PROBLEMS IN SuperKEKB VACUUM SYSTEM DURING PHASE-1 COMMISSIONING AND THEIR MITIGATION MEASURES

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Abstract

The vacuum system of the SuperKEKB main ring worked well through the first (Phase-1) commissioning as a whole, but simultaneously experienced several problems, such as the electron cloud effect (ECE) in the positron ring, the pressure bursts accompanying beam loss, the heating of connection flanges in the wiggler sections due to the steered synchrotron radiation (SR), etc. Towards the next (Phase-2) commissioning, countermeasures to these problems are prepared during the shutdown period. For example, permanent magnets generating magnetic fields in the beam direction are attached to the beam pipes at drift spaces for the suppression of ECE. Bellows chambers with SR masks inside antechambers are installed at wiggler sections to protect the connection flanges from the steered SR.

VACUUM SYSTEM IN PHASE-1

SuperKEKB is an energy-asymmetric electron-positron collider in KEK, Japan. The main ring (MR) consists of two rings, each with a circumference of 3016 m, as schematically drawn in Fig. 1 [1]. The high-energy ring (HER) and low-energy ring (LER) are for 7.0 GeV electrons and 4.0 GeV positrons, respectively. Each ring has four arc sections, and four straight sections for the particle detector (BELLE-II), the RF-cavity section, the wiggler section and the beam injection/extraction section. The Phase-1 commissioning of the SuperKEKB started in February 2016 and ended in June 2016. From the viewpoint of the vacuum system, the major tasks of the Phase-1 commissioning were the vacuum scrubbing of the new beam pipes and checking the stabilities of various new vacuum components at high beam currents of approximately 1 A.

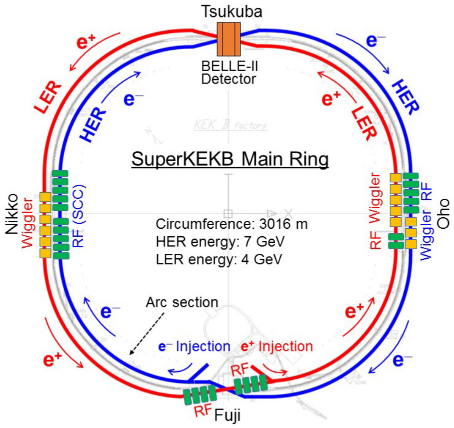

Figure 1: Layout of the SuperKEKB Main Ring (MR).

The vacuum system of the MR worked well through the commissioning as a whole [2, 3]. The coefficient of the photon stimulated desorption (PSD) rate, η (molecules photon^{-1}), decreased steadily with increasing photon dose at arc sections as expected. The temperature increases in the bellows chambers with a comb-type RF-shield, the MO-type connection flanges, etc. were less than 5 °C at approximately 1 A, and no serious problem was found [3]. The effectiveness of the antechambers and TiN coating for suppressing the electron-cloud effect (ECE) in the LER was also confirmed. The new beam collimators functioned well as prospected [4]. Furthermore, the control system operated stably. At the same time, however, we experienced several problems in Phase-1. Towards the Phase-2 commissioning, countermeasures to these problems are prepared during the shutdown period as described in the following sections.

PROBLEMS AND MEASURES

ECE in the Positron Ring

At a beam current of approximately 600 mA with 1576 bunches and approximately 6 ns (3 RF buckets) bunch spacings, the ECE was first observed in the positron ring [2]. Blow-up of the vertical beam size, non-linear pressure rise against the beam current, and coupled bunch instability were observed. The dedicated beam studies found that the ECE was excited by the electron cloud formed inside the aluminum-alloy bellows chambers in the ring.

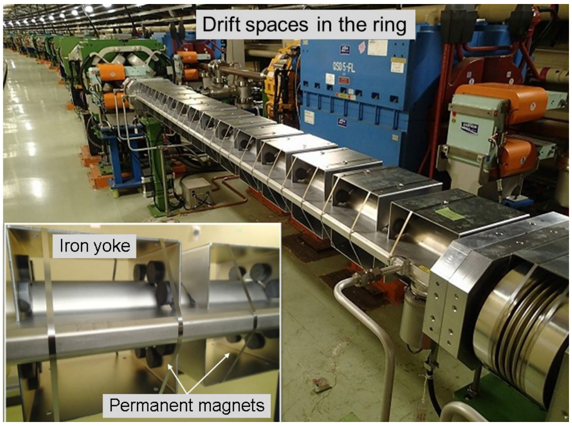

Figure 2: Permanent magnets with iron yokes attached to the beam pipes at the drift spaces of the LER arc sections for the suppression of the ECE.

These bellows chambers were not coated with TiN, unlike the beam pipes [3]. Therefore, the inner surface had a high secondary electron yield, and the multiplication of

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electrons is likely to occur. As a measure, permanent magnets generating a magnetic field of approximately 100 G in the beam direction were attached to approximately 820 aluminum-alloy bellows chambers in the ring. The ECE was suppressed up to a beam current of 900 mA as a result.

At a beam current over 900 mA, however, the ECE was again excited. One possible location of the electron cloud is the beam pipes at the drift spaces, although these beam pipes basically have antechambers and the inner surface is coated with TiN. Actually, the permanent magnets attached to several beam pipes in some drift spaces for a test suppressed the non-linear pressure rises against the beam current in the region. Another possible location is the aluminium beam pipes without TiN coatings, which have been used since the KEKB era.

As countermeasures, permanent magnets are attached to most of the beam pipes at drift spaces in the ring. The permanents magnets with iron yokes are placed in series around the beam pipe as shown in Fig. 2, and a magnetic field of approximately 60 G is produced in the beam direction. A simulation showed that the electron density around the beam orbit reduced to 1/50–1/100 of that in the case without a magnetic field. Furthermore, in the case of the old aluminum beam pipes without Tin coatings, the solenoids wound in the KEKB era are returned to operation.

Pressure Bursts Accompanying Beam Loss

Local pressure bursts accompanying beam losses were observed in the LER [2]. These pressure bursts were frequently observed from the early stages of the commissioning. The frequency of bursts increased when the beam current exceeded the recorded value, while it tends to decrease when the beam current remains almost constant. Pressure bursts were observed at more than 10 points around the ring, but were observed most frequently in the Tsukuba straight section (Fig. 1). Furthermore, most of the pressure bursts occurred near or inside the aluminum-alloy beam pipes in dipole magnets.

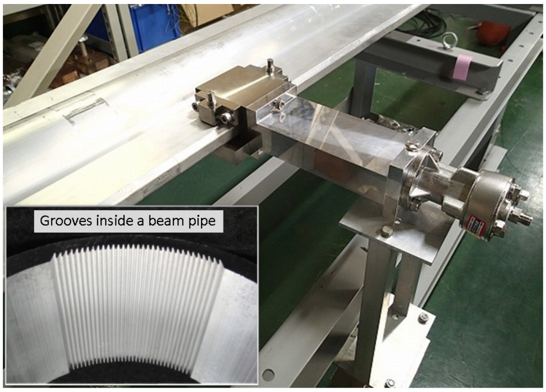

Figure 3: Knocker for test fixed to a beam pipe to shake and to artificially drop dust particles.

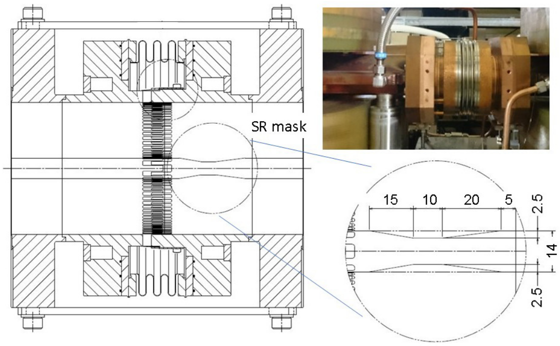

Figure 4 Cross-sectional view of a bellows chamber with SR masks inside antechambers.

The causes of the pressure bursts and the beam loss are not well understood yet. However, the most probable cause is the collision between the circulating beam and dust particles in the beam pipes [3]. In fact, we found lots of small dust particles in the beam pipes that were composed of Al_2O_3, carbon oxide (i.e., plastic or fiber), Si (i.e., some polishing material?), or V and Ti (NEG ingredients), and some have a size of over 50 µm. Furthermore, the longitudinal grooves in the beam pipes for the dipole magnets, which counteract the ECE by reducing the secondary electron yield, are likely to trap dust particles during the manufacturing and installation process. It is difficult to clean the dust out from the bottoms of the grooves. As further evidence, the pressure bursts and simultaneous beam loss were reproduced during a test using a knocker, which oscillates the beam pipe in pulses, attached to several aluminium beam pipes in dipole magnets at the Tsukuba straight section.

Further studies about the pressure bursts are in progress. Based on the dust particle hypothesis, we are planning to knock the beam pipes, in which the pressure bursts had been frequently observed in Phase-1, before starting the Phase-2 commissioning. The knocker is activated by a high pressure of approximately 4–6 atm. A knocker for the test, attached to a beam pipe, is shown in Fig. 3.

Heating of Flanges at Wiggler Sections

Several connection flanges of the beam pipes in the LER wiggler sections heated up during the Phase-1 commissioning (Fig. 1). The connection flanges and the beam pipes in the wiggler section have antechambers on both sides, and the SR emitted from wiggler magnets passes through the antechambers. The temperatures, measured at the outside of the antechambers near to the connection flanges, were over 50 °C at a beam current of 1 A. In the worst case, air leaked through a metal seal of the connection flange. 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 hitting of SR emitted from the wiggler magnets upstream of the beam pipes in question. The total length of the wiggler section is approximately120–140 m, and the SR passes through the antechambers with a height of 14 mm. Therefore, if the beam orbit has a vertical slope or the beam pipe is misaligned vertically, the SR is likely to hit the upper or lower walls of the antechambers.

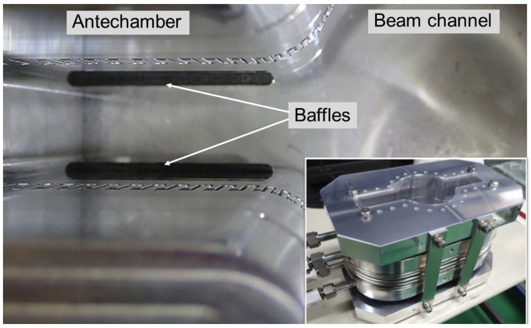

Figure 5: Baffles against scattered photons with a height of 2 mm inside an antechamber of a bellows chamber.

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. The schematic cross section is presented in Fig. 4. They are installed at several locations between the adjacent beam pipes in the wiggler section. If the vertical slope of the beam orbit is 0.1 mrad, for example, the masks will create a 25 meters long shadow of the SR downstream of it. Simultaneously, the beam pipes in the wiggler section are re-aligned with respect to the nearby quadrupole magnets. Furthermore, the beam orbit in the wiggler section should be kept as flat as possible during the beam operation.

Distortion of SR Image by Scattered Photons

SuperKEKB MR uses a beam size monitor using the SR in the visible range emitted from a bending magnet. The image of the SR is reflected by a mirror placed in an antechamber outwards, and is transported to the camera [2]. The monitor provides very important information for the optics tuning and for the study of various beam instabilities. They were installed at the Fuji and Oho straight sections for the LER and HER, respectively (Fig. 1). However, during the Phase-1 commissioning, the calibration and precise measurement of the beam size was difficult. During the shutdown time, the insides of the beam pipes at the monitor region were checked and it was pointed out that the photons scattered in the antechambers at the upstream side of the SR extraction mirror distorted the image of the SR in the camera.

As a countermeasure, the bellows chambers located approximately 15 m upstream from the mirror are exchanged for new ones having baffles, each with heights of 3 or 2 mm in an antechamber, as shown in Fig. 5. The baffles are made of aluminum-alloy and the surfaces are blackened by Ni coating to avoid the scattering of photons.

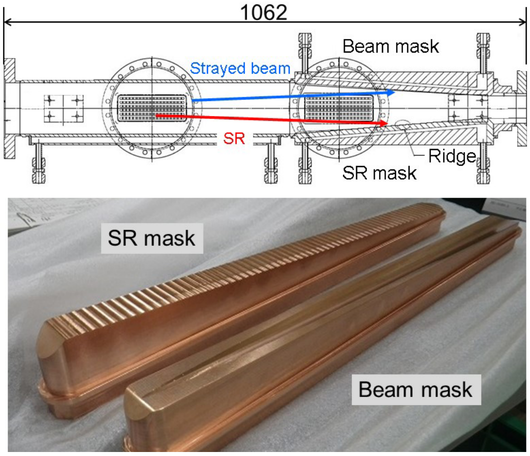

Figure 6: Horizontal cross-sectional view of the tapered beam pipe, and the SR and beam masks.

Air Leak at a Tapered Beam Pipe

An air leak occurred at an end flange of a beam pipe at the Fuji straight section of the HER (Fig. 1). The beam pipe is tapered and the aperture changes from the race-track of dimensions 104×50 mm (upstream side) to that of 60×40 mm (downstream side). The vacuum seals were metal O-rings with the same apertures. Air leaked from the downstream connection flange at the same time of a beam abort. Actually, local pressure bursts had been frequently observed near this location at the same time of beam aborts. In addition, it was found that the residual radioactivity was high around the flange. Based on these observations, it was suspected that a part of the beam hit the flange at the time of beam aborts, and the O-ring was damaged by the beam. Another possible reason is the irradiation of SR reflected from the SR mask, upstream of the flange.

For the protection of the flange, a new tapered beam pipe with a mask for the beam (beam mask), as well as a mask for the SR (SR mask), was fabricated, and the existing beam pipe was replaced with the new one. The schematic drawing of the new beam pipe and these two masks are presented in Fig. 6. The surface of the SR mask has small ridges to suppress the reflection of the SR.

PRESENT STATUS AND PLAN

The Phase-2 commissioning, which will be operated with a new particle detector BELLE-II, is planned to start in fiscal year of 2017. A stored current of more than 1 A is expected in this phase. During the shutdown time before the start of Phase-2, the necessary countermeasures are prepared against the various problems found in Phase-1. Other than these preparations, new vacuum components for the particle detector are installed. Moreover, additional beam collimators will be installed to suppress the background noise of the detector. Furthermore, the construction of a damping ring for the positron beam is in progress. The beam pipes at the positron injection region are changed to adapt the new injection scheme using the damping ring.

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