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Full Length Article

Beam scrubbing of beam pipes during the first commissioning of SuperKEKB

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ABSTRACT

The first (Phase-1) commissioning of SuperKEKB—an electron-positron collider with asymmetric energies located at KEK, in Tsukuba, Japan—started in February 2016, after more than five years of upgrading work on KEKB, and successfully ended in June of the same year. This paper describes one major task of Phase-1 commissioning: beam scrubbing the surface of the beam pipes, to prepare them for a sufficiently long beam lifetime and low background noise in the next commissioning, when a new particle detector will be installed. The pressure rises per unit beam current (dP/dI [Pa A^{-1}]) were continuously monitored, and the coefficient of photon-stimulated desorption (PSD), η [molecules photon^{-1}], was evaluated in the arc sections. The value of η decreased steadily with the beam dose, as expected. For arc sections in the positron ring, where most of the beam pipes were newly fabricated, the decrease in η against the photon dose (D) was similar to that previously reported; that is: $\eta \propto D^{-0.5\sim0.8}$. At high storage beam currents, the evolution of η was affected by gas desorption resulting from the multipacting of electrons—that is, the electron cloud effect (ECE), which is a phenomenon particular to high-intensity positron rings. For the arc sections in the electron ring, η also decreased smoothly with the photon dose D, approximately as $\propto D^{-0.8}$. Given that most of these beam pipes were reused from KEKB, the value of η was much lower than that of the positron ring, and also lower than that of the electron ring of KEKB from the early stages of D. This implies that the surface of the reused beam pipes remembered the conditions in the KEKB, which is a known memory effect. The results obtained for η are compared with those obtained in various other accelerators.

1. Introduction

The SuperKEKB is an electron-positron collider with asymmetric energies located at KEK, in Tsukuba, Japan, and is a successor to the former KEKB (KEKB B-factory) [1–3]. It consists of an injector, a damping ring for positrons, a main ring (MR), and the Belle II particle detector (Fig. 1). The MR itself consists of two rings, each one with a circumference of 3016 m. The high-energy (HER) and low-energy (LER) rings are for 7.0 GeV electrons and 4.0 GeV positrons, respectively. Each ring is composed of four arc sections and four straight sections, with the lengths of approximately 550 m and 200 m, respectively. The straight sections include a beam injection/abort region, wiggler regions, radio-frequency accelerating cavity regions, and a beam collision region (Tsukuba section). Table 1 lists the MR key design parameters relevant to the vacuum system. The designed beam currents are 2.6 A and 3.6 A for the HER and LER, respectively, with a maximum bunch number of 2500. The designed luminosity is 8×10^{35} $cm^{-2}s^{-1}$, which is approximately 40 times higher than the one achieved in KEKB [3].

The upgrade of the MR vacuum system started in 2010, as one of the key items in the SuperKEKB [4,5]. Approximately 93% of the LER vacuum components were replaced with new ones. In contrast, approximately 80% of the HER components were reused, because the layout of the magnets did not change significantly. In the arc sections in particular, all the LER beam pipes were replaced by new ones, whereas 97% of the HER beam pipes were reused.

The upgrade work on the vacuum system was almost finished by the end of 2015 [6]. Fig. 2 shows a present-day view of the beam pipes at an arc section of the MR tunnel. After the final tuning of the overall system, the first beam commissioning—named Phase-1 commissioning—started in February 2016, and ended in June of the same year [1]. Phase-1 commissioning was dedicated to accelerator tuning; no particle detector was installed. A central task of Phase-1 commissioning was beam scrubbing the surface of the beam pipes, to prepare them for a sufficiently long beam lifetime and low background noise at the particle detector to be installed in the next

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Fig. 1. Layout of the SuperKEKB at the KEK Tsukuba campus.

Table 1
Main design parameters of the SuperKEKB MR.

	LER	HER	Units
Beam energy	4.0	7.0	GeV
Beam current	3.6	2.6	A
Circumference	3016		m
Bunch numbers	2500		
Bunch length	6.0	5.0	mm
$\varepsilon_x/\varepsilon_y$	3.2/8.64	4.6/11.5	nm/pm
β_x/β_y (at the collision point)	32/0.27	25/0.3	mm
Luminosity	8×10^{35}		$cm^{-1}s^{-1}$
SR[a] parameters in the arc (design current)			
Total power	1.1	5.3	MW
Critical energy	1.9	7.3	keV
Average photon density	5.3×10^{18}	6.7×10^{18}	photons $s^{-1}m^{-1}$

[a] Synchrotron radiation.

commissioning (Phase–2) planned for 2017. The pressure rises per unit beam current (dP/dI [Pa A^{-1}]) were monitored from the beginning, and the coefficient of photon-stimulated desorption (PSD), η [molecules photon^{-1}], was evaluated at the arc sections, where the photon density can be clearly defined and the beam pipes are made of the same material. In the remaining of this paper, the status of the beam scrubbing of the arc sections during Phase-1 commissioning is presented. The results for η are compared with those of KEKB and other accelerators.

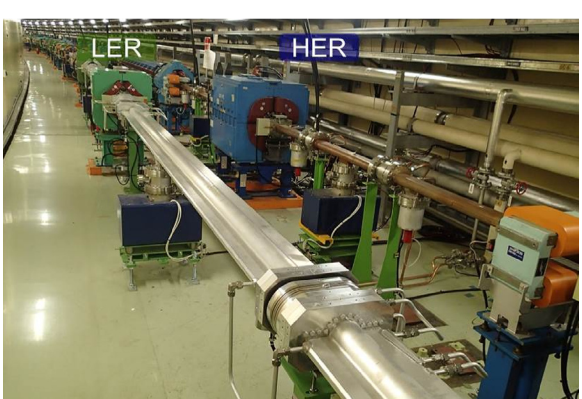

Fig. 2. Present-day view of the SuperKEKB tunnel.

2. Beam pipes and pumping system in the arc sections

The beam pipes of the LER in the arc sections were newly fabricated for the SuperKEKB [4–6]. The beam pipes have antechambers, as shown in Fig. 3(a), where the synchrotron radiation (SR) directly hits the sidewall of one of the antechamber. The antechamber structure can reduce the beam impedance and also relax the irradiation power density of the SR [7,8]. Given that the SR hits the sidewall far from the beam, the antechamber also reduces the contribution of photoelectrons to the electron cloud effect (ECE) [9–11]. The surface of the sidewall was roughened to approximately Ra = 20 µm, to reduce the SR reflection. The inner diameter of the beam channel—where the circulating beam passes—is 90 mm. The total width including antechambers is 220 mm. The depth of an antechamber is 65 mm, and its height is 14 mm.

The main pump consists of non-evaporable getter (NEG) strips installed into the antechamber located inside the ring [4,12,13]. A schematic of the pumping system for the arc sections of the LER is presented in Fig. 4(a). The NEG strips provide an effective distributed pumping system. The average linear pumping speed along the ring just after activation is approximately 0.12 $m^3 s^{-1} m^{-1}$ for carbon monoxide (CO), including the radio-frequency (RF) screen between the pump and beam channels [4]. The auxiliary pumps are sputter ion pumps with a nominal pumping speed of 0.4 $m^3 s^{-1}$ located at every 10 m, on average. The beam pipe is made of aluminum-alloy (A6063-T6) by extrusion, and was chemically polished after machining [4]. The inside of the beam pipe was finally coated with titanium nitride (TiN) by sputtering, using a DC-magnetron discharge as a countermeasure against ECE [14–16]. Note that the TiN film was formed mostly around the beam channel, because an electrode for the discharge was set at the center of the beam pipe (see Fig. 3(a)). The thickness of the TiN coat-

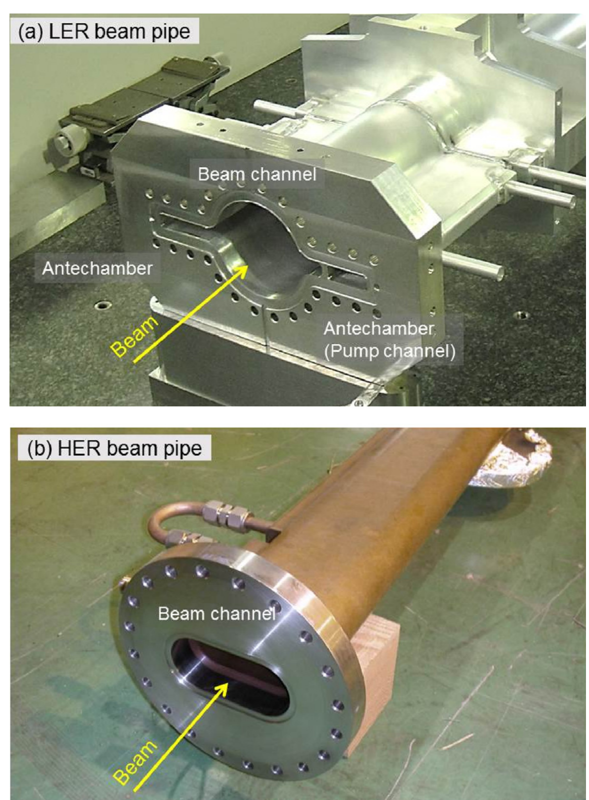

Fig. 3. Cross sections of the beam pipes at the arc sections of the (a) LER and (b) HER.

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