stage, particularly below 10 K when the heat capacity of the He is dominant. For the operation of niobium-based superconducting electronics (NbSCE), a common practice is to warm the circuits above the critical temperature (~9 K) and then cool to the operating point in order to redistribute trapped magnetic fluxons, so for NbSCE users, the time to cool from 10 K is important. The gas in the helium damper is shared between a room-temperature canister and the 2nd stage vessel, which are connected by a capillary tube. We show that the total cool-down time below 10 K can be substantially reduced by introducing a combination of thermal linkages between the cryocooler and the capillary tube and in-line relief valves, which control the He mass distribution between the warm canister and cold vessel. The time to reach operating temperature from the superconducting transition has been reduced to <25% of the time needed without these low-cost modifications.

Primary author: WEBBER, Robert (Hypres, Inc.)
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Presenter: WEBBER, Robert (Hypres, Inc.)
Session Classification: C3OrD - 4K Cryocoolers
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Nanoparticle Ag-enhanced textured-powder Bi-2212/Ag wire technology

Wednesday, 1 July 2015 15:15 (15 minutes)

A new approach to the preparation of cores for Bi-2212/Ag wire is being developed. Nanoparticle Ag is homogeneously dispersed in Bi-2212 fine powder, and the mixture is uniaxially compressed to form highly textured, cold-sintered core rods. The rods can be assembled with a Ag matrix and drawn to form multifilament wire. Preliminary studies using tablet geometry demonstrate that a non-melt heat treatment produces densification, grain growth, intergrowth among grains, and macroscopic current transport. The status of the development is reported.

Primary author:  MCINTYRE, Peter (Texas A&M University)

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Presenter:  Mr KELLAMS, Joshua (Texas A&M University)

Session Classification:  M3OrC - Superconductor Wires V: BSCCO Processing and Properties

Track Classification:  ICMC-03 - BSCCO Processing and Properties
Development of a sorption-based Joule-Thomson cooler for the METIS instrument on E-ELT

Wednesday, 1 July 2015 17:00 (15 minutes)

METIS, the Mid-infrared E-ELT Imager and Spectrograph, is one of the proposed instruments for the European Extremely Large Telescope (E-ELT) that will cover the thermal/mid-infrared wavelength range from 3-14 μm. Its detectors and optics require cryogenic cooling at four temperature levels, 8 K for the N-band detectors, 25 K for the N-band imager, 40 K for the L/M-band detectors and 70 K for the optics. To provide cooling below 70 K, a vibration-free cooling technology for the METIS instrument based on sorption coolers is developed at the University of Twente in collaboration with Airbus Defence and Space Netherlands B.V. (former Dutch Space B.V.). We propose a sorption-based cooler with three cascaded Joule-Thomson (JT) coolers of which the sorption compressors are all heat sunk at the 70 K platform. A helium-operated cooler is used to obtain the 8 K level with a cooling power of 0.4 W. Here, three pre-cooling stages are used at 40 K, 25 K and 15 K. The latter two levels are provided by a hydrogen-based sorption cooler, whereas the 40 K level is realized by a neon-based sorption cooler. In order to prove the theoretical designs, three demonstrators were built and tested: 1. Full-scale helium JT cold stage; 2. Down-scaled helium sorption compressor; 3. Close-to-full-scale neon sorption JT cooler. In this paper, we present the design of these demos and we discuss the experimental results obtained so far, the lessons that were learned from these demos and the future development towards a real METIS cooler.

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Presenter: TER BRAKE, Marcel (University of Twente, The Netherlands)
Session Classification: C3OrK - Special Session: JT Coolers
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
The processing and superconducting properties of large scale single domain GdBCO bulk fabricated from graded solid phase source powders by the modified infiltration growth method

The top-seeded infiltration and growth process (TSIG) is a very effective method for the preparation of REBCO bulk superconductors. In this paper, we investigate the effect of preparing GdBCO bulk superconductors by the modified TSIG process using spatially graded solid phase source precursor powder. The single domain GdBCO bulk were prepared with the graded solid phase which was pressed with a maximum composition of 3 wt% BaO doping in the solid phase powders in the vicinity of the seed, which decreased to 2 wt% and then 1 wt% towards the middle and the edge of the solid phase source pellet. The growth morphology, microstructure, and the superconducting properties of the GdBCO bulk had been investigated. It is found that the graded solid phase source pellet can be used to fabricate the large scale single domain GdBCO bulk successfully.

Primary author: Dr WANG, Miao (Shaanxi Normal University)

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Presenter: Dr WANG, Miao (Shaanxi Normal University)

Track Classification: CEC-06 - Superconducting Magnet Systems
Liquid Nitrogen Spray Cooling for Superconducting Power Cable

Tuesday, 30 June 2015 14:00 (2 hours)

Most modern-day high temperature superconducting (HTS) power systems are designed to immerse the entire cable in subcooled nitrogen, taking advantage of favorable thermal and electrical properties. This project investigates the use of nitrogen in two phases, gas and liquid. The latent heat of vaporization of nitrogen provides a means of absorbing heat leaked into the cryostat or generated in a power cable with without an associated temperature rise in the cryogen. Using this phase change approach cryostats of long length can be held at nearly constant temperatures using only fraction of the cryogen compared to a conventional sub-cooled liquid cryogen approach. This paper provides an overview of the demonstrator and its key design points, while discussing improvements planned for ongoing efforts.

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Presenter: Dr KEPHART, Jacob (Navy)

Session Classification: C2PoN - Cryogenic Power Cables and Leads II

Track Classification: CEC-08 - Cryogenic Power Cables and Leads
Cold head maintenance with minimal service interruption

Thursday, 2 July 2015 09:00 (15 minutes)

Turn-key superconducting magnet systems are increasingly conduction-cooled by cryogenerators. Gifford-McMahon systems are reliable and cost effective, but require annual maintenance. The most common maintenance method is to simply replace the cold head of the cryocooler with a re-conditioned one. For conduction-cooled magnets, the direct replacement method requires a complicated design with a vacuum chamber separate from the main vacuum of the cryostat, as well as detachable thermal contacts, which add to the thermal resistance of the conduction cooling path and reduce the reliability of the system.

We present a rapid warm-up scheme to bring the cold head body, which remains rigidly affixed to the cold mass, to room temperature, while the cold mass remains at cryogenic temperature. Electric heaters thermally attached to the cold head stations are used to warm them to room temperature. Rapid warm-up of the cold head body permits conventional cold head maintenance with no danger of contaminating the inside of the cold head body. This scheme increases the efficiency of the cooling system, facilitates annual maintenance of the cold head and return of the magnet to service with minimal interruption.

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Presenters: RADOVINSKY, Alexey (MIT Plasma Science and Fusion Center); MICHAEL, Philip (MIT Plasma Science and Fusion Center)

Session Classification: C4OrA - System Issues and Regenerator Performance

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Development of HTS induction/synchronous drive motor aiming for low carbon emission transportation systems

Tuesday, 30 June 2015 16:30 (15 minutes)

Our research group has developed 20 kW class High Temperature Superconductor (HTS) Induction/Synchronous Motor (HTS-ISM) for the realization of low carbon emission transportation systems, such as ship, train, bus, track, middle sized automobile. We have developed (1) high efficiency and high torque density HTS-ISM, (2) optimal operation code for the variable speed and/or torque control, (3) low thermal invasion and small sized cryostat and (4) high efficiency stirling-type cryocooler.

It was shown that the fabricated motor could realize rated output power of 20 kW at the synchronous mode rotation (1800 rpm). Furthermore, the motor showed the slip mode rotation with the output power of 26.8 kW, and this result indicates the realization of so-called "overload tolerance". The fabricated motor was also operated for the variable speed control, and the rotation stability was successfully clarified. Current status of Stirling-type cryocooler development is also to be presented and discussed.

This work has been supported by Japan Science and Technology Agency under the program of Advanced Low Carbon Technology Research and Development Program (JST-ALCA).

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Presenter: NAKAMURA, Taketsune (Kyoto University)

Session Classification: C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Transport testing of MgB2 and Nb3Sn solenoid coils for magnet applications

Advancements in superconducting wire manufacturing has enabled the design and fabrication of superconducting coils for practical magnet applications. To apply superconducting wire for most commercial applications requiring many kilometers of wire, long-length characterization in coil form is important. This study discussed the transport properties of two different solenoid coil wound with long length of MgB2 and Nb3Sn strands by Hyper Tech. The MgB2 coil was wound on a solenoidal 101 OFE copper former with 18” ID using the react-and-wind method. The stainless steel former with 30” ID was used for Nb3Sn coil. The strands were insulated with single S-glass braid insulation for both coils. The total lengths of conductor used for MgB2 and Nb3Sn coils were ~330 m and ~1.5 km, respectively. Transport Ic measurements were performed at various taps along the coil lengths. Measurements were made at various temperatures by conduction cooling. Homogeneity of response along the coils was investigated and a comparison to the short sample results was made. Temperature gradient of coil was also monitored for transition region between current leads and coil.

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Presenter: KIM, Hyun Sung (The Ohio State University)
Session Classification: C1PoK - Superconducting Magnets I
Track Classification: CEC-06 - Superconducting Magnet Systems
The ITER Central Solenoid (CS) coils utilize cable-in-conduit conductor (CICC) and the conduit alloy is JK2LB. The production grade conduit alloy (and it’s welds) must meet strict requirements for strength, toughness, fatigue crack resistance, and fabricability. The conduit alloy must retain good mechanical properties after additional fabrication steps such as welding, coil winding strain and exposure to the Nb3Sn superconductor’s reaction heat treatment. Here we present data from cryogenic tensile, fracture toughness, fatigue crack growth rate, and axial fatigue tests of JK2LB alloy and conduit butt welds, before and after the exposure to the reaction heat treatment. The tests of specimens removed directly from the conduit provide confirmation of the materials properties and its resistance to the effect of the cold work and aging. The 4 K fatigue performance is extremely important to the reliability of the CS is covered both by axial cyclic fatigue tests and the fatigue crack growth rate measurements.

Primary author: WALSH, Robert (Florida State University)
Co-authors: Mr MCRAE, Dustin (FSU/NHMFL); Dr KE, Han (NHMFL/FSU); MARTOVETSKY, Nicolai (Oak Ridge National Laboratory)
Presenter: WALSH, Robert (Florida State University)
Session Classification: M2OrD - Cryogenic Materials V: Structural Materials
Track Classification: ICMC-11 - Metallic and Composite Materials
[Invited] Effectiveness of laser striation for AC loss reduction in SuperOx coated conductor.

Monday, 29 June 2015 16:00 (30 minutes)

The physical properties of REBCO (RE=rare earth) high temperature superconductors require a flat tape architecture enabling them to carry high current densities. This architecture has an enormous ratio between the width and the thickness of the tape, typically ranging between 1,000 and 10,000. This very large aspect ratio has a detrimental effect on the AC losses, specifically the losses caused by the presence of an AC magnetic field perpendicular to the tape’s flat face. Since the magnitude of the magnetization loss is proportional to the square of the tape’s width, one obvious way to reduce it is by dividing the tape into narrow striations. This can be done either during the tape’s manufacture process or successively on the end product. Different techniques have been successfully applied on tapes with just a thin Ag layer on top of the superconducting film. Unfortunately, most CC applications require tapes with Cu stabilization and an effective method to reliably achieve striation on Cu-stabilized tapes needs to be optimized. For this purpose, we used pico-second laser to produce samples with different numbers of filaments from 12 mm-wide tape manufactured by SuperOx. In order to produce Cu-stabilized samples with filaments, two different approaches were followed: 1) striation of Ag-stabilized coated conductor followed by electroplating; 2) striation of already Cu-stabilized coated conductor with different copper thicknesses. In this work the results of the different approaches will be shown and compared by means of microscopic analysis as well as of DC current and AC loss characterization. These results are expected to provide useful insight on the efficiency of this technique to produce application-ready low-loss coated conductors.

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Presenter: Dr KARIO, Anna (Karlsruhe Institute of Technology, Institute for Technical Physics)

Session Classification: M1OrC - Superconductor Stability and AC Losses

Track Classification: ICMC-08 - Superconductor Stability and AC Losses
ADVANCED AND ENERGY SAVING THERMAL INSULATIONS FOR CRYOGENIC APPLICATIONS

Monday, 29 June 2015 16:30 (15 minutes)

The power consumption in large scale superconducting devices is due to the refrigeration system and the cryogenic devices used in special applications often require an extremely long cryogen holding time. All cryogenic devices and superconducting instruments, regardless of size, small, large or huge, are all working at cryogenic temperature. To economically maintain the device at its operating temperature and minimize the refrigeration losses, high performance thermal isolation is essential. This includes the thermal insulation system as well as minimizing heat leaks from penetrations and supports. The current advanced developments of various cryogenic thermal insulation technologies are briefly and systematically introduced, discussed and reviewed in the paper as follows:

1. Highly thermal efficient and energy saving cryogenic transfer lines for LH2 and LHe.
2. Advanced designs to reduce the heat transfer through sophisticated support structures in large accelerator magnets, SRF cavities, detectors and electric power leads.
3. The traditional evacuated powers insulation and newly developed aerogels insulation for large scale cryogenic tanks and special applications.
4. The performance, materials and design combinations of various super-insulations (MLI) for commercial products and research labs.
5. The specific design and implements of MLI with various penetrations, slots and cracks in its MLI for large cryogenic applications.
6. The development of novel thermal isolation devices, such as the energy efficient cryogenic transfer line with magnetic suspension; a smart cryogenic actuator as the warm support structure automatically operated by temperature changes; superconducting thermal switch for interception of heat transfer, etc. are also briefly reviewed.

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Presenter: Dr SHU, QuanSheng (Retired Senior Scientist)
Session Classification: C1OrF - Thermal Insulation Applications and Measurements
Track Classification: CEC-14 - Thermal Insulation Systems
Persistent Current Characteristics at Temperatures Below 77K in Closed Superconducting Loops Made Out of RE123 Coated Conductors

Tuesday, 30 June 2015 17:45 (15 minutes)

We will report recent experimental observations of persistent current in closed loops made out of the currently manufactured coated conductors. Two types of coated conductors were investigated. One was developed for high magnetic field application and the other for cable applications. Data was taken in the range of 23K to 38K with the persistent current being induced by field cooling the loops and then turning off the external field. The relaxation rate in this temperature range is very low and these results suggest that coated conductors can be considered as a viable option for persistent current applications such as energy storage, MRI magnets, and magnetic levitation. We also obtained the values of the persistent critical current as determined by a slow warming of the loops and monitoring the magnetic field created by the circulating current. These values will be compared with the resistive critical current usually specified by the manufacturers.

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Presenter: Dr RONG, Charles (U.S. Army Research Laboratory)

Session Classification: M2OrC - Superconductor Wires II: Coated Conductors and Applications

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Bi2Sr2CaCu2Ox (Bi2212)/Ag multifilamentary wires are manufactured via the powder-in-tube process using metallic precursors (MP). After deformation, the MP is converted to Bi2212 by heating in flowing oxygen. Previous results on pellets show that via mechanical alloying, a controlled stoichiometry and homogeneous MP powder was synthesized. The MP powder was then converted to superconducting Bi2212 through a simple two-step heat treatment. By introducing oxygen at a temperature at which Bi2212 is a stable phase, and holding at an elevated temperature for a sufficient time, the metallic precursors were oxidized and transformed into Bi2212. Here, several factors that impact the formation and growth of Bi2212 grains are discussed. Furthermore, a multifilamentary wire containing metallic precursors is made, heat treated and analyzed. Results of chemical analysis, transport properties, magnetic behavior, microstructure and phase assemblage of metallic precursors and heat treated wires are reported.

Primary author: Ms ZHANG, YUN (North Carolina State University)

Co-authors: Prof. SCHWARTZ, Justin (north carolina State University); Prof. KOCH, carl (north carolina state university)

Presenter: Ms ZHANG, YUN (North Carolina State University)

Session Classification: M3OrC - Superconductor Wires V: BSCCO Processing and Properties

Track Classification: ICMC-03 - BSCCO Processing and Properties
Effects of oxygen doping on vortex pinning and connectivity in highly dense Bi-2212 round wire

Wednesday, 1 July 2015 14:30 (15 minutes)

It is now understood that the critical current density $J_c$ of Bi-2212 is optimized when the density of the filaments is maximized by overpressure processing. What is not yet clear is the way that the intrinsic current density determined by vortex pinning may be compromised by poor connectivity. Overpressure processing almost completely removes obstructions to the current path introduced by voids, but the potential for blockage at grain boundaries remains, although it is largely unknown. The recent demonstration by Kametani et al. that there is a strong biaxial growth texture in Bi-2212 in principle suggests that grain boundary blocking is significantly reduced compared to Bi-2223 where only uniaxial texture is possible. Here we describe a set of experiments in which we vary the doping state after OP reaction. Varying the doping state from the underdoped to the overdoped state should strongly decrease the electronic anisotropy, increase the vortex stiffness, and thus increase the vortex pinning contribution to $J_c$. We follow these changes in vortex pinning strength by measuring the change in irreversibility field with doping state, finding that indeed the irreversibility field increases significantly as we moved to the overdoped state. Measurements of the transport current and magnetization hysteresis at 4K are also maximized as we over dope the material. We are also trying to follow changes in the connectivity using measurements of the critical current hysteresis to give us insight into whether overdoping is also enhancing the connectivity across grain boundaries. We will report on these detailed experiments at the conference.

The work at the NHMFL was supported by the US Department of Energy Office of High Energy Physics under DE-SC0010421, by National Science Foundation Cooperative Agreement No. DMR-1157490, and the State of Florida.

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Presenter: OZ, Yavuz (National High Magnetic Field Laboratory)

Session Classification: M3OrC - Superconductor Wires V: BSCCO Processing and Properties

Track Classification: ICMC-03 - BSCCO Processing and Properties
S.S. Cored 27-strand Nb3Sn Rutherford Cable was pressed onto a U-shaped holder and kept at magnet-relevant conditions throughout reaction, instrumentation, epoxy-impregnation, and measurement. Current was injected into a single strand of the cable under applied fields up to 15 Tesla and with varying I/Ic. Then, a graphite-paste heater pulse was used to initiate current sharing. ICR and current sharing was then measured using a hall-probe array and voltage taps. These measurements were performed using a small research magnet and are screening for cable and cable preparation protocol for larger scale measurements.

Primary author: KOVACS, Chris (Ohio State University)

Co-authors: Prof. COLLINGS, Edward (Ohio State University); Prof. SUMPTION, Michael (Ohio State University)

Presenter: KOVACS, Chris (Ohio State University)

Session Classification: M1PoA - Superconducting Materials and Applications

Track Classification: ICMC-08 - Superconductor Stability and AC Losses
A Cryogen Recycler with Pulse Tube Cryocooler for Simultaneously Recondensing Helium and Nitrogen

Thursday, 2 July 2015 09:15 (15 minutes)

Liquid helium cooled NMR magnets often use liquid nitrogen cooled radiation shields. Among these NMR magnets cryogen boil-off rates of 3L/day of liquid helium and 6L/day of liquid nitrogen are common. We have developed a cryogen recycler for closed loop operation of the helium and nitrogen circuits. With these closed loops, the recycler maintains zero boil-off of both helium and nitrogen.

The recycler uses a 4 K pulse tube cryocooler, Cryomech model PT407. The PT407 cryocooler has simultaneous cooling capacities of >0.7W at 4.2 K and >25W at 55 K. The recycler has two liquid return legs for liquid helium and liquid nitrogen respectively, which are inserted into the fill ports of the helium and nitrogen reservoirs. The first stage of the PT407 is used to recondense nitrogen boil-off at 77K. The 4 K stage of the PT407 is used to re-liquefy helium vapor.

The recycler was tested at Cryomech and demonstrated recondensing performance of 7.8 L/day of nitrogen while simultaneously re-liquefying 3.3 L/day of helium. The recycler has been installed in an NMR magnet at the University of Sydney for 6 months, where it is operating smoothly and maintaining zero cryogen boil-off.

Primary author: Dr WANG, Chao (Cryomech)
Co-author: Mr LICHTENWALTER, Benjamin (Cryomech)
Presenter: Dr WANG, Chao (Cryomech)
Session Classification: C4OrD - Novel Concepts and New Devices III
Track Classification: CEC-17 - Novel Concepts and New Devices
Thermal-hydraulic analysis of transients in the HELIOS loop including a CICC section

Wednesday, 1 July 2015 09:00 (2 hours)

The HELIOS facility at CEA Grenoble is a supercritical helium (SHe) loop for the study of pulsed heat loads effects on the cryogenic cooling system as typical of superconducting tokamak operation. In order to avoid instabilities in the refrigerator, mitigation strategies with a thermal buffer have been investigated to smooth the pulsed heat loads.

In the standard HELIOS configuration no cable-in-conduit conductors (CICC) are present and the pulsed heat loads are generated through electrical heaters wrapped around a section of the cryolines. In such configurations the 4C code was shown in the recent past [R. Zanino et al, CEC 2013] to be able to accurately reproduce and even predict the thermal-hydraulic behaviour of the HELIOS loop in different configurations.

In the present work, the heated pipes are substituted in the 4C HELIOS model by an equivalent multi-channel volume made of JT-60SA CICC. The model is then used to highlight the differences between simple heated pipes and an actual magnet wound with CICCs, checking the representativity of the present HELIOS configuration. New drivers are used such as the non-homogeneous distribution of the heat loads on the multi-channels. Their effects on the dynamic behaviour of the SHe loop (pressure, temperature, mass flow) are studied with the new model. The results of the present work will highlight new features which do not arise in the present HELIOS configuration: redistribution and additional smoothing of the pulsed heat loads, distribution of the flow in multi-channels (bundles and central channels) in parallel, local acceleration/deceleration of the flow when pulsed loads are applied on the CICC strands and jacket.

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Presenter: ZANINO, Roberto (politecnico di torino)

Session Classification: C3PoD - Superconducting Magnets Cryogenic Systems I

Track Classification: CEC-06 - Superconducting Magnet Systems
Tokamak-type nuclear fusion reactors like ITER, under construction in France, use superconducting (SC) magnets cooled by supercritical helium (SHe) to confine the plasma. The small temperature margin available between operation and quench of the magnet requires a careful design of the magnet operating scenarios to guarantee adequate cooling in all phases. Sophisticated thermal-fluid dynamic models are available for that, e.g. the 4C code [L. Savoldi Richard, et al., Cryogenics 2010], but they are computationally very expensive. Therefore cheaper alternatives are needed, if real-time control has to be achieved.

Soft computing techniques, like Artificial Neural Networks (ANNs), were recently applied for the first time by our group to the problem of the cooling of the ITER SC magnets in the absence of controls [L. Savoldi Richard, et al., Cryogenics 2014] to predict the global evolution of the heat load to the cryoplant during plasma operation.

Here we concentrate on the ITER Toroidal Field (TF) coils, and we show how an ANN-based model of the coil, suitably inserted in the 4C TF circuit models and capable to cope with control/regulation of the cooling circuits, can be used to investigate and test control strategies for mitigation of the heat load from the coils to the cryoplant. The strategies are based on the opening of the bypass valve or on the variation of the cold circulator speed in the casing cooling loop. The results obtained using the ANN model are compared with those fully based on the 4C model in order to assess the accuracy of the model, and the computational time needed is checked to guarantee the applicability to real-time control.

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**Session Classification:** C3OrF - Superconducting Magnets Cryogenic Systems II

**Track Classification:** CEC-06 - Superconducting Magnet Systems
Assessment of Critical Factors Affecting the Performance of Trapped Field Magnets using Thin Film Superconductor Tapes

Wednesday, 1 July 2015 09:00 (2 hours)

Thin film superconductor tapes are composites with 98% metallic content and so, Trapped Field Magnets (TFMs) using such tapes can be much more robust than those using bulk superconductors. Trapped magnetic field profiles were investigated in Zr-added (Gd,Y)Ba2Cu3Ox tapes stacked in a criss cross configuration with three 12 mm wide tapes per layer. A crisscross arrangement of the tapes was found to yield a more uniform trapped field profile than a straight arrangement. Also, the decay of the trapped field with increasing distance from the tape stack surface was found to be less in the crisscross arrangement. Among tapes with 0%, 7.5% and 15% Zr addition, those with 7.5% Zr addition led to the highest trapped magnetic field at 77 K. Also, the trapped field increases and the time dependent decay of the trapped field decreases with increasing number of layers of tapes in the stack. A logarithmic time-dependent decay of trapped field was observed in all tape stacks, consistent with thermally-activated flux creep. The profiles and the magnitude of the trapped fields obtained from the simulation match well with those obtained experimentally. At all temperatures from 30 to 77 K, the trapped field values increase non-linearly with increasing number of layers in the stack. Further, the maximum trapped field values from simulation increase with decreasing tape thickness from 0.055 mm to 0.02 mm i.e. with increasing number density of tapes in the stack. Unexpectedly, at 77 K, a sharp rise in trapped field values was seen at a tape thickness of 0.03 mm. Trapped field values at 77 K at 1 mm from the surface of stacks with 0.02 mm tapes reached nearly 2 Tesla in the simulation, which is above that feasible with permanent magnets.

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**Presenter:** Ms SELVA, Kavita (Clear Lake High School)

**Session Classification:** M3PoA - Superconductor Materials IV: Properties and Applications

**Track Classification:** ICMC-02 - RE123 Conductors Processing and Properties
Synthesis of Bi2Sr2CaCu2Ox oxide precursor from nano-oxides and its relationship with multifilamentary wire transport properties

Wednesday, 1 July 2015 15:30 (15 minutes)

Bi2Sr2CaCu2Ox (Bi2212)/Ag multifilamentary wires are manufactured via the powder-in-tube process using oxide powders. The properties of the precursor powders, including stoichiometry, purity, grain size and morphology, packing density and phase assembly, have significant impact on wire properties after heat treatment. Most research has focused on the processing of wire after deformation due to limited control of the precursor powders, resulting in several challenging, unsolved problems. In particular, inconsistency in stoichiometry, content of carbon residue and Bi2Sr2CuOy (Bi2201) impurity of the precursor powders limit wire transport. Here, nano-size oxides produced by NanoSpray CombustionTM (nGimat, LLC) are used as starting materials to synthesize Bi2212 oxide precursors via solid-state calcination. After calcination, high purity Bi2212 powders with controllable stoichiometries, ultra-low carbon content and absence of Bi2201 are produced. In our study, properties of nanosize oxides, general trend of processing parameters of Bi2212 precursor powders and their influence on precursor properties including stoichiometry, phase transformation, carbon content, grain size and morphology are discussed. Furthermore, multifilamentary round wires are made from these powders, melt processed and analyzed. Results of transport property, magnetic property, microstructures and phase assemblage correlated to precursor properties are reported.

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Presenter: ZHANG, YUN (North Carolina State University)

Session Classification: M3OrC - Superconductor Wires V: BSCCO Processing and Properties

Track Classification: ICMC-03 - BSCCO Processing and Properties
Commercialization of a Turbo-Brayton cycle refrigerator for HTS power applications

Monday, 29 June 2015 09:00 (2 hours)

Approaching to commercializing of High Temperature Superconducting (HTS) power applications is becoming more active. And cooling system is very important and essential for practical HTS power applications. HTS power applications on commercial scale will require cooling system which has cooling capacity from 2kW to 10kW at 65K, high reliability (long maintenance interval) and compactness. Taiyo Nippon Sanso Corporation (TNSC) is developing a turbo-Brayton cycle refrigerator using neon gas as working fluid (Neon-Refrigerator) for HTS power applications. And a 2kW class Neon-Refrigerator has been marketed in May 2013. Some Neon-Refrigerators were supplied for cable projects in Japan. Furthermore, development of 10kW class Neon-Refrigerator is under going. Detail of commercial type 2kW class Neon-Refrigerator and present status of development of 10kW class Neon-refrigerator will be introduced in this presentation.

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Session Classification: C1PoA - Cryogenics for Power Applications, Energy, Fuels and Transportation I

Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation

December 4, 2021
Impact of Cryogenic/Superconducting Components for Hybrid-Electric Aircraft Propulsion

Tuesday, 30 June 2015 16:15 (15 minutes)

Hybrid-electric-vehicle (HEV) or electric-vehicle (EV) propulsion is well understood from the automotive industry, and achieves very significant increases of energy efficiencies of 2-3x from the use of non-combustion technologies and ‘smart’ energy management including brake regeneration. The possibility of battery-electric and hybrid-electric propulsion for aircraft has increasingly been considered in the last 5 years, and has been successfully implemented in 2 and 4 passenger aircraft. This paper will summarize recent progress in this field for aircraft, and present impact studies of how cryogenic/superconducting components can positively impact hybrid-electric or all-electric power systems and capabilities, for different size and power level aircraft. Drivetrain components studied include generators and motors, power transmission cables, power storage devices including Li-batteries and superconducting magnetic energy storage (SMES), power electronics including inverters, and cryogenic technologies. Properties of cryogenic systems and components will be compared to Cu-wire or conventional based systems.

Acknowledgments: Air Force Office of Scientific Research (AFOSR), and Aerospace Propulsion Directorate of The Air Force Research Laboratory (AFRL/RQ).

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Presenter: HAUGAN, Timothy (U.S. Air Force Research Laboratory)
Session Classification: C2OrH - Cryogenics for Power Applications, Energy, Fuels and Transformation II
Track Classification: CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
Computational Investigation of Superconducting Magnetic Energy Storage (SMES) Devices to Maximize Energy Density

Monday, 29 June 2015 14:00 (2 hours)

Superconducting magnetic energy storage (SMES) devices offer attractive and unique features including no theoretical limit to specific power, high cycling efficiencies and charge/discharge rates, and virtually no degradation with cycling. The mass specific energy density (MSED) of SMES systems; however, falls short of many needs. This paper examines SMES energy densities of solenoid-type magnets for YBCO, MgB2 and Nb3Sn using present-manufactured wires and future advancements predicted from lab-scale samples. Scaling of maximum energy density with the stored energy, length of the conductor and radius of the bore were established with numerical simulations, and studied for a range of stored energies from 0.1 MJ to 250 MJ and operating temperatures of 4.2, 18, 40 and 65 K. With dependence of critical current on field taken into account, the optimum magnet design for varying superconducting wires also including H//c is a pancake coil with scaling of energy density $\epsilon \sim E^{1/3}$. Thus, current and magnetics limits achievable $\epsilon$ only at a fixed $E$. The overall limit on $\epsilon$ is also imposed by the virial theorem. Without additional structural support $\epsilon$ of SMES magnets is limited to $\sim 30$Wh/kg. However with introduction of light-weight and strong support materials the upper limit MSED of SMES is expected to exceed that of the best batteries $\epsilon \sim 150$ Wh/kg.

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Session Classification: M1PoC - Cryogenic Electronics
Track Classification: ICMC-15 - Cryogenic Low and High Power Electronics
Optimizing Flux Pinning of YBa2Cu3O7-δ (YBCO) Thin Films with Unique Large Nanoparticle Size and High Concentration of Y2BaCuO5 (Y211) Additions

Addition of second-phase nanosize defects to YBa2Cu3O7-x(YBCO) superconductor thin films is known to enhance flux pinning and increase current densities (Jc). The addition of Y2BaCuO5 (Y211) was studied previously in (Y211/YBCO)N multilayer structures, and in Y211+YBCO films deposited from pie-shaped targets. This research systematically studies the effect of Y211 addition in thin films deposited by pulsed laser deposition from YBCO1-xY211x (x = 0 - 20 vol. %) single targets, at temperatures of 785 - 840 °C. Interestingly, the resulting size of Y211 particles is 20 to 40 nm, with reduced number density. This is in contrast to 10 to 15 nm in previous studies of Y211, and 5 - 10 nm for other 2nd-phase defect additions. A slight increase of Jc(H,T) was achieved, compared to previous optimization studies. Results and comparisons of flux pinning, intrinsic stresses imaged by TEM, current densities, critical temperatures, and microstructures will be presented. The overall low intrinsic stress on YBCO from Y211 lattice mismatch is smaller than previously studied 2nd-phase defect additions known, which is hypothesized to be the driving force in achieving the unusually large 2nd-phase nanoparticle size and volume fraction thus-far in YBCO thin films.

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Presenter: HAUGAN, Timothy (U.S. Air Force Research Laboratory)
Session Classification: M1PoA - Superconducting Materials and Applications
Track Classification: ICMC-10 - Flux Pinning and Critical Current
Optimizing Flux Pinning of YBCO Thin Films with BZO + Y2O3 Double-Mixed Phase Additions

Monday, 29 June 2015 09:00 (2 hours)

Adding nanophase defects to YBa2Cu3O7-z (YBCO) superconductor thin films is well-known to enhance flux pinning, resulting in an increase in current density (Jc). While many previous studies focused on single phase additions, the addition of several phases simultaneously shows promise in improving current density by combining different pinning mechanisms. This paper encompasses the effect of the addition of insulating, nonreactive phases of barium zirconium oxide (BZO) and yttrium oxide Y2O3. Processing parameters varied the target composition volume percent of BZO from 2 - 6 vol. %, while maintaining 3 vol. % Y2O3, and the remaining vol. % YBCO. Pulsed laser deposition produced thin films on LaAlO3 (LAO) and SrTiO3 (STO) substrates at various deposition temperatures. Comparison of strong and weak flux pinning mechanisms, current densities, critical temperatures, and microstructures of the resulting films will be presented.

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Presenter:  HAUGAN, Timothy (U.S. Air Force Research Laboratory)

Session Classification:  M1PoA - Superconducting Materials and Applications

Track Classification:  ICMC-10 - Flux Pinning and Critical Current
Quench detection via Rayleigh scattering based fiber optic distributed sensors

A novel quench detection method is developed and tested using optical fibers as distributed sensors of temperature and strain. In particular, the technique is based on the comparison of Rayleigh backscattering signals of a reference and perturbed state. A spectral shift quantifies the mismatch between the two conditions, which depends on temperature and strain changes between the two compared states. Several HTS coils have been fabricated and instrumented with voltage taps, thermocouples and an embedded heater to initiate a quench. An optical fiber has been co-wound with YBCO tape using different schemes. The results showed that the spectral shift correlates with normal zones developed in the coil. In all the experiments the fiber optic based detection system was able to rapidly detect and locate normal zones, with very high spatial resolution (5 mm) and fast measurement (a measurement cycle lasts 30 ms). Moreover, the spectral shift raised as soon as a thermal perturbation occurred, without any time delay whatsoever, whereas the voltage signal started rising only after the temperature crosses Tc. The combination of high spatial resolution (5 mm) and high speed (a measurement cycle lasts 30 ms) allowed for a very rapid detection and localization of a hotspot. These capabilities enable the use of a minimum propagating zone (MPZ) as a criterion to identify unstable (propagating) normal zones, instead of the conventional threshold voltage.

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Presenter: SCURTI, Federico (NC State University)
Session Classification: M2PoB - Cryogenic Materials III: Testing and Methods
Track Classification: ICMC-08 - Superconductor Stability and AC Losses
Effect of Transport Current on Magnetization of an IBAD Coated Conductor

Wednesday, 1 July 2015 09:00 (2 hours)

In this work susceptometry was used to measure the magnetization, as a function of transverse applied magnetic field, sample temperature, and transport current of an IBAD coated conductor. The M-H loops of four samples of the conductor which had different lengths (from 12-4 mm), and which were approximately 3 cm in length and approximately 100 µm in thickness, were measured. The widths were modified so that the M-H loops could be measured at different I/Ic ratios (from 0.1-1). The susceptometry setup was constructed by modifying a transport current probe with the addition of a rectangular pickup coil and a Bucking coil to its end. The region of the probe containing the sample was placed into the center of a 12 T max field cryogen-free magnet, which was the source of the applied magnetic field. Two different techniques were used to measure the M-H: (1) The transport current was applied and then the magnetic field was increased and (2) the field and current were increased at the same time with a given proportionality constant between the current and field. M-H was measured in applied transverse magnetic fields of 0-12 T, sample temperatures of 4.2 K and 77 K, and transport currents of 0-100 A. The results of the measurements are presented.

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Presenter: MYERS, Cory (Ohio State University)

Session Classification: M3PoA - Superconductor Materials IV: Properties and Applications

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
In this paper, we try to develop highly efficient Stirling-type cryocooler for the next generation drive motor. Target motor is a High Temperature Superconducting Induction/Synchronous Motor (HTS-ISM). Although basic structure of HTS-ISM is almost the same as that of the conventional squirrel-cage induction motor, it can rotate at synchronous speed by use of the superconducting rotor windings. It has been clarified that the torque density can be enormously enhanced at the synchronous rotation. By enhancing torque density, it is possible to realize the direct-driven operation without transmission gears. The transmission system brings some loss because the gears always rotate during the driving. In order to improve the overall energy conversion efficiency of power-train system, the direct-drive motor is expected to be realized.

On the other hand, HTS-ISM has been operated in liquid nitrogen. This method, however, has several disadvantages such as the mechanical loss due to the viscosity of liquid nitrogen, the safety reason, etc. Therefore, we have studied the conducting cooling system. It is necessary to develop small sized high power cryocooler in order to realize the high efficiency of overall HTS-ISM power-train system. Generally speaking, Stirling-type cryocooler has advantages in terms of size and efficiency.

We firstly designed, fabricated, and tested the actuator at various frequency and in several wave patterns, and we realized the high efficiency of the actuator. Next, we set up pulse-tube cryocooler to this compressor, and measured the cooling capacity of this Stirling-type cryocooler. Experimental and analysis results are to be reported and discussed.

This work has been supported by Japan Science and Technology Agency under the program of Advanced Low Carbon Technology Research and Development Program (JST-ALCA).

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Presenter: Mr WATANABE, Jun (Kyoto University)
Session Classification: C1OrA - Cryocoolers for Superconducting Applications
Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)
Dimensional Changes of Nb3Sn Cables during Heat Treatment*

Tuesday, 30 June 2015 16:45 (15 minutes)

The LHC-Accelerator Research Program (LARP) has been designing and fabricating R&D magnets for the High Luminosity Upgrade (U.S.-Hi-Lumi) for over ten years. The magnets require keystoned Nb3Sn Rutherford cables in minimum unit lengths of up to 500 m. The cables are fabricated from wires with different diameter and filament layouts of RRP® fabricated by Oxford Superconducting Technology. During heat treatment the cable dimensions change: the cable typically becomes thicker, wider, and shorter, if not constrained. This paper compares the dimensions of cables in a reacted potted coils to those measured on cables reacted in tooling that leave the cable un-constrained.

This work was supported by the Director, Office of Science, High Energy Physics, U.S. Department of Energy under contract Nos. DE-AC02-05CH11231 and DE-AC02-98CH10886.

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Session Classification: C2OrF - Superconducting Magnets II
Track Classification: CEC-06 - Superconducting Magnet Systems
Obatining of Massive MgB2 superconductor

Magnesium diboride bulk superconductor samples (targets) with a diameter >50 mm has been obtained in an induction furnace, using hot press and spark-plasma synthesis methods. Those methods enable to obtain small diameter (up to <25 mm) samples without any difficulties by gradual temperature increase 20-10500°C during 5-12 minutes. Increased diameter (>50 mm) of the samples reveal a number of problems. Despite the fact that big diameter samples phase content is like small ones, their porosity is increased and in some cases samples crashed wholly. Homogenization and activation of powders were conducted in a planetary nano-mill by WC balls in an inert area. Pressing of the obtained powders was conducted in an argon atmosphere. MgB2 nonstoichiometric powders contained excess boron and magnesium. Magnesium hydride was used as source of excess magnesium, which is fragile compound and easy to grind in nano-mill. It decomposites with metallic magnesium and hydrogen up to 280°C temperature. Powders systems of MgB2-Mg, MgB2-MgH2,MgB2-B has been pressed at the pressure p=100 MPa. The targets were cylinders with diameters of 10-52mm and height of 5-15mm. Phase content of the obtained targets were established by XRD method after dry polishing in Glove Box. Superconducting characteristic of the obtained samples were measured by vibrational magnetometer. The superconducting transition with an onset at 39K was observed in a good agreement with the results of the other groups obtained on samples prepared by conventional techniques.

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Track Classification: ICMC-04 - MgB2 Processing and Properties
The Processing of Bulk, Melt Processed (RE)BCO Superconductors with World Record Fields

Monday, 29 June 2015 16:00 (30 minutes)

(RE)-Ba-Cu-O [(RE)BCO, where RE = rare earth element such as Y, Nd, Sm, Eu, Gd, etc.] high temperature superconductors (HTS) have significant potential for high field engineering applications at 77 K when fabricated in the form of large single grains by the so-called top seeded melt growth process (TSMG). A novel Y2Ba4CuMOy (Y-2411, where M = U, Zr, Hf, Nb, Ta, W and Mo) phase that is effective at pinning magnetic flux quanta in bulk (RE)BCO HTS on the nm scale has been developed at Cambridge with a number of desirable properties, including crystallographic compatibility with the superconducting (RE)Ba2Cu3O7 (RE-123) phase, chemical stability at the melt processing temperature and an ability to resist coarsening during the melt process. This novel phase, which is more effective at pinning flux than the RE2BaCuO5 (RE-211) phase produced as a by-product of the melt growth process, has been used to develop a practical processing method for the fabrication in air of large, single grain RE-Ba-Cu-O superconductors. The process also includes a new type of generic seed crystal (Mg-doped NdBCO) that can promote effectively the epitaxial nucleation of any (RE)-Ba-Cu-O system and secondly by suppressing the formation of (RE)/Ba solid solution in a controlled manner within large (RE)BCO grains processed in air. This process has enabled fabrication of single grain samples of GdBCO that exhibit a record trapped field of 17.6 T at 26 K. The recent development of multi-seeding and recycling techniques for the fabrication of larger sample of conformal geometry has improved further the prospects of these technologically important materials for practical applications.

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Presenter: CARDWELL, David (University of Cambridge)
Session Classification: M1OrD - Superconductor Materials I: Bulk and New Materials
Track Classification: ICMC-06 - HTS and MgB2 Bulk
Multi-slope warm-up calorimetry of Integrated Dewar-Detector Assemblies

Boil-off isothermal calorimetry of Integrated Dewar-Detector Assemblies (IDDA) is a routine part of their acceptance testing. In this traditional approach, the cryogenic liquid coolant (LN2, typically) is let to naturally boil and evaporate from the cold well to the atmosphere; the parasitic heat load is then evaluated as the product of the latent heat of vaporization and the “last drop” boil-off rate monitored by the mass flow meter. The inherent limitation of this technique is that calorimetry may be performed at only the fixed, namely boiling, temperature of the chosen liquid coolant. There is a need, therefore, in using other (often exotic) cryogenic liquids when calorimetry at other than 77K temperature is needed. Further drawbacks are related to the transitional type of last drop boiling manifesting itself in bubbles explosions and geysering; this results in uneven flow rate and also affects natural temperature gradient along the cold finger. Additionally, the mass flow meters are known to have limited measurement accuracy and repeatability.

The above especially holds true for the advanced High Operational Temperature IDDAs typically featuring short cold fingers and working at 150K and above. The authors make adaptation of the well-known technique of dual-slope calorimetry. They show how the accurate calorimetry may be performed by precooling IDDA and comparing the slopes of the thermal transient processes during the warm-up at different trial added heat loads. Because of the simplicity, accuracy and ability to perform calorimetry literally at any temperature of interest, this technique shows good potential of replacing the traditional boil-off calorimetry.

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Session Classification: C2PoL - Thermal Fluids (Aerospace Applications)
Track Classification: CEC-12 - Fluid Mechanics, Heat Transfer, and Cryogen Properties
Toward Further Improvements in the Powder-In-Tube Process.

Powder-in-Tube (PIT) Nb3Sn conductors have been fabricated. In this paper, we determine the effect of the nanoscale alumina on strengthening the tin through milling as a function of time to better match the mechanical properties of the Matrix NbTa. A closer match of the tin cores to the NbTa matrix is expected to help in uniform processing to achieve concentric tin cores. Characterization of the microstructure and non-Cu critical current density with applied field is presented.

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**Presenter:** Dr MOTOWIDLO, Leszek (SupraMagnetics, Inc.)

**Track Classification:** ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Study of Thermocurrents in SCRF cavities via measurements of the Seebeck Effect in niobium, titanium, and stainless steel thermocouples

Tuesday, 30 June 2015 14:00 (2 hours)

The goals of Fermilab’s Superconductivity and Radio Frequency Development Department are to engineer, fabricate, and improve superconducting radio frequency (SCRF) cavities in the interest of advancing accelerator technology. Improvement includes exploring possible limitations on cavity performance and mitigating such impediments. This report focuses on investigating and measuring the Seebeck Effect observed in cavity constituents titanium, niobium, and stainless steel arranged in thermocouples. These junctions exist between cavities, helium jackets, and bellows, and their connection can produce a loop of electrical current and magnetic flux spontaneously during cooling. Such currents could induce trapped flux in cavity surfaces, and lead to loss of quality factor after cool down. Our findings show that welded junctions behave differently than intrinsic junctions, perhaps due to inter-diffusion of elements. An estimate of thermally-induced current is made from the observed voltages and resistivity of the components.

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Presenter: COOLEY, Victoria (University of Wisconsin-Madison)
Session Classification: M2PoD - Cryogenic Materials IV: Physical Properties
Track Classification: ICMC-01 - NbTi/Nb3Sn/A15 Processing and Properties
Pulsed activation studies previously done on zero-field-cooled high Jc YBCO bulks have exhibited giant field leaps (GFL), among other anomalies.[1] Additional experiments, with varying Jc, have now been performed, searching for regularities to illuminate the underlying physics. Thirty single-grain melt-textured YBCO samples with varying Jc (6,700 ≤ Jc ≤ 60,000 A/cm² at 77 K) were prepared. These had dominant pinning centers (PCs) of either broken-columnar or point geometry. GFL was observed for all samples with Jc ≥ 15,000 A/cm². Results showed that PC geometry does not modify GFL magnitude or systematics, at least to first order. The threshold of the field leap, measured 2 minutes after the pulse, was found to decrease monotonically with increasing Jc. The magnitude of the field leap was found to increase monotonically from zero at Jc = 60,000 A/cm² to ~3 Tesla at highest Jc. The Bean model rule that the ratio of applied field, BA, required to activate maximum trapped field, BT,max, is BA/BT,max ≥ 2. We find this rule holds only for Jc < 10,000 A/cm². BA/BT,max decreases sharply at about the same value of Jc which initiates GFL, and has a value of ~1.2 at the highest value of Jc. It is difficult to reconcile results with the critical state model (CSM). We suggest that two dominant GFL modifications are needed. Creep, at short times is a "cascade" not a "creep," and the very large Lorentz force, FL ∝ Jc × B, enhances the fluxoid cascade. These effects combine to cause large internal flux transfers whereas the CSM assumes no internal flux transfer.


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**Presenter:** WEINSTEIN, Roy (University of Houston)

**Session Classification:** M1OrD - Superconductor Materials I: Bulk and New Materials

**Track Classification:** ICMC-10 - Flux Pinning and Critical Current
The Role of Cryogenics in the U.S. Hydrogen Bomb Program and Vise Versa

Tuesday, 30 June 2015 08:15 (45 minutes)

Research on the H-bomb (called the “super” during early work) began at a low level at Los Alamos National Laboratory during the early- to mid-1940s as part of the Manhattan Project. Theorists felt the thermonuclear reaction within liquid deuterium was the simplest and best understood at that time. On January 31, 1950, President Truman gave the order to pursue the H-bomb, which resulted in an arms race with the Soviet Union at a cost of trillions of dollars. Another outcome was the construction of the world’s largest hydrogen liquefier (320 L/hr) at that time, along with the establishment of the NBS Cryogenic Engineering Laboratory (CEL) in Boulder. A duplicate liquefier on Eniwetok Atoll in the Marshall Islands of the Pacific was used to liquefy deuterium gas generated from electrolysis of heavy water at NBS CEL and shipped to Eniwetok. The first full-scale test of thermonuclear fusion used a liquid deuterium secondary enclosed inside a thick steel shell containing the fission primary. Details of the massive cryogenic program, including declassified video clips, leading up to the test of this “wet” device will be discussed. The yield of 10.4 Mt in the November 1, 1952, Ivy Mike test was about 500 times that of the WWII fission bombs. During the next year and a half, lighter versions of the “wet” device were under development, but their tests were cancelled after the success of the first “dry” bomb that used lithium deuteride. Funding from the Atomic Energy Commission for further cryogenic research pertaining to weapons quickly evaporated, but the newly acquired expertise at NBS in liquid hydrogen and cryogenics in general was put to good use in the space program, which had just begun, and in some other classified programs. The first Cryogenic Engineering Conference held at NBS/Boulder in September, 1954, was organized because of the need to quickly spread the word about the cryogenic expertise available to new programs. Some of the significant cryogenic advances that came out of the H-bomb program will be discussed.

Primary author: Dr RADEBAUGH, Ray (National Institute of Standards and Technology)

Presenter: Dr RADEBAUGH, Ray (National Institute of Standards and Technology)

Session Classification: C2PL - Tuesday CEC Plenary Session - sponsored by Cryomech, Inc.

Track Classification: CEC-02 - Large-Scale Systems, Facilities, and Testing
Bulk Superconducting Materials – Ready for Applications?

Monday, 29 June 2015 08:15 (45 minutes)

In 2003 Tomita and Murakami set the record for the trapped field in a bulk superconductor of a shade over 17.2 T. Last year, not without significant effort, this record was raised to 17.6 T. This apparently slow progress may suggest that the pace of progress in Bulk Superconductors has been very slow. In fact nothing could be further from the truth. The growth of bulk materials from (RE)BCO has seen innovations which have permitted a wider range of materials to be successfully grown, engineered pinning enhancement to provide improved critical currents, progressively larger samples and significant progress towards batch processing. In the meantime MgB$_2$ has emerged, in spite of its relatively low critical temperature, as a cheap, easy to make and rare earth free competitor. In this presentation I will discuss the significant advances that have taken place over the last ten or so years in the materials science of (RE)BCO and MgB$_2$ bulk superconductors. I will address the challenges to practical application, in particular that of charging, and discuss the approaches being taken around the world to solve them. In parallel with rapid materials development a range of innovative applications for Bulk Superconductors have appeared. I will outline some of these applications which are in domains as diverse as non-destructive testing, energy storage and medicine.

Primary author: Dr DURRELL, John (University of Cambridge)
Presenters: Dr DURRELL, John (University of Cambridge)
Session Classification: M1PL - Monday ICMC Plenary Session
Track Classification: ICMC-06 - HTS and MgB2 Bulk
Design studies for a direct drive superconducting generator rated 2 MW 3.3 kV 18 rpm have been performed using various commercially available superconductors for the field coils. The electromagnetic design is performed using two-dimensional transient nonlinear finite element analysis by following three-step modeling approach. In the first step, an open circuit model is analyzed and the appropriate ampere-turns are used for field excitation using YBCO second generation (2G), Bi 2223 and MgB2 superconductors to obtain the required no load stator induced voltage. In the second step, the stator windings are energized with rated load current at an instant time to calculate the rotor position angle for the necessary torque. Finally, a transient simulation is performed for the rated load to calculate the torque using the initial rotor position determined in the second step. Many design iterations have been performed using various geometrical topologies to minimize the cost of superconductors at selected operational field coil temperatures. The paper discusses the design iterations performed and future technical challenges to be resolved for commercial application of the superconducting technology.
Development of MgB2 conductors for low field coils and feeders in DEMO fusion energy reactors

Monday, 29 June 2015 12:15 (15 minutes)

An International Collaboration for Advancement of Magnesiumdiboride Superconductors (ICAMS) has been initiated to develop MgB2 superconductors for fusion reactor magnets. Today NbTi is the undisputed superconductor for use in the Poloidal Field coils (PF), Correction Coils (CC), graded Toroidal Field (TF) coils and Feeders of a fusion machine. A major advantage of MgB2 is its higher operating temperature and larger temperature margin. The larger temperature margin allows cost reduction of the cryogenic system and improvement of reliability. For any fusion machine design in the next decade, it is likely that NbTi will be used for the lower field PF, CC or graded TF coils and feeders but MgB2 wire is a serious candidate for future machines. A Cable-In-Conduit Conductor (CICC) concept is adopted with a strand cable pattern designed for minimum interstrand coupling loss to limit the heat load and maximum strand mechanical support to avoid degradation from thermal and electromagnetic stress. The lead for the design and eventual test is a full-size MgB2 Poloidal Field conductor. The prospective to use state of the art MgB2 strands for the PF and CC superconductors of a fusion device is analyzed with the code JackPot-ACDC. The strand critical parameters for second-generation multifilamentary HyperTech MgB2 strand with a diameter of 0.83 mm serve as a critical input for the analysis of the computed conductor performance. The predicted MgB2 PF CICC performance is compared with the requirement of the present ITER PF design with maximum operating current of 45 kA and nominal peak field of 6 T. The organization scheme of the ICAMS collaboration and first results are presented.

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Presenter: NIJHUIS, Arend (University of Twente)

Session Classification: M1OrA - Superconductor Cables I: HTS and LTS

Track Classification: ICMC-04 - MgB2 Processing and Properties
Development of powder-in-tube-processed multifilamentary MgB2 long wires with different reinforcement structure

Wednesday, 1 July 2015 11:45 (15 minutes)

In this paper, we present recent progress of long multifilamentary MgB2 wires and tapes in our group. Now we have fabricated the MgB2 wires with unit length of 1500 m and diameter of 1.0 mm by in-situ Powder-in-Tube (PIT) method using Nb as the barrier and copper as the stabilizer. To improve the strength of wires, the Cu, Cu–Nb and NbTi core was used as the central filament. The Cu–Nb reinforcing core is more appropriate for manufacturing MgB2 wires. It is observed that the Cu–Nb reinforced wire sintered at 750 ºC for 2 h has the highest yield strength of 101.8 MPa. With the sintering temperature increasing, the yield strength of the Cu–Nb and NbTi reinforced wires increased while the value slightly decreased in the case of Cu reinforced one in this study. According to our calculations, those mechanical properties are suitable for the application requirements of superconducting magnets in low field with the critical engineering current $I_c$ of 197 and 205 A ($J_{ce}$ exceeding $1.7 \times 10^4$ and $1.8 \times 10^4$ A/cm²) before and after 70 MPa axial load on the wire at 20 K, 1.5 T respectively. The reasons leading to the enhancement of high field $J_{ce}$ were discussed. The results show a good potential to fabricate high performance MgB2 wires and tapes at ambient pressure on an industrial scale.

Primary author: Dr PAN, Xifeng (Western Superconducting Technologies Co. Ltd.)

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Presenter: Dr PAN, Xifeng (Western Superconducting Technologies Co. Ltd.)

Session Classification: M3OrB - Superconductor Wires IV: MgB2 and Applications

Track Classification: ICMC-04 - MgB2 Processing and Properties
[Invited] Demonstration of Advanced Superconductors with Four-fold Improved Performance for High Power Wind Generators

Wednesday, 1 July 2015 16:15 (20 minutes)

Superconducting generators are a viable alternative to permanent-magnet-based generators for direct-drive, high-power wind turbines especially because of their potential low operating cost, reduced weight, and near elimination of rare-earth materials. A major challenge with the commercialization of superconducting generators for wind turbines is the high cost of present day’s high temperature superconductors (HTS). The University of Houston along with its industrial partners SuperPower, E2P Solutions and TECO-Westinghouse and the National Renewable Energy Laboratory were awarded a program in 2012 by the Advanced Research Projects Agency-Energy (ARPA-E) to develop transformative technologies to improve coated conductor performance by a factor of four in the operating condition of superconducting wind generators (30 K, 2.5 T). This improved conductor performance will lead to approximately four-fold less wire needed for the same generator rating resulting the significant cost and weight savings.

In the ARPA-E funded program, we were able to successfully exceed a four-fold improvement in coated conductor performance at 30 K, 2.5 T by engineering nanoscale defects in the superconductor tapes made by a metal organic chemical vapor deposition (MOCVD) process. Critical currents over 4200 A corresponding to a critical current density of 16 MA/cm² have been achieved at 30 K, 2.5 T in the advanced superconductors made in this program. This value compares with a critical current of 750 A at 30 K, 2.5 T of HTS tapes produced by industry today. By overcoming the primary shortcoming, namely the high wire cost, the advanced coated conductor technology developed in the ARPA-E program can spur the commercial feasibility of superconducting wind generators.

This work was supported the Advanced Research Projects Agency-Energy award DE-AR0000196.

Primary author: SELVAMANICKAM, Venkat (University of Houston)

Presenter: SELVAMANICKAM, Venkat (University of Houston)

Session Classification: M3OrE - Invited Panel Session Part II: Superconducting Wind Turbines, Rotating Machines, and Materials

Track Classification: ICMC-02 - RE123 Conductors Processing and Properties
Several groups have worked to develop many different types of superconducting (SC) machines, successfully demonstrating different aspects of the technology. In spite of these efforts, commercial adoption has not taken place because of the perceived unfavorable risk/benefit assessment of SC technology. In this talk, we will describe efforts to try and break this impasse by leveraging advances in the commercially successful MRI industry to further increase machine power density while reducing many of the risks with mature technology. High power density is obtained with increased air-gap flux density and an ‘air-core’ machine architecture. Technical risks related to the high field SC coils, the cryogenic cooling system, the mechanical suspension system and torque transfer mechanism, air-gap armature winding, protection, etc. need to be overcome to make this practical. A NASA funded project is starting to evaluate the value of this approach for future electric aircraft applications. A status update on this project, and extrapolation to other applications like wind turbine generators will be provided.

**Primary author:** HARAN, Kiruba (University of Illinois)

**Presenter:** HARAN, Kiruba (University of Illinois)

**Session Classification:** M3OrE - Invited Panel Session Part II: Superconducting Wind Turbines, Rotating Machines, and Materials

**Track Classification:** CEC-09 - Cryogenics for Power Applications, Energy, Fuels and Transportation
[Invited] Recent advances in iron-based superconducting wires and tapes

Monday, 29 June 2015 17:30 (30 minutes)

122 type pnictide superconductors are of particular interest for high-field applications because of their large upper critical fields $H_c^2 (>100 \text{T})$, low anisotropy $\gamma (<2)$ and the materials and processes to fabricate wires appear to be relatively inexpensive. However, the porous nature of powder-in-tube (PIT) processed iron-based tapes is one of the important reasons for low critical current density ($J_c$) values. Here we report our recent achievement in the developing Sr$_{0.6}$K$_{0.4}$Fe$_2$As$_2$ tapes with transport $J_c$ up to $1.2 \times 10^5 \text{ A/cm}^2$ at 10 T and 4.2 K. More importantly, the field dependence of $J_c$ turns out to be very weak, such that in 14 T the $J_c$ still remains $\sim 1.0 \times 10^5 \text{ A/cm}^2$. These $J_c$ values are the highest ever reported so far for iron-pnictide wires and tapes, and have surpassed the threshold for practical application. These results clearly demonstrate that PIT pnictide wire conductors are very promising for high-field magnet applications.

**Primary author:** MA, Yanwei (Institute of Electrical Engineering, Chinese Academy of Sciences)

**Presenter:** MA, Yanwei (Institute of Electrical Engineering, Chinese Academy of Sciences)

**Session Classification:** M1OrD - Superconductor Materials I: Bulk and New Materials

**Track Classification:** ICMC-07 - Pnictides and New Superconducting Materials
[Invited] Modular and Repairable Superconducting Wind Turbine Generators 5-20MW

Wednesday, 1 July 2015 16:55 (20 minutes)

The desire is for lightweight wind turbine generators for both land and offshore wind that can be serviced on top of the wind towers. Hyper Tech has developed a modular concept design so the components can be shipped over conventional highways and assembled on top of a tower. The design can be scaled from 5-20MW. There is also the desire to have low operational and maintenance costs for these large wind turbine generators. The Hyper Tech design concept allows for the replacement of any of the superconducting coils or cryogenic components on site on top of the tower. Using these modular concepts if a failure occurs, the entire generator would not have to be taken down off the tower to be repaired. In addition, with the development of fine filament MgB2 wires there is the potential of developing all cryogenic MgB2 wind turbine generators. All cryogenic wind turbine generators will result in lower weight compared to superconducting wind turbine generators where only the rotor is using superconductor wire.

Primary author: Mr TOMSIC, Michael (Hyper Tech)
Presenter: Mr TOMSIC, Michael (Hyper Tech)
Session Classification: M3OrE - Invited Panel Session Part II: Superconducting Wind Turbines, Rotating Machines, and Materials
Track Classification: CEC-06 - Superconducting Magnet Systems
The study of large superconducting generators for wind turbines has been ongoing for several years both in Europe and in the US. Several very promising fully and partially superconducting designs have been developed using both YBCO and MgB2 conductors. Most of the activities entails detailed designs and derisking activities, however, no full size prototype has been fabricated and tested yet. The development of wind turbine superconducting generator is a multi-disciplinary activity and requires advanced optimization tools considering the full turbine or even the wind farm as a system targeting the minimization of the cost of energy. The value proposition of large superconducting generators has been reported in numerous publications and documents (i.e. NREL, DOE). However, technology development is still required before such machines can be deployed. This paper will discuss the technology development (superconductor, protection, fault management, cooling systems, structural materials...) still required and propose a roadmap for the development of large HTS generators. The impact of the generator topology and superconducting material on the cost of energy and generator performance will also be presented.

Primary author: MASSON, Philippe (University of Houston)

Presenter: MASSON, Philippe (University of Houston)

Session Classification: M3OrD - Invited Panel Session Part I: Superconducting Wind Turbines, Rotating Machines, and Materials

Track Classification: ICMC-09 - HTS Cables
AC LOSSES MODELS FOR LOW-TC SUPERCONDUCTORS

Tuesday, 30 June 2015 12:15 (15 minutes)

AC losses still represent an important heating source when operating superconducting magnets. This is even more the case when powering-up the superconducting magnet, even at DC currents. We have developed new methods to evaluate the heat produced by ac losses during powering procedures of superconducting magnets. These include the Bean model assuming the penetration in a cylindrical form, and also an approach with parabolic penetration, and general exponential penetration of the magnetic field (four sub-models). We then compare all the models between themselves and also with the classical models (Bean – flat and Wilson approach).

3D simulations were done for all the models considering several study cases for Nb3Sn and NbTi. These cases were selected bearing in mind the design options of a high to moderated field superconducting magnet (being designed for a new separating device), namely operating at 9T, 10T, 12T and 8T, 9T, 10T, respectively. All the models seem appropriate to describe the losses.

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Presenter: AUGUSTO, Paulo (APLICAMA Research Group - Univ Salamanca - SPAIN)

Session Classification: M2OrB - Superconductor Wires I: Testing and Characterization

Track Classification: ICMC-08 - Superconductor Stability and AC Losses
DESIGNING VAPOUR-COOLED AND FORCED-FLOW COOLED CURRENT LEADS FOR A NEW SEPARATING DEVICE

Tuesday, 30 June 2015 14:00 (2 hours)

We are designing a new separating device and among several other components we had designed vapour-cooled current leads. This current leads are based on a classical design (for proper stability and robustness of the full device that does not allow many degrees of freedom) and therefore made of Low-Tc material connected with copper wires and some parts of High-Tc material. Its design is calculated keeping in mind the heat transfer by diffusion to a vapour-cooled stream that surrounds the conductive materials. We have also designed forced-flow cooled current leads, for comparison purposes. The actual current lead heat influx is best determined in the vapor cooled mode. The design and the calculations performed, and also the background theory of the heat diffusion applied in this part of the device will be described.

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Presenter: AUGUSTO, Paulo (APLICAMA Research Group - Univ Salamanca - SPAIN)

Session Classification: M2PoC - Superconductor Cables II: HTS

Track Classification: CEC-08 - Cryogenic Power Cables and Leads
In the field of wind power generation, there is a general trend of developing wind turbines larger than the present 5 MW size because use of larger capacity turbines can increase the total capacity of a wind farm and reduce the cost of power generation. An extension of the conventional technologies (copper coils or permanent magnets) to build gearless, direct-drive generators may result in an oversize and overweight, and the realization of compact and light-weight superconducting wind turbine generators is desired. We first examined what type of superconducting rotor design is suitable, and from a cost standpoint selected salient-pole type iron-cored rotor design, in which much less amount of expensive high-temperature superconducting (HTS) wires are needed than in an air-cored rotor design. We then proposed and conducted a feasibility study project for over 10 MW-class superconducting wind turbine generators sponsored by NEDO (2013–14), collaborating with Furukawa Electric Co. Ltd., Mayekawa Manufacturing Co. Ltd., Niigata University, Sophia University and University of Tokyo. This study has focused on three key components necessary for the fabrication of an iron-cored HTS wind turbine generator: (1) superconducting coil module, (2) highly reliable Brayton Cryocooler (~1 kW@20–40 K, maintenance interval >30,000 h) and (3) cryogenic gas transfer coupling employed for superconducting rotor. Note that each superconducting coil module, consisting of an HTS racetrack coil and a vacuum vessel, is placed around each salient pole and the HTS coils are cooled by cryogenic He gas. Additionally, we have made a general design of a 10 MW-class HTS wind turbine and realized the advantages of HTS wind turbine generators over conventional generators. In this presentation we will report primary results of the NEDO project.

Acknowledgement: This presentation is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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Co-author: Dr FURUSE, Mitsuho (National Institute of Advanced Industrial Science and Technology)

Presenter: Dr YAMASAKI, Hirofumi (National Institute of Advanced Industrial Science and Technology)

Session Classification: M3OrD - Invited Panel Session Part I: Superconducting Wind Turbines, Rotating Machines, and Materials

Track Classification: CEC-06 - Superconducting Magnet Systems
Panel Wrap-up & Discussion

Wednesday, 1 July 2015 17:15 (30 minutes)

Session Classification:  M3OrE - Invited Panel Session Part II: Superconducting Wind Turbines, Rotating Machines, and Materials
Test Presentation for Upload My Talk or Poster Material

Presenter: D’ANTONIO, Annett (Centennial Conferences)
Air Force Research Laboratory Spacecraft Cryocooler Endurance Evaluation Final Report

Monday, 29 June 2015 14:00 (2 hours)

The Air Force Research Laboratory (AFRL) Spacecraft Component Thermal Research Group has been devoted to evaluating lifetime performance of space cryocooler technology for over twenty years. Long-life data is essential for confirming design lifetimes for space cryocoolers. Continuous operation in a simulated space environment is the only accepted method to test for degradation. AFRL has provided raw data and detailed evaluations to cryocooler developers for advancing the technology, correcting discovered deficiencies, and improving cryocooler designs. At AFRL, units of varying design and refrigeration cycles were instrumented in state-of-the-art experiment stands to provide space-like conditions and were equipped with software data acquisition to track critical cryocooler operating parameters. This data allowed an assessment of the technology's ability to meet the desired lifetime and documented any long-term changes in performance. This paper will outline a final report of the various flight cryocoolers tested in our laboratory. The data summarized includes seven cryocoolers with a combined total of 433,326 hours (49.5 years) of operation.

Primary author: Ms ARMSTRONG, Jordan (Glacier Technical Solutions, Air Force Research Laboratory)

Co-authors: Mr MARTIN, Kyle (A-tech Corporation dba Applied Technology Associates aka ATA); Mr FRASER, Thomas (Air Force Research Laboratory)

Presenter: Ms ARMSTRONG, Jordan (Glacier Technical Solutions, Air Force Research Laboratory)

Session Classification: C1PoH - Aerospace Cryocoolers Analysis and Experimentation

Track Classification: CEC-04 - Cryocoolers (Aerospace)
UPS LNG Use & Future Intended Use

Thursday, 2 July 2015 08:00 (45 minutes)

UPS is an engineering company with a large fleet of trucks. We have been running a “Rolling Laboratory” for many years and believe there are opportunities for many technologies to be deployed to improve the environments we operate in. We have been using LNG since 1999 in our fleet and want to share the following information.

Primary author: Mr BRITT, Michael (UPS)
Presenter: Mr BRITT, Michael (UPS)
Session Classification: C4PL - CEC Plenary Session
Track Classification: CEC-17 - Novel Concepts and New Devices
Superconducting Turboelectric Distributed Aircraft Propulsion

Wednesday, 1 July 2015 08:15 (45 minutes)

Current developments in superconducting and cryogenics technologies offer the potential for dramatic impacts on the future of aviation. The prospective of a modular means for high power dense and highly efficient power transmission is an attractive enabler for decoupling the production of power from the production of thrust on an aircraft. The resulting spatial flexibility removes critical mechanical and geometric restrictions on the propulsion system and allows for greater synergies with air vehicle aerodynamic performance. Nevertheless, significant technology progression is required to prepare cryogenic and superconducting technologies for the unique operational environment of an aircraft system. Power density and efficiency currently dominate concept feasibility studies. However, the practicality of operating a fleet of aircraft driven by superconducting propulsion systems requires consideration of requirements like reliability, fail-safe operations, infrastructure compatibility, and system maintainability. In addition to individual technology developments, innovative systems architectures are required which provide novel means for balancing redundancy, reconfigurability, and fault recovery in a manner which capitalizes on the unique behaviors of cryogenics and superconducting.

Primary author: ARMSTRONG, Michael (Rolls-Royce North American Technologies Inc)
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Session Classification: M3PL - ICMC Plenary Session - sponsored by the IEEE Council on Superconductivity
Track Classification: CEC-01 - Large-Scale Refrigeration and Liquefaction
Large Jc enhancement and matching effects by Ba2Y(Nb/Ta)O6 nanocolumns in YBa2Cu3O7-x thin films

Wednesday, 1 July 2015 12:15 (15 minutes)

YBa2Cu3O7-x based coated conductors have large potential in such diverse applications as wires/cables, motors/generators, high-field coils, and superconducting permanent magnets, each of them with a certain range of temperature and magnetic field and a certain need in magnitude and isotropy in critical current density Jc. In order to use the full potential of YBa2Cu3O7-x, it is mandatory to tailor its transport properties for the envisaged application. This is done by inserting artificial pinning centers, such as perovskites (e.g. BaZrO3) or (mixed) double-perovskites, which precipitate as nanoparticles and/or nanorods.

We report on a study on the addition of the mixed double perovskite Ba2Y(Nb/Ta)O6 to YBa2Cu3O7-x thin films on SrTiO3 single crystals prepared by pulsed laser deposition. Size, shape, density and orientation distribution of these pinning centers are analysed by X-ray diffraction and TEM. The electrical transport properties are determined in 4-point geometry in maximum-Lorentz force configuration in fields up to 9 T on bridges prepared by laser cutting.

For small deposition rates, Ba2Y(Nb/Ta)O6 grows as well oriented, densely distributed nano-columns (d ~ 10 nm). We achieved a pinning force density of 25 GN/m³ at 77 K at the matching field of 2.3 T, which is among the highest values reported for YBa2Cu3O7-x. The field dependence of the pinning force density and the anisotropy of the critical current density show a complex behavior which is explained by a matching effect of the magnetic field’s c-axis component and the superposition of up to three pinning components. The exponent N of the current-voltage characteristics (inversely proportional to the creep rate S) elucidates the depinning mechanism, changing from double-kink excitation below the matching field to pinning-potential-determined creep above.

The authors acknowledge financial support from EUROTAPES, a collaborative project funded by the European Unions’s Seven Framework Programme (FP7 / 2007-2013) under Grant Agreement no. 280432.

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Presenter: Dr HAENISCH, Jens (Karlsruhe Institute for Technology)

Session Classification: M3OrA - Superconductor Wires III: Thin Films

Track Classification: ICMC-10 - Flux Pinning and Critical Current
Hydrogen refrigeration via kinetic para-ortho manipulation in a vortex tube

Hydrogen has two separable nuclear-spin isomers, denoted by ortho and para, with potentially significant differences in thermophysical properties. The entropy change with ortho-para conversion is the largest of any material phase change known to occur at cryogenic temperatures. A prior experimental study demonstrated that the endothermic reaction of para-ortho conversion can be utilized to increase the effective cooling capacity of liquid parahydrogen boil-off vapors below 100 K. This work expands the concept of endothermic para-ortho conversion to primary refrigeration below 77 K via kinetic manipulation in a vortex tube. Vortex tubes are non-moving devices that utilize a kinetic energy differential to partition a fluid into hot and cold streams. The vortex tube could use a hydrogen stream pre-cooled in a liquid nitrogen bath and catalyzed to the 50-50 equilibrium composition at 77 K. By catalyzing the hot fluid on the outer wall of the vortex, endothermic para-ortho conversion will cause bulk cooling after which the orthohydrogen is separated and recycled to the liquid nitrogen bath. The statistical partition function is utilized to establish performance limits of the concept. Initial experimental results in bare and catalyzed vortex tubes are presented. Based on the theoretical analysis and initial experiments, the potential for para-ortho conversion as a new approach to hydrogen refrigeration is assessed.
Hydrogen refrigeration via kinetic para-ortho manipulation in a vortex tube

Monday, 29 June 2015 14:00 (20 minutes)

Hydrogen has two separable nuclear-spin isomers, denoted by ortho and para, with potentially significant differences in thermophysical properties. The entropy change with ortho-para conversion is the largest of any material phase change known to occur at cryogenic temperatures. A prior experimental study demonstrated that the endothermic reaction of para-ortho conversion can be utilized to increase the effective cooling capacity of liquid parahydrogen boil-off vapors below 100 K. This work expands the concept of endothermic para-ortho conversion to primary refrigeration below 77 K via kinetic manipulation in a vortex tube. Vortex tubes are non-moving devices that utilize a kinetic energy differential to partition a fluid into hot and cold streams. The vortex tube could use a hydrogen stream pre-cooled in a liquid nitrogen bath and catalyzed to the 50-50 equilibrium composition at 77 K. By catalyzing the hot fluid on the outer wall of the vortex, endothermic para-ortho conversion will cause bulk cooling after which the orthohydrogen is separated and recycled to the liquid nitrogen bath. The statistical partition function is utilized to establish performance limits of the concept. Initial experimental results in bare and catalyzed vortex tubes are presented. Based on the theoretical analysis and initial experiments, the potential for para-ortho conversion as a new approach to hydrogen refrigeration is assessed.

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Session Classification: C1PoJ - Novel Concepts and New Devices I