中国科學院強磁場科學中心
High Magnetic Field Laboratory, Chinese Academy of Sciences

Development of a 40 T hybrid magnet at CHMFL

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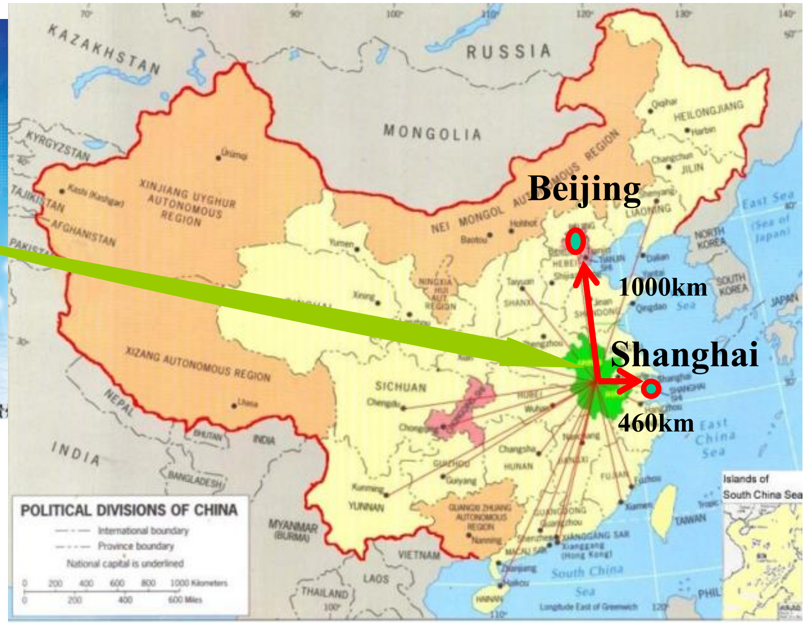
High Magnetic Field Laboratory, CAS (CHMFL)

Jan.19, 2017

Where is CHMFL ?

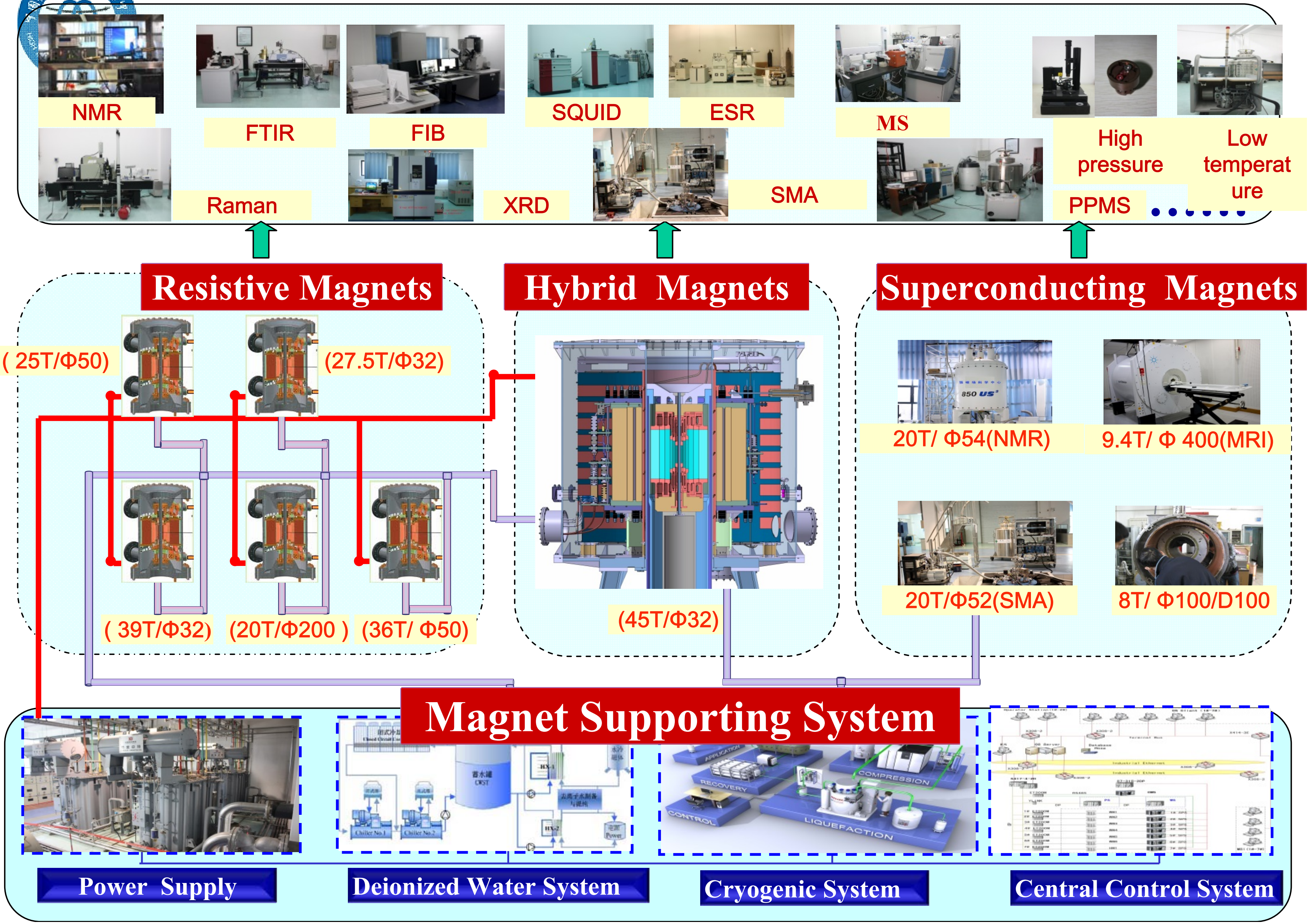
Science Island | *Anhui Province* | *P. R. China*



Science Island ---- a very beautiful peninsula!

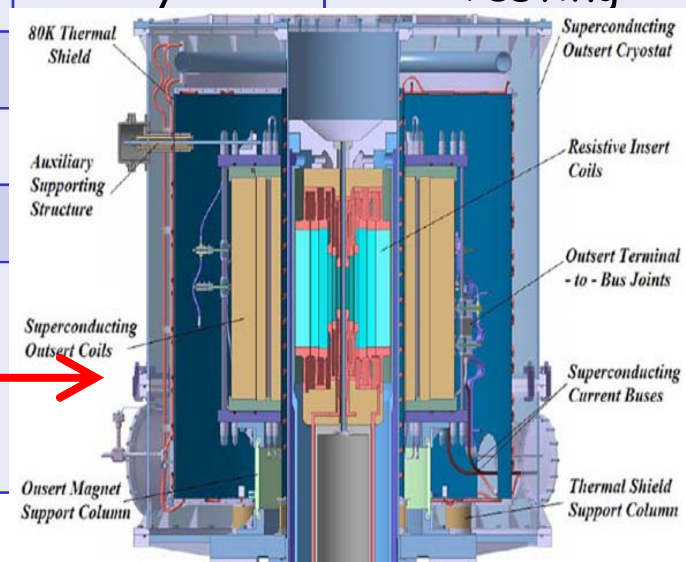
Area: 2.6 km2

Overview of SHMFF



Magnets Constructed at CHMFL

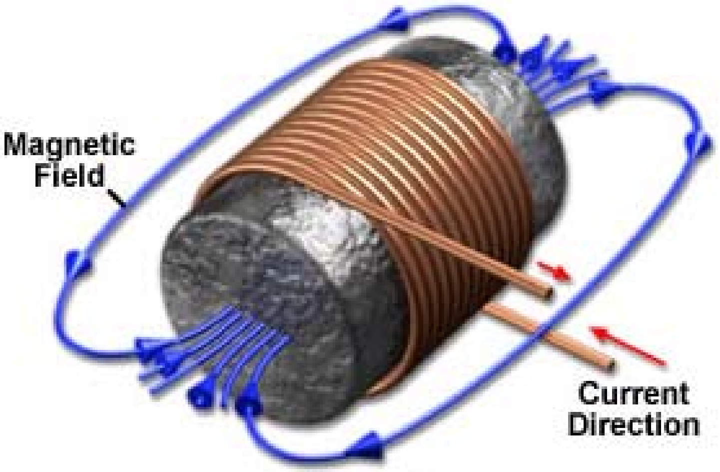
	Magnets	Magnet Field, T	Bore, mm	Power, MW	Current Status
Resistive Magnets	WM1	**38.5***	32	25.2	Open for users
	WM2	25	50	15	Testing
	WM3	19.5	200	20	Testing
	WM4	**27.5***	32	10	Open for users
	WM5	**35***	50	24	Open for users
Superconducting Magnet	SM1	8-10	100	/	Testing
	SM2	20	52	[illegible]	[illegible]
	SM3	20	54	[illegible]	[illegible]
	SM4	9.4	400	[illegible]	[illegible]
Hybrid Magnet	HM1	45 T **Resistive insert 34 T** **SC outsert 11 T**	32	[illegible]	[illegible]



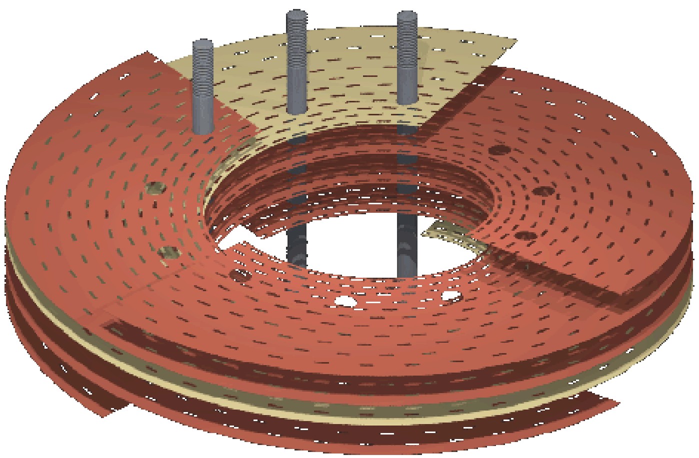
45 T Hybrid Magnet

CAS

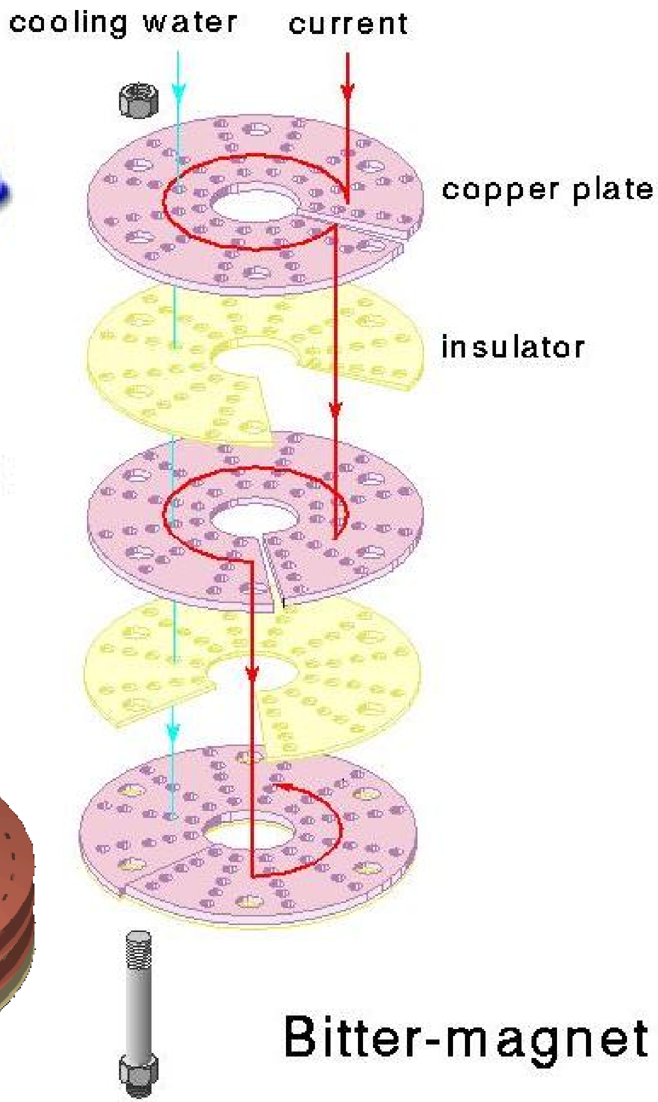
Bitter Magnet



Solenoid can generate strong magnetic fields



Bitter plate



Schematic diagram of a Bitter Magnet

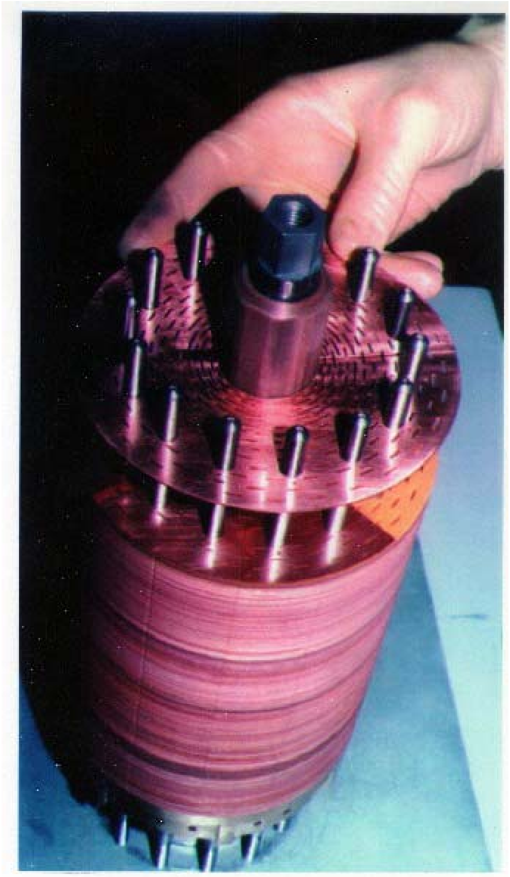


Photo of a Bitter Magnet

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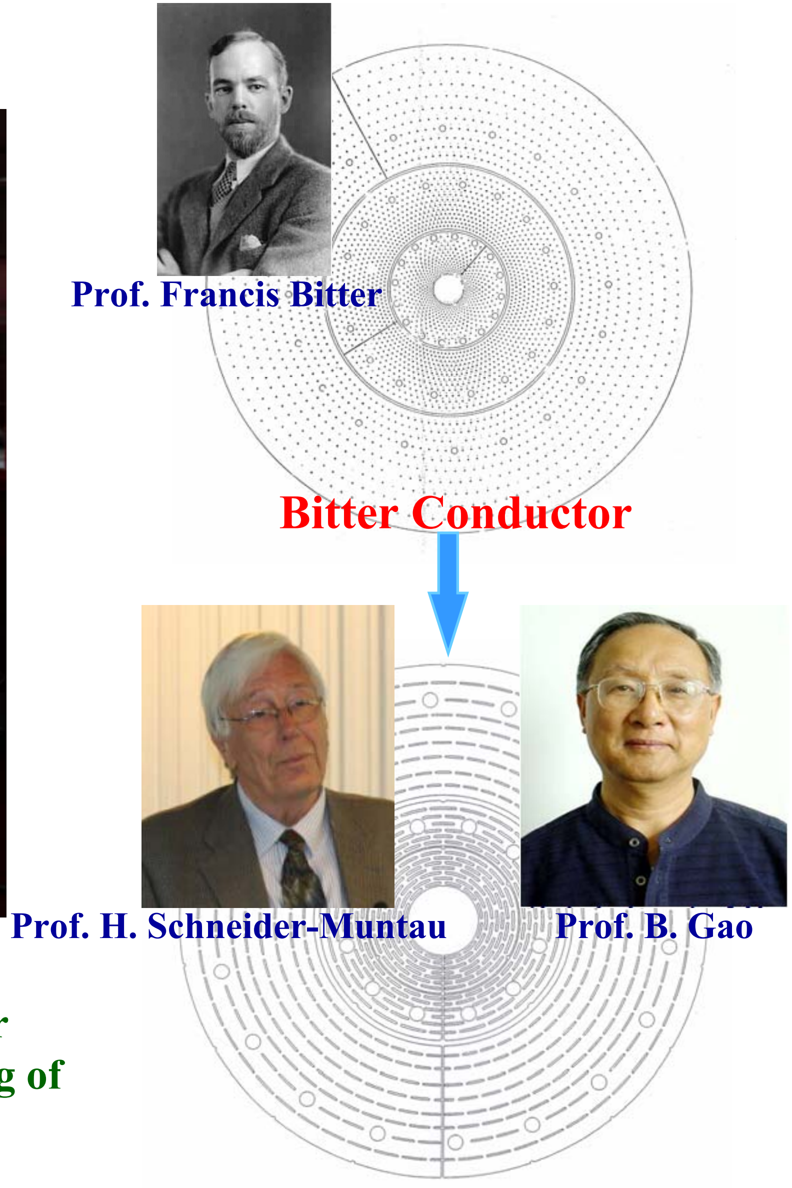
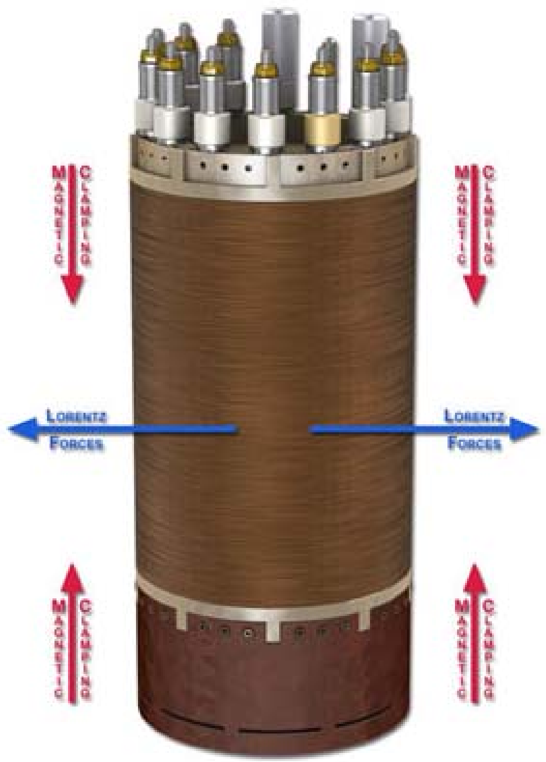
Resistive Magnet Technology at CHMFL



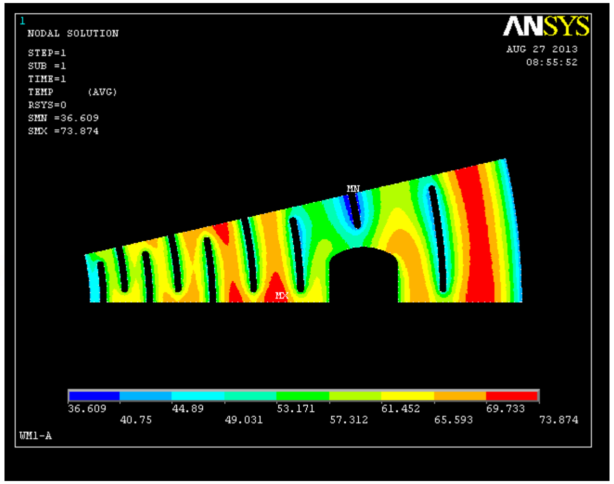
Florida-Bitter Conductor

Prof. Bingjun Gao is currently the chief engineer of our project, he is in charge of the design and manufacturing of the Bitter Magnets at CHMFL.

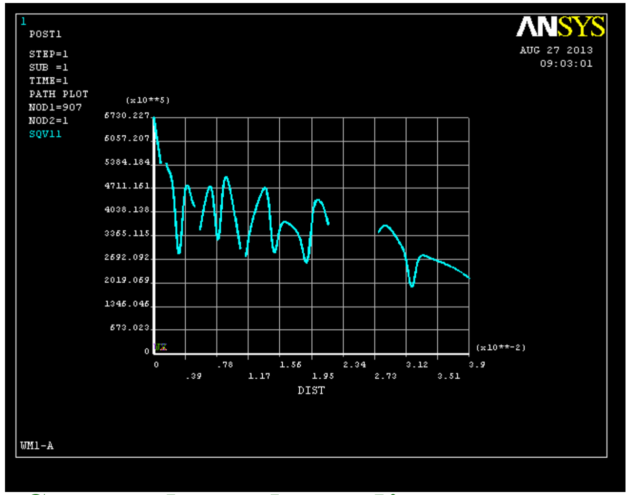
Performance Analysis of Resistive Magnet



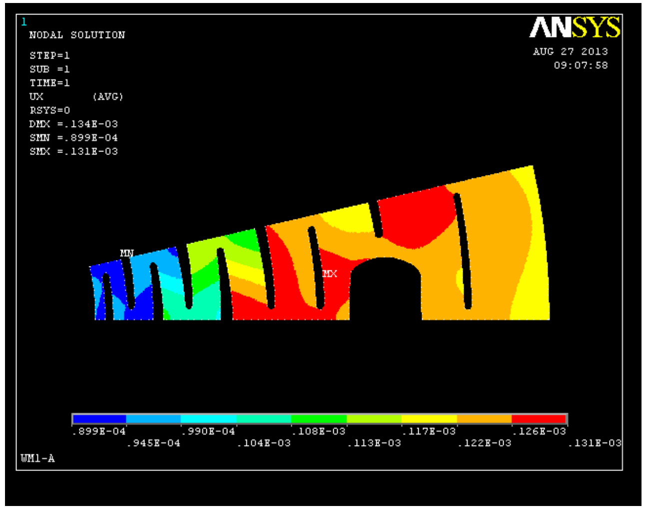
Forces within the Bitter Magnet



Temperature distribution in the Bitter plates

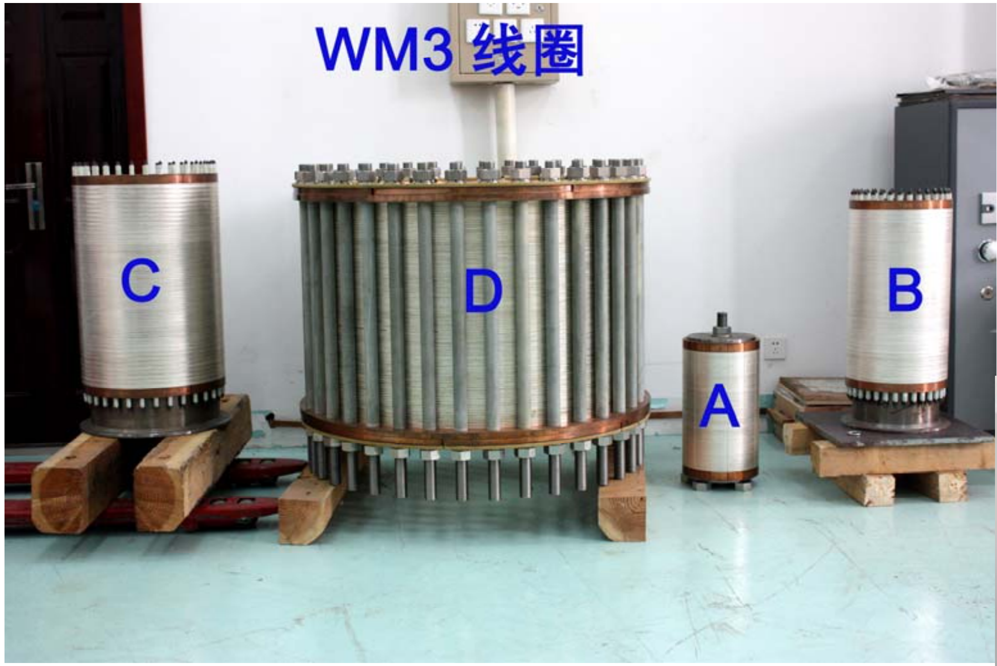


Stress along the radius

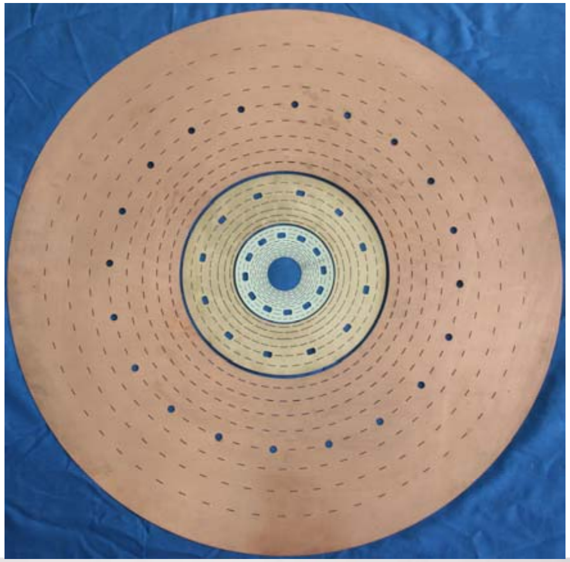


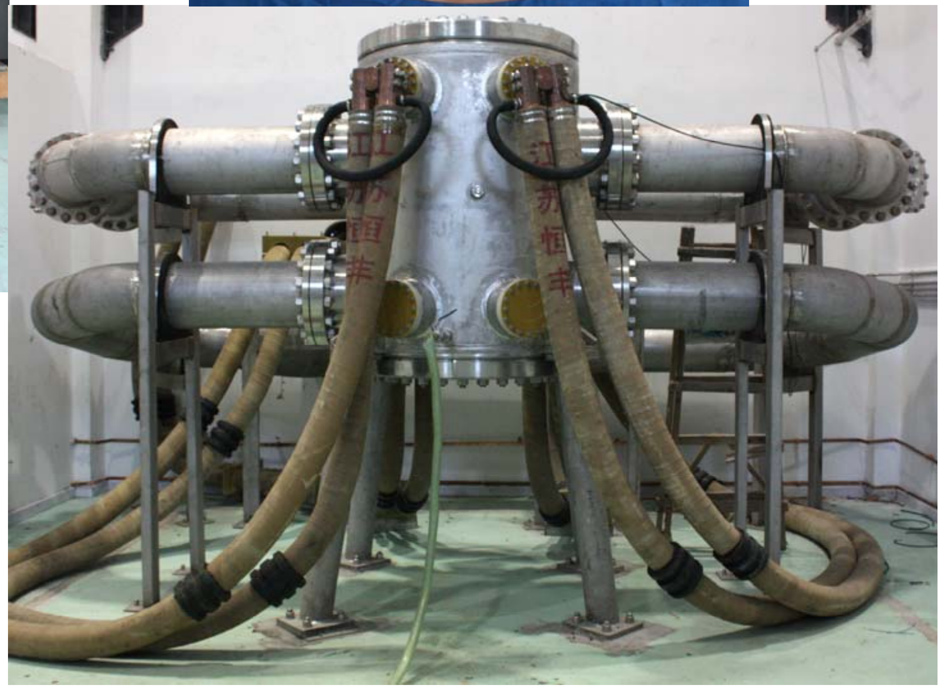
Displacement distribution in the Bitter plates

Fabrication and stacking of Bitter Plates



The stacked sub-coils



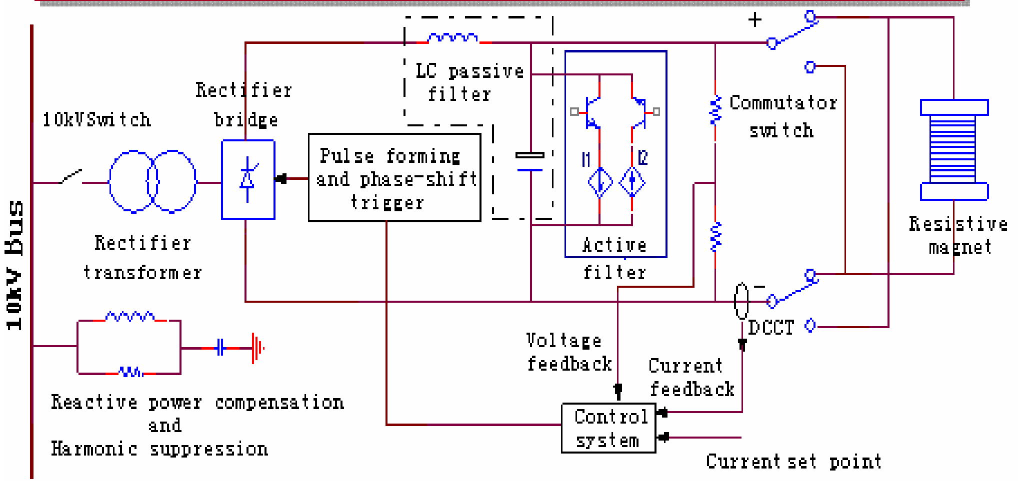


The assembled Bitter magnet

Magnet Supporting System

28 MW power supply, deionized water system and the central control system

Diagram of 28 MW Power Supply



Specifications

Rated output voltage	500 V, 600 V, or 700 V
Rated output current	2×20 kA
Ripple and noise	50 ppm
Stability (8 hours)	10 ppm
Efficiency	>90%

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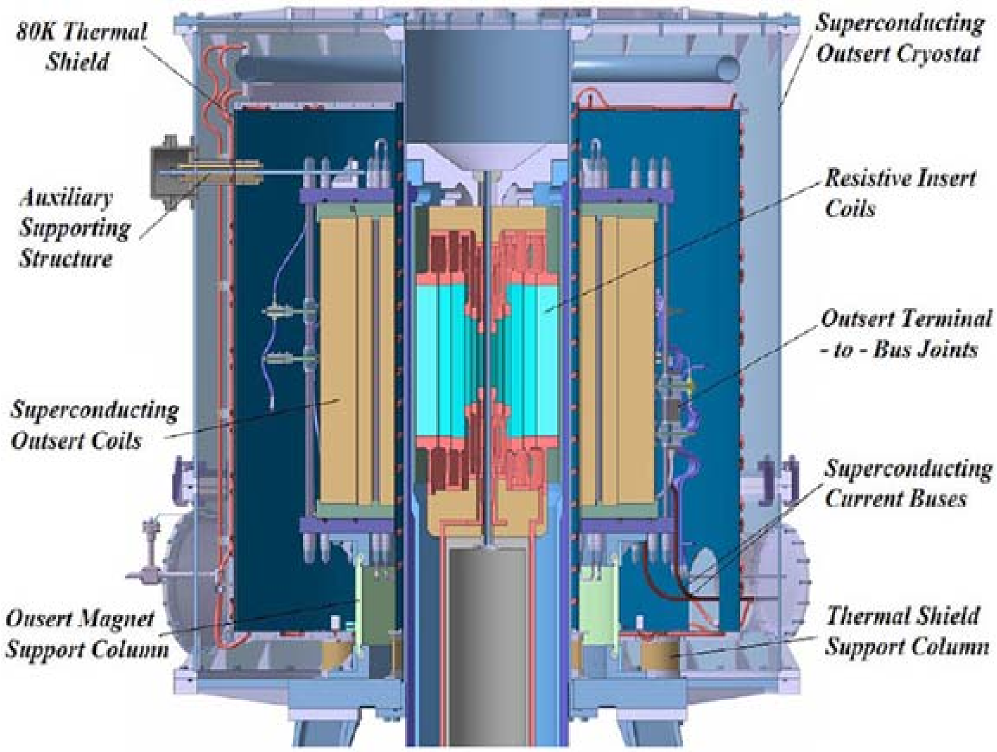
Hybrid Magnet at CHMFL



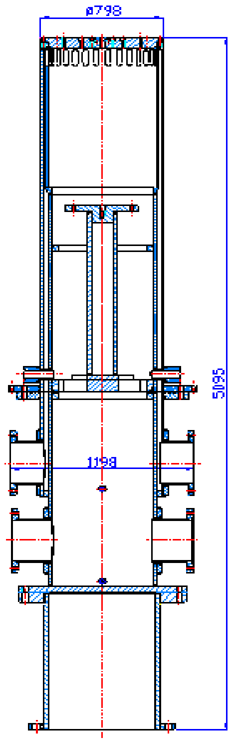
It consists of a SC outsert and two interchangeable water-cooled inserts with inner bores of 32 and 50 mm.

Specifications

No.	Field (T)	Bore (mm)	Temp. (K)	Current/ Power
HSM	11	800	4.5	13.41kA
HWM1	34	32		26.1MW
HWM2	31	50		26.1MW

The hybrid magnet is the best way to generate the highest steady high field.

Resistive Insert



Specifications

Coil	A	B	C	D	E	F
Conductor type	Florida-Bitter-type					
Current (kA)	39.8					
Inner radius (mm)	19.0	49.0	81.0	116.0	178.0	244.0
Outer radius (mm)	47.0	79.0	114.0	175.0	241.0	350.0
Height (mm)	234.8	356.6	386.9	662.8	653.2	652.7
Disc thickness(mm)	6.2	7.44	7.44	9.48/18.96	9.48/18.96	6.32/12.64
Insulation thickness(mm)	0.15					
Number of turns	37	47	51	49/10	48/10	93/4
Material	CuAg	CuAg	CuAg	Cu	Cu	Cu

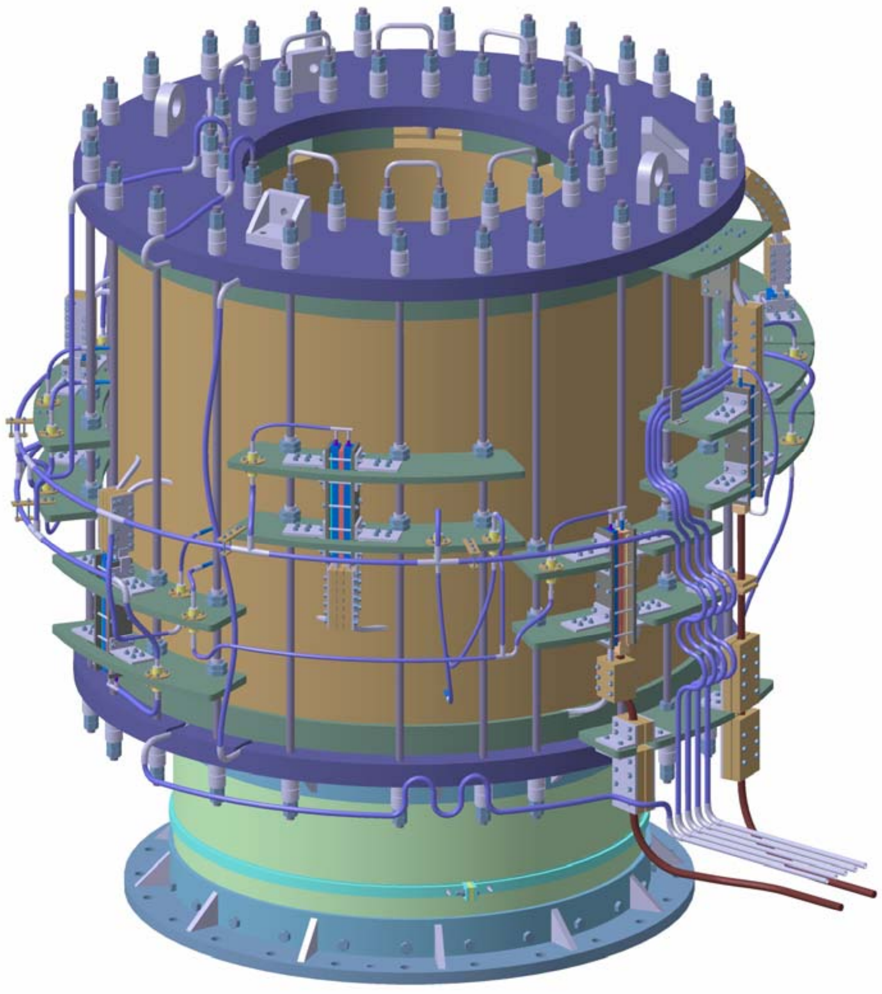
The resistive insert consists of 6 subcoils, all the resitive coils are made of Bitter conductors.

Development of Resistive Coils

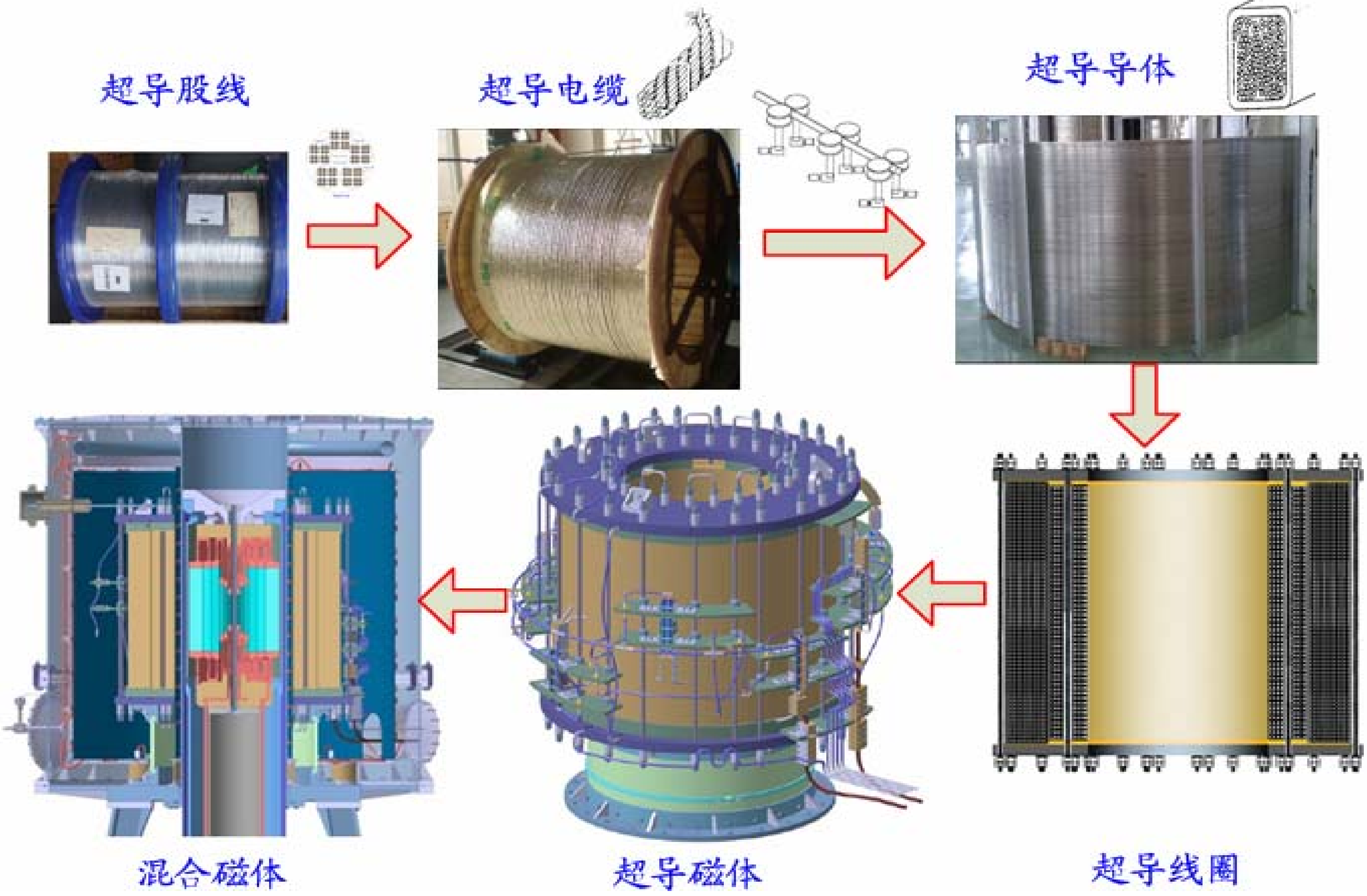
Overview of Superconducting Outsert

MAIN PARAMETERS OF THE SUPERCONDUCTING OUTSERT

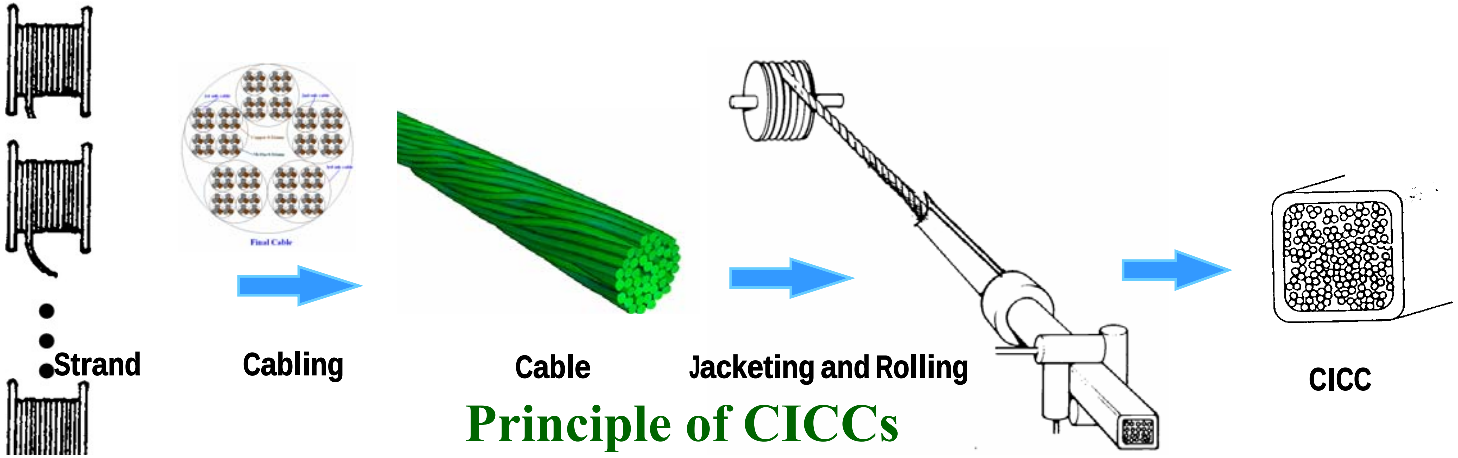
	Coil A	
	Grade I	
Type of winding	layer	
Conductor type	Nb_3Sn (	
Conduit material		
Strands configuration	(2SC+1Cu)×4×4×5	
CICC size (mm×mm)	22.0×15.0	
Conduit thickness (mm)	2.2	
Void fraction of conductor (%)	~ 30	
Compressive peak load [a], (MPa)	10.20	
Number of turns	104 (2 layer × 52 turns/layer)	
Inner diameter of winding (mm)	930.0	
Outer diameter of windings (mm)	996.0	
Height of windings (mm)	1196.0	
Turn insulation (mm)	0.5	
Layer/pancake insulation (mm)	1.0	
Nominal current (A)		
Operation temperature (K)		
Maximum field at the windings (T) [b]	12.732	
Temperature margin w/o degradation (K) [b]	2.15	
Temperature margin with 15 % degradation (K) [b]	1.91	
Total length of the superconducting wire (km)	66.7	
Field contribution at center (individual coils) (T)	1.20 [b] (1.14) [c]	
Field contribution at center (combined coils) (T)		[illegible]
Combined inductance (H)		1.02975
Combined stored energy (MJ)		102.362 [b] (92.589) [c]



Development of SC Coils



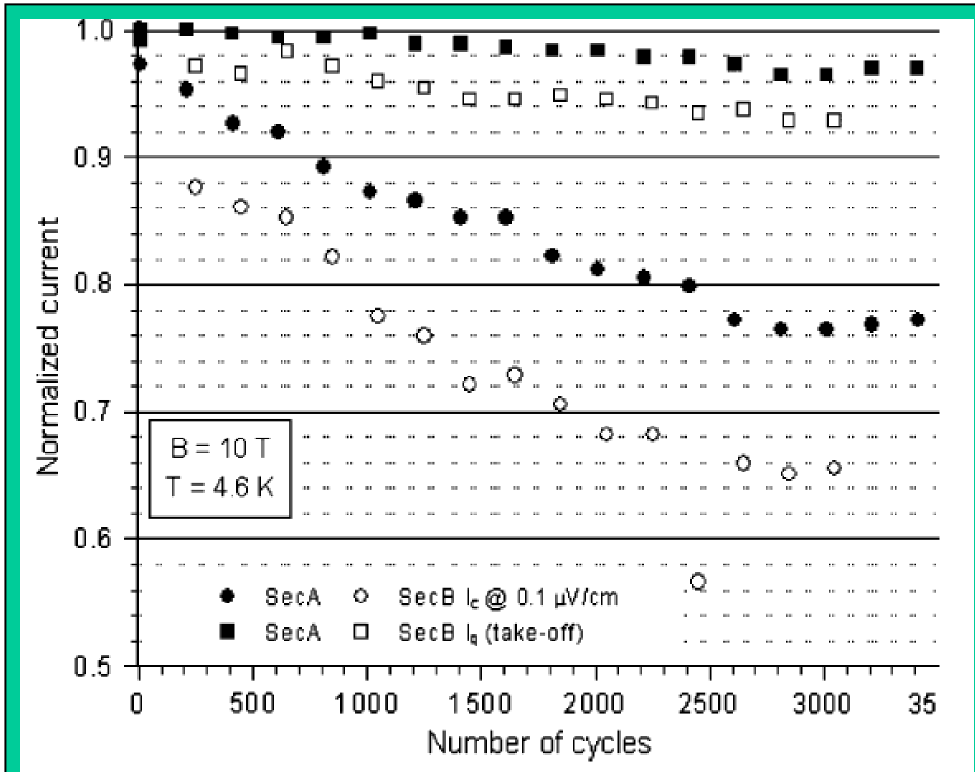
Cable-in-Conduit Conductor



Principle of CICCs

Different CICC structures manufactured for different devices

Performance Degradation of Nb3Sn CICC



Critical current versus electromagnetic cycles

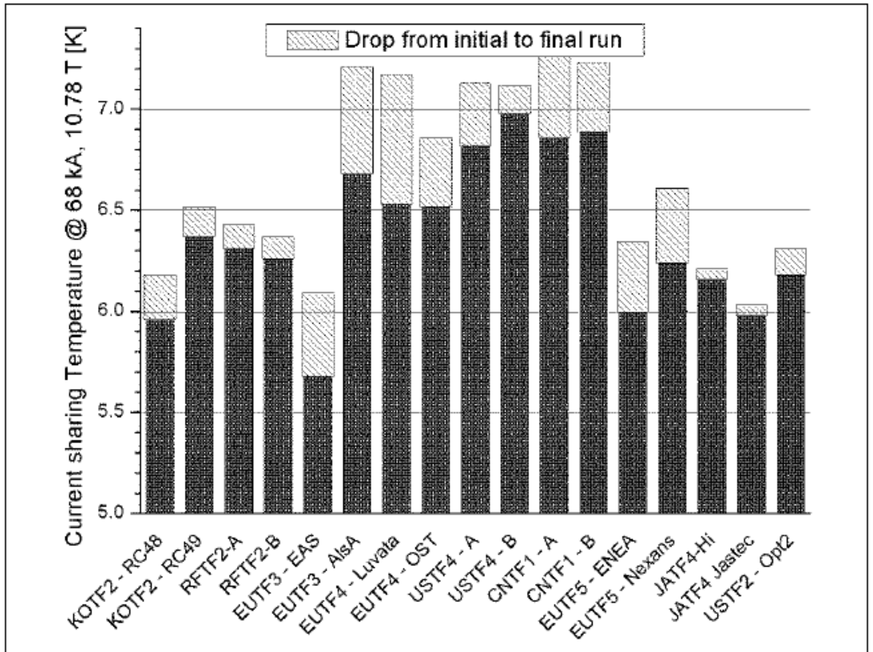
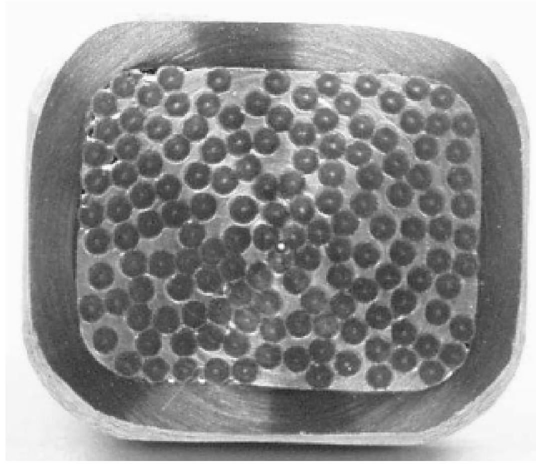


Figure 5. Initial and final performance of the ITER TF conductor samples built to the same specification from different Nb_3Sn strands [52].

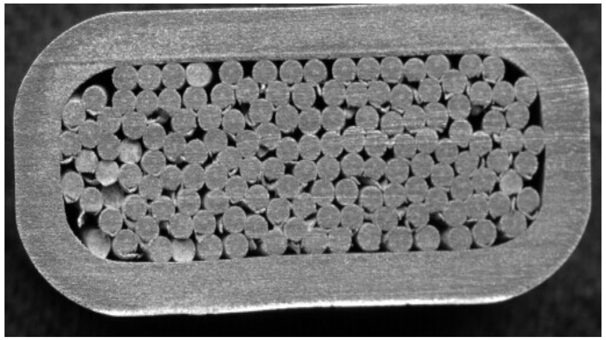
ITER TF conductor performance made from different Nb3Sn strands

Nb3Sn CICC design at CHMFL

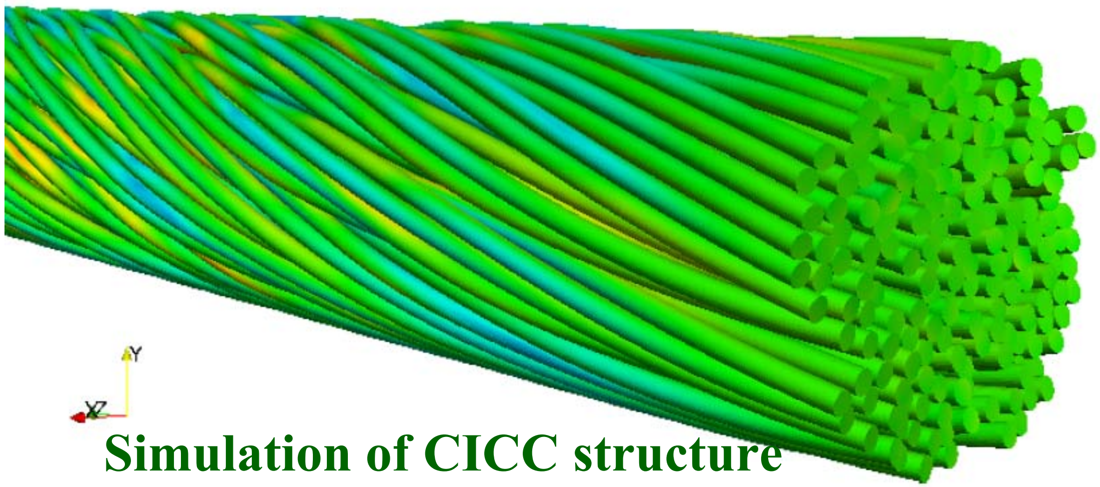
- ✓Reduce void Fraction
- ✓Elongate twist pitch of the first stage
- ✓Decrease electro-magnetic pressure



Provide better mutual support between superconducting strands in the CICC and prevent degradation of strand performances.



Improved CICC structure



Simulation of CICC structure

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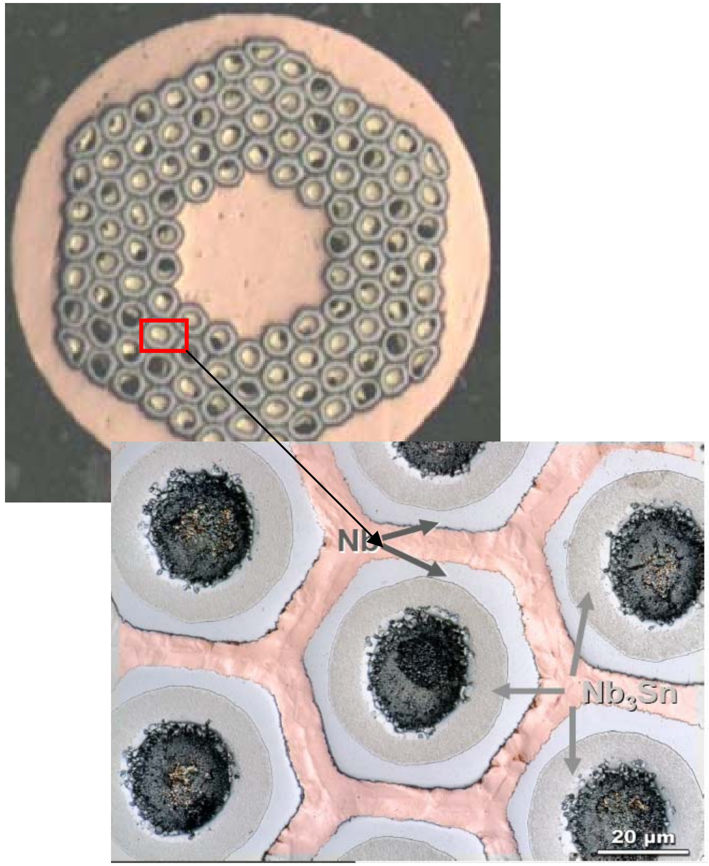
Selection of Superconducting strands

Specification of Nb_3Sn strands

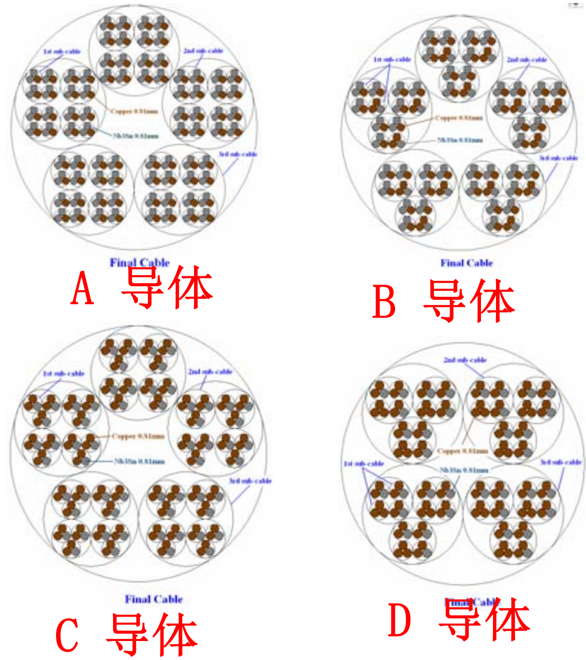
Wire diameter (mm)	Ø0.81±0.005
Bare wire diameter (mm)	0.806
Cr plated (μm)	1-2
Cu/non-copper	1.0±0.1
d_{eff}（μm）	≤80
Critical current, Ic (A)（4.2K,12T,0.1μV/cm）	≥540 (non-Cu Jc≥2100A/mm²)
RRR	≥ 100
n value	≥20
Twist pitch (mm)	15 ± 3
Hysteresis loss (7T-0-7T cycle) (kJ/m³)	≤1600



Design of CICC

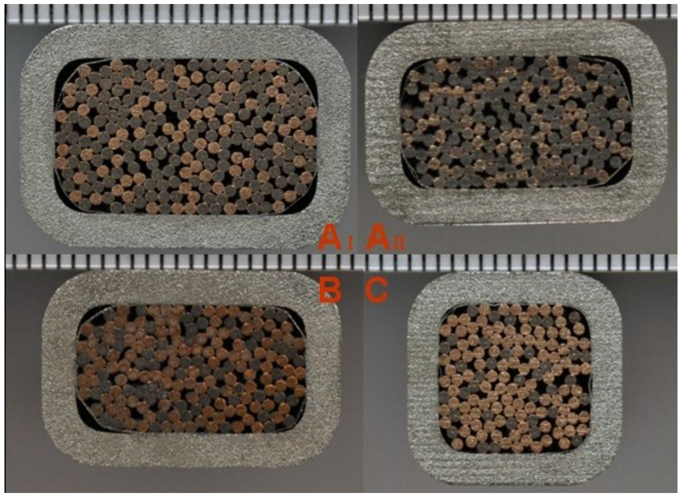
Specifiction of Cable

	线圈A	线圈B	线圈C	线圈D
电缆配置	(2Sc+1Cu)×4×4×5	((2Sc+1Cu)×3 + (1Sc+2Cu))×3×5	(1Sc+2Cu))×3×4×5	((1Sc+2Cu)×3 + 3Cu)×3×4
超导股线数目	160	105	60	36
铜股线数目	80	75	120	108



Specification of CICC

	线圈A	线圈B	线圈C	线圈D
导体尺寸(mm×mm)	22×15	20.2×13.4	20.2×13.4	15×14.4
铠甲材料	Modified 316LN			
铠甲厚度(mm)	2.2	2.2	2.2	2
空隙率(%)	~30	~30	~30	~30
最大磁压(Mpa)	10.2	10.13	8.97	10.3



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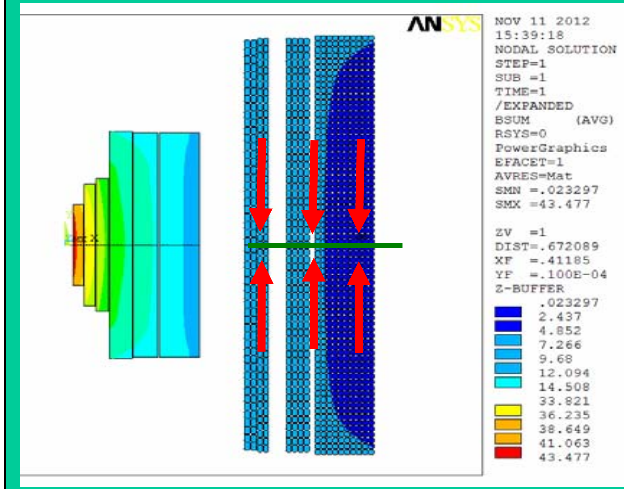
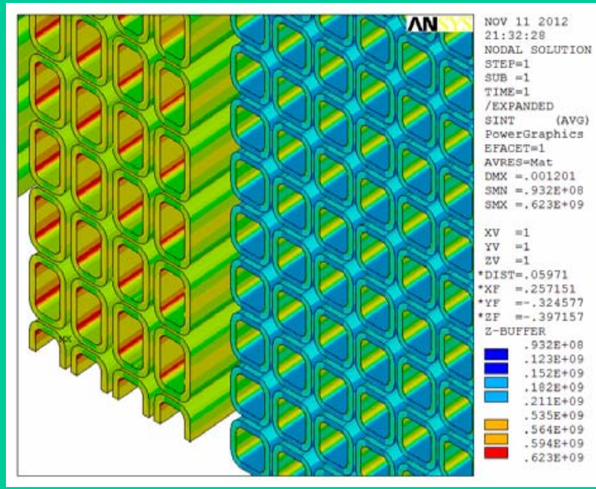
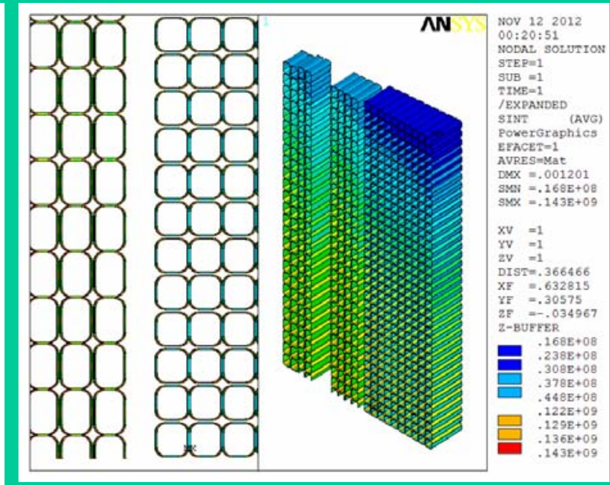
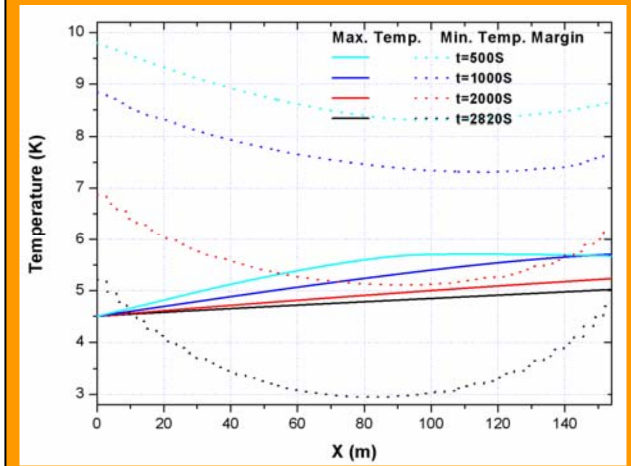
Performance analysis of Superconducting Outsert

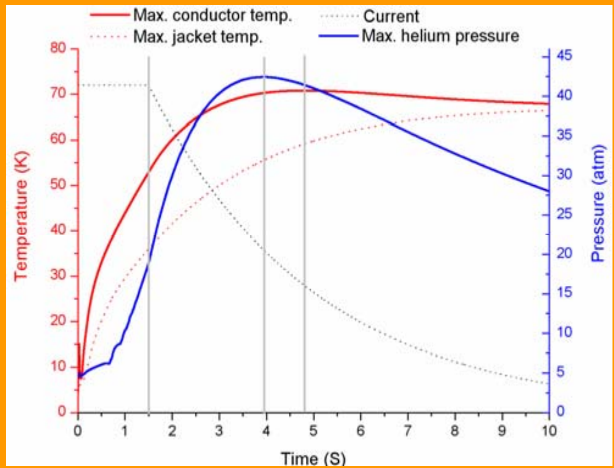


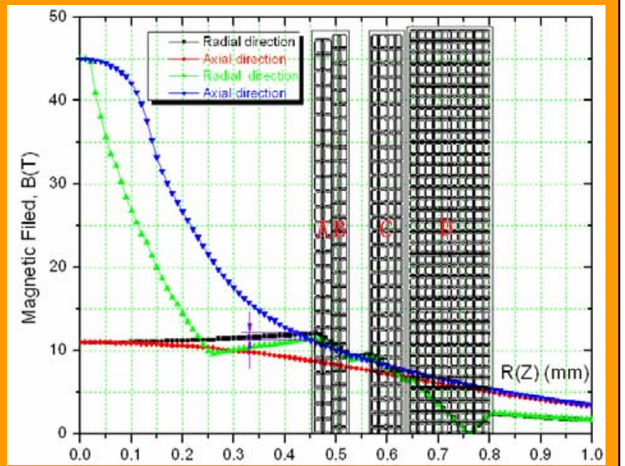




Mechanical performances analysis of the SC Outsert

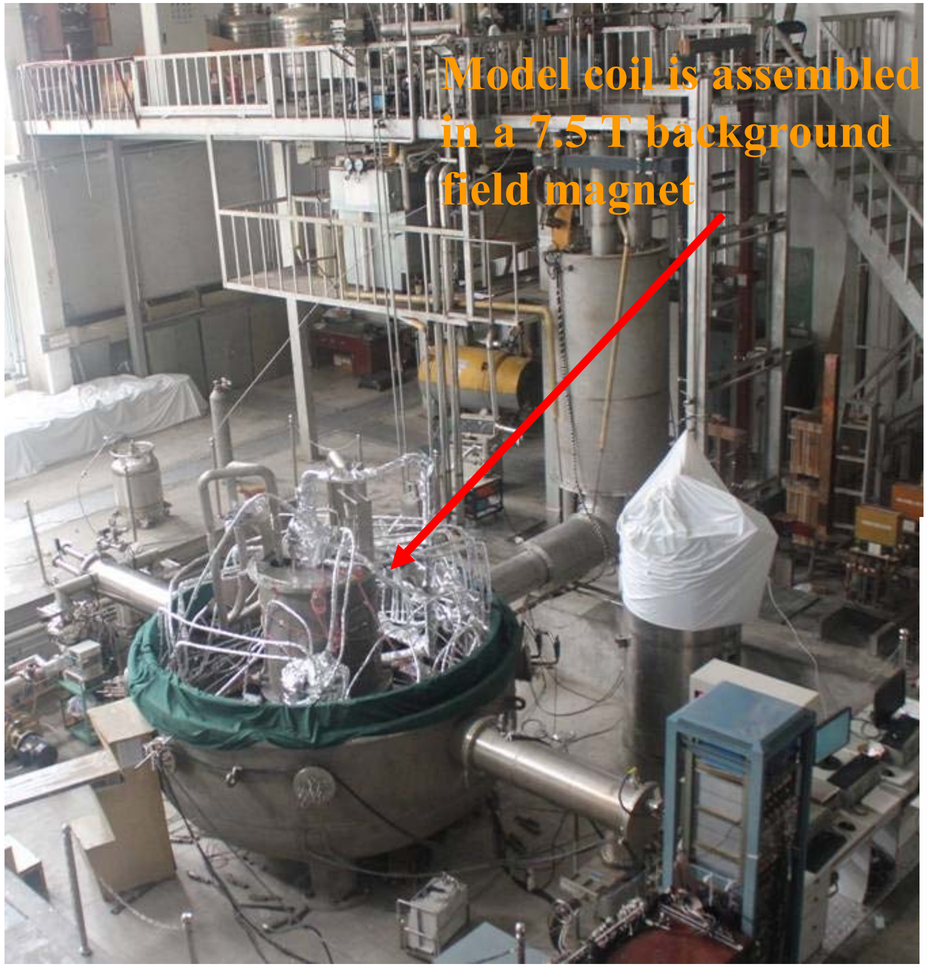


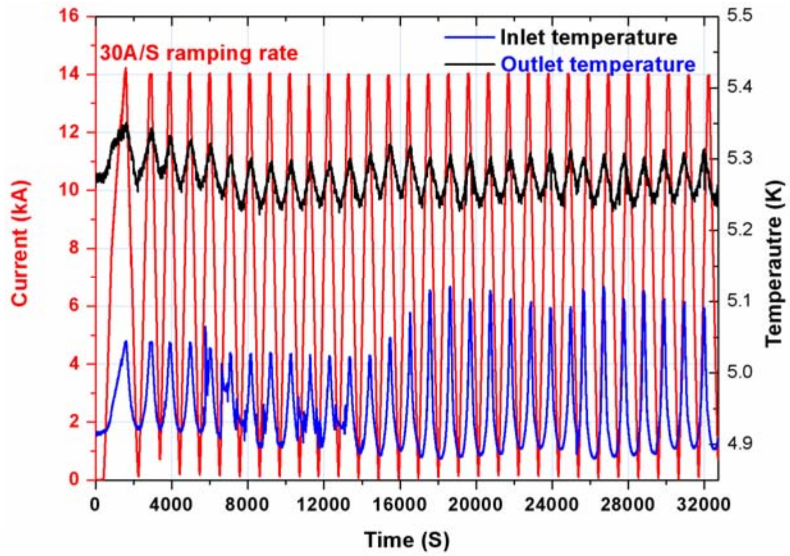


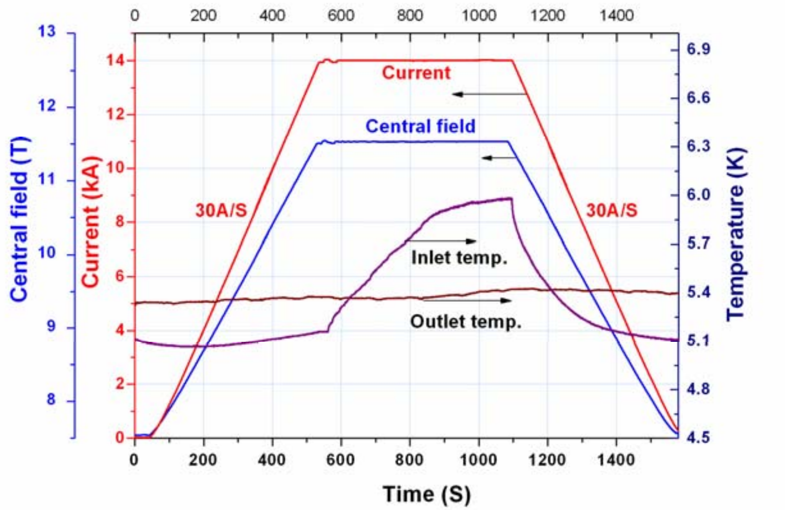


Thermal and electro-magnetic performances analysis of SC Outsert

Performance Test of Model Coil







Performance tests of the model coil included: DC operation, fast discharging, AC losses, cyclic loading, etc.

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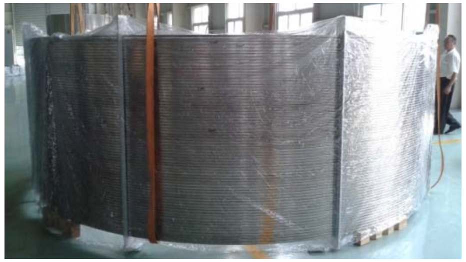
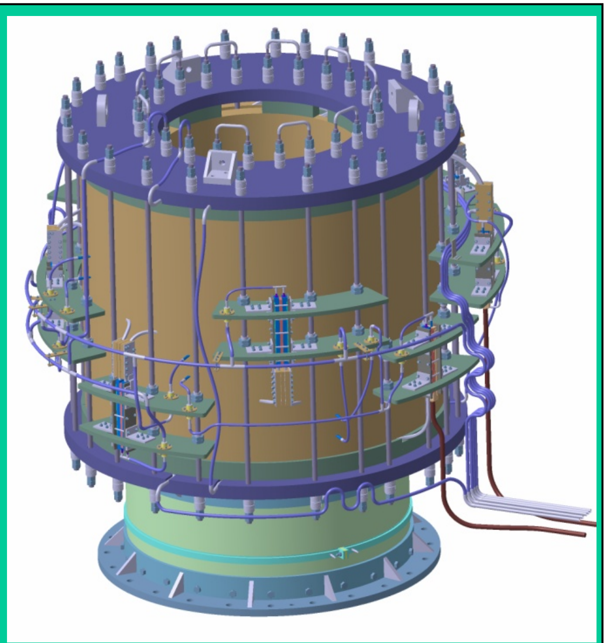
Processing of SC Coils

Nb3Sn superconducting fable



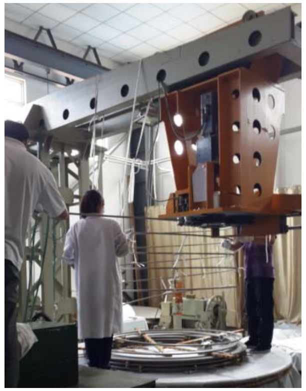
Nb3Sn CICC

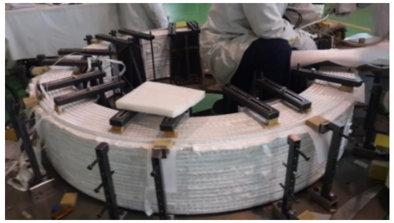

Superconducting cable (top) and conductor (bottom) processing



11T/800mm outsert

Cooling support

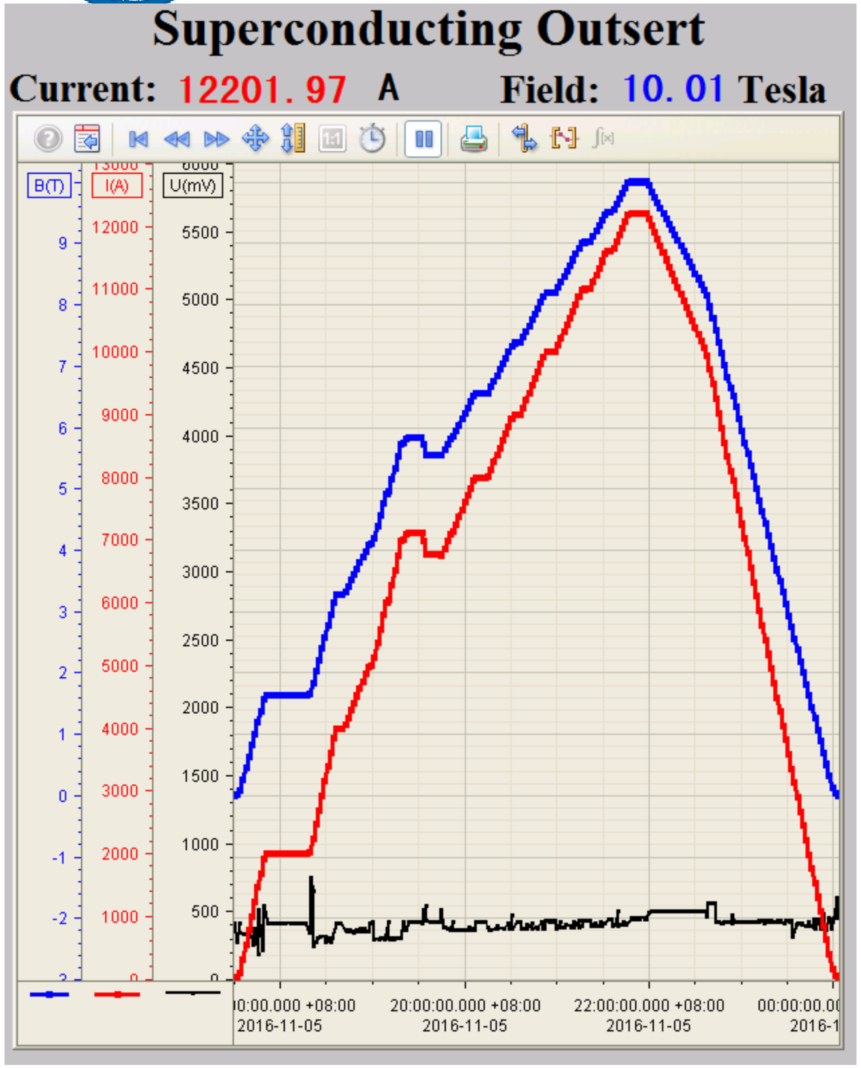


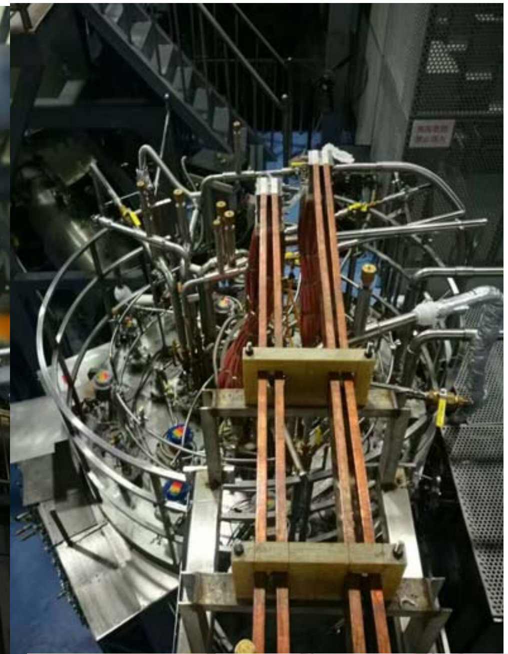


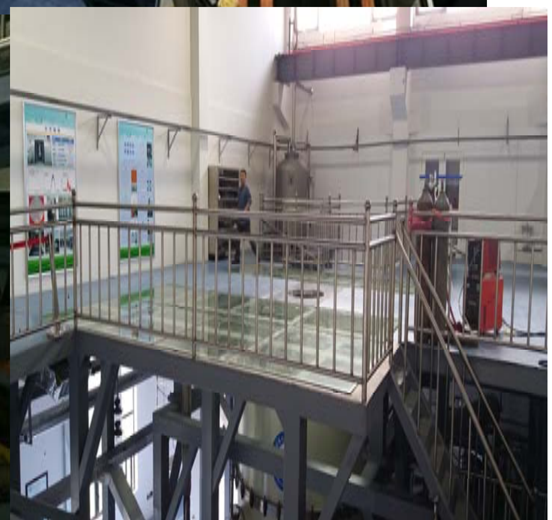
Superconducting coil winding

- ✧ manufacturing superconducting coil (2014) ;
- ✧ assembly (2015).

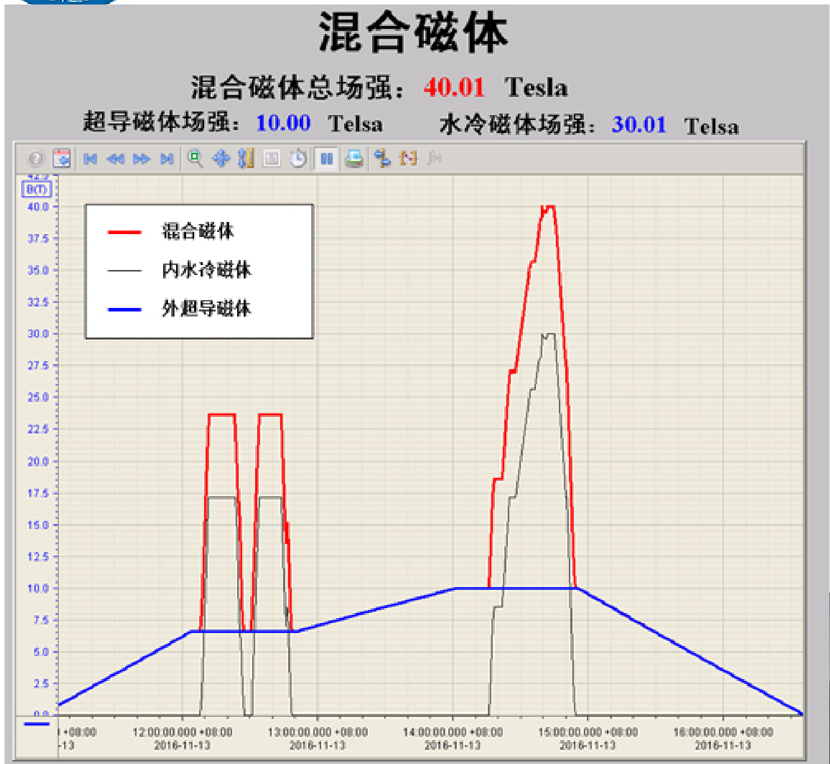
Test of Superconducting Magnet







Commissioning of Hybrid Magnet



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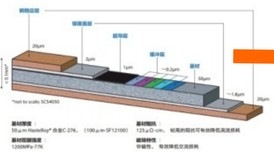
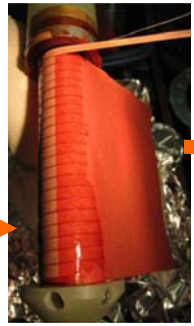
A best test facility for HTS Insert

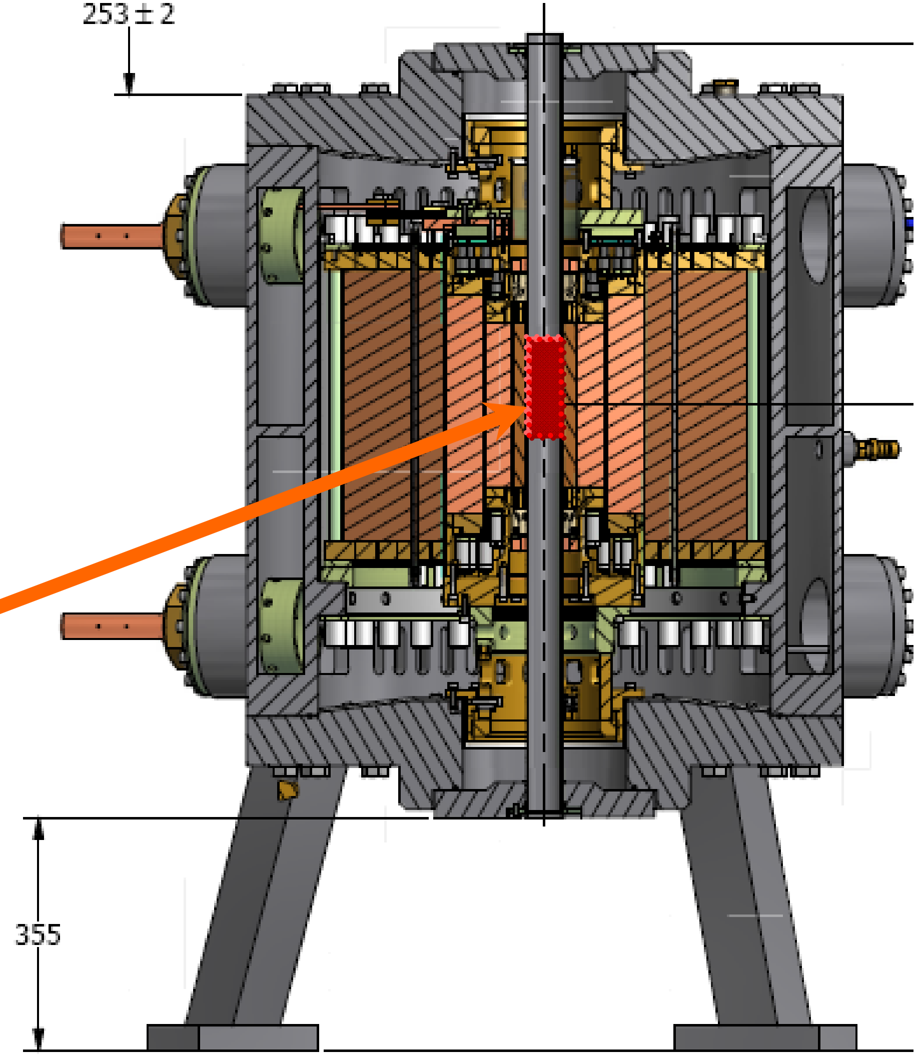


YBCO



内插磁体

低温杜瓦



水冷磁体实验平台

Summary

- Three resistive magnets have been constructed at CHMFL, the highest field can arrive 38.5T.
- The commissioning of our hybrid magnet can provide 40 T central field, a higher field more than 45 T can be expected.
- The resistive magnets developed in our lab will be a best test facility for developing HTS Insert.

Thanks for your attention!