DESIGN AND MEASUREMENT OF THE SSRF MAGNET PROTOTYPES

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Abstract

The manget prototypes of the 3.5 GeV Shanghai Synchrotron Radiation Facility (SSRF) have been constructed and magnetically measured. These magnets include the storage ring dipole, quadrupole and sextupole and the booster dipole, quadrupole and sextupole. The magnetic fields of the storage ring magnets were optimized for 3.5 GeV operation. The booster magnets will operate at the varying energy with a rate of 1 Hertz, so the field quality was maintained not only at 3.5 GeV but also at the injection energy 300MeV. This paper reviews the designs and the main parameters for these magnets and presents some of the magnetic measurement results for prototypes.

1 INTRODUCTION

Strict field quality is specified for the SSRF magnets, especially for the storage ring magnets [1]. For the dipoles and quadrupoles of the storage ring, the systematic and random tolerances for the harmonic contents of the integral fields in the good field regions are required to be in the order of 10^{-4}. For the booster magnets the line integral field errors of the order of 10^{-3} in the good field regions are specified for the varying energy from 300 MeV to 3.5 GeV with a rate of 1 Hertz.

Magnetic fields of all magnets have been optimized with the two-dimensional design [2,3]. The three-dimensional field effects were corrected by chamfering the magnet ends to meet the integrated field quality specifications.

2 STORAGE RING MAGNETS

The C-shape dipoles, the Collins type quadrupoles and the C-shape sextupoles of the SSRF storage ring are straight magnets and allow easy extraction of the synchrotron radiation and the accommodation of the vacuum chamber. The magnet core is fabricated from DW540G-50 steel laminations 0.5 mm thick. All the main coils of the magnets are made of water-cooled hollow copper conductor insulated with fiberglass and vacuum impregnated with epoxy. In addition to the main coils, there are trim coils in the dipoles and quadrupoles and skew quadrupole coils in the sextupoles.

2.1 Dipole Magnet

In the SSRF storage ring there are 40 dipole magnets. The C-type configuration simplifies the design of the magnet and provides the good stiffness and field quality. The dipoles are made of one-piece laminations. After precisely stacking on a fixture laminations are compressed and glued with a packing factor no less than 97% and the side plates are pinned to the end plate. The voids between the side plates and the step in each lamination are filled with a steel loaded epoxy (Devcon). All the dipoles are powered in series and equipped with individually powered trim coils that allow a 3% magnetic field adjustment. The prototype of the dipole is shown in Figure 1.

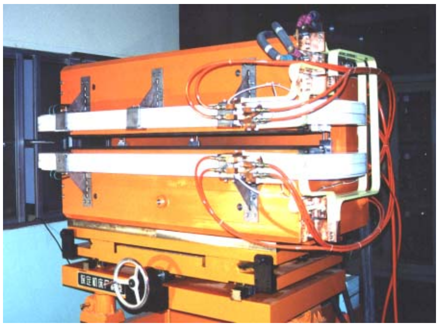

Figure 1: The storage ring dipole prototype.

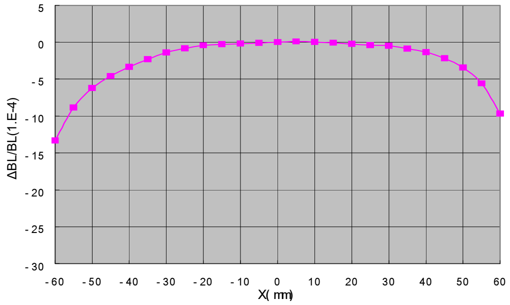

Figure 2: The distribution of the integral field error of the storage ring dipole prototype.

The dipole is a straight magnet. The magnetic length is 1.66 m with half sagitta of 16.3 mm. The pole gap is 56 mm, which takes into account the vacuum chamber size and some clearances. The pole width of 220 mm is determined from the good field region and the sagitta of the curved beam orbit. The good field region extends horizontally from -40.3 mm to +40.3 mm in respect to the pole reference line (coincident with the half sagitta), and vertically from -18 mm to +18 mm. The gap flux density is 1.105 T for 3.5 GeV operation and the specified integral field error in the good field region is less than 5×10^{-4}. Some main parameters of the magnet are listed in Table 1.

The translating long coil technique was used to characterize the transfer function and the integral field quality of the prototype. Figure 2 shows the distribution of the integral field error of the prototype at the nominal excitation. In the good field region x(-40.3,40.3), the integral field error is less than 4×10^{-4}.

2.2 Quadrupole Magnets

The SSRF storage ring quadrupoles have 3 different lengths (0.66, 0.30, 0.20m) and 10 different excitation currents. The total number of the quadrupoles is 200. All the quadrupoles have the same bore diameter 72 mm. In order to reduce the number of different parts and components, they are designed with the same cross section. Laminations of the core are compressed and glued with a packing factor no less than 97% after precisely stacking on a fixture and the side plates are bolted with tie rods. The yoke consists of upper and lower halves attached together via non-magnetic spacers. In order to accommodate the varying sizes of the vacuum chamber, non-magnetic C-shape and flat spacers of different widths will be used between the upper and lower yokes. Individually powered trim coils on each quadrupole allow a 1.8 T/m tuning to compensate for the changes due to wigglers and undulators. The prototype of the quadrupole is shown in Figure 3. The core length of the prototype is 0.30m. Some main parameters of the magnet are listed in Table 1.

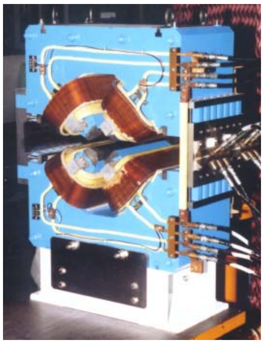

Figure 3: The storage ring quadrupole prototype.

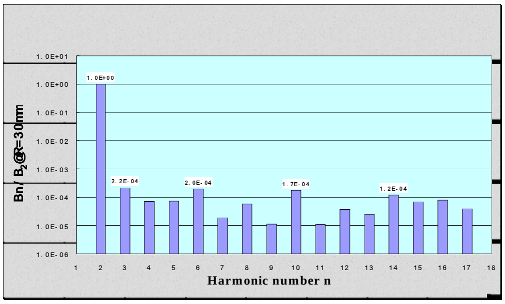

Figure 4: The harmonic contents of the integral field error of the storage ring quadrupole prototype.

The field quality specifications of the storage ring quadrupoles call for the integrated multipole errors of the order of a few parts in 10^{-4}. The compensated rotating coils and a data acquisition system which includes a digital integrator are used to measure the harmonic contents of the integral field error of the prototype [4]. Figure 4 shows the results at the maximum excitation required for 3.5 GeV.

2.3 Sextupole Magnets

The SSRF storage ring has 140 sextupoles with the same length 0.20 m and 7 different excitation currents. All the sextupoles have the same bore diameter 88 mm and are designed with the same cross section. Laminations of the core are compressed and glued with a packing factor no less than 97% after precisely stacking on a fixture and the side plates are bolted with tie rods. The yoke consists of three sections with a single type of laminations but 2/3 laminations are sheared to produce the required space for vacuum chamber. The three sections are indexed by positioning pins and matching surfaces and bolted to each other or via the flat spacer. In order to accommodate the varying sizes of the vacuum chamber and provide the mechanical strength, non-magnetic C-shape spacers of different widths are used between the upper and lower yokes. Individually powered trim coils on two vertical poles allow a 0.45 T/m skew quadrupole correction. The prototype of the sextupole is shown in Figure 5. The core length of the prototype is 0.194m. Some main parameters of the magnet are listed in Table 1.

Figure 5: The storage ring sextupole prototype.

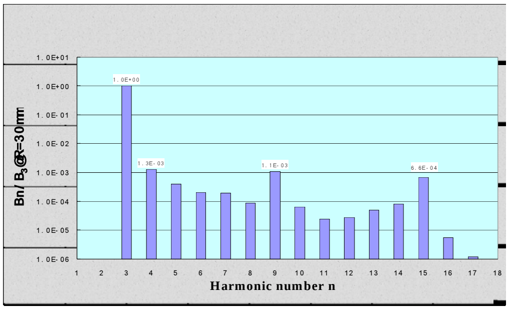

Figure 6: The harmonic contents of the integral field error of the storage ring sextupole prototype.

Figure 6 shows the harmonic contents of the integral field error of the prototype at the maximum excitation required for 3.5 GeV. Also the compensated rotating coil technique is used to perform the magnetic measurement.

3 BOOSTER MAGNETS

SSRF booster will operate at the energy from 300 MeV to 3.5 GeV with a frequency of 1 Hz and a rise time 450 ms. Dipoles, quadrupoles and sextupoles are straight magnets and all magnets have symmetric closed yokes. The yoke of each magnet consists of an upper and a lower half bolted vertically with each other and indexed horizontally by positioning pins at the end plates. The magnet core is fabricated from DW315-50 steel laminations 0.5 mm thick coated with semiorganic insulation. The DW315-50 steel has a lower coercivity than the DW540G-50 steel. After precisely stacking the laminations will be compressed and glued with a packing factor no less than 97% and then bolted with tie rods. The magnet coils are made of water-cooled hollow copper conductor except the sextupole coils which are made of the solid copper conductor and cooled by natural air convection. Each coil was insulated with fiberglass and vacuum impregnated with epoxy. The prototypes of the booster dipole, quadrupole and sextupole are shown in Figure 7, 8, 9 and some main parameters of the prototypes are listed in Table 1.

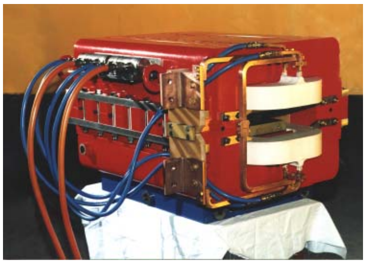

Figure 7: The booster dipole prototype.

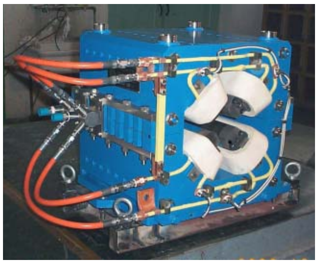

Figure 8: The booster quadrupole prototype.

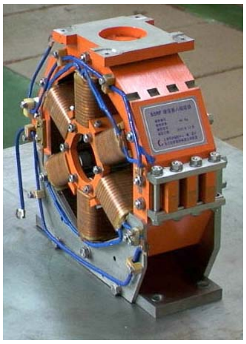

Figure 9: The booster sextupole prototype.

Figure 10 shows the distributions of the arc-line integral field errors of the prototype at the excitations for 300 MeV, 1.75 GeV and 3.5 GeV operations. X_0 is the position of the arc vertex from the magnet centre. The measurements were performed with the Hall probe device and the arc-line integrals along the beam trajectory were calculated from the field maps.

The magnetic measurements of the quadrupole and sextupole prototypes were performed with the rotating coil systems. The harmonic contents of the integral field error were measured with the compensated rotating coils and the integral field errors were calculated from the harmonic contents. Figure 11 and Figure 12 show the iso-error curves of the prototypes at the excitations for 300 MeV, 1.75 GeV and 3.5 GeV operations.

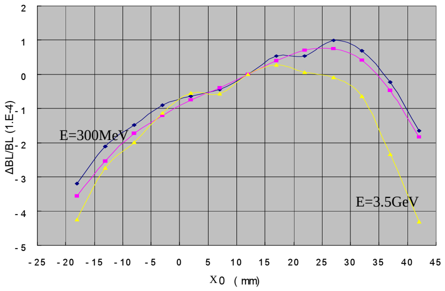

Figure 10: The distributions of the arc-line field errors of the booster dipole prototype.

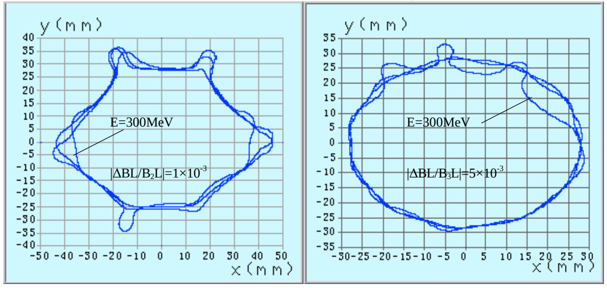

Figure 11, 12: The iso-error curves of the booster quadrupole (left) and sextupole (right) prototypes.

Table 1: Main parameters of the SSRF magnet prototpyes

Magnet	Storage ring Dipole	Storage ring Quadrupole	Storage ring Sextupole	Booster Dipole	Booster Quadrupole	Booster Sextupole
Max. Field / Gradient	B= 1.105 T	dB/dr= 16.7+1.8 T/m	d^2B/dr^2= 440 T/m^2	B= 1.09 T	dB/dr= 15.9 T/m	d^2B/dr^2= 132 T/m^2
Gap height / Inscribed radius	56 mm	36 mm	44 mm	44 mm	30 mm	30 mm
Core length	1590 mm	300 mm	194 mm	750 mm	360 mm	100 mm
Good field region	X: 80.6mm	R<30mm	R<30mm	X_0: 60mm	R<24mm	R<24mm
Field quality specification	$\Delta BL/B_1L$ $<5\times10^{-4}$	$B_n<3\times10^{-4}$ n>2	$B_6<1\times10^{-3}$ $B_9<2\times10^{-3}$	$\Delta BL/B_1L$ $<5\times10^{-4}$	$\Delta BL/B_2L$ $<1\times10^{-3}$	$\Delta BL/B_3L$ $<5\times10^{-3}$
Conductor size	16×16 Φ7mm	7.4×8 Φ4.6 mm	6.5×6.5 Φ3.5 mm	12×12 Φ5mm	6.3×7 Φ3.4 mm	2.24×4 mm
Current	692.1 A	322.2 A	303.4 A	688.4 A	442.4 A	17.68 A
Resistance	0.026 Ω	0.0454 Ω	0.0424 Ω	0.0185 Ω	0.0275 Ω	0.1023 Ω
Inductance	54.85 mH	11.7 mH	6.5 mH	16.76 mH	2.82 mH	4.61 mH

4 ACKNOWLEDGEMENTS

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