Precise Transfer Measurement of the Magnetic Axis to outside Monuments

Y. Holler, B. Krause, A. Petrov, J. Prenting, M. Schloesser
Deutsches Elektronen-Synchrotron DESY

***Abstract*— The paper describes a new, precise method for the transfer of the magnetic quadrupole axis to the outside survey monuments. The magnetic axis is determined by the rotating coil method. The transversal coil position is shifted until the measured dipole component is at a minimum. Two optical targets are placed directly onto the coil ends. While the coil rotates slowly these targets perform a circular motion. The centers of these circles define the rotating axis of the coil in a very precise way. This axis is then transferred to several outside monuments using two laser trackers.**

***Index Terms*—laser tracker alignment, quadrupole magnet, rotating coil method.**

I. Introduction

AT DESY the PETRA II machine is in the process of reconstruction into the third generation synchrotron light source PETRA III [1]. One eighth of the machine circumference is completely redesigned to produce proper synchrotron radiation for the external user beam lines. The beam guiding elements and diagnostic parts are mounted on 34 girders. On each girder three magnets are located. The position accuracy of the quadrupole magnetic axis with respect to the beam trajectory must be within 100 µm (± 50 µm on average). The quadrupole magnets (Fig. 1) are of the "eight" type [2] with lengths of 0.44 m and 0.72 m and apertures of 70 mm in diameter. The integral field nonlinearity in the good field region (r < 25 mm) is better than $5 \cdot 10^{-4}$.The magnets are in detail described in [3].

All the magnets, 17 dipole magnets, 68 short (PQK) and 17 long (PQL) quadrupole magnets were fabricated at the Efremov Institute in St. Petersburg and delivered to DESY. Before these magnets will be installed on the girders the magnetic length and the multipole spectrum at several current values are measured with the rotating coil method.

After the rotating coil is centered to the magnetic axis of the quadrupole magnet two laser trackers measure its position which is transferred to the outside monuments on the magnet.

All the measurements are performed in an air-conditioned test lab. The temperature is stabilized to 21 ± 0.5 ^{0}C as intended in the PETRA III tunnel.

Manuscript received August, 27, 2007.

Y. Holler, B. Krause, A. Petrov, J. Prenting, M. Schloesser are with the Deutsches Elektronen-Synchrotron, Hamburg, Germany (+49-40-8998-2873; fax: +49-40-8998-3438; e-mail: bernward.krause@desy.de).

Fig. 1. The long quadrupole magnet PQL

II. Magnetic Measurement rig

In order to check the magnetic measurements done with Hall probes by the manufacturer a rotating coil system was used to determine the (gradient) field integral, the harmonics and the position of the magnetic axis. This coil has four separate windings and was manufactured by Danfysik [4]. The body of the coil consists of a glass-fiber reinforced epoxy tube with dimensions of 1580 mm x 66 mm outer diameter.

The radii and number of turns of the primary and the compensating winding (Fig. 2) are chosen in such a way that the dipole as well as the quadrupole component of the field will be suppressed when the coil is used in the bucking mode. Two additional windings each spanning half the length of the coil provide the precise centering of the coil in the magnet (see III.).

The coil is carried and positioned by remote-controlled cross tables [5] at both ends with resolutions of 2.5 µm in horizontal as well as in vertical direction. It is driven by a stepping motor [6] with a rotational speed of 1 Hz. The induced voltages are fed via a slip-ring transducer and a DC coupled precision amplifier into a Multifunction Data Acquisition Card [7]. A LabVIEW program [7] controls the hardware, analyzes, displays and stores the results.

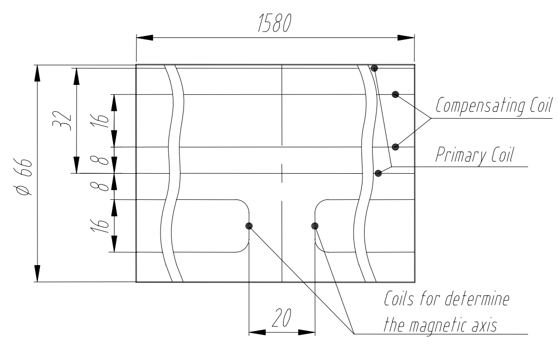

Fig. 2: Sketch of the four windings of the rotating coil.

III. LOCATING THE MAGNETIC AXIS

A deviation of the coil axis from the magnetic axis of the quadrupole causes a spurious dipole component in the multipole spectrum. This corresponds to the kick that the particle beam experiences when it travels off axis through a quadrupole. The sine and cosine components of this dipole term in the Fourier spectrum provide the position offset.

The centering of the coil with the cross tables consists of a calibration procedure and the correction of the initial misalignment. In the beginning the coil is moved in four separate steps with intentionally added offsets of 0.5 mm in horizontal and vertical direction The changes in the output signals yield 8 calibration factors (unit: V/mm). Finally the dipole components and thus the spatial offsets are eliminated by moving the coil in the opposite direction. Within three to four iterations of measurements and subsequent corrections the remaining offsets of the coil axis can be reduced to less than 2 µm. For this procedure both half windings have to be evaluated because otherwise a centered but tilted orientation of the coil would result.

The comparatively long and slender outline of the coil entails a sag of about 200 µm and necessitates an according correction of the vertical position of the axis. A future coil, now in preparation will be reduced to a length of about 1 m and made of CRP (carbon fibre reinforced plastic). These coil measures will minimize the sag to about 1/10.

IV. SURVEY OF THE MAGNETIC AXIS

For fiducialization of these quadrupoles in an easy and efficient way two laser trackers [8] are used simultaneously. It is essential that both laser trackers operate in a common coordinate system. Both trackers are measuring 20 grid points (GP) which are fixed to the floor and to the walls. The magnet is equipped with 12 (four on each side and on top) reference supports (RP). Both ends of the rotating coil carry a support for a survey target (Fig. 3).

To determine the tilt of the magnet, a special survey target is placed in four boreholes in the front and the back face of the quadrupole. From these eight points it is possible to calculate four independent values of the tilt of the magnet. If these tilt values match within a certain tolerance the mean value is calculated.

Afterwards the optical targets which are placed on both ends of the coil are measured with both laser trackers while the coil rotates slowly. That results in two independent half circles at each end of the coil. The center of each half circle is then calculated. The two centers at each end of the coil are averaged if they meet within a certain tolerance. The resulting two center points define the axis of the rotating coil within an accuracy of 5 µm.

This axis intersects the front and the back plane of the magnet. The midpoint between these two is forming the origin of the magnet coordinate system. The X-Axis is represented by the intersection point at the back side of the magnet. The direction of the Y-Axis is determined by the tilt of the magnet. The Z-Axis is perpendicular to the other two.

For the fiducialization of the magnet the 12 reference points (RP) are then measured in this magnet coordinate system. All the measurements are done twice to improve the reliability and accuracy.

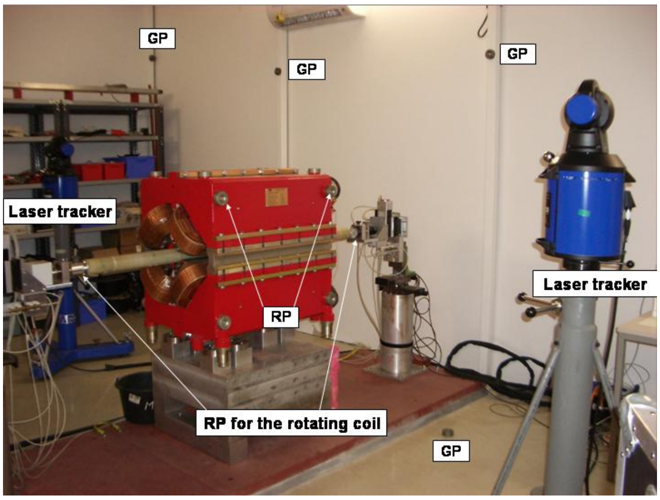

Fig. 3: Experimental set-up for the determination and surveying of the magnetic axis of the quadrupole magnet.

V. VERIFICATION OF THE SYSTEM

According to the magnetic specifications and the magnetic measurements we can expect that the magnetic axis differs from the geometric axis by less than 40 µm. To verify this the rotating coil with its two survey targets was replaced by two mechanical fixtures that sit very precisely in the bore hole on both sides of the magnet. In the center of these fixtures is a support for the survey target (Fig. 4). For the survey the same grid and reference points were used in which the magnetic axis was determined. The connecting line of the measured targets on the mechanical fixtures is defined as the geometrical axis of the magnet. The comparison of the analyses of the geometric and magnetic axis surveys shows that the offset of theses axes is in the order of 20 µm. The accuracy of the laser tracker alignment for this survey grid is in the order of 10 µm.

Important in the determination of the magnetic axis is the reproducibility of the measurements. After the survey of the rotating coil it was taken out of the quadrupole magnet and the magnet kept in its position on the measuring stand. Later the rotating coil was reinserted and the magnetic axis determined once more with the two half length windings. The comparison of the two survey measurements differs in the horizontal and vertical direction by less than 10 µm which is again in the range of the measuring precision.

Fig. 4: Inserted mechanical fixture for surveying the geometrical axis of the quadrupole magnet. The fixture is made from brass.

VI. Conclusion

A new precise method for determining the magnetic axis of a quadrupole magnet was introduced. Plausibility and reproducibility checks have shown that the individual magnetic quadrupole axis could be transferred to the outside survey monuments with an accuracy of $\sigma < 21$ µm. The later magnet alignment on the girder (magnetic axis to magnetic axis) has to be in the range of $\sigma < 50$ µm which is achievable with our girder design based on simple and cost-efficient adjustment elements for the magnets.

References

[1] The Technical Design Report (TDR) "PETRA III: A low Emitance Synchrotron Radiation Source" (DESY 2004-035).

[2] G. T. Danby, J. W. Jackson, ”Theory, design and measurement of the Brookhaven narrow quadrupoles”, US National Part. Accel. Conf., Washington, “*IEEE Transact. On Nucl. Sience”,* vol. NS-14, num.3, pp. 414–419, june 1967.

[3] E. Bondarchuk et al. “Magnets for the PETRA-III Project”, *IEEE Trans. Appl. Supercond.*, vol. 16, no. 2, pp. 220-223, June 2006.

[4] Danfysik A/S, Mollehaven 31, DK-4040 Jyllinge, Denmark.

[5] LINOS Photonics GmbH & Co.KG, Königsallee 23, 37081 Göttingen, Germany.

[6] Phytron Elektronik GmbH, Industriestr. 12, 82194 Gröbenzell, Germany.

[7] National Instruments Corporate Headquarters, 11500 N Mopac Expwy, Austin, TX 78759-3504.

[8] FARO Technologies Inc., 125 Technology Park, Lake Mary, FL 32746.