SuperKEKB MAIN RING MAGNET SYSTEM

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Abstract

SuperKEKB is a next-generation electron-positron B-factory machine, which aims to achieve a peak luminosity 40 times higher than that of KEKB by using the so-called "nano-beam" scheme. A major upgrade to the Main Ring magnet system was needed to realize this scheme. The upgrade includes: 1) new beam lines in the entire interaction region as well as in the straight sections on either side of the interaction point; 2) replacement of the main dipole magnets in the positron ring; 3) a completely new layout of the wiggler sections in the positron ring, and newly added wiggler section in the electron ring; and, 4) sextupole magnets with tunable tilting tables to control the ratio of skew/normal sextupole components in the positron ring. More than 400 main magnets were newly designed, fabricated, field-measured, installed in the tunnel and aligned in time for Phase I commissioning. Construction of the main ring magnet system and its initial commissioning are reported.

MAGNETS

SuperKEKB[1,2,3] construction started in 2010, and the beam commissioning started in February 2016. The final focus quadrupole magnets are superconducting, but the rest of the magnets in the Interaction Region (IR), as well as in the entire tunnel, are resistive magnets. We reused as many of the KEKB main ring MR magnets [4] as possible to reduce the cost of construction. Table 1 summarizes the parameters of the newly fabricated SuperKEKB MR main magnets. There are more than 800 vertical and horizontal correction magnets in the HER and LER, and about 250 vertical correction magnets needed to be newly designed and fabricated in order to accommodate the new ante-chamber in the LER. Figure 1 shows the fractions of recycled and newly fabricated magnets in the electron ring (HER) and the positron ring (LER).

Figure 1: Fractions of new and recycled magnets.

Most of the LER dipole magnets, including the wiggler magnets, were newly designed and fabricated. Eight sextupole magnets were installed in the HER local chromaticity correction (LCC) sections on either side of the interaction point (IP). The magnets in the IR were designed to fit in the small space, as shown in Fig. 2.

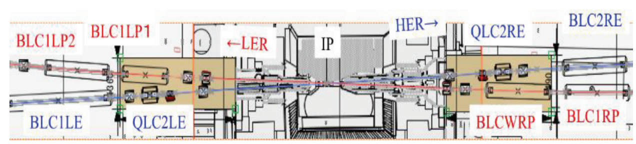

Figure 2: Top view of the SuperKEKB IR.

The tolerances for the magnetic fields are the same as for the KEKB MR magnets [4], except for the IR magnets. The tolerances on the multipole field errors of the IR magnets were determined from simulations of the dynamic aperture. The tolerances for the IR magnets are shown as the ratio of the sextupole component to the main dipole component, and of the dodecapole component to the main quadrupole component, in Table 2.

Table 1: Magnet Parameters

Ring	Magnet (main locations)	g/2 (mm)	Leff (m)	Max. B, B', B" (T),(T/m),(T/m^2)	I(A) × # turns/pole	# of magnets (Phase I)
HER	B (LCC sections)	55	3.96	0.3	1325×10	11
	B (IR)	55	3.60/2.23	0.112	500×10	1/1
	Q (LCC, etc.)	50	1.12/0.57	18.0	700×26	2/33
	Q (Arc sections)	50	0.82	12.8	500×26	8
	Q (IR)	55	0.53	2.0	500×6	2
	Sx (LCC sections)	56	0.608/0.509/0.335	472/465/447	600×22	4/4/2
LER	B (Arc sections, etc.)	55	4.19	0.19	840×10	114
	B (LCC sections)	55	3.96	0.3	1325×10	5
	B (IR)	55	2.2/1.6	0.223	1000×10	2/1
	Wiggler	55	0.34/0.22	1.18/0.76	1400×36	56/112
	Q (LCC, etc.)	83	0.58	6.3	500(600) ×35	12

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ISBN 978-3-95450-147-2

Table 2: IR Magnet Tolerances Evaluated at r = 50 mm

Magnet	Mag. B or B'	B3/B1, or B6/B2
Dipole	0.112/0.223 T	1%@50mm
Quadrupole	2.04 T/m	0.5%@50mm

FIELD MEASUREMENT RESULTS

The field strength and uniformity of the magnetic field are evaluated using long flip-flop coil and harmonic coil measurements. The effective lengths and longitudinal field profiles are evaluated using a small flip-flop coil, which moves along the longitudinal direction. The magnetic field evaluation was carried out on the recycled magnets, which are operated at higher currents than at KEKB, and also for the new magnets. The field strength variation among the magnets connected to the same power supply must be small. Figures 3 and 4 show the integrated field strength variation among the LER dipole magnets and the wiggler magnets. The standard deviations are measured to be 2×10^{-4} for the LER dipoles, which is sufficiently small. The wigglers vary more in strength, with a standard deviation of $\sim1\times10^{-3}$. This larger variation was expected as the wigglers are much shorter than the dipoles, as seen in Table 1. This variation is not a problem, since the errors can be compensated for by optical correction during beam operation.

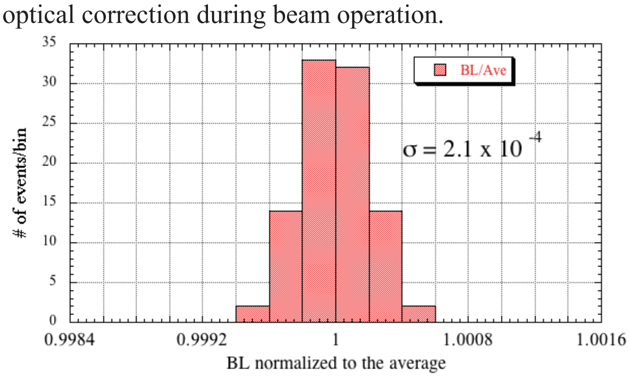

Figure 3: Field strength variation of the LER dipole magnets.

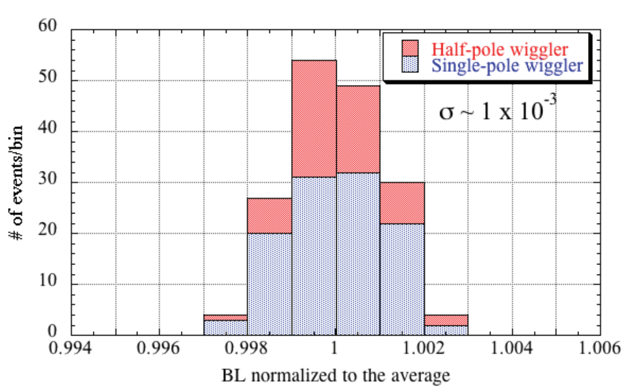

Figure 4: Field strength variation of the wiggler magnets.

Higher order multipole components were measured with the harmonic coil system and found to satisfy the requirements. As an example, the higher order components of the new IR quadrupole magnets are shown in Fig. 5.

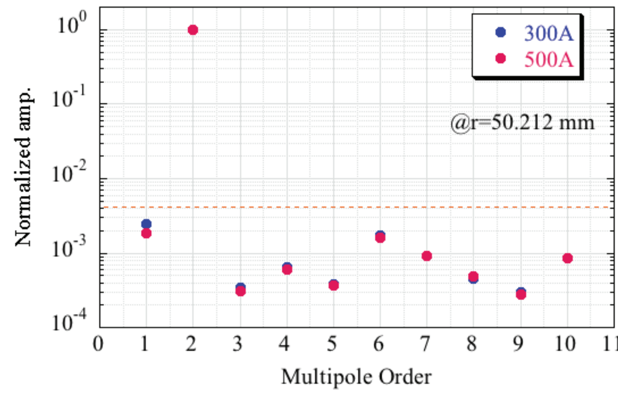

Figure 5: The measured higher order multipole components of the IR quadrupole magnets are plotted against the multipole order. Blue and red solid circles correspond to I=300 A and 500 A, respectively. The tolerance is indicated by the red dotted line.

The magnet fabrication and field measurements went smoothly for the most part, though there was a water leak caused by bad silver alloy brazing. The magnet data, the excitation curves and the effective lengths obtained from the field measurements were installed in the database in time for beam commissioning.

TILTING SEXTUPOLES

Skew sextupole magnets were found to be very effective in controlling the X-Y coupling at the IP during KEKB operation [5]. At SuperKEKB, the ratio of the skew and normal sextupole field will be controlled by tilting the sextupole magnets. The required range of the tilt is ±30 degree (~523 mrad), corresponding to 0~100% skew field.

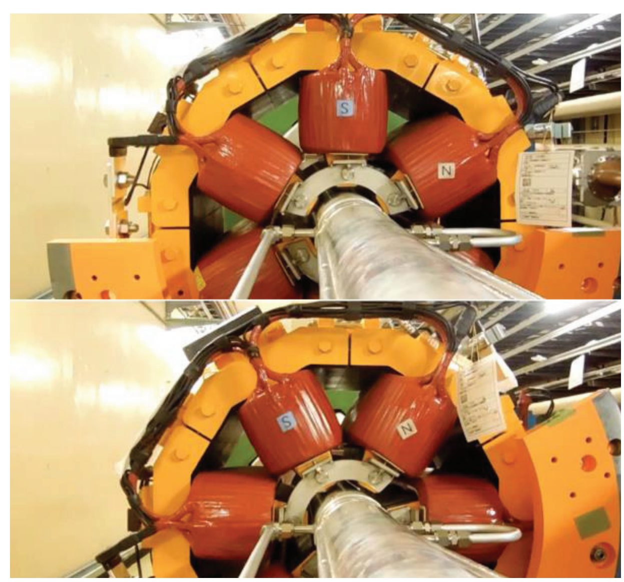

Figure 6: Sextupole on the tilting table.

ISBN 978-3-95450-147-2

Twenty four sextupole magnets, recycled from KEKB, were mounted on newly fabricated tilting tables to control the normal-to-skew-sextupole field ratio of each magnet. The tables were designed to allow for tilting of the sextupole magnets from -30° to +30°, with a high setting accuracy of 0.1 mrad [6]. Figure 6 shows a sextupole magnet with tilting table installed in the LER. The top picture shows the standard position, where the sextupole field is 100% normal and the bottom picture shows the magnet tilted by ~30 degrees. A precision inclinometer is used to monitor the tilt, and the setting accuracy of 0.1 mrad is achieved by iterative processes. This tilting sextupole system is scheduled to be tested during the SuperKEKB Phase I commissioning.

ALIGNMENT

The Great East Japan Earthquake in 2011 destroyed the reference points in the tunnel inherited from the KEKB alignment. This resulted in the need to build a new survey network. In parallel with the SuperKEKB magnet installation and alignment work in the tunnel, new utility buildings for new power supplies and water supply systems were being constructed. A new beam transport line to another accelerator complex was also being built just a few meters above the SuperKEKB tunnel. This heavy construction work made the establishment of the new survey network and alignment work very difficult.

The survey campaign was carried out using laser trackers. All the magnet fiducials and survey network reference points in the tunnel, which add up to more than 4700 points, were surveyed and analyzed. A reference curve was obtained and the magnets were aligned to this curve. Figure 7 shows the result of the 1st alignment in the HER. The magnets with errors larger than the tolerances were realigned in the 2nd alignment campaign.

The magnet roll was measured and adjusted using a digital inclinometer, while the horizontal and vertical positions were adjusted using a laser tracker. The analysis predicted the circumference of the ring correctly within ~2 mm out of ~3016 m, which facilitated the achievement of the first beam circulation. The difference between the HER and LER circumferences is compensated by chicane magnets. It was found that the difference was only ~0.2 mm.

The details of the alignment strategies, and the very successful alignment work, will be reported at IWAA (International Workshop on Accelerator Alignment) 2016 [7].

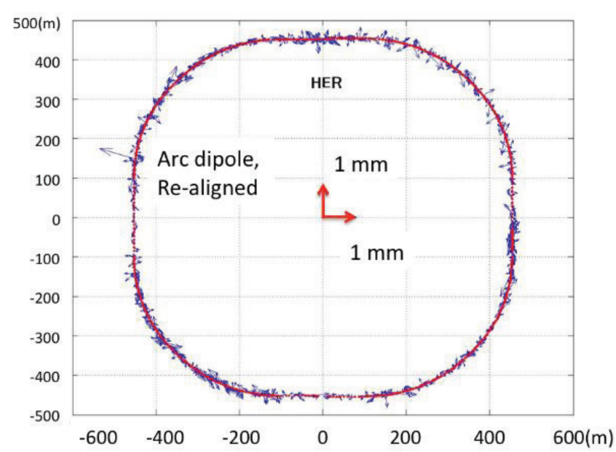

Figure 7: The magnitudes and directions of the magnet misalignments are indicated by arrows, in this example for the HER.

POWER SUPPLIES

Most of the ~2300 power supplies are reused from KEKB, with ~620 being overhauled. There are ~700 power supplies newly fabricated for SuperKEKB, which includes the large (~1 MW class) power supplies for the main dipole and wiggler magnets. They are operated using a "digital feedback" scheme in order to control the output current to within ±1 ppm [8]. The LER dipole power supply output is shown in Figure 8 as an example of the performance of this scheme; the drift over the course of 36 hours is observed to be less than 1ppm.

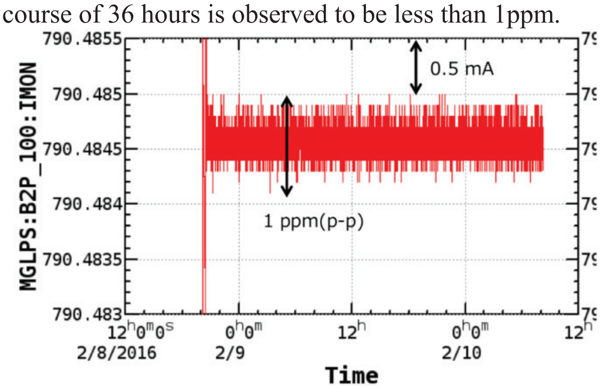

Figure 8: LER dipole power supply output with digital feedback on.

CONCLUSION

The SuperKEKB MR magnet system was completed in time for Phase I commissioning. The field measurements were carried out on all newly-fabricated magnets and some recycled magnets. The dipole magnets were replaced by longer ones in the LER. New wigglers were installed at two straight sections in the LER, and recycled wigglers were installed in the HER. The magnets in the IR, and the straight sections on either side of the IP, were removed after the KEKB operation was finished. The magnets were then installed to these areas according to the completely new required layouts. The alignment work was carried out using laser trackers and digital inclinometer. The difference in the circumference in both rings was found to be ~0.2 mm. The power supply system is up and running smoothly with very high stability. We are preparing for the installation of the final focusing superconducting quadrupole system, which will take place in July, 2016.

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ISBN 978-3-95450-147-2