SEY AND CLEARING STUDIES AT KEKB
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Abstract
Studies on the structure of beam ducts, the inner surfaces with a low secondary electron yield (SEY) and clearing electrodes have been continuously progressing at the KEK B-factory (KEKB), in order to mitigate the electron cloud effect. Copper beam ducts with ante-chambers were installed in the positron ring. Test chambers with TiN and NEG coatings were also installed in the ring, and the effect of those on the electron cloud was investigated. A rod-type clearing electrode with low beam impedance was proposed, and the RF properties were preliminarily evaluated.

INTRODUCTION
A great attention has been given to the electron cloud instability (ECI) in positron/proton accumulation rings, since it significantly affects the performance of accelerators. Various methods to cure the ECI have been investigated experimentally and theoretically. At KEK, the studies have been proceeding using the B-factory (KEKB), focused on the structure of beam ducts, inner surfaces with a low secondary electron yield (SEY) and clearing electrodes [1 - 7]. Copper beam ducts with ante-chambers were designed and manufactured for tests [3, 6, 7]. They were installed into the 3.5GeV positron ring (called as the Low Energy Ring, LER), and the effect on the electron cloud formation was investigated [4 - 7].

BEAM DUCT WITH ANTE-CHAMBER
The beam duct consists of two channels, that is, a beam channel where a beam circulates, and an SR channels (ante-chambers) aside where the synchrotron radiation (SR) passes through [3]. By using the ante-chamber scheme, photoelectrons inside the beam channel, which could be a seed of the electron cloud, was expected to be reduced compared to that of a simple circular duct from a simulation.

Several kinds of copper beam ducts with ante-chambers have been manufactured, and installed into the KEKB LER. Copper (Oxygen Free Copper, OFC) was adopted for its high thermal strength and good radiation shielding property, considering a future high current operation [8, 9]. The inner diameter of the beam channel was 94 mm. The depth and the height of the ante-chamber were 65 mm and 15 mm, respectively. A copper beam duct with two ante-chambers is presented in Fig. 1, for example.

Beam ducts with one ante-chamber were installed in an arc section of LER. The photon density was about $8.5 \times 10^{18}$ photons s$^{-1}$ m$^{-1}$ at a beam current of 1 A. The critical energy was 5.8 keV.

The number of photoelectrons inside the beam was measured by an electron monitor [10]. A reduction in the number of photoelectrons by one or two orders of magnitude compared to a simple circular duct was confirmed at a low-current region, less than 0.1 A, where the photoelectrons were dominant. The electron number at a high-current region, such as 1.5 A, was also smaller, but the reduction was only by a factor of 4. This is because the main component of the electrons at that region is the secondary electrons, which are generated in a multiplication process by highly-charged bunches. A typical behaviour of the measured electron current is presented in Fig.2, where the bunch spacing was 3.77 RF-
buckets in average, and the total bunch number was 1284 (1 RF-bucket = 2 ns). The repeller voltage of the electron monitor was -30 V. The beam duct with antechambers was found to be very effective to reduce the effect of photoelectrons. Beam ducts with two ante-chambers, on the other hand, were installed at a wiggler section, where the SR hits the duct at both sides. The photon density was about \(7.5 \times 10^{17}\) photons m\(^{-1}\) s\(^{-1}\) at a beam current of 1 A. The similar results were obtained. The present circular beam ducts in a part of the wiggler section will be replaced to those with ante-chambers this year.

**COATING WITH LOW SEY**

To apply a surface with a low SEY to the inner surface of a beam duct is a promising way to suppress the electron cloud at a high beam current regime. Secondary electron and photoelectron yields (SEY and PEY) of a NEG coating and a TiN coating have been also studied using KEKB LER [4, 5]. Test chambers with the NEG and the TiN coating were first installed at an arc section of the KEKB positron ring. The test chambers have a simple circular cross section (\(\phi 94\) mm). The thicknesses of the coatings were about one micro-metre. The number of electrons around a beam was measured up to a beam current of about 1.7 A, and compared with each other. The photon density was \(6.5 \times 10^{17}\) photons s\(^{-1}\) m\(^{-1}\) at a beam current of 1 A.

Figure 3 shows typical behaviours of the measured electron currents for the TiN-coated, NEG-coated and copper chambers, where the SR hits the duct at both sides. The photon density was about \(7.5 \times 10^{17}\) photons m\(^{-1}\) s\(^{-1}\) at a beam current of 1 A. The electron number (~ electron current) for the TiN coating was clearly smaller than that of the copper by a factor of 2. The electron number of the NEG coating, on the other hand, was almost the same as that of the copper. Only a small difference was observed at a high current region, around 1.5 A.

Using a simulation, the maximum SEY \((\delta_{\text{max}})\) and the PEY \((\eta_e)\) of the TiN coating, the NEG coating and the copper were estimated based on the measured electron currents [5]. The \(\delta_{\text{max}}\) and \(\eta_e\) for the TiN coating, the NEG coating and the copper were 0.8 - 1.0, 0.9 - 1.1 and 1.1 - 1.3, and 0.13 - 0.15, 0.22 - 0.27 and 0.28 - 0.31, respectively. It was found that the TiN coating had an SEY \((\delta_{\text{max}} \sim 0.9)\) as low as that of the NEG coating \((\delta_{\text{max}} \sim 1.0)\), but the electron current was clearly smaller than that of the NEG coating, due to its lower \(\eta_e\) (~ 0.14). The electron numbers in the case of the copper and the NEG coating seems to be saturated, that is, limited by the space charge, because of abundant photoelectrons. This study indicated that suppression of photoelectrons is important to make effective use of a surface with a low SEY.

To see the effect of SEY more clearly, similar studies were performed at a straight section of the LER, where the photon density was less than 1/10 of that at an arc section (about \(3 \times 10^{15}\) photons s\(^{-1}\) m\(^{-1}\) at a beam current of 1 A). The electron numbers around beams were again measured during the beam operation, and compared with each other. A typical result is presented in Fig.4, where the bunch spacing was 3.5 RF-buckets in average, and the total bunch number was 1389. The repeller voltage was -1000 V. The electron numbers for the TiN coating and the NEG coating were about 1/3 and 2/3 of that in the case of the copper chamber, respectively. The difference between the NEG coating and the copper was clear in this case due to the small amount of photoelectrons. Assuming almost the same \(\eta_e\) values as in the previous experiment at the arc section, the \(\delta_{\text{max}}\) values for three cases were again estimated using the previous simulation. The results were 0.8 - 1.0, 1.0 - 1.15, and 1.1 - 1.25 for the TiN coating, the NEG coating and the copper, respectively. They were almost consistent with those previously obtained at the arc section.

**CLEARING ELECTRODE**

Considered here was a conventional type as proposed by L. Wang et al. [11], where an electrode was a wire. Schematic structure of the electrode is shown in Fig. 5.
The feed-through had a high resistivity, which contributes to reduce the impedance of the electrode [12 - 14]. The estimation of the impedance and the loss factor has just begun using the MAFIA code.

In the calculation model, the electrode (rod) was set at 8 mm apart from the duct wall, and had a width, a thickness and a length of 3 mm, 4 mm, and 1 m, respectively. One end was supported by a ceramic rod (Al₂O₃, εᵣ = 9.0) with a diameter of 4.8 mm. The other end was supported by a feed-through with a length of 40 mm. The feed-through was a ceramics rod with a metal layer on the surface with a thickness of 0.8 mm, and a width of 2 mm. The conductivity of the metal layer was designed so that the ratio of the thickness to the skin depth was about 40 at a frequency of 1.35 GHz. The model had a diameter of 94 mm, and the total length was 2.4 m. The simulation was done for a 1/4 model, that is, two electrodes were up and bottom of the duct.

Typical longitudinal impedance is shown in Fig.6. The longitudinal shunt impedance was about 1 Ω at 1.35 GHz. The $R/Q$ was about 0.05. The transverse shunt impedance, on the other hand, was about 10 Ω, and the $R/Q$ was about 5. The output voltage from the feed-through was estimated as a few volts at most. The loss factor was about 1.1 $\times$ 10¹¹ V/C for a bunch with a length of 8 mm. Issues to be further investigated are to reduce the loss, to estimate the heating of electrode, and to evaluate the growth rate for the coupled-bunch instability and the microwave instability.

Beam test of the clearing electrode at a wiggler section of the LER is planed. The magnet has a length of 250 mm, and the magnetic field is 0.75 T. Design of a test chamber with an electrode and an electron monitor is now proceeding. The electron monitor will have 5 strips to see the spatial distribution of the electron cloud.

**REFERENCES**


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Fig. 5 Schematic drawing of a rod-type clearing electrode.

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Fig. 6 Longitudinal impedance for a rod-type clearing electrode with a high-resistive feed through.


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