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THE DEVELOPMENT OF PERMANENT MAGNET QUADRUPOLES FOR XiPAF DTL

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Abstract

Permanent magnet quadrupoles (PMQs) are developed for the DTL of Xi'an 200 MeV Proton Application Facility (XiPAF). In this paper, we describe the fabrication and measurements for the Halbach-type PMQs. The main procedure of the PMQ manufacture is presented. And the magnetic measurements of PMQs are carried out with the help of vibrating wire, Hall probe and rotating coil respectively. The results show the PMQs are able to meet the requirements of XiPAF DTL.

INTRODUCTION

The Alvarez-type DTL is being built to accelerate the H-beam from 3 MeV to 7 MeV for Xi'an 200 MeV Proton Application Facility (XiPAF). The permanent magnet quadrupoles (PMQs) are adopted for focusing the beam. The Halbach-type PMQ is developed by our team to meet the requirements obtained by beam dynamics calculations. All the PMQs are fabricated and measured.

The main parameters and requirements of the PMQs are listed in Table 1 and Table 2. The gradient of the PMQ is about 80 ~ 90 T/m. It is worth noting that the integrated gradient *Gl* makes more sense in accelerators. Therefore, *Gl* is listed in the requirements rather than the gradient.

Table 1: Main Parameters of the PMQs

Parameter	Symbol	Values
Inner diameter	*DI*	22 mm
Outer diameter	*DO*	60 mm
Length	*l*	40 mm
Integradient gradient deviation	$\Delta Gl/Gl$	1.5%

Table 2: Integrated Gradient Requirements of the PMQs

Type	Integrated Gradient *Gl* (T)	Quantity
A	3.293	1
B	3.540	1
C	3.570	1
D	3.587	1
E	3.336	19

PMQ DEVELOPMENT

The 16-segment type PMQ is adopted in our facility. Figure 1 illustrates the cross section of a PMQ consisting 16 SmCo segments wherein the arrows indicate the easy axis orientation of each segment.

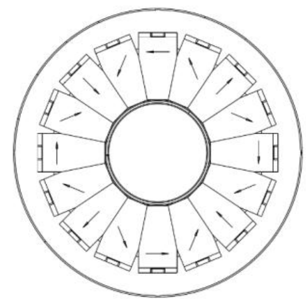

Figure 1: Cross section of the PMQ.

The fabrication procedure of the PMQs can be summarized as follows. Firstly, a number of SmCo segment blocks, which are shown in Figure 2, are produced in order to achieve enough qualified PMQs. Secondly, all the blocks are aged for 12 hours at 180 degrees Celsius. Thirdly, the magnetic field direction and strength of each blocks are measured and screened. Fourthly, the qualified blocks are then sorted by the strength and direction. Lastly, the blocks are assembled together with specified accuracy. Figure 3 and Figure 4 show one PMQ being assembled and after assembling respectively.

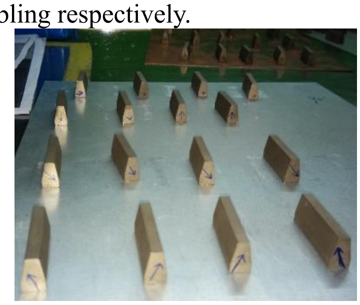

Figure 2: The aged blocks.

Figure 3: One PMQ being assembled.

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Figure 4: One completed PMQ.

PMQ MEASUREMENTS

The magnetic measurements are very important for the PMQ development. The magnetic measurements are dedicated not only to verifying that the PMQs meet the requirements, but also to guiding us for better designs. The magnetic center, integrated gradient and multipole contents are measured separately.

Magnetic Center Measurements

The magnetic center is measured and related to the mechanical center with the help of the vibrating wire. Our team have developed one vibrating wire setup. The study of the improved vibrating wire method has been detailed in ref [1] and [2].

Typically, the magnetic center of the PMQ is not exactly coincides with the mechanical center at the beginning. It is because of the assembling errors and the imperfections of the blocks. After the measurement, the mechanical center is reprocessed to coincide with the magnetic center according to the measurement result. For our PMQ, the mechanical center is the symmetric axis of the cylindrical surface. And the position of the mechanical center can be changed by reprocess the cylindrical surface. At the beginning, the outer diameter of the PMQ is 61 mm. After the reprocessing, the deviation between the mechanical center and the magnetic center is smaller than 0.02 mm. Meanwhile, the final diameter of the PMQ is reduced to 60 mm.

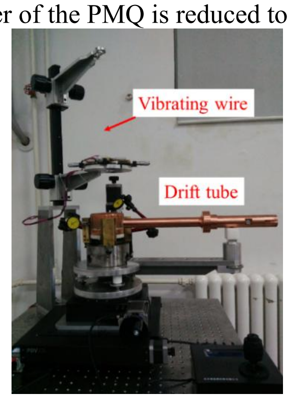

Figure 5: Vibrating wire measurement for the drift tube.

As shown in Figure 5, this vibrating wire setup is also suitable for measuring the magnetic center of the drift tube. The magnetic center measurements were kept going after the PMQs were installed into the drift tubes. These measurements are dedicated to ensuring the magnetic center coincides the mechanical center of the drift tube during the following process.

Integrated Gradient Measurements

The integrated gradient value indicates the strength of a quadrupole. The measurements of integrated gradient are especially important for PMQs. Because it is very hard to adjust it after one PMQ is installed into the drift tube. The integrated gradient should be precisely measured and screened before the installation.

The Hall probe method is adopted and improved for measuring PMQs. It is different from the electromagnet that the Halbach-type PMQ has a circularly symmetrical shape. Accordingly, the roll angle alignment for the magnet, the Hall probe and the motor stage is very difficult for the PMQs. Our team have proposed a roll angle alignment method based on the field distribution. And a setup has been built.

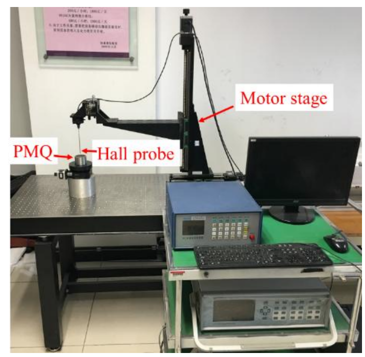

Figure 6: Hall probe measurement.

The setup is shown in Figure 6. The PMQ to be measured is placed on a rotary table. The symmetric axis of the PMQ is adjusted along vertical z axis. The PMQ can be rotated around its symmetric axis with the help of the rotary table. The Hall probe is mounted on the motor stage. A computer controls the motion of the motor stage and records the magnetic field data.

The measurement results for the 5 types of PMQs are shown in Figs. 7 to 11. They show enough quantity of PMQs to meet the requirements listed in Tables 1 and 2.

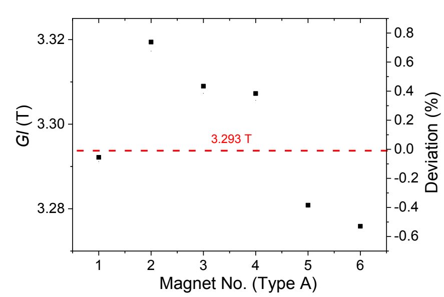

Figure 7: Measured integrated gradient and deviation of Type A PMQs.

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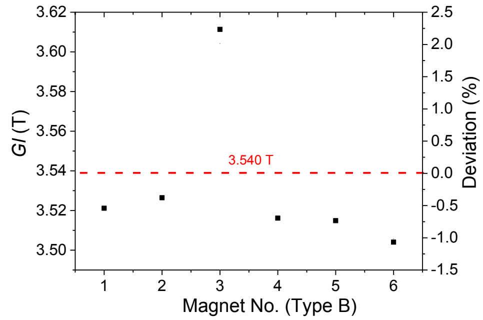

Figure 8: Measured integrated gradient and deviation of Type B PMQs.

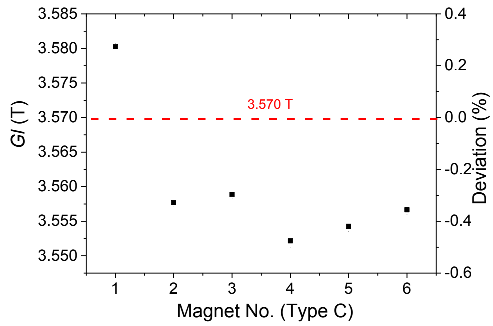

Figure 9: Measured integrated gradient and deviation of Type C PMQs.

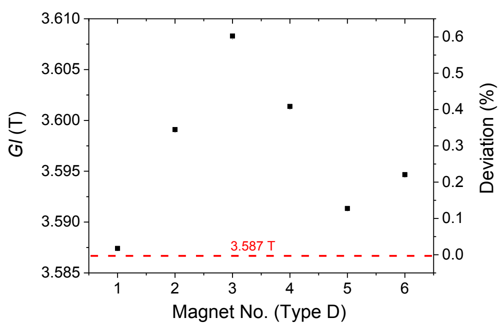

Figure 10: Measured integrated gradient and deviation of Type D PMQs.

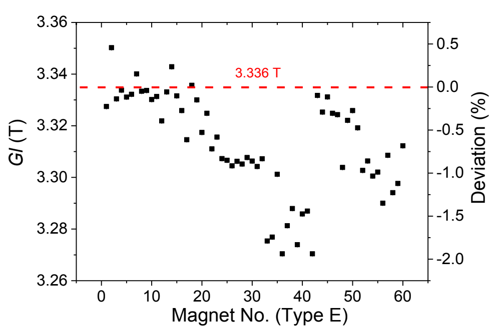

Figure 11: Measured integrated gradient and deviation of Type E PMQs.

Multipole Measurements

The multipole contents indicate the quality of the quadrupole field. They are measured by the rotating coil provided by IHEP. As shown in Figure 12, the PMQ to be measured is placed on a platform. The 8 mm-diameter coil penetrates the PMQ. The rotating axis is along the vertical z axis.

Figure 12: Rotating coil measurement.

The measurements show 85% of PMQs can meet the multipole requirements. The PMQs with larger multipole contents may be due to the imperfections of blocks and assemblings. Figure 13 presents a typical measurement result of one PMQ E-4. It shows that the multipole contents of orders less than 15 are smaller than 1% individually.

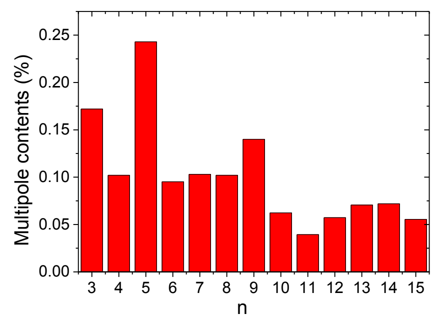

Figure 13: Multipole measurement result of PMQ E-4

CONCLUSIONS

The PMQs with the inner diameter of 22 mm and outer diameter of 60 mm are developed successfully. Magnetic measurements including vibrating wire, Hall probe and rotating coil are carried out. And results confirm enough quantity of PMQs meet the requirements.

ACKNOWLEDGEMENTS

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