

Eighth CW and High Average Power RF Workshop



Report of Contributions

Contribution ID: 2

Type: **Oral presentation**

Precision manufacturing considerations of 200 MHz LINAC amplifier

Tuesday, May 13, 2014 2:30 PM (30 minutes)

Tubes remain the most effective solution for 200 MHz Final Power Amplifier (FPA) design. An overview of design and manufacturing considerations of a 201.25 MHz FPA, built to Los Alamos Neutron Science Center (LANCE) specifications, will be presented. Precision manufacturing and assembly of amplifier components is critical for optimizing performance of advanced tube design, such as the Thales TH628 Diacrode®. Topics to be presented include an update on system performance at LANCE of their newly designed and manufactured Diacrode Amplifiers, the importance of select raw materials used in manufacturing, and special devices required for heating, component assembly and alignment. Additional system components required such as High Voltage Power Supplies and liquid and air cooling of components will also be presented.

Primary author: Mr COZAD, Kerry (Continental Electronics Corporation)

Presenters: Mr COZAD, Kerry (Continental Electronics Corporation); TROJE, Michael (Continental Electronics Corp)

Session Classification: Tuesday afternoon 1

Track Classification: SPC judgements

Contribution ID: 3

Type: **Oral presentation**

Status and Operating Experience of the ELBE RF System based on 10kW SSPAs

Tuesday, May 13, 2014 11:30 AM (30 minutes)

H. Büttig, A. Arnold, A. Büchner, M. Justus, M. Kuntzsch, U. Lehnert, P. Michel, R.Schurig, G. Staats, J.Teichert.

Radiation Source ELBE, Helmholtz Zentrum Dresden- Rossendorf, Germany

Abstract:

In January 2012 the 10 kW klystrons of the CW LINAC ELBE were replaced by pairs of 10kW solid state power amplifiers (SSPA).

The talk gives an overview on the SSPA based ELBE RF system. The experience gained during the first two years of operation is reviewed.

Primary author: BÜTTIG, Hartmut (Helmholtz Zentrum Dresden-Rossendorf)

Co-authors: Dr ARNOLD, Andre (HZDR); Dr BÜCHNER, Andre (HZDR); Dr STAATS, Gerald (HZDR); TEICHERT, Jochen (Helmholtz-Zentrum Dresden-Rossendorf); Mr JUSTUS, Matthias (HZDR); Mr KUNTZSCH, Michael (HZDR); Dr MICHEL, Peter (HZDR); Mr SCHURIG, Rico (HZDR); Dr LEHNERT, Ulf (HZDR)

Presenter: BÜTTIG, Hartmut (Helmholtz Zentrum Dresden-Rossendorf)

Session Classification: Tuesday morning 2

Track Classification: SPC judgements

Contribution ID: 4

Type: **Oral presentation**

The Advanced Photon Source RF Systems – Performance and Upgrades, 2012-2014

Wednesday, May 14, 2014 10:00 AM (30 minutes)

Technical performance of the Advanced Photon Source rf systems from May 2012 to May 2014 is discussed. Significant hardware problems and failures affecting rf system reliability, and approaches taken to resolve them, are described in detail. System upgrades to enhance performance and reliability are described. The design and construction details of a 5kW S-band cw amplifier developed for the APS Upgrade effort will be presented.

Primary author: Mr HORAN, Douglas (Argonne National Laboratory)

Presenter: Mr HORAN, Douglas (Argonne National Laboratory)

Session Classification: Wednesday morning 1

Track Classification: SPC judgements

Contribution ID: 5

Type: **Oral presentation**

A Significant Increase of the Efficiency at the Operating Point of Very High Power Solid State RF Amplifiers (50 MHz to 1.3 GHz) by Remote P1 Control

Wednesday, May 14, 2014 11:30 AM (30 minutes)

A new technique was developed to increase the efficiency of very high power RF amplifiers (50 MHz to 1.3 GHz) at a freely chosen operating point. This improvement can be achieved for a large range of output power by a remote P1-point control. The choice of the P1-point of an RF amplifier is a compromise between increased efficiency vs. increased harmonics and decreased linearity. Typically, the P1-point power in the operation of particle accelerators is fixed to cover the maximum required output power including a large safety margin and for all operational situations. This safety margin is typically at least 20-30%. As a consequence, the effective efficiency of the amplifier is significantly below the one obtainable with an optimized setting of the P1-point for each required operating power. Using a new modular AC-DC-power supply with a maximum efficiency of 95% and a special amplifier control system, an adjustment of the P1-point over a wide power range can be made possible and thereby an increased effective efficiency of the amplifier at its operating point can be obtained. In addition, the new architecture of the ACDC-distribution results in a very low phase noise level, which is of higher importance for all light sources. A detailed description of the system and the achieved power savings will be presented.

Primary author: Dr PUPETER, Nico (Cryoelectra GmbH)

Co-authors: Mr BORISOV, Alexey (Cryoelectra GmbH); Dr AMINOV, Bachtior (Cryoelectra GmbH); Prof. PIEL, Helmut (Cryoelectra GmbH); Dr NEDOS, Mirco (Cryoelectra GmbH); Dr KOLESOV, Sergei (Cryoelectra GmbH)

Presenter: Dr PUPETER, Nico (Cryoelectra GmbH)

Session Classification: Wednesday morning 2

Track Classification: SPC judgements

Contribution ID: 6

Type: **Oral presentation**

SOLEIL RF SYSTEMS : OPERATIONAL EXPERIENCE, UPGRADES, R&D'S

Thursday, May 15, 2014 9:00 AM (30 minutes)

In the SOLEIL storage ring, two cryomodules provide to the electron beam an accelerating voltage of 3-4 MV and a power of 575 kW at 352 MHz. Each cryomodule contains a pair of superconducting cavities, cooled with liquid Helium at 4.5 K, which is supplied by a single 350 W cryogenic plant. The RF power is provided by four solid state amplifiers (SSA), each delivering up to 180 kW. The parasitic impedances of the high order modes (HOM) are strongly mitigated by means of four coaxial couplers, located on the central pipe connecting the two cavities. We report about the operational experience with this system, its upgrades and more generally about R&D's, carried out at SOLEIL in the SSA field.

Primary author: MARCHAND, Patrick (Synchrotron SOLEIL)

Presenter: MARCHAND, Patrick (Synchrotron SOLEIL)

Session Classification: Thursday morning 1

Track Classification: SPC judgements

Contribution ID: 7

Type: **Oral presentation**

Digital measurement system for the klystron HV modulator

Thursday, May 15, 2014 11:30 AM (30 minutes)

Important HV electrical parameters of the LHC klystron amplifier are monitored by the control system. The currents are measured by external DCCTs on HV cables at ground potential, voltage dividers are isolated by V to f converters. The system performs well, but many components are at the end of their lives and measurement accuracy and access to the data for trouble shooting could be improved.

A new, state of the art digital measurement system, which allows to measure all important HV quantities directly at the source in the HV tank (Vcath, Icath, Vma, Vheater, Iheater...) was developed. It provides 3 orders of magnitude improvement in sample rate, 10 fold increase in accuracy and comfort of online observation and post mortem buffers.

We have demonstrated, that we can introduce and run a sophisticated electronic devices into the harsh HV environment. They provide reliable data even during very energetic fault scenarios, e.g. crowbar or arcing.

A prototype will be installed in the LHC klystron HV modulator for long time testing in the coming run 2.

Primary author: Dr VALUCH, Daniel (CERN)

Co-authors: MIKKELSEN, Anders (Bergen University College (NO)); RAVIDA, Gianfranco (CERN); BRUNNER, Olivier (CERN)

Presenter: Dr VALUCH, Daniel (CERN)

Session Classification: Thursday morning 2

Track Classification: SPC judgements

Contribution ID: 8

Type: **Poster**

Update on the CERN arc detectors

Thursday, May 15, 2014 3:39PM (1 minute)

A new generation of Arc Detectors was developed at CERN for the Linac4. For reliability reasons the detectors do not use optical fibres. Each sensor head is equipped by four independent photo detectors with optional two “blind” sensors for environments with high radiation background. Since the first introduction in 2012 the detector design has been finalised, the housing ruggedised and made compatible with industrial, series production process. The project is supported by the CERN technology transfer group and the detectors are made available as a product for external users.

This contribution presents the current status of the Arc Detector project.

Primary author: Dr VALUCH, Daniel (CERN)

Presenter: Dr VALUCH, Daniel (CERN)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 9

Type: **Oral presentation**

Solid State Amplifier using a cavity combiner

Thursday, May 15, 2014 9:30 AM (30 minutes)

A 12 kW amplifier operating at 352 MHz has been designed, developed and built at ESRF. It uses a resonant cavity to combine the power of 18 home made RF modules. This is a prototype for a bigger amplifier which is currently under construction. The main features of this smaller version will be described, together with hopefully interesting considerations on manufacturing. The performances measured with both CW and pulsed test conditions will be given. These data will be completed by a status of the bigger amplifier project.

Primary author: Mr LANGLOIS, Michel (ESRF)

Co-authors: Dr JACOB, Jörn (ESRF); Mr BARBIER, Pierre (ESRF)

Presenter: Mr LANGLOIS, Michel (ESRF)

Session Classification: Thursday morning 1

Track Classification: SPC judgements

Contribution ID: 10

Type: **Oral presentation**

Test of a 500MHz / 65kW Solid State Amplifier

Thursday, May 15, 2014 5:00 PM (30 minutes)

High Power Solid State RF Amplifiers are being pushed in the market. With the latest generation of LDMOS transistors a high RF power per unit can be generated. Many of these RF modules combined in a single system is a serious competitor to the long established tube technology. Several solid state RF systems have already been realized and used very successfully for RF generation at particle accelerators.

Ampegon has a long tradition in engineering and in the manufacture of tube-based amplifier systems and transmitters, while solid state technology was, so far, dominant in medium wave transmitters up to 300kW. In collaboration with the Paul Scherrer Institut we have successfully industrialized a PSI development of a solid state RF amplifier for 500MHz. The result is that both technologies could be tested and compared. The presentation will give an overview over our work and give an idea about the peculiarities of each technology.

Primary author: Mr FRITSCHÉ, Bodo (Ampegon AG, Turgi)

Co-author: Mr GASPAR, Marcos (PSI, Villigen)

Presenter: Mr FRITSCHÉ, Bodo (Ampegon AG, Turgi)

Session Classification: Thursday afternoon 2

Track Classification: SPC judgements

Contribution ID: 11

Type: **Oral presentation**

RF Related Issues Encountered during over 15years of Operation of SPring-8

Friday, May 16, 2014 9:00 AM (30 minutes)

Over 15 years of operation of the SPring-8 storage ring, we encountered several troubles in the RF system. Some of them will be picked up for the report.

As an example, we experienced the water leakage from the photon absorbers for the synchrotron radiation to protect RF cavities.

The cause was found to be the pinholes created by corrosion of the absorber water channel wall by the chemical reactions of the oxygen in the cooling water with the copper water channel wall. The improper structure of the absorber, the photon beam went through the water, made the chemical reaction possible for the copper wall with dissolved oxygen in the cooling water.

In addition to the improper structure, we found that the control of the water quality was important. The density of the copper ion has been monitored since then.

We encountered also to the water leakage from the output window part of the klystrons. The cause was found to be excess water flow to the cooling channels.

In conjunction with the investigation of the cause, control of the quality was important for the water inside the cooling channel during the storage period as backup stockage of the klystrons. The residual components solved in the water might cause damages to the cooling water channel.

Primary author: Dr SASAKI, Shigeki (SPring-8/JASRI)

Presenter: Dr SASAKI, Shigeki (SPring-8/JASRI)

Session Classification: Friday morning 1

Track Classification: SPC judgements

Contribution ID: 12

Type: **Oral presentation**

Status and Operation of the ALBA RF System

Thursday, May 15, 2014 10:00 AM (30 minutes)

Status and Operation of the ALBA RF System

J.Ocampo, B.Bravo, A.Salom, F.Perez

Abstract

ALBA is a 3 GeV, 400 mA, 3rd generation Synchrotron Light Source in operation for users since May 2012, in Barcelona, Spain. The RF System has to provide 3.6 MV of accelerating voltage and restore up to 540 kW of power to the electron beam. For that six RF plants, working at 500 MHz, are in operation. A RF plant includes a Dampy cavity (HOM damped) which is feed by two 80 kW IOT amplifiers combined via CaCo; a cavity combiner; and a Digital LLRF fully designed at ALBA using commercial components. Operation with a single IOT is also made possible thanks to the CoStub, a Coaxial Short to isolate the non-operational IOT from the CaCo. This presentation shortly describes the actual status of these systems and reports their performance since the start of the ALBA operation. It also covers the commissioning status of the new RF test laboratory, which is powered by a 80kW IOT amplifier and will be capable of testing either the Dampy cavity or the 5 cell cavity of the Booster.

Primary author: Mr OCAMPO PÉREZ, Jesús Ramón (CELLS-ALBA)

Co-authors: SALOM SARASQUETA, Angela (Synchrotron ALBA); BRAVO, Beatriz (CELLS); PEREZ, Francis (CELLS-ALBA)

Presenter: Mr OCAMPO PÉREZ, Jesús Ramón (CELLS-ALBA)

Session Classification: Thursday morning 1

Track Classification: SPC judgements

Contribution ID: 13

Type: **Oral presentation**

Improvements to the APS LINAC & SR / Booster klystron high-voltage power supplies and accomplishments of the 352MHz RFTS

Thursday, May 15, 2014 2:30 PM (30 minutes)

Two of the Fiscal Year 2014 Radio Frequency (RF) Group machine operation goals are to maintain mean time between faults at 100 hours or better and maintain injector, storage ring (SR), and x-ray production availability at 97% or better. To continue to meet these goals, an aggressive approach was instigated to combat parts obsolescence and aging of the accelerator systems. The latest improvements to the linac and SR/booster klystron high-voltage power supplies will be highlighted.

The APS 352MHz RF Test Stand (RFTS) was constructed to test and condition booster and SR rf cavity components. The adaptation of a pulsed rf conditioning method was introduced and tested. This methodology and performance of the RFTS will be discussed.

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

Primary author: Mr TRENTO, Gianfranco (Argonne National Laboratory)

Co-author: Mr COURS, Alex (Argonne National Laboratory)

Presenter: Mr TRENTO, Gianfranco (Argonne National Laboratory)

Session Classification: Thursday afternoon 1

Track Classification: SPC judgements

Contribution ID: 14

Type: **Oral presentation**

RF Operation, HOM Damped Cavities and 150 kW Solid State Amplifiers at the ESRF

Tuesday, May 13, 2014 4:30 PM (30 minutes)

In the frame of the ongoing ESRF upgrade phase 1, a new RF section has been recently commissioned with three strongly HOM damped cavities powered by three 150 kW Solid State Amplifiers (SSAs). On the booster, four 150 kW SSAs are replacing the former klystron transmitter since April 2012. Twelve additional HOM damped cavities have been ordered at the end of 2013 for the projected low emittance ring that will replace the existing machine at the end of this decade. The status of RF operation, the commissioning of the new SSAs and the HOM damped cavities and the RF system for the new machine will be presented.

Primary author: Dr JACOB, Jorn (ESRF)

Co-authors: Dr D'ELIA, Alessandro (ESRF); Mr GAUTIER, Georges (ESRF); MERCIER, Jean-Maurice (ESRF); LANGLOIS, Michel (European synchrotron radiation facility); Dr SERRIÈRE, Vincent (ESRF)

Presenter: Dr JACOB, Jorn (ESRF)

Session Classification: Tuesday afternoon 2

Track Classification: SPC judgements

Contribution ID: 15

Type: **Oral presentation**

Early Commissioning Results of the NSLS-II High Power RF Systems

Tuesday, May 13, 2014 12:00 PM (30 minutes)

The NSLS-II has completed early commissioning with the booster synchrotron utilizing a 80 kW IOT transmitter powering a 7-cell “PETRA”like cavity and the storage ring a 300 kW klystron transmitter powering an identical cavity. The 7-cell cavity in the storage ring will be replaced with a “CESR-B”like superconducting cavity during the May 2014 shutdown. Both the klystron and IOT transmitters use switching HV power supplies with redundant switches and programmable switching algorithms that can suppress AC power line harmonics. Early results are presented.

Primary author: Mr ROSE, James (Brookhaven)

Co-author: Dr GAO, Feng (Brookhaven Lab)

Presenter: Mr ROSE, James (Brookhaven)

Session Classification: Tuesday morning 2

Track Classification: SPC judgements

Contribution ID: 16

Type: **Oral presentation**

Operation and Developments of High Power RF Systems at ORNL Spallation Neutron Source (SNS)

Wednesday, May 14, 2014 9:00 AM (30 minutes)

SNS has been operating successfully and ramping beam power steadily to 1.4 MW the design power at 1.0 GeV beam energy. Availability of RF systems has been improved to ~95% over the years since commissioning of SNS. Improvements have been made in operation of accelerating structures, RF windows and couplers, and high voltage converter modulators (HVCM) for klystrons for powering nearly 100 cavity structures: Radio frequency quadrupole (RFQ), drift tube linac (DTL), coupled cavity linac (CCL) and superconducting cavity linac (SCL). New waveguide RF windows have been built and tested for improved reliability and future beam power and energy upgrades of SNS. A new spare RFQ also has been manufactured and delivered to SNS for more robust performance of the linac front-end system aiming the future upgrades. The four vane RFQ with octagonal cross section and end-wall dipole rods operates at 402.5 MHz. Integrated Test Station Facility (ITSF) is being setup to allow full beam test with H- Ion Source together with the RFQ. High power RF tests are performed for performance acceptance and RF conditioning of the RFQ and systems. The results of high power tests and performance of the RF systems and the components are presented.

Primary author: Dr KANG, Yoon (Oak Ridge National Laboratory)

Co-authors: VASSIOUTCHENKO, Alexandre (Oak Ridge National Laboratory); ANDERSON, David (Oak Ridge National Laboratory); MOSS, John (Oak Ridge National Laboratory); CHAMPION, Mark (Oak Ridge National Laboratory / Spallation Neutron Source); CROFFORD, Mark (Oak Ridge National Laboratory/SNS); MIDDENDORF, Mark (ORNL); LEE, Sung-Woo (Oak Ridge National Laboratory)

Presenter: Dr KANG, Yoon (Oak Ridge National Laboratory)

Session Classification: Wednesday morning 1

Track Classification: SPC judgements

Contribution ID: 17

Type: **Poster**

Availability improvements for the LIPAc RF Power System: tetrodes and solid state solutions

Thursday, May 15, 2014 3:33 PM (1 minute)

The IFMIF/EVEDA Accelerator Prototype (LIPAc) is currently under construction in Rokkasho (Japan). LIPAc will generate a 9 MeV deuteron beam at 125 mA current with a 100% of duty cycle, and it will serve to validate the final IFMIF accelerator concept.

The radiofrequency (RF) Power System, which is being integrated by CIEMAT (Spain) and its partner companies and institutes, consists of 18 RF amplifier chains operating at 175 MHz: eight 200 kW chains for the radio-frequency quadrupole (RFQ); two 105kW chains for the re-buncher cavities of the Medium Energy Beam Transport (MEBT); and eight 105 kW chains for the superconducting half-wave resonator (HWR) cavities. It also comprises 12 high voltage power supplies (HVPS), which feed the final amplifiers, 18 coaxial transmission lines to reach the accelerator cavities, and the water cooling system primary circuit. Very high availability, high performance, and easy maintainability are the main objectives for this development. Dealing with such a challenging goals has required successive improvements in the reference design. All the details regarding the different proposals and developments will be described in this paper.

This work has been funded by the Spanish Government (MINECO) under project AIC-A-2011-0654 and the agreement published in BOE (BOE 16/01/2013, pp. 1988).

Primary author: Mr WEBER, Moises (Ciemat)

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Presenter: Dr DE LA MORENA, Cristina (Ciemat)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 18

Type: **Poster**

Stability test of 7 kW SSPA for 325 MHz Single Spoke Resonator

Thursday, May 15, 2014 3:38 PM (1 minute)

the RAON accelerator complex is planned in Korea for nuclear science research, and solid state power amplifiers will be used to provide superconducting cavities with rf power. The RAON main accelerator is composed of a normal conducting injector and a superconducting linac. The SC linac uses 3 types of SC cavities which are QWR, HWR and SSR. The SSR is divided into two families of low and high betas. Each cavity is driven by a SSPA. The SSPA, which is developed in house, is based on a 2 kW module. This 2 kW module employs four units of 600 W transistors including isolatr, which are combined by a 4 way combibner utilizing the Gygel method (Isolated combiner). Four modules are combined again with the same kind combiner to produce 7 kW of rf power. This paper describes the stability test result for 325 MHz, 7 kW SSPA.

Primary author: HAN, Jae Eun (I)**Co-authors:** Dr DO, HeeJin (Institute for Basic Science); Dr KIM, Jong Won (Institute for Basic Science); Mr CHOI, O-ryung (Institute for Basic Science)**Presenter:** HAN, Jae Eun (I)**Session Classification:** Poster session**Track Classification:** SPC judgements

Contribution ID: 19

Type: **Oral presentation**

STATUS OF THE RF SYSTEM FOR SESAME

Friday, May 16, 2014 10:00 AM (30 minutes)

The SESAME (Synchrotron Light Source For Experimental Science And Applications in The Middle-East) Accelerator consists of a 22 MeV Microtron , and 800MeV Booster and 2.5 GeV storage Ring . Each accelerator has its own RF system. The Microtron RF frequency is 3 GHz generated by 2 MW pulsed Magnetron, including 41KV modulator works as power supply for magnetron , while the Booster and SR have a common 500MHz CW RF source.

The Booster RF system consists of DORIS cavity fed by 2 kW CW solid state amplifier, but the storage Ring RF system design based on 4x 500MHz plants , each comprising a Elettra- Type cavity, powered by 80kW (CW) RF power via WR1800 waveguide lines.

This presentation shows the status of installed Microtron RF system and upgrades for RF system from BESSY I, as well as design SESAME SR high power RF system. Also this presentation shows the progress of collaboration with SOLEIL.

Primary author: Mr SAWAI, NASHAT (RF group SESAME)

Presenter: Mr SAWAI, NASHAT (RF group SESAME)

Session Classification: Friday morning 1

Track Classification: SPC judgements

Contribution ID: 20

Type: **Oral presentation**

Powering CEBAF's Extraction Cavities At 12 GeV

Tuesday, May 13, 2014 11:00 AM (30 minutes)

CEBAF (Continuous Electron Beam Accelerator Facility) at Jefferson Lab was initially designed to deliver up to a 4 GeV electron beam simultaneously to three experimental halls. The maximum deliverable energy was raised to 6 GeV and CEBAF ran there until May of 2012 after which CEBAF entered an extensive, upgrade shutdown. After the upgrade, scientists plan to use CEBAF to deliver 11 GeV beam to the three original experimental halls and 12 GeV to new hall –Hall D. Delivering beams to multiple halls at the new energy requires increased RF power to drive the separation cavities and adding a 750 MHz beam repetition rate to deliver beam to all halls simultaneously. Doubling the beam energy means doubling field strength in the cavities by quadrupling delivered power. 750 MHz beam repetition rate requires new 750 MHz capable cavities and a frequency change to one of the existing IOT amplifiers powering these cavities, and new 499 MHz SSAs to power four downstream cavities. Topics covered will include: verifying the Cavity's power capabilities, modifications to the 750 MHz system and new cavities, and the decision process in selecting an amplifier type to power four downstream cavities.

Primary author: WISSMANN, Mark (J)

Co-authors: Mr HOVATER, Curt (Jefferson Lab); Mr CHENG, Gary (Jefferson Labs); WANG, Haipeng Wang (Thomas Jefferson Lab); NELSON, Richard (Jefferson Lab)

Presenter: WISSMANN, Mark (J)

Session Classification: Tuesday morning 2

Track Classification: SPC judgements

Contribution ID: 21

Type: **Oral presentation**

A New 9MHz Cavity Design for RHIC

Friday, May 16, 2014 9:30 AM (30 minutes)

A new 9MHz RF system operating at 180KV per ring is required to increase the luminosity of low energy gold ion collisions at the Relativistic Heavy Ion Collider. In order to accommodate all planned collision energies each cavity will be required to operate between 8.7MHz and 9.4MHz while continuously providing 60KV of gap voltage. The proposed design includes a new capacitively loaded gap assembly that was specifically designed for this application. All pertinent design considerations and stress analysis performed to this point will be presented and discussed.

Primary author: POLIZZO, Salvatore (Brookhaven National Lab)

Presenter: POLIZZO, Salvatore (Brookhaven National Lab)

Session Classification: Friday morning 1

Track Classification: SPC judgements

Contribution ID: 22

Type: **Oral presentation**

Operational Experience with Superconducting RF Cavities at the Canadian Light Source

Wednesday, May 14, 2014 12:00 PM (30 minutes)

The Canadian Light Source synchrotron has been using the CESR-B type 500 MHz superconducting cavity for over 10 years. This presentation will discuss operating experience with these cavities to date.

Primary author: Mr STAMPE, Jonathan (Canadian Light Source)

Co-authors: Dr REGIER, Chris (Canadian Light Source); Dr DE JONG, Mark (Canadian Light Source)

Presenter: Mr STAMPE, Jonathan (Canadian Light Source)

Session Classification: Wednesday morning 2

Track Classification: SPC judgements

Contribution ID: 23

Type: **Poster**

Development of a RF Power Coupler for the Rare Isotope Science Project (RISP) RFQ Prototype

Thursday, May 15, 2014 3:34PM (1 minute)

RAON, heavy ion accelerator for rare isotope science, is under development for the Rare Isotope Science Project (RISP) at Institute for Basic Science in South Korea. Radio-Frequency Quadrupole (RFQ), a component of RAON, accelerates heavy ion beams from 10 keV/u up to 500 keV/u at the current of 12 μA and the frequency of 81.25 MHz. For RISP RFQ prototype, a 15kW CW RF power coupler has been designed using 3D electromagnetic, mechanical computer simulation codes. Here, the test results of the fabricated RF power coupler are presented.

Primary author: Ms HAN, Woo-Kyung (Institute for Basic Science)

Co-authors: Dr CHOI, Bong Hyuk (Institute for Basic Science); Dr HAN, Jaeun (Institute for Basic Science)

Presenter: Ms HAN, Woo-Kyung (Institute for Basic Science)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 24

Type: **Poster**

Test results of feedback control of LLRF system for RAON QWR

Thursday, May 15, 2014 3:30 PM (1 minute)

TEM-like superconducting quarter wave resonator (QWR) is adopted for the lowest optimum beta (0.047) section of the RAON. For the proper acceleration of heavy ions in QWR, 3 kW, 81.25 MHz RF power is supplied through coaxial couplers. For acceleration of heavy ion beam in the superconducting linear accelerator, the Low-Level RF (LLRF) should have feedback control of accelerating field and resonance frequency in the cavity and protection of High Power RF (HPRF) system. The integrated test of the LLRF prototype for QWR with the QWR, mockup copper cavity is underway. Field stabilities are required within $\pm 1\%$ in amplitude and $\pm 1^\circ$ in phase, the RF amplitude and phase are controlled within $\pm 0.2\%$ and $\pm 0.05^\circ$, respectively. In this paper, the integration test details and results of the LLRF prototype with the QWR are described.

Primary author: DO, Heejin (I)**Co-authors:** Dr HWANG, Churl Kew (IBS); HAN, Jae Eun (I); Dr KIM, Jong Won (IBS); Mr CHOI, Oh-ryong (IBS); JUNG, hoechun (I)**Presenter:** DO, Heejin (I)**Session Classification:** Poster session**Track Classification:** SPC judgements

Contribution ID: 25

Type: **Oral presentation**

High Power RF System Status and Experience for the PLS-II Storage Ring

Tuesday, May 13, 2014 2:00 PM (30 minutes)

The RF system of the Pohang Light Source-II (PLS-II) storage ring is operating at the 3.0 GeV/300 mA with three superconducting RF (SRF) cavities. PLS-II RF system was upgraded to 3.0 GeV/400 mA(max.) beam storage from 2.5 GeV/ 200mA of PLS. Each high power RF (HPRF) station is composed of a 300 kW klystron with power supply unit, transmission components including a 350 kW circulator and load, and water cooling system. Also three digital type LLRFs, three cryomodules with SRF cavities, and a cryogenic system are operating with HPRF system for the PLS-II storage ring. This paper describes the present operation status of 300 kW HPRF system and experiences of the former PLS 75 kW HPRF system.

Supported by the Ministry of Science, ICT and Future Planning in Koreamhchun@postech.ac.kr*

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Presenter: CHUN, Myunghwan (PAL(Pohang Accelerator Laboratory)/POSTECH)

Session Classification: Tuesday afternoon 1

Track Classification: SPC judgements

Contribution ID: 26

Type: **Oral presentation**

CW RF System for the ATLAS Efficiency and Beam Intensity Upgrade

Thursday, May 15, 2014 3:00 PM (30 minutes)

In order to increase beam transmission efficiency and intensity of ion beams, a major upgrade project has been conducted at Argonne Tandem Linac Accelerator System (ATLAS). A 4-meter long 60.625 MHz CW radio-frequency quadrupole (RFQ) has been developed, built and commissioned with beam in 2012. The RFQ has been used in the regular operation since January, 2013 and is capable of providing 295 keV/u for any ion from proton to uranium. A new cryomodule Booster A consisting of seven 72.75 MHz superconducting (SC) quarter-wave resonators (QWR) has also been developed and installed in 2013. This cryomodule was commissioned in Feb. 2014 and demonstrated acceleration voltage about 3 MV per cavity which exceeded the required performance of maximum 2.5 MV per cavity. Transmission through Booster A is almost 100%. In this paper, the new CW RF system is presented. Two 60 KW electron tube type amplifiers are controlled to provide the power for the 60.625 MHz RFQ. The resonance frequency is regulated to the master oscillator (MO) frequency by adjusting the cooling water temperature. Seven 4 KW solid state amplifiers are used to operate the cryomodule in the overcoupled mode. Circulators and dummy loads are used to protect the amplifiers.

Primary authors: SHARAMENTOV, Sergey (A); LUO, Yong

Co-authors: BARCIKOWSKI, Albert (Argonne National Lab); PASKVAN, Dan (Washington state University); ZINKANN, Gary (Argonne National Lab); KELLY, Mike (Argonne National Lab); OSTROUMOV, Peter (Argonne National Laboratory)

Presenter: LUO, Yong

Session Classification: Thursday afternoon 1

Track Classification: SPC judgements

Contribution ID: 27

Type: **Poster**

Overview on high power/high efficiency RF sources development at Thales Electron Devices

Thursday, May 15, 2014 3:32 PM (1 minute)

Thales ED has an experience of more than fifty years in high power RF tubes design and manufacturing, from klystrons and grid tubes amplifiers to gyrotrons oscillators.

This talk presents recent high power / high efficiency solutions (experimental results and designs) which are suited for the next generation of particles accelerators. Namely, one of the future large scale linacs main challenges is to reduce the large electrical power consumption (in the TWh per year order of magnitude). To make these facilities more environmental friendly and power efficient, research and development is encouraged at Thales ED to increase RF sources electrical to RF power conversion. One ultimate goal for the vacuum tubes would be for instance to deliver the required high peak power with a targeted 70% efficiency.

The presentation will introduce different tubes solutions comparing parameters such as performance, maturity and lifetime, as well as possible innovations for each technology (klystrons, tetrodes and IOTs), in order to give an overview of Thales ED capability to deliver efficient RF solutions for long pulse and CW applications for the next decade.

Primary authors: Mr BEUNAS, Armel (THALES Electron Devices); Mr GREZAUD, Michel (THALES Electron Devices); Mr THOUVENIN, Philippe (THALES Electron Devices); Mr MARCHESIN, Rodolphe (THALES Electron Devices); Mr BETHUYS, Stephane (THALES Electron Devices)

Co-authors: Mr DARGES, Bernard (THALES Electron Devices); Mr BEL, Claude (THALES Electron Devices)

Presenters: Mr MARCHESIN, Rodolphe (THALES Electron Devices); Mr BETHUYS, Stephane (THALES Electron Devices)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 28

Type: **Oral presentation**

The High Power RF System of the European XFEL

Thursday, May 15, 2014 2:00 PM (30 minutes)

The European XFEL requires twenty-seven high power RF stations at 1.3GHz capable of a peak RF power of 10MW at 1.37ms pulse duration and 10Hz repetition rate. Twenty-five RF stations supply RF power to one-hundred cryogenic modules each with eight nine-cell superconducting cavities. Two RF stations are reserved for the RF gun and one cryogenic module in the injector of the European XFEL. Each station consists of a HV modulator, pulse cables, pulse transformer, multi beam klystron, waveguide distribution and several other auxiliary components. This presentation describes the layout and status of the RF system for the European XFEL.

Primary author: CHOROBA, Stefan (DESY)

Presenter: CHOROBA, Stefan (DESY)

Session Classification: Thursday afternoon 1

Track Classification: SPC judgements

Contribution ID: 29

Type: **Oral presentation**

Impact of RF Source Efficiency on RF Accelerator Sustainability

Tuesday, May 13, 2014 3:00 PM (30 minutes)

RF accelerator electrical energy consumption at the U.S. DOE laboratories was 1 TW-hr in FY2012, and is projected to rise to 1.5 TW-hr by 2018. A major fraction of this energy is used to produce RF power (e.g. this fraction is >50% at SLAC, which is ~40% of the total site energy usage). Although it has long been recognized that improving the efficiency of RF sources would improve sustainability and reduce accelerator program operating costs, developing and implementing higher efficiency systems is typically beyond the means of the programs at individual labs. With the encouragement of the new DOE Accelerator Stewardship program, we have performed a complex-wide survey of RF sources to identify upgrades that could impact multiple lab programs, potentially enabling new sustainability improvement opportunities.

Primary author: BURKHART, Craig (S)**Presenter:** BURKHART, Craig (S)**Session Classification:** Tuesday afternoon 1**Track Classification:** SPC judgements

Contribution ID: 30

Type: **Oral presentation**

RF System Conceptual Design for the LCLS-II CW, SCRF Linac

Tuesday, May 13, 2014 4:00 PM (30 minutes)

At SLAC, a 4 GeV, 1.3 GHz, CW, SCRF linac will be constructed for the LCLS-II project. About 7 kW of rf power will be required per cavity, which will allow operation at 16 MV/m with up to 300 uA beam currents. In the rf system design presented in the project CDR, each cavity in the upstream portion of the machine is powered by a solid state amplifier, while the bulk of the cavities are powered in groups of 48 by 300 kW klystrons. This paper describes these design choices and their related operations issues.

Primary author: ADOLPHSEN, Chris (SLAC)

Presenter: ADOLPHSEN, Chris (SLAC)

Session Classification: Tuesday afternoon 2

Track Classification: SPC judgements

Contribution ID: 31

Type: **Oral presentation**

Gallium Nitride Transistor in continuous wave RF applications

Wednesday, May 14, 2014 9:30 AM (30 minutes)

Gallium nitride (GaN) RF transistors have higher power handling capacity, higher efficiency and higher operation frequency compared with silicon RF transistors, which makes GaN device a better choice for continuous wave (CW) RF applications. Due to low yield in device fabrication, GaN transistors used to have a much higher price than silicon ones. As a result, high power RF source using GaN devices is only seen in the most demanding applications. Development in GaN transistor fabrication technology in the last 5 years largely reduced the price of GaN devices. Nowadays, cost of L-Band GaN devices are at about the same level as the silicon equivalents, which makes GaN CW RF design an economically competitive solution. In this paper a design using GaN transistors is presented for the proposed LCLS-II RF source. Capital cost and operational cost of both GaN and Si designs are compared. The estimation suggests a reduction of 32% in both capital and operational cost by adopting the GaN technology. GaN solution also enables amplifier topology with high efficiency, which will reduced the operational cost by 47% compared with solution using Si devices.

Primary author: TANG, Tao (S)**Presenter:** TANG, Tao (S)**Session Classification:** Wednesday morning 1**Track Classification:** SPC judgements

Contribution ID: 32

Type: **Poster**

Prototyping of superconducting cavities for RAON the heavy ion accelerator

Thursday, May 15, 2014 3:35 PM (1 minute)

Four kinds of superconducting resonators (Quarter wave resonator, half wave resonator, and Single spoke resonator type 1, type 2) are designed and developed for the heavy ion accelerator the RAON. Resonators which have extreme high Q-factor $10E9 \sim 10E10$, are filled up through coaxial RF power couplers of over coupling at 81.25MHz (QWR), 162.5MHz (HWR), 325MHz (SSR) respectively. Cavities are fabricated from 3mm RRR300 Niobium sheets by the collaboration with domestic vendors. 325MHz 10kWatts RF power couplers are prototyped and will be tested with a dummy cavity in the room temperature.

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Presenter: Dr JUNG, Hoechun (Institute for Basic science)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 33

Type: **Oral presentation**

Status of the rf-system for the high intensity proton accelerator facility at PSI

Thursday, May 15, 2014 4:30 PM (30 minutes)

This year PSI celebrated the 40 years anniversary of the Ring cyclotron. This is the main accelerator of the high intensity proton accelerator facility, where protons are accelerated up to 590 MeV. In several upgrade programs the beam current was increased from the initial design value of 100 μA up to 2.4 mA. The rf-system of this separated sector cyclotron consists of 4 copper cavities running at 50 MHz for the main acceleration. To increase the phase acceptance of the Ring, an aluminium flattop cavity is operated on a gap voltage of 555 kVp at the 3rd harmonic frequency.

In 2013 after half a year of regular operation the flattop cavity caused about 3 weeks of unscheduled downtime. Multipactoring discharges overheated the finger contacts on the coupling loop. A description of the observed phenomena and the taken actions will be presented.

The Injector 2 cyclotron is the preaccelerator for the Ring. An upgrade program on the rf-system will replace the two flattop cavities (150 MHz) by accelerating cavities (50 MHz). This program includes the replacement of amplifiers, for those the tubes are no longer produced by the supplier. A status report of this project will be given.

Primary author: SCHNEIDER, Markus (Paul Scherrer Institut)

Presenter: SCHNEIDER, Markus (Paul Scherrer Institut)

Session Classification: Thursday afternoon 2

Track Classification: SPC judgements

Contribution ID: 34

Type: **Oral presentation**

Almost 40 years of operation with tetrodes in the CERN-SPS

Thursday, May 15, 2014 11:00 AM (30 minutes)

A brief description of the two tetrode power plants of the CERN-SPS. Some statistics accumulated with more than 100 tetrodes over almost 40 years of operation. Some horrors that occurred over the period...

Primary author: MONTESINOS, Eric (CERN)

Presenter: MONTESINOS, Eric (CERN)

Session Classification: Thursday morning 2

Track Classification: SPC judgements

Contribution ID: 35

Type: **Oral presentation**

20 years of high average Fundamental Power Coupler designs at CERN

Wednesday, May 14, 2014 11:00 AM (30 minutes)

Description of high average Fundamental Power Coupler designed at CERN over the last 20 years. Main difficulties and power limitations. Some tips to propose better designs.

Primary author: MONTESINOS, Eric (CERN)

Presenter: MONTESINOS, Eric (CERN)

Session Classification: Wednesday morning 2

Track Classification: SPC judgements

Contribution ID: **36**

Type: **Poster**

New Solid State driver Amplifiers for the CERN-SPS

Thursday, May 15, 2014 3:37PM (1 minute)

Summary of the recent purchasing of the new Solid State driver Amplifiers for the LHC Injectors Upgrade programme. Technical Specifications description and offers from suppliers analysis.

Primary author: MONTESINOS, Eric (CERN)

Presenter: MONTESINOS, Eric (CERN)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 37

Type: **Oral presentation**

RF Upgrades and Operating Experience at JLab

Thursday, May 15, 2014 12:00 PM (30 minutes)

Designed as a 4 GeV electron machine, CEBAF was run at 6 GeV. Major upgrades implemented over the past several years increased capabilities to 12 GeV. 80 CW RF channels of a new design were added to the existing 340 channels to achieve this energy. As previously reported, a new, higher power klystron design, new HV power supplies, plus new controls and interlocks were required. Deliveries of some major components were late, with some requiring working closely with vendors to meet requirements.

RF installation is complete and focus has moved to providing operational support for commissioning of the accelerator as well as improving familiarity with the new systems while working to maintain the existing, aging infrastructure. New systems have generally operated well but not without some early glitches. One klystron failure has occurred to date, numerous support electronics (power supplies, interlocks, cabling, and other failures) have surfaced. Learning these new systems for troubleshooting and repair is ongoing. This talk will review the systems, experiences, discuss select issues and failures.

Primary author: NELSON, Richard (Jefferson Lab)

Presenter: NELSON, Richard (Jefferson Lab)

Session Classification: Thursday morning 2

Track Classification: SPC judgements

Contribution ID: 38

Type: **Oral presentation**

The ESS RF Systems and the plans for new developments

Friday, May 16, 2014 11:00 AM (30 minutes)

The European Spallation Source, a 5 MW average power, pulsed proton linac, will accelerate 62.5 mA of protons to an energy of 2 GeV. Each pulse is 2.86 ms and repeats at 14 Hz, resulting in a power-to-beam requirement per pulse of 125 MW of RF power. The split installation schedule means that existing, more mature technology is considered for the first part of the programme but for the later parts of the linac, which contribute approximately 80% of the final beam energy, development of new, high power and high efficiency sources and power supply systems can be investigated. This talk will review some of the key RF sources and new developments being pursued for ESS.

Primary author: JENSEN, Morten (European Spallation Source)

Presenter: JENSEN, Morten (European Spallation Source)

Session Classification: Friday morning 2

Track Classification: SPC judgements

Contribution ID: 39

Type: **Poster**

RF Development Status at Iranian Light Source Facility

Thursday, May 15, 2014 3:31 PM (1 minute)

The Iranian Light Source Facility (ILSF) RF system was conceptually designed in accordance with the requirements for ILSF 3GeV storage ring with 400 mA beam current at 500 MHz RF frequency. The development of the solid state amplifiers initiated with the design and fabrication of two amplifier modules based on BLF578 and MRFE6VP1K25HR6 transistors and 670W and 540W stable RF power were delivered respectively. Combining of 8 such modules is under test to achieve 4kW output power as the first stage of the conceptually designed combining network. The measured characteristics are presented in this poster. Motivated by the development of HOM damped cavity with simpler structure at 100MHz at MAX Lab., 100MHz RF system is under exploration as an alternative to 500 MHz at ILSF. In addition to thorough study of the frequency change effects on the beam and machine parameters, the design of a 100MHz cavity based on MAX Lab. design has also been performed. Fabrication of a prototype cavity is planned in order to conclude the possibility of the cavity development in house.

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Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 40

Type: **Oral presentation**

Operational experience of high-power RF at Diamond Light Source

Tuesday, May 13, 2014 5:00 PM (30 minutes)

Diamond Light Source is a synchrotron light source facility that has been providing beam for users since January 2007. Diamond consists of a 3 GeV storage ring powered by two 300 kW amplifiers each containing four IOTs, a full energy booster also driven by an IOT-based amplifier and a 100 MeV linac using pulsed klystrons. RF performance and reliability are reviewed for all three accelerators and current operating and conditioning procedures are presented. Efforts to minimise the RF-related disturbance of user beam are detailed and plans for possible future upgrades are presented, including an upgrade of beam current towards an ultimate goal of 500 mA from the present 300 mA and the introduction of a third superconducting cavity to the storage ring.

Primary author: CHRISTOU, Chris (D)

Co-authors: Mr WATKINS, Alun (Diamond Light Source); Dr GU, Pengda (Diamond Light Source); Mr PANDE, Shivaji (Diamond Light Source)

Presenters: Mr WATKINS, Alun (Diamond Light Source); CHRISTOU, Chris (D); Dr GU, Pengda (Diamond Light Source)

Session Classification: Tuesday afternoon 2

Track Classification: SPC judgements

Contribution ID: 41

Type: **Oral presentation**

Workshop summary

Friday, May 16, 2014 12:00 PM (30 minutes)

Workshop summary

Primary authors: Dr FABRIS, Alessandro (Sincrotrone Trieste); Dr NASSIRI, Alireza (Argonne National Laboratory); Mr HORAN, Doug (Argonne National Laboratory)

Presenters: Dr FABRIS, Alessandro (Sincrotrone Trieste); Dr NASSIRI, Alireza (Argonne National Laboratory); Mr HORAN, Doug (Argonne National Laboratory)

Session Classification: Friday morning 2

Contribution ID: 42

Type: **Oral presentation**

Workshop opening

Tuesday, May 13, 2014 9:00 AM (20 minutes)

Workshop opening, practical information.

Primary author: Dr FABRIS, Alessandro (Sincrotrone Trieste)

Presenter: Dr FABRIS, Alessandro (Sincrotrone Trieste)

Session Classification: Tuesday morning 1

Track Classification: SPC judgements

Contribution ID: 43

Type: **Oral presentation**

A tribute to Ti Ruan

Tuesday, May 13, 2014 9:30 AM (30 minutes)

Primary author: LOPES, Robert (Soleil)

Co-author: MARCHAND, Patrick (Synchrotron SOLEIL)

Presenter: LOPES, Robert (Soleil)

Session Classification: Tuesday morning 1

Track Classification: SPC judgements

Contribution ID: 44

Type: **Oral presentation**

Elettra and FERMI, The Accelerator Facilities at Elettra Sincrotrone Trieste

Tuesday, May 13, 2014 10:00 AM (30 minutes)

Elettra Sincrotrone Trieste is a multidisciplinary international laboratory of excellence, specialized in generating high quality synchrotron and free-electron laser light and applying it in materials science. The main assets of the research center are two advanced light sources, the electron storage ring Elettra and the free-electron laser (FEL) FERMI.

This presentation provides an overview of the machines, their development and their operation. Special focus will be dedicated to the RF systems that have been designed and are now in operation both for the storage rings and the linacs.

Primary author: Dr FABRIS, Alessandro (Sincrotrone Trieste)

Presenter: Dr FABRIS, Alessandro (Sincrotrone Trieste)

Session Classification: Tuesday morning 1

Track Classification: SPC judgements

Contribution ID: 45

Type: **Poster**

Very High Power Solid State Amplifiers in the Range of 50MHz to 1.3GHz of Industrial Design with Very High Efficiency

Thursday, May 15, 2014 3:36 PM (1 minute)

A new series of solid-state RF amplifiers will be presented, which cover the frequency range from 50MHz to 750MHz with an output power of more than 100kW. The amplifiers are of industrial design regarding their space and maintenance requirements. They have been designed for the operation of Cyclotrons, Synchrotrons, Storage Rings and Linear Accelerators.

The specific design of the Cryoelectra Amplifiers can be extended to frequencies of 1.3 GHz and beyond. Their output power is scalable to several hundreds of kW. The new features of these amplifiers are the optimization of their efficiency by a remote adjustment of the P1- operation point to the required output power and an extraordinary low phase noise, which is important for the operation of Storage Rings.

Primary author: Dr PUPETER, Nico (Cryoelectra GmbH, Germany)

Presenter: Dr PUPETER, Nico (Cryoelectra GmbH, Germany)

Session Classification: Poster session

Track Classification: SPC judgements

Contribution ID: 46

Type: **Oral presentation**

Welcome address by Prof. Giovanni Comelli, vice-president Elettra-Sincrotrone Trieste S.C.p.A.

Tuesday, May 13, 2014 9:20 AM (10 minutes)

Welcome address by Prof. Giovanni Comelli, vice-president Elettra-Sincrotrone Trieste S.C.p.A.

Primary author: Dr FABRIS, Alessandro (Sincrotrone Trieste)

Session Classification: Tuesday morning 1

Track Classification: SPC judgements

Contribution ID: 47

Type: **Oral presentation**

Solid State Thyatron Replacement for the LHC Klystron Crowbar

Friday, May 16, 2014 11:30 AM (30 minutes)

The counter-rotating proton beams in the Large Hadron Collider (LHC) are captured and accelerated to their final energies by two identical 400 MHz Radio Frequency (RF) systems. The RF power source required for each beam comprises eight 300 kW klystrons. Each unit of four klystrons is powered by a 100kV/40A AC/DC power converter. A fast protection system (crowbar) protects the four klystrons in each of these units.

Although the LHC RF system has shown very good performance, operational experience has shown that the five-gap double-ended thyatrons used in the crowbar system suffer, from time to time, from auto-firing, which result in beam dumps.

A solid state solution, based on a stack of thyristors, has been designed for a direct thyatron replacement and has been fully validated and installed in one of the four bunkers in the LHC in September 2012. After five month it has proven to give full satisfaction. Ten thyristors stack based crowbar are under production and tests to equip the three other bunkers, the tests stand and spare part.

Primary author: RAVIDA, Gianfranco (CERN)

Co-authors: Dr VALUCH, Daniel (CERN); BRUNNER, Olivier (CERN)

Presenter: Dr VALUCH, Daniel (CERN)

Session Classification: Friday morning 2

Track Classification: SPC judgements