Magnetic Field Measurement, Amending and Processing for 230 MeV Superconducting Cyclotron

Tianjue Zhang, Ming Li, Chuan Wang, Yinlong Lv, Fei Wang, Tao Cui, Zhiguo Yin, Lei Cao, Jun Lin, Pengfei Zhu

China Institute of Atomic Energy，Beijing，102413

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China Institute of Atomic Energy

Introduction

A superconducting cyclotron CYCIAE-230 has been designed and is being constructed by the China Institute of Atomic Energy to extract about 230 MeV proton. Magnetic field mapping and shimming are the necessary processes for the development of cyclotrons to achieve isochronous acceleration. In the construction of CYCIAE-230, a fully automated magnetic field mapping system is developed to measure the field on the median plane with the relative accuracy of 5×10^{-5} and also a shimming algorithm suitable for the spiral sector type magnet is built to complete the correction of magnetic field with high precision.

TABLE I THE MAIN PARAMETERS FOR CYCIAE-230

Parameters	Value	Parameters	Value
Extracted Energy	>230 MeV	Cavity Number	4
Pole Type	Spiral	Harmonic Number	2
Pole Gap	5 cm	RF Frequency	71.3 MHz
Pole Radius	85 cm	RF Voltage	70~110 kV
Radius of Return Yoke	160 cm	Extraction Method	Electrostatic deflectors
Magnetic field Value	1.8T~3.8T	Extraction efficiency	80%
Coil Type	NbTi/Cu SC Coil		

Conclusion

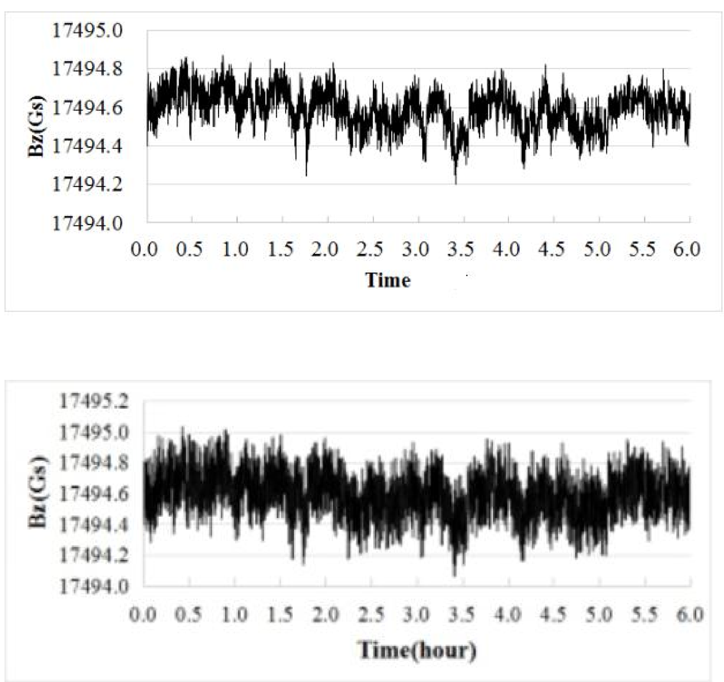
Through strict control of the room temperature and EMC, a fully automated field mapper is built to measure the magnetic field in the CYCIAE-230 with the relative accuracy of 5×10-5. A simple device is used to obtain the field distribution at the extraction region. Based on the measured field map, four times of magnet amending and processing are completed to achieve the isochronism and adjust the tune diagram. Considering the effect of RF induced magnetic field on beam dynamics, another time of shimming is being carried out to further optimize the phase slip. The number of the acceleration turns is expected to be within 670 and the extraction efficiency is larger than 80%.

At present, the RF system is installed and tested on the magnet model bench. The RF frequency is about to be adjusted in place and the measured voltage distribution is highly in accordance with the calculated results. After the installation and test of the the RF cavities in the magnet, the whole cyclotron will be moved to the factory. The beam commissioning is expected to be carried out by the end of this year.

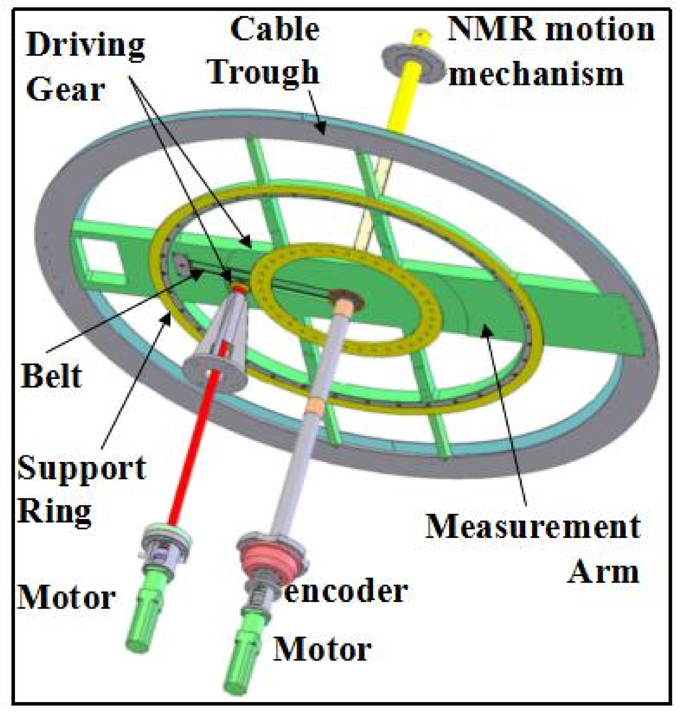
Magnetic Field Measurement

Temperature Control

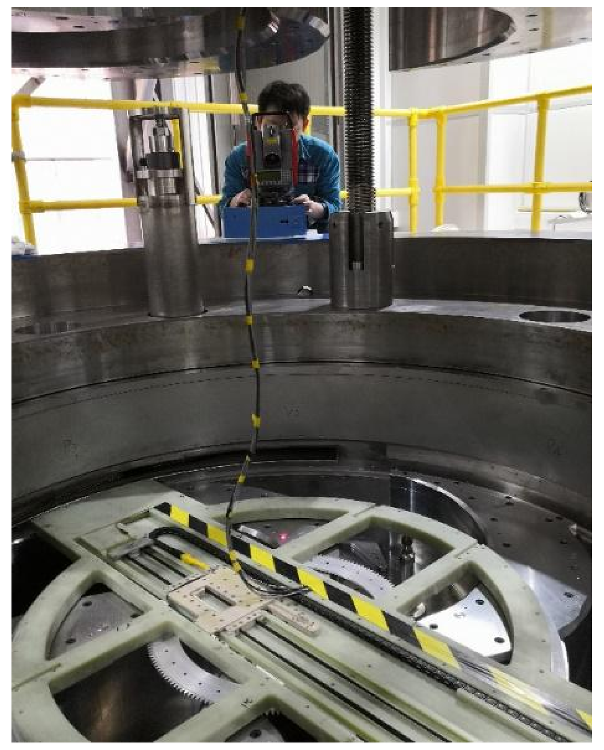
A hall probe is placed in the magnet valley to monitor the field during mapping, the results of which indicate that a temperature change of 1 ℃ will bring about 2.5 Gs of field fluctuation at that position. Therefore, a constant temperature room dedicated to field measurement was built.



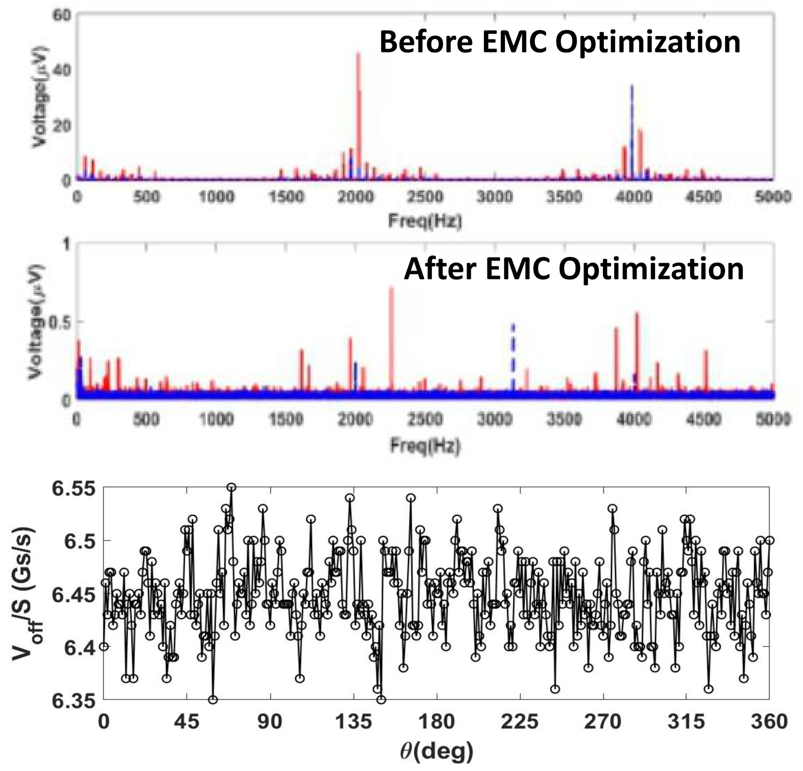
Mechanical Apparatus



The mechanical apparatus includes the measurement arm, the drive mechanism, the position feedback mechanism and the field acquisition probe mounting mechanism. A slider carrying the searching coil could move forward and backward on the arm smoothly. Driving by the gear wheel, the measurement arm could rotate in the angular direction. In the central hole, a motion mechanism can insert the NMR probe to obtain the field at the cyclotron center. Through the pre-calibration, a hall probe mounted on the slider is used to replace the NMR probe for central field acquisition, so the top central hole can be used to lead out the cable, greatly simplifying the apparatus installation.



Field Acquisition System



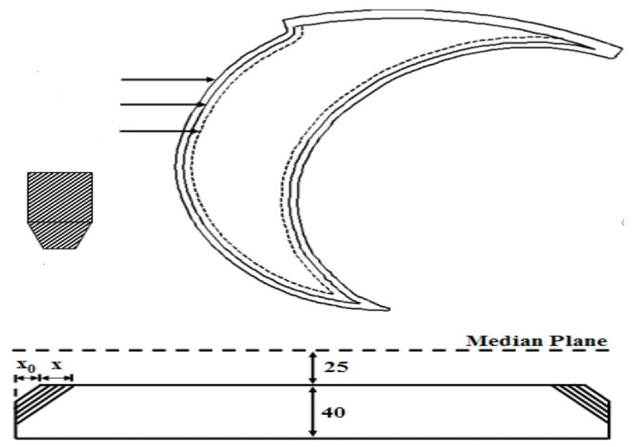
Due to a bad electromagnetic compatibility (EMC) design, large noises are generated and the measurement accuracy is seriously impacted. Thus, some work has been done to improve the EMC:

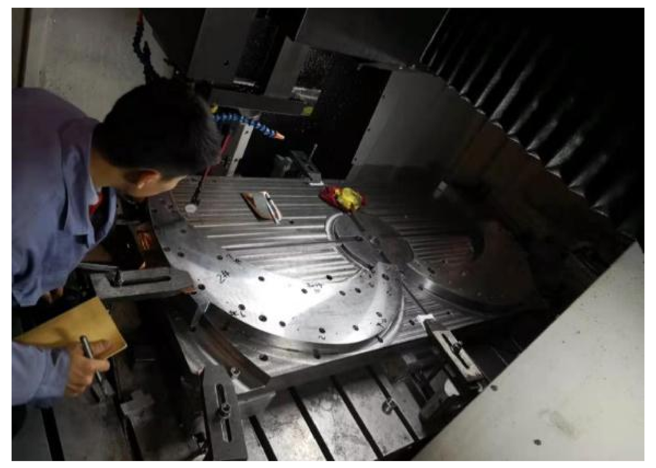
- The field measurement devices are grounded separately, with grounding resistance less than 0.3 Ω.
- Instruments and cables with high electromagnetic interference are shielded, especially the step motors and the drivers.

Magnet Amending and Processing

Shimming Method

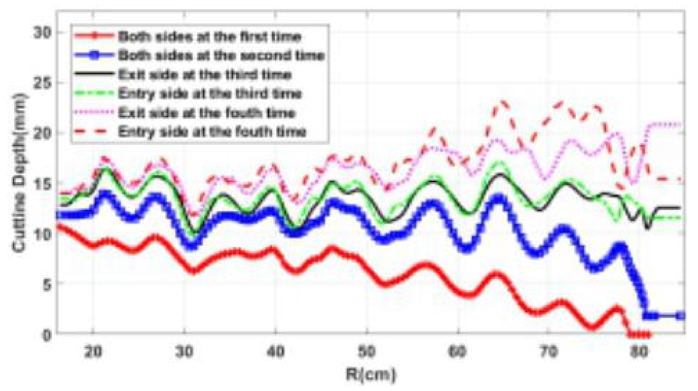
The magnetic field amending method for large scale spiral sectors of SC cyclotron based on 45º chamfering on the pole edges is proposed and implemented for the first time.The magnet pole is divided into the upper and lower two parts. The upper part, named the shimming plate, is fixed on the lower part by many bolts, which can be easily disassembled and used to process the two edges.



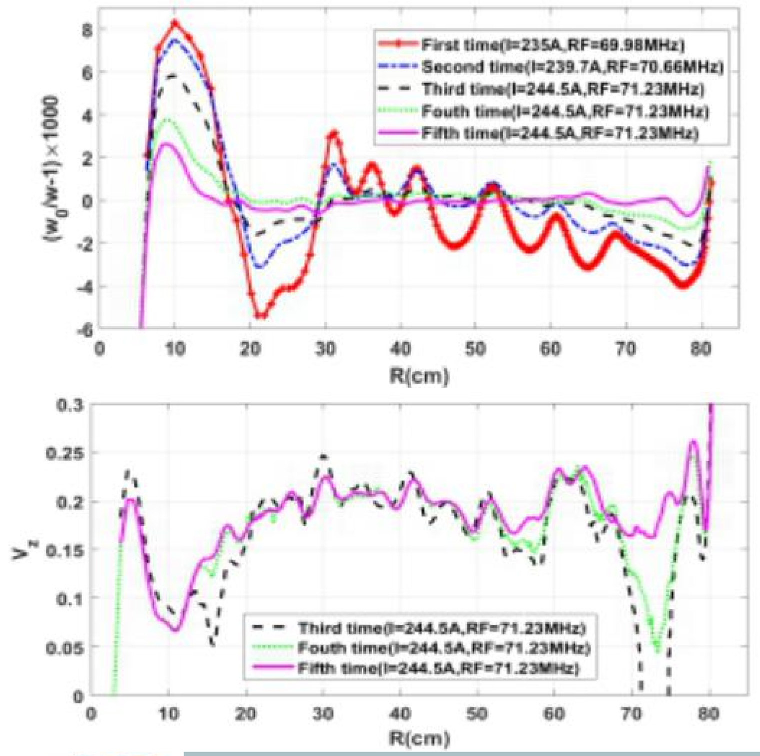


Isochronism and Tune Adjustment

After the first shimming, bolts, made of 20# steel and with smaller size to reduce filling air, are replaced. The current of the superconducting coils has been raised two times to match the field with the designed RF frequency. After four times of shimming, the particles could achieve isochronous acceleration in the machine.

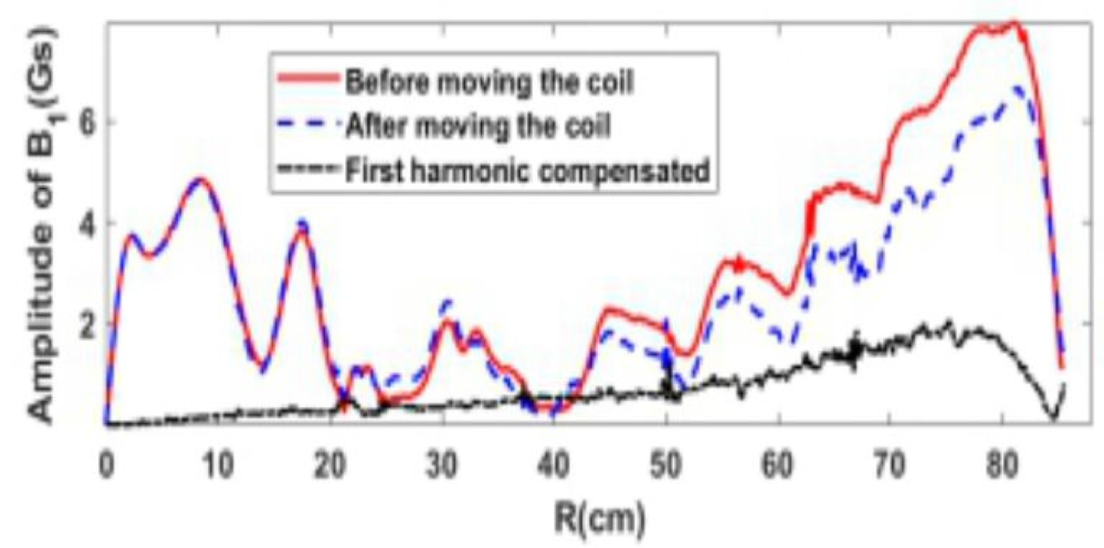


Asymmetrical amending of the two pole edges are introduced to adjust the local spiral angle and thus enhance the vertical tune. After two times of asymmetric amending, the vertical value reaches 0.15 .



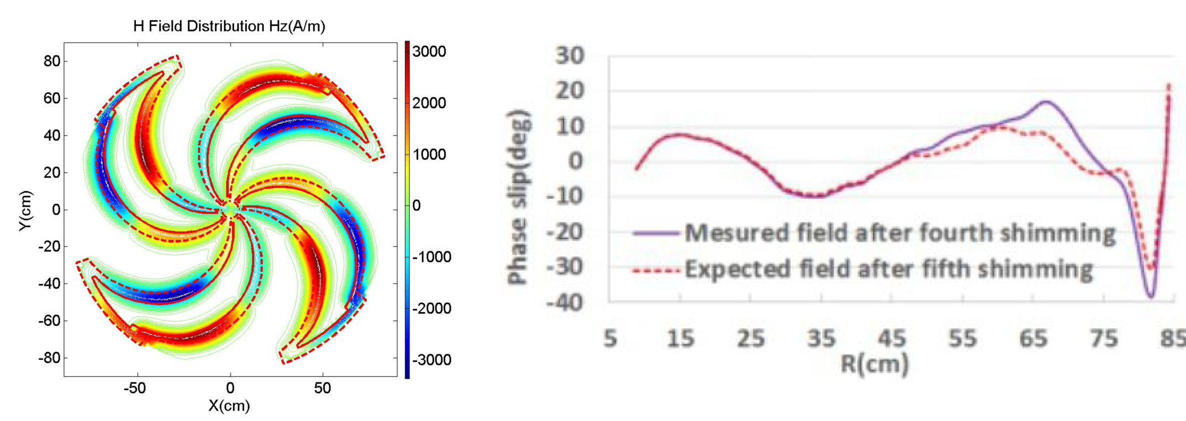
First Harmonic Compensation

Superconducting coil shift is the effective way to compensate the first harmonic globally. As a test, the coil is shifted to verify the compensation effect. The first harmonic at the large radius decreases by 2 Gs as expected, and that at the small radius increases only a little. Next, larger offset is anticipated to compensate the overall first harmonic field at large radius.



Further Optimization

Due to the spiral cavities used, the magnetic field induced by the RF has an impact on particle rotating frequency, which means it is not accurate enough to consider the isochronism only with the static magnetic field. The field is subjected to the last shimming considering the RF induced magnetic field. The phase slip of the machine will be improved and corresponding turn number of acceleration is expected to be less than 670.



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