DEMONSTRATION OF ELECTRON CLEARING EFFECT BY MEANS OF CLEARING ELECTRODES AND GROOVE STRUCTURES IN HIGH-INTENSITY POSITRON RING

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Abstract

Beam instability caused by the electron cloud is expected to be a limiting factor in the performance of future advanced positron and proton storage rings. In a wiggler magnet of the KEKB positron ring, we have installed a vacuum chamber with an insertion to study the mitigation techniques of the electron-cloud effect in a high magnetic field. The tested insertions are a clearing electrode, a triangular groove structure and a flat surface. The design of the clearing electrodes, grooves and smooth insertions have been intensively studied and then manufactured at KEK and SLAC. We report here about the large reduction in the measured electron density when the clearing electrode and the groove structures are installed with respect to the flat insertion. These experiments are the first ones demonstrating the principle of the clearing electrode and groove structure in a magnetic field.

INTRODUCTION

One of the most important problems in recent high-intensity positron/proton storage rings is the electron-cloud effect [1, 2]. The electron cloud excites single or multi-bunch beam instabilities and deteriorates the performance of the ring. Various types of techniques for mitigating the effect have been proposed and studied so far [3]. These techniques involve the use of a clearing electrode and a groove structure in a beam pipe [4–9].

The clearing electrode attracts or repels electrons through a static electric field [4, 5]. Recently, an experiment performed at CERN has demonstrated the effectiveness of a clearing electrode for a long proton bunch (bunch length $\sigma_z \sim 1$ m) [10]. However, any experiments have not been tried in high-intensity positron rings, where a high beam impedance and excessive heating of the electrode due to short bunches ($\sigma_z \leq 10$ mm) and high bunch currents (≥ 1 mA) can be serious problems. On the other hand, a groove structure geometrically reduces the secondary electron yield (SEY) [6, 7]. An experiment was carried out at SLAC, and the effectiveness in a field-free region was demonstrated [8].

This paper reports the results of experiments carried out using a clearing electrode and a groove structure in a high-intensity positron ring of the KEKB B-factory [11]. In these experiments, a significant reduction in the electron density around the beam orbit in a vertical magnetic field of 0.77 T was verified.

EXPERIMENTAL SETUP

The experiments were performed using a vacuum chamber with an insertion and an electron monitor facing it. The cross section of the test chamber and the chamber installed into a wiggler magnet are shown in Fig. 1 [5, 9].

The insertions were a clearing electrode, a triangular groove structure and a flat surface. The electron monitor comprised four layers: a copper-plated stainless-steel plate that had monitoring holes (ϕ 2 mm), an RF-shielding grid of stainless-steel mesh, a retarding grid of stainless-steel mesh, and a layer of collectors, which formed the outermost layer. The collectors consisted of seven copper strips (#1–#7), each with a length and width of 140 and 5 mm, respectively (see Fig. 1). These collectors enabled the measurement of the horizontal spatial distribution of the electrons. The DC voltage, 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 test chamber was installed in a wiggler magnet with a maximum vertical magnetic field of 0.77 T in the KEKB positron ring [10]. The positron beam had an energy of 3.5 GeV. The maximum beam current was approximately 1.6 A (1585 bunches, $\sim 1\times10^{-8}$ C/bunch). The bunch length was approximately 7 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.

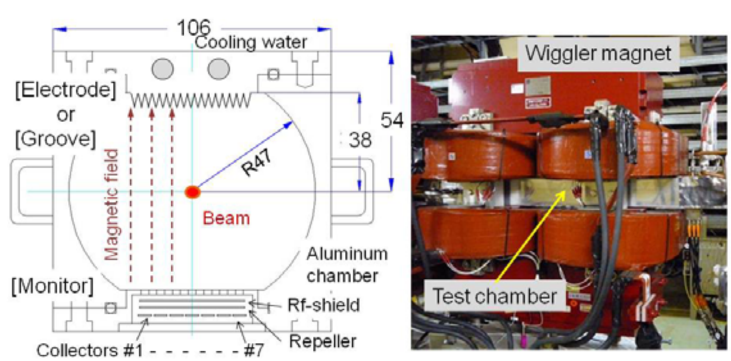

Figure 1: Test chamber with an insertion and an electron monitor.

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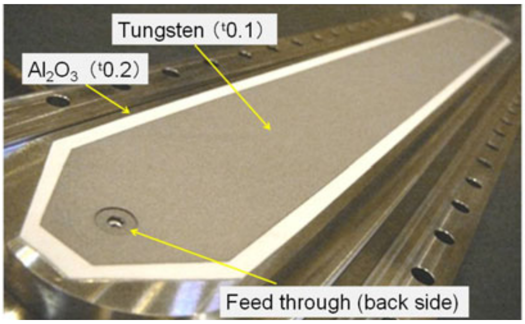

Figure 2: Newly developed strip-type clearing electrode.

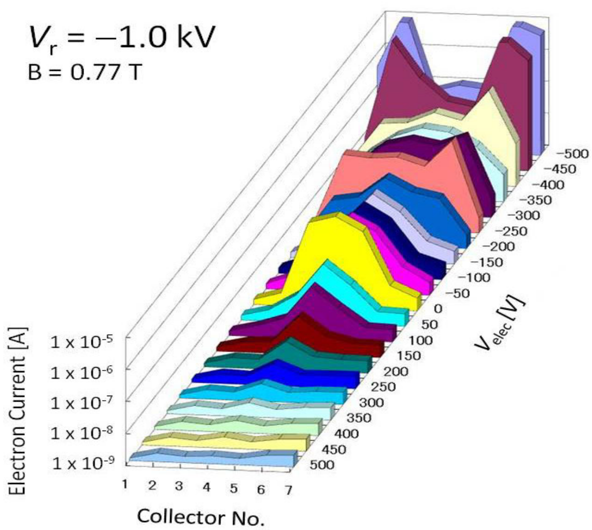

Figure 3: Electron current versus V_{elec} for V_r = −1 kV, where the beam current is 1.6 A (1585 bunches).

CLEARING ELECTRODE

Structure

The structure of an insertion with a clearing electrode was in the form of a thin strip line [5]. The electrode is shown in Fig. 2. An alumina ceramic layer with a thickness of approximately 0.2 mm functioned as an insulator. It was formed by the thermal spray method. A thin layer of tungsten with a thickness of approximately 0.1 mm also coated by the thermal spray method on the alumina ceramic layer functioned as the electrode. The width and the length of the electrode were 40 and 440 mm, respectively. The calculated loss factor was approximately 7×10^9 V C^{-1} for σ_z = 6 mm. The expected parasitic loss was approximately 110 W (1.6 A, 1585 bunches). Due to the water cooling at the back side and the good thermal conductivity of the thin electrode structure, the rise in the temperature of the electrode was small. The electrode was connected to a coaxial feed-through at one end. A DC power supply with the maximum voltage and current of 1 kV and 30 mA, respectively, was connected to the feed-through by a coaxial power cable.

Results

The electron currents were measured for V_{elec} (electrode voltage) ranging from −500 to +500 V, while V_r (retarding voltage) was varied from −1 kV to 0 V. The typical dependence of the electron current on V_{elec} for V_r = −1 kV is shown in Fig. 3. For the positive values of V_{elec}, the electron current decreased monotonically with an increase in $|V_{elec}|$. The measured current had a peak at collector #4. The reduction ratio of the electron current at collector #4 was more than 100 for V_{elec} > +300 V. In the case of V_r = −1 kV, only the high-energy electrons generated in the region close to the beam orbit contributed to the electron current. Thus, the electron current indicates the electron density around the positron beam. For a measured electron current of 1×10^{-9} A when V_r = −1 kV, the expected electron density was roughly estimated to be approximately 1×10^9 electrons m^{-3}. The behavior of the measured electron currents for the negative values of V_{elec} was more complex than that for the positive values of V_{elec}. A detailed simulation is required to understand the electron dynamics and the measured electron current in this range.

The electron currents were measured for other bunch filling patterns with bunch spacings of 4, 8, and 16 ns. Similar dependences of the electron current on the V_{elec} as described here were observed. The clearing electrode was effective for a wide range of bunch filling patterns.

GROOVE STRUCTURE

Structure

The structure of an insertion with a groove structure is presented in Fig. 4. The insertion was composed of isosceles-triangular grooves that ran longitudinally along the beam orbit and had a depth and an aperture angle of 5 mm and 20°, respectively [9]. The total length and width were 524 mm and 54 mm, respectively. The groove surface was coated with TiN. The average thickness of the coating was estimated to be approximately 50 nm. The tips and valleys have a radius of 0.05 mm. For comparison, another insertion that had a flat surface was prepared. The surface was also coated with TiN.

Figure 4: Triangular groove structure with TiN coating.

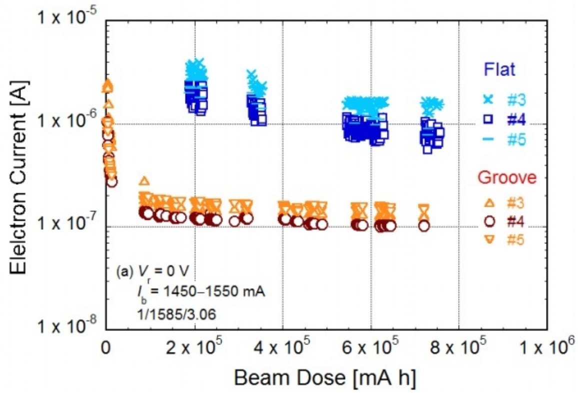

Figure 5: Changes in the electron currents (collectors #3–#5) of the groove structure and the flat surface as a function of the integrated beam dose.

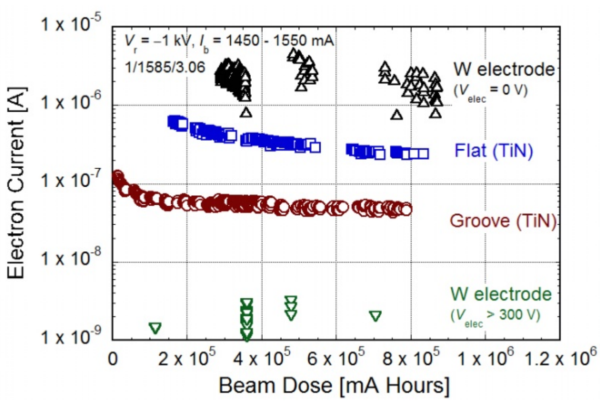

Figure 6: Changes in the electron current (collector #4) for the groove structure, the flat surface, and the clearing electrode with V_{elec} = 0 V and > +300 V as a function of beam dose.

Results

Figures 5 shows the changes in the electron currents in collectors #3–#5 as a function of the beam dose (i.e., the integrated beam current) for the flat and groove structures for V_r = –1 kV. The beam currents were in the range of 1450–1550 mA (0.9–1 mA/bunch). A comparison of these two surfaces reveals that the effective SEY for the groove surface is much smaller than that of the flat surface. The electron currents decreased monotonically with the beam dose, and this implies that the surface aging was in progress. Similar results were obtained for other bunch filling patterns, as in the case of a clearing electrode.

Comparison with the Case of Clearing Electrode

Figure 6 shows a comparison of the electron currents in the center collectors (#4) for the flat surface, the groove structure, and the clearing electrode with V_{elec} = 0 V and > +300 V. Here, the beam currents were in the range 1450–1550 mA (0.9–1 mA/bunch) and V_r was –1 kV. For V_{elec} = 0 V, the clearing electrode behaved like a flat tungsten surface. The SEY of the TiN-coated surface seemed to be smaller than that of the tungsten surface. On the other hand, for V_{elec} > +300 V, the electron currents were by one order of magnitude smaller than those for the TiN-coated groove surface.

Both methods can be used in magnetic fields, unlike a solenoid. A common key issue for these is the beam impedance. The clearing electrode was the most effective in reducing the electron cloud. The clearing electrode, however, requires a power supply. The manufacturing cost may be low for the clearing electrode if a thermal-spray method is available.

The experiments clearly demonstrated the effectiveness of the clearing electrode and the groove structure in reducing the electron density in a strong magnetic field. The results yield an effective technique for mitigating the electron-could effect in magnetic fields, such as the field in a bending magnet and a wiggler magnet in the ring.

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