PRECISE MAGNETIC MEASUREMENTS OF THE SLS STORAGE RING MULTIPOLES: MEASURING SYSTEM AND RESULTS

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Abstract

The 306 quadrupoles and sextupoles for the Swiss Light Source with severe requirements were manufactured, and magnetically measured at BINP and, after delivery, also at PSI. The Rotating Coil Systems for precise magnetic measurements is described, and the main results of the magnetic measurements for the series magnets are presented.

1 INTRODUCTION

The high brightness Swiss Light Source (SLS), a specialized synchrotron radiation source was recently built at the Paul Scherrer Institute (PSI) in Switzerland ([1] – [3]). The consequence of these leads to very demanding requirements on the manufacturing accuracy, and alignment of the magnetic elements along the ideal beam axis, which is defined with respect to horizontal and vertical reference surfaces on the girders.

Table 1. Requirements on SLS multipoles at 120 A.

Parameter	Quadrupoles	Sextupoles
Magnetic strength	20 T/m	640 T/m^2
Horizontal position	± 30 μm	± 30 μm
Vertical position	± 30 μm	± 30 μm
Roll angle	± 0.35 mrad (0.02°)	± 0.35 mrad (0.02°)
$\sigma_{(\Delta B/B)}$at R=28mm	$2.5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$

The high precision 306 multipoles of 8 types: narrow and wide quadrupoles of 200mm (QA, QAW), 320mm (QB, QBW) and 440 mm (QC, QCW) length, and 200 mm (SR, SRW) narrow and wide sextupoles, were manufactured by BINP. Requirements on SLS multipoles are shown in Table 1.

The 5-7 multipoles are accurately aligned along the ideal beam axis and fixed in vertical and horizontal planes on the 48 girders of the SLS Storage Ring, which differ in length, type, and number of installed elements.

2 THE MEASURING SYSTEM

To perform the magnetic measurements on the SLS multipoles BINP designed and built the Rotating Coil System (RCS) and a special multipole measuring bench [4]. The position of the magnetic axis and the roll angle relatively to RCS reference surfaces and the harmonic coefficients were measured with high accuracy. Table 2 presents the RCS main parameters.

The rotating windings were calibrated with a prototype multipole; its magnetic field map was measured with a set of 11 Hall probes at different excitation currents. The magnetization curve, and the magnetic strength of the series magnets were also measured using the same Hall probes, located for this measurement in the centre of the multipole.

Table 2. Rotating Coil System performance

Parameter	Reprodu-cibility	Error	Sensi-tivity
Harmonic coefficients	$\pm 0.5 \cdot 10^{-4}$	$\pm 0.5 \cdot 10^{-4}$	$0.3 \cdot 10^{-4}$ – quads $0.5 \cdot 10^{-4}$ – sexts
Axis position, μm	± 2	± 10	1
Roll angle, mrad	0.05	± 0.35	0.03

As shown in Fig.1, two concrete blocks (2) are rigidly fixed to the large concrete base block (1). Between the two concrete blocks, is the girder (3) installed on four spherical supports (12). The measured production accuracy of the girder reference surfaces was within 5 μm. The supports (4) for the rotating unit were mounted on the two concrete blocks (2), on both sides of the girder. The position of these supports (4) can be adjusted, vertically ±4 mm, and horizontally ± 5 mm, to match the rotational axis of the unit with the ideal one.

The compact, cylinder-like measuring unit of length L and of radius R contains four radial windings. Two rollers (7) support it from both its ends.

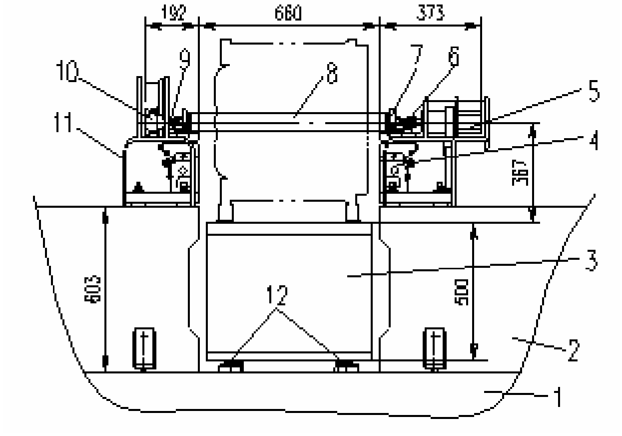

Fig.1.General view of the RCS.

When measuring the unit was inserted into the magnet aperture and rotated around its axis to integrate the voltages induced in the windings. The connecting couplings (6, and 9) transmit the circular motion from the step motor (5) to the measuring unit (8), and further to the angular encoder (10), they also damp the transversal mechanical vibrations.

The horizontal axial orientation of the measuring unit was made with respect to two vertical reference surfaces on the girder, using a spirit level fitted to the unit reference surfaces. The angle between the plane defined by the spirit level and the electrical plane of the windings is repeatedly checked.

Two of four rectangular, independent windings are $L/2$ long windings with a width equals to R and located along the unit seriously, and two other windings have the same length with only $R/2$ width and inserted in R-width windings. Connecting the full and half radius windings by the subtracting scheme, one can eliminate the contribution of the main harmonics in the resulting signal, thereby increasing the measuring accuracy for the higher harmonics. The signals of any half-length windings of the equal width are used for measuring the yaw and angles of the multipole's axis.

The measuring unit is rotated with a step motor and the angle is measured with a angular encoder. An 8-channel ADC picks up the signals of the four windings. A multiplexing amplifier produces the compensated signal, i.e. the combination (sum and/or difference) of the measured signals, which does not contain the contribution of the main harmonic (for quadrupoles n_{main} = 2, and for sextupoles n_{main} = 3). The compensated signal consisted of the higher harmonic contributions and the main harmonic signal are simultaneously recorded, and subsequently integrated numerically.

The computer control program sets the multipole current, the combination of the measured signals, and the parameters of the rotation. The program reads the compensated and main signals, the angular position of the unit and records it as a digitized voltage. After the measurement the program is used to analyze the data: to calculate the harmonic coefficients of the magnetic field, the position of the magnetic axis, and roll angle of the multipole.

In the described system the measuring unit with windings was rotated with angle steps of about 5º. The measurement procedure was made on each step, total circle measuring time was ~ 80 seconds. Such fragmentation of rotation allows us to obtain the 1-27 harmonics without considerable losses of accuracy.

3 THE MAGNETIC MEASUREMENT RESULTS

The resulting harmonic coefficients (A_n, B_n) were calculated by using the Fast Fourier Transform method (FFT) to expand the angle dependent function at the normalization radius of R_{norm} =28 mm. The low-order harmonic coefficients give the offset of the n-multipole axis from the unit rotation axis. The vertical position of the magnet axis includes a temperature contribution. The roll angle was also calculated from the main harmonics. The accuracy of the magnetic measurements are influenced by the mechanical accuracy of the equipment, the alignment of the element on the RCS, and by the time dependent processes occurring during the measurement.

The results of the measurement show good agreement of the multipole parameters with the requirements. Table 3 presents the average values and standard deviations for the positions of the magnet axis (<x>, <y>, σ) and the roll angles (φ) for multipoles. The results of the magnetic measurements at BINP and SLS have the good coincidence. Table 4 lists BINP`s statistical data of main harmonic coefficients of some SLS multipoles, normalized on the fundamental harmonic values and multiplied by 1000 (at 120 A of excitation current). Fig.2 presents the most important harmonic coefficients of QB40 lens and shows the good quality of produced quadrupole. Fig.3 shows a relationship of the octupole magnetic harmonics and the mechanical gaps between shims of the QA quadrupoles neighbour poles.

Table 3. Average axis positions, roll angles and deviations.

Type of multipole (number of magnets)	Effective length, cm	$\langle x\rangle \pm \sigma_x$, μm BINP (SLS)	$\langle y\rangle \pm \sigma_y$, μm BINP (SLS)	$\langle \varphi\rangle \pm \sigma_\varphi$, mrad BINP (SLS)
QA (43)	22.79	-1±16 (0±17)	8±13 (19±14)	0.13±0.16 (-0.01±0.16)
QAW (13)	22.77	-4±8 (-7±11)	6±12 (14±14)	-0.02±0.20 (0.02±0.17)
QB (54)	34.74	2±14 (2±14)	8±11 (13±12)	-0.02±0.17 (0.00±0.17)
QBW (13)	34.72	-3±11 (-4±17)	5±15 (5±18)	-0.02±0.21 (0.01±0.16)
QC (54)	46.7	-2±11 (1±12)	7±11 (14±12)	0.03±0.17 (0.08±0.15)
QCW (13)	46.68	-2±14 (0±12)	-2±14 (2±12)	-0.09±0.16 (0.03±0.13)
SR (84)	21.77	1±11 (3±12)	8±9 (18±11)	-0.02±0.19 (-0.07±0.26)
SRW (39)	21.74	0±9 (-1±15)	4±11 (8±11)	0.08±0.18 (-0.02±0.28)

Table 4. BINP`s statistical data of main harmonic coefficients (×1000) for some multipoles.

Quadrupole type	$\langle B_3\rangle$ $\pm\sigma_{B3}$	$\langle A_3\rangle$ $\pm\sigma_{A3}$	$\langle B_4\rangle$ $\pm\sigma_{B4}$	$\langle A_4\rangle$ $\pm\sigma_{A4}$	$\langle B_6\rangle$ $\pm\sigma_{B6}$	$\langle B_{10}\rangle$ $\pm\sigma_{B10}$
QA	-0.02 ± 0.28	-0.07 ± 0.29	0.01 ± 0.19	0.04 ± 0.14	0.18 ± 0.13	-0.62 ± 0.03
QCW	-0.04 ± 0.12	-0.12 ± 0.13	0.35 ± 0.16	0.00 ± 0.06	0.19 ± 0.04	-0.29 ± 0.03
Sextupole type	$\langle B_1\rangle$ $\pm\sigma_{B1}$	$\langle A_1\rangle$ $\pm\sigma_{A1}$	$\langle B_4\rangle$ $\pm\sigma_{B4}$	$\langle A_4\rangle$ $\pm\sigma_{A4}$	$\langle B_5\rangle$ $\pm\sigma_{B5}$	$\langle B_9\rangle$ $\pm\sigma_{B9}$
SR	-1.05 ±0.76	0.08 ±0.63	0.03 ±0.52	-0.38 ±0.49	0.17 ±0.35	-0.41 ±0.08
SRW	-1.12 ±0.83	0.07 ±1.18	0.03 ±0.44	-0.46 ±0.48	-0.52 ±0.36	-0.29 ±0.08

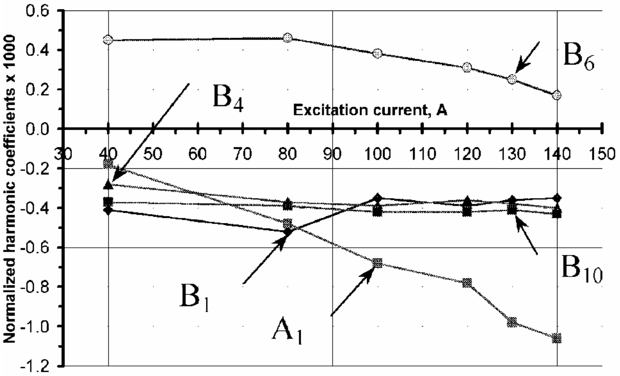

Fig.2. Some harmonic coefficients of QB40 quadrupole.

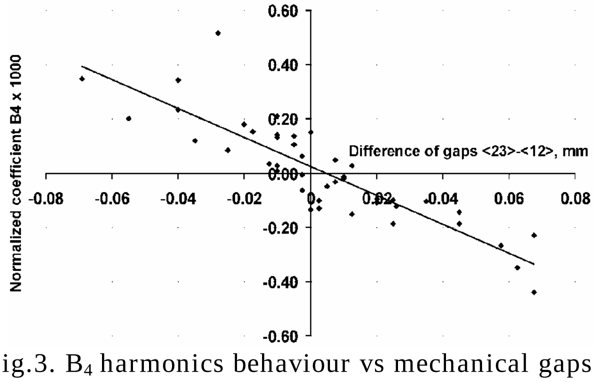

Fig.3. B_4 harmonics behaviour vs mechanical gaps between shims of the QA quadrupoles.

4 CONCLUSION

The precise magnetic measurements proved high mechanical accuracy of the SLS multipoles manufactured by BINP. Now the Swiss Light Source (SLS) is working with good parameters and stored current of 400 mA.

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