

SuperKEKB VACUUM SYSTEM

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Abstract

SuperKEKB, which is an upgrade of the KEKB B-factory (KEKB), is a next-generation high-luminosity electron-positron collider. Its design luminosity is $8.0 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, which is about 40 times than the KEKB's record. To achieve this challenging goal, bunches of both beams are squeezed extremely to the nanometer scale and the beam currents are doubled. To realize this, many upgrades must be performed including the replacement of beam pipes mainly in the positron ring (LER). The beam pipes in the LER arc section are being replaced with new aluminium-alloy pipes with antechambers to cope with the electron cloud issue and heating problem. Additionally, several types of countermeasures will be adopted in the LER to deal with the electron cloud issues. In the wiggler section, electrons will be attracted by the clearing electrode, which is mounted on the inner surface of the beam pipe. On the other hand, in the bending magnet, the effective secondary electron yield (SEY) will be structurally reduced by the groove surface with a TiN coating. In the drift space, the electron cloud will be mitigated by the TiN coating and a conventional solenoid field.

INTRODUCTION

SuperKEKB [1, 2], which is an upgrade of the KEKB B-factory (KEKB), is a next-generation high-luminosity electron-positron collider with asymmetric energies of 7 GeV (e-) and 4 GeV (e+). Its predecessor, the KEKB, was operated from 1998 to 2010 and had been a leader in the race to provide the world's highest luminosity since 2001. It delivered a total integrated luminosity of more than 1 ab^{-1} to the Belle detector and made a great contribution to confirmation of CP violation in the neutral B meson system. To pursue research on flavour physics, however, much more luminosity is required and the SuperKEKB project was begun in 2010.

At the SuperKEKB project, a 50-fold increase in integrated luminosity is expected just over ten years after inauguration. The design luminosity is $8.0 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, which is about 40 times than the KEKB's record. To achieve this challenging goal, the beam sizes at the interaction point are extremely squeezed and the beam currents are doubled at the SuperKEKB. When the beam sizes and the beta functions of both beams are equal at the interaction point (IP), the luminosity is expressed by the following formula:

$$L = \frac{\gamma_{\pm}}{2er_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \left(\frac{I_{\pm} \xi_{y\pm}}{\beta_{y\pm}^*} \right) \left(\frac{R_L}{R_{\xi y}} \right) \propto \frac{I_{\pm} \xi_{y\pm}}{\beta_{y\pm}^*},$$

where γ_{\pm} is the Lorentz factor, e is the elementary electric charge, r_e is the classical electron radius, $\sigma_{x,y}^*$ is the beam

size in the horizontal and vertical directions at the IP, I_{\pm} is the beam current, $\xi_{y\pm}$ is the vertical beam-beam parameter, $\beta_{y\pm}^*$ is the vertical beta function at the IP, R_L and $R_{\xi y}$ are the reduction factors for the luminosity and vertical beam-beam tune-shift parameter, respectively, owing to the crossing angle and the hourglass effect. The subscripts + and - indicate a positron or electron, respectively. At the SuperKEKB, crossing the beams by using the "nanobeam scheme" [3] makes it possible to squeeze $\beta_{y\pm}^*$ to about $1/20^{\text{th}}$ of KEKB's size. In the nanobeam scheme, bunches of both beams are squeezed extremely to the nanometer scale (0.3 mm across and 100 nm high) and intersect only in the highly focused region of each bunch at a large crossing angle (4.8 degrees). This collision scheme should produce 20 times the luminosity produced in the KEKB. The luminosity will also be doubled by increasing the beam current to 2.6 A (e-) and 3.6 A (e+), which are twice as much as in the KEKB.

To realize this, many upgrades must be performed. The outline of the upgrade to the SuperKEKB is shown in Fig.1 and the main parameters of the KEKB and the SuperKEKB are summarized in Table 1. The SuperKEKB is constructed on the site of the KEKB. To reduce the construction costs, many facilities and components of the KEKB, such as the tunnel, buildings, magnets and RF cavities, are reused. The main upgrade is the positron ring (LER). The electron ring (HER) is left as it is for the most part because the present cells in HER can be reused at the SuperKEKB. In this paper, vacuum system of the SuperKEKB and countermeasures against the electron cloud issues are reported in detail.

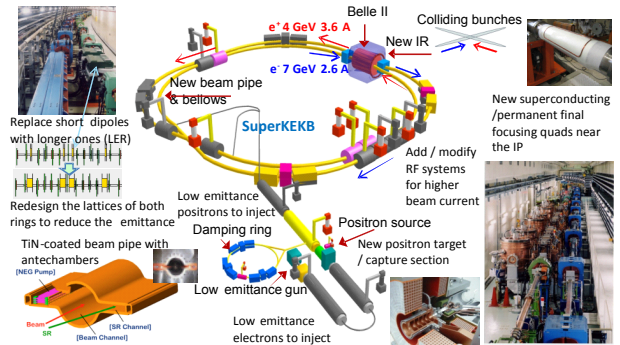


Figure 1: Outline of upgrade to the SuperKEKB.

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Table 1: Machine parameters of KEKB (LER/HER) and SuperKEKB(LER/HER)

	KEKB design	KEKB Achieved: with crab	SuperKEKB	Unit
Energy	3.5/8.0	3.5/8.0	4.0/7.0	GeV
β_y^*	10/10	5.9/5.9	0.27/0.30	mm
β_x^*	330/330	1200/1200	32/25	mm
ϵ_x	18/18	18/24	3.2/5.3	nm
x-y coupling (ϵ_y/ϵ_x)	1	0.85/0.64	0.27/0.24	%
σ_v^*	1.9	0.94	0.048/0.062	μm
ξ_y	0.052	0.129/0.090	0.09/0.081	
σ_z	4	6-7	6/5	mm
I	2.6/1.1	1.64/1.19	3.6/2.6	A
N_{bunch}	5000	1584	2500	
Luminosity	1	2.11	80	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

VACUUM SYSTEM

New Beam Pipe with Antechambers

To increase the beam currents, almost all beam pipes of LER will be replaced with new ones with antechambers [4] that can deal with the unfortunate side effects of a high-beam current in the positron ring (namely, the electron-cloud effect [5]) as well as excessive heating in the beam pipe due to the strong synchrotron radiation (SR). In addition to suppressing the effect of photoelectrons and SR power density, the antechamber can reduce the beam impedance by putting SR masks and pumping ports in the antechamber for taking a distance from the beam. NEG strips are used as main pump and installed in one antechamber isolated by the screen for RF shield (only in arc section). The cross section of the beam pipe was designed to fit existing magnets. A flange, bellows and a gate valve applicable to the antechamber scheme were also developed. On the other hand, most of copper beam pipes of the HER excluding the wiggler section will be reused. Because the beam energy of the electron is reduced from 8.0 to 7.0 GeV, the power of the SR decreases to the tolerance level of a conventional beam pipe without antechambers, in spite of doubling the beam current.

In the LER arc section, the beam pipes are being replaced with new aluminium-alloy pipes with antechambers (Fig. 2). The length of the replacement is about 2000 m. On the other hand, in the HER arc section,

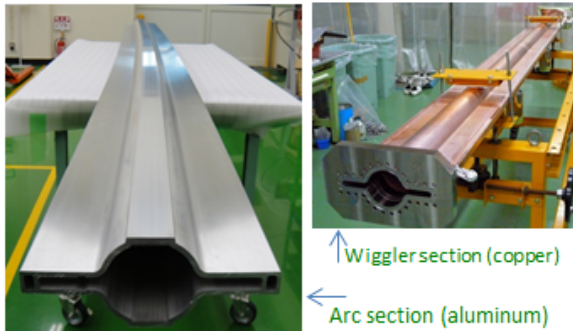


Figure 2: Beam pipe with antechambers.

the present copper beam pipes will be reused without any modification as mentioned above. In wiggler section of both rings, copper beam pipes with antechambers are newly installed because the SR power is much larger than that in the arc section and the aluminium-alloy pipe can't withstand it.

Countermeasures against Electron Cloud Effect

The electron cloud instability can be a serious problem for the LER. It is expected that the threshold of the electron density to excite the head-tail instability is about $1.6 \times 10^{11} \text{ m}^{-3}$, and it is necessary to prepare the LER for the electron cloud. The countermeasures against the electron cloud adopted at the SuperKEKB are summarized at Table 2 [6]. These mitigation techniques were evaluated at the KEKB LER and it is expected that the average electron density on the order of 10^{10} m^{-3} will be obtained by using them. The results of the tests of them at the KEKB LER are discussed below.

The effect of the antechamber is shown in Fig. 3 [7]. This graph shows that the electron currents measured in the beam pipe with and without antechambers versus LER beam current. The electron current in the beam pipe with antechambers is smaller than that in the circular pipe, especially when the beam current is low and the photoelectron is dominant. By roughening the side wall of the antechamber to reduce the photon reflection, its effect can be enhanced more.

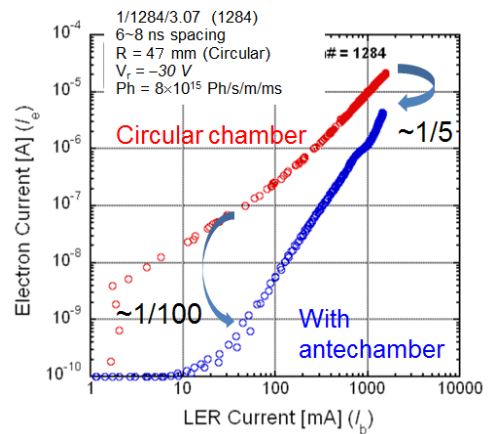


Figure 3: Measured electron currents in the beam pipes with and without antechambers.

Table 2: Countermeasure against electron cloud [6]

Sections	Length [m]	Length [%]	Countermeasure	Material
Total	3016	100	TiN coating + Solenoid	
Drift space (arc)	1629	54	TiN coating + Solenoid	Al (arc)
Steering mag.	316	10	TiN coating + Solenoid	Al
Bending mag.	519	17	TiN coating + Grooved surface	Al
Wiggler mag.	154	5	Clearing electrode	Cu
Q & SX mag.	154	9	TiN coating	Al (arc)
RF section	124	4	(TiN coating +) Solenoid	Cu
IR section	20	0.7	(TiN coating +) Solenoid	Cu or ?

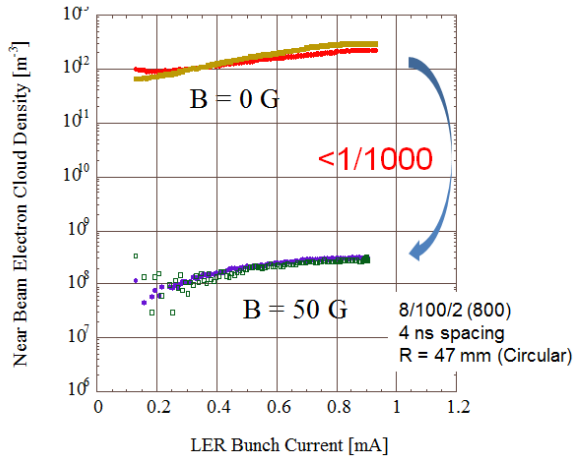


Figure 4: Electron cloud density versus beam current with and without the solenoid field.

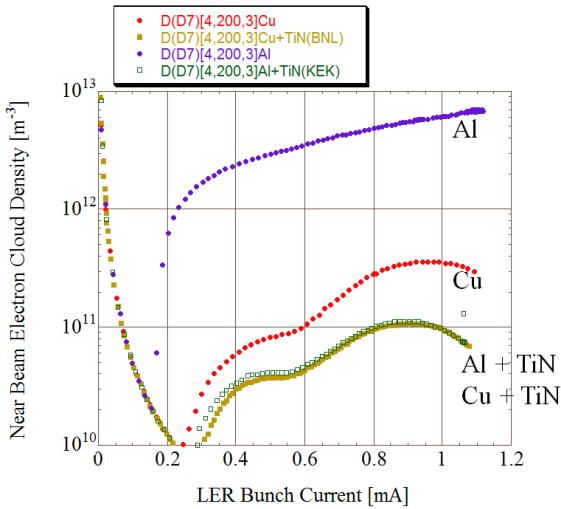


Figure 5: Electron cloud density versus beam current in the beam pipes with and without TiN coating.

Figure 4 shows the electron cloud density versus beam current with and without the solenoid field [8]. The beam pipe is circular copper one (without antechambers). This result indicates that the solenoid field at the drift section is very effective to both photoelectrons and secondary electrons.

TiN coating is also effective to reduction of the secondary electrons. As the result of the beam test at the

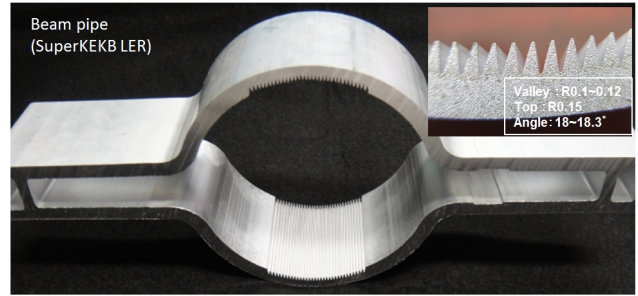


Figure 6: Beam pipe with grooved surface (Al).

KEKB LER with circular beam pipes, it was found that the TiN coated surface has a same property irrespective of base material. There is not much difference between the results of the TiN coatings on the aluminium beam pipe and copper one (Fig. 5) [9]. At the SuperKEKB, almost all pipes for the LER are coated with TiN. Typical thickness of TiN coating is 200 nm which was decided as the results of the preliminary experiment [10].

In the bending magnet, where it is difficult to install the electron clearing electrodes, the grooved surface with TiN coating will be adopted to reduce effective SEY [11]. The effect of grooved surface was tested in the KEKB and CEsrTA and as results it is expected to reduce the electron density by factors. The beam pipe for the bending magnet of the SuperKEKB has the groove structure at the top and bottom of the beam channel as shown in Fig. 6. In case of aluminium beam pipe, it can be formed by extrusion method.

On the other hand, in the wiggler section the clearing electrode is adopted to attract the electrons by the electric field [12]. The electrode consists of a tungsten electrode with a thickness of 0.1 mm on an alumina insulator with a thickness of 0.2 mm. It is mounted on the inner surface of the beam pipe. It was also tested in the KEKB and CEsrTA. The results of the test of the grooved surface and the clearing electrode in the KEKB LER are summarized in Fig. 7. These results show that the grooved surface and the clearing electrode can reduce the electron density by factors and up to 1/100, respectively.

TiN Coating Facility

In order to coat more than 1000 beam pipes with TiN within 2 years, coating facility for large-scale production (5 vertical equipments for the straight beam pipes and 3

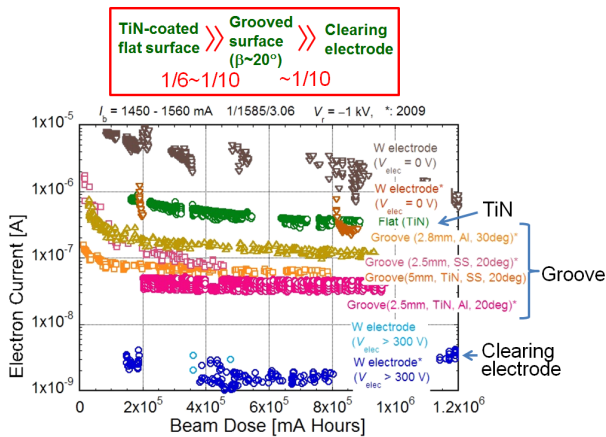


Figure 7: Measured electron current in the beam pipes with grooved surface and clearing electrode.

transverse equipments for the bent pipes) were constructed at the OHO vacuum laboratory in KEK Tsukuba site (Fig. 8). The TiN coating is done by a DC magnetron sputtering of Ti in Ar and N₂ atmospheres (2-4 Pa). A Ti cathode rod (-400 V) is set on the center axis of the beam pipe, and the gases are supplied into the beam pipes uniformly through the Ti rod. Magnetic field (16 mT) is supplied by a solenoid coils in which beam pipes are set. Two lines of the beam pipes can be mounted side-by-side in one equipment. The length of the beam pipe which can be coated by this equipment is up to 5.5 m. To keep the temperature of beam pipes of 130-150 degree C during the coating and pre-baking process, combination of hot-air oven and circulators are adopted. The coating work consists of installation of beam pipes, baking (24 hours), coating (70 min. per 1 line, thickness: 200 nm), cooling down (24 hours) and de-installation. The total time required for the coating by one equipment is about 3 days. The expected weekly output at the OHO vacuum laboratory is 12-16 beam pipes.

Construction Works and Schedule

Fabrication of more than 750 beam pipes has been finished so far. Before the installation, the beam pipes with the clearing electrode are baked and other beam pipes without the electrode are coated and then baked at the OHO vacuum laboratory. To cope with the large number of beam pipes, combination of hot-air oven and circulators is used for the baking to avoid the trouble of having to set heaters, cover and uncover aluminium foils and thermal insulators. Four baking equipments were installed at the OHO vacuum laboratory. The weekly output of the baking will reach up to 16 beam pipes.

The baking of the beam pipes with the clearing electrode which require no coating and the coating of other beam pipes began on April and July in 2012, respectively. At the present (September 2012), the number of the coated and baked beam pipe is about 80 and 140, respectively. After the baking, beam pipes were filled with dry nitrogen up to atmospheric pressure and kept in

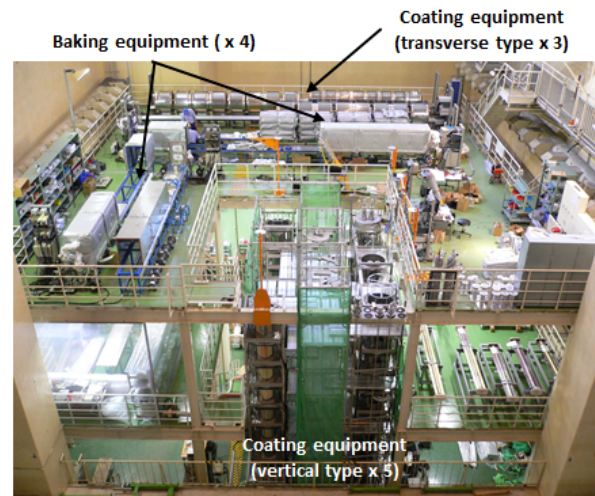


Figure 8: TiN coating facility for large-scale production in KEK Tsukuba site.

stockrooms until the installation which will start this winter.

SUMMARY

Construction works of the SuperKEKB are going on now toward commissioning of the SuperKEKB in the second half of JFY2014. Almost all LER and part of HER beam pipes become new. To cope with the electron cloud issues and heating problems, antechamber type beam pipes are adopted. As the countermeasure against the electron cloud, various mitigation techniques are adopted, such as the solenoid field, TiN coating, grooved surface and clearing electrode. Large-scale TiN coating is done in KEK Tsukuba site by newly constructed coating facility. Fabrication of more than 750 beam pipes has been finished so far, and the coating and baking of the new beam pipes are now in progress.

ACKNOWLEDGMENT

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