APPLICATION OF STAINLESS-STEEL, COPPER-ALLOY AND ALUMINUM-ALLOY MO (MATSUMOTO-OHTSUKA) -TYPE FLANGES TO ACCELERATOR BEAM PIPES

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Abstract

The MO (Matsumoto–Ohtsuka) -type flange is suitable for a connection flange of a beam pipe for various accelerators because it uses a metal gasket that exactly fits the aperture of the beam pipe, and therefore has a small beam impedance. We had developed a stainless-steel MO-type flange for a copper beam pipe with antechambers at first. Based on the experience, a possibility of employing copper and aluminum-alloy flanges has been studied. They can mitigate heating problem found in the case of stainless-steel flanges under high-intensity beams, and also simplify the manufacturing procedure of copper and aluminium beam pipes. Copper-alloy flanges showed a comparable vacuum sealing property to the stainless-steel one. The R&D on aluminum-alloy flanges has recently started, and a promising result was obtained. The large linear expansion rate of aluminium-alloy, however, seems to bring a difficulty in baking the connection with flanges made of different materials.

INTRODUCTION

For future advanced particle accelerators, it is important to avoid beam instabilities since they easily lengthen the bunch and/or increase the beam emittance, and deteriorate the performance. For this purpose, the beam impedance of vacuum beam pipes and components must be kept as low as possible [1]. A connection flange, which connects adjacent beam pipes, has impedance due to its transverse step or groove at the connection. The impedance of a flange connection is usually small, but the total impedance of all the flanges in a ring becomes sometimes considerable. A smooth inner surface as well as a secure electrical contact is highly required at the connection.

The Matsumoto–Ohtsuka (MO) -type flange is a promising solution to this problem [2, 3]. The flange is a modified version of a flange that had been used in DESY. The flange needs a metal gasket that exactly fits the aperture of the beam pipe, and has a small transverse step at the inner surface. The structure is simple and unisex. The gasket has a role as a secure RF-bridge in the gap between the flanges as well as a vacuum seal.

We developed a stainless-steel MO-type flange for a copper beam pipe with antechambers at KEK in 2004 [3, 4]. Note that a copper beam pipe is essential to cope with high storage beam current in future high-intensity accelerators. Several beam pipes and vacuum components having the MO-type flange had been installed in the KEKB positron ring and tested. Although no serious problem was observed, the flanges in some components were found to be heated up probably due to the irradiation by SR and/or Joule heating at the surface of stainless steel. Furthermore, there was difficulty in directly welding the stainless-steel flange to copper beam pipes. The similar problem should occur for the case of aluminium-alloy beam pipes, which have been commonly used in various light sources.

Hence we began to develop a copper- and an aluminum-alloy MO-type flange [5]. Copper and aluminium alloys have higher thermal conductivities and lower electrical resistivities than stainless steel. Furthermore, they can be directly welded to a copper- or aluminium beam pipe, which should lead to good productivity of beam pipes. Here described are the recent results of R&D conducted on copper- and aluminum-alloy flanges at KEK, after a brief review of the stainless-steel flange.

STAINLESS-STEEL FLANGES

The MO-type flange for a beam pipe with antechambers developed in KEK is presented in Fig. 1. The circular beam channel has an inner diameter of 90 mm. The height of an antechamber is 14 mm and the total inner width of beam pipe is 220 mm. At first, the flange was manufactured from stainless steel (SS316) having a hardness greater than 200 in Hv. The width, height, and thickness were 390 mm, 190 mm, and 30 mm, respectively. The gasket with a thickness of 1.5 mm was annealed copper (C10200) and its hardness was approximately 40 in Hv. Vacuum sealing was achieved by 28 stainless-steel bolts (ϕ 8mm) at fastening torques of 16–19 Nm. Baking the flange up to 200 °C for 24 h had no effect on the vacuum sealing ability.

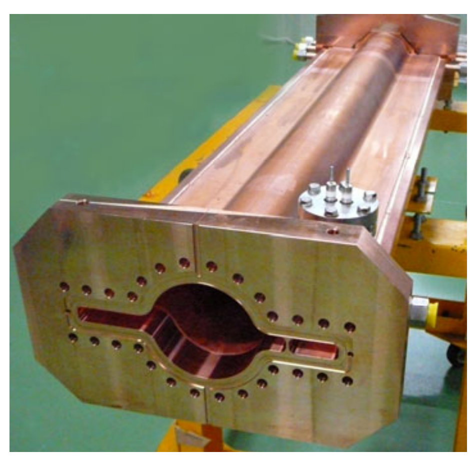

Figure 1: MO-type flange developed for a beam pipe with antechambers in KEK.

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In assembling a copper beam pipe, the stainless-steel flange was welded to a small piece at first using TIG. The piece enabled the transition from stainless steel to copper. The flange assembly was then welded to the copper beam pipe using an electron beam. These beam pipes were installed in the KEKB positron ring and tested. No serious problems such as vacuum leak and/or discharging were observed up to a beam current of 1.6 A (1585 bunches, ~10 nC/bunch, ~6 ns bunch spacing).

However, at beam currents close to the maximum, we found a heating problem. The flanges of some beam pipes located at a wiggler section was heated up to more than 80 °C (ΔT = 55 °C). A cause was the irradiation of the synchrotron radiation. The low thermal conductivity of stainless steel seemed to increase the extent of heating. Another cause of the heating was the Joule loss at the inner surface due to the high-current beam. Temperatures of most of stainless-steel flanges were over 40 °C.

Another problem in the case of stainless-steel flanges is the complexity of the manufacturing process used for copper beam pipes. The use of a transition piece increases the risk of vacuum leaks during manufacturing as well as the cost.

COPPER-ALLOY FLANGE

A method of solving the above problems associated with application of stainless-steel flanges to copper beam pipe is to use copper alloys as the material [5]. A key issue in utilizing copper alloy as the material of MO-type flange is its hardness at the vacuum sealing part as well as the flange body itself. Good mechanical strength at high temperatures, commercial availability, properties of machining and welding should be also taken into account. Here, CrZrCu (C18100) alloy was chosen for test as the most suitable material for the flange. The longitudinal elastic modulus and the linear expansion ratio are ~1.3×10^{11} Pa and ~1.7×10^{-5} $m^{-1}K^{-1}$, respectively, and are almost the same to those of stainless steel.

A test model of the CrZrCu-alloy flange was manufactured, and the vacuum sealing test was performed in the similar way as in the case of stainless-steel flanges.

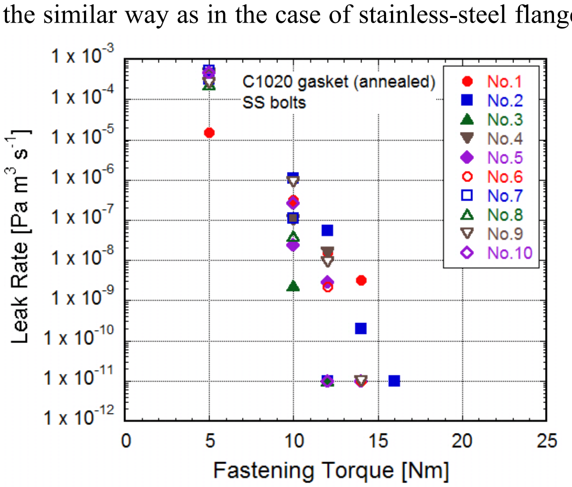

Figure 2: Measured leak rates as a function of the fastening torque of one bolt for copper-alloy (CrZrCu) flanges.

The size of a flange was the same to the previous stainless-steel flange. The hardness of the flange was approximately 165 in HV. The helium leak rate and the gap between the flanges were measured with an increase in fastening torque. The test was repeated ten times, and the results are shown in Fig. 2. Vacuum seal was achieved at a fastening torque of approximately 12–16 Nm, which was comparable to or slightly smaller than that for a stainless-steel flange, where annealed copper gaskets were used.

After the first fastening test, the edge of the sealing part was slightly deformed. However, the deformation did not proceed after successive tests. The vacuum sealing properties were not affected by the damage.

The test flange was baked up to a temperature of 200 °C for 24 h. The change in the hardness of the flange was negligible, and vacuum seal was achieved at the same fastening torque after the baking. A vacuum sealing test was also performed between a copper-alloy flange and a stainless-steel one in the same manner; here, stainless-steel (SS304) bolts and annealed copper gaskets were used. Vacuum sealing was achieved at a fastening torque of approximately 18 Nm. The vacuum sealing was maintained even after baking up to 150 °C.

CrZrCu-alloy flanges were finally applied to a copper beam pipe with antechambers. The beam pipe was installed into the KEKB position ring. The copper-alloy flange of the beam pipe was connected to the stainless-steel flange of a bellows chamber in the ring. No air leak was detected from the flange connections during the beam operation. The temperatures of the copper-alloy flanges were less than 30 °C even at a beam current of 1.6 A.

Considering the welding property, CrCu-alloy (C18200) is superior to CrZrCu-alloy. The hardness was almost the same to that of CrZrCu-alloy. The CrCu-alloy flange was also tested and the comparable results were obtained to the case of CrZrCu-alloy flange.

ALUMINUM-ALLOY FLANGE

The aluminum alloys selected for test were A2219 and A2024, which are usually called as duralumin. The longitudinal elastic modulus (~7×10^{10} Pa) is a little bit smaller, and the linear expansion ratio (~2.3×10^{-5} $m^{-1}K^{-1}$) is higher than those of stainless steel and copper alloy. The electrical conductivity is approximately 30% of copper, but still higher than that of stainless steel. A typical hardness was approximately 160 in Hv. The baking over 200°C, however, should be avoided to prevent aluminium alloy form softening.

The flange with the same sizes to the precedent copper-alloy case except for the thickness was used for the vacuum sealing test. The thickness of the flange was increased to 40 mm considering the small elastic modulus of aluminium alloy. An aluminium pipe was welded to a blank flange by TiG welding assuming an actual case. The softening of the sealing part was not observed even after the welding.

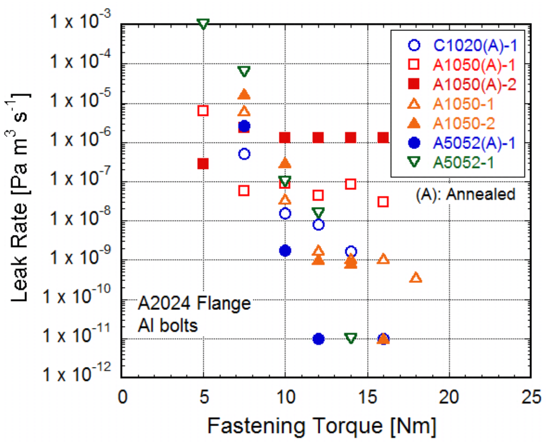

Figure 3 (a): Measured leak rates as a function of the fastening torque of one bolt for aluminum-alloy (A2024) flanges.

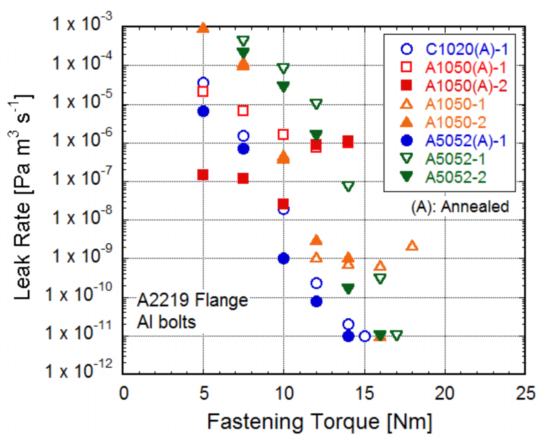

Figure 3 (b): Measured leak rates as a function of the fastening torque of one bolt for aluminum-alloy (A2219) flanges.

The gaskets used for test were pure aluminium (A1050, annealed/non-annealed), aluminium-alloy (A5052, annealed/non-annealed) and pure copper (C10200, annealed). The bolt was basically aluminium alloy (A2219). The results of the vacuum sealing tests are shown in Fig.3 (a) and (b) for the cases of A2024 and A2219 flanges, respectively. Both materials showed the similar properties. As seen in these figures, a vacuum seal was not achieved for the case of A1050 gasket. For the case of non-annealed A5052 gasket, a vacuum sealing was achieved at room temperature, but a vacuum leak was occurred after a baking at 150 °C for 24 h. A stable vacuum seal was obtained for other gaskets with a fastening torque of 13–16 Nm even after a baking at 150 °C for 24 h. For reference, the hardness in Hv of these gaskets before and after the vacuum sealing test are listed in Table.1. In the case of A1050, the hardness of the gaskets did not increase sufficiently after the fastening, which should be a cause of vacuum leak.

The connection between an aluminium-alloy flange and a copper or stainless-steel flange was also tried. A stable vacuum seal was obtained in a room temperature.

Table 1: Hardness of several gaskets before and after fastening tests.

Gasket material	Hardness [HV] Before fastening	Hardness [HV] After fastening
C1020 (A)	39	78
A1050(A)	20	42
A1050	40	46
A5052(A)	53	69
A5052	85	90

(A): Annealed

However, a vacuum leak was observed after a baking at 150 °C for 24 hours. The combinations of gaskets of aluminium and copper, bolts of stainless-steel, aluminium-alloy and bronze were tried, but the stable vacuum sealing was not obtained after the baking for every case. The difference of the linear expansion ratio between aluminium alloy and stainless-steel or copper-alloy should be a reason of the vacuum leak during the baking process. For reference, a baking at 80 °C for 24 h had no effect on the vacuum sealing property. The transverse expansion as well as the longitudinal one may affect the vacuum sealing property in such a large flange. Further investigations are required in this point.

FUTURE PLANS

It was found that copper and aluminum-alloy can be employed to manufacture the MO-type flange. The long-term performance of the flanges will be studied further. For the case of aluminium-alloy flanges, however, more detailed investigation is required to the case of connections between flanges made of different materials.

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REFERENCES

[1] e.g., B. W. Zotterand and S. A. Kheifets, “Impedances and Wakes in High-Energy Particle Accelerators”, World Scientific (1998).
[2] H. Matsumoto, F. Furuta, K. Saito, H. Inoue, N. Sakamoto, K. Ueno and D. Iwai, EPAC2006, Edinburgh, June 2006, p.753 (2006).
[3] Y. Suetsugu, M. Shirai and M. Ohtsuka, J. Vac. Sci. Technol., A 23, 1721 (2005).
[4] Y. Suetsugu, K. Kanazawa, K. Shibata, H. Hisamatsu, K. Oide, F. Takasaki, A.E. Bondar, V. Kuzminykh, A. Gorbovsky, R. Dostovalov, K. Sennyu and H. Hara, NIM-PR A, 538, 206 (2005).
[5] Y. Suetsugu, M. Shirai, M. Ohtsuka, T. Nishidono, K. Watanabe, Y. Suzuki, M. Tsuchiya, A. Yonemoto, K. Sennyu and H. Hara, . Vac. Sci. Technol., A 27, 1303 (2009).