DESIGN PROGRESS AND CONSTRUCTION STATUS OF SuperKEKB

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Abstract

The upgrade of KEKB to SuperKEKB is going on. The construction started in FY2010, and the beam commissioning is scheduled in FY2014. This paper describes recent design progress and construction status of the SuperKEKB main rings and the positron damping ring.

INTRODUCTION

Operation of KEKB finished in June 2010, and the upgrade to SuperKEKB[1] is now going on in full swing. The design luminosity of SuperKEKB is 8×10^{35} $\mathrm{cm^{-2}s^{-1}}$, which is 40 times higher than that achieved at KEKB. The design strategy for SuperKEKB is based on the Nano-Beam Scheme, originally proposed by P. Raimondi for SuperB[2]. In the Nano-Beam Scheme, the vertical beta functions at the interaction point (IP) are squeezed to be β_y^* ~300 μm (1/20 those of KEKB) with a large Piwinski angle ($\phi_{\mathrm{Piw}} \equiv \theta_x\sigma_z/\sigma_x^* \geq 20$). Not only β_y^* but also β_x^*, emittances and x-y couplings are to be deceased drastically. In addition, the stored beam currents in the LER and the HER are doubled those in KEKB. Machine parameters are summarized in Table 1. This paper describes status of the SuperKEKB main rings and the positron Damping Ring (DR). The status of the injector linac will be presented elsewhere[3].

Table 1: Main machine parameters of SuperKEKB. The values in parentheses denote parameters without intra-beam scattering.

	LER (e+)	HER (e-)	units
Beam energy	4	7.007	GeV
Circumference	3016.315		m
Half crossing angle θ_x	41.5		mrad
Piwinski angle	24.6	19.3	rad
Horizontal emittance	3.2 (1.9)	4.6 (4.4)	nm
Vertical emittance	8.64	11.5	pm
Coupling	0.27	0.28	%
Beta function at IP (x/y)	32 / 0.27	25 / 0.30	mm
Vertical beam size at IP	48	62	nm
Energy spread	8.14	6.49	10^{-4}
Beam current	3.60	2.60	A
Number of bunches	2500		
Energy loss/turn	1.87	2.45	MeV
RF frequency	508.9		MHz
RF voltage	9.4	15.0	MV
Bunch length	6.0	5.0	mm
Beam-beam param. (x)	0.0028	0.0012	
Beam-beam param. (y)	0.088	0.081	
Total beam lifetime	324	357	sec
Luminosity	8×10^{35}		$\mathrm{cm^{-2}s^{-1}}$
Integrated luminosity	50		$\mathrm{ab^{-1}}$

DESIGN PROGRESS

To achieve the extremely small β_y^*, a new final focus system (Fig.1) consisting of 8 superconducting quadrupoles and compensation solenoids is built[4], and the interaction region (IR) which includes local chromaticity correction sections on each side of the IP is fully reconstructed.

The dynamic aperture is very sensitive to nonlinear magnetic fields of the final focus section, then precise modeling of IR beam optics is indispensable[5]. As well as the nonlinear fields associated with the final quadrupoles, skew multipole fields along the beam line in the nonuniform solenoid fields are also taken into account, since a large horizontal crossing angle with respect to the solenoid axis is adopted in the Nano-Beam Scheme. Normal and skew higher multipoles up to K21 and SK21 ($\mathrm{Kn} = \int \frac{1}{\mathrm{B}\rho}\frac{\partial^{(\mathrm{n})}\mathrm{B}}{\partial \mathrm{x}^{(\mathrm{n})}}\mathrm{ds}$) are included in the lattice model. Optimization of the higher multipoles and the compensation solenoid fields are in progress by checking their impact on the dynamic aperture (Fig.2). So far, the Touschek lifetime is estimated to be 480 (580) sec in the LER (HER). Further improvements are expected by adjusting sextupoles (54 families/ring), skew sextupoles (12), and octupoles (4).

Overall optimization of the final focus system is going on in various viewpoints: magnets, vacuum chambers, assembly of components, support, beam background, collimation, collision feedback, and so on[6].

Estimation of error tolerances and development of optics correction are being in progress[7]. Requirements for beam diagnostics and control system (a number of single-pass beam position monitors, accuracy, speed, etc.) are being decided step by step. Various knobs for optics correction and luminosity tuning are to be newly equipped or revitalized: correction windings of quadrupoles connected to common power supplies (a tuning range of 0.5%), skew quadrupole windings and movers of sextupoles to correct their vertical offsets, sextupole rotators and skew sextupoles to correct chromatic couplings, and so on. Realistic methods to maintain good conditions for optics and collision are being intensively investigated.

CONSTRUCTION STATUS

An overview of the SuperKEKB construction schedule is shown in Fig.3. The construction started in FY2010, and the beam commissioning is planned to start in the sec-

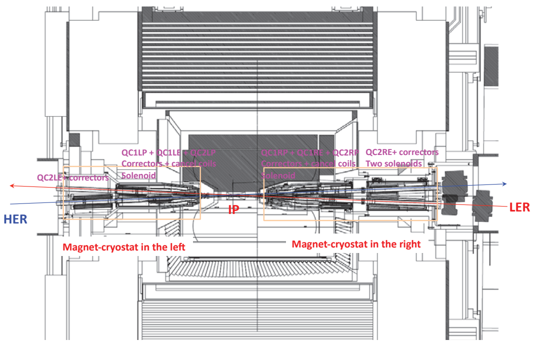

Figure 1: IR magnets and the Belle II detector[4]. Each quadrupole has four types of corrector windings (a horizontal and a vertical dipoles, a skew quadrupole, and an octupole). Cannel correctors of 6-, 8-, 10-, 12-poles are also installed in the HER to cancel the nonlinear leakage fields from the LER innermost quadrupoles without iron yokes.

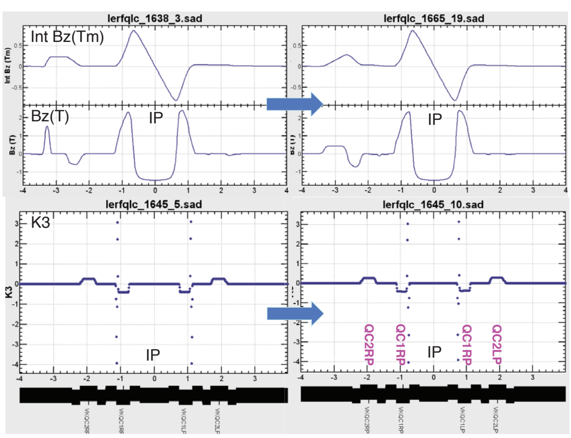

Figure 2: Example of optimization of the solenoid and higher multipole fields. The Touschek lifetime is improved by decreasing a peak field of Bz on the arc side of QC2RP (upper) and by swapping the lead end and the return end of QC1Ps (lower). There are non-negligible octupole fields at the lead end. Note that the direction of the beam line is reversed from Fig.1.

ond half of FY2014. Current status of the construction is briefly described below. More details will be described elsewhere[8].

The Great East Japan Earthquake on March 11, 2011 caused damages on the KEKB tunnel, buildings and some of the accelerator components such as klystrons, beam pipe bellows, magnets at stock area, cooling system, control system, and so on. Temporary measures were adopted quickly, and complete recovery works started after a supplementary budget for recovery was allocated in autumn. The DR tunnel construction started in December 2011, which had delayed for a half year due to budget suspension.

Although dismantling KEKB rings was suspended for about two months due to the earthquake, it has almost re-

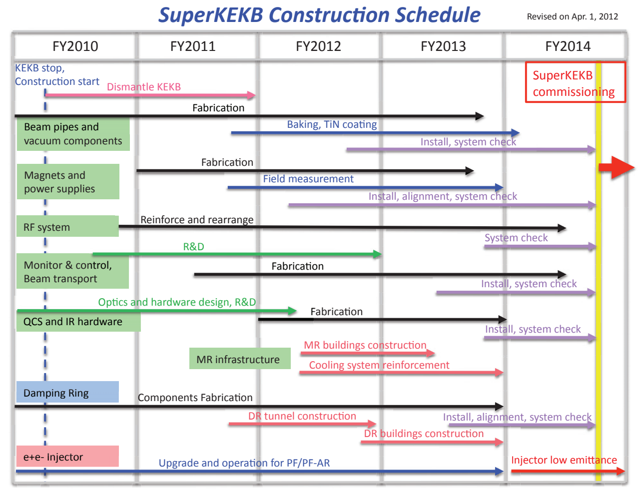

Figure 3: Construction schedule.

covered on schedule. Most of the beam pipes, approximately 100 main dipole magnets, and most of the wiggler magnets in the LER were removed from the tunnel. More than 200 magnets and other components in the IP and the sections that extend out to about 150 m on each side of the IP are removed from the tunnel to completely rebuild the beam line. The magnets and monuments in the tunnel were surveyed to evaluate the damage on the tunnel. Serious deformation of the tunnel was observed in the whole ring. The existing datums in the KEKB tunnel became useless for the alignment of beam line. To reconstruct new datums for SuperKEKB, more thorough survey work is underway.

The basic design of the vacuum system is near completion, and mass production of main components is going on. They include aluminum beam pipes with an antechamber scheme for the LER arc sections of 2 km length, copper beam pipes for the wiggler sections and the straight sections, bellows chambers and gate valves with comb-type RF shields, and non-evaporable getters pumps. As countermeasures against the electron cloud issues, the inner surface of the LER beam pipes will have the titanium nitride coating. The first vertical coating station for straight beam pipes has been built on the deck at the Oho laboratory (Fig.4(1)). Other four vertical stations and three transverse stations for bent pipes are under construction. New baking stations were also installed on the deck to perform pre-baking of the beam pipes. A new baking method of heating with hot air is adopted there instead of the conventional one with sheathed or tape heaters. The full-scale operation of these equipments will start in the first half of FY2012, and more than 1100 beam pipes will be processed in two years.

One of the major upgrade for the magnet system is to replace the short arc dipoles in the LER with longer ones. The new dipoles for the LER arc sections and those for the LER and HER straight sections have been manufactured. They have already been delivered to KEK, and the precise magnetic measurements have been performed. The magnetic measurement bench is shown in Fig.4(2). The mea-

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Figure 4: (1) upper left; experimental decks for vacuum works at the KEKB Oho laboratory, (2) upper right; the magnetic measurement bench for new dipole magnets for the LER, (3) lower left; the QC1P R&D magnet, and (4) lower right; six ARES cavities relocated from the HER to the LER beam line in the D5 straight section.

surement result is acceptable. Another major upgrade is to reduce wiggle pitch of the existing LER wiggler sections by half by interleaving two new types of short dipole magnets between the existing wiggler magnets. These new dipole magnets as well as some quadrupole magnets and steering magnets have been fabricated, and delivered to KEK. Fabrication of power supplies for the bending, wiggler, and other magnets is also ongoing.

The optics and hardware design for the IR has not been completed, as mentioned in the previous section. Meanwhile, a test superconducting quadruple magnet for the QC1P with a small diameter has been fabricated (Fig.4(3)). It was tested at 4K in the vertical cryostat, and the magnetic field successfully reached up to 74.56 T/m. The design of the beam pipes in the IR has progressed well. Its basic shape, material, and fabrication technology are nearly finalized.

To cope with the higher beam current and larger beam power, the RF system needs be strengthened: each ARES cavity will be powered by one klystron. (In KEKB, two ARES cavities were powered by one klystron.) To change to the new scheme, klystrons, power supplies for the klystrons, high-power and low-level RF system will be added, while the ARES cavities will be modified and relocated. In FY2011, six ARES cavities in the Oho D5 straight section, which were used for the HER in KEKB, were relocated to the LER beam line (Fig.4(4)), and two ARES cavities were added in the Oho D4 straight section for the HER. The input couplers for the ARES cavities will be replaced with improved ones to increase the input-coupling factor from 3 to 6. Development of new low-level RF control system is in progress: a prototype system has been completed, and a test with an ARES cavity is going on[9].

Cooling system needs to be reinforced for the vacuum system to cope with three times higher beam power, and also for the magnet system for a larger number of magnets than before. Four new buildings for additional cooling system will be built. In addition, a large number of existing cooling pipes in the tunnel in the whole rings need to be replaced with larger bore ones. Possible methods to minimize the interference of the work of replacing cooling pipes with installation of magnets and beam pipes are under investigation.

Development of new detectors for the beam position monitors, X-ray beam size monitors, bunch-by-bunch feedback system, and other beam instrumentations are in progress. Mass production of button electrodes has already started.

The DR tunnel construction will be completed in February 2013, and the construction of buildings for the DR will follow. Design and fabrication of magnets and power supplies for the DR is in progress. An ante-chamber type of beam pipes will be adopted to avoid the electron cloud issues. A test chamber made of aluminum was fabricated successfully, and mass-production of the chambers will be conducted in FY2012. A new accelerating cavity for the DR has been designed, based on the accelerating cavity of the ARES cavities. A prototype one was fabricated in FY2011, and will be high-power tested in FY2012.

SUMMARY

The construction of SuperKEKB is going on in full swing, in parallel with recovery work from the earthquake. Design work still remains, in particular for very difficult parts including the IR, and is being finalized step by step to meet the construction schedule.

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