Present Status of KEKB

Shin-ichi KUROKAWA
KEK, High Energy Accelerator Research Organization

Abstract

KEKB, a high-luminosity, asymmetric-energy, two-ring, electron-positron collider aimed at B-physics was completed by the end of November 1998 and the commissioning of the accelerator took place from December 1st to April 19th with the BELLE detector waiting outside the interaction point. The maximum stored current reached 514 mA in the electron ring and 542 mA in the positron ring. BELLE detector then had been rolled in to the interaction point and the operation of the full KEKB started on May 24th. After the first successful beam collision on June 1st and 2nd with a luminosity of 1.5 x $10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ the luminosity of KEKB increased step by step and finally reached 3 x $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ on August 4th a few hours before the start of the long summer shutdown. The integrated luminosity from June –August run amounted to 25/pb. During the summer shutdown we will modify the vacuum system near the interaction to reduce beam background to BELLE. The operation will resume in mid October and continue until the end of June 2000 with some break around New Year.

1. Introduction

By the end of November 1998, the construction of KEKB was completed and on December 1st commissioning started.

KEKB[1,2] is a high-luminosity, asymmetric-energy, two-ring, electron-positron collider in a 3-km tunnel, which housed TRISTAN, a 30-GeV × 30-GeV single ring electron-positron collider. At KEKB, 8-GeV electrons and 3.5-GeV positrons are stored in separate rings, circulate in opposite directions, and collide at one interaction point (IP), which the BELLE detector surrounds. The electron ring is called high-energy ring (HER) and the positron ring low-energy ring (LER).

The cross section of the tunnel is large enough to enable a side-by-side installation of LER and HER (see Fig. 1). The two rings change their inner and outer position at the IP and at a crossover point opposite to the IP, where HER and LER have different heights so as to avoid collisions of electrons and positrons. An interchange of the inner and outer position of the rings is necessary to make the two rings have the same circumference. Electrons and positrons are directly injected into the KEKB rings from the linac. Figure 2 shows the schematic layout of KEKB.

The design luminosity of KEKB is $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. This luminosity is 250-times as large as that of TRISTAN and more than one-order of magnitude higher than the maximum luminosity ever achieved by existing electron-positron colliders.

In order to obtain a high luminosity, we should increase the beam currents in the rings and squeeze the beams at the IP as much as possible. At KEKB, we need to store 1.1 A in HER and 2.6 A in LER and make the horizontal and vertical beam sizes at the IP 90 μm and 1.9 μm, respectively. The main issue is, therefore, how to store such large currents in the rings and at the same time maintain stable collisions between electron and positron beams. At KEKB, the beam

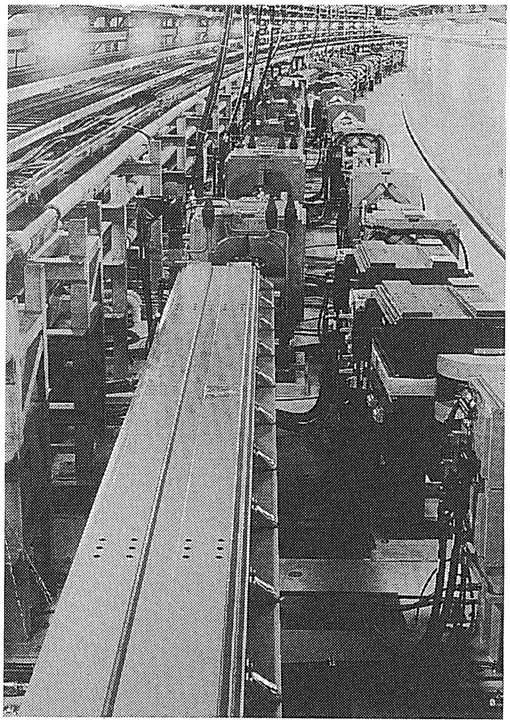

Fig. 1 Two rings installed side-by-side in the tunnel.

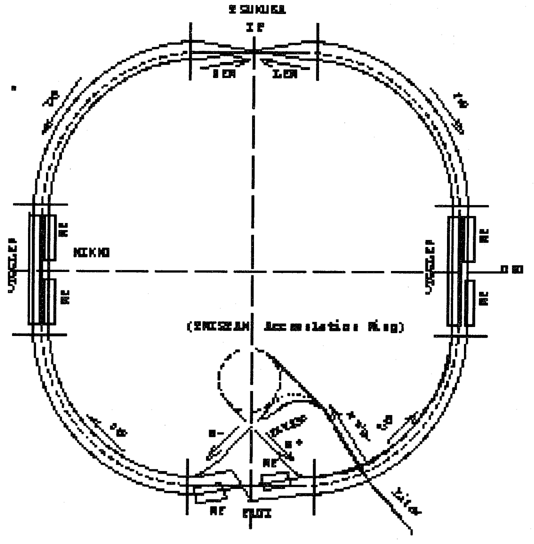

Fig. 2 Shematic layout of KEKB

is distributed to 5000 bunches with a bunch spacing of 59 cm.

KEKB adopts a finite-angle crossing scheme, where the electron and positron bunches collide at ± 11 mrad. In this scheme bunches are naturally separated after a collision. A pair of superconducting final-focus quads is used to squeeze the beams. Anti-solenoids in front of each quad effectively cancel out the solenoid field of the BELLE detector. Crab crossing scheme is a fallback option and superconducting crab cavities are being developed.

The main parameters of the KEKB rings are summarized in Table 1.

Table 1. Main Parameters of KEKB.

Ring		LER		HER	
Energy	E	3.5		8.0	GeV
Circumference	C		3016.26		m
Luminosity	L		1×10^{34}		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Crossing angle	θ_x		± 11		mrad
Tune shifts	ξ_x / ξ_y		0.039 / 0.052		
Beta function at IP	β^*_x/β^*_y		0.33 / 0.01		m
Beam current	I	2.6		1.1	A
Natural bunch length	σ_z		0.4		cm
Energy spread	σ_d	7.4×10^{-4}		6.7×10^{-4}	
Bunch spacing	S_b		0.59		m
Particles/bunch		3.3×10^{10}		1.4×10^{10}	
Emittance	$\varepsilon_x / \varepsilon_y$		$1.8\times10^{-8}/ 3.6\times10^{-10}$		m
Synchrotron tune	ν_s		0.01 ~ 0.02		
Betatron tune	ν_x/ν_y	45.52 / 45.08		46.52 / 46.08	
Momentum compaction factor	α_p		$1 \times 10^{-4} \sim 2\times10^{-4}$		
Energy loss/turn	U_0	$0.81^{\dagger}$ / $1.5^{\dagger\dagger}$		3.5	MeV
RF voltage	V_c	5 ~ 10		10 ~ 20	MV
RF frequency	f_{RF}		508.887		MHz
Harmonic number	h		5120		
Longitudinal damping time	τ_E	$43^{\dagger}$ / $23^{\dagger\dagger}$		23	ms
Total beam power	P_B	$2.6^{\dagger}$ / $4.5^{\dagger\dagger}$		4.0	MW
Radiation power	P_R	$2.1^{\dagger}$ / $4.0^{\dagger\dagger}$		3.8	MW
HOM power	P_{HOM}	0.57		0.15	MW
Bending radius	ρ	16.3		104.5	m
Length of bending Magnet	l_B	0.915		5.86	m

† without wigglers †† with wigglers

2. Hardware System

Magnet system

The total number of magnets installed in the tunnel amounted to 3400, 1700 main magnets (dipoles, quads and sextupoles) and 1700 small steering magnets. We measured the magnetic fields of all magnets before installation and found that all of the magnets satisfied the requirement.

Alignment of these magnets was performed by using SMART systems, which can measure 3-D positions of the magnets with 10 ppm accuracy. For example, the standard deviations and averages of the position error perpendicular to and along the beam direction at arc sections of the rings were less than 0.14 mm and 0.04 mm, respectively. This good accuracy of the alignment lead to the result that the circumference of the rings differed from the design values by + 5.1 mm in LER and + 5.4 mm in HER. The plus sign means that the ring is longer than the design value.

RF system

A high current stored in a KEKB ring requires single-mode cavities with high stored energies in order not to excite coupled-bunch instabilities. Two types of cavities are used at KEKB: a normal-conducting cavity, called ARES, and a superconducting, single-cell, single-mode cavity, SCC. The final number of cavities in the rings is 20 ARES in LER and 12 ARES and 8 SCC in HER. 12 ARES have been installed in LER and 4 ARES and 4 SCC in HER by the start of the commissioning.

ARES is a three-cell cavity system where an accelerating cell is resonantly coupled with a large energy-storage cell via a coupling cell in between.

A superconducting cavity can be operated at a high accelerating field having a large stored energy, and is immune to high beam loading. The performance of the cavities were measured first in a vertical cryostat and then in a final horizontal cryostat. All of these cavities showed that they satisfied the requirement of KEKB (1.5 MV/cavity).

These ARES cavities and superconducting cavities were being operated stably from December 1998 to August 1999 and accelerated up to 514 mA in HER and 542 mA in LER. During these operation the total number of breakdowns of SCC was about 10.

Vacuum system

Except for some vacuum ducts around the IP and the crossover point, all vacuum ducts of KEKB are made of copper. The number of ducts amounts to 2000 and the ducts are connected to each other by a piece of shielded bellows. The photodesorption coefficients of these copper ducts decreased, as planned. By August 4th, the integrated stored currents in LER and HER reached 130 and 75 Ah and the photodesorption coefficient η was reduced down to 10^{-5}. No serious heating of vacuum components was observed.

3. Commissioning

The commissioning of KEKB started on December 1st and continued until April 19th[3]. BELLE was not rolled in the interaction point. Without the BELLE detector, cancellation of the BELLE solenoid was unnecessary and excitation of anti-solenoids was lowered to the 10% level. A small detector for the commissioning, BEAST, was installed at the IP to measure the beam background.

The first storage of the beam in HER was on December 13th, whereas that in LER took place on January 14th. During the commissioning period, the beam currents were increased step by step and reached 514 mA in HER and 542 mA in LER.

The commissioning started with β^*_y= 2 cm lattice, and later this value was reduced to the design value of β^*_y= 1 cm in both rings. No degradation in the injection efficiency, maximum current, or lifetime was observed. Single-bunch currents higher than the design values (4 mA in HER and 2.3 mA in LER compared to the design values of 0.22 mA and 0.52 mA, respectively) were achieved without any instabilities or serious bunch lengthening. Transverse multi-bunch instabilities were observed in both rings. Bunch-by-bunch feedback systems were effective for these instabilities.

Collisions of the two beams were first tried in February by making single-bunch electrons and positrons collide. The horizontal and vertical beam-beam deflections were clearly observed. In the case of a finite-angle crossing scheme, the horizontal distance between the electron and positron bunches was changed by changing the RF phase of LER. The change in the RF phase in one ring shifts the longitudinal collision point, which simultaneously changes the horizontal separation of the beams. The vertical deflection was measured by scanning a vertical bump orbit in one beam and measuring the kick of the other beam.

In March, collisions of the beams were tried again between multi-bunch electrons and positrons. The estimated luminosity calculated from this beam-beam deflection data was 1.7 x 10^{31}cm^{-2}s^{-1}.

The third trial of collisions was not successful. After extensive study we found that the LER beam had a 0.4 Hz vertical oscillation caused by a small leakage field from the 12 GeV Proton synchrotron: DC power cables connecting power supplies in a hut to magnets of the PS and a dummy magnet housed in the hut produced a leakage field of 20 mGauss over 10 m in the KEKB tunnel below. We cancelled out this field by installing an additional current loop near the source; remaining oscillation of the beam was reduced to 0.1-0.2 μm at the IP.

The operation of the full KEKB started on May 24th. After the first successful beam collision on June 1st and 2nd with a luminosity of 1.5 x 10^{30}cm^{-2}s^{-1} the luminosity of KEKB increased step by step and finally reached 3 x 10^{32}cm^{-2}s^{-1} on August 4th a few hours before the start of the long summer shutdown. The integrated luminosity from June –August run amounted to 25/pb. Figure 3 shows the increase of the luminosity from June to August. Beam size monitors on the basis of double-slit interferometry were helpful to tune the beams for collision[4].

During the summer shutdown we will change one aluminium vacuum duct near the IP with a copper duct to reduce back-scattered X-rays that enter into BELLE. The operation will resume in mid October and continue until the end of June 2000 with some break around New Year.

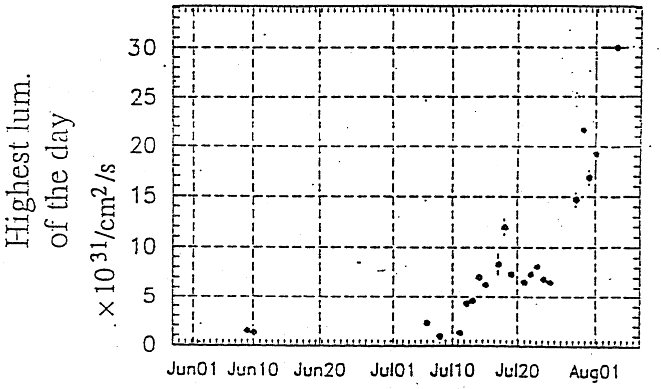

Fig.3 Increase of luminosity from June to August

References

[1] KEKB B-Factory Design Report, KEK Report 95-7, August 1995.

[2] S. Kurokawa, "Present Status of KEKB Project", Proceedings of EPAC-98, Stockholm, June 1998, pp.123-127.

[3] K. Oide, "Commissioning of KEKB", to be published in the Proceedings of PAC-99, New York, March 1999.

[4] T. Mitsuhashi, in these Proceedings.