VIBRATING WIRE MEASUREMENTS FOR THE XiPAF PERMANENT MAGNET QUADRUPOLES

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Abstract

Vibrating wire technique is a promising measurement method for small-aperture Permanent Magnet Quadrupoles (PMQs) in linear accelerators and scanning nuclear microprobes. In this paper, we describe the improved vibrating wire setup for measuring an individual PMQ with the minimum aperture of several millimeters. This setup is aiming at measuring the magnetic center. The advantage of this setup is that any mechanical measurement on the wire, which may be the main error source, is avoided. Experiments of the 20 mm-aperture Halbach-type PMQs for Xi'an Proton Application Facility (XiPAF) DTL has been carried out. The research results of the magnetic center measurements show a precision of about 10 μm and robustness against the background magnetic field. Results of the magnetic center and field multipoles measurements agree with the ones obtained from the rotating coil.

INTRODUCTION

The 325 MHz Alvarez DTL for the Xi'an Proton Application Facility (XiPAF) will be used to accelerate the H- beam from 3 to 7 MeV. As shown in Figure 1, the 20 mm-aperture Halbach-type Permanent Magnet Quadrupoles (PMQs) are used in the DTL. The tolerance for the PMQs are list in Table 1. The measurement of the magnetic center is very important. The misalignment of the magnetic center will cause the beam to deviate. Rotating coil is the conventional method to achieve the magnetic center position as well as the multipole contents of the quadrupoles. However, it is difficult to measure the magnets with small apertures of several millimeters. To achieve high efficiency, the apertures of the magnets has been smaller and smaller in new linear accelerators. A new measuring method which is free from the restriction of the aperture should be developed.

Vibrating wire method is a high accuracy method adapt for measuring the magnetic center of the small-aperture magnets. This method is quite sensitive to make the wire coincides with the magnetic center. However, it is difficult to relate the wire to external fiducials. The improved fiducialization method is described in ref [1]. The advantage of this method is that the measurement of the wire position, which may be the main error source, is no longer needed. This method has been adopted to measure the XiPAF PMQs.

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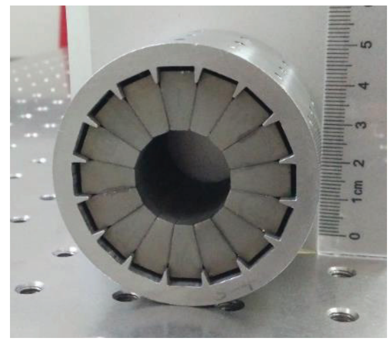

Figure 1: The PMQ to be used in XiPAF.

Table 1: PMQ Tolerances

Errors	Name	Values
PMQ position	δx, δy	± 0.17 mm
PMQ pitch and yaw	φ*x*, φ*y*	± 3 deg
PMQ roll	φ*z*	± 0.6 deg
PMQ integrated gradient	Δ*Gl*/*Gl*	± 1.5 %
PMQ multipole contents	*B*n/*B*2 @R=8 mm n=3…15	1%

MEASUREMENT SETUP

As shown in Figure 2, a vibrating wire setup was constructed as described in [1]. A 1.2 m-long wire is stretched vertically by a plumb. The plumb is submerged into the water in order to rebalancing quickly after some disturbances. The 100 μm-diameter wire carries the sinusoidal current. The function generator is used to excite the wire to vibrate in the fundamental mode. The lower end of the wire is connected to the function generator, and the upper end is connected to the ground in the consideration of isolation. The fixed point of the plumb is separated from the lower end of the wire. The extra slack between the fixed point and the lower end is long enough in order to avoid disturbing the hanging plumb. The PMQ to be measured is on the top of the rotary table. The rotary table is installed on the mover in order to move in x and y directions. A vertical linear guide is beside the mover. It is used to check the perpendicularity of the PMQ. Two optocouplers, mounted in the perpendicular directions, are used as the wire vibration detectors to transduce the wire displacement into an electrical voltage. The signals from the sensor are sent to an oscilloscope. Two dial indicators are used to measure the magnet position change.

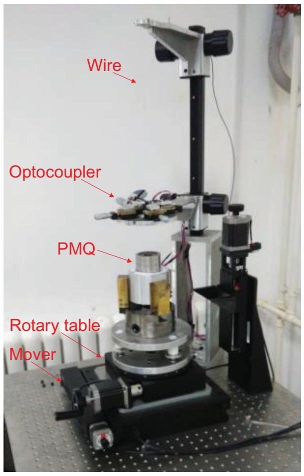

Figure 2: The vibrating wire setup.

EXPERIMENTS AND RESULTS

Robustness in the Background Magnetic Field

In Ref. [1], it has been illustrated that the results of the method mentioned will not be influenced by a stable background magnetic field. As shown in Figure 3, a 0.5 T dipole magnet is placed beside the set up. The magnetic center of one PMQ is measured with and without the dipole magnet beside. As shown in Figure 4, the difference between the results are smaller than 10 μm.

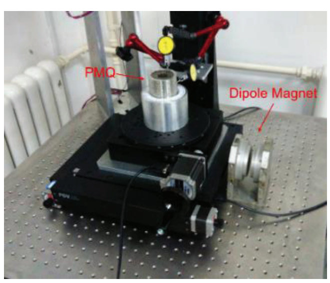

Figure 3: Experiments on the influence of background magnetic field.

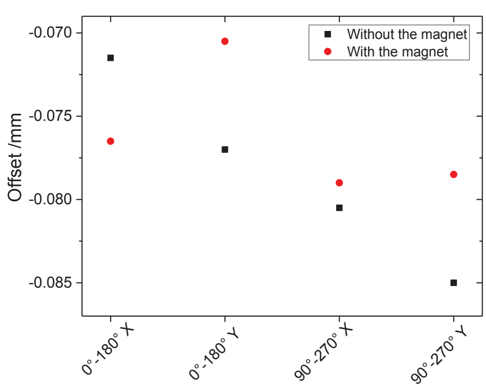

Figure 4: Results compared for different direction measrements.

Magnetic Center

60 PMQs have been measured by the vibrating wire and the rotating coil respectively. The results are shown in Figure 5 and Figure 6.

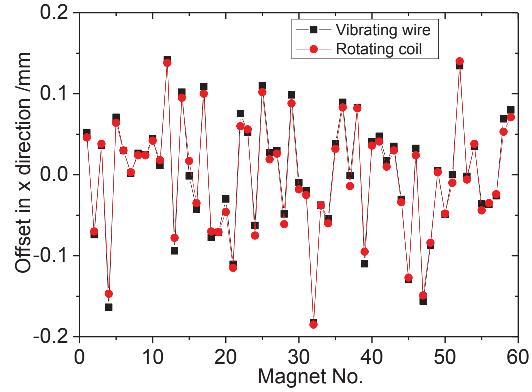

Figure 5: The measured magnetic center in x direction compared with the rotating coil.

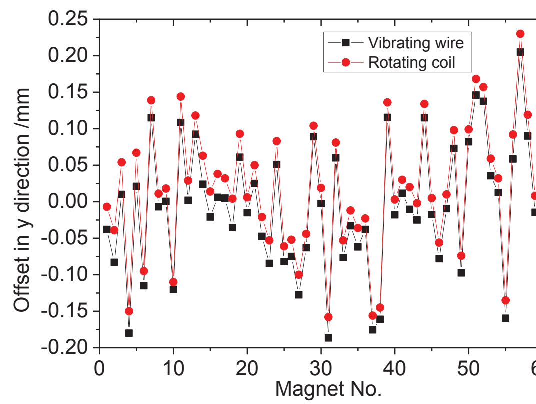

Figure 6: The measured magnetic center in y direction compared with the rotating coil.

The offset in y direction measured by the rotating coil is 30 μm larger than the one measured by the vibrating wire. Further study shows the uniform error is the systematic error of the rotating coil. The standard deviation of the differences between the two methods is about 8 μm both in x and y directions.

The setup works well in measuring the magnetic center. Next, we will machine the cylindrical surface of the PMQ holder to make the mechanical center coincides with the magnetic center.

Multipole Contents

This setup is designed mainly for measuring the magnetic center. Some measurements of the multipoles compared with the rotating coil has been carried out. As shown in Figure 7, the PMQ to be measured is rotated step by step. After each rotation, the amplitude of the vibration signal is recorded. The amplitude of the vibration is proportion to the magnetic field [2].

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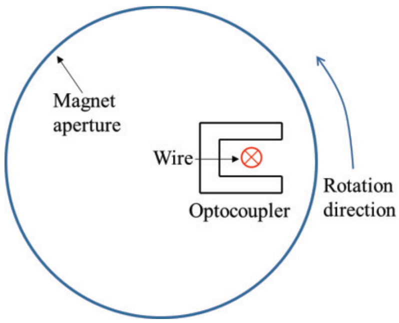

Figure 7: The schematic diagram of the measurement procedure in top view.

In cylindrical coordinate system, the magnetic field is in the following form

$$B_\theta = \sum_{n=1}^{\infty} B_n \left(\frac{r}{a}\right)^{n-1} \cos(n\theta - \alpha_n)$$

$$B_r = \sum_{n=1}^{\infty} B_n \left(\frac{r}{a}\right)^{n-1} \sin(n\theta - \alpha_n)$$

The optocoupler in Figure 7 measures the radial vibration, which corresponds to B_θ . Another perpendicular optocoupler measures the vibration due to B_r . The signal is recorded by the oscilloscope. Then the signal is processed via the Fourier transformation to extract the amplitude of the vibration at the driving frequency. Thus the noise signal is removed. The measured amplitude along the 8 mm-radius circle is shown in Figure 8. Note the amplitude of the vibration is always positive while the magnetic field has different directions. The magnetic field is shown in Figure 9.

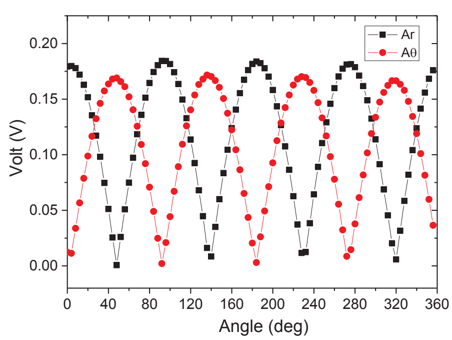

Figure 8: The vibration amplitude measured by the two optocouplers.

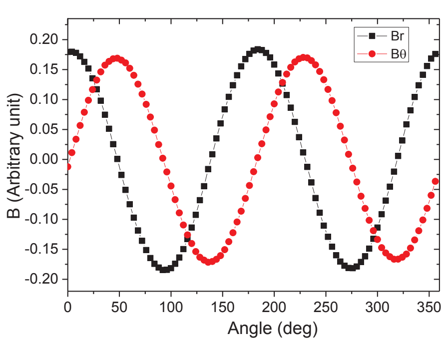

Figure 9: The magnetic field in different angle.

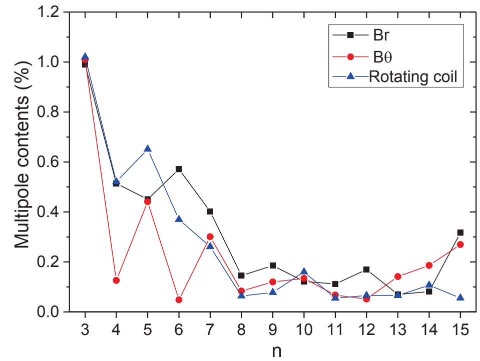

Figure 10: The multipole contents measured by the two optocouplers and the rotating coil respectively.

The measurement results are shown in Figure 10. The multipole contents calculated separately on the data set of B_r and B_θ should be the same. The difference between them may be due to the error of the optocouplers. The output voltage is not exactly proportion to the wire displacement in the working region.

CONCLUSIONS

Experiments on the vibrating wire setup confirm the method for measuring the magnetic center is robust against the background magnetic field. All PMQs have been measured by the setup and rotating coil respectively. The results show the setup works well in measuring the magnetic center of the PMQs. First attempt to measure the multipole contents by this setup has been made.

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