DESIGN OF MAGNETS FOR THE 8 GEV STORAGE RING

S.Motonaga, J.Ohnishi, and H.Takebe
RIKEN-JAERI SPring-8 Project Team
Honkomagome 2-28-2, Bunkyouku, Tokyo, 113 Japan

Abstract

Design of dipole, quadrupole, and sextupole magnets of the 8 GeV storage ring has been finished. Their full scale prototypes were fabricated to verify the design. Field measurement is in progress. The designs for these magnets are reviewed, and comparisons between the design and measurement are presented.

Introduction

Storage ring of SPring-8 (8 GeV Super Photon ring) is being designed at RIKEN to be a highly-brilliant synchrotron radiation source. The ring has 48 cells and the circumference is 1436m[1], There are four symmetirically lacated long straight sections of 34m and 44 short straight sections of 6.5m in the ring.

The unit cell of the storage ring is of so-called Chasmann-Green type and composed of 2 dipole, 10 quadrupole, and 7 sextupole magnets as shown in Fig.1.

The long straight section is realized by excluding eight bending magnets from the four unit cells located in the long straight sections. The other magnets in the four cells are remained there in early stages of operation. Then total numbers of dipole, quadrupole, and sextupole magnets are 88, 480, and 336, respectively. For COD (closed-orbit distortion) correction, dipole and sextupole magnets have extra correction coils which can produce additional vertical or horizontal correction fields. In addition to these, 192 individual steering magnets are installed, 96 of them for horizontal correction, and the others for vertical and horizontal correction. Four bump and septum magnets are also installed for beam injection.

The field quality required for the dipole, quadrupole, and sextupole magnets is given in Table 1.

These requirements are very tight. In order to design these magnet, we carried out numerical calculation of magnetic field by using 2-D program codes LINDA. Parameters designed for them are listed in Table 2.

All magnets are made by laminating 0.5mm thick silicon steel plates to guarantee the field of all magnets as identical as possible. The silicon steel plates are stacked and under compression by welded exterior surfaces extending between SUS-316 end plates. Tight tolerance limits are imposed on both core material and fabrication.

Prototypes of dipole, quadrupole, and sextupole magnets were delivered to our site. Filed measurement of them is now under going. Design of the power supply system is under way. Prototypes of septum magnet is being fabricated at factories together with its power supplies. Detailed design of bump magnet is also in progress.

Table 1. Required field quality of the dipole, quadrupole, and sextupole magnets.

Magnet	Dipole	Quadrupole	Sextupole
Maximum field strength	0.665 T	17 T/m	360 T/m^2
Gap distance or bore diameter	65 mm	85 mm	100 mm
Effective field length	2.863 m	0.45, 0.5, 0.55, 1.1 m	0.4, 0.53 m
Field uniformity	$\Delta B/B$	$\Delta G/G$	$\Delta G/G$
	$<5 \times 10^{-4}$	$<5 \times 10^{-4}$	$<1 \times 10^{-3}$
	H:±40 mm	H:±35 mm	H:±35 mm
	V:±17 mm	V:±15 mm	V:±15 mm

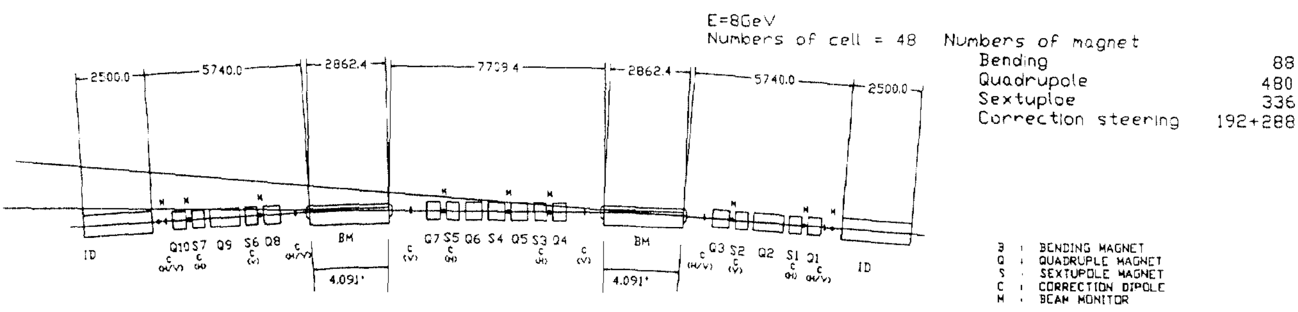

Fig.1. Layout of lattice main magnets for 1 cell of the 8 GeV storage ring.

Dipole Magnets

The dipole magnet has a C-shaped rectangular configuration as shown in Fig.2 and its designed parameters are listed in Table 2. The pole is flat over a horizontal range of 200 mm and has radial shims of 2 mm in thickness at both radial end.

The distance of the gap between the shims is sufficient to allow the vacuum chamber to be installed from the open side of the magnet gap. Required gap distance is 65mm, which provides 40mm beam clear space inside the vacuum chamber and 7mm for vacuum wall thickness, 2mm for thermal insulation, 1.5mm for clearance. The coil are composed of main and auxiliary ones. The auxiliary coil will be used to adjust for magnetic strength to the magnet to magnet, and also for COD correction.

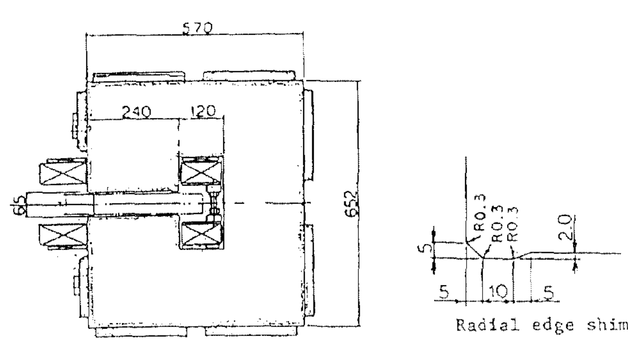

Fig.2. Cross-sectional view of a dipole magnet.

Table 4. The maximum field strength is 0.06T. Ninety-six individual correction magnets provide both horizontal and vertical correction fields. Other small magnets also provide a horizontal dipole field. The detailed design of individual correction dipole magnets is now in progress.

Table 4. Parameters of steering windings.

		horiz.		vert.
		Coil A	Coil B	Coil C
Family		S1,S3,S5,S7		S2,S6
Number of magnets		192		96
Physical length	(m)	0.45		0.45
Kick angle	(mrad)	1.0		1.0
Peak field	(T)	0.059		0.059
Number of coils		2	4	4
Turns per pole		340	136	275
Conductor size	(mm^2)	2.4 x 4		2.4 x 4
Current, max.	(A)	12.4	12.4	9.5
Current density	(A/mm^2)	1.3	1.3	1.0
Voltage per coil	(V)	12.6	5.1	7.3
Power per coil	(W)	105	63	70

Field Measurements

Dipole Magnets

Magnetic field of the prototype dipole magnet has been measured with a hall probe (SIEMENS SBV604) whose temperature is stabilized at 26±0.1°C. The fields are mapped on the median plane (y=0) at intervals of 5mm in a transverse direction (x) and 20mm in longitudinal (z). The hall probe was carried by a 3D moving table (4m x 0.2m x 0.2m). These measurement devices was controlled by a personal computer through a GP-IB interface.

Figure 5 shows transverse distribution of field integration along z-axis (beam direction), which is calculated by summing up the mapped data. Its uniformity ($\Delta Bl/Bl$) was found to be within 5×10^{-4} in the region of ±45mm. The strength of a sextupole field was 0.35 T/m^2.

On the other hand, an effective magnetic length of the dipole magnet was measured to be 2.877m at the nominal field strength (0.665 T) though we had expected it to be 2.863m as shown in table 2.

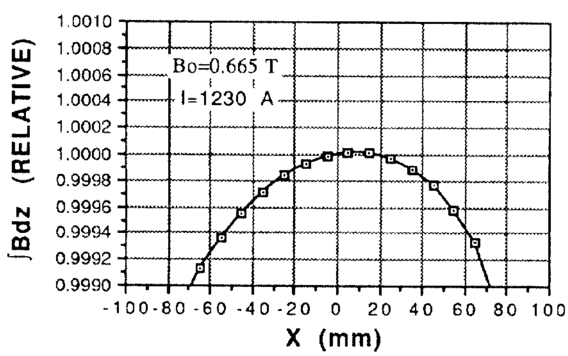

Fig.5. Transverse distribution of field integration of a prototype dipole magnet.

Quadrupole magnets

Magnetic field of the prototype quadrupole has been measured with the small twin flip coils. A small coil is wound 200 turns on a bobbin with a diameter of 5 mm and a length of 10 mm. Two coils are fixed in a plastic block kept the axes parallel at intervals of 10 mm. The coil block is supported with a pipe of 1 m long and is flipped for about 0.7 seconds by a stepping motor. Figure 6 shows a block diagram of this

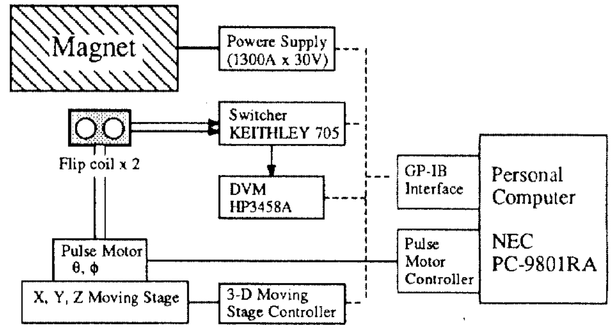

Fig.6. Block diagram of field measurements system.

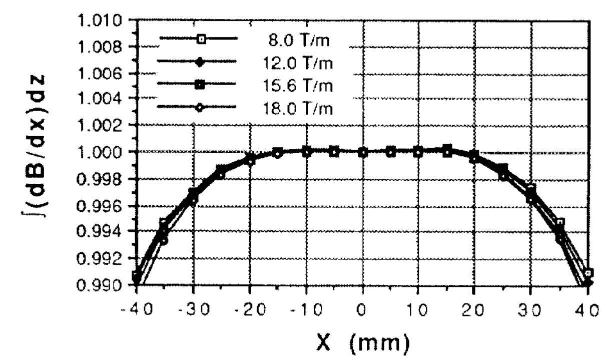

Fig.7. Transverse distributions of integrated field gradients of a prototype quadrupole magnet.

measurement system. Output signal from two coils is integrated separately with a high precision AD convertor (HP3458A) and logged in a personal computer. The fields is mapped at intervals of 5mm and 20mm on a median plane of ±45mm (transverse) x 920mm (longitudinal).

Figure 7 shows transverse distributions of integrated gradients for four exciting levels. It is found in the figure that the integrated gradients decrease obviously with distance from the center for a dodecapole field. But we think we can correct the distributions to be satisfied with the required specifications by attaching end shims since their difference in exciting levels is small enough.

An effective magnetic length was measured to be 514mm in 8 T/m and 508mm in 18 T/m for iron core length of 465mm, though we had expected it to be 500mm. The power loss factor due to magnetic resistance was 10% for 18 T/m.

Conclusion

We have designed magnet systems for the SPring-8 storage ring and have constructed prototypes of a dipole, quadrupole, and sextupole magnet. Presently, the measurements of their magnetic field is undergoing and preliminary results have been acquired for a dipole and a quadrupole. We are planned to do the detail measurements and design actual magnets by taking account of the results.

References

[1] M. Hara, S. H. Be, R. Nagaoka, S. Sasaki, H. Takebe, H. Tanaka, T. Wada and H. Kamitsubo, "Storage ring design of SPring-8, 8 GeV synchrotron radiation facility in Japan," in Proceedings of this conference.

[2] J. Ohnishi and S. Motonaga, "Design of the sextupole magnet for an 8 GeV storage ring," presented at 11th International Conference on Magnet Technology, Tsukuba, Japan, Aug.28-Sep.1, 1989.

Table 2. parameters for dipole, quadrupole, and sextupole magnets

Family		dipole	Q1,Q10	Q4,Q7	quadrupole Q3, Q8	Q5,Q6	Q2,Q9	sextupole S1,S2,S3 S5,S6,S7	S4
Number of magnets		88	96	96	96	96	96	288	48
Bore diameter	(mm)	65			85			100	
Effective field length	(m)	2.863	0.45	0.45	0.5	0.55	1.0	0.4	0.53
Magnet length	(m)	3.08	0.59	0.59	0.64	0.69	1.14	0.53	0.61
Field strength, max	(T, T/m, T/m^2)	0.665	13	16	17	17	17	280	360
Magnetomotive force	(x10^4 AT)	3.5	0.95	1.17	1.25	1.25	1.25	0.5	0.625
Turn numbers per pole		14			16			24	
Conductor size	(mm)	14x23-Ø10			11.5 x 16 - Ø5			8x8 -Ø5	
Current, max	(A)	1250	600	730	780	780	780	208	260
Current density	(A/mm^2)	5.1	3.7	4.5	4.8	4.8	4.8	3.8	4.8
Voltage drop, max	(V)	20.3	6.3	7.7	8.9	9.5	15.0	8.7	13.4
Power dissipation	(KW)	25.3	3.7	5.6	6.9	7.4	11.7	1.8	3.5
Cooling circut		2	4	4	4	4	4	6	6
Water flow	(l/min)	18.1	13.4	13.4	12.9	12.4	9.5	6.6	5.9
Pressure drop	(Kg/cm^2)	5	5	5	5	5	5	5	5
Temperature rise	(°C)	20	4.0	6.0	7.7	8.5	17.6	3.9	8.4

Quadrupole Magnets

The cross-sectional view of the quadrupole magnet is shown in Fig.3. All magnets have the same pole contour. the structure was designed to remove parts of the yoke on both radial side at a median plane, because an enlarged vacuum chamber having a photon beam channel is to be installed. There are three different lengths provided; 1.1m, 0.6m. and 0.5m. Designed parameters are given in Table 2.

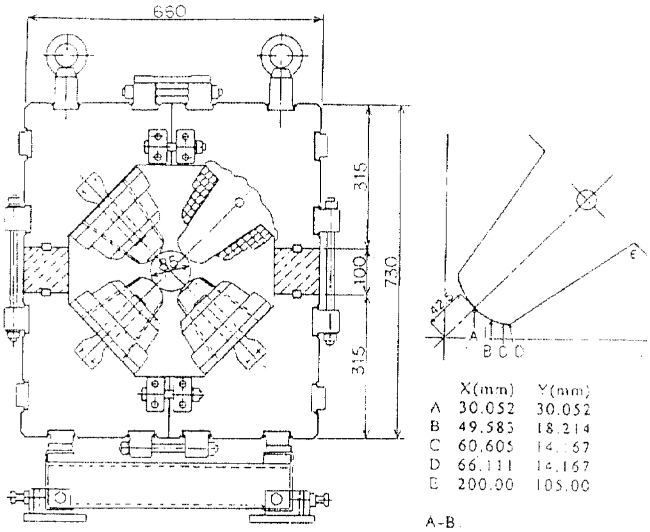

Fig.3. Cross-sectional view of a quadrupole magnet.

The yoke of the prototype was designed to insert a pair of spacers (hatching parts) at radial both sides on the medium plane. The top and bottom halves are jointed through non magnetic material. Therefore, the structure is not completely four-hold symmetric, magnetic flux does not cross the medium plane. Two kind of metals for yoke spacer are prepared. One is non magnetic metal and the other is magnetic steel. We will be carried out field measurement in both cases with non magnetic and magnetic metal of spacer. Then we will design the yoke structure in final.

Sextupole Magnets

Two types of magnets having different yoke structures have been designed: one is completely six-hold symmetric (a solid line) and the other is asymmetric (a dotted line) [2]. All magnets have the same pole contour shaped with $r^3\cos\theta^3=r_o{}^3$ with a radial shim as shown in Fig.4. Auxiliary coils for COD correction were wound on the sextupole magnets. The designed parameters are given in Table 2. The auxiliary coils in a sextupole magnet are indicated in Fig.4 as "H" for horizontal and "V" for vertical steering. In actual magnets, either H-coils or V-coils are mounted as shown in Table 3. The region of a uniform field gradient within 1.5×10^{-3} is expected to be in a radius of 35mm from a calculation.

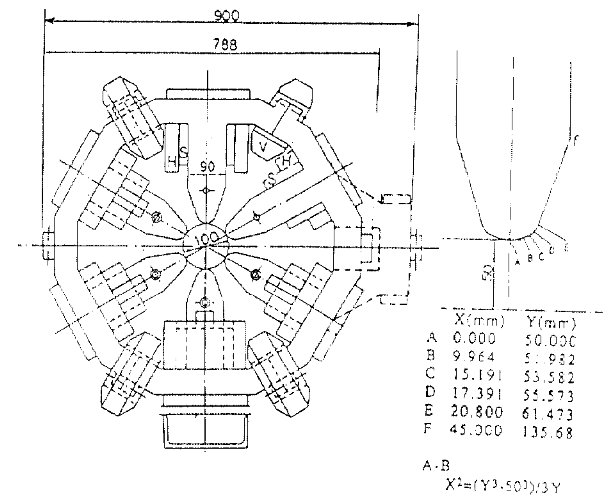

Fig.4. Cross-sectional view of a sextupole magnet.

Table 3. Family of sextupole magnets

	S1(S1)	S2(S2)	SD(S3)	SF(S4)	SD(S5)	S3(S6)	S4(S7)
B" (T/m^2)	208	-257	-273	354	-273	-147	268
L_{eff} (m)	0.40	0.40	0.40	0.55	0.40	0.40	0.40
Steering	H	V	H	None	H	V	H

H: Horizontal steering coils
V: Vertical steering coils

Correction Magnets

The maximum field strength of 0.02 T.m is required, which gives 0.8 mrad kick to a beam. Totally 576 magnetic elements for COD correction are installed.

Six of seven families of the sextupole magnets provide a vertical or a horizontal dipole correction field as shown in Table 3. Desined parameters of steering coils mounted in the sextupole magnet are in