R&D ON COPPER BEAM DUCTS WITH ANTE-CHAMBERS AND RELATED VACUUM COMPONENTS

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Abstract

Copper beam ducts with ante-chambers have been studied for future high-current accelerators. Bellows chambers with a comb-type RF-shield to fit the beam duct were also developed in parallel. A specially designed MO-type flange was adopted for a connection flange. The beam ducts and the bellows chambers were installed into the KEK B-factory (KEKB), and the temperatures and vacuum pressures were observed during beam operation. They showed no problem up to a storage current of 1.7 A. Electron numbers in the beam duct were also measured to confirm the effect of ante-chamber. Based on the studies so far, the replacement of the present circular beam ducts at a wiggler section of the KEKB by the beam ducts with ante-chambers is planed.

INTRODUCTION

A beam duct with ante-chambers consists of two channels, i.e. a beam channel where a beam circulates, and SR channels (ante-chambers) aside where the synchrotron radiation (SR) passes through [1]. By using the ante-chamber scheme, the maximum power density of SR can be diluted at the side wall. The beam impedance decreases by putting pumping ports at the SR channels. Photoelectrons inside the beam channel, furthermore, are also expected to be small compared to that of a usual circular duct, which is a big merit for a positron ring to suppress the electron cloud instability.

Several kind of copper beam ducts with ante-chambers have been manufactured for test at KEKB [2]. A bellows chambers with the same cross section to the beam duct was developed in parallel. The comb-type RF-shield was used for that, since it could smoothly fit to the complicated cross section [3]. A specially designed MO-type (Matsumoto-Ohtsuka-type) flange was adopted as a connection flange [4]. The flange is able to connect the duct and the bellows chamber uniformly without any extra RF-shields inside.

Figure 1 Beam duct with two ante-chambers at both sides for a wiggler section.

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The beam ducts and the bellows chambers were installed into the KEKB positron ring. The temperatures and the vacuum pressures around them were measured during beam operation up to 1.7 A, where the bunch number was 1389 and the bunch length was about 7 mm. The electron numbers in the beam ducts were also measured, and compared to those of simple circular ducts.

BEAM DUCT

For Arc Section

The R&D began with a beam duct with an ante-chamber for an arc section of KEKB in 2003. Two types of copper beam ducts were manufactured by different methods, that is, by pressing and by cold drawing [2]. The material is OFC (Oxygen Free Copper), and the electron beam was used to weld copper to copper. The total length was about 5.1 m. The inner diameter of the beam channel was 94 mm, and the thickness was 6 mm. The depth and the height of the ante-chamber were 65 mm and 15 mm, respectively. The pressing method was cheaper compared to the cold drawing, but the manufacturing accuracy was poorer. Two NEG pump channels were at top and bottom of the ante-chamber. The thermal gas desorption rate was less than 3.5×10^{-9} Pa m^3 s^{-1} m^{-2} after a baking at 150°C for 24 hours.

They were installed into the arc section of the KEKB positron ring, at just downstream side of a bending magnet. The SR power and the photon density was 3 kW m^{-1} and 8.5×10^{18} photons s^{-1} m^{-1}, respectively, at a beam current of 1 A. The critical energy of SR was 5.8 keV. The number of electrons in the beam channel was measured by a electron monitor, and was found to be reduced by a factor of 4 at 1.5 A compared to the case of a simple circular chamber. The reduction, however, was by a factor of 100 at a beam current of about 20 mA, where the photoelectrons were dominant. The effective reduction of the photoelectron was confirmed experimentally. The temperature of the duct was a little bit higher, but almost in agreement with the expectation.

For Wiggler Section

As a next step, a beam duct with two ante-chambers for a wiggler section was manufactured, as shown in Fig.1. Since the SR hit both side walls, the ante-chambers are at both sides of a beam channel. The beam channel had a diameter of 94 mm. The depth of an ante-chamber was

Figure 2 Pressed copper plates for beam duct with two antechambers.

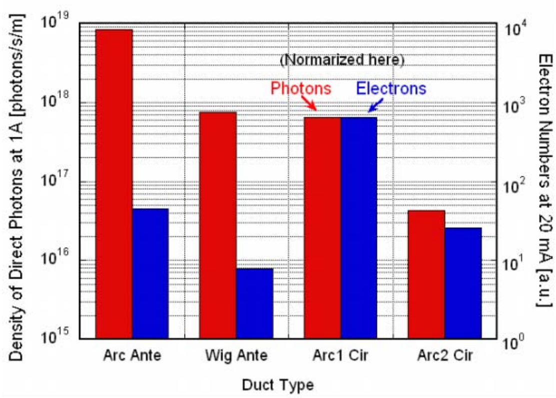

Figure 3 Comparison between measured electron numbers and line densities of direct photons for four types of beam ducts. The electron numbers were normalized to photon numbers at “Arc1 Cir”.

again 65 mm and the height was 14 mm. The material was again OFC, and the total length was 4.6 m. Two pressed plates and two cooling channels consisted of the beam duct, as shown in Fig. 2. Four NEG strips were inserted to pump channels, at top and bottom of the both ante-chambers. The thermal gas desorption rate on the order of 10^{-9} Pa m^3 s^{-1} m^{-2} was again obtained after a baking at 150°C for 24 hours.

The beam duct was installed into a wiggler section of the KEKB positron ring. The SR with a critical energy of 6.1 keV hit the side walls. The maximum power density and the photon density were about 227 Wm^{-1} and 7.5×10^{17} photons m^{-1} s^{-1} at a beam current of 1 A.

The electron number was measured as in the previous case. Figure 3 shows the comparison between the measured electron numbers at a beam current of 20 mA and the photon densities at the measured points, for two test ducts with ante-chambers at the arc section and the wiggler section (“Ante”), and two circular chambers at other arc sections (“Cir”). The electron numbers were normalized to the photon numbers at “Arc1 Cir”. The reduction of the photoelectron by two orders of magnitude was clearly seen for the beam duct with ante-chambers. Any problem, such as vacuum pressure bursts, was not found up to 1.7 A storage current during about one year’s operation. The temperatures of the duct were within the expected range.

BELLOWS CHAMBER

Bellows chambers with an RF-shield structure are indispensable to connect beam ducts with one another smoothly. The cross section of bellows chambers has to fit to that of the beam ducts. The RF shield should have uniform inner surface to avoid exciting HOM (Higher-Order Modes), reliable electric contact to smoothly flow the beam-induced wall current, and high thermal strength. The conventional finger-type RF shield, however, can hardly follow the complicated cross section such as that of the beam duct with ante-chambers.

Here a bellows chamber with a comb-type RF shield, which had been developed for future high current machines, was developed for the test duct [3]. The RF shield has a higher thermal strength and lower beam impedance compared to a conventional finger-type one. The structure can easily fit to the complicated cross section. The manufactured bellows chamber and its inside view are shown in Fig. 4 and Fig. 5, respectively. The comb-teeth and the cooling channel were made of OFC. The nominal length of the bellows chamber was 200 mm, and the stroke was ±4 mm.

Two bellows chambers were installed into the KEKB positron ring, together with the beam duct described above. The installed bellows chambers and the beam ducts are shown in Fig. 6. The bellows chambers also showed no problem up to the beam current of 1.7 A for about 1 year. The temperature of bellows (corrugation) was about 31°C at 1.7 A, and almost the same as that of standard circular bellows chambers with a usual finger-type RF shield (33°C).

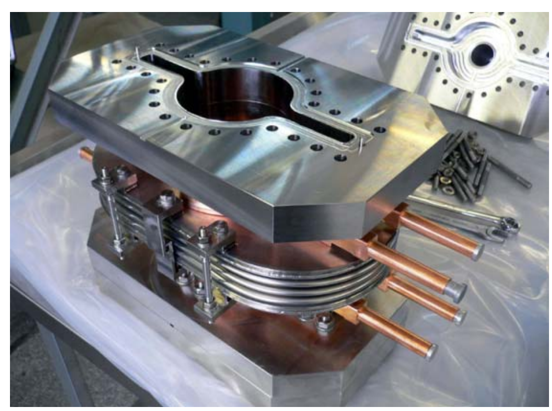

Figure 4 Bellows chamber for beam duct with two antechambers for a wiggler section.

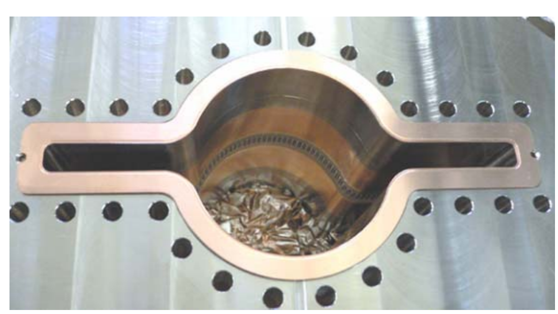

Figure 5 Inside view of comb-type RF-shield.

Figure 6 Beam duct and bellows chambers installed at a wiggler section in the KEKB positron ring.

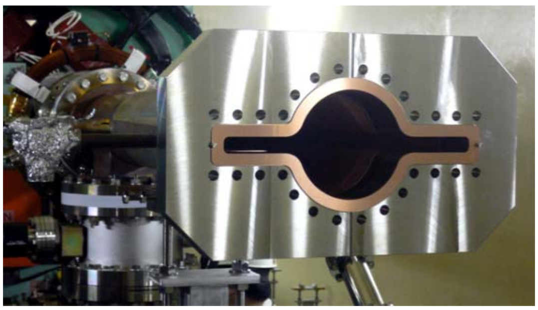

Figure 7 MO-type connection flange and copper gasket for beam ducts with ante-chambers.

CONNECTION FLANGE

The connection flange of beam ducts requires an RF bridge to fill the gap inside. The RF-bridge should have the similar properties as the RF-shield of the bellows chamber described above. The conventional RF-bridge is thin metal fingers or metal O-rings. The small fingers may be able to follow the complicated shape as the beam duct with ante-chambers, but the uniform electric contact can hardly be guaranteed. O-rings are not available for such an aperture with small curvatures at corners. The development of connection flanges applicable to beam ducts with a complicated cross section has been a key issue in the R&D.

Here, the MO-type flange was adopted for the test beam duct. The MO-type flange can seal a vacuum at only the inner surface using a copper gasket [4]. The copper gasket also works as an effective RF bridge that has no gap and step at the inner surface. Because the vacuum is sealed, electrical contact is highly secure. The thermal strength of the copper gasket is much higher compared to that of thin metal fingers or O-rings.

The MO-type flange for the beam duct with two ante-chambers has a width, a height and a thickness of 320 mm, 190 mm and 30 mm, respectively. The inner shape was the same as the aperture of the beam duct. The material was stainless-steel 316. The flange was welded to the duct via stain-less steel - copper transition. The gasket is an annealed OFC with the same inner aperture.

The bench test using a simple blank flange was successful. The vacuum seal was achieved with a fastening torque of about 16 Nm, which is almost the same as in the case of a standard conflate flange with a similar diameter. Several times of baking up to 200°C showed no problem.

Following the bench test above, four MO-type flanges were used for the beam ducts and the bellows chambers as shown in Fig. 5 and Fig. 7. The vacuum seal was achieved with a fastening torque of about 15 Nm, which is almost the same as the case of a bench test. No problem was found up to 1.7 A storage current. The temperature of flanges was about 40°C at the beam current of 1.7 A. The temperature was almost the same as that of standard circular flanges with a metal O-ring near to the test duct.

FUTURE PLAN

Following the basic R&D as described above, a plan to replace the present circular beam ducts at a wiggler section of the KEKB positron ring by the beam ducts with ante-chambers is proposed. The wiggler section has a length of about 130 m. The region includes 25 straight ducts (about 3.5 m), 13 Q-duct (ducts for quadrupole magnets, about 1.7 m) with BPM (Beam Position Monitors) and 37 bellows chambers (200 mm). The specification for the beam ducts and the BPM should be matched to those for Super KEKB [5]. The inner surface of the beam duct will be coated by TiN to reduce the secondary electron yield [6]. The replacement can be a final test for the upgrade of KEKB in the future. A region with a length of about 30 m will be replaced next year as a first step.

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