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STATUS OF THE SuperKEKB VACUUM SYSTEM IN THE PHASE-2 COMMISSIONING

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Abstract

The SuperKEKB is an electron-positron collider with asymmetric energies in KEK aiming at an extremely high luminosity of 8×10^{35} cm^{-2} s^{-1} [1]. The main ring (MR) consists of two rings, that is, the high energy ring (HER) for 7 GeV electrons and the low energy ring (LER) for 4 GeV positrons (Fig. 1). In the Phase–1 commissioning of the MR from February to June, 2016, the vacuum system worked well as a whole. During the shutdown period before the next Phase–2 commissioning, various countermeasures were taken against the problems revealed in the Phase–1 commissioning, such as the attachment of permanent magnets around beam pipes to suppress the electron cloud effect (ECE) in the LER. Other than these works, new beam pipes were installed in the collision point and the LER beam injection region. Additional six beam collimators were also placed in the both rings. The Phase–2 commissioning started in March 2018, and since then, the MR vacuum system has been functioning well.

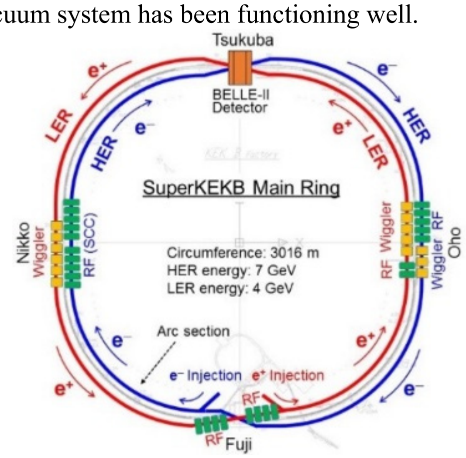

Figure 1: Layout of the SuperKEKB Main Ring (MR).

VACUUM SYSTEM IN PHASE-1

Major Results

In the Phase–1 commissioning that continued from February to June 2016, the MR vacuum system worked well with stored beam currents of approximately 1 A [2, 3]. The beam scrubbing of beam pipes proceeded smoothly [4]. The pressure rise per unit beam current steadily decreased as expected. The coefficient of photon stimulated gas desorption, η, in the arc sections decreased steadily to 7×10^{-6} and 1×10^{-7} molecules photon^{-1} at the end of Phase–1 commissioning assuming the pumping speeds of 0.04 and 0.03 m^{3}s^{-1}m^{-1} for the LER and HER, respectively. A distributed pumping scheme using a strip-type NEG, (ST707, SAES GETTERS Co. Ltd.), which was adopted as the main pump for the arc sections of MR, was activated over seven times in total. Problems were not found in these processes.

Countermeasures more effective than ever before against the ECE are required for the LER. Beam pipes with antechambers and a TiN film coating were used for most of the new beam pipes. Longitudinal grooves or clearing electrodes were also adopted in the beam pipes of dipole magnets. Approximately 90 % of the beam pipes in the ring had the antechambers and the TiN coating. After suppressing the ECE that was caused by electrons in Al-alloy bellows chambers (approximately 5 % of the circumference in total) with permanent magnets as described later, the ECE was revealed at the beam current density, I_d, that is, the bunch current divided by the bunch spacing, of 0.18–0.2 mA RF-bucket^{-1}, which is much higher than that of the case at the early stage of KEKB without these countermeasures, 0.04 mA RF-bucket^{-1}. This indicated that the antechambers and the TiN coating effectively suppressed the ECE.

Various newly developed vacuum components, such as the bellows chambers and gate valves with a comb-type RF-shield, the MO-type connection flanges with little step inside, were adopted for the first time on a large scale. Abnormal temperature rises or discharges were not observed in these components up to beam currents of approximately 1 A. Two horizontal-type beam collimators, the beam pipes for the beam size monitors, and those for the electron injection regions also functioned well.

Major Problems

The ECE, such as the blow up of vertical beam size, was first observed from the I_d of 0.12 mA RF-bucket^{-1}, although various countermeasures were taken as described above [5]. It was finally found that this ECE was caused by the electrons in Al-alloy bellows chambers without TiN coating. The use of permanent magnets forming axial magnetic fields eliminated this ECE. However, the ECE began to appear again at the I_d of approximately 0.2 mA RF-bucket^{-1}, which corresponds to 0.9 A at a bunch fill pattern of 3.06 RF-bucket spacing. It was observed that the density of electrons in a beam pipe at drift space, which had the antechambers and the TiN coating, was close to the threshold density for exciting ECE. Furthermore, permanent magnets that were partially attached for tests around beam pipes at a drift space suppressed the abnormal pressure rise caused by electron multipactoring. From these observations, it was suspected that the source of electrons should be in the beam pipes at drift spaces.

Another major problem during the Phase–1 commissioning was the localized pressure burst phenomena accompanying beam losses in the LER [6]. Pressure bursts were observed around the ring, but most of them occurred

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near or inside the Al-alloy beam pipes in dipole magnets. The most probable cause is the collision between the circulating beams and dust (small particles) in the beam pipes. In fact, we found lots of small dust in the beam pipes composed of Al_2O_3, Al, Si, Ti and so on. As further evidence, the pressure bursts and simultaneous beam losses were reproduced by knocking several beam pipes in the dipole magnets during beam operation.

Several connection flanges and beam pipes in the LER wiggler sections heated up. The connection flanges and the beam pipes in the wiggler section have antechambers with a height of 14 mm, and the synchrotron radiation (SR) should pass through them. It was found that the temperature was sensitive to the vertical beam orbit upstream of the beam pipes, and also to the vertical position of the beam pipes themselves. From these results, it was concluded that the heating was caused by the irradiation of SR emitted from the wiggler magnets upstream of the beam pipes in question. In the worst case, an air leak due to excess heating was observed through a metal seal of the flange.

WORK FOR PHASE-2

Countermeasures Against Major Problems

As a countermeasure against the ECE, permanent magnets are attached to most of the beam pipes at drift spaces in LER. The permanent-magnet units with iron yokes (Type−1unit) are placed in series around the beam pipe as shown in Fig. 2, which produces a magnetic field of approximately 60 G in the beam direction. A simulation showed that the electron density around the beam orbit reduced to approximately 1/10 of that in the case without a magnetic field even for the design beam current, as indicated in Figs. 3 (a) and (b). However, the Type−1 unit cannot be used near the electro-magnets, such as the quadrupole and sextupole magnets, because the iron yokes affect their magnetic field. Therefore, another type of permanent-magnet unit (Type−2 unit), which consists of Al-alloy cylinders with permanent magnets inside and Al-alloy supports, was placed just near the electro-magnets, as also shown in Fig. 2. The axial magnetic field inside the Type−2 unit is approximately 100 G. For the beam pipes that had been used since the KEKB era, solenoid windings were revived. At present, approximately 86% of the drift space (approximately 2000 m) was covered with a magnetic field higher than 20 G.

Analysis of the beam loss process due to collision with dust particles showed that the beam loss lasted for several milliseconds before the beam abort. The simplest inference was that the size of dust particle is relatively large, such as over several 100 μm. Actually, we found large-size Al and Al_2O_3 particles in one of the beam pipes where the pressure bursts were frequently observed in the Phase−1 commissioning. Based on the hypothesis above, we knocked most of the beam pipes in which the pressure bursts had been frequently observed, and dropped dust particles from their ceilings prior to starting the Phase−2 commissioning.

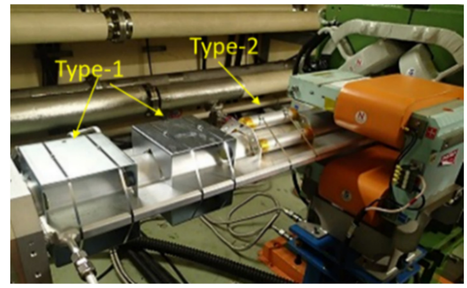

Figure 2: Type-1 and Type-2 units of permanent magnets at drift space.

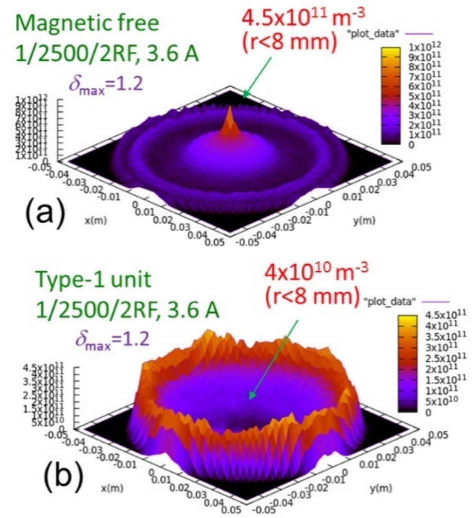

Figure 3: Simulation results of the electron density in a beam pipe (a) without magnetic field and (b) with Type-1 permanent units for a beam current of 3.6 A at a 2-RF bucket spacing.

As for the heating of flanges in wiggler sections, new bellows chambers having SR masks with a height of 2.5 mm inside the antechambers were fabricated for protecting the connection flanges from the steered SR [5]. Two bellows chambers with the masks were installed between beam pipes in the wiggler section where the increase in temperature had been observed. Simultaneously, the beam pipes in the wiggler section were re-aligned in the vertical direction with respect to the nearby quadrupole magnets. Furthermore, the beam orbit in the wiggler section will be kept as flat as possible during beam operation in the Phase−2 commissioning.

Installation of New Components

The most important work in MR during the shutdown period before the Phase−2 commissioning was to install new beam pipes and components for the BELLE-II detector and the superconducting final-focusing magnets around the collision point. Although some problems occurred in the cooling system of the components, the difficult task was successfully completed by January 2018 (Fig. 4). The details will be presented elsewhere.

Six additional beam collimators were installed to suppress the background noise of the detector, following the successful results of the two models used in the Phase−1

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commissioning [7]. Two vertical-type collimators were newly developed and installed (Fig. 5). Including the KEKB-type beam collimators, 5 and 19 beam collimators were prepared for the LER and HER, respectively, around the rings in the Phase–2 commissioning.

The beam pipes at the LER injection region were changed to adapt a low emittance beam injected through the damping ring (DR). The construction of DR, as well as its vacuum system, was also a big work for the Phase–2 commissioning [8].

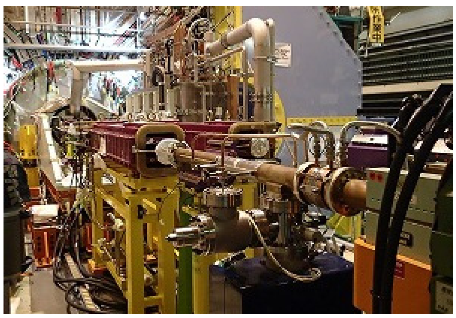

Figure 4: Installation of beam pipes near the collision point.

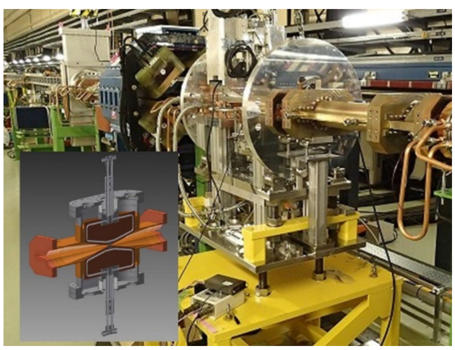

Figure 5: Vertical-type beam collimator in the tunnel.

PRESENT STATUS IN PHASE-2

The Phase–2 commissioning of MR started on March 19, 2018, and will be continued until July 2018. After necessary machine tunings, squeezing of the beam sizes at the collision point, which is an important step to the nano-beam scheme collision, began in April 2018. The stored beam currents were increased gradually paying attention to various newly installed vacuum components, such as the beam pipes and bellows chambers at the collision point, the beam collimators, and so on. Until 24th, April, the beam doses (integrated beam currents) are 33,3 Ah and 40.5 Ah, and the maximum stored beam currents are 0.31 A and 0.25 A for LER and HER, respectively. The vacuum pressures at the regions where we opened to air for vacuum works are steadily decreasing. Trends of the average pressures and the beam currents for both rings are presented in Fig. 6. Although we have experienced air-leak trouble in the LER, the vacuum system is functioning well.

The preliminary tuning of beam collimators watching the detector background and the beam injection rate has just started. The pressure burst accompanying beam loss in the LER has not been observed in the Phase–2 commissioning up to a beam current of 0.2 A. The ECE in the LER, such as the beam-size blow up has not been also observed up to this beam current. The study on the pressure bursts and the ECE are planned at higher beam currents. The results of countermeasures taken before the Phase-2 commissioning will be checked then.

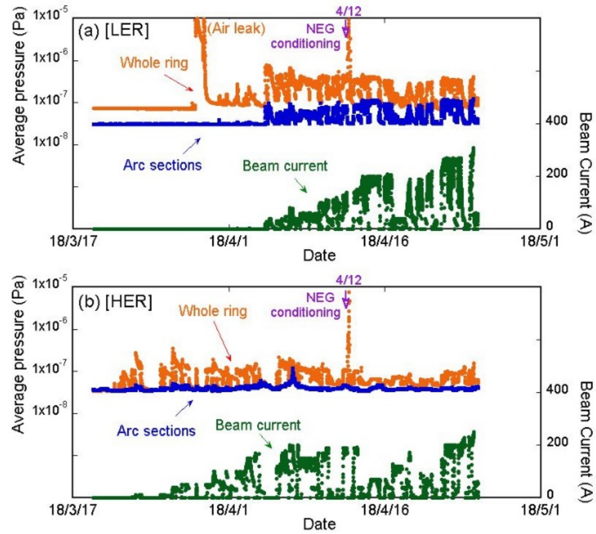

Figure 6: Trends of average pressures and stored beam currents for (a) the LER and (b) the HER.

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