BEAM TESTS OF A CLEARING ELECTRODE FOR ELECTRON CLOUD MITIGATION AT KEKB POSITRON RING*

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Abstract

In order to mitigate the electron cloud instability in an intense positron ring, an electron clearing electrode with a very thin structure has been developed. The electrode was tested with a positron beam of the KEKB B-factory (KEKB). A drastic reduction in the electron density around the beam was demonstrated in a wiggler magnet with a dipole-type magnetic field of 0.78 T. The clearing electrode was then applied to a copper beam pipe with antechambers assuming an application of the electrode to a wiggler section in the Super-KEKB. The beam pipe was installed at a magnetic-free region in the ring and tested with beam. No extra heating of the electrodes and feed-throughs were observed. A reduction in the electron density reasonable in a magnetic-free region was also obtained.

INTRODUCTION

One of the most important problems in recent high-intensity positron/proton storage rings is the electron-cloud effect [1]. The electron cloud excites single or multi-bunch beam instabilities and deteriorates the performance of the ring. A clearing electrode in a beam pipe had been said to be an effective method to reduce the electron density around the beam by absorbing electrons through a static electric field [2]. Heating and impedance issues, however, have been precluding the use of the electrode in high-intensity positron rings, where the bunch length is relatively short (≤ 1 cm).

This paper reports the experimental results on a new-type of clearing electrode carried out in the positron ring of the KEKB B-factory (KEKB) [3]. The electrode has a very thin structure, which enables to solve the heating and impedance problems. The clearing electrode was studied at first in a wiggler magnet with a dipole-type magnetic field. The efficacy of the electrode in the strong magnetic field was investigated with an intense positron beam. The electrode was then applied to a copper beam pipe with antechambers, which will be used in an upgrade project of KEKB (i.e., Super-KEKB). The beam pipe was placed at a magnetic-free region in the ring. The heating of the electrode and the effect of the electrode on the electron density were studied there.

EXPERIMENTS IN A WIGGLER MAGNET

The first experiment was performed using a test chamber with a clearing electrode and an electron monitor facing it [3]. The chamber was installed into a wiggler magnet in the ring. The inside view of the test chamber and the chamber in the magnet are shown in Fig. 1. The wiggler magnet had a maximum vertical magnetic field of 0.78 T. The positron beam had energy of 3.5 GeV. The maximum beam current was approximately 1.6 A (1585 bunches, 10 nC/bunch, 6 ns spacing). The bunch length was approximately 6 mm at this beam current. The synchrotron radiation was incident on the side-wall of the test chamber with a line density of 2×10^{17} photons $s^{-1} m^{-1}$ at a beam current of 1.6 A.

The structure of a clearing electrode was a thin strip line, as shown in Fig. 2. An alumina ceramic layer with a thickness of approximately 0.2 mm functioned as an insulator. A thin layer of tungsten with a thickness of approximately 0.1 mm on the alumina ceramic layer functioned as the electrode. These two layers were formed by a thermal spray method, and were tight on the chamber. The width and length of the electrode were 40 and 440 mm, respectively. The calculated loss factor was approximately 5×10^{8} V C^{-1} for $\sigma_z = 6$ mm (by GdfidL). The expected parasitic loss was approximately 10 W for 1.6 A beam. The rise in the temperature of the electrode was small. The electrode was connected to a coaxial feed-through at one end as shown in the figure. The connection part was designed to make the inner surface as smooth as possible while keeping a secure electrical contact. The

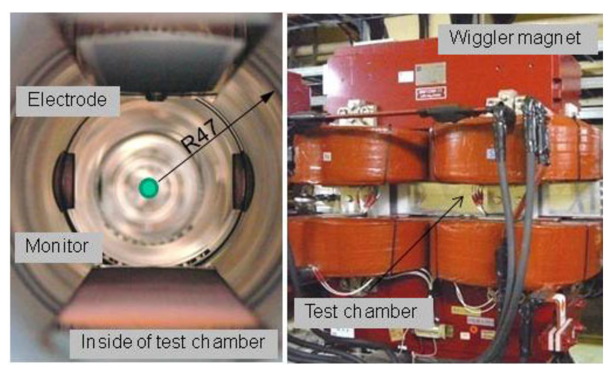

Figure 1: Inside view of the test chamber and the chamber in the wiggler magnet.

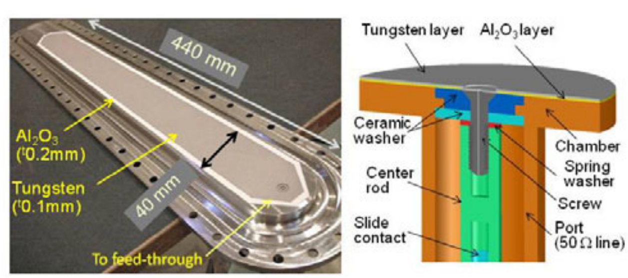

Figure 2: Structure of a thin clearing electrode for test and the connection part.

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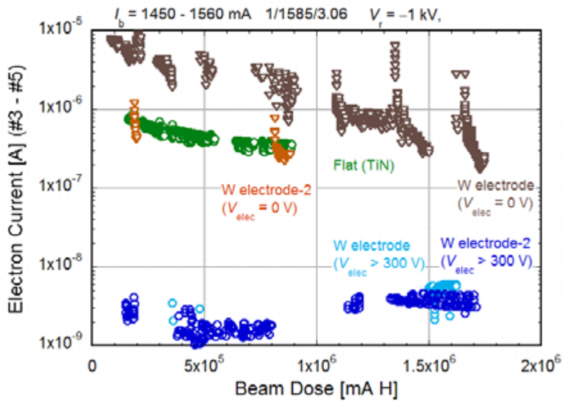

Figure 3: Changes in the electron currents in collectors #3–#5 as a function of the beam dose (i.e., the integrated beam current) for the cases of the clearing electrode ($V_{elec} \geq$ 300 V) and a flat surface with TiN coating.

voltage of the electrode (V_{elec}) was applied from an external power supply up to ±1 kV.

The electron monitor had seven strip-type collectors (#1–#7). These collectors enabled the measurement of the horizontal spatial distribution of the electrons. The DC voltage (V_r), which is varied from –1 kV to 0 V, was applied to the retarding grid. A constant DC voltage of +100 V was applied to the collectors. The electron current flowing into the collectors was measured in the DC mode. The gap between the electrode and the monitor was 74 mm.

Figure 3 shows the changes in the measured electron currents of collectors #3–#5 (central part) as a function of the beam dose (i.e., the integrated beam current) for the cases of the clearing electrode ($V_{elec} \geq$ 300 V) and a flat surface with TiN coating at V_r = –1 kV. In this case, the electron current indicates the electron density around the beam orbit. The beam currents were in the range 1450–1550mA. The measurements were carried out twice for two different electrodes. As shown in this figure, the electron currents were lower by two orders of magnitude than in the flat TiN-coated surface or the tungsten surfaces (V_{elec} = 0 V). The result demonstrated a drastic effect of the clearing electrode in reducing the electron density in a strong magnetic field. Although an abnormal discharge was observed at the connection to the feed-through in the tests of a first model, discharge and extra heating was not found after using the latest connection structure as shown in Fig. 2. The heating of the connection cable was not observed either.

APPLICATION TO A BEAM PIPE FOR WIGGLER MAGNETS

The electrode was then applied to a copper beam pipe with antechambers for wiggler magnets, which is planned to be adopted in the Super KEKB. The beam pipe and the inside view are shown in Fig. 4 (a) and (b). The beam channel has a diameter of 90 mm. The height of an antechamber is 14 mm, and the total width of the beam pipe is 220 mm. Two electrodes with each length of 950

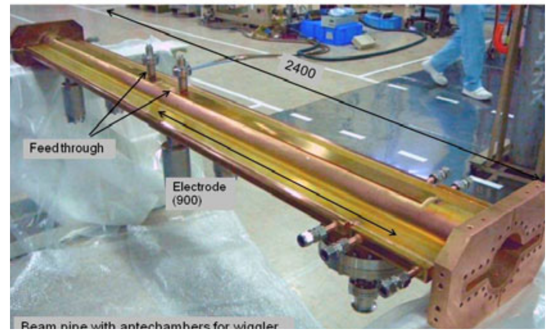

Figure 4 (a): Beam pipe with antechambers for wiggler magnets, where two clearing electrode are prepared at top of the beam channel.

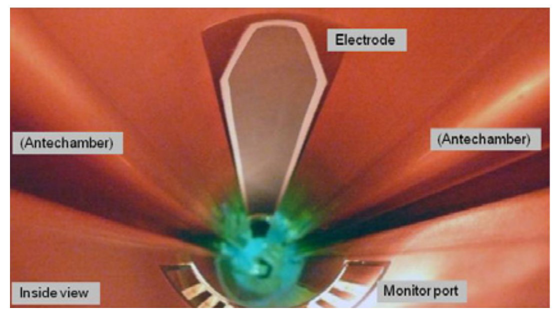

Figure 4 (b): Inside view of a beam pipe with antechambers and clearing electrodes. An electron monitor is placed facing to an electrode.

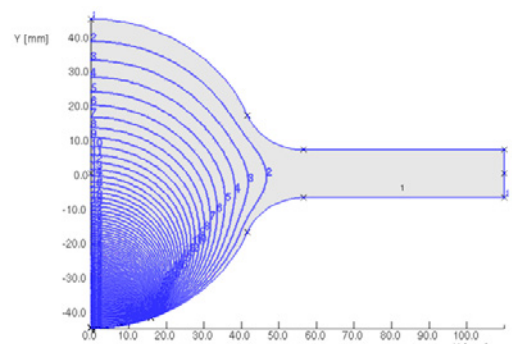

Figure 5: Calculated equipotential lines due to an electrode at the bottom of a beam pipe with an antechamber.

mm were welded on the top of the beam channel in series. The width is 32 mm. One electrode has a feed-through at the upstream side and other has it at the downstream side for test. The chamber has an electron monitor with a retarding field analyzer (RFA) at the bottom of the chamber, facing the electrode. The calculated equipotential lines in the beam pipe created by an electrode at the bottom of the beam pipe are shown in Fig. 5. The voltage at the beam position is ~ 75 V when a voltage of 500 V is applied to the electrode. The feed-through was changed to improve the thermal strength, based on the structure of a feed-through adopted for a bunch feedback kicker at KEKB.

The beam pipe was installed into the KEKB position ring in summer, 2009. The beam pipe was placed at a magnetic-free region due to the existing conditions. A

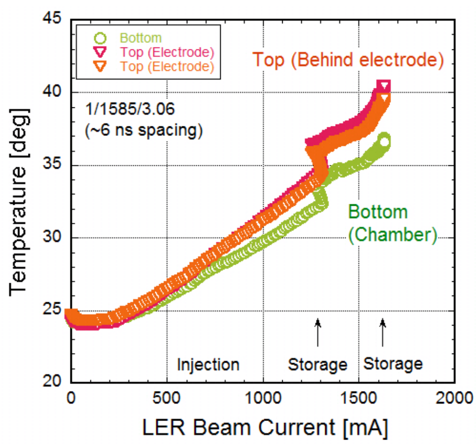

Figure 6: Temperatures at the top (behind electrodes) and the bottom of the beam pipe during beam operation.

weak vertical magnetic field (up to ~70 G) can be applied at the position of the electron monitor.

Temperatures at the top (behind electrodes) and bottom of the beam pipe were monitored during the beam operation, and a typical result is presented in Fig. 6. The input power estimated from the difference of temperatures is approximately 40 Wm^{-1}. Considering the joule loss on the thermal-sprayed (i.e., rough) tungsten surface (~20 W), and the parasitic loss at the electrode (~10 W), the temperature rise was reasonable. Small difference in the temperatures was found between the two electrodes.

The effect of the electrode on the electron density was also briefly checked by applying a positive voltage to the electrode. Figure 7 shows the measured electron currents for B = 0 and ~60 G against the applied voltage. The electron density reduced even for B = 0, but the reduction is much smaller than that in the wiggler magnet experiment (0.78 T). A reason could be the difference in the beam pipe aperture, but probably the main reason should be the presence of a magnetic field. Actually, with an increase in the magnetic field up to ~60 G, the reduction rate of the measured electron current became larger. The electrode works more effectively in the dipole magnetic field. For reference, a calculated electron density around the beam orbit by simulations is also presented in the figure for the cases of B = 0, 20 and 30 G. The computed electron currents against the applied voltage (V_{elec}) are similar to the measured ones. More detailed experiments are planned for this year.

IMPACT ON IMPEDANCE AND INSTABILITIES

A big concern for clearing electrodes in future application will be their impedance. The calculation of impedance of the electrode had started in parallel to the experiments. Small impedance for the thin structure was confirmed by simulation. Estimation of the impedance on a stored beam has recently started assuming that electrodes are used in the wiggler section of Super-KEKB. In this case, the total length of the electrodes will be

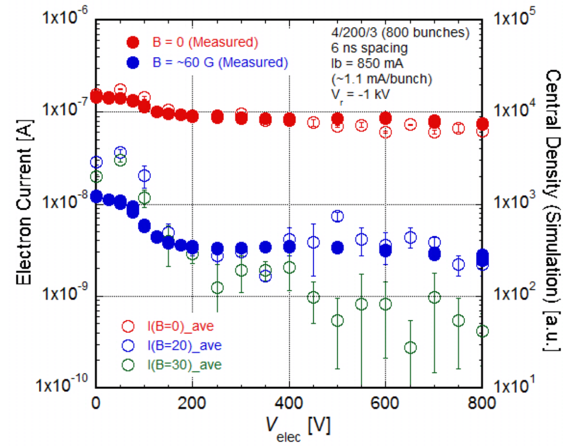

Figure 7: Behaviours of measured electron currents against the applied voltage for B = 0 and ~60 G. The calculated central electron densities for B = 0, 20 and 30 G are also plotted for comparison.

approximately 160 m (100 electrodes) out of 3016 m circumference. In a preliminary estimation, the total loss factor of the electrode is approximately 1.7×10^{11} VC^{-1}. The total loss factor for the ring is estimated to be 1.8×10^{13} VC^{-1}, including resistive wall (ϕ90 mm, 3016 m), various vacuum components and accelerating cavities. The contribution of the loss factor from the electrodes to the total one is then approximately 1%. The impact on the microwave instability also seems small. On the other hand, the total vertical kick factor of electrodes was estimated to be 1.6×10^{13} $VC^{-1}m^{-1}$. The threshold bunch current of the transverse mode coupling instability is 430 mA/bunch [4], which is much higher than the design value (~1.44 mA/bunch). Further detailed investigation will continue.

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