INVESTIGATION OF QUADRUPOLE MAGNETS FOR THE XFEL PROJECT USING A ROTATING COIL SETUP

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Abstract

A rotating coil system has been set up at the Manne Siegbahn Laboratory to characterize the magnetic field of quadrupole magnets in the XFEL undulators. The system measures the relative position of the magnetic axis better than 1 μm and can be used to study the movement of the magnetic center caused by magnet excitation and temperature changes. The rotating coil system is presented together with results from measuremets of prototype magnets made from soft magnetic materials.

INTRODUCTION

The XFEL undulators are divided into 5 m long segments. After each segment there is a quadrupole magnet to focus the electron beam. It is necessary for the center of all quadrupole magnets to be aligned along a straight line with accuracy better than 2 μm. This can only be achieved with beam based alignment (BBA). For BBA to work, it is essential that changes of field strength do not significantly change the position of the magnetic centre of the quadrupole. Also, temperature stability of the position of the magnetic center is important. To investigate magnet excitation effects and sensitivity to temperature changes, a rotating coil system has been setup at the Manne Siegbahn Laboratory. This instrument can measure the stability of the magnetic centre with accuracy better than 1 μm. It is also planned to be used in combination with a coordinate measuring machine to measure the absolute distance from the magnetic center to reference marks on the magnet. The reference marks will be used for initial alignment of the quadrupole magnets in the XFEL undulators before the beam based alignment procedure takes place. In this paper the rotating coil instrument is described and results from measurements of prototype quadrupole magnets are presented. DESY has made four prototype magnets, each one made of different soft magnetic material. These materials have properties such as low remanence and hysteresis, symmetric fields and should give magnets with good center stability. Measurements of two prototypes are presented here and compared with a magnet made of steel 10 used for FLASH.

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ROTATING COIL SETUP

The rotating coil setup is shown in figure 1. Two coils are inserted side by side into a slit in a 12 mm diameter epoxy G-10 rod (see figure 2). Each coil consists of 60 turns of 100 μm copper wire wound on a 170 mm long and 6 mm wide piece of epoxy. The epoxy rod extends from one end of a 20 mm diameter steel rod supported by ball-bearings. The steel rod is rotated with a frequency of approximately 1 Hz using a stepper motor situated next to the rod. An incremental angular encoder monitors the position of the rod. The coils are connected to a preamplifier via a mercury wetted slip ring and the amplified signal is monitored with a data acquisition card in a computer.

The induced voltage can be represented by a Fourier series and for a quadrupole magnet the distance r from the axis of rotation to the magnetic axis is directly proportional to the ratio of the dipole and quadruple components,

$$r = R\frac{V_{dipole}}{V_{quadrupole}}, \tag{1}$$

where R is the width of the coils. Figure 3 shows a typical Fourier spectrum and the ratio between the dipole component ($n = 1$) and the quadrupole component ($n = 2$) is 0.05 and the distance from to the magnetic center is 300 μm. Higher order field components are also seen above the background level. In a four-fold symmetry $n = 6, 10, 14...$ are possible. The magnetic center measurement is influenced not only by mechanical vibrations and electrical noise, but also on temperature changes. The temperature of the laboratory is controlled and kept within $\pm 0.1°$C, but the temperature of the cooling water can change within $\pm 0.5°$C. The stability of the system under these temperature conditions has been measured for the FLASH magnet and has shown that the magnetic axis x- and y-positions both moved approximately ± 1 μm during a 12 hours long measurement [1].

PROTOTYPE QUADRUPOLE MAGNETS

The magnetic center for all quadrupoles in a XFEL undulator must be closer than ± 2 μm to a straight line and it will be done with beam based alignment (BBA). For BBA to work the magnetic axis must not move more than ± 5 μm when the magnet current is changed by 10% [2]. To investigate the influence of the magnetic material four protype magnets were made with similar design to the one which is used in the FLASH accelerator. They are 80 mm long and the bore radius is 7.5 mm. Two of these magnets were sent to MSL to be evaluated with the rotating coil setup.

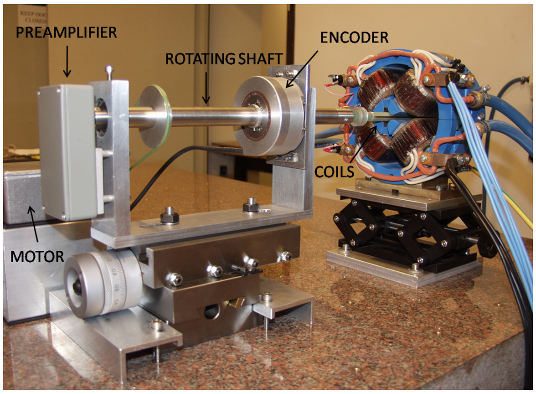

Figure 1: Rotating coil setup.

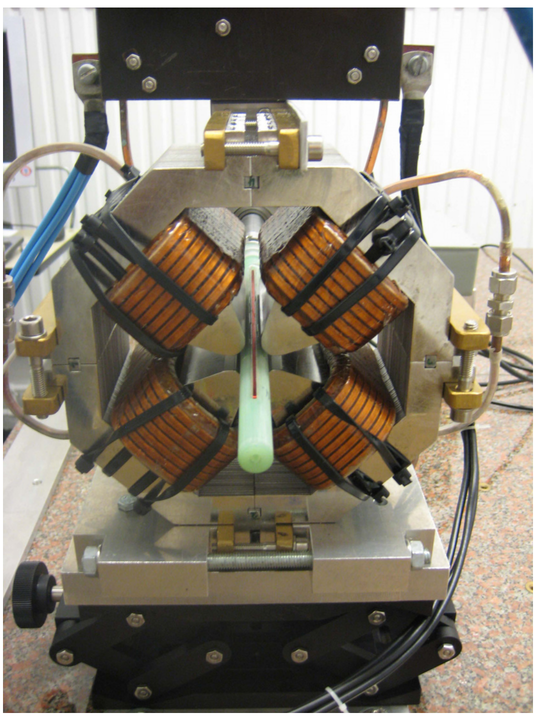

Figure 2: Coil inserted in a quadrupole magnet.

Both magnets have laminated cores and are made of soft magnetic material, Permenorm and Vacofer, respectively. Permenorm is a nickel-iron alloy and Vacofer is made from pure iron. Soft magnetic materials have low remanence field and hysteresis and magnets made of these material should have good magnetic center stability.

The effect of magnet excitation on magnetic axis stability was tested in a series of measurements where the current was ramped up and down between 5 and 75 A in steps of 10 A and starting at 25 A. Two complete cycles were performed. Figure 4 shows the measurement on the Permenorm magnet. The x and y positions are normalized so the first data point is at the origin. This simplifies comparison between the different magnets. Each measurement was done only a few seconds after the current was changed. The same series of measurements was done with the coil

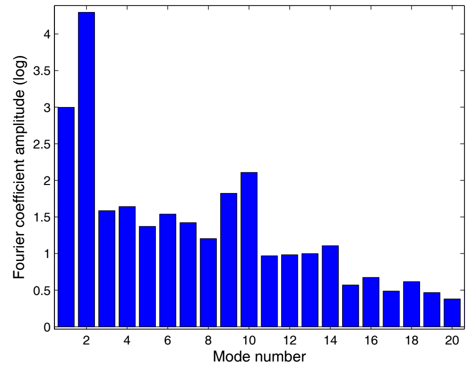

Figure 3: Fourier coefficient spectrum measuered with the rotating coil setup.

inserted into the magnet made of Vacofer and the results are shown in figure 5. For both Permenorm and Vacofer the magnetic center does not move more than a few micrometers between 15 and 75 A. This can be compared with measurements of a quadrupole magnet type made for the FLASH undulator. The magnet geometry is similar to the Permenorm and Vacofer magnets, the bore radius is the same, but the magnetic length is 120 mm compared with 80 mm for the other two. Previous measurements of this magnet showed a distorted voltage signal from the rotating coils at currents above 45 A. It resulted in an incorrect calculation of the position of the magnetic axis (figure 9 in reference [1]). This problem has been rectified and it is now possible to do measurement up to 75 A. Results in figure 6 shows a greater change in magnetic center compared with the Vacofer and Permenorm magnets. These soft magnetic materials may be the reason for the better magnetic axis stability but an improved mechanical construction may also contribute.

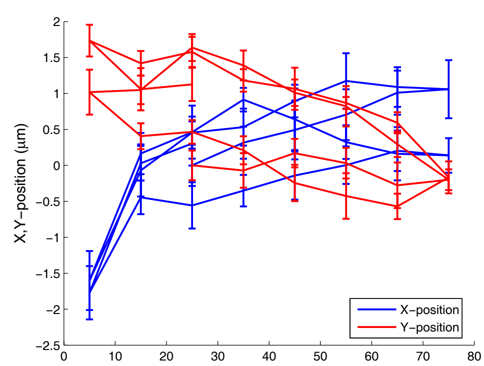

Figure 4: Change in position of magnetic axis for Permenorm magnet when coil current was ramped.

Figure 7 shows the results from a series of measurements where each measurement was done 5 minutes after the new current was set. This procedure influences the magnetic

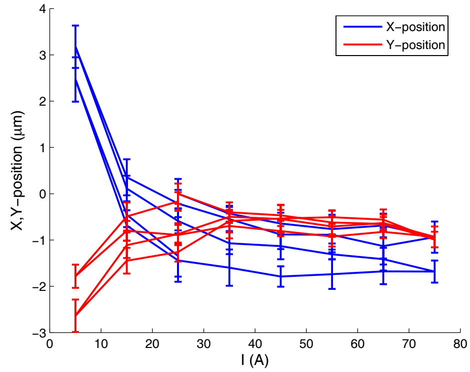

Figure 5: Change in position of magnetic axis for Vacofer magnet when coil current was ramped.

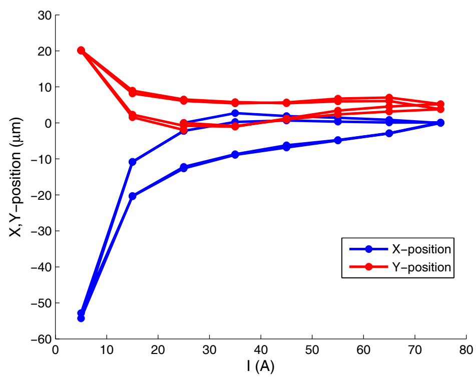

Figure 6: Change in position of magnetic axis for the FLASH magnet when coil current was ramped.

center along the y-axis. It can be explained by a larger temperature change during the measurements since the magnet is heated for a longer time. A change in the y-center position when the temperature of a quadrupole magnet is changed has also been measured by Spencer *et. al.* [3] and their explanation was that the change in y-coordinate was due to the steel changing height. This is something that will be further studied.

SUMMARY

A rotating coil setup recently built at the Manne Siegbahn Laboratory was used to evaluate the magnetic center stability of prototype XFEL quadrupole magnets. The prototype quadrupole magnets made of soft magnetic materials (Permenorm and Vacofer) show better magnetic center stability during current scan between 5 and 75 A than the FLASH magnet made of steel 10. The permenorm magnet show slightly better magnetic center stability in the x-direction than the Vacofer magnet. However, for both these magnets the magnetic axis position changes by less than 5 μm, which is within the requirements for BBA. The next step will be to study in detail how the magnet temperature

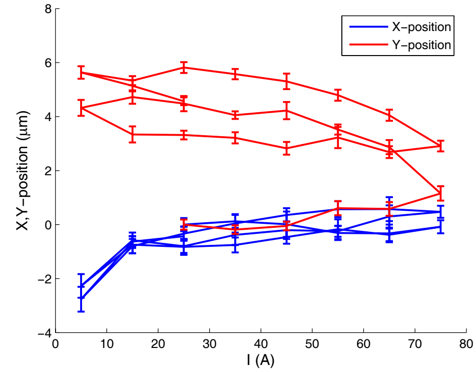

Figure 7: Change in position of magnetic axis for the Permenorm magnet when coil current was ramped. Each measurement was done 5 minutes after the new current was set.

influence the magnetic center position for the XFEL prototype magnets.

REFERENCES

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