FIRST COMMISSIONING OF THE SUPERKEKB VACUUM SYSTEM

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Abstract

The first commissioning of the SuperKEKB, which is an electron-positron collider with asymmetric energies in KEK, has started in February 2016. A major task of the commissioning was the vacuum scrubbing of new beam pipes to increase the beam lifetime and decrease the background noise of the particle detector in anticipation of the coming physics run. The vacuum pressures along the ring were monitored, and the rate of decrease was measured to estimate the vacuum scrubbing effect. The residual gases were monitored at the same time. The temperatures of new vacuum components such as the bellows chambers, gate valves, and beam collimators were continuously checked. The effects of the antechambers and TiN coating on the electron cloud effect were preliminarily evaluated.

INTRODUCTION

The main ring (MR) of the SuperKEKB consists of two rings, each with a circumference of 3016 m [1]. The high energy ring (HER) and low energy ring (LER) are for 7.0 GeV electrons and for 4.0 GeV positrons, respectively. Table 1 lists the key design parameters of the MR relevant to the vacuum system.

The vacuum system for the SuperKEKB MR was newly designed on the basis of various experiences with the KEKB while also introducing leading-edge concepts [2]. Construction of the SuperKEKB MR vacuum system started in 2010. Most of the beam pipes and vacuum components of the LER, which comprises approximately 93% of the ring, were replaced with new ones. On the other hand, most of the components in the HER were reused because the layout of the magnets did not change significantly. Figure 1 shows a typical view of the beam pipes and magnets in an arc section of the MR tunnel. After approximately 5 years of construction work, the first beam commissioning started in February 2016. The present status and latest results from the first commissioning of the vacuum system are presented below.

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 IP)	32/0.27	25/0.3	mm
Luminosity	8×10^{35}		$cm^{-1}s^{-1}$
Total power of the SR*	1.1 (arc) 6.3 (wig)	5.3 (arc) 1.8 (wig)	MW
Critical energy of the SR	1.9 (arc) 9.2 (wig)	7.3 (arc) 17 (wig)	keV
Total photon flux of the SR	1.2×10^{22} (arc) 1.4×10^{22} (wig)	1.5×10^{22} (arc) 2.1×10^{21} (wig)	photons s^{-1}
Avg. photon density	5.3×10^{18}(arc) 4.7×10^{19}(wig)	6.7×10^{18}(arc) 2.1×10^{19}(wig)	photons $s^{-1}m^{-1}$

*Synchrotron radiation

PRESENT STATUS

Operation Status

The beam injection to the LER and HER started on February 8 and 22, respectively, in 2016. The beams were successfully stored after several days of tuning. Until the end of April 2016, the integrated beam currents (i.e., the beam doses) were 240 and 190 Ah for the LER and HER, respectively. The maximum stored currents were 650 and 590 mA, respectively.

The vacuum system has been running without any serious problem from the beginning. All of the vacuum components in the MR are monitored and controlled through the graphical user interface (GUI) based on Control System Studio (CSS). The status of various components such as the vacuum pressures along the ring, the temperatures of bellows chambers, and so on can be checked at a glance. The average vacuum pressures are on the order of 10^{-6} and 10^{-7} Pa for the LER and HER, respectively, at the maximum beam currents. The interlock and beam-abort logic using the ladder-sequence programs are working well and are contributing the steady operation of the system.

The SuperKEKB has adopted new vacuum components at a large scale, such as step-less MO-type flanges, comb-type RF shields for the bellows chambers and gate valves, and clearing electrodes to suppress the electron cloud effects (ECE) [2]. Confirming the stability of these components was also a major subject for the first beam commissioning. No extra heating or abnormal pressure rise in

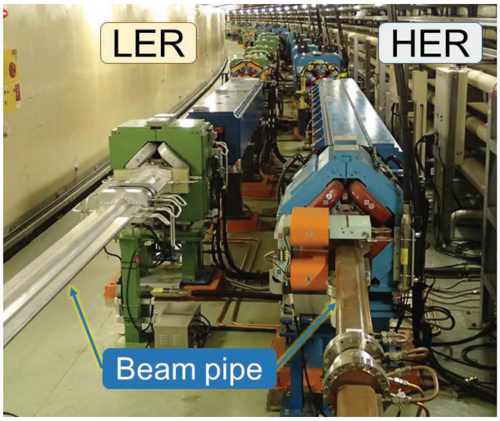

Figure 1: Typical view of an arc section of the MR tunnel.

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these components has been observed so far. The temperature rises in the bellows chambers and the gate valves have been less than 2 °C on average, for example.

Vacuum Scrubbing

Figures 2 and 3 present the average vacuum pressures normalized by a unit beam currents (i.e., the pressure rise *dP*/*dI* [Pa mA^{-1}]) for the LER and HER, respectively, as a function of the beam dose. The circles (red) and squares (blue) present the average pressure of the whole ring, including the wiggler sections and only arc sections, respectively. The figures also indicate the timings of the NEG conditioning. The upper axis is the photon dose (i.e., the integrated photons per unit length [photons m^{-1}]) in the arc section. The right axis is the expected photon stimulated gas desorption rate η [molecules photon^{-1}] at the arc sections, for which the linear pumping speeds of 0.4 and 0.3 m^3 s^{-1} m^{-1} were assumed for the LER and HER, respectively.

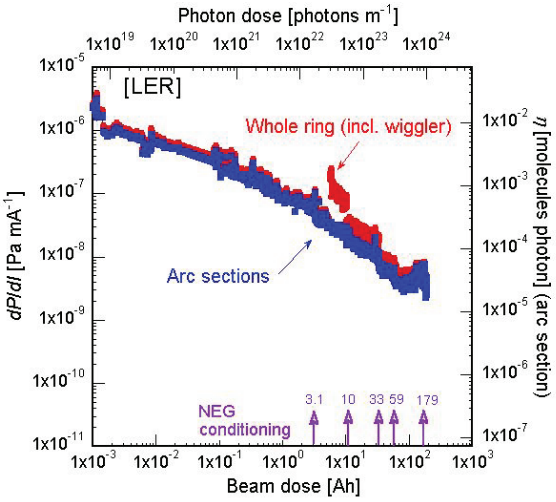

Figure 2: Decreases in *dP*/*dI* [Pa A^{-1}] and η [molecules photon^{-1}] as functions of the beam dose [Ah] and photon dose [photons m^{-1}] in the LER.

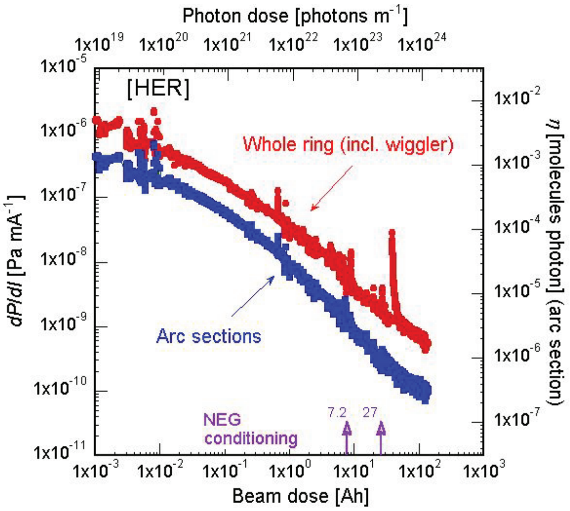

Figure 3: Decreases in *dP*/*dI* [Pa A^{-1}] and η [molecules photon^{-1}] as functions of the beam dose [Ah] and photon dose [photons m^{-1}] in the HER.

The *dP*/*dI* value for the LER arc section (Fig. 2), where all of the beam pipes were newly fabricated, was approximately 5×10^{-6} Pa A^{-1} at the beam dose of 100 Ah. These pipes are made of aluminium alloy, and the inside was coated with TiN as a countermeasure against the ECE. Compared to the KEKB, which used circular copper beam pipes without any coating, *dP*/*dI* at the initial stage was lower by several factors [3]. Recently, however, *dP*/*dI* has been almost the same as the KEKB case at the same beam dose. The *dP*/*dI* value steadily decreased up to a beam dose of 70 Ah, but the rate of decrease slowed down afterwards. The main cause was the nonlinear pressure rise against the beam current due to the gas desorption from the electron multipacting at the aluminum bellows chambers without TiN coating. The application of solenoidal magnetic field at the bellows chamber will be required in the future to suppress the multipacting (see also the later section).

For the HER (Fig. 3), on the other hand, the *dP*/*dI* value at the arc section was approximately 1×10^{-7} Pa A^{-1} at the beam dose of 100 Ah. Here, *dP*/*dI* was much lower than that for the LER from the beginning. Note that most of the beam pipes in the HER arc section were reused from the KEKB. The above *dP*/*dI* value is comparable to that in the KEKB at the final stage [3]. This means that the surface of the reused beam pipes “remembers” the conditions in the KEKB, even though the beam pipes were exposed to the air for vacuum work.

NEG pumps in the LER and HER have been activated five and two times, respectively, as shown in Figs. 4 and 5. The *dP*/*dI* value has decreased in stepwise pattern timed with NEG activation.

Residual Gases

Residual gases during the beam operation have been monitored with a quadrupole mass analyser (QMA) at an arc section. The QMA is located just above a sputter ion pump. Figure 4 presents the change in ion currents for major residual gases normalized by the beam current for

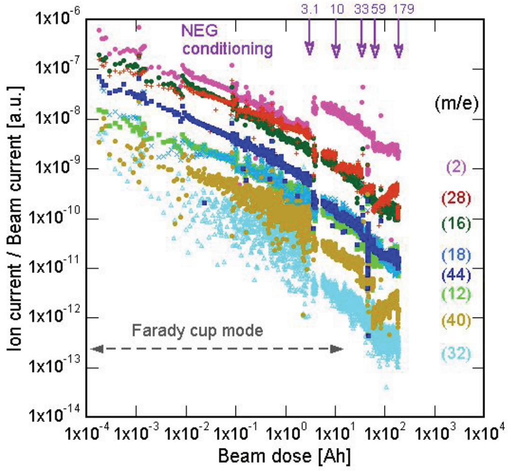

Figure 4: Ion currents of major residual gases normalized by the beam current as a function of the beam dose for the LER.

ISBN 978-3-95450-147-2

LER as a function of the beam dose. The main gases are hydrogen (m/e = 2), carbon monoxide (m/e = 28), methane (m/e = 16), water (m/e = 18), and carbon dioxide (m/e = 44) in descending order. The high partial pressure of methane should be due to the pumping system using NEG as a main pump. Because the beam pipes were not baked in the tunnel, water vapor still remains in the beam pipe. The stepwise pattern represents the timing of NEG activation.

Electrons in the LER Beam Pipe

Electron numbers around the circulating beam in the new aluminum beam pipe were measured with the same electron current monitors as those used in the experiment in KEKB [4]. The electron currents at the locations of the aluminum beam pipes with and without TiN coating were measured at the same time. Figure 5 presents the results together with the results obtained in the KEKB experiments. The bunch spacing was approximately 6 ns, and the bunch numbers were approximately 1580. The numbers in the parentheses represent the photon density [photons s^{-1} m^{-1}] at the measurement points. The voltages of the repeller electrode and the electron collector were −30 and +100 V, respectively. The measured electron currents almost reflect the electron density around the beam orbit. The stored beam current is still low, and the main electrons are photoelectrons rather than the secondary electrons except for the case of the aluminum part without TiN coating. The effect of the antechambers was clearly observed, and the effect of TiN coating was also reflected in the measurement. For the case of aluminum beam pipes without TiN coating, the multiplication of secondary electrons could be observed from a beam current around 400 mA. The results indicate that the secondary electron yield (SEY) of bare aluminum is much higher than the case of TiN-coated aluminum or copper. The multiplication of electrons should cause the nonlinear pressure rise against the beam current, as described above.

Problems

No serious trouble has occurred so far during the commissioning. One big concern is that beam aborts accompanied by localized pressure bursts have been frequently observed from the early stage of the commissioning in the LER. The beam loss monitors trigger the beam aborts. The locations of the pressure bursts have spread to more than 10 points along the ring, but the frequent pressure bursts have been observed in several particular beam pipes. Most pressure bursts have occurred near or inside the aluminum beam pipes in dipole magnets. Furthermore, the beam current where the bursts occurred has increased gradually. The reason for the pressure bursts is not well understood. Possible causes are the discharge at poor electrical contacts by the wall current and the collision of dusts (small particle) with circulating beams. Careful and continuous observation is required in any way.

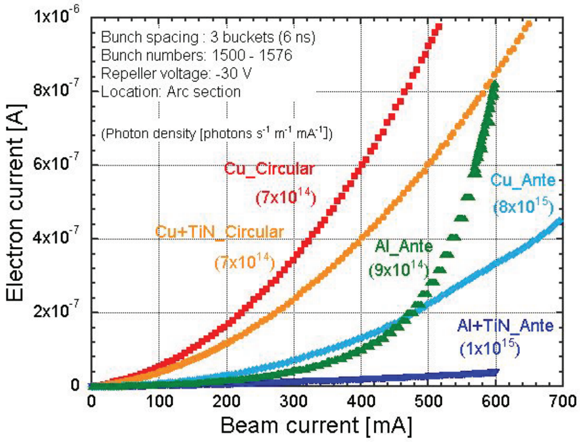

Figure 5: Beam current dependences of electron currents for copper circular beam pipe (Cu_Circular), TiN-coated copper circular beam pipe (Cu+TiN_Circular), copper beam pipe with antechamber (Cu_Ante), aluminum beam pipe with antechamber without TiN coating (Al_Ante), and TiN-coated aluminum beam pipe with antechamber (Al_Ante+TiN), where the numbers in the parentheses are photon densities.

CONCLUSIONS

The first commissioning of the SuperKEKB vacuum system started satisfactorily. No abnormal temperature rises or vacuum pressure has been observed for the new vacuum components so far. Vacuum scrubbing is progressing steadily. Nonlinear rise in the pressure has been observed in the LER, which is due to the electron multipacting at the aluminium bellows chambers. The residual gases are typical one for the NEG pump system. The effects of the antechambers and TiN coating can be observed in the electron densities in the LER. The pressure burst accompanying beam aborts has been a major concern recently. The stored beam currents will gradually be increased to close to 1 A before the particle detector is installed at the end of this year.

ACKNOWLEDGEMENT

We thank all staff of the KEKB accelerator division for their cooperation and continuous encouragement during the construction phase.

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