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OBSERVATION OF PRESSURE BURSTS IN THE SUPERKEKB POSITRON RING

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Abstract

The SuperKEKB is an electron-positron collider with asymmetric energies in KEK aiming an extremely high luminosity of 8E35 cm^{-2} s^{-1} using a nano-beam scheme. In the Phase-1 commissioning from February to June 2016, the vacuum system of the main ring worked well as a whole at stored beam currents of approximately 1 A [1]. However, the localized pressure bursts accompanied by beam losses were observed in the positron ring [2]. The beam loss monitors triggered beam aborts, and the phenomena have become an obstacle to the beam commissioning. These pressure bursts were frequently observed from the early stage of the commissioning. Most of the pressure bursts occurred near or inside of aluminum-alloy beam pipes in bending magnets, which have grooved surface at the top and bottom sides. The various observations indicate that the most probable cause of this phenomenon was the collision between the dusts dropped from the grooves and the circulating positron beam. We report the properties and the probable causes of the pressure bursts, and the possible mitigation methods. Some results of the countermeasures taken prior to the ongoing Phase-2 commissioning are also presented.

INTRODUCTION

The SuperKEKB, which is an upgrade of the KEKB B-factory (KEKB), is a high-luminosity electron-positron collider with asymmetric energies of 7 GeV (electron) and 4 GeV (positron). At the SuperKEKB project, a 50-fold increase in integrated luminosity is expected, just over 10 years after inauguration. The design luminosity is 8E35 cm^{-2} s^{-1}, which is approximately 40 times the KEKB's record.

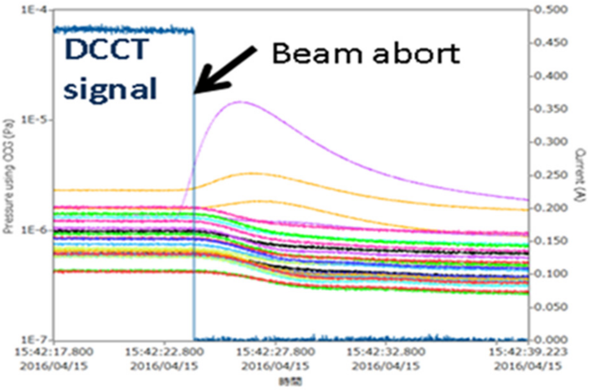

Figure 1: Typical example of a pressure burst accompanied by a beam abort.

The trends of the beam current (DCCT signal) and the pressures (output of cold cathode gauges (CCG)) at the timing of a typical pressure burst accompanied by a beam abort are plotted in Fig.1, where the data were recorded every 10 ms. It can be seen clearly that pressure burst occurred prior to beam abort. From this observation, we thought beam loss was happened due to accident accompanied by pressure burst.

FREQUENCY OF OCCURRENCE AND ORIGIN POINT ESTIMATION

Figure 2 shows the frequency of pressure bursts and the maximum stored beam currents as a function of the beam operation time. There is a tendency that the pressure burst was more frequent on the morrow of increasing the maximum beam current.

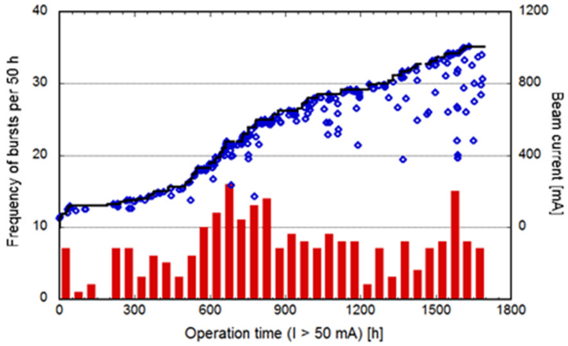

Figure 2: Frequency of pressure bursts (red bar), the beam currents when the bursts occurred (blue dot) and the maximum stored beam currents (black line) as a function of the operation time with a beam current larger than 50 mA.

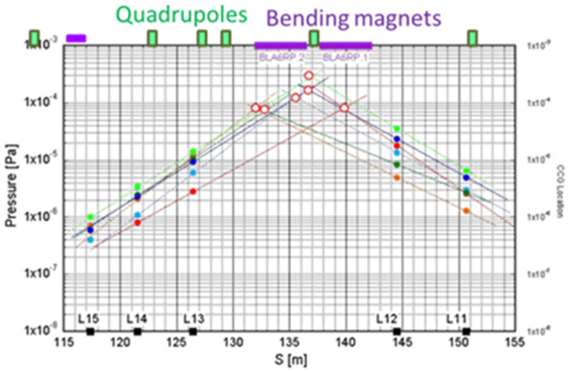

Figure 3: Estimates of the origins of pressure bursts using the height distributions of measured pressures along the ring for 6 samples.

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We tried to estimate the origins of pressure bursts using the height distributions of measured pressures assuming that the origin point of pressure bursts is highest and the gas evenly diffuse. Here, the pressures were measured approximately every 10 m along the ring. Figure 3 shows a typical result of the estimation, here the vertical axis is the pressures in logarithmic scale values and the horizontal axis is the location along the ring. The data taken from several times of pressure bursts are plotted, and the crossing points of the lines (red circles) are the estimated origins of pressure bursts. These points are located at the beam pipe in the bending magnet. The beam pipe for bending magnets in the positron ring has the groove structure, which is shown in Fig. 4, to suppress the electron cloud effect (ECE) [3].

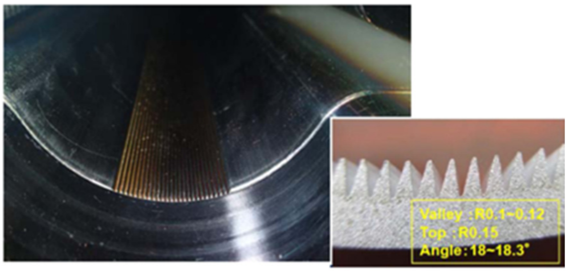

Figure 4: Inside view of a beam pipe with grooves fo bending magnet, and the detailed structure.

PRESSURE BURST MECHANISM AND KNOCKER

We considered what the cause of the pressure burst is. At first, we suspected the discharge, that will be caused by the pulsed wall current and/or the higher order mode (HOM) excited by a beam. However, we could not observe the signals from loss monitors located at the points where the pressure bursts were frequently observed. Furthermore, we could not also detect HOM signal from the beam position monitors there. As a result, it is difficult to imagine that the discharge is a cause of the pressure bursts.

Next, we suspected the colliding of the circulating beam with dust particles in the beam pipe. It was hypothesized that the energy deposited by the collision with beam evaporated the dust particles, and this is observed as a pressure burst phenomenon.

Figure 5 shows a typical behaviors of beam phase, loss monitor (pin diode) signal and beam current just before the beam abort with pressure burst [4]. The oscillation of beam phase indicates the synchrotron oscillation, and it means that the beam lost the energy due to the collision with dust particles.

To substantiate the hypothesis, we tried to knock the beam pipes in question and drop dust particles from their ceiling by a knocker, which gives an impulse to the beam pipe. Figure 6 shows the knocker attached to a beam pipe in a bending magnet. We made a remote-control system, as shown in Fig, 7, to knock the beam pipe during the beam operation.

Regardless the materials, i.e. aluminum-alloy or copper-alloy, we could observe the beam aborts accompanied by pressure bursts for beam pipes with the groove structure when they were knocked. We could reproduce the phenomena with a probability of 100% (14 times out of 14 tries). On the other hand, for the beam pipes without the groove structure, we could not observe the beam aborts accompanied by pressure bursts.

From this result, we guess the cause of pressure burst is relevant to the groove structure. The groove structure is likely to catch the dust particles, as shown in Fig. 4

Figure 2 indicated that the frequency of pressure bursts tends to increase when the beam current is raised. It will be explained by the reason that the dust particles, which were caught in the groove structure at top side, are likely to fall at that timing, since the intervals of grooves should broaden because of thermal expansion due to the higher synchrotron radiation power.

Figure 5: Typical behaviors of beam phase (red line) , loss monitor signal (purple and blue line) and beam current (yellow green line) just before the beam abort with pressure burst.

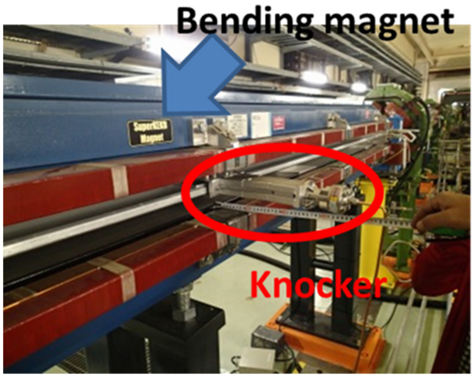

Figure 6: Knocker attached to the beam pipe in a bending magnet.

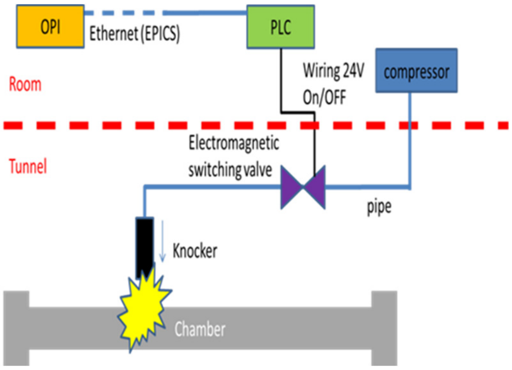

Figure 7: Remote control system for the knocker test.

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COMPONENTS OF DUST

We collected the dust particles from a spare beam pipe with the groove structure. The component analysis by XPS showed that the collected dust particles had a variety of components, that is, there were particles of the principal ingredients of (1) Al, (2) Si, O, (3) Al, O, (4)V, Zr, and (5) Ti, O. Figure 8 shows an example of the case (1) Al.

COUNTERMEASURE OF PRESSURE BURST TOWARD PHASE-2

After Phase-1 commissioning, we gathered the dust particles from the beam pipes where the bursts were frequently observed. A special tool to clean up the inside of beam pipes with antechambers was developed (Fig. 9 (a), (b)). After knocking the beam pipe kept in vacuum, the beam pipe was slowly filled with N_2. Then the dust particles at the bottom of beam channel were sucked out with a powerful vacuum cleaner (Fig. 9 (c)). As a result, lots of large dusts were found from one of the two beam pipes (Fig. 9 (d)).

It is hardly possible to clean up the all beam pipes. Therefore, we selected 24 beam pipes with the groove structure for bending magnets in which the pressure bursts were frequently observed, and dropped dust particles from the ceiling of them by using the knocker. We knocked 150 times for each beam pipe. We expect the reduction of the frequency of bursts in Phase-2 commissioning.

Five weeks had passed since Phase-2 commissioning start in March 2018. The beam current in the positron ring reached to 220 mA by the end of April 2018. The pressure bursts accompanied by beam losses has not been observed in Phase-2 commissioning.

CONCLUSION

The knowledge about the pressures bursts accompanied by beam loss obtained from the Phase-1 commissioning and the current status are reported in this paper. However, we have not yet understood this problem completely. The investigation on the phenomena will be further continued during the Phase-2 commissioning.

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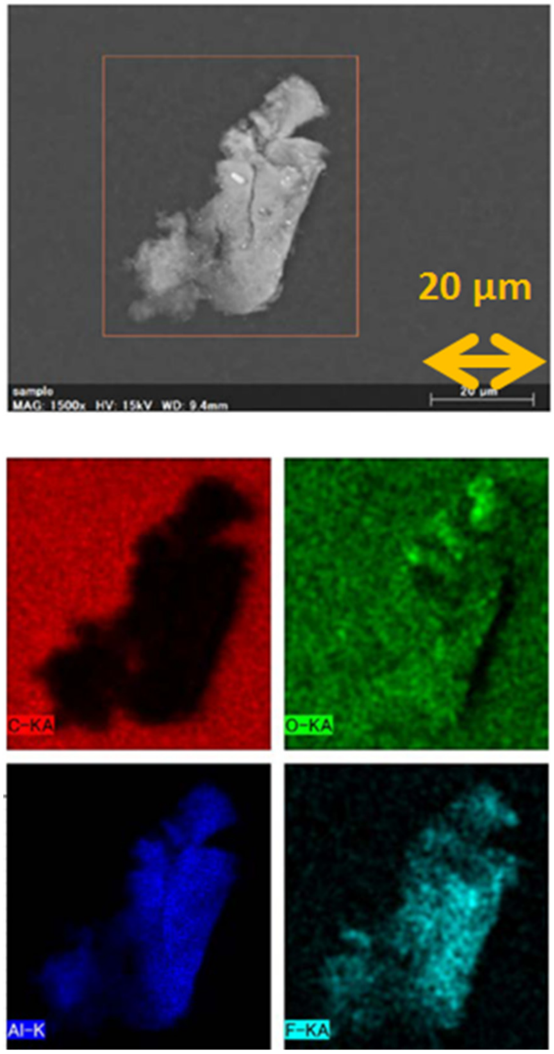

Figure 8: A typical dust considered to be generated from the aluminum pipe chip found in a beam pipe, and the result of semi-quantitative analysis of it.

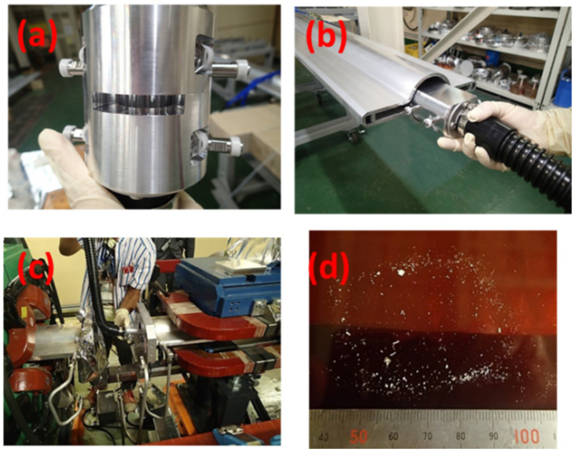

Figure 9:
(a), (b) a special tool to clean up the inside of beam pipes
(c) the testing scenes
(d) the dusts that were gathered from beam pipe