EXPERIMENTAL STUDIES ON GROOVED SURFACES TO SUPPRESS SECONDARY ELECTRON EMISSION

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Abstract

Grooved surfaces are effective to suppress the secondary electron emission, and can be a promising technique to mitigate the electron cloud effect in positron/proton storage rings. Aiming for the application in a dipole-type magnetic field, various shapes of triangular grooved surfaces have been studied at KEK. The grooves tested here have vertex angles of 20–30°, depths of 2.5–5.0 mm, and vertex roundness of 0.05–0.2 mm. In a laboratory, the secondary electron yields (SEY) of small test pieces were measured using an electron beam in a magnetic-free condition. The grooved surfaces clearly had low SEY compared to flat surfaces of the same materials. The grooves with sharper vertexes had smaller SEY. A test chamber installed in a wiggler magnet of the KEKB B-factory positron ring was used to investigate the efficacy of the grooved surface in a strong magnetic field. In the chamber, a remarkable reduction in the electron density around the beam orbit was observed compared to the case of a flat surface with TiN coating.

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 beam instabilities and deteriorates the performance. Various types of techniques for mitigating the effect have been studied so far, including a grooved surface in a beam pipe [2]. The groove structure geometrically reduces the secondary electron yield (SEY) [3].

This paper reports the recent results of experiments about the grooved surface performed at KEK. Aiming to applications in dipole-type magnetic field, such as a wiggler magnet or a bending magnet, we focused on the isosceles triangular groove that is more effective in a magnetic field compared to the rectangular one [3, 4]. The groove structure with various vertex angles, depth, and vertex roundness were investigated. In a laboratory, the SEY of the grooved surfaces were measured in a magnetic-free condition, and the dependence of these parameters on SEY was studied. Furthermore, the efficacy of grooves in a dipole-type magnetic field was studied using a wiggler magnet of the positron ring of the KEKB B-factory (KEKB) [5]. The electron densities in a test chamber were measured and compared for various grooved surfaces.

EXPERIMENTS IN A LABORATORY

The grooves for test had isosceles triangular shape as shown in Fig. 1. The grooves have vertex angles (β) of 20–30°, the depths (d) of 2.5–5.0 mm, and the vertex roundnesses (R) of 0.05–0.2 mm. The materials were aluminium alloy (A5052 and A6063), copper (C1020) and stainless-steel (SS304). They were machined, de-greased and cleaned for high vacuum after the machining. Some grooved surfaces were coated by TiN. The roughness of triangle sides was less than 0.8 μm in Ra.

The setup for the SEY measurement in the laboratory is presented in Fig. 2. An electron beam was normally irradiated on a sample piece (ϕ15 mm). The energies of the primary electron were 100–2000 eV with a typical beam current of 2 μA. The irradiated area on the sample piece was ~20 mm^2. The change of SEY for various grooved surfaces at an incident electron energy of 250 eV against electron dose (integrated electron density) are shown in Fig. 3 (a) and (b). The measured SEY decreased monotonically with the beam dose, which implies that the surface aging was in progress. The results for the flat surfaces with and without TiN coating for copper and aluminium are shown in Fig. 3 (a) as a reference. The SEY of the TiN-coated surfaces reduced to less than 1.0 after a sufficient electron aging for both copper and aluminium surfaces.

The values in Fig. 3 (b) are those for triangular grooves with various β, d and R, without TiN coating. Most of samples are made of aluminum alloy. The grooves with relatively large β and R were tested here assuming a realistic cases of beam pipes with grooved surface manufactured by an extrusion process. As shown in the

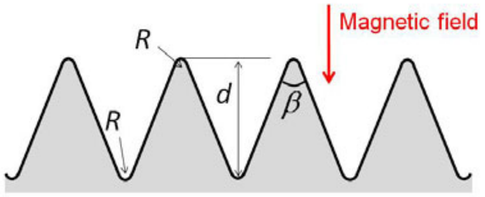

Figure 1: Geometrical parameters of isosceles triangular groove used for tests.

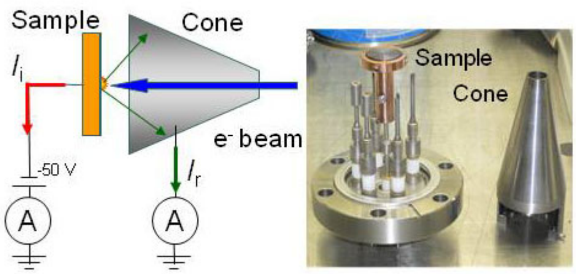

Figure 2: Setup for SEY measurement in a laboratory in magnetic-free condition.

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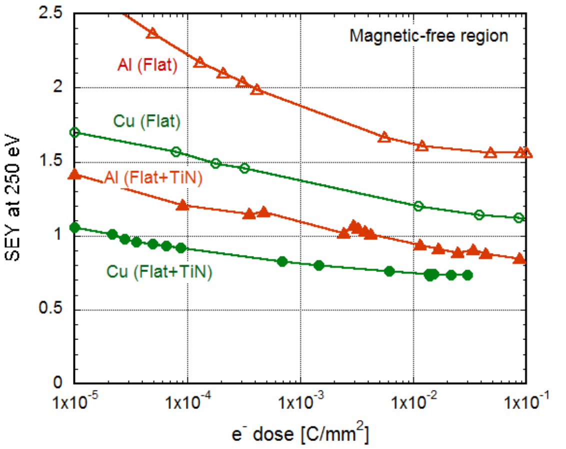

Figure 3 (a): Measured SEY at an incident electron energy of 250 eV for aluminium and copper flat surfaces.

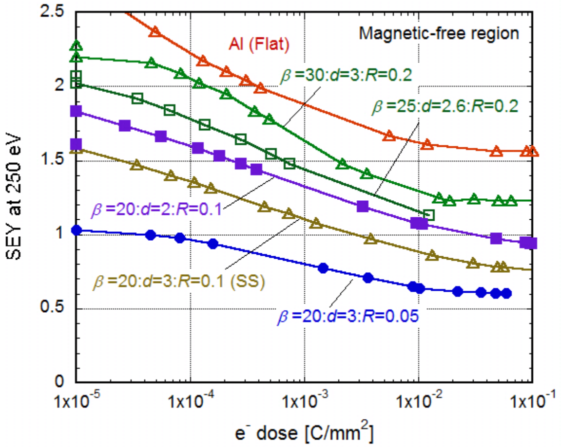

Figure 3 (b): Measured SEY at an incident electron energy of 250 eV for aluminium grooved surfaces without TiN coating.

figure, all of the values are smaller than the case of aluminium flat surface, and comparable to or smaller than the case of flat copper surface after a sufficient electron dose. Similarly the copper grooved surface showed lower SEY than a copper flat surface. In particular, the aluminium grooved surface with $\beta = 20°$ and $R \leq 0.1$ mm have comparable values to TiN-coated flat surfaces. A simulation gave the values that were not so far from the measurement, where the δ_{max} of 1.6 at 250 eV was assumed. Although the data were not plotted in the figure, the grooves with TiN coating showed further smaller values than those without coating. These results indicate that the grooved surface is very effective to reduce SEY in magnetic-free condition, and sharp grooves ($\beta \sim 20°$, $R \leq 0.1$) have comparable SEY to TiN-coated flat surface even without TiN coating.

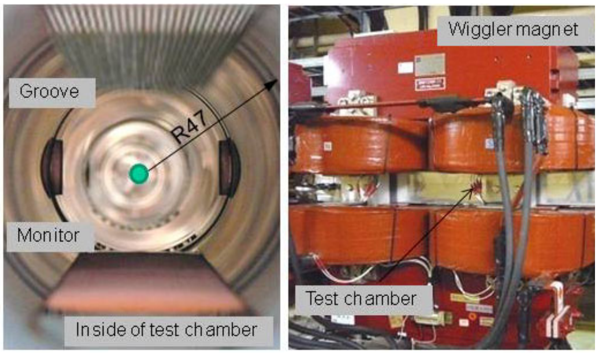

Figure 4: Cross section of the test chamber and the chamber installed into a wiggler magnet.

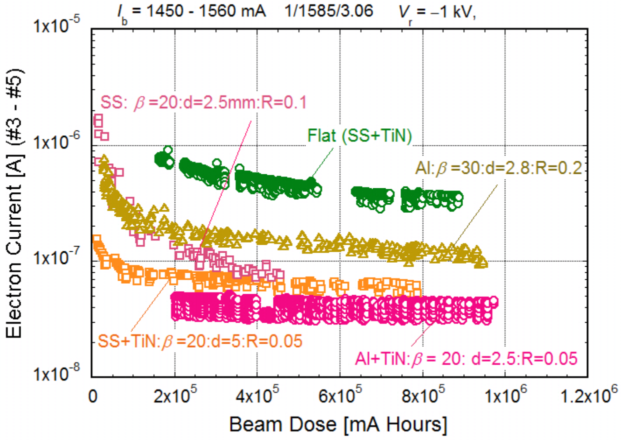

Figure 5: Changes of measured electron currents at the center part against the integrated beam current (beam dose) for a flat surface with TiN coating and four grooved surfaces.

EXPERIMENTS IN THE KEKB POSITRON RING

The experiments in the KEKB positron ring were carried out using a test 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. 4 [5]. The insertion to the test chamber had isosceles-triangular grooves that ran longitudinally along the beam orbit. The total length and width were 524 mm and 54 mm, respectively. The electron monitor had seven strip-type collectors (#1–#7) which 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 a retarding grid in the monitor. The collector was always biased to + 100 V. The wiggler magnet has a maximum vertical magnetic field of 0.78 T. The test chamber was located at the center of a magnet core. 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 test chamber was made of aluminium-alloy, and the synchrotron radiation was incident on the side-wall with a line density of 2×10^{17} photons s^{-1} m^{-1} at a beam current of 1.6 A.

Figure 5 shows the changes in the electron currents in the central collectors #3–#5 as a function of the beam dose (i.e., the integrated beam current) for a stainless-steel (SS) flat surface with TiN coating and four grooved surfaces for $V_r = -1$ kV. In this case, the electron current indicates the electron density around the beam orbit. The beam current was in the range 1450–1550 mA. Measured electron currents were smaller for all grooved surface with or without coating than for the TiN-coated flat surface. Even for the bare aluminium grooved surface with $\beta = 30°$ and $R = 0.2$ mm without TiN coating, the electron current was lower by a factor of 4 than for the flat surface. Note that an Al grooved surface with such profile had about the same SEY of a flat copper surface in a magnetic-free condition as shown in Fig. 3 (a) and (b). Similarly for the case of stainless-steel grooves ($\beta = 20°$ and $R = 0.1$ mm). TiN coating on grooves was also effective. The effect of grooved surface seems much more effective in magnetic field than in magnetic-free regions. This is due to higher efficiency of triangular grooves in magnetic field [3, 4]. Experiments clearly demonstrated the effectiveness of triangular groove structure in reducing the electron density in a strong magnetic field, as in the case of rectangular groove in magnetic-free conditions [4]. Sharpness, that is, smaller β and R, is a key point in the application of triangular grooved surface.

FUTURE PLANS

To establish a method to manufacturing desirable grooved surfaces in a beam pipe is a key issue in the future. Sharp grooves can be obtained by machining. Welding along the beam pipe, however, might be required to assembling the beam pipe. Figure 6 shows a test beam pipe with antechambers made of aluminium alloy, where machined groove blocks are welded at the top and bottom along a beam channel after extrusion. If the grooved surface is adopted for a beam pipe in a bending magnet, the beam pipe should be bent with a proper radius and welding could be an issue. Another possible method is to form the groove during the extrusion process of an aluminium-alloy beam pipe. Figure 7 presents a prototype of an extruded beam pipe with grooved surface, which has $\beta = 25°$, and $R = 0.2$ mm. Improving the sharpness will require further R&D in this case.

Another serious issue might be beam impedance. Estimation of the longitudinal and transverse impedances is ongoing assuming a grooved surface in the beam pipe of bending magnets in an upgraded KEKB (Super-KEKB). The bending magnet region has a total length of approximately 520 m out of the circumference of 3016 m. The longitudinal impedance of grooves is generally smaller if they run parallel to the beam. In a preliminary estimation, the loss factor of the grooved surfaces is about 0.5 % of the total loss factor, where the increase in the loss factor by resistive wall by 40 % is included for the grooved surface area [6]. The effect on the microwave instability also seems small. On the other hand, the transverse impedance can be a more critical issue for the grooved surface when the beam orbit is not parallel to the groove, i.e., in wigglers. More detailed investigation will be required.

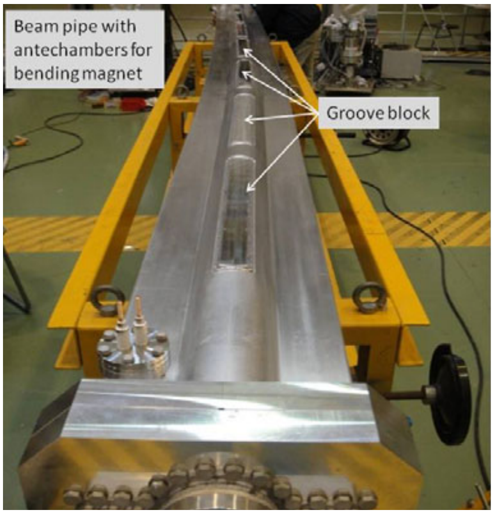

Figure 6: Test beam pipe with groove blocks for a bending magnet of Super-KEKB, where the groove block were machined and welded on the chamber.

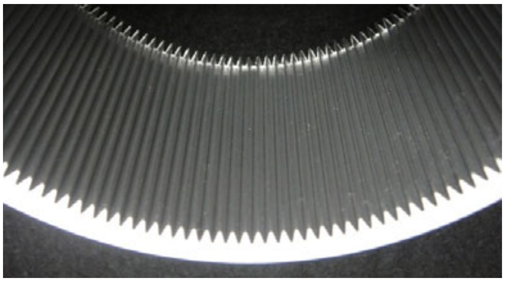

Figure 7: Grooved surface manufactured by the extrusion method of the aluminium beam pipe.

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