Effects of the SRRC Second prototype dipole magnet on the SRRC Ring

J. C. Lee

Synchrotron Radiation Reserach Center
P.O. Box, 19-51, Hsinchu 30077, Taiwan, R. O. C

Abstract

After correcting the second prototype combined function dipole magnet to the nominal condition, the integrated gradient strength and the integrated sextupole strength remain larger than the specification. The excessive integrated gradient strength can be overcome by retuning the triplet quadrupoles. The integrated sextupole strength is composed mainly of two systematic thin sextupole lens on both edges of the magnet. The integrated sextupole strength inside the magnet is less than that specified. Strength of the ring regular sextupoles are readjusted accordingly. After retuning and adjusting chromaticities, the dynamic aperture tracking is studied with and without multipole field. It is found that the second prototype combined function dipole magnet is acceptable.

I: Overview of the magnet

The first combined function dipole magnet prototype of SRRC storage ring has been constructed and the measurement has been conducted using the Hall probe[1]. Due to edge effects, the integrated gradient strength of the first prototype is too small by 5.31%. Efforts of shim correction scheme have been introduced. However, using shims to correct the gradient error, which is a first order strength of course, has to be avoided if possible. Furthermore, to ease problems related to hardware constructions, it was decided to increase the opening of the magnet from 50 mm to 52 mm to have larger gradient strength at magnet center such that the total integrated gradient strength will equal the design value.

Based on these considerations, the second prototype magnet was constructed and measured[2]. Table 1 lists some of the raw data. It is clear that the error of integrated gradient strength has been improved.

The agreement of the design $\Delta B/B$ and $\Delta G/G$ with the measurement along the horizontal plane at the magnet center is good. The result of $\Delta B/B$ can be found in figure 1. Distributions of the dipole field and the gradient field (including edge effect) along the longitudinal direction is shown in figure 2 and the sextupole field distribution is given in figure 3. It is clear that these field distributions are homogeneous at the magnet center and show significant variation at the magnet edges. The octupole and decapole distributions exhibit the same behavior. This implies that the field homogeneity within the magnet is good and the effect of fringe field is large.

Table 1: Summary of the Uncorrected Magnet

		Measured	Specification	Deviation
B(0,0,0)	T	1.23270	1.24071	-0.65%
G(0,0,0)	T/m	-1.69674	-1.71022	-0.79%
S(0,0,0)	T/m^2	-0.269	0.	
O(0,0,0)	T/m^3	2.9	0.	
D(0,0,0)	T/m^4	642.	0.	
$\int B(0,0,s)\,ds$	Tm	1.50572	1.51367±0.0015	-0.53%
$\int G(0,0,s)\,ds$	T	-1.95587	-1.95742±0.002	-0.08%
$L_{bending}$	m	1.22147	1.22	0.12%
$L_{gradient}$	m	1.15272	1.14454	0.71%
$\int S_{center}(0,0,s)ds$	T/m	-0.284	0 ± 0.565	
$\int S_{edge}(0,0,s)\,ds$	T/m	-1.08		
$\int O(0,0,s)\,ds$	T/m^2	13.2	0 ± 18	
$\int D(0,0,s)\,ds$	T/m^3	339.	0 ± 345	

$S = \frac{1}{2}\frac{\partial^2 B_y}{\partial x^2}$ $\quad O = \frac{1}{6}\frac{\partial^3 B_y}{\partial x^3}$ $\quad D = \frac{1}{24}\frac{\partial^4 B_y}{\partial x^4}$

II: The Correction on the Magnet

The integrated field error can be decomposed approximately into the field error, due to the current error, and the length error, coming from fringe field. From table 1, it is clear

$$\Delta(B_0L) / B_0L = \Delta B_0 / B_0 + \Delta L_B / L_B \qquad (1)$$
$$\Delta(GL) / GL = \Delta G / G + \Delta L_G / L_G \qquad (2)$$

where L_B and L_G are the effective length of the dipole and the gradient field respectively. These two relations can help the analysis of the following corrections.

On the correction of the magnet the current is first increased to cancel the -0.65% error of dipole field . After this correction the gradient field error is reduced to -0.14%. When the dipole field error is corrected its integrated strength error is then purely coming from the length error and has value of 0.12%, which is larger than the tolerance of 0.1% and need to be corrected. As the dipole length is corrected by taken some lamination plates away, the gradient length changes according to[3]

$$L_G = L_B + (B_0 / G)(dL_B / dx)_{x=0} \qquad (3)$$

0-7803-0135-8/91$01.00 ©IEEE

where x is the horizontal coordinate. Since in equation (3) only L_B has significant variation by reducing the number of lamination plates, it is clear $\Delta L_G = \Delta L_B$. Therefore the shrinkage of gradient length is 0.13% and the gradient length error becomes 0.58%. After these corrections, the integrated gradient error is 0.44%.

After the magnet is corrected to the nominal condition, the multipole field is also changed accordingly. The behavior of multipole field is something like what eqs. (1) and (2) predict and the correction factor is chosen to be 0.5%. Table 2 is the summary after these corrections.

Table 2 : Performance Guess after the Magnet is corrected

		Measured	Specification	Deviation
B(0,0,0)	T	1.24071	1.24071	0.0%
G(0,0,0)	T/m	-1.7078	-1.71022	-0.14%
S(0,0,0)	T/m^2	-0.271	0.	
$\int B(0,0,s)\,ds$	Tm	1.51367	1.51367±0.0015	0.0%
$\int G(0,0,s)\,ds$	T	-1.96609	-1.95742±0.002	0.44%
$L_{bending}$	m	1.22	1.22	0.0%
$L_{gradient}$	m	1.15121	1.14454	0.58%
$\int S_{center}(0,0,s)ds$	T/m	-0.285	0 ± 0.565	
$\int S_{edge}(0,0,s)\,ds$	T/m	-1.085		
$\int O(0,0,s)\,ds$	T/m^2	13.27	0 ± 18	
$\int D(0,0,s)\,ds$	T/m^3	341.	0 ± 345	

III: Retuning of the Magnet

The second prototype of the dipole magnet effectively increases the gradient strength at the middle of the dipole and reduce the gradient strength on both ends of the magnet to achieve the same integrated gradient strength. The effect of this change will increase ν_y and decrease ν_x by the formula

$$\Delta\nu_{x(\text{or } y)} = -(1/4\pi)\int\Delta K\cdot\beta_{x(\text{or } y)}\,ds \qquad (4)$$

because β_y has maximum near dipole center while β_x has minimum near the dipole center. The triplet quadrupoles outside the achromat can be used to restore the tune produced by the excessive 0.44% integrated gradient error. Table 3 gives some parameters for the original design, design lattice with adjusted gradient (AG) and retuned lattice (RL). The strength deviation of triplet quadrupoles after retuning is within 1.1%. The increased integrated gradient strength of the second dipole prototype also has effects on the dispersion. The quadrupoles within the achromat are tuning accordingly. While the strength changing is very small and can be negligible.

Table 3:

	Original	AG	RL
ν_x	7.18	7.176	7.18
ν_y	4.13	4.163	4.13
β_{xmax} [m]	19.742	19.789	19.685
β_{ymax} [m]	12.293	12.318	12.236
η_{xmax} [m]	0.655	0.659	0.659
$\beta_{x\text{ insertion middle}}$ [m]	10.478	10.510	10.474
$\beta_{y\text{ insertion middle}}$ [m]	2.905	2.896	2.967

IV: Effects of the Thin Edge Sextupole Lens

The integrated sextupole error remains larger than the design after retuning. Since most of the sextupole error comes from the edges, this problem can be seen more clearly by dividing the integrated sextupole strength into three parts: one in the magnet center and two at edges. The two thin edge sextupole lens (ES) are then taken as systematic elements in the ring and the central integrated sextupole strength is within tolerance.

The edge sextupole lens produces additional chromaticities. While it can be compensated by tuning regular sextupoles. To check the effects of thin edge sextupole lens, tracking simulations were done with 1000 turns using RACETRACK. It is found that the regular sextupole strength of the retuned lattice is slightly below the original design. After the chromaticity adjustment (CA) the regular sextupole strength is further shrunk down and the dynamic aperture becomes bigger. The results are given in table 4. The effects of thin edge sextupole lens can then be summarized as:

i): a net positive effect on the chromaticities, ii):smaller regular sextupole strength for chromaticity compensation.

Table 4:

	Original	RL	RL+ES	RL+ES+CA
$\delta\nu_x / \delta P/P$	0.0	0.0	-0.17	0.0
$\delta\nu_y / \delta P/P$	0.0	0.0	0.82	0.0
Regular Sextupole: [simulation/design]				
Defocusing	1.	0.993	0.993	0.935
Focusing	1.	0.994	0.994	0.987
Dynamic Aperture				
$[X_{max}/Y_{max}]$	37.5/19.7	36.9/19.1	37.7/20.0	37.1/20.5

V: The adjusted Lattice with Multipole Errors

The dynamic aperture simulations at insertion middle were done with ten random machines. Since there are no any other magnets to be compared now, the multipoles in the dipole prototype are taken as systematic errors. Multipoles of quadrupole magnets are cited from the tolerance. It is found that the tune is deviated by the random quadrupole component from 7.18 to 7.182 for the horizontal and from 4.13 to 4.128 for the vertical. The random multipoles also produce an uncertainty area of the dynamic aperture with average aperture of 22.7mm and 17mm for the horizontal and vertical respectively, which are larger than the horizontal and vertical beam stray clear of 22mm and of 8mm. The regular sextupoles can be retuned again to cancel the additional chromaticities from the sextupoles of multipole field. While no obvious improvement can be found. Figure 4 is the tracking results.

Since the prototype can be taken as a reference of the series production magnets, a simulation with additional 10% random multipoles w.r.t. the dipole prototype and 0.1% random integrated gradient for dipole magnets was also done to simulate the situation of series production. The results don't have significant difference from the above simulation and will give the same conclusion.

VI: Conclusion

From the simulation results it is clear that the tune shift due to the adjusted integrated gradient can be restored by tuning triplet quadrupoles. The strength deviation of quadrupoles after retuning is small. The excessive integrated sextupole strength can be divided into three parts to have the tolerable sextupole field inside the magnet. Additional chromaticities from edge sextupole field can be canceled by tuning regular sextupoles. The reduced regular sextupole strength after chromaticity adjustment reduces the higher order effect and hence gives positive contribution on the dynamic aperture. The dynamic aperture of the corrected magnet with multipole errors remains larger than the beam stay clear of both planes and the tune shift due to the random quadrupole component in both planes is less than 0.002. Hence the second combined function dipole prototype of SRRC is acceptable after retuning and taking its edge sextupole field as a systematic element in the ring.

Acknowledgement

The author would like to thank Prof. C. S. Hsue for his helpful corrections and to the people of Magnet Measurement Group of SRRC, especially to Mr. C. S. Hwang, for providing the measured data.

Reference

[1]: C. S. Hwang, W. C. Chou, J. H. Huang, P. K. Tseg, J. C. Lee, C. C. Kuo, C. S. Hsue and J. Le Duff," Mapping and Analysis of the Prototype Bending Magnet", SRRC/CB/IM/89-1.

[2]: P. K. Tseg, C. S. Hwang and F.Y. Lin," The Analysis Methods of Hall Probe Mapping System for the Combined Function Dipole Magnet", also presented in this conference.

[3]: E. Keil, Y. marti, B. W. Montague and A.Sudboe,"AGS, the ISR Computer Program for Synchrotron Design", Report CERN 75-13, P. 11, Eq. 11,1975.

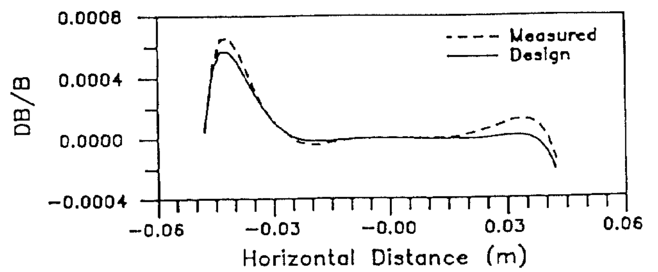

Figure 1: The $\Delta B/B$ along the horizontal at magnet center

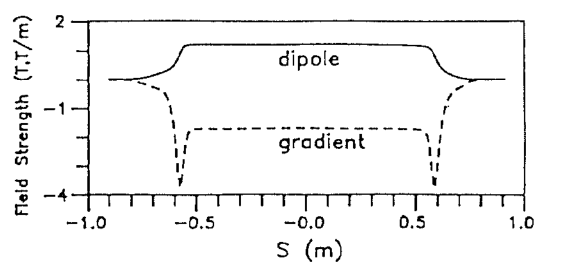

Figure 2: Dipole and gradient field distributions along the longitudinal

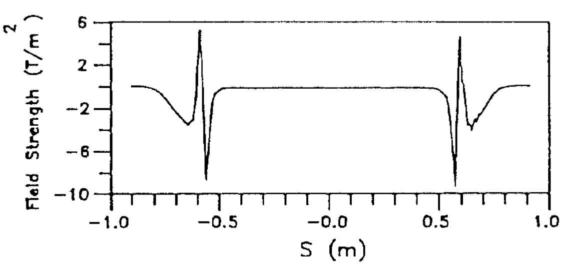

Figure 3: Sextupole field distribution along longitudinal

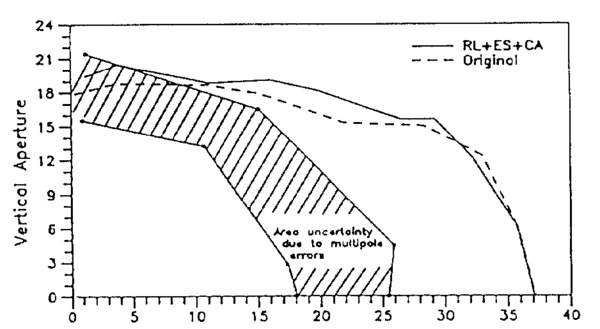

Figure 4: Dynamic aperture of the adjusted lattice with multipole errors