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MAGNETIC FIELD MEASUREMENT AND SHIMMING FOR A MEDICAL COMPACT CYCLOTRON

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Abstract

A compact cyclotron is developed by Cyclotron Research and Design Center at China Institute of Atomic Energy (CIAE) to extract 14 MeV proton beam for medical radioisotopes production, so as to meet the market demands of early diagnosis of malignant tumors, cardiovascular and cerebrovascular diseases. Owing to the small size and limited space of small medical cyclotrons, critical requirements are imposed on magnetic field measurement. For this reason, a magnetic field measurement system, with high-precision and high-stability, suitable for small cyclotrons is adopted and then an efficient magnetic field shimming method is used, which greatly reduces the construction period. It provides a strong guarantee for the stable operation of medical small cyclotrons.

INTRODUCTION

The Cyclotron Research and Design Center at China Institute of Atomic Energy developed a 14 MeV medical cyclotron for boron neutron capture therapy (BNCT). The main magnet of the cyclotron adopts a compact size, and the diameter is 1 m. Four straight sectors are adopted and the harmonic number is 4 in the cyclotron. The gap between the magnetic poles is between 23 mm and 26 mm, and the beam current is 1 mA. For the above characteristics of the BNCT cyclotron, a fully automated magnetic field measurement system for the magnetic field mapping and shimming is adopted.

DESIGN OF THE MAGNETIC FIELD MAPPING INSTRUMENT

Principally it should be ensured that the components of the field mapping system placed inside the accelerator are non-magnetic and the eddy current is not obvious during the movement of the system. Hall probe is used for measuring the magnetic field ranging from 400 G to 20 kG with the calibrated precision of 10^{-4} which means the field measurement errors is less than 2 G. The measuring arm can rotate freely clockwise and counterclockwise around the central axis of the accelerator with the angular positioning precision of 20 s. The Hall probe on the measuring arm can move in the radial direction with the range from -2 cm to 50 cm based on the center of the cyclotron and the radial positioning precision reaches 0.1 mm. The period of the magnetic field measuring is less than 8 hrs for one mapping in which the radial interval is 1 cm and the angular interval is 1° [1]. The random error and system error are shown in Table 1.

Table 1: Parameters of Measuring Precision

Random Error	Value
Magnetic field measuring error/Gs	2
Radial measuring error/mm	0.1
Radial positioning error/mm	0.1
Angle measuring error/s	12
Angle positioning error/s	20
System Error	**Value**
Measuring arm horizontal error/mm	0.1
Measuring arm axial error/mm	0.2
Center shaft tilt error/deg	0.2

MECHANICAL STRUCTURE

The main mechanical structure is mainly composed of the support rail, the measuring arm, the Hall probe base, the angular rotating component, the radial driving component, and the center shaft component [2]. The support rail adopts aluminum alloy material, which is the support of the measuring arm with two rounds of balls supporting between to reduce the resistance during the movement. The angular rotating component built-in circular grating drives the arm rotation via the central shaft. Both ends of the Hall probe base are connected to the transmission rope, and the radial movement is driven by the radial drive component, and the radial position is indirectly determined according to the rotation angle of the rope wheel. The mechanical structure is shown in Fig. 1.

CONTROL MODULE

The radial motion controller sends the analog signal to the servo motor driver to drive the motor according to the position reference and feedback. In the angular direction, the controller drives the stepping motor by calculating the output count pulse to realize open loop control. Indirect closed-loop control is implemented by a software algorithm according to the position signal fed back by the

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angle encoder. The control flow is shown in Fig. 2.

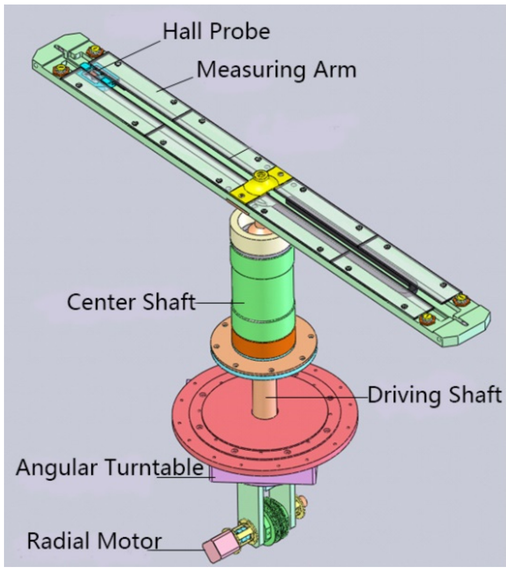

Figure 1: Mechanical structure of the measuring instrument.

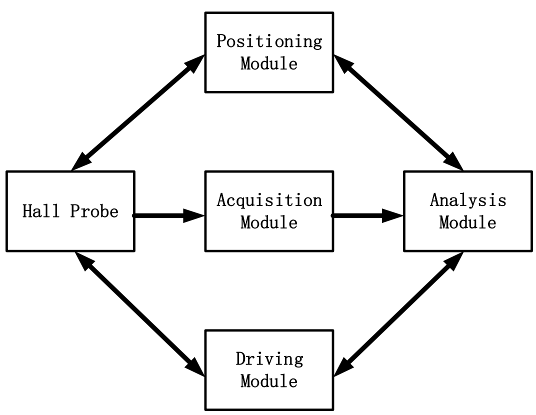

Figure 2: Control flow chart.

The issuance of the control commands of the control system and the data recording are implemented by the industrial computer. In the automatic mode, the magnetic field value of each point is measured in turn, and finally the measurement result file is formed, and the magnetic field measurement task is automatically completed. The manual mode is set as a motion mode for debugging and moving to a certain position to set working origin, positive and negative soft limit.

SHIMMING METHOD

The center plane magnetic field is shimmed by adjusting the width of the strips on both sides of the magnetic poles of the main magnet by the strip shimming method. For the purpose of improving the convergence speed of the magnetic field shimming process and reducing the period of shimming, the strips are divided into odd and even triangles in the radial direction, as shown in Fig. 3.

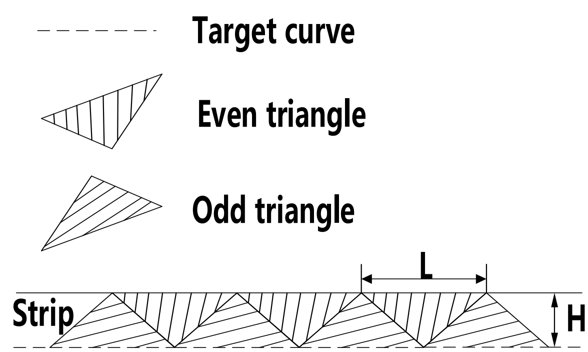

Figure 3: Even and odd triangle on the strip.

The effect on the average magnetic field, by cutting the triangular areas of length L and height H on the region near one point on the strip in the radial direction, is calculated by finite element method. To calculate the average field variation caused by the odd-even triangle, the same split mesh is used in the finite element simulation to reduce the magnetic field deviation. The shimming results are shown in Fig. 4.

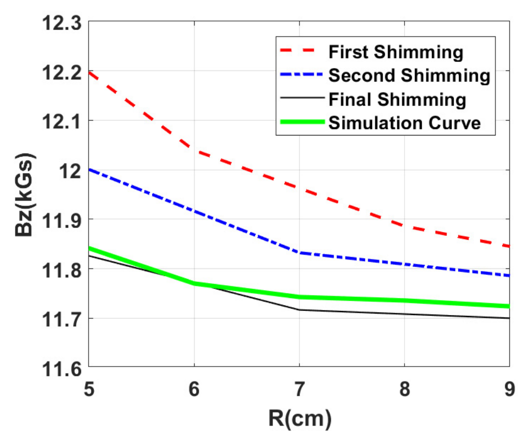

Figure 4: Average magnetic field of shimming results in the BNCT cyclotron.

RESULTS

The BNCT 14 MeV cyclotron has completed the final task after five times of magnetic field mapping and three times of shimming under the condition of ensuring the measurement accuracy and repeatability, which has experienced a total of 6 weeks. Through the final measurement results, the average field can meet the physical design requirements of the isochronism of the magnetic field.

The first harmonic is controlled at a lower level. The amplitude of the first harmonic in the small radius is less than 10 G, and the amplitude of the first harmonic in the large radius is less than 5 G, which is crucial for the 1 mA beam of the cyclotron, as shown in Fig. 5. Figure 6 shows that integral phase slip can be kept within ±15°.

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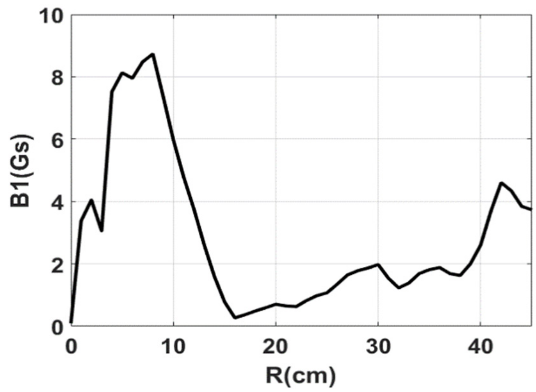

Figure 5: Amplitude of first harmonic.

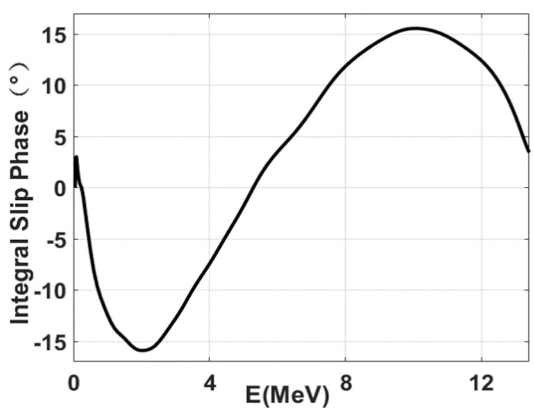

Figure 6: Integral phase slip of the final shimming.

CONCLUSION

There are still many aspects to be considered in the work of magnetic field measurement, such as magnetic performance test of main magnet, main magnet power supply stability test, cyclotron temperature monitoring, environmental humidity monitoring, and so on, which are also important factors affecting the magnetic field distribution. During the measurement process, the measuring system has been further improved and completed, which laid a solid foundation for the subsequent industrialization of medical compact cyclotron.

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