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MEASUREMENT OF MAGNETIC FIELD CENTER OF THE QUADRUPOLES AND SEXTUPOLES FOR THE SPRING-8 STORAGE RING

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abstract

The quadrupole and sextupole magnets for the SPring-8 storage ring were made the measurement of the magnetic field center with a rotating coil one by one to define the position of the fiducial points above the upper part of yokes. The measurement accuracy was estimated to be about 10 μm . This paper describes the measurement system, method and error estimation.

1. Introduction

The SPring-8 storage ring has a circumference of 1436 m with a Chasman-Green lattice of 48 unit cells and contains 88 dipole, 480 quadrupole and 336 sextupole magnets. Their mechanical design and fabrication was started in 1991 and finished all in this spring by Hitachi, Sumitomo Heavy Industries and Mitsubishi Electric Corp. Field Measurements have been made in the SPring-8 site for all of about nine hundreds magnets. It took nine months from September 1994 to June 1995 for the measurement of the quadrupoles and sextupoles. The magnetic lengths and multipole field strengths were measured for all magnets and the position of the magnetic field center also measured for the quadrupoles and sextupoles. A long flip coil was used for the measurement of the dipoles and a rotating coil for the quadrupoles and sextupoles.

Main parameters of the storage ring magnets is listed in table 1. They are normal ones with water cooled coils. Magnet yokes are made of laminated silicon steel of a thickness of 0.5 mm. Manufacturing accuracy was achieved within $\pm 40 \mu\text{m}$ in bore diameter and minimum gap for the quadrupoles and $\pm 50 \mu\text{m}$ for the sextupoles.

All magnets have two machined fiducial points for alignment at the upper part of the yokes in front and rear. Fig. 1. shows the fiducial points for the quadrupoles. The fiducial points consist of a plane with a hole. The fabrication accuracy of the fiducial plane is $\pm 0.04 \text{ mm}$ in the height from the magnet median plane and 0.04 mm in the degree of parallelization to the median plane. Since the horizontal position of the fiducial hole is changed with tilt of the magnet, position accuracy of the hole is dependent on the parallelization of the fiducial plane. The target position for alignment is in a height of 500 mm from the median plane and the position accuracy of the fiducial hole corresponds to $\pm 0.13 \text{ mm}$.

Five or seven of the quadrupoles and sextupoles are placed on one girder and aligned along a straight line. Alignment accuracy is required to be within $\pm 50 \mu\text{m}$ in a

TABLE I
MAIN PARAMETERS FOR THE SR MAGNETS

	Dipole B	Quadrupole Qa-Qf	Sextupole Sa-Sc
Number	88	480	336
Gap / Bore Diameter (mm)	64	85	92
Length (m)	2.8	0.35, 0.41, 0.51, 0.97	0.3, 0.45
B(T), B'(T/m), B''(T/m ²)	0.679	17.5	420
I (A)	1232	550	300

girder so that the manufacturing accuracy of the fiducial points of each magnet is not sufficient. Therefore, We had to measure the position of the fiducial points with more accuracy during the field measurement.

2. Measurement System and Method

A rotating coil system was used for the field measurement of the quadrupoles and sextupoles. Fig. 2. shows the side view of the measurement system. Two measurement probes were used and both have measuring coil windings in a cylinder made by FRP with a length of 1960 mm and a diameter of 80 mm. Fig. 3. shows cross-sectional views of the both probes. Probe A is used for the measurement of the main field component and probe B is a type of a bucking coil which cancels out the quadrupole component and used for the multipole fields of quadrupole magnets. The measurement cylinders are

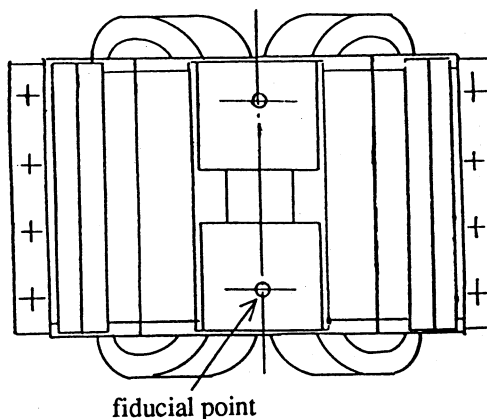


Fig. 1. A top view of the quadrupole magnet. Fiducial points are located on top of yokes, which consist of planes with a hole ($\phi 20$) parallel to the median plane.

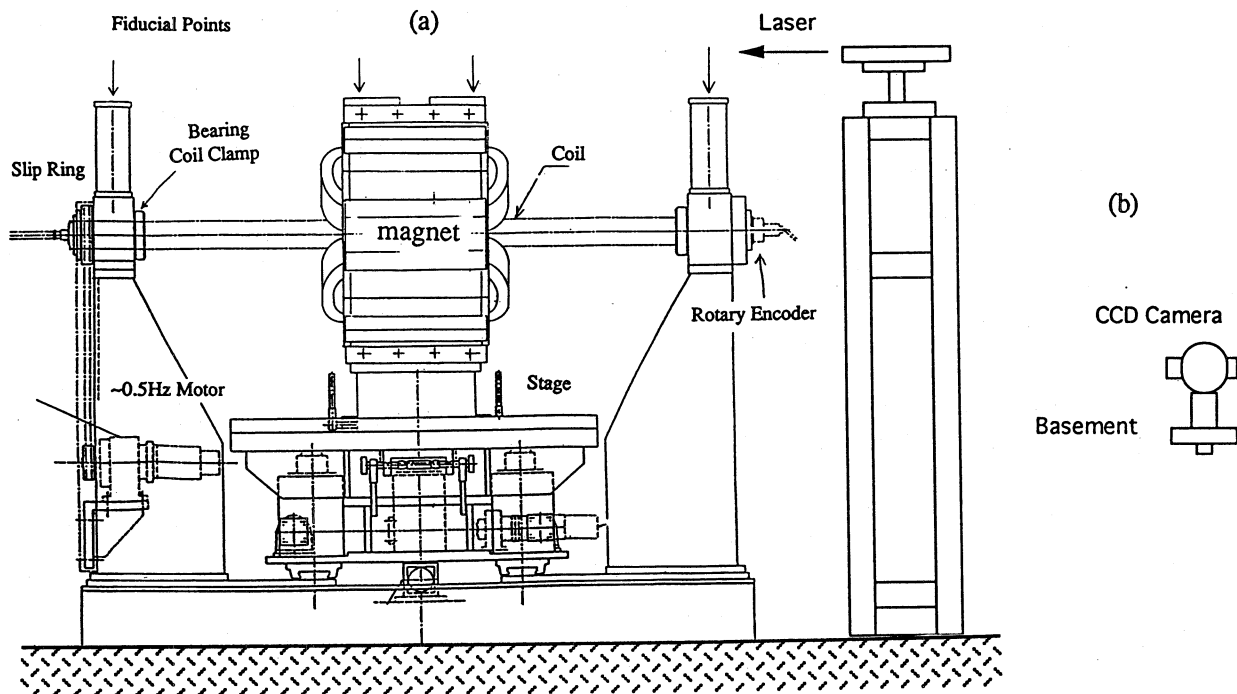


Fig. 2. (a) A side view of the rotating coil system. Four arrows indicate fiducial points. We place a CCD camera and basement (b) on each fiducial point and measure the position of the laser beam.

supported with bearings at the both sides and can be pulled out during the exchange of magnets or probes on left side in the figure. The coil is rotated at about 30 r.p.m. The output from the coil is integrated with a PDI 5025 (METROLAB) by a constant angle (ex. $2\pi/32$ rad.). The main and multipole components of the magnetic fields can be calculated by the Fourier transformation. The multipole components can be separated into normal and skew component against the direction of the main field.

In case of quadrupoles, a deviation between a rotating axis of the probe and a magnetic field center induces a dipole component in the output signal. The ratio of the both components is proportional to the deviation as the follow equations.

$$dx = \Phi_{1n} / \Phi_{2n} \times R / 2, \quad dy = \Phi_{1s} / \Phi_{2n} \times R / 2$$

Φ_1 and Φ_2 indicate the maximum flux of dipole and quadrupole fields which goes through the coil. Suffix n and s denotes normal and skew components. R means a reduce radius of the coils. In case that a quadrupole is measured with coil 1 of probe A, maximum flux is 0.24 Vs at maximum current level and output voltage is about ± 0.75 V. The resolution of the integrator is 4×10^{-6} Vs in five times amplification because a V-F converter of 500 kHz / 10 V is used for voltage integration. Consequently, the resolution of position measurement of the magnetic center corresponds to $0.2 \mu\text{m}$. Actually measurement stability was about $2 \mu\text{m}$ due to coil vibration and others.

The rotating coil measures an average field along

beam axis because measuring coils are longer than the magnets. In the measurement of the field center, only an average position is measured and the direction of magnet axis cannot be measured. However, the direction of magnet axis does not affect the beam if it is not very large.

The measurement procedure of the field center is following: First, a sample magnet is pre-aligned on the rotating coil system in about 0.1 mm. In the first measurement after the initialization process, the deviation of the field center from a rotating axis of the coil is measured. The stage where the magnet is located can be driven with motors with accuracy of several microns. Actually, the field center is made coincidence

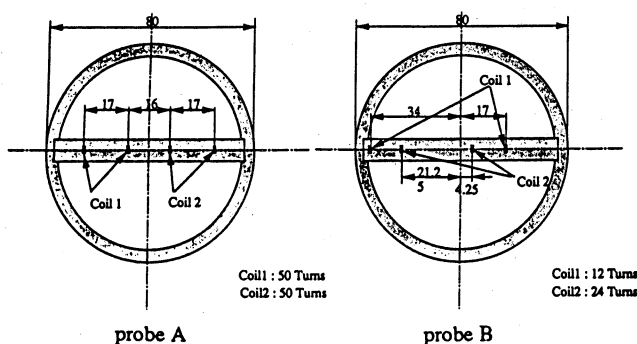


Fig. 3. Cross-sectional views of the rotating coil probes. Probe A is for the measurement of the main term and probe B for multipole fields.

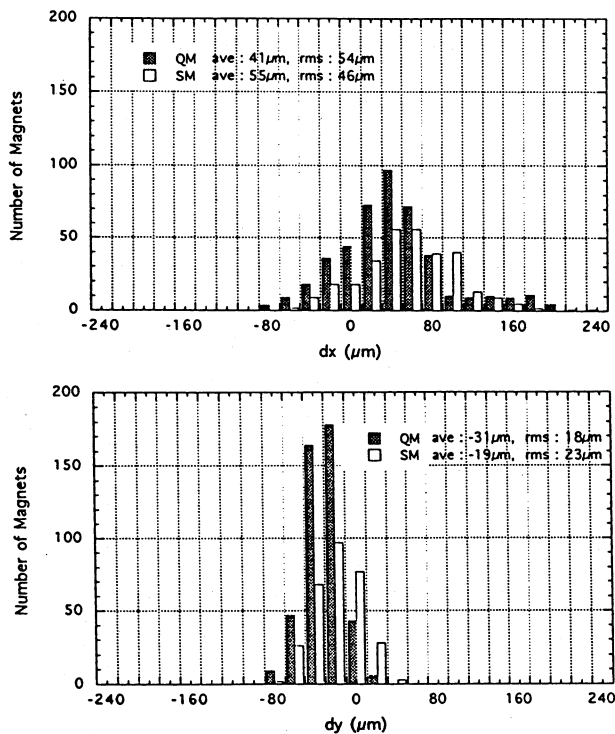


Fig. 4. Histogram of the position of the magnet fiducial points measured with the rotating coil system. Dx and dy indicate horizontal and vertical deviations.

with the rotating axis of the coil by moving the magnet with the stage. After that, the main term and multipole field strengths are measured in some current levels. Finally, the position of the fiducial points on top of the magnet is measured. The method is as follows.

The rotating coil system has two fiducial points just above the bearings on the both sides. A laser beam goes through above the four fiducial points and its positions are measured by locating the target with CCD camera on each fiducial point by turns. The accuracy of these position measurements is about five micron meters in the farthest point from the laser source because of the fluctuation of the laser beam. This system is also used for the magnet alignment in the ring and being reported in another paper of this meeting.

In addition, the tilt of the magnet has to be measured at the same time because the position of the laser beam is located in a height of 500 mm from the median plane of the magnet as already mentioned. The tilt is measured with an electrical level instrument TALYVEL (RANK-TAYLOR-HOBSON). The TALYVEL had to be located in the same position on the fiducial plane every time because the roughness of the surface was not very good. This positioning of the TALYVEL could obtain the reproducibility of 10~15 μ rad between the position measurements and magnet alignment.

3. Result and Analysis

Each quadrupole and sextupole was made the measurement of position of the fiducial points. Fig. 4.

TABLE II

ESTIMATIONS OF MEASUREMENT ERRORS OF THE MAGNETIC CENTER		
	x (μ m)	y (μ m)
Instability of coil rotation	2	2
Reproducibility of coil clamp	2	3
Position stability of the fiducial points	5	
Measurement of magnet tilt	3	
position measurement with the laser-camera system	6	6
Temperature effect		5
Total	9	9

shows the histogram of the measured position of the fiducial points. The fluctuation of the position deviations is within ± 140 μ m for horizontal direction and ± 50 μ m for vertical. This fluctuation indicates the fabrication error of the fiducial points though a measuring error of about 10 μ m is included as mentioned later and it is found that the magnitude is agreement with the specification of the fabrication accuracy. The reason why the averages do not equal to zero is that some kinds of offset exists in fabrication and measurement such as position error of the fiducial point of the rotating coil, coil sag and so on.

Now, it is important to estimate the accuracy of the measurement because all magnets are aligned in the ring according to each measured position of the fiducial points. Table 2 lists the estimation of the measurement errors of the field center. The magnitude of errors indicated in the table is about half of the maximum and may correspond to the standard deviation. The first, fourth and fifth error sources listed have been mentioned in a previous section. The second source means the reproducibility of the coil position in clamping on the bearings. This reproducibility was confirmed by measuring the field center with two probes for every magnet. The third means that a slight tilt of the bearing supports with the fiducial points is changed with time and the points are moved. Though the tilt of the supports was being monitored and the position of the fiducial points corrected, this order of error was remained. The sixth is the effect due to the temperature difference between the apparatus and the magnet generated by the change of the room temperature.

Total of these errors is estimated to be 9 μ m in the standard deviation for both horizontal and vertical directions.

4. Conclusion

Strong quadrupole and sextupole magnets are used in an electron storage ring with low emittance beams and beam dynamics are very sensitive to their alignment. Accordingly, the alignment accuracy of 50 μ m is required to the SPring-8 storage ring. This value is comparable to the dimensional accuracy of usually fabricated magnets and it is impossible to make fiducial points mechanically with more accuracy. Therefore, it is significant and essential to position the fiducial points by measuring the magnetic field center.