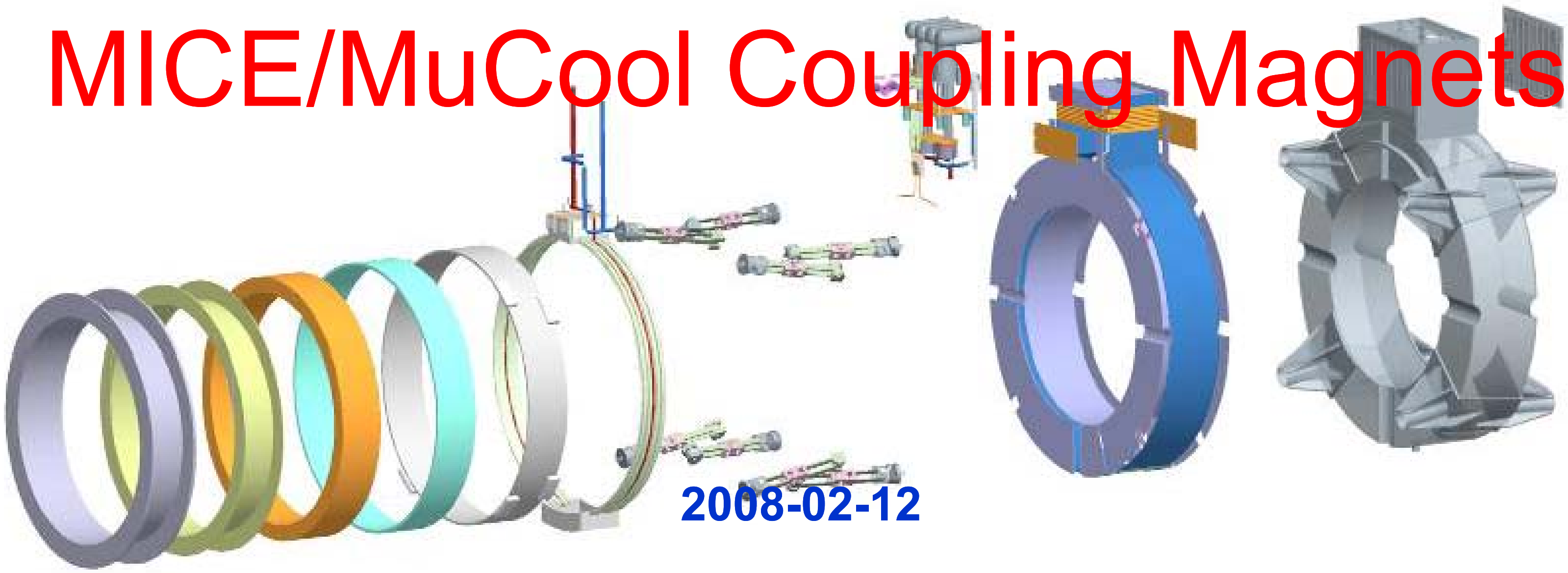
Progress on MICE/MuCool Coupling Magnets



2008-02-12

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Progress

Since the last meeting in October, 2007,

- **Test Coils**
- **Cryo-test System for test coils & coupling coils**

  PID, Layout, control valve box, cryo-transfer lines, test cryostats, measurement & control etc.
- **Coil Winding System**

  Winding system, winding procedure, some key tests, etc.
- **Updated Design of MICE/MuCool Coupling Magnets**

  Cold mass support system, cooling connections, etc.
- **Simulations**

  Quench & quench protection, AC losses, stress and strain, cooling system, etc.

Test Coils

- ✓ Introduction
- ✓ Basic design parameters
- ✓ Load lines of test coils
- ✓ Small coil & its winding tooling
- ✓ Prototype coil & its winding tooling

Introduction

- **Due to relatively high magnetic field** (peak field above 7.4T in the coil), **largest diameter of the coil in MICE** (ID 1.5m), **high strain and stress in the coupling coil, two test coils were proposed in order to validate design methods and winding skills, and to practice the worst case in the coupling coil. It was approved by the international review committee on the engineering design of coupling magnets at the early of last May.**
- **The originally proposed test coils include:**
  Small coil: ID of 350mm, 24 layers and 166 turns per layer
  Large coil: ID of 750mm, 96 layers and 166 turns per layer
- **To meet with the total length of 20km conductors provided by LBNL for the test coils, we reduced the layers from 24 to 12 for the small coil, and from 96 to 80 for the prototype coil in last November.**
- **Considering the purpose of test coils and performance tests such as that for quench cold diodes at possible magnetic fields, finally, we prefer to get back to the originally proposed test coils' design. The total length of conductors for test coils is required as 28km instead of 20km.**

Basic design parameters

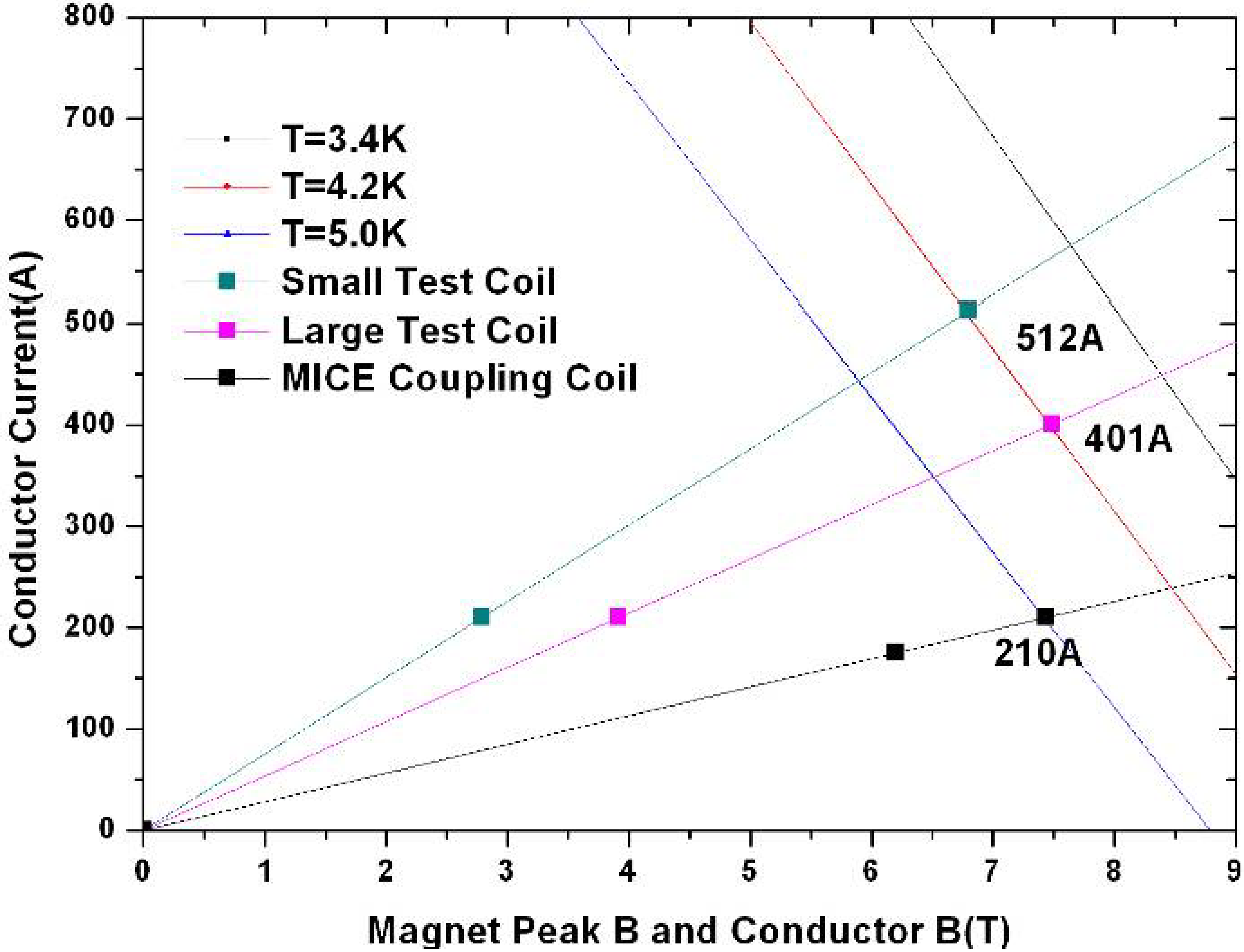
Coil	Small		Large		Coupling
	24layer	12layer	96layer	80layer	
Coil Length (mm)	285	285	72	72	285
Coil Inner Radius (mm)	175	175	750	750	750
Coil Thickness (mm)	25.5	12.8	102.5	85.4	102.5
Number of Layers	24	12	96	80	96
No. Turns per Layer	166	166	42	42	166
Magnet J (A mm-2)*	114.6	114.6	114.6	114.6	114.6
Magnet Current (A)*	210	210	210	210	210
Magnet Self Inductance (H)	4.529	1.11	50.059	35.88	592.5
Peak Induction in Coil (T)	2.79	1.429	3.906	3.558	7.44
Magnet Stored Energy (KJ)	99.867	24.4	1104	791.2	13069
4.2 K Temp. Margin (K)	--	3.856	--	2.868	0.792
Length of conductors per coil (km)	4.701	2.27	20.299	16.735	~ 80.118

Main structure design parameters

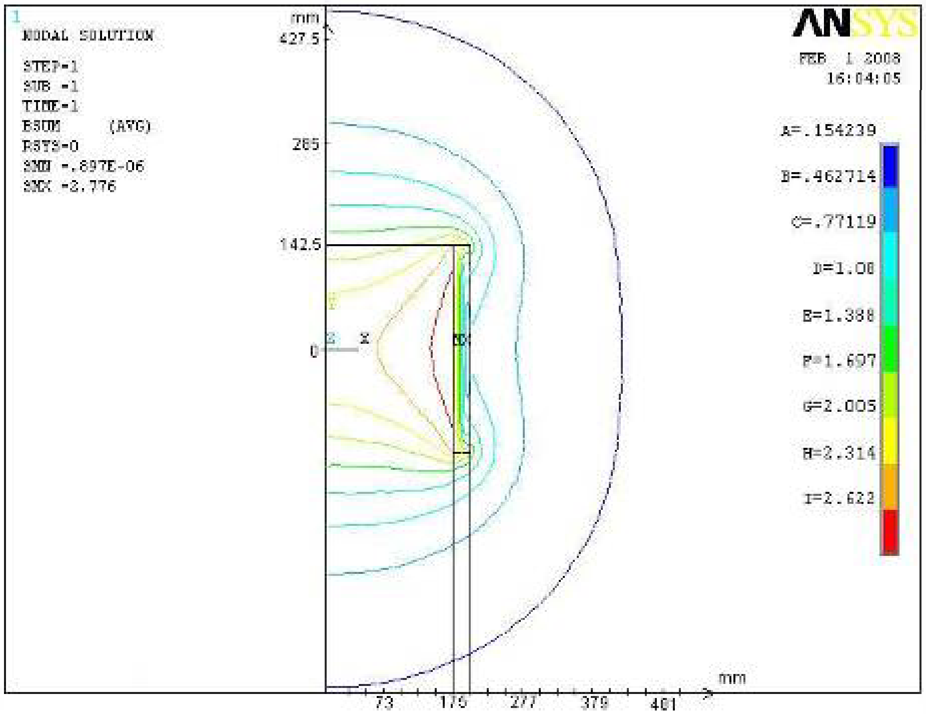
	Small coil	Large Coil	Coupling Coil
G-10 insulation for coil-to-ground (mm)	1.0 (0.5x2)	1.0 (0.5x2)	1.0(0.5x2)
G-10 Insulation between coil and end plates (mm)	3.0	3.0	3.0
G-10 Insulation for coil to banding (mm)	1.0	1.0	1.0
Thickness of coil bobbin (mm)	8	13	13
Thickness of coil end plates (mm)	8	19	19
Thickness of cover plate (mm)	8	13	13
Thickness of banding (mm)	Φ1.2x5	Φ 1.2x10	Φ 1.2x10

- The thickness of coil bobbin and end plates may be changed (thicker) later up to the approach to connect them together.
- All the design for the test coil assemblies including tube cooling are in consistence with the coupling coil as much as possible.

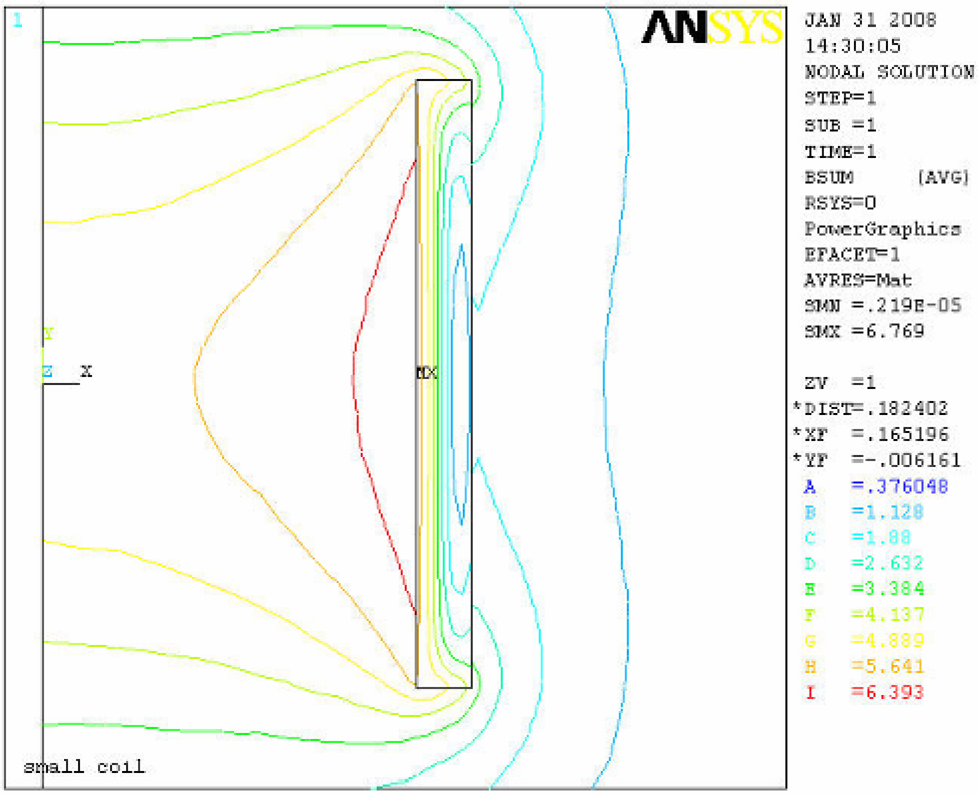
Load lines of test coils



Magnet field isolines for small coil (T)

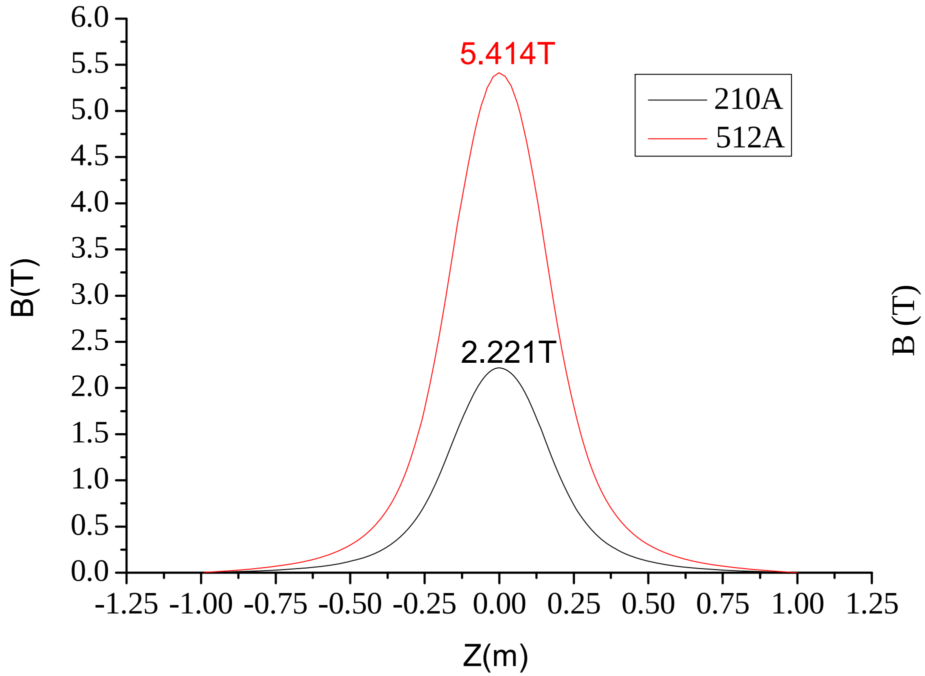


210A

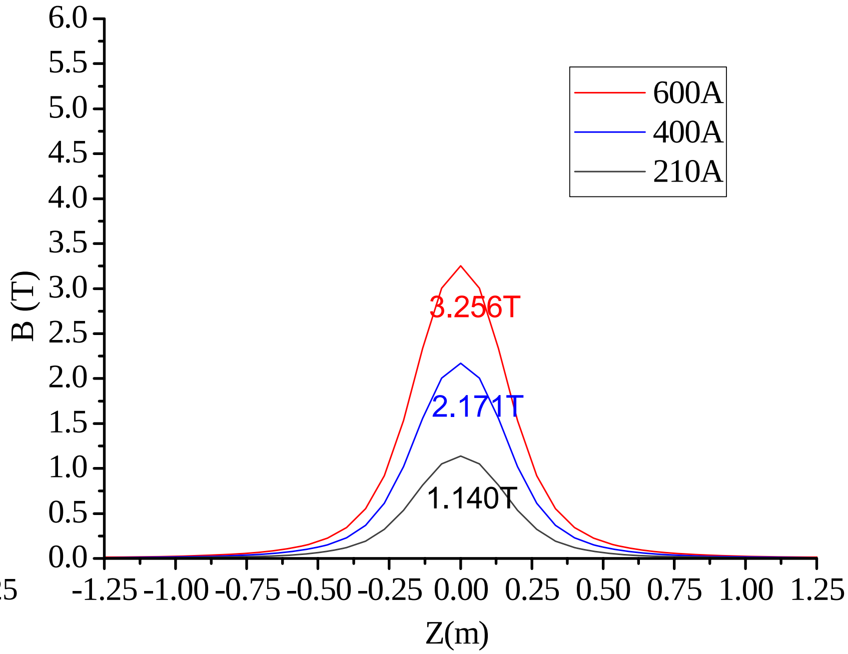


512A

Magnetic field along the central axis of small coil

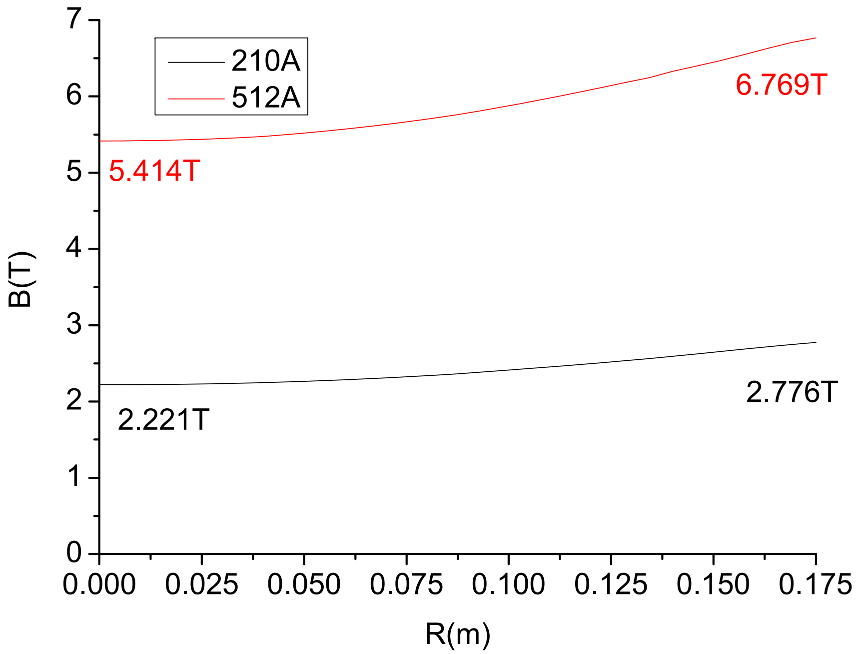


24-layer for small coil

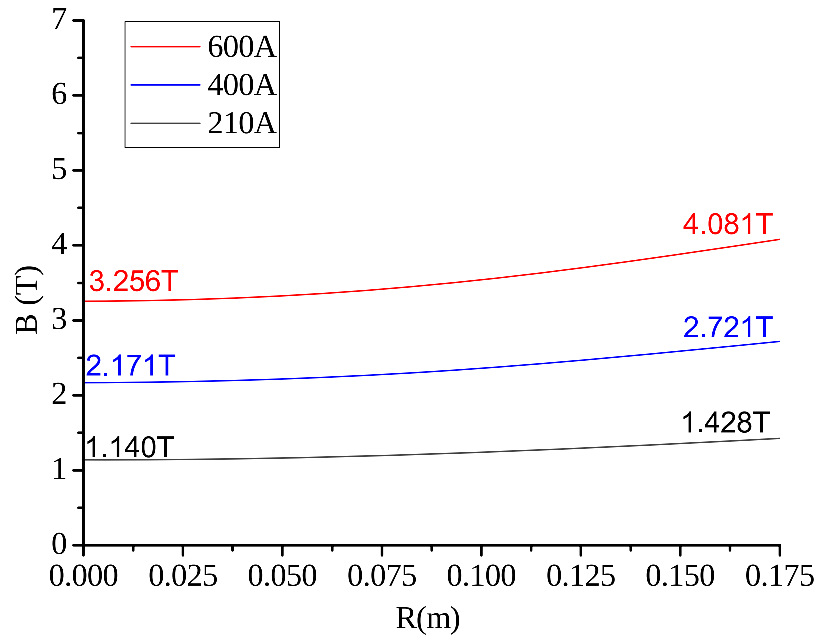


12-layer for small coil

Magnetic field along the radial direction of small coil in the center



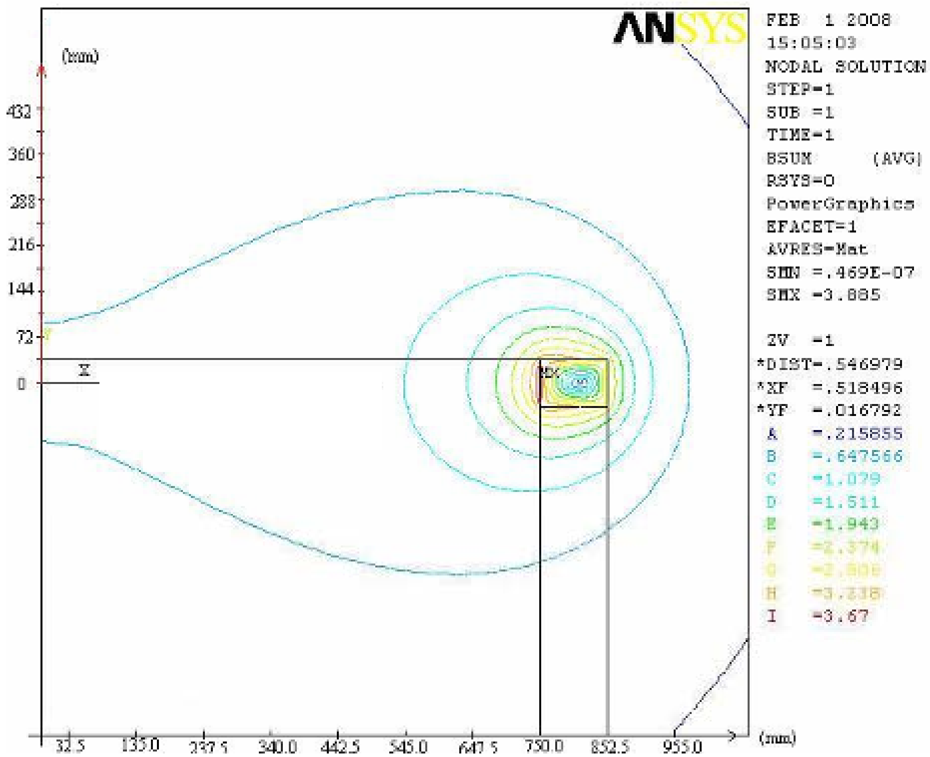
24-layer for small coil



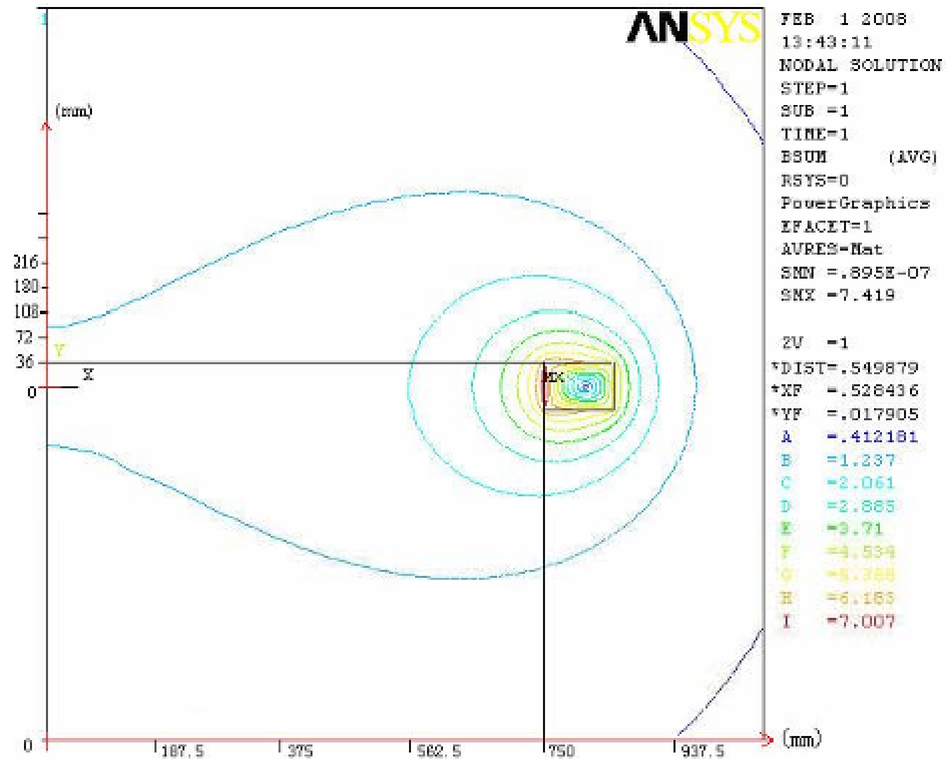
12-layer for small coil

Z=0

Magnet field isolines for large coil (T)

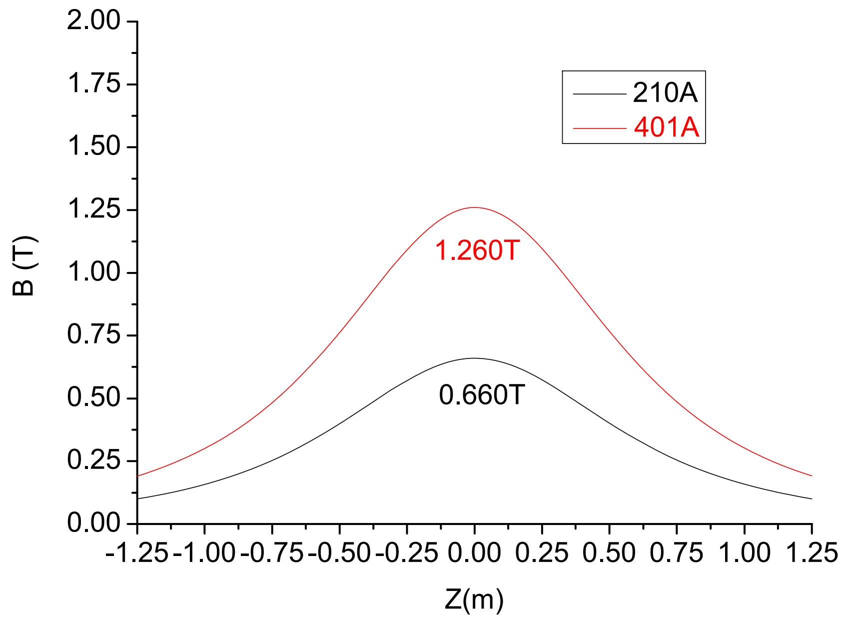


210A

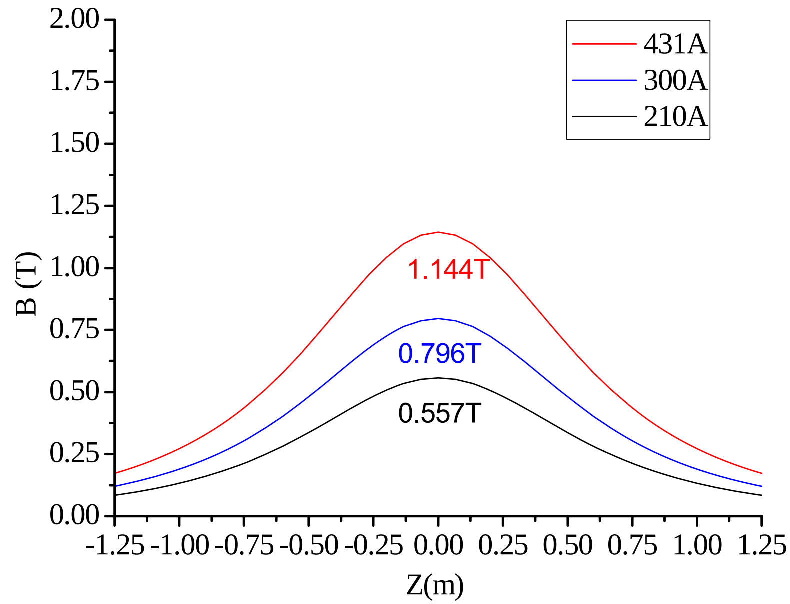


401A

Magnetic field along the central axis of large coil (T)

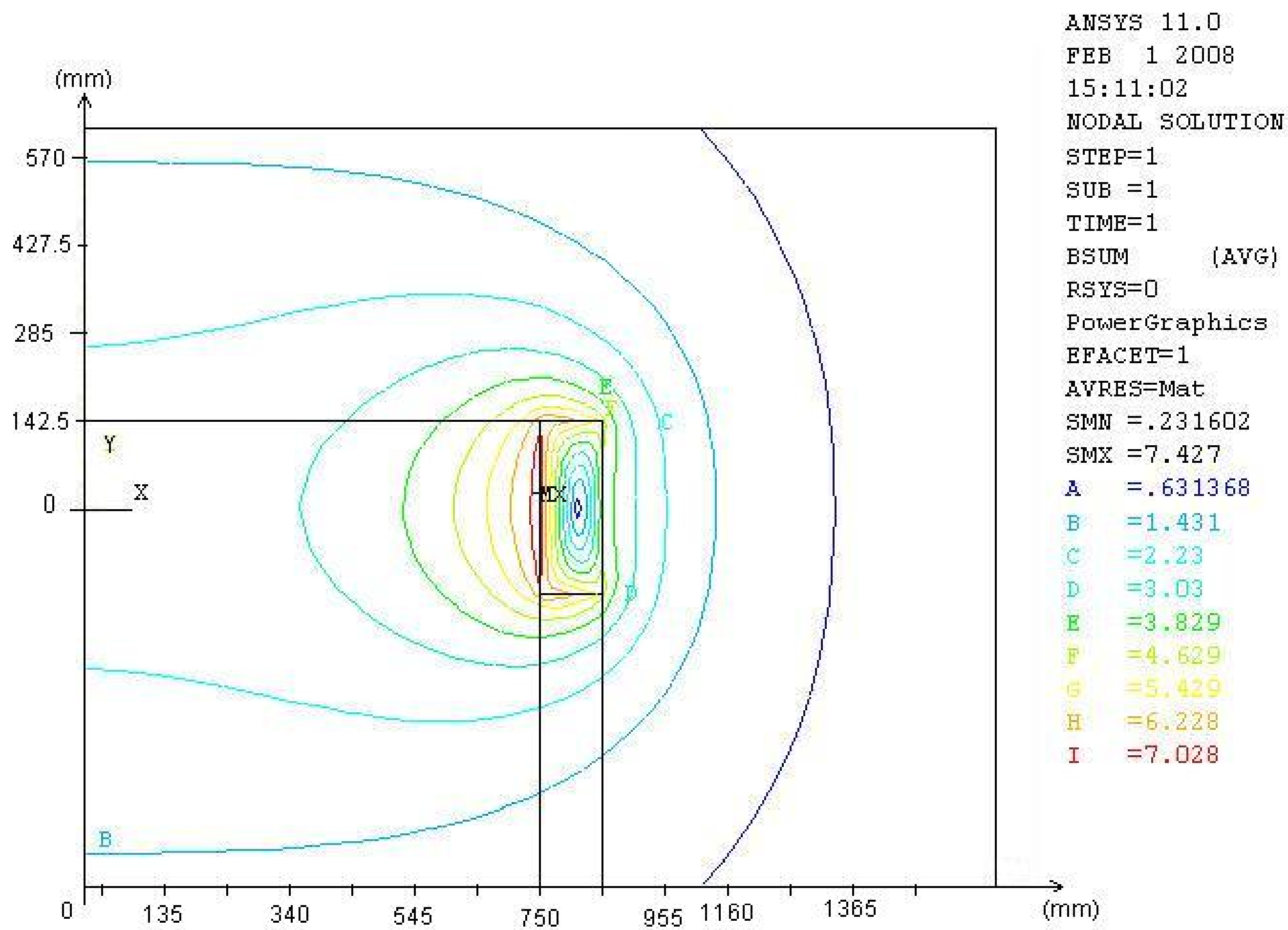


96-layer for large coil



80-layer for large coil

Magnet Field Isolines for Coupling Coil (T)



210A

Quench Simulation: passive quench protection

Parameter		0mΩ	60mΩ
1-Section	Hot Spot Temperature (K)	127	126
	Max Internal Voltage (V)	2424	2376
2-Section	Hot Spot Temperature (K)	122	120
	Max Internal Voltage (V)	1247	1198

Small coil

Parameter		0mΩ	60mΩ
2-Section	Hot Spot Temperature (K)	136	136
	Max Internal Voltage (V)	6043	6006
4-Section	Hot Spot Temperature (K)	129	129
	Max Internal Voltage (V)	3112	3074
6-Section	Hot Spot Temperature (K)	127	126
	Max Internal Voltage (V)	2077	2043

Large coil

Parameter		0Ω	5Ω
8-Section	Hot Spot Temperature (K)	135	88
	Max Internal Voltage (V)	2669	1391

Coupling coil

Comments

- **The test coils are expected to be tested under the equivalent or greater strain state than the coupling coil would encounter.**
- **The test coils will be powered to a higher current than 210A.**

  Small coil (ϕ350mm x 285 mm): 500 A

  Large coil (ϕ1500mm x 72 mm): 400 A
- **The stress and deflection of test coil assemblies were simulated considering the pre-tension during winding the coil and banding, the thermal stress and the magnetic force. The winding pre-stress will be around 70MPa in the coil and 30MPa in the banding made of brass wires.**
- **For small coil, 2-section of quench protection circuit consisting of cold diodes and resistors is to be applied. For large coil, 4-section is to be used. The resistor is sized between 0mΩ to 60mΩ.**

Small coil

- **To wind a small coil using about 5.0 km of tracker solenoid conductor.**

Purpose to wind the small coil:

- **To test and debug the winding machine and the wire tension device**
- **To validate the winding skills:**

  Wet lay-up winding technology

  Layer-layer transition

  Bringing the conductor out of the coil for voltage taps and for the quench protection

  Welding of SC conductor joints

  Elec-insulations……

Purpose to cryo-test the small coil:

- **To gain experience :**

  Quench and training

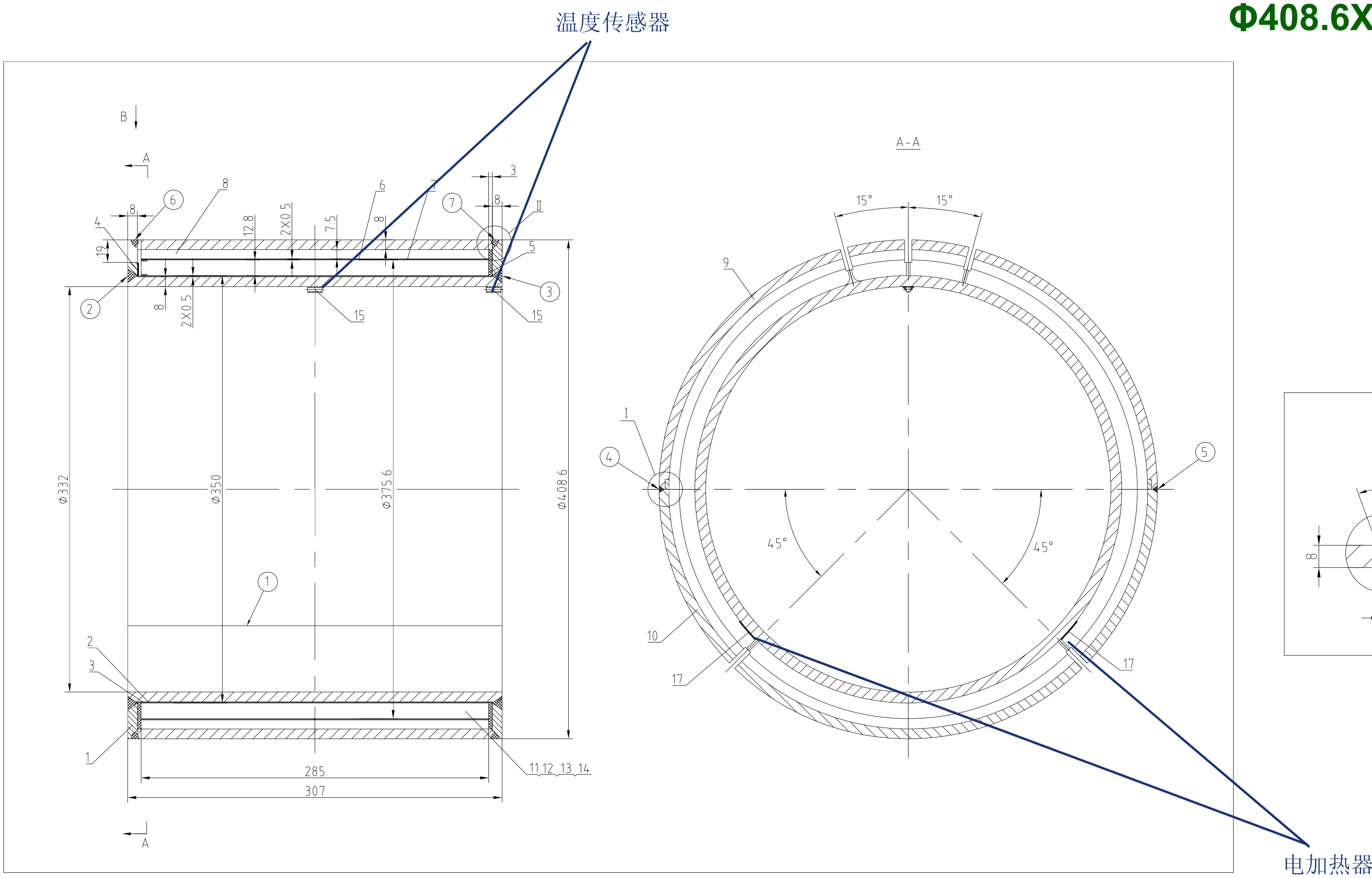
  Winding pre-tension

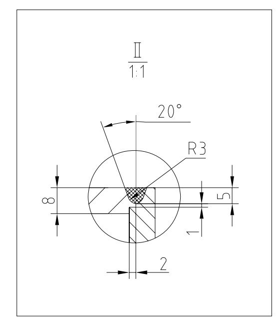
  Magnetic field measurement……

Small coil assembly: Design-done, Materials procurement-done, under fabrication

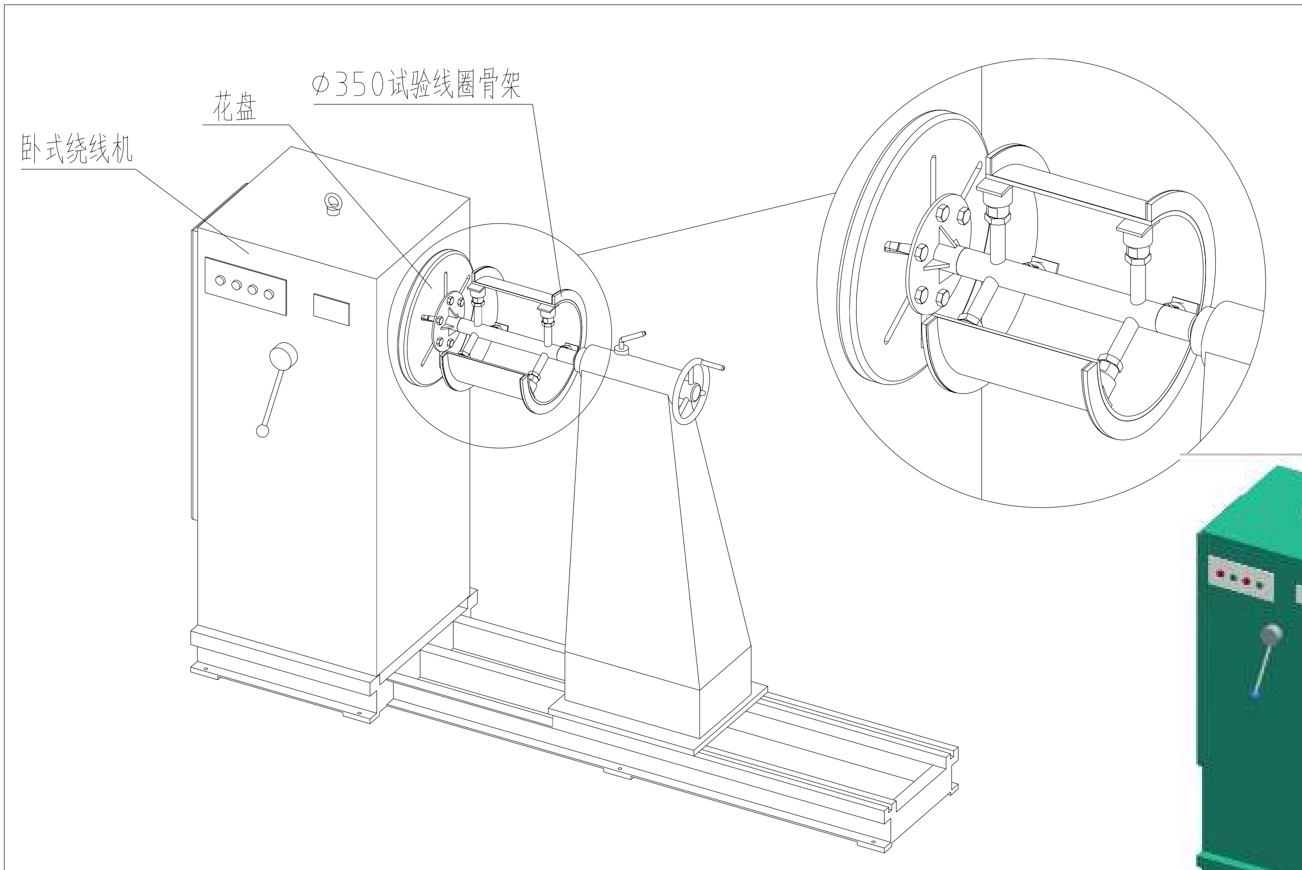
Test cryostat for small coil: Design-done, materials' procurement is going on

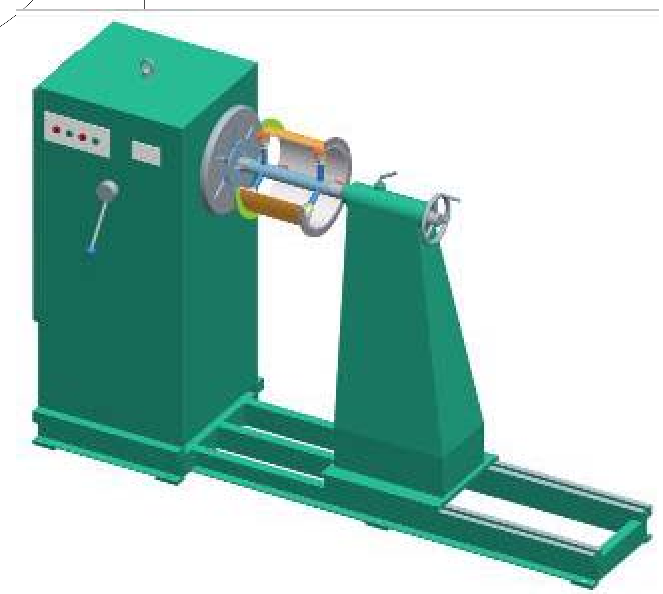
- **Overall size:**
  Φ408.6X307mm





Provided by Han,G.





Provided by Han,G.

Large coil

- **To wind a full diameter but one-quarter long prototype coil with about 20 km of the tracker conductor**

Purpose to wind and cryo-test the prototype coil:

- **To test the coil under strain conditions that are greater than would be encountered in the coupling coil**
- **To gain experience:**

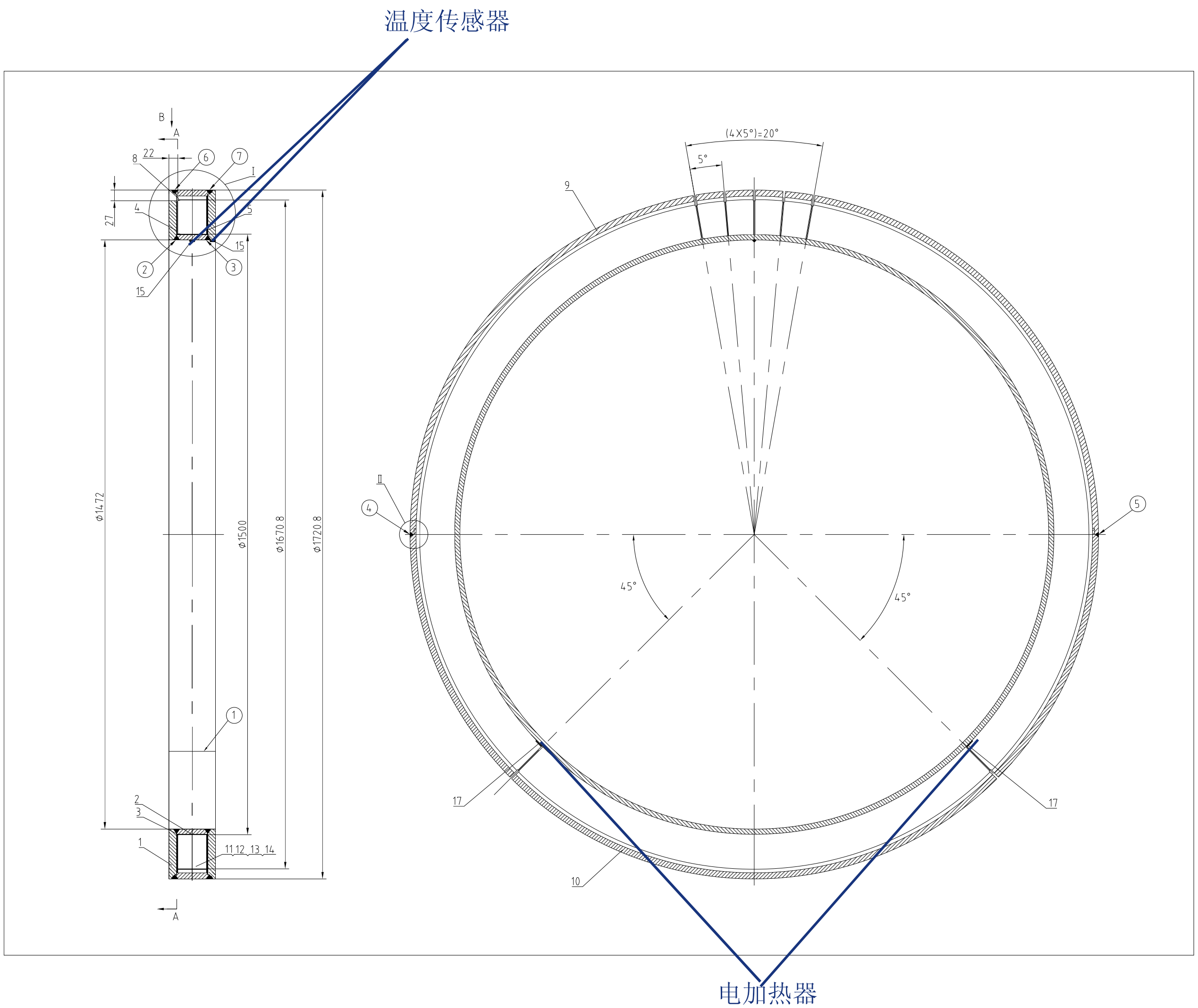
  Training and quench

  Winding pre-tension

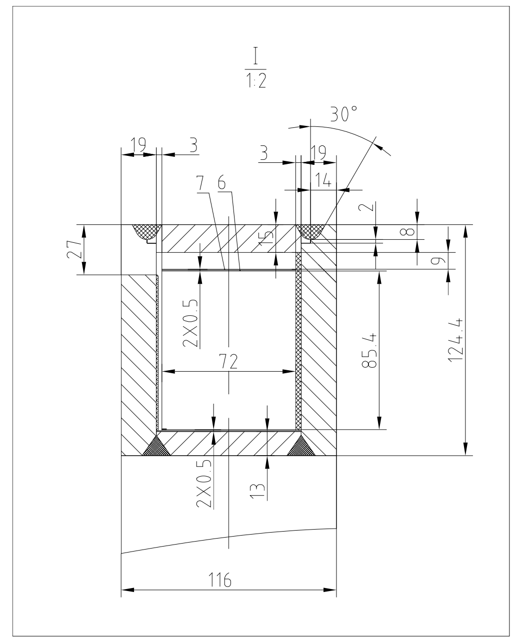
  Magnetic field measurement……

Large coil: Design-done, materials to be procured

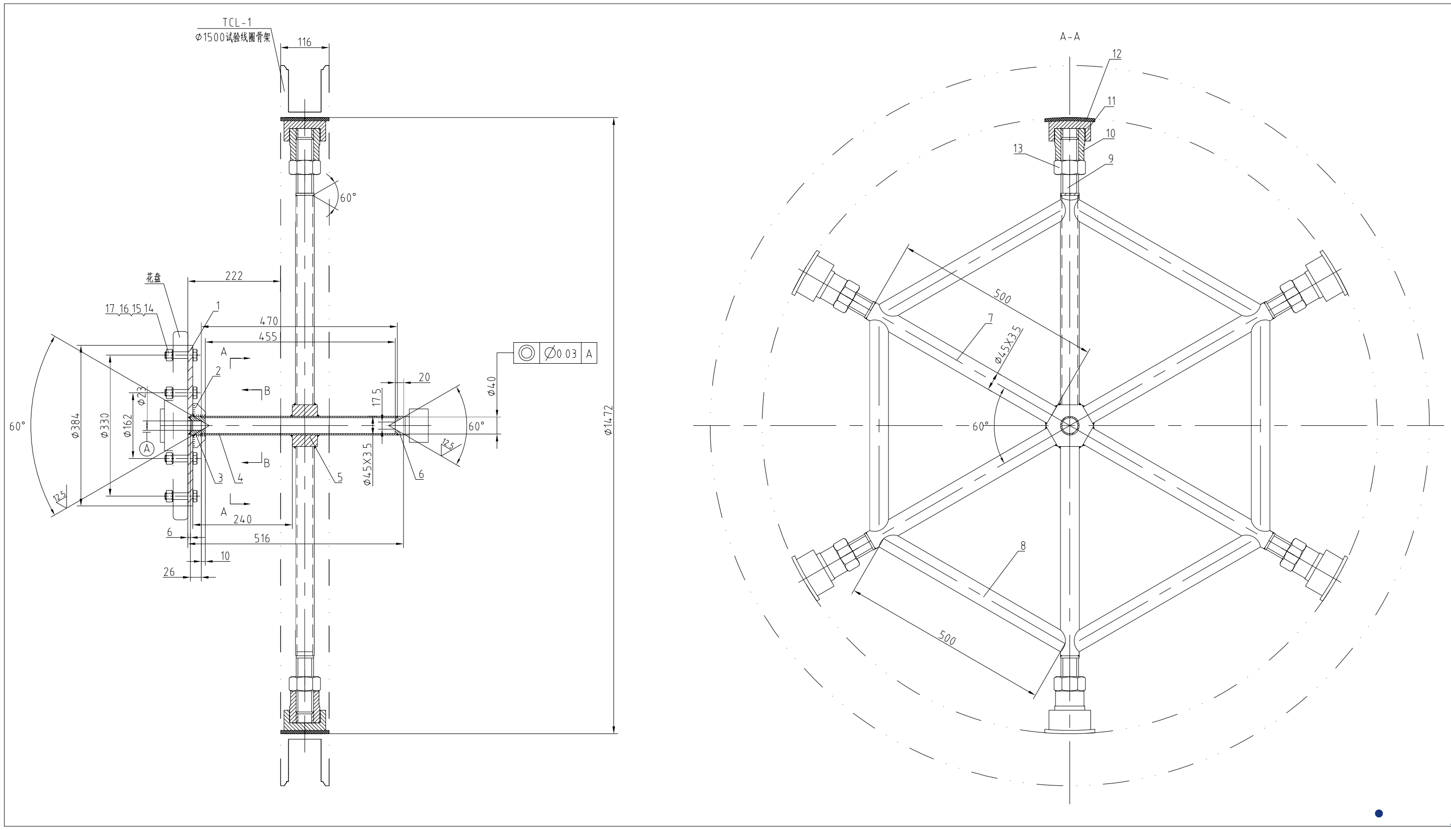
The prototype coil is to be cooled using the ICST TCF20s refrigerator. The design of test cryostat and cryogenic test system is almost done. The same system could be used to test and train the actual coupling coils before they are installed in the coupling coil cryostat.



- **Overall size:**
  Φ1720.8X116mm



Provided by Han,G.



Provided by Han,G.

- 工装特点：
- 前后顶尖支撑保证同轴度
- 纵向螺纹调节支撑
- 双螺母防松
- 与花盘螺栓连接传递扭矩

6061-T6 Al for coil mandrel

Brass wires for banding

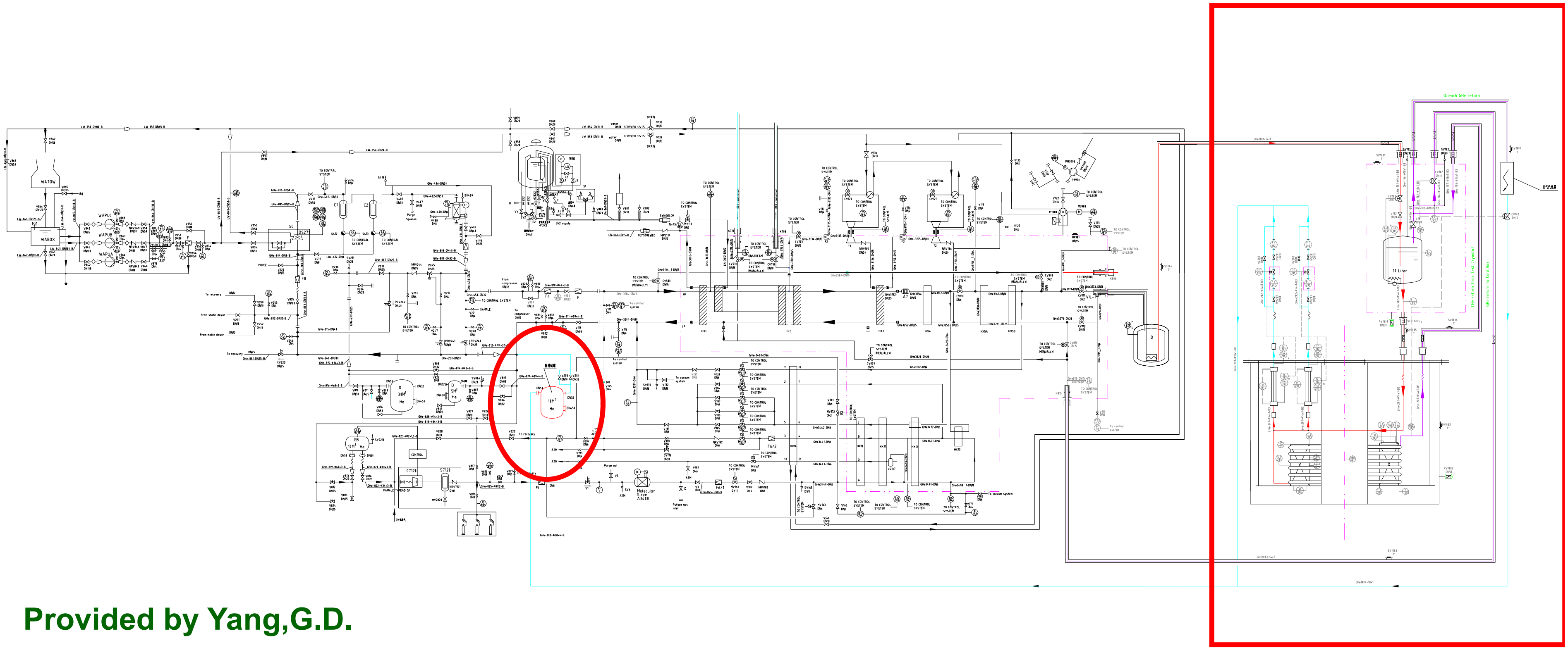
Cryo-test system for test coils & coupling coils

✓ Functions of cryo-test system

To provide the LHe cryogen at around 4.2K for performance tests of test coils and MICE/MuCool coils

✓ Main Components of cryo-test system

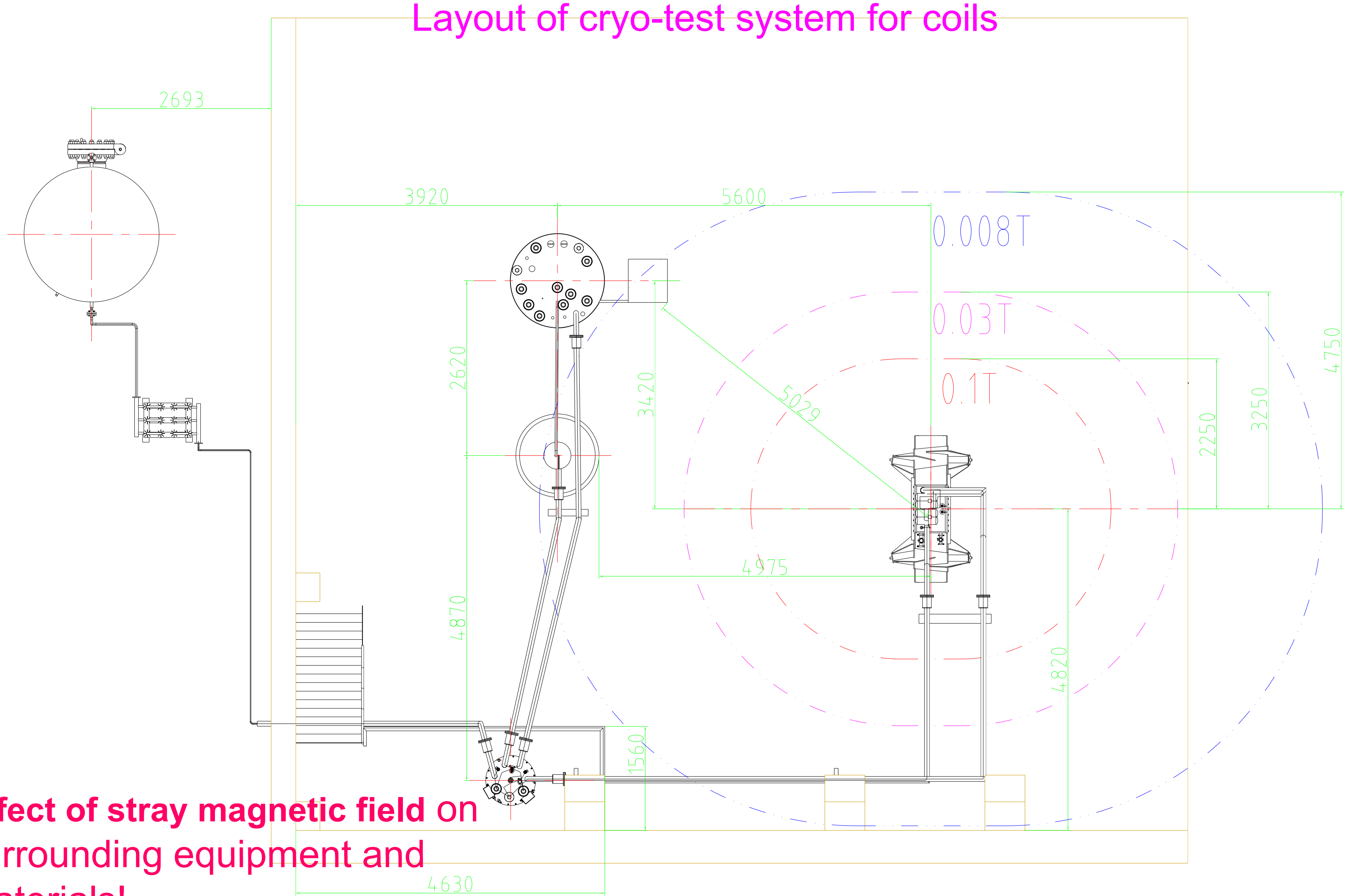
- **TCF20s refrigerator system** √
- **500L LHe dewar** √
- **Control valve box** **Design done, to be fabricated**
- **Test cryostats for small coil and MICE/MuCool coupling coils** **Design done, to be fabricate**
- **Cry-o transfer lines** **Design done, to be fabricated**
- **Instrumentation and control system** **to be purchased**
- **Vacuum pumping system** √
- **10m^3/3bara GHe tank** **to be contracted out for fabrication**



Provided by Yang,G.D.

PID of cryo-test system for coils

Layout of cryo-test system for coils



Effect of stray magnetic field on surrounding equipment and materials!

Provided by Liu,C.S.

Layout for 350mm ID small coil testing

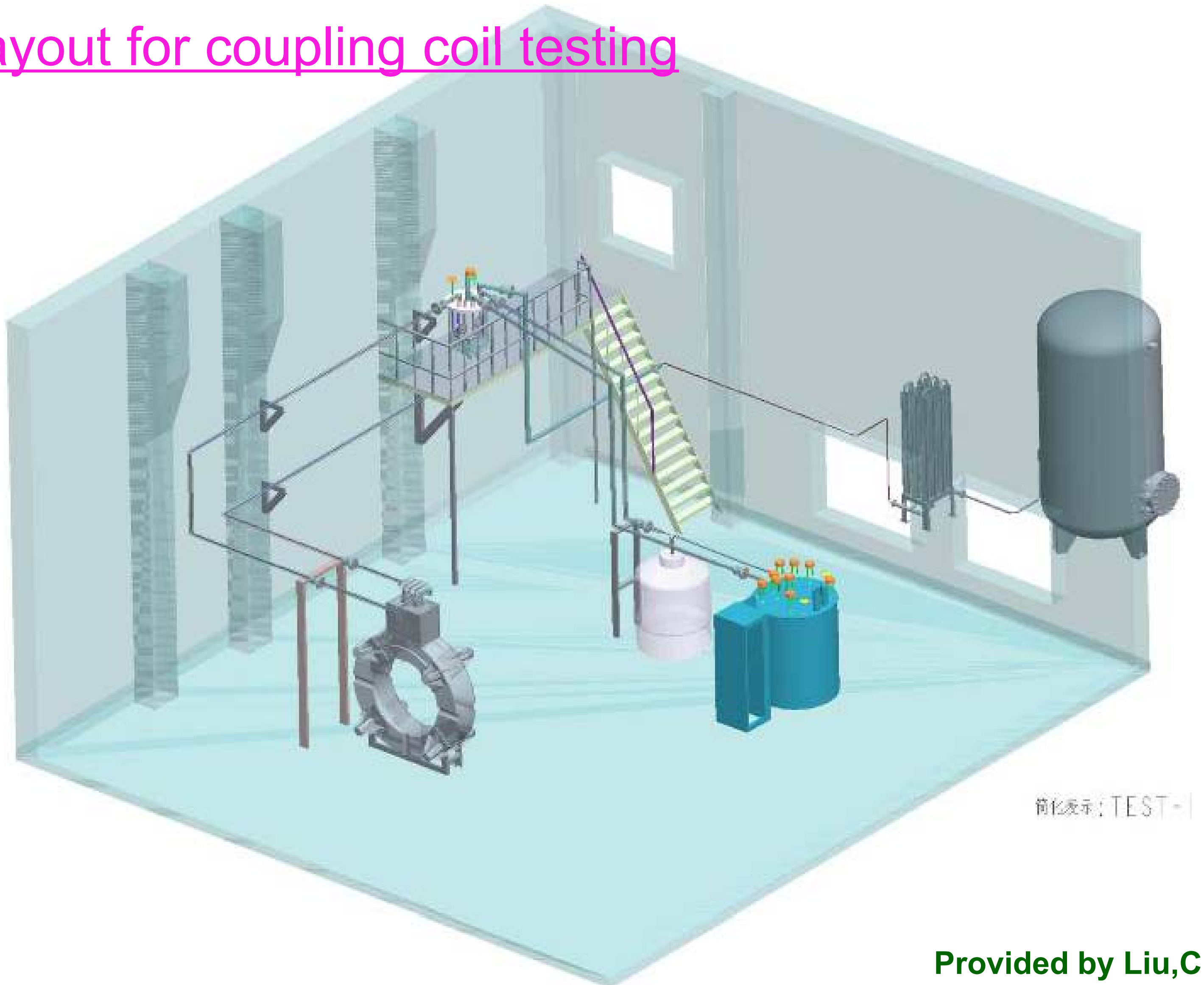
Provided by Liu,C.S.

Cryo-test Hall

Layout for 1500mm ID coil testing

Provided by Liu,C.S.

Layout for coupling coil testing



Provided by Liu,C.S.

✓ Control valve box

To deliver and control the LHe cryogen to the tested SC coils during cool down, charging, normal operation, and discharging, as well as performing quench and training of the SC coils.

Main components:

- **LHe vessel: ~8 liter**
- **Automatic control cryo-valve: 1**
- **Auto on-off cryo-valve: 1**
- **Auto on-off valve: 1**
- **Cryo-check valve: 1**
- **Instrumentation:** temp.sensors, pressure transducer, level meter, flow meters, etc.

The engineering design for the valve box has been completed. The materials are to be purchased. The construction will start soon after our Spring Festival holidays (till Feb. 12th).

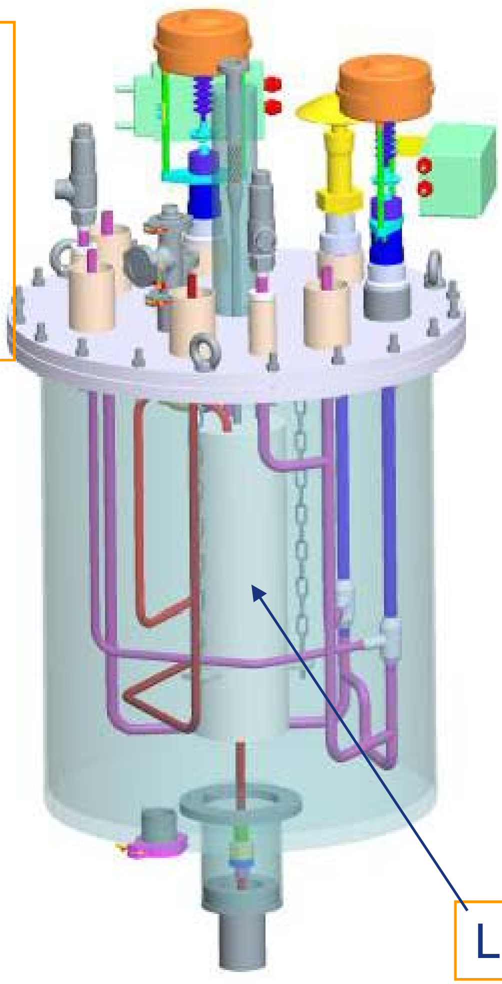
Provided by Liu,C.S.

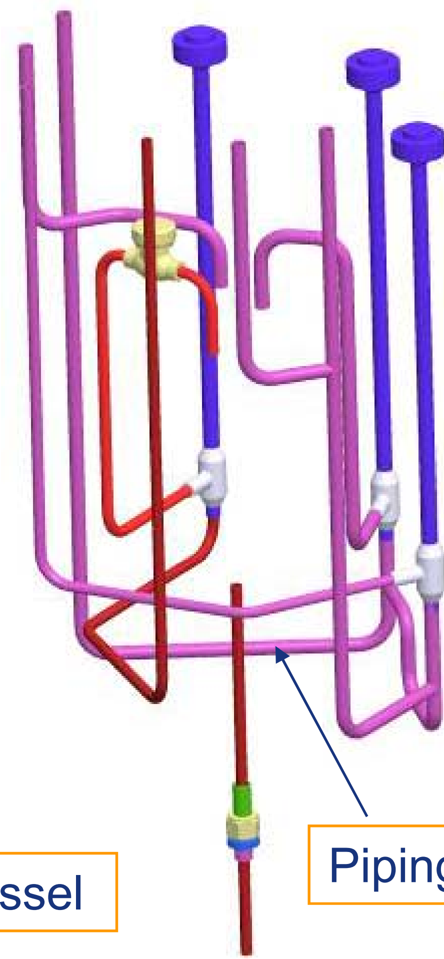
OD: 640mm

Height:1500mm

Flange OD: 750mm

Weight: 220kg

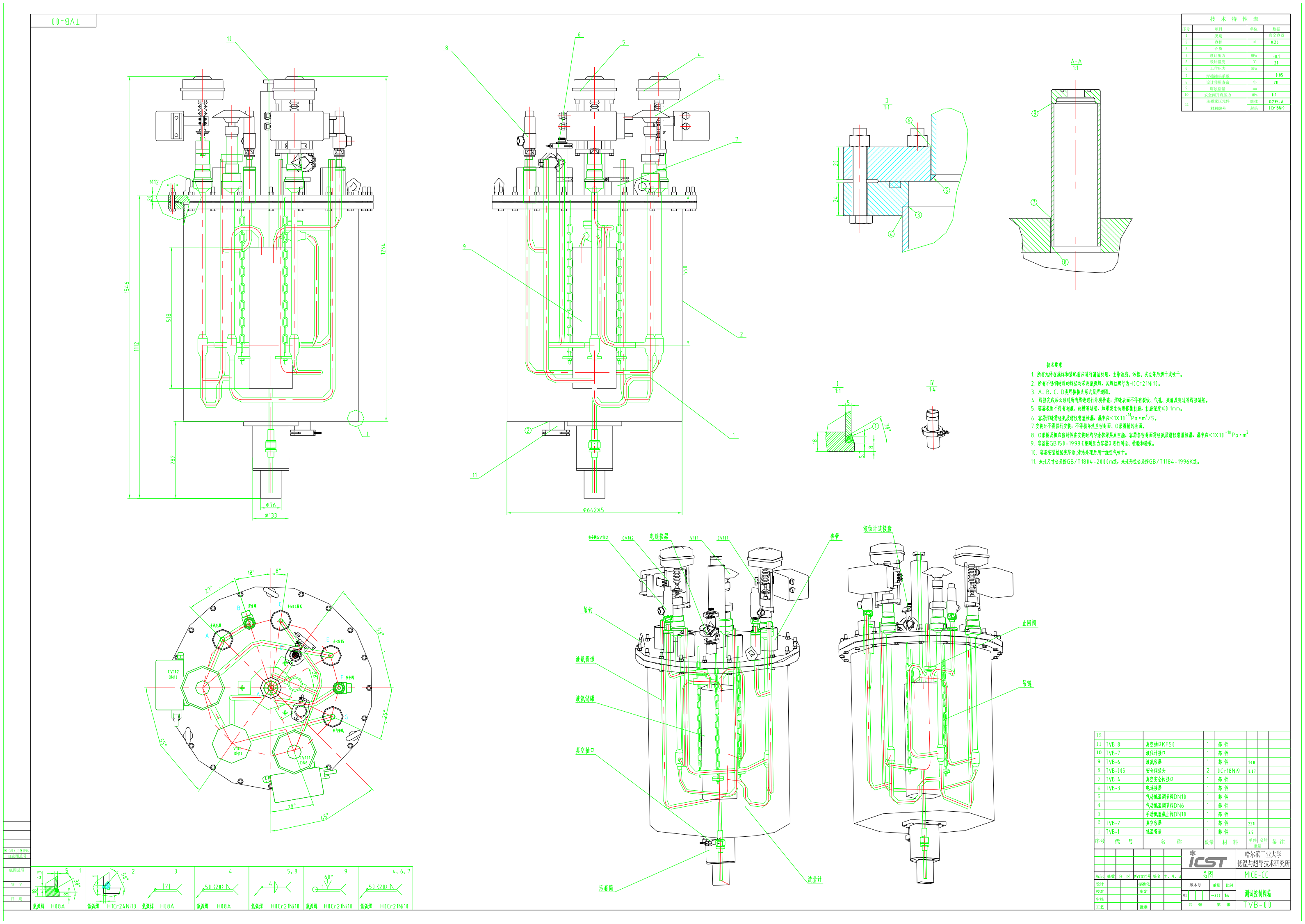




LHe vessel

Piping

3-D design for control valve box



Provided by Liu,C.S.

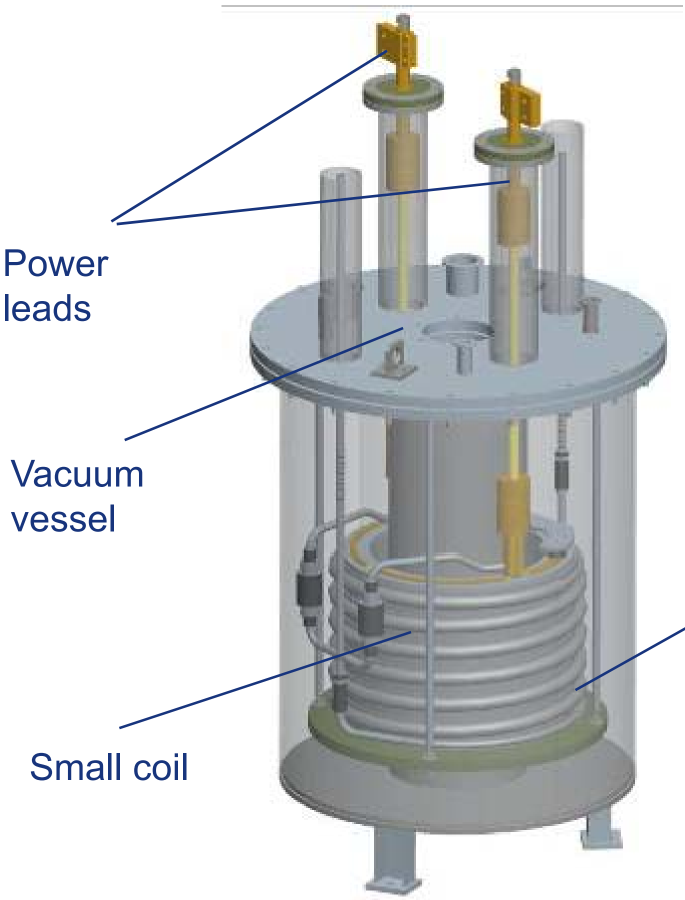
Test Cryostats

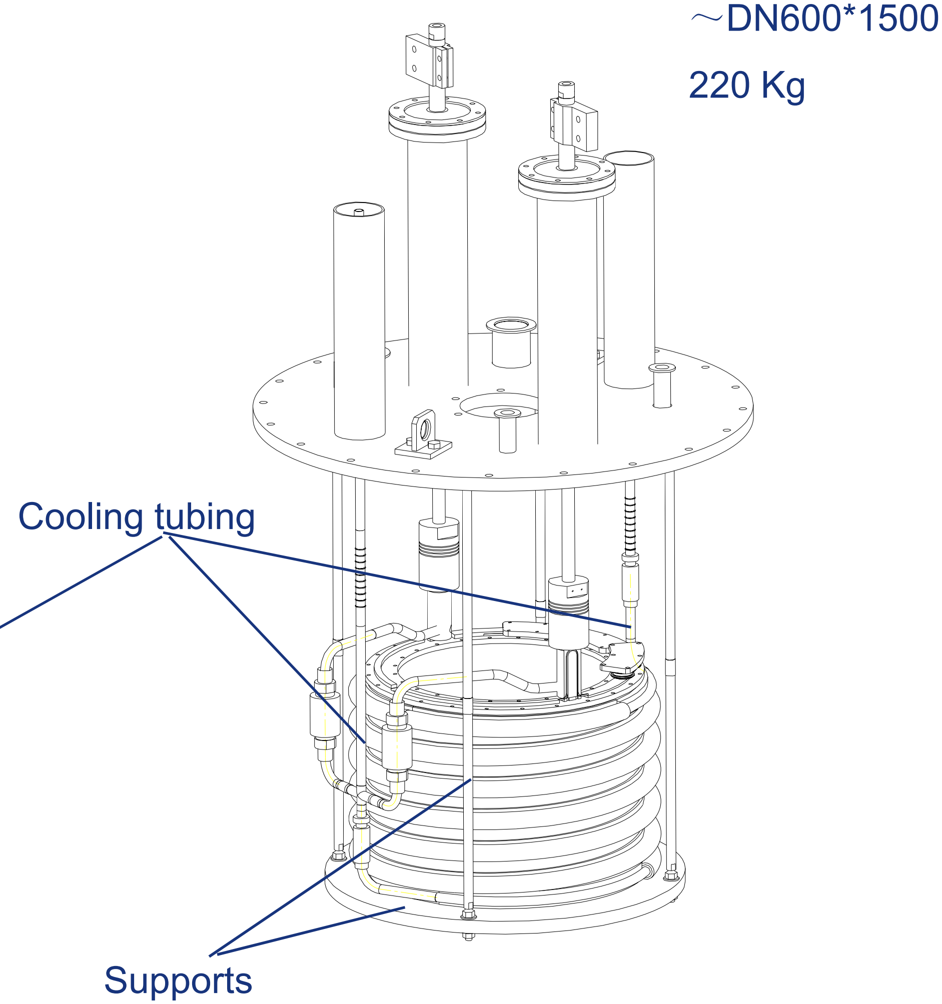
✓ Test cryostat for small coil

To cool the small coil by using helium fluid flowing in Ω cooling tubing welded onto the coil mandrel (thermosyphon). The test cryostat primarily consists of:

- **Vacuum vessel**
- **Copper leads**
- **Supports for small coil**
- **Ω Cooling tubing**
- **Quench protection circuit (one-section)**
- **Elec-insulators**
- **MLI insulations**
- **Elec-feedthroughs**
- **Instrumentation:** Temperature sensors & monitor, pressure transducers & monitor, He level meter & monitor, heater, voltage taps, strain sensors, cold diodes, quench detector, hall probe and gauss meter, vacuum gauge etc.

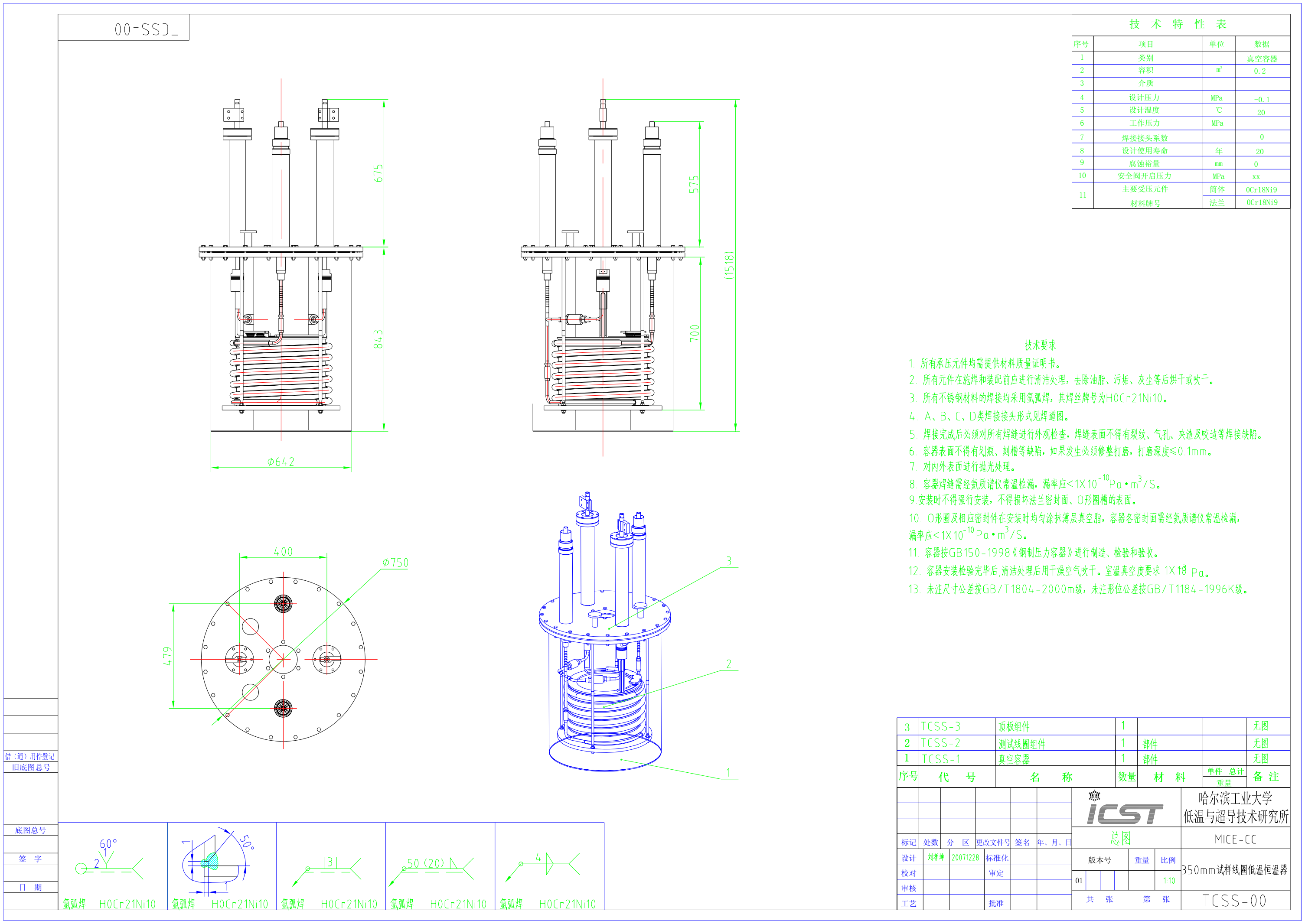
The engineering design for the small coil test cryostat has been completed. Some of the materials have been purchased. The construction will start soon after our Spring Festival holidays (till Feb. 12th).





Provided by Liu,X.K.

Test cryostat for small coil



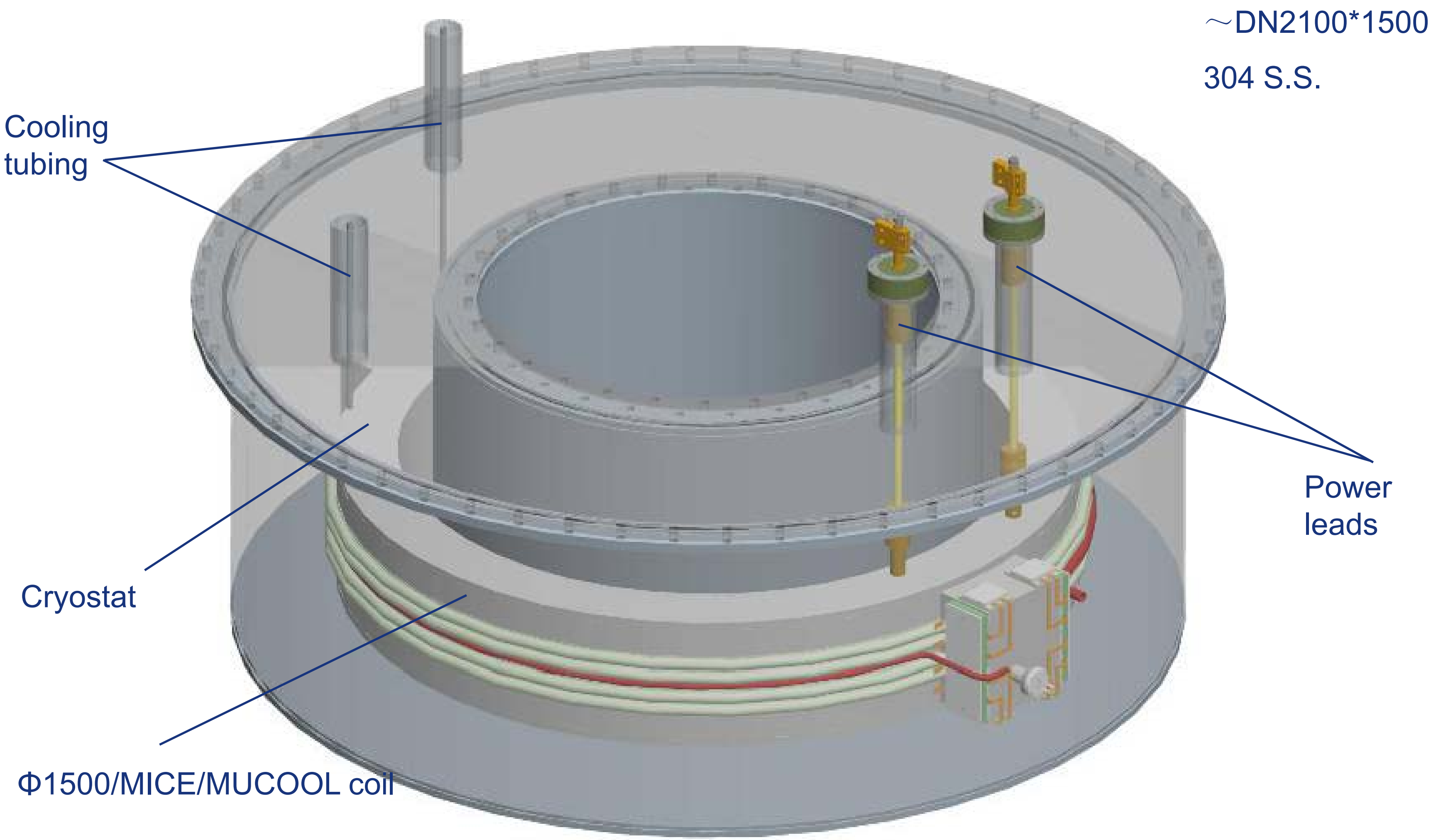
Provided by Liu,X.K.

✓ Test cryostat for large coil and coupling coils

To cool the prototype coil by LHe flowing in Ω tubing attached to the outer surface of the coil case, similar as the cooling approach for the MICE/MuCool coils (thermosyphon). The test cryostat primarily consists of:

- **Prototype coil assembly**
- **Ω cooling tubing & Helium containers**
- **Copper leads**
- **Supports for prototype coil**
- **Vacuum vessel**
- **MLI insulations**
- **Neck tubes**
- **safety relief valves**
- **Elec-feedthroughs**
- **Instrumentation:** Temperature sensors & monitor, pressure transducers & monitor, He level meter & monitor, heater, voltage taps, strain sensors, quench detector, cold diodes, hall probe and gauss meter, vacuum gauge etc.

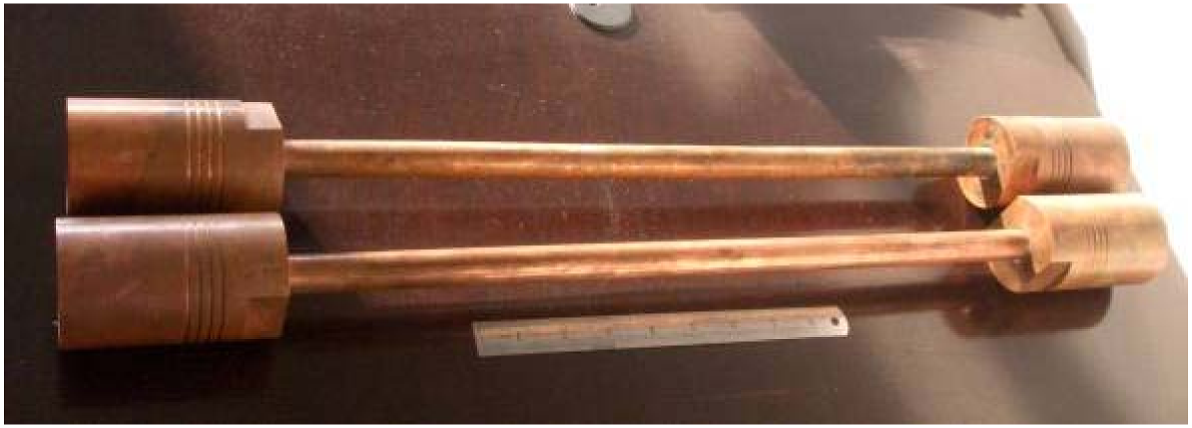
The engineering design is almost done.



Provided by Liu,X.K.

Test cryostat for large coil

Cooling tubing



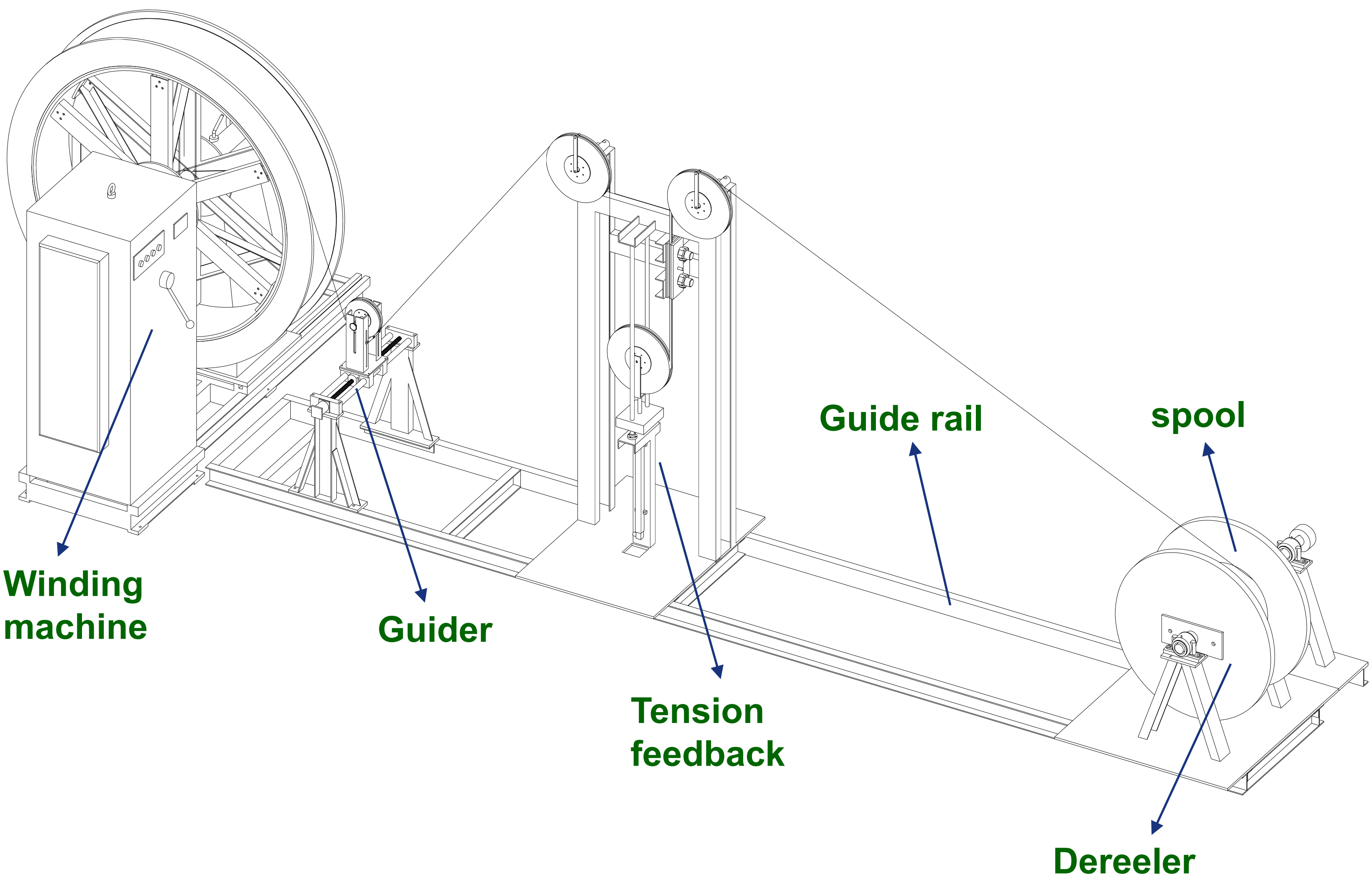
650A power leads

Coil Winding System

- ✓ The coil winding system was completed and runs for nearly 2 months by using steel wire (~1.5 mm diameter), normally, its operation is very smoothly.
- ✓ The winding system is composed of:

Wiring machine, Guider, tension read-back assembly, active dereeler, guide rail assembly, and control system

- ✓ The function of the winding system includes:
  - Switch between automatic and manual
  - Switch between forward and reverse rotation
  - Stop at anytime by one key or button
  - All motors are of power-failure brake
  - The tension system can stably operate in range of 5kg~50kg
  - Wire length is expected to be auto-counted
  - The status of each component is monitored……



The final 3-D drawing of winding system

- ✓ The winding procedure for the coils has been drafted, but it will be finalized once some key tests are done.


SW-2 型螺线管绕线机控制面板
用户名
00:00:00
YYYY/MM/DD
历史
线圈内径
层间厚度
合计长度
主轴控制面板
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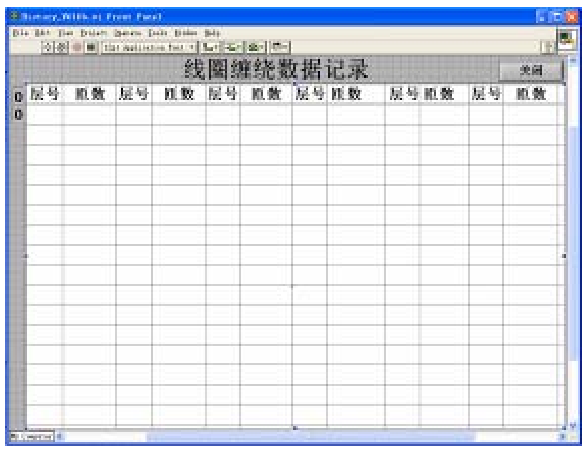
线圈缠绕数据记录
层号
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Some Key Tests

✓ Performance of SC joints

- **Because the SC pieces to be provided by LBNL to ICST will be most probably more than those to be expected (form a maximum of 16 pieces to at least 30 and probably 40 to 40 pieces in the end), it results in much more (~3 times) SC joints than those expected (about 4 joints) in one coupling coil. The SC joints must be made so that their resistances are as low as possible in order to reduce the induced heat load and quench possibility. Hence, the conductor joint design becomes critical for the coupling coil.**
- **The conductor joint design needs to be validated and the joint resistance needs to be tested at low temperature and at magnetic field. LBNL and ICST should work together to figure out these.**

✓ Performance of Cold diodes

- **Due to high magnetic field of the coupling coil, performance (such as forward voltage etc.) of cold diodes at low temperature and at high magnetic field (2~3T) must be tested in order to design quench protection circuit, charging and fast discharging system before they are installed inside the cryostat. The test may be realized by using test coils in ICST.**

✓ Others

layer-to-layer breakdown voltage, layer-to-layer thickness etc.

Update Design of MICE/MuCool Coupling Magnets

✓ Cold mass supports

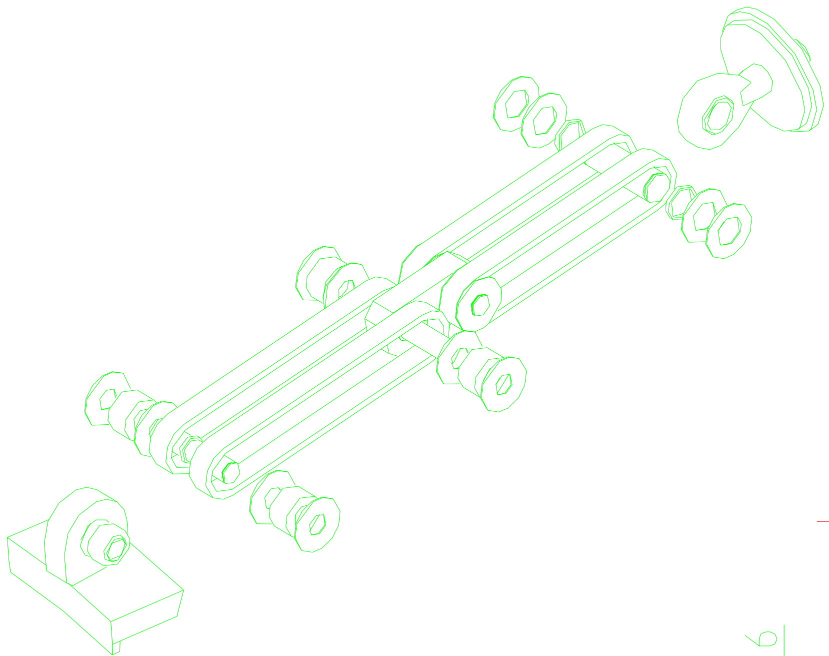
- **The cold mass support will be double-band type considering 500kN force in the longitudinal direction at the worst case. and 3g shipping load in any direction.**
- **Because the materials of most components of cold mass supports, such as band, bolts, joints, bearing etc., are not available in China, according to Dr. Mike Green's suggestion, ICST will provide specification of cold mass support design to LBNL, and the cold mass supports may be fabricated and tested in US.**

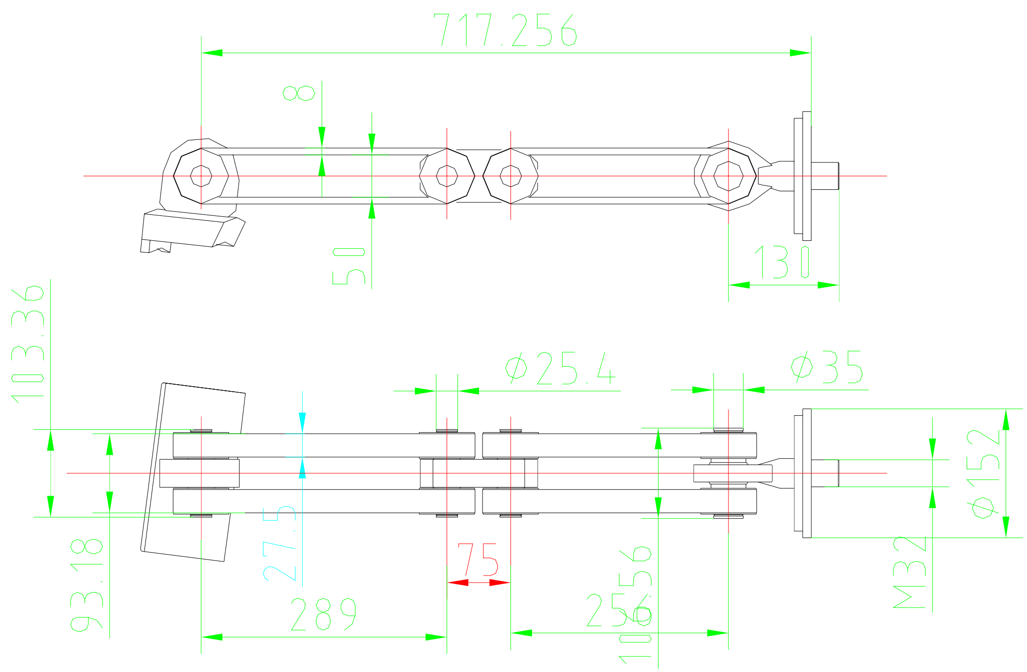
✓ Vacuum chamber of cryostat

- **The design of the outer vacuum chamber of magnet cryostat and warm end connections of cold mass supports will be modified according to final double-band structure of cold mass supports and requirement for 3g shipping force in any direction.**

✓ Cooling connections between HTS leads and cryocoolers

- **The copper-epoxy-kapton-epoxy-copper configuration will be used for thermal conductive and elec-insulation connection between HTS leads and coolers.**





Double-band support design

Summaries

- ✓ The formal collaboration MOU between LBNL and HIT was both signed by June, 2007.
- ✓ The formal Addendum to MOU between LBNL and HIT, and Technical Agreement for MICE/MUCOOL coupling magnets was both signed by September, 2007.
- ✓ The subcontract for procurement of MICE/MuCool coupling magnets' standard materials and subcomponents in China between LBNL and HIT was both signed by November, 2007.

ICST has gotten 0.5 million RMB of the first funding from HIT at the early of this January, and another 1.0 million RMB funding from HIT was approved at the end of this January and is coming soon (~this March)!

However, the 1.5 million RMB funding can only be used for hardware (materials, components, instrumentation, etc.) to fabricate test coils, cryo-test system and MICE/MuCool coils.

- ✓ The first materials (10km SC conductors, Stycast epoxy, Kapton film, fiberglass cloth, 12 cold diodes etc.) provided by LBNL will arrive in Harbin around the middle of this month.
- ✓ Some key tests should be carried out before the winding of coupling coils and fabrication of coupling magnet system.

  Performance of SC joints and cold diodes at low temp. and magnetic field, etc.
- ✓ Winding and cryo-test of test coils

  To be expected to complete by this May which is mainly up to the materials', subcomponents' and instrumentation's procurement (SC wires etc.) and shipment to ICST by LBNL
- ✓ Construction of cryo-test system

  To be finished by the middle of this April.
- ✓ Winding of the first MuCool coil

  To be expected to start from this May.
- ✓ Design of the support stand for the MuCool RFCC module at MTA/Fermilab

  To be done by this June. Interface information of updated MTA in Fermilab is needed.

Thank You !