Measurement facility and test results for FRIB superconducting magnets at IMP

YANG Wenjie[1,2] , WU Beimin [2,3], WU Wei [2], NI Dongsheng[2] , MEI Enming[2], MA Lizhen[2]

1. University of Chinese Academy of Sciences
2. Institute of Modern Physics, Chinese Academy of Sciences
3. The Key Laboratory of Mechanics on Western Disaster and Environment, College of Civil Engineering and Mechanics, Lanzhou University

中国科学院大学 University of Chinese Academy of Sciences

中国科学院近代物理研究所 Institute of Modern Physics, Chinese Academy of Sciences

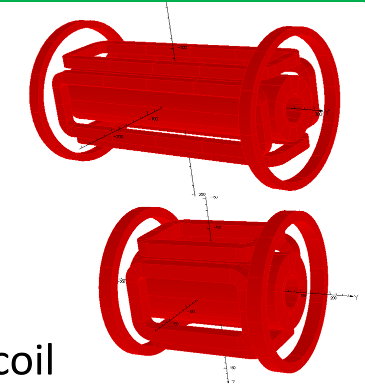
Ⅰ Overview

- The Facility for Rare Isotope Beams (FRIB) will be a new national user facility for nuclear science. It is funded by the DOE-SC, MSU and the State of Michigan.The FRIB driver linac can accelerate all stable isotopes to energies beyond 200 MeV/u at beam powers up to 400 kW.
- FRIB SC magnet are used to focus and steer the heavy ion beams of the driver linac. 80 magnets have purchased from XSMT Co. Ltd, China. It Include 9 short and 71 long magnets.IMP undertaken the simulation design and 30 of the them have been tested at IMP.

Ⅱ Introduction of the SC magnet

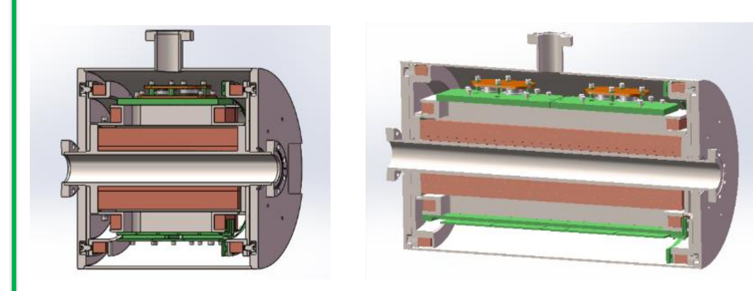
Each SC magnet package consisting of:

①A main focusing SC solenoid
②SC dipole correctors (both horizontal and vertical)
③A helium vessel
④A stray field suppressor (bucking coils)
⑤A quench protection system (protection by diodes)
⑥Fiducials for showing the magnetic axis of the solenoid coil



Parameter	Unit	Long SC	Short SC
Operation temperature	K	4.5+0.5/-0.0	4.5+0.5/-0.0
Main solenoid nominal current	A	90	90
Peak solenoid filed at Inom	T	8	8
$\int B_z^2 dz$ at Inom	T^2m	28.2	13.6
$\int B_z^2 dz$ uniformity within 80%*R	%	2	2
$\int B_x dz$, $\int B_y dz$,integrated field strength	Tm	0.06	0.03
$\int B_x dz$, $\int B_y dz$ uniformity within 15mm	%	5	5
Maximun current of dipole	A	19	19
maximum tolerated magnetic stray field	T	0.027 (z ≥ 390 mm)	0.024 (z ≥ 260 mm)

- ✓Due to the stringent space restriction inside the cryo-modules, the solenoids is designed as compact as possible.
- ✓Solenoid coil length is 25cm and 50cm respectively.
- ✓Cold bore inner diameter is 40mm.
- ✓The helium vessel made of 316L stainless steel to minimize remanent. field. The welding done in a way to minimize remanent field.
- ✓Perpendicularity tolerance between the X and Y dipoles is 1 degree.
- ✓Deviation of the field center from the mechanical center within 0.3mm.
- ✓The Helium vessel shell diameter is 304.8mm. The length of the SC magnet is 589.53mm and 349.76mm respectively.



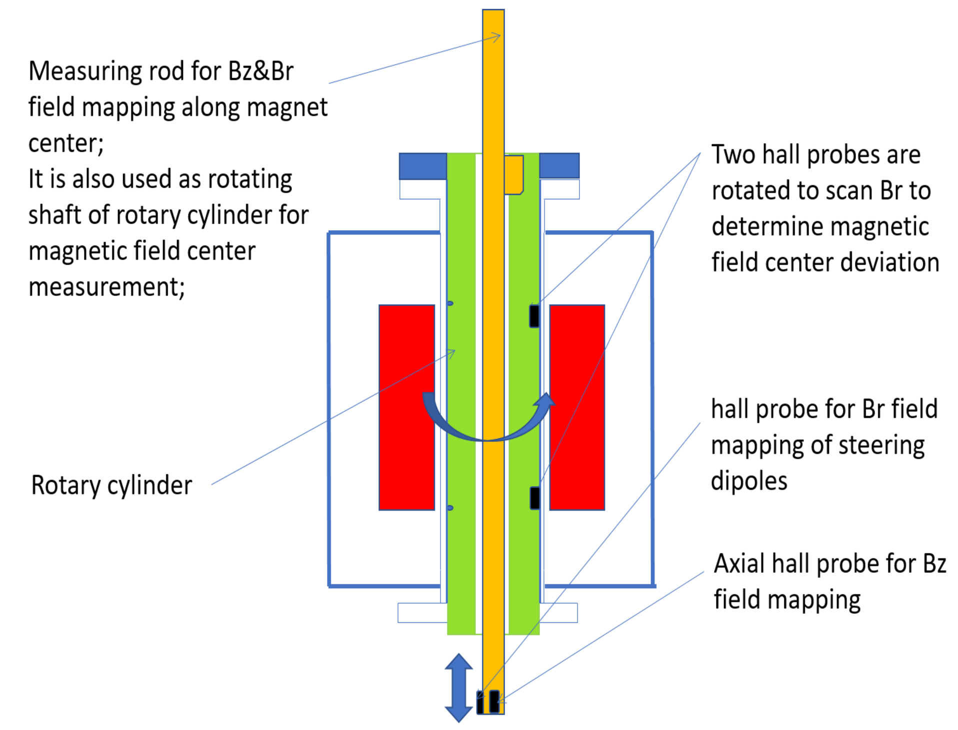
Mechanical model

50cm SC

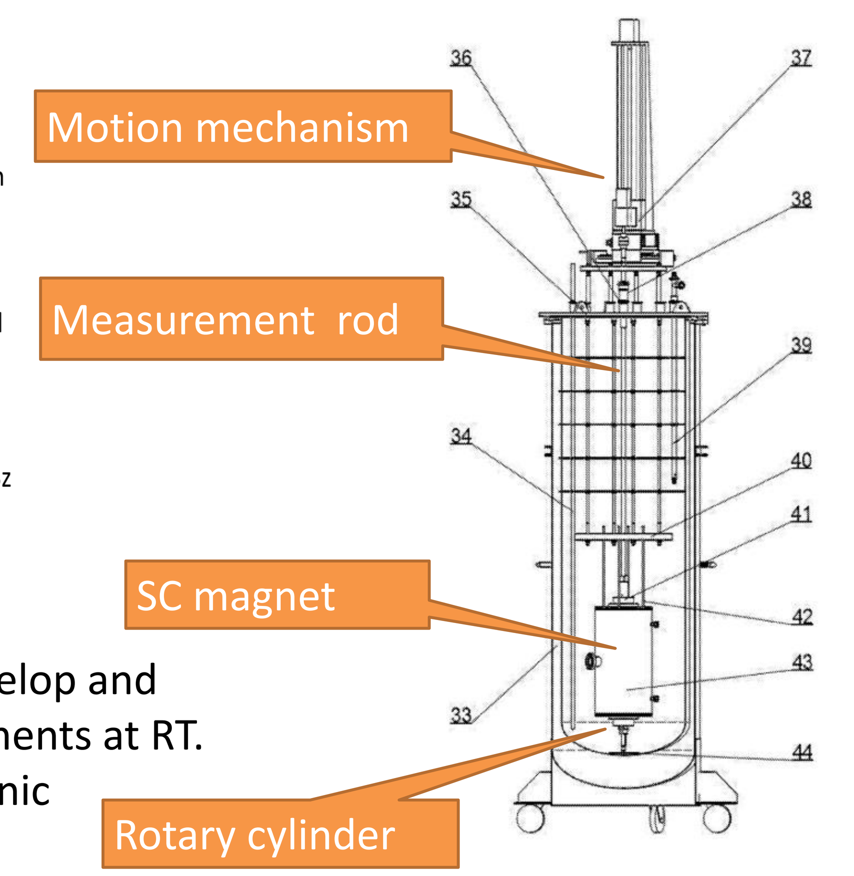
25cm SC

Ⅲ Measurement facility at IMP

TCF10 cryogenic plant (35L/h)



The SC magnet install in the Dewar



- Due to the small bore size (40 mm), it is hard to develop and insert a anti-cryostat into the magnet for measurements at RT.
- So the measurement system are operated at cryogenic temperature.

Ⅴ Conclusion

- It is the first time for serial cold test of SC magnet at IMP and all of them are accepted by FRIB.
- The measurement facility works well during the test . Can't get the stray field and the uniformity.
- The vertical test consume more time and LHe, and has a great risk of failure.(Data acquisition failure, move not smooth etc.)

Ⅳ Results

Cooling down and training

- ●Pre-cooling by LN2 to reduce the consumption of LHe
- ●Minimum ramp rate of 0.5% of nominal current per second.
  - A. Solenoid magnet training
  - B. Dipole correctors training
  - C. Solenoid and correctors triple training simultaneously.
- ●Most of the SC magnet reach their nominal field without quenches. Some of the them needs two or three times training.

Field integral

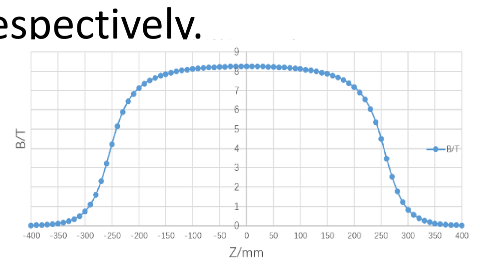
◆The solenoid field Bz measured at I_{nom} every 5 mm along the z-axis

– 400 mm ≤ z ≤ +400(50mm)

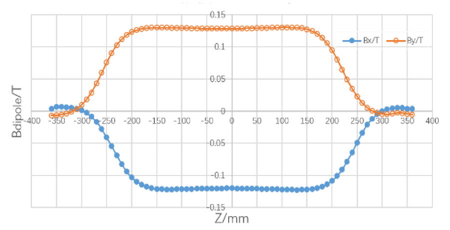
-200 mm ≤ z ≤ +200 (25mm)

In order to obtain integrated squared field. $\int Bz^2dz$ [T²m]

◆Rotating the measuring rod can dipole increments $\int Bx$dz and $\int By$dz respectively.



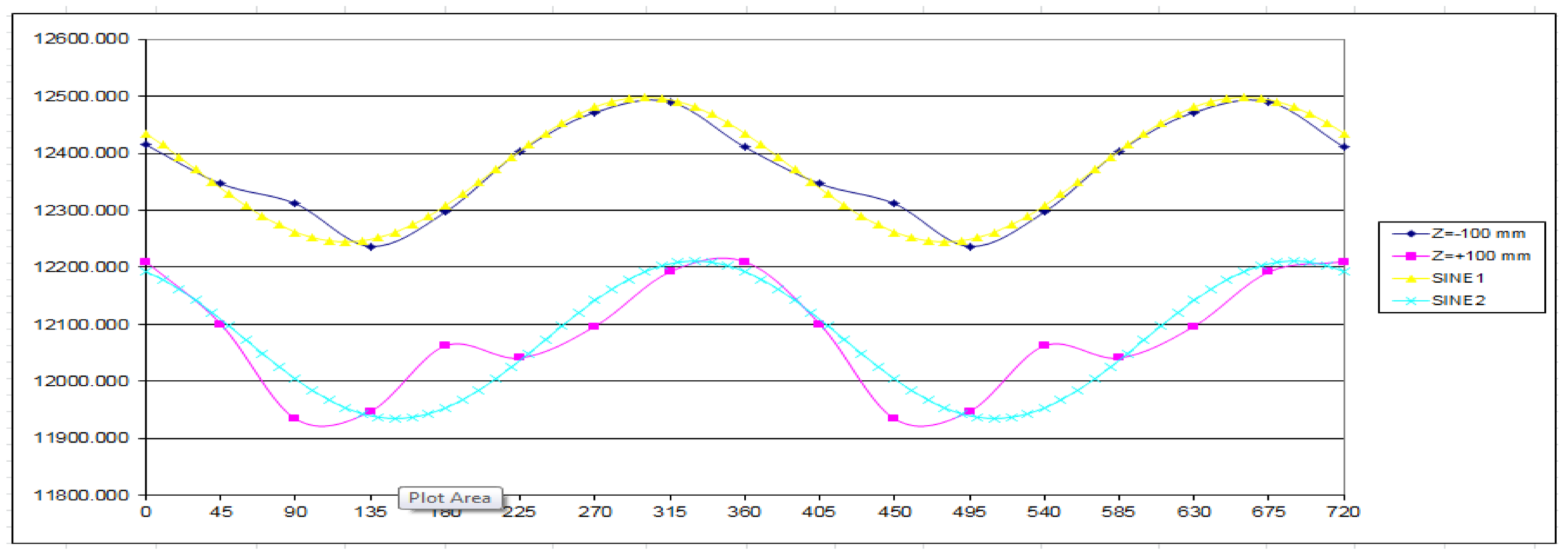
Field distributed of solenoid



Field distributed of dipoles

Determining solenoid field axis

- ◆The alignment scans are performed at both ends of the solenoid
- ◆ Preferably where the Br component is a maximum
- ◆The increments of measurement is set 45° at I_{nom} （dipoles off）
- ◆Fit data using sin wave to get the orientation of the misalignment.



- ◆The requirement of deviation of the field center from the mechanical center are smaller than 0.3 mm.
- ◆ After the cold test, we mark the field center on the helium vessel for the solenoid alignment.

NO	Solenoid Field /T	Integrated field of dipole /Tm	Integrated Field of solenoid /T²m	Mechanical Center error /mm	Quench times
25cm SC					
1	8 (87.96A)	N/A	14.408	0.305	0
2	8 (87.3A)	0.036 (19A)	13.87	-0.285	1
3	8 (88.44A)	0.042 (19A)	13.85	0.373	1
4	8 (86.8A)	0.03 (19A)	13.8	-0.284	3
5	8 (86.8A)	0.031 (19A)	13.76	0.2	0
6	8 (86.8A)	0.03 (19A)	13.73	0.145	0
7	8 (86.8A)	0.032 (19A)	13.77	0.282	0
8	8 (86.75A)	0.031 (19A)	13.78	0.042	0
9	8 (87.3A)	N/A	N/A	0.203	0
50cm SC					
1	8 (89.8A)	0.078 (19A)	28.291	0.298	0
2	8 (89.86A)	0.06 (19A)	28.263	0.153	0
3	8 (88.36A)	N/A	28.324	0.307	0
4	8 (88.98A)	N/A	29.153	0.172	0
5	8 (86.4A)	0.084 (19A)	30.809	0.135	2
6	8 (87.4A)	0.08 (19A)	30.05	0.398	2
7	8 (89.9A)	0.066 (19A)	28.3	0.267	0
8	8 (87.40A)	0.066 (19A)	28.1	0.347	0
9	8.09 (90A)	0.062 (19A)	28.77	0.186	0
10	8.04(90A)	0.063 (19A)	28.46	-0.274	0
11	8 (87.3A)	0.063 (19A)	28.2	0.173	1
12	8 (90A)	0.063 (19A)	28.24	0.275	0
13	8 (89.9A)	0.063 (19A)	28.5	0.11	0
14	8.02 (90A)	0.064 (19A)	28.64	0.257	0
15	8.04 (90A)	0.064 (19A)	28.65	-0.102	1
16	8.04 (90A)	0.064 (19A)	28.56	0.290	0