REDUCTION IN RESISTIVE-WALL IMPEDANCE OF INSERTION-DEVICE VACUUM CHAMBER BY COPPER COATING

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Abstract

Effects of a copper coating on the stainless-steel insertion-device(ID) vacuum chamber of the VSX light source are presented. It is shown that a copper coating with thickness of 100 to 200 µm effectively reduces the resistive-wall impedance of the ID vacuum chamber. As a result, the growth rate of the transverse coupled-bunch instability and the parasitic loss are greatly decreased. The coating is not so thick that the beam is affected by the eddy currents induced during the gap change of the insertion device. A test ID chamber with the copper coating is also described.

1 INTRODUCTION

Insertion-device(ID) vacuum chamber is usually made of stainless steel having a high mechanical strength in order that the thickness may be thin as possible for both reducing the magnetic gap of the insertion device and widening the vertical aperture. However, its resistive-wall impedance can be much high because of the comparatively low conductivity of stainless steel as well as a narrow vertical aperture of the ID chamber. The growth rate of the transverse coupled-bunch instability in the VSX light source[1], a Japanese high-brilliance synchrotron radiation source being planned by the University of Tokyo, reaches 6000 sec^{-1} for the ID vacuum chamber with a total length of about 60 m. Furthermore, the heat load of the chamber due to the parasitic loss might be large. In order to suppress these influences of the resistive-wall impedance, we propose that the inner surface of the stainless-steel ID vacuum chamber should be coated with a highly conductive metal such as copper or silver. In this paper, the effects of a copper coating for the ID chamber and a test stainless-steel chamber for the copper coating are presented.

2 RESISTIVE-WALL IMPEDANCE

Calculations of the resistive-wall impedance (the real part) were performed by solving the Maxwell equations analytically[2]. The elliptical cross-section of the stainless-steel(SUS) ID chamber of the VSX light source was approximated by a circle with a radius equal to the vertical half aperture of 8 mm.

2.1 Transverse Impedance

Figures 1 shows the calculated transverse impedances of the stainless-steel ID chambers without and with copper coatings of 50, 100, 150 and 200 µm in thickness and the copper ID chamber. The transverse impedances of the copper-coated stainless-steel chambers become equal to that of the copper chamber in a high frequency range(>1 MHz).

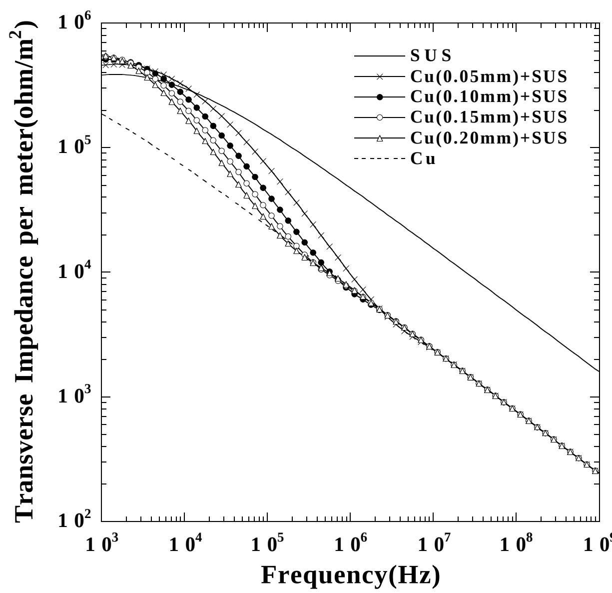

Figure 1: Calculated transverse impedances(the real parts) per unit length of the ID chambers as a function of frequency.

The growth rate of the transverse coupled-bunch instability with a mode number µ in terms of the rigid bunch model is given by

$$g_t^{\mu} = -\frac{e n_b I_b f_0 \beta_t}{2E} \sum_{p=-\infty}^{+\infty} \mathrm{Re}\left[Z_t(f_t^{p,\mu})\right] \quad (\mu=1,\, 2,\, \cdots,\, n_b)$$

$$f_t^{p,\mu} = (p n_b + \mu + \nu_t) f_0. \quad (1)$$

Here E, n_b, I_b, f_0, ν_t and β_t are the beam energy, the number of bunches, the bunch current, the revolution frequency, the betatron tune and the averaged betatron function at the vacuum chamber. $\mathrm{Re}[Z_t(f_t^{p,\mu})]$ is the real part of the transverse resistive-wall impedance. As shown in Figure 1, the transverse impedances become quite high as the frequency goes to zero. In this case, the growth rate has the maximum for the mode number where $f_t^{p,\mu}$ is equal to $f_0\Delta\nu$ or $f_0(1-\Delta\nu)$ ($\Delta\nu$: the fractional part of the betatron tune). The corresponding frequency ranges from 129 kHz to 1.16 MHz for the VSX light source (f_0 = 1.29 MHz) if $\Delta\nu$ changes from 0.1 to 0.9. As shown in Figure 2, the stainless-steel chamber with the 200-µm thick copper coating has the same impedance as the copper chamber in the frequency range. Even the 100-µm thick copper coating effectively reduces the impedance. By the 100 - 200 µm thick copper coating, the growth rate of the transverse instability is lowered to about 1000 sec^{-1}, the value of which is comparable to the damping rate achieved by an ordinary bunch-by-bunch feedback system.

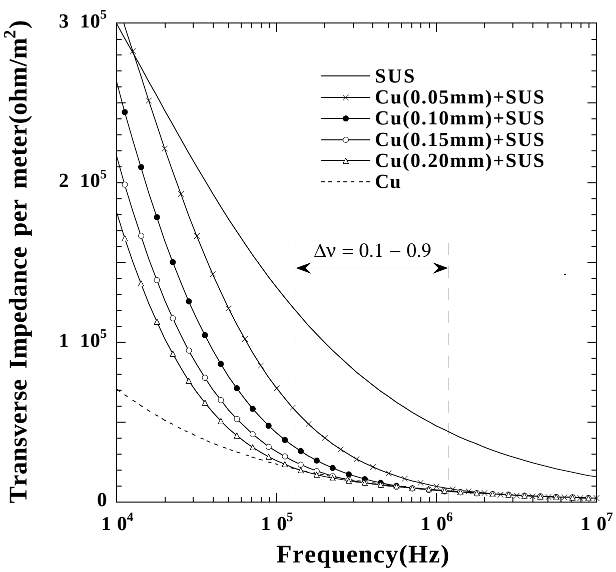

Figure 2: Calculated transverse impedances(the real parts) per unit length of the ID chambers as a function of frequency. The frequency range corresponding to $\Delta\nu$ of 0.1 to 0.9 is shown by dashed lines.

2.2 Longitudinal Impedance

Figure 3 shows the calculated longitudinal impedance as a function of frequency in the same cases as Figure 1. The longitudinal impedances of the copper-coated stainless-steel chambers are also equal to that of the copper chamber in a high frequency range. The parasitic losses calculated from the longitudinal impedances have almost the same value except for the uncoated stainless-steel chamber. The parasitic loss power per unit length is about 1.0 W/m for the copper-coated stainless-steel chamber and 6.7 W/m for the uncoated stainless-steel chamber. The thermal analysis was performed with a 3D calculation code ANSYS, and it showed that the calculated temperature rise of the copper-coated ID chamber due to the parasitic loss was only about 1 ˚C. The longitudinal coupled-bunch instability does not cause a serious problem, because the growth rate calculated from the longitudinal impedance is negligibly small in all the cases.

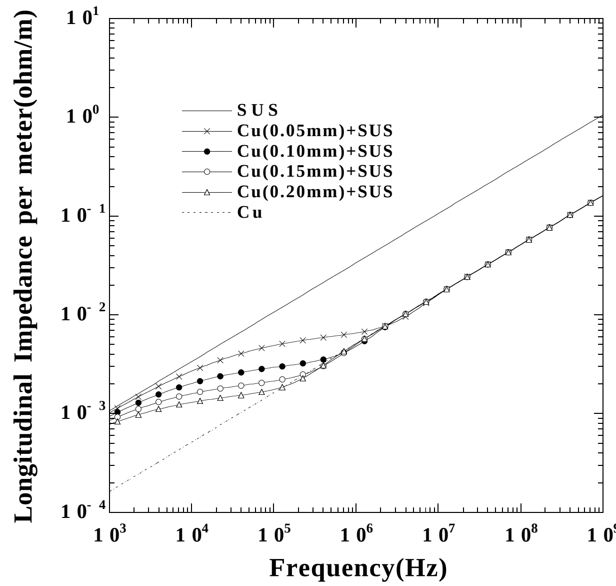

Figure 3: Calculated longitudinal impedances(the real parts) per unit length of the ID chambers as a function of frequency.

3 EDDY CURRENTS

The thickness of the copper coating required for effective reduction in the resistive-wall impedance is 100 to 200 µm, as described in the previous section. It is very thin compared to that of the ID chamber itself (1.5 mm). However, the influence of the eddy currents induced in the copper coating during the gap change of the insertion device should be estimated, because copper is much more conductive than stainless steel.

The eddy currents in the 200-µm thick copper coating were calculated by a 3D field calculation program ELF/MAGIC for a three-pole undulator which has a period of 4.6 cm, a gap change speed of 2.5 mm/sec and a maximum magnetic field of 0.55 T at a minimum magnetic gap of 20 mm. Figure 4 shows the difference between the static and dynamic magnetic fields along the beam orbit obtained from the calculated eddy currents. The maximum difference is 0.041 G, i.e., 7.5×10^{-6} of the maximum static field. The eddy currents of a 1.5-mm thick stainless-steel chamber were also calculated and the maximum field difference was estimated to be less than 10^{-7} of the maximum field. Although the 200-µm thick copper coating generates higher eddy currents than the stainless-steel chamber itself, the eddy currents are negligibly small and does not affect the beam seriously.

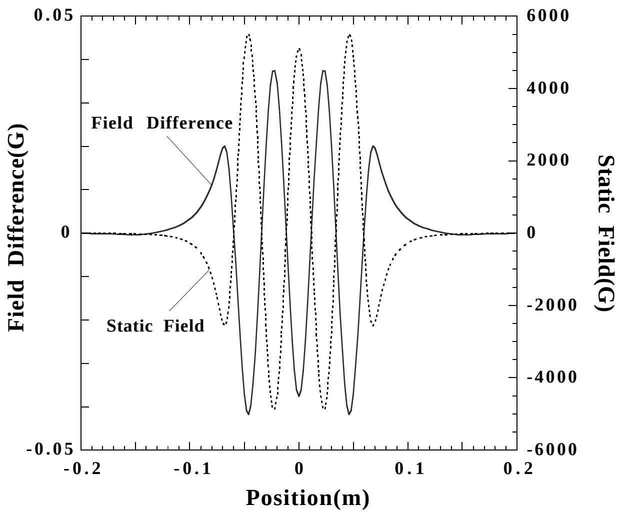

Figure 4: Difference between static and dynamic magnetic field of a three-pole undulator(solid line) caused by eddy currents in the 200-μm thick copper coating. The static field is also shown by a dotted line.

4 TEST CHAMBER

A stainless-steel(SUS316L) chamber with the total length of 250 mm was fabricated to test the copper coating on the inner surface of the chamber. The chamber cross-section and thickness has almost the same as those of the ID chamber of the VSX light source.

Figure 5 shows the photograph of the test chamber. The copper coating was made between -25 and +25 mm from the inner surface center of the test chamber. Any flaw and crack were not found on the copper coating. In addition, the test result of adhesion between the chamber surface and coating was satisfactory. A copper coating made on a stainless-steel plate under the same conditions as that on the chamber surface were examined with a microscope to measure its coating thickness. Figure 6 shows a cross-sectional view of the copper coating. The measured coating thickness at five points on the plate varied from 110 to 140 μm, within an allowable range of 100 to 200 μm.

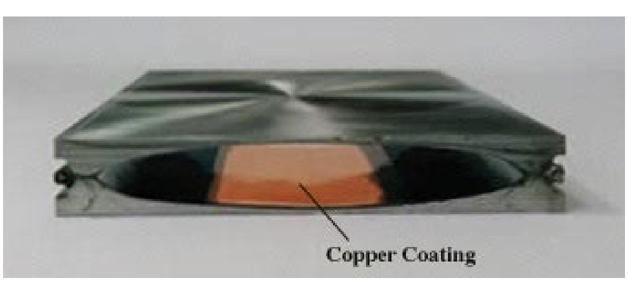

Figure 5: A test stainless-steel chamber coated with copper.

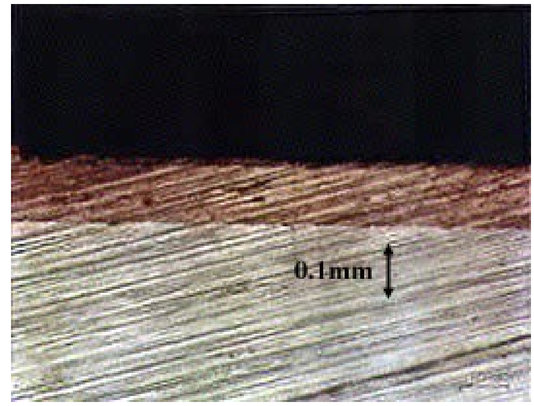

Figure 6: Cross-section of the copper coating on the stainless steel plate measured with a microscope.

5 CONCLUSIONS

Impedance calculations showed that the copper coating with thickness of 100 to 200 μm can reduce the resistive-wall impedance of the stainless-steel ID chamber down to that of the copper chamber in the frequency range where the transverse coupled-bunch instability becomes very serious. At the same time, the parasitic loss due to the longitudinal impedance is decreased by a factor of 1/6 to 1/7. Eddy currents in the copper coating due to the gap change of the insertion device are sufficiently small to have little effect on the beam. A test chamber for the copper coating was manufactured without any technical difficulty and the required coating thickness was obtained.

Although the calculated parasitic loss is negligibly small, a heavy heat load may be imposed on the copper coating by baking of the ID chamber or accidental irradiation of synchrotron radiation due to a large beam orbit distortion. We will examine the heat resistance of the copper coating by the test chamber.

REFERENCES

[1] Y. Kamiya, T. Koseki, N. Nakamura and H. Takaki, "A Lattice for the Future Project of the VUV and Soft X-Ray High Brilliance Light Source", These Proceedings.

[2] N. Nakamura and T. Koseki, "Influence of Resistive Wall Impedance on the VSX Light Source", Proc. of the 1997 PAC, Vancouver, 12-16 May 1997.