

Chapter 7

Magnet System

In this chapter, we describe designs of magnet system including the parameters for SuperKEKB. Special magnets in the near beam collision points are also discussed.

7.1 Magnets in the Arc and Straight Sections

The basic design concepts for SuperKEKB are:

- Use the KEKB tunnel,
- Use the components of KEKB as much as possible;
 - Preserve the present cells in the HER,
 - Replace dipole magnets, keeping other main magnets in the LER arcs.

While utilizing existing resources, we also have major upgrade plan to achieve new low emittance beam optics for both LER and HER.

- Replace dipoles and change the wiggler layout for LER,
- Install wiggler magnets in HER,
- Increase number of quadrupole magnets in HER.

7.1.1 LER

To achieve a few nm in emittance, there are two steps to be taken. First, bending magnets in the arc have to be from 0.9-m types to 4.0-m types, which allow to decrease field strength. And, the number of quadrupole magnet is increased. Second, shortening

Designation	Half gap or bore radius (mm)	L_{lam} or L_{eff} (m)	$B,$ $B'(T/m),$ $B''(T/m)$	current \times turns / pole	Number of magnets	Usage	new or reuse
Dipole magnets							
B_{lc}	57 (min. 55)	2.23	0.22	1000A \times 24 or 1000A \times 24	11	local correction	reuse
	55	3.99	0.17	860A \times 10	5	local correction	new
B_{arc}	55	4.19	0.22	860A \times 10 or 1100 \times 10	14	normal	new
	55	4.19	0.18	860A \times 10	100	normal	new
	57 (min. 54)	0.89	0.42	200 – 1250A \times 32	20	normal	reuse
B_s	57 (min. 54)	0.43	0.21	500A \times 20	1	transIR	reuse
B_{v2}	55	1.4	0.2	500A \times 18	4	vertical	reuse
Quadrupole magnets							
Q_{rf}	83	0.58	7.2	600A \times 35	10	RF section	new
	83	0.58	7.2	500A \times 35	37	RF section arc,	reuse
Q_{arc}	55	0.46	9.0	500A \times 25	120	straight arc,	reuse
	55	0.46	7.5	500A \times 25	271	straight	reuse
Sextupole magnets							
SL	56	0.3	98.83	425A \times 21	8	focus defocus	reuse
SF, SD	56	0.3	327.6	425A \times 21	100	f,d	reuse
wiggler magnets							
double pole	55	0.75	0.77	1400A \times 36	112	wiggler	new
single pole	55	0.75	0.77	1400A \times 36	56	wiggler	new
half pole	55	0.75	0.77	1400A \times 36	56	wiggler	new

Table 7.1: LER (e+) Magnet types.

Designation	Half gap or bore radius (mm)	Lam. length (m)	$B,$ $B'(T/m),$ $B''(T/m)$	current \times turns /pole	Number of magnets	Usage	new or old
Dipole magnets							
B_{lc}	55	4	0.20	860, 880 or $1100A \times 10$	11	local correction	new
B_{arc}	35 (33.15)	5.9	0.2	$840A \times 10$	113	normal	reuse
	57 (54)	0.76	0.22	$500A \times 32$	1	arc	reuse
	35 (33.15)	1.14	0.02	$500A \times 12$	1	arc	reuse
	35 (33.15)	1.14	0.2	$1000A \times 24$	2	arc	reuse
Quadrupole magnets							
Q_{arc}	55	0.46	5.0	$500A \times 25$	4	arc arc,	reuse
	50	0.56	13.6	$700A \times 27$	33	straight	new
	50	1.12	14.2	$700A \times 27$	2	arc	new
	50	0.55	14.2	$500A \times 26$	80	straight arc,	reuse
	50	0.83	8.7	$500A \times 17$	195	straight arc,	reuse
	50	0.83	8.7	$500A \times 26$	8	straight arc,	new
	50	1.0	6.9	$500A \times 17$	97	straight arc,	reuse
Q_x	50	0.82	8.9	$500A \times 26$	4	straight	reuse
Q_{rf}	83	1.0	4.35	$500A \times 35$	31	RF section	reuse
Q_{wig}	55	0.46	9.7	$500A \times 25$	7	wigg. section	reuse
Sextupole magnets							
SL	56	0.6	353	$600A \times 22$	4	normal	new
	56	0.5	322	$600A \times 22$	4	normal	new
SX_{abort}	56	0.3	322	$600A \times 22$	2	abort	new
SF	56	0.3	304	$425A \times 21$	52	focus	reuse
SD	56	1.0	316	$425A \times 21$	48	defocus	reuse
Wiggler magnets							
55	help	0.77	$800A \times 36$	36	wiggler	recycle	

see details for recycled magnets KEKB design report.

Table 7.2: HER (e-) Magnet types.

Tolerance at 50mm radius	
Dipole magnets	$B_3 / B_1 < 0.12\%$
	$B_5 / B_1 < 0.45\%$
Quadrupole magnets	$B_6 / B_2 < 0.12\%$
	$B_{10} / B_2 < 0.14\%$

Table 7.3: Tolerances of systematic multipole errors.

the wiggler period by half is also effective for lower emittance. Wiggler magnets, which are usually installed as synchrotron radiation sources, deflect the electron (or positron) beam in alternate directions, producing an angular excursion of the beam and emitting electromagnetic radiation. However, the electrons leave the magnet in the same way they would if the magnet were turned off, that is, they produce no net deflection or displacement of the beam orbit. We will discuss details of about Wiggler magnets later in this section.

Table 7.1 summarizes the magnets the magnets that required for the LER. Four types of dipole bend magnets are needed in the LER: B_{arc} , B_{lc} , B_s and B_v . Two types of quadrupole magnets (Q_{arc} and Q_{rf}), and three types of sextupole magnets (SL, SF and SD) are presented. In addition to them, wiggler magnets are also presented.

Dipole Magnets

The LER requires 155 dipole magnets except near IR region. They include 119 new magnets. Cross section view of B_{arc} and B_{lc} are same and shown in Figure 7.1.

Quadrupole Magnets

There are 438 quadrupoles in the LER. The 391 will be used for the arc and the straight sections, except for the beam line that includes RF cavities. For the RF sections, 47 which have larger aperture will be used. Cross section view of Q_{rf} is shown in Figure 7.2.

Table 7.3 depicts the tolerances on the multipole field errors for the dipole and quadrupole magnets. These values have been determined from studies on the expected dynamic aperture and emittance coupling. We should emphasize that these requirements are well met by existing magnets in the KEKB Main Ring.

	LER	HER
Vertical steering		
Number of Magnets	195	215
Bore radius	133	133
Lamination core length	0.2m	0.2m
Current \times turns/pole	5A \times 162	5A \times 162

Table 7.4: Parameters of the vertical steering magnets for the LER and HER.

Wiggler Magnets

The wiggler magnets will be used to control the radiation damping time. Figure 7.4 depicts a double pole wiggler, called a "KEKB wiggler". The type of electromagnetic radiation produced depends on how quickly the beam wiggles. The role of the wiggler magnets in KEKB and Super KEKB is to control the emittance of the beam. Therefore, we shorten the wiggler period by half and increase the peak field from 0.77 T to 0.98 T. We expect emittance to decrease to one-fifth that of KEKB. As shown in Figure 7.3, this new wiggler system design requires two new H-type magnets (single-pole wigglers (WS) and half-pole wigglers (HS)), and they are interleaved between the existing "KEKB wigglers".

Vertical steering Magnets

Table 7.4 depicts parameters of the new vertical steering magnets. They include 225 new magnets. The maximum kick angle of 1 mrad is assumed for the vertical steering magnets. Almost same number of horizontal steering magnets are needed as well, which are reuse of KEKB horizontal steering magnets.

7.1.2 HER

Table 7.2 summarizes the magnets the magnets that required for the HER. The HER emittance can be decreased to 5 nm by preserving the KEKB cell structure and reducing the electron beam energy down to 7 GeV (24 nm at 8GeV in KEKB). But there is one major change in the HER. A wiggler section is newly installed in one of the straight sections, which the KEKB HER did not have. In the current design, the rest of the "KEKB" wigglers are installed. In case of full wiggler installation, we expect emittance reduction down to 4 nm.

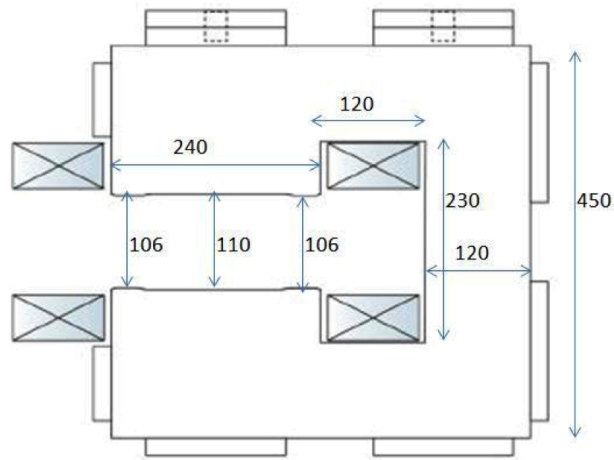


Figure 7.1: Cross section view of the design of a LER dipole magnet (B_{lc} and B_{arc}).

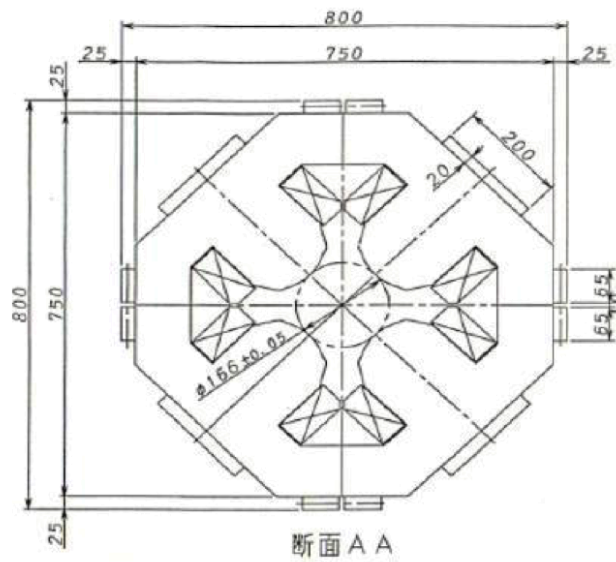


Figure 7.2: Cross section view of the design of a LER quadrupole magnet (Q_{rf}).

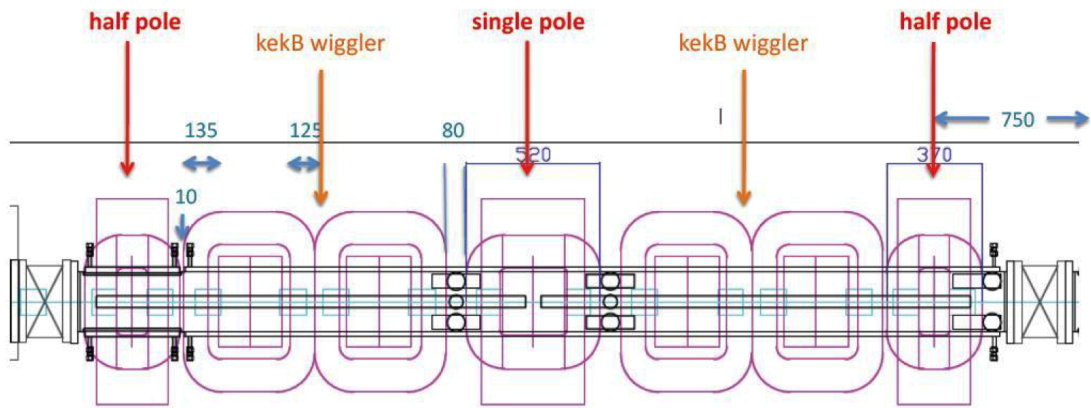


Figure 7.3: New wiggler system. Pole size of "KEKB", "single-pole" and "half-pole" types are 250mm, 280mm and 150mm, respectively.

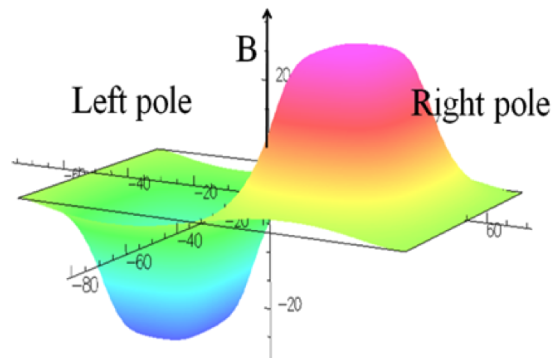


Figure 7.4: Left: Picture of double-pole wiggler magnet "kekB wiggler". Right: Field strength for left and right poles calculated by OPERA-3D.

Designation	Half gap or bore radius (mm)	Lam. length (m)	$B,$ $B'(T/m),$ $B''(T/m)$	current \times turns /pole	Number of magnets
Dipole magnets					
BLC1LP1, BLC1RP	112	1.59,2.13	0.2232	1000A \times 10	2
other BLC type	112	2.13, 3.5	0.117	500A \times 10	4
vertical steering bend					
BC1RP, BC1LP	66	0.2	0.048	10A \times 25	2
BC* E, BC*P, (* = 1 - 4)	133	0.2	0.136	20A \times 720	8
Quadrupole magnets					
QLC2LE, QLC2RE	55	0.5, 0.54	2.04	500A \times 6	2
QK*E, QK*P	134	0.3	2.04	10A \times 20	17

Table 7.5: Summary of new near IR Magnets.

Dipole Magnets

The HER requires 128 dipole magnets except near IR region. They include 11 new magnets for local correction. But we reuse most of magnets from KEKB.

Quadrupole Magnets

There are 461 quadrupoles in the HER. They include 54 new magnets. For the RF sections, 31 of Q_{rf} which have larger aperture will be used. Seven of Q_{wigg} are installed at wiggler section.

7.1.3 Magnets in the near Interaction Region

Figure 7.5 and figure 7.6 depict the beam lines in the very near IR region for SuperKEKB. To achieve a few nm in emittance, the new design of beam line in the near interaction region is completely changed from KEKB. Crossing angle of the LER and the HER changes from 23 mrad to 83 mrad. Some magnets get closer to the interaction point. It turns out that distance between the LER and the HER beam lines can be 340 mm in the smallest case (BC1LP and QKALE in figure 7.5, and BC1RP and QKARE in figure 7.6). Therefore, magnets in the near interaction region should be carefully designed taking in to consideration of their alignment and installation procedure. Table 7.5 depicts parameters of the magnets in the near interaction region, which are newly fabricated for SuperKEKB.

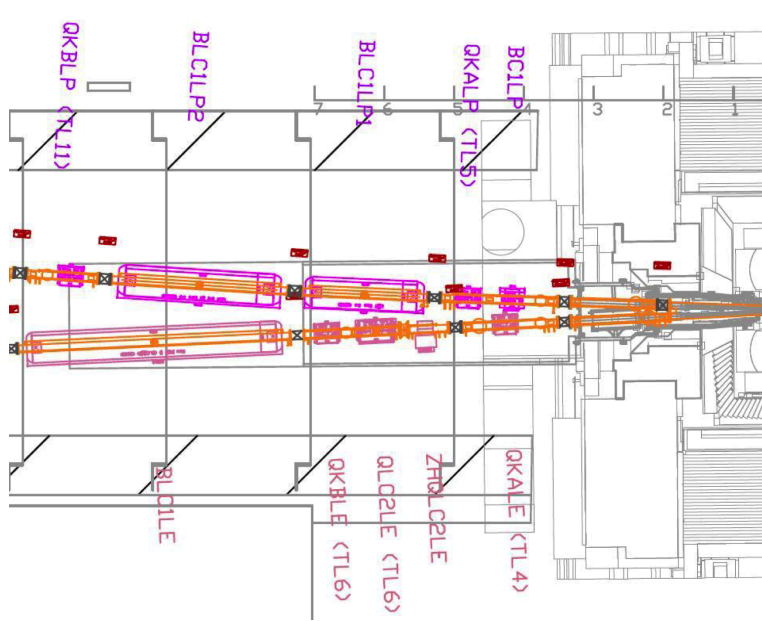


Figure 7.5: "D2" side of the near IR beam line

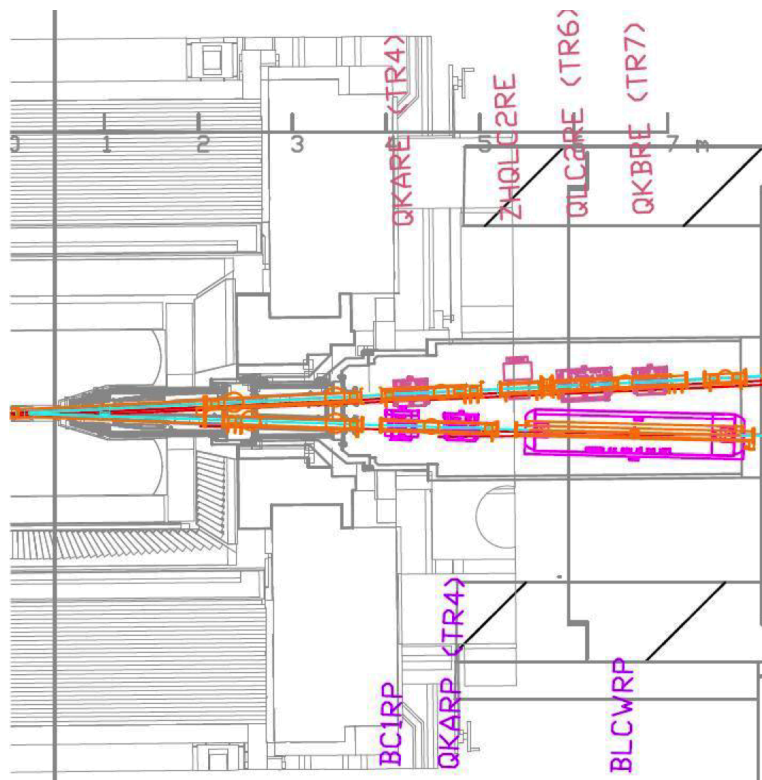


Figure 7.6: "D1" side of the near IR beam line

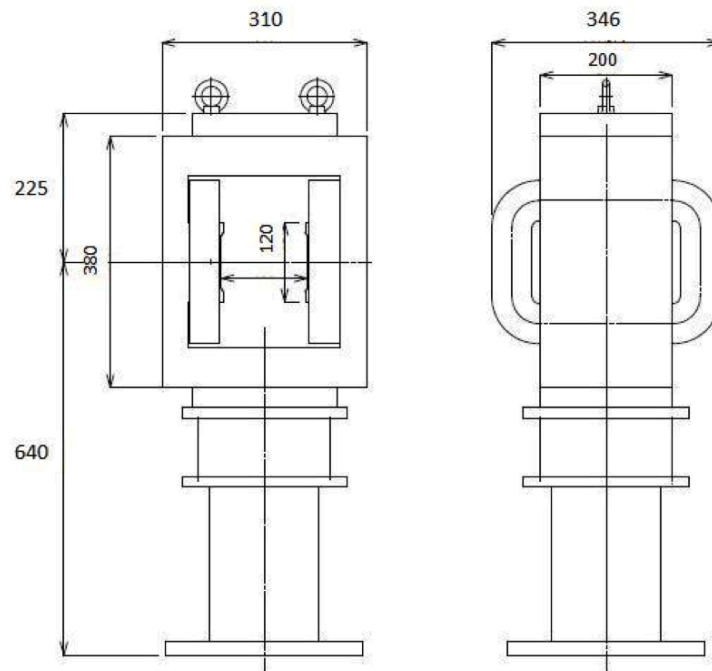


Figure 7.7: Design of vertical steering magnet (BC1LP and BC1RP).

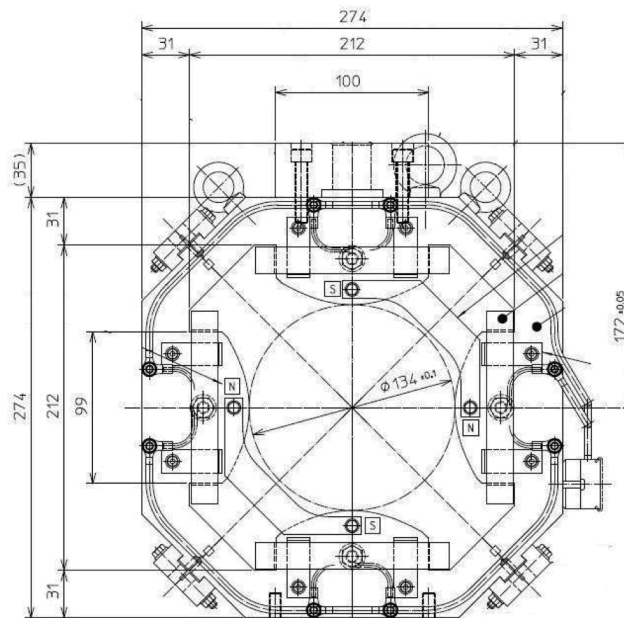


Figure 7.8: Design of skew quadrupole magnet (QK type).

7.2 Cooling water system for the magnets

Most of the SuperKEKB magnets are water-cooled resistive magnets of hollow copper conductor. The number of water-cooled magnets is increasing from ~ 1600 in KEKB to ~ 2000 in SuperKEKB, mainly in the Oho and Nikko straight sections where newly fabricated wiggler magnets are installed. The water to the ~ 1600 magnets was supplied by the four pumping systems located near the Tsukuba, Oho, Fuji and Nikko experimental halls for KEKB. Each pumping system is capable of supplying pure water at up to 4000 liters/minute. New utility buildings are to be built at four locations in between the existing experimental halls to meet the needs of the increased number of water-cooled magnets for SuperKEKB. Modifications to the water distribution systems, including the addition of pipes from the new utility buildings to the tunnel, will also take place. The water system for the SuperKEKB main ring magnets follows that of KEKB. For example, flow rates to the individual magnets will be measured using ultrasonic flow meters, and the flow rates are adjusted by closing/opening the globe valves if needed. Each magnet is equipped with a flow switch and the interlock level will also be adjusted.

7.3 Alignment

The alignment tolerance is of the same order as that for KEKB. The KEKB magnet positions would have provided excellent reference points for aligning new magnets in the Tsukuba straight section had it not been for the effects of the Great East Japan Earthquake on March 11th, 2011. The earthquake created considerable damage in the tunnel area with large movements and changes in alignment being observed, particularly on either side of expansion joints. This is not surprising, as the expansion joints completely decouple the adjacent concrete structures so that they will move independently of each other in the event of an earthquake. This created very large misalignments where the beams and magnets crossed these expansion joints. The locations of all the expansion joints are easily seen when looking at the post-earthquake alignment measurements. Several types of earthquake-related damage occurred within the tunnel complex, including: cracking of platforms and concrete structures, liquefaction in places, surface soil disruption cracks, floor movement, cracks (both structural and superficial), and large shifts in magnet and equipment stands. The environmental conditions could no longer be controlled in the tunnel after the earthquake, and the temperature variation is ± 7 degrees of the nominal operating temperature. Precision alignment of the magnets is therefore planned to be carried out once the environmental

controls and temperature stability of the tunnel have been re-established.

7.4 Magnet Power Supplies

The main issues of the upgrade from KEKB to SuperKEKB related to the magnet system are as follows:

1. full rearrangement of the magnets in the Tsukuba straight section, including superconducting magnets and correction coils in the interaction region,
2. replacement of the LER main bending magnets by longer ones,
3. increase of LER wiggler magnets in magnet type and number, and new installation of wiggler magnets in HER.
4. higher precision of magnetic fields, particularly of the main bending magnets and the superconducting quadrupole magnets in the interaction region.

The tasks on the magnet power supplies are hence set as bellow:

1. R&D to attain high stability of output current and precision of current setting,
2. fabrication of new power supplies,
3. maintenance of existing power supplies,
4. management of cables and power-supply stations,
5. upgrade and maintenance of the control system.

7.4.1 Improvement of Output-Current Stability and Current-Setting Precision

At KEKB, the typical specifications of the power supplies were as follows:

output-current stability : ≤ 100 ppm/month, ≤ 20 ppm/day
magnetic-field ripple : ≤ 10 ppm
precision of current setting : ± 50 ppm

In SuperKEKB, the power supplies for the main bending magnets and the superconducting quadrupole magnets should have higher performance:

output-current stability : ≤ 10 ppm/month, ≤ 2 ppm/day
current ripple : ≤ 1 ppm (rms)
precision of current setting : ≤ 1 ppm
temperature coefficient of output current : ≤ 0.1 ppm/K

In order to regulate the output current with high stability, the followings are important: (1) electronic parts with small temperature coefficients should be used, and if necessary, they will be contained in a thermostatic box; (2) the devices for current monitoring and setting should have high resolutions; (3) the current-control circuit should be elaborately designed and fabricated.

Our current-control circuit should have two feedback loops: a major loop and a minor one. The former, having fast response, shares coarse control, and the latter, having slow response, shares fine control. Since an analogue feedback loop of a standard current-control circuit has fast response, it will be applied to the major feedback loop. It will work efficiently in a transient stage, where the current-setting value changes, and will suit also reduction of low-frequency components ($<$ a few kHz) of current ripple. The analogue feedback will, however, fail in fine regulation, because an analogue circuit is inherently noisy. A digital feedback loop shall hence take over the fine regulation. The output current is measured on a high-performance DCCT (DC current transformer) and an 8.5-digit digital multimeter. The measured current value is compared with the reference value; the both values are digital. The difference between them is fed back into the input of a DAC (digital to analog converter). The DCCT electronics and the multimeter will be installed in a thermostatic chamber beside the power supply.

The DAC should have a resolution of more than 20 bits, the current measurement in the feedback loop should be accurate. Since high-performance 20-bit DAC's are commercially available, we will develop a 24-bit DAC circuit by combining 20-bit DAC's. For instance, 20 bits of one DAC are used for coarse setting and 4 bits of another for fine setting. Another idea is to divide the full range into 16 and allot one division to one 20-bit DAC.

Noise suppression is another key issue for a switch-mode power supply. The switching, of which the typical frequency is a few kHz or higher, generates noises with high-frequency components below a few MHz. Because the analogue feedback loop is not effective at all in such high frequencies, proper passive filters should be prepared.

7.4.2 Fabrication and Maintenance of Power Supplies

In KEKB, the number of power supplies for normal-conducting magnets was about 2300: 28 large-size power supplies (rated output power \geq 135 kW), 374 middle-size ones (6 ~ 105 kW), and ~1900 small-size ones (325 ~ 700 W). Most of them shall operate in SuperKEKB. Overhaul is planned to the large- and middle-size power supplies to be reused. Old electronic parts, such as electrolytic capacitors, variable resistances, DC power supplies, circuit breakers, and IGBT's (Insulated Gate Bipolar Transistors) are

Ring	Rated current	voltage	power	Number of PS's	Number of magnets/PS	DAC resolution
HER	860 A	1100 V	946 kW	1	105	24 bits
LER	860 A	1100 V	946 kW	1	100	24 bits

Table 7.6: The power supplies (PS's) for the main bending magnets.

	Rated current	voltage	power	Number of PS's	Number of magnets/PS	DAC resolution
HER	800 A	500 V	400 kW	1	36	24 bits
LER	1400 A	350 ~ 750 V	490 ~ 1050 kW	8	26 ~ 52	24 bits

Table 7.7: The power supplies for the wiggler magnets

to be replaced. Overhaul of small-size power supplies hinge on budget.

In SuperKEKB the number of power supplies for normal-conducting magnets is about 2400, and about 60 for superconducting magnets. About 400 new power supplies are to be fabricated.

Power Supplies for the Main Bending Magnets

In each of the KEKB rings, two power supplies operated for the main bending magnets. Their rated outputs were 840 A, 590 V (HER) and 1250 A, 770 V (LER). The power modules were thyristors. The four power supplies were too old to be used in SuperKEKB, because they had worked not only in KEKB but also in TRISTAN. As listed in Table 7.6, the new power supplies are two identical ones (1 power supply/ring) with rated outputs of 860 A and 1100 V. The power modules are IGBT's, and the resolution of the DAC's are 24 bits.

Power Supplies for Wiggler Magnets

There were 76 identical wiggler magnets in each of the Oho and Nikko straight sections of KEKB LER. Four identical power supplies with rated outputs of 1000 A and 700 V excited them (38 wiggler magnets per power supply). Except for rated outputs, they were same as the power supplies for the main bending magnets. Replacement by new ones is hence necessary. In SuperKEKB, most of the KEKB magnets are reused, and two different types of magnets are added. Moreover, a set of wigglers are to be installed in the Oho straight section of HER. The number of new power supplies is accordingly nine: 1 in HER Oho, 4 in LER Oho, 4 in LER Nikko (see Table 7.7). The power supplies are same as those for the main bending magnets, except for rated outputs.

Ring	Rated current	voltage	power	Number of PS's	Number of magnets/PS	DAC resolution
HER	500 A	270 ~ 930 V	135 ~ 465 kW	7	22 ~ 48	20 bits
LER	500 A	440 ~ 800 V	220 ~ 400 kW	7	22 ~ 48	20 bits

Table 7.8: The power supplies for the main quadrupole magnets.

Power Supplies for the Main Quadrupole Magnets

There were seven sets of main quadrupole magnets in each of LER and HER of KEKB. The magnets were excited by fourteen 500-A power supplies. They shall work in SuperKEKB after being overhauled and improved (see Table 7.8). For more precise regulation of the tune values of betatron oscillation, the resolution of the DAC's for current setting, which was 18 bits in KEK HER and 16 in LER, is to be increased to 20 bits. The current-monitor signals were so noisy that circuits and cable paths are to be improved. The cabinets of the power supplies lie in contact with the floor. For better grounding, the cabinets will be isolated from the floor and the water pipes.¹

Middle-Size Power Supplies

There were 374 middle-size power supplies for local bending, quadrupole, and sextupole magnets in KEKB. In SuperKEKB, 335 out of them will be used, and 39 will be kept as spare. Reused power supplies are listed in Table 7.9.

The number of power supplies to be fabricated is 92 (see Table 7.10); 53 out of them are for magnets in the Tsukuba straight section. The specifications of the 92 power supplies (> 10 kW) are as follows.

- output-current stability : ≤ 100 ppm/year, ≤ 20 ppm/day
- current ripple : ≤ 10 ppm (peak-to-peak)
- DAC resolution : 20 bits
- temperature coefficient of output current : better than ± 0.6 ppm/K

Small-Size Power Supplies

In KEKB, the number of small-size power supplies was about 1820: ~ 1220 were used for steering magnets, auxiliary coils, and skew sextupole magnets, and ~ 600 for solenoids, which suppressed the electron-cloud effect in LER. The power supplies are bipolar ones with rated output current of ± 5 A and ± 10 A. Most of them are to be used

¹ The cabinets of the power supplies were not isolated from floors in KEKB. In SuperKEKB, the cabinets of large- and middle-size power supplies will be isolated.

Magnet, coil	Rated			Number of PS's
	current	voltage	power	
Local	1250 A	30 V	38 kW	3
bending, quadrupole, sextupole magnets	1000 A	105 V	105 kW	2
	840 A	15, 30 V	13, 25 kW	4
	600 A	15 ~ 60 V	9 ~ 36 kW	16
	500 A	10 ~ 120 V	5 ~ 60 kW	198
	425 A	35 ~ 80 V	15 ~ 34 kW	104
	300 A	60 V	18 kW	1
	200 A	40 V	8 kW	1
Lambertson magnet (HER) [†]	230 A	80 V	18 kW	1
Lambertson magnet (LER) [†]	200 A	70 V	14 kW	1
Auxiliary coils [‡]	±30 A	±200 V	6 kW	4

[†] for beam abort. [‡] for beam-based alignment.

Table 7.9: Middle-size power supplies to be overhauled for SuperKEKB

Magnet	Rated			Number of PS's
	current	voltage	power	
Local	1100 A	30 ~ 45 V	33 ~ 50 kW	6
bending, quadrupole, sextupole magnets	1000 A	30 ~ 45 V	30 ~ 45 kW	3
	880 A	35 V	31 kW	2
	860 A	25 ~ 35 V	22 ~ 30 kW	11
	700 A	40 ~ 60 V	28 ~ 42 kW	17
	600 A	38 ~ 75 V	23 ~ 45 kW	11
	500 A	35 ~ 75 V	18 ~ 38 kW	42

Table 7.10: Middle-size power supplies to be fabricated

Magnets, coils	Rated			Number of PS's
	current	voltage	power	
Steering magnets	± 5 A	± 65 V	325 W	439
Steering magnets	± 5 A	± 100 V	500 W	385
Vertical bending magnets	± 10 A	± 50 V	500 W	2
Auxiliary coils on bending magnets	± 10 A	± 50 V	500 W	80
Auxiliary coils on chicane magnets	± 5 A	± 65 V	325 W	2
Skew quadrupole magnets	± 10 A	± 50 V	500 W	16
Skew sextupole magnets	± 10 A	± 50 V	500 W	10
Correction coils on quadrupole	± 5 A	± 65 V	325 W	546
Skew quad. coils on sextupole magnets	± 10 A	± 50 V	500 W	169
Skew quad. coils on sextupole magnets	± 10 A	± 80 V	800 W	47
Bump magnets in interaction region (DC)	± 60 A	± 50 V	3,000 W	12
Bump magnets in interaction region (AC)	± 60 A	± 50 V	3,000 W	16
Vertical bending magnets	20 A	120 V	2,400 W	10

Table 7.11: Small-size power supplies

Rated		Number of	
current	voltage	power	PS's
10 A	300 V	3,000 W	~ 160
5 A	300 V	1,500 W	~ 80

Table 7.12: The power supplies for solenoids to suppress electron cloud

in SuperKEKB, where about 1700 small-size power supplies are necessary, as listed in Table 7.11. The number of reused power supplies is so large that implement of overhaul hinges on budget. We need about 320 power supplies of ± 10 A, but we have only 120 in stock. It is necessary to fabricate 140 power supplies of ± 10 A, ± 50 V and 60 ones of ± 10 A, ± 80 V. For vertical bending magnets placed near the interaction region, we will fabricate ten 20-A unipolar power supplies.

Power supplies for Solenoids against Electron-Cloud

During the KEKB operation, power supplies prepared for LER steering magnets were utilized for solenoids that suppress the electron-cloud effect in LER. The rated outputs were ± 5 A, ± 65 V and ± 5 A, ± 100 V. In SuperKEKB, unipolar power supplies with higher rated voltages shall replace the bipolar ones, as shown in Table 7.12.

Power Supplies for Superconducting Magnets and Correction Coils

Superconducting magnets are installed in the interaction region. In KEKB, the number of power supplies was 9: 1 (rated output current was 4000 A), 6 (50 A), and 2 (650 A).

Magnet, coil	Rated			Number of PS's	DAC resolution
	current	voltage	power		
Quadrupole magnets	1000 ~ 2000 A	10 V	10 ~ 20 kW	8	24 bits
Solenoids	200 ~ 500 A	15 V	3 ~ 7.5 kW	4	20 bits
Correction coils	±60 A	±5 V	0.3 kW	~45	16 bits

Table 7.13: The power supplies for superconducting magnets in the interaction region.

The 4000-A power supply was for quadrupole magnet. The 50-A ones were connected to correction coils for beam steering and skew-quadrupole correction. A pole-changer was attached to each of the power supplies. The 650-A power supplies excited solenoids, which canceled the magnetic field produced by the Belle solenoid.

In SuperKEKB, about 60 power supplies are necessary, as listed in Table 7.13. All of them are to be newly fabricated. The power supplies for quadrupole magnets are difficult in their circuit design for the following reasons: 1) high performance is required in stability, precision, and ripple; 2) the inductances of the superconducting coils are very small (0.9 mH at minimum); 3) the output current has to fall to zero immediately after quench (in 20 ms or less). We plan to fabricate first a prototype power supply; we will be thereby able to solve the technical problems.

7.4.3 Management of Cables and Power-Supply Stations

Every power supply of KEKB connects with cables for AC input, DC output, interlock, output-current monitor, and control. In SuperKEKB the existing cables will be used for as many as possible. In the Tsukuba straight section, where the magnets are to be fully rearranged, we will remove the power cables between the magnets and the power supplies and lay new cables. An estimated cable length is 50 km or longer.

The earth-leakage circuit breakers and molded-case circuit breakers in AC lines (100 V, 210 V, 420 V) are so old that they should be replaced with new ones. In the D2 power station, where power supplies for the magnets in the Tsukuba straight section are installed, the circuit-breaker boards are to be rearranged in accordance with the increase of power supplies. Compact arrangement of the power supplies is required in D2 because of its limited area. The power supplies for superconducting magnets stood by those for normal conducting magnets in KEKB. In SuperKEKB, another area is necessary for the new power supplies.

7.4.4 Upgrade and Maintenance of the Control System

The network system for the control of the power supplies from the central control room will be ARCNET in SuperKEKB as well as in KEKB. The interface boards, which are slotted into the power supplies, are so old that they will be replaced with new ones. Since some electronic parts on the board are unavailable today, we must design new interfaces. Three types of interface are necessary in accordance with the three DAC resolutions: 16, 20, and 24 bits.

The current monitor system for measuring output currents of the power supplies and transferring them to the data-logging system in the central control room will not be changed. In the system, one digital multimeter is connected to several tens power supplies via a switching circuit. These devices will be overhauled, and a few will be purchased.

A power supply is forced to stop by external interlock in a case of insufficient water-flow in a magnet coil, increase of coil temperature, turning off of warning lights, and emergency stop from the central control room. The PLC (Programmable Logic Controller) system that controls these interlocks will be renewed for two reasons: one is that the KEKB's PLC is old, and the other is that its capacity is insufficient for the increase of power supplies.