Magnetic Measurement of the VSX Prototype Magnets

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Abstract

The prototype models of the dipole, quadrupole and sextupole magnets for the VSX storage ring have been fabricated. The field measurement of the prototypes is now in progress at the Institute for Solid State Physics (ISSP), the University of Tokyo. The measurement is being carried out using three-dimensional actuator with a Hall probe for the dipole, and radial coils (long and short) for the quadrupole and sextupole. The first results of the measurement are presented in this paper.

1 INTRODUCTION

The University of Tokyo is promoting a future project to construct VUV and soft X-ray synchrotron radiation (SR) facility in a new campus of the university, Kashiwa Campus. The project, VSX project, is composed of two phases. The first phase is to construct a 1.0-GeV racetrack ring which has a circumference of about 230 m and an emittance of about 0.7 nm·rad [1]. A 27 m long undulator installed in the one of the long straight sections generates extremely high brilliance SR in the VUV region. The second phase is to construct a 2.0 GeV ring which has a circumference of 388 m, an emittance of about 5 nm·rad and 16 long straight sections [2]. High brilliance SR over a wide wavelength range from VUV to Soft X-ray will be generated by various kinds of insertion devices.

As one of the R&D's of the VSX project, prototypes of the dipole, quadrupole and sextupole magnets for the ring of the second phase have been designed and fabricated. The magnetic field measurement of these prototypes is well under way.

The VSX ring of the second phase contains 32 identical dipoles (1.3 m long), 144 quadrupoles (0.4 m and 0.6 m) and 128 sextupoles (0.15 m and 0.2 m). The ring has three operational modes with different optics; high beta mode (standard optics), hybrid mode and very low emittance mode [2]. The quadrupole and sextupole magnets are, therefore, required to have a good field quality over the wide range of excitation. The design of these main magnets and some correction magnets are presented in Ref. [3].

The prototype magnets have been manufactured at Mitsubishi Electric Corporation and delivered to ISSP. Table 1 summarizes the main parameters of the prototypes.

2 DIPOLE PROTOTYPE

The field measurement of the dipole prototype is being carried out using a new field mapping system with a Hall probe unit. The Hall probe is mounted on the three-dimensional actuator which is driven by stepping motors. Magnescales in three directions read the probe position with a resolution of 1 μm. The Hall probe unit is calibrated using an NMR system.

Table 1: Parameters of the prototype magnets.

	Dipole	Quadrupole	Sextupole
Gap or Bore diameter [mm]	50	80	90
Core length [m]	1.298	0.4	0.2
Max. strength [T, T/m, T/m^2]	1.26	14.9	540
Turns / pole	30	12	18
Conductor size [mm]	16×15-ø9	9.5×9.5-ø5	9×9-ø6
Max. current [A]	960	1000	445
Resistance [mΩ]	21.0	17.7	27.2
Max. voltage drop [V]	20.2	17.7	12.1
Max. power dissipation [kW]	19.4	17.7	5.4
Number of water circuits	4	4	2
Water flow [l/min]	37.8	13.5	6.8
Water temperature rise [˚C]	7	13	11.3
Water pressure drop [kg/cm^2]	4	5	5
Auxiliary coil	Backleg	Wound on every pole	-
Turn numbers of auxiliary coil	280 / magnet	200 / pole	-
Total weight [kg]	3500	660	250

The dipole magnet has a C-type rectangular configuration and the bending radius of 6.62 m. The magnetic field is 1.01 T for a nominal 2.0-GeV operation. The magnet core is made of forged low-carbon solid-steel.

The excitation curve measured at the center of the magnet is shown in Fig. 1. The solid line in this figure indicates an excitation curve without saturation effect. The magnet begin to saturate larger than 1 T. The excitation efficiency at the nominal field of 1.01 T is 95.2 %.

Figure 2 shows the horizontal field profile measured at a current of 750 A (B= 1.06 T). The measured profile is in good agreement with the one calculated by 2-dimensional code, LINDA [3]. The horizontal field uniformity is $\Delta B/B < 5 \times 10^{-4}$ in the region of ± 40 mm.

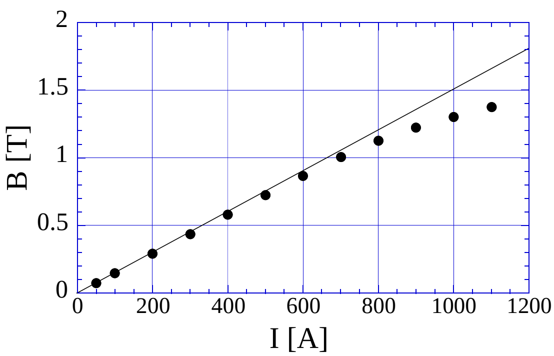

Figure 1: Excitation curve of the dipole prototype.

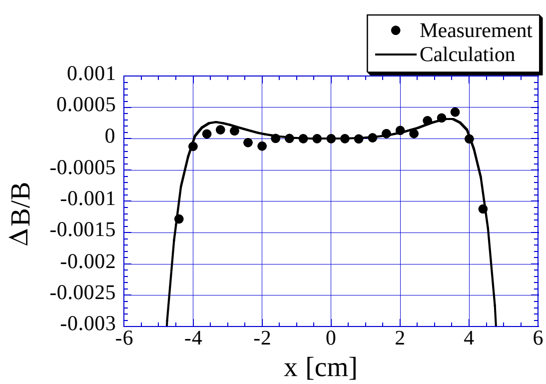

Figure 2: Field profile of the dipole at B=1.06 T.

3 QUADRUPOLE AND SEXTUPOLE PROTOTYPES

The field measurement of the quadrupole and sextupole prototypes is being carried out using the harmonic coil system of KEK-PF [4]. The system has two radial coils mounted in a rotating cylinder. One is the long coil (length ; 1000 mm, radius ; 29.9 mm, turn number ; 10) for measuring the integrated field gradient, and the other is the short coil (length ; 20 mm, radius ; 29.5 mm, turn number ; 50) for measuring the central field gradient. The induced signals in the long and short coils are taken with a two- channel digital integrator (voltage-to-frequency converter), which is triggered by a coil angular-position signal. The digitized signals are fourier-analyzed by a workstation in real time.

3.1 Quadrupole

The ring has 120 standard type and 24 Collins type quadrupoles. The prototype manufactured is the standard type magnet with a core length of 0.4 m. The yoke is made of 0.5 mm-thick laminated silicon-steel and assembled by gluing with no supporting plate on each end.

Figure 3 shows excitation curve measured by the short coil probe. Field gradient of 20 T/m has been obtained for the prototype, although the typical field strength is 10 T/m for the standard optics at 2.0-GeV operation. The effective length calculated from the ratio of the integrated and central field gradients is 448 mm at 600A and 439 mm at 1100 A.

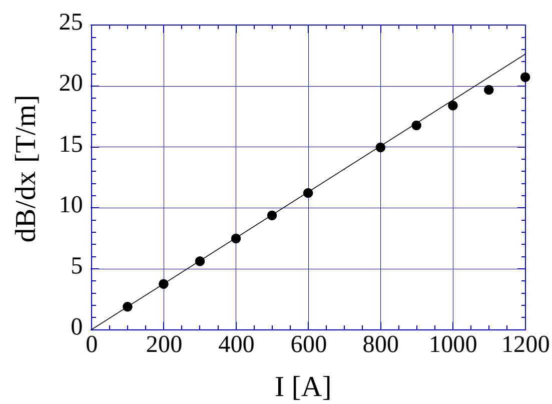

Figure 3: Excitation curve of the quadrupole prototype.

The end correction of the magnet was carried out by shimming to the pole end. The end-shim is a pure-iron plate of 20 mm × 119.5 mm with various thickness. They are attached to both edges of the magnet poles. The dodecapole component is the most dominant in higher multipoles of the quadrupole magnet. Figure 4 shows the dodecapole dependence on the thickness of the end-shimming. The dodecapole component without end-shimming is 0.13 % of the quadrupole component. As shown in this figure, it decreases gradually with thickness of the shimming. At the thickness of 13 mm, the dodecapole becomes 0.03 % of the quadruple, the same order as the other multipole components.

The other multipoles are not affected by the end-shimming Figure 5 shows the multipole field components at three different excitation currents for the thickness of the end-shimming of 13 mm. Each component is normalized by the quadrupole (n=2) component. No significant variation with excitation current was observed.

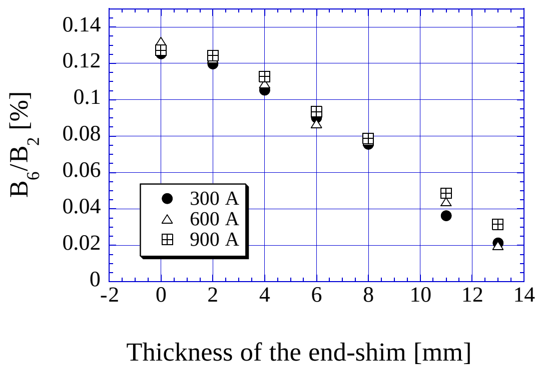

Figure 4: Dodecapole dependence on the thickness of end-shimming.

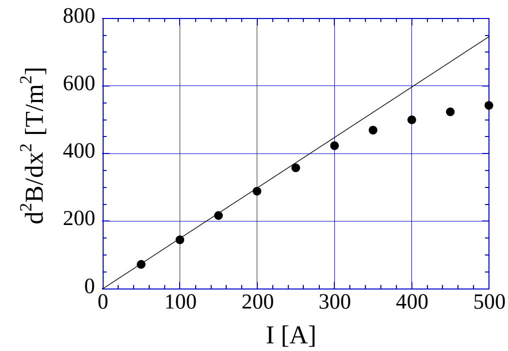

Figure 6: Excitation curve of the sextupole prototype.

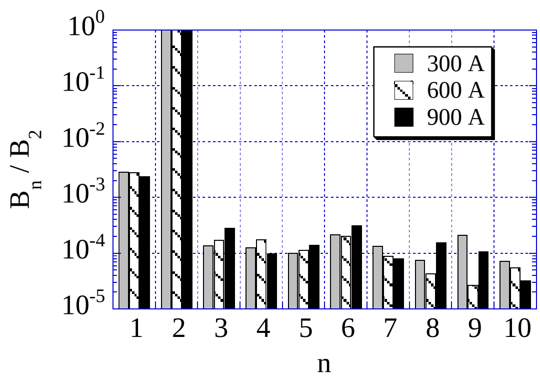

Figure 5: Multipole field components normalized by the quadrupole component.

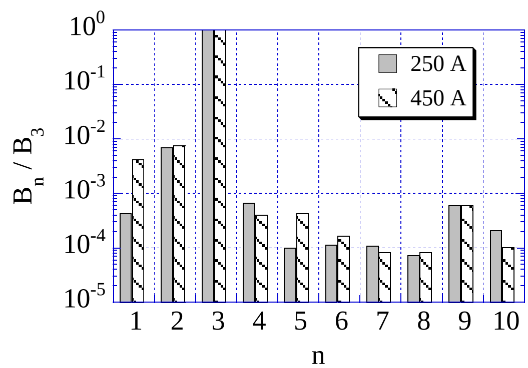

Figure 7: Multipole field components normalized by the sextupole component.

3.2 Sextupole

The prototype of sextupole is 0.2 m long. It is made of 0.5 mm-thick laminated silicon-steel and assembled by gluing in the same manner as the quadrupole prototype.

The measured excitation curve is shown in Fig. 6. For the standard optics, the maximum field strength of 389 T/m^2 is required at 2.0 GeV. The saturation becomes apparent at the magnetic field larger than 400 T/m^2 for this prototype. The excitation efficiency at 400 T/m^2 is 94.8 %. The effective lengths at 250 A and 450 A were measured to be 238 mm and 235 mm, respectively.

Figure 7 shows the multipole field components normalized by the sextupole (n=3) component. The dominant higher component, the 18-pole (n=9) component, is 0.06 % of the sextupole. Since it is an acceptable level, no end correction is necessary for the sextupole.

4 FUTURE PLAN

The field measurement of the prototypes is still in progress. For the dipole, field mapping and end-shimming correction will be completed soon. For the quadrupole and sextupole, the measurement using tangential coil is now under way, which is a more sensitive probe to higher multipole components than the radial coil. On the other hand, the fast steering prototype has been already fabricated, and field measurement is being prepared.

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