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BAKEABLE ALUMINIUM VACUUM CHAMBER AND BELLOWS WITH AN ALUMINIUM FLANGE AND METAL SEAL FOR ULTRAHIGH VACUUM

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Introduction

In general, the vacuum chambers of proton synchrotrons are made of stainless steel. If the stainless-steel vacuum chamber were to be replaced by an aluminium chamber, the residual radioactivity could be reduced by one or two orders of magnitude 100 hours after machine shutdown.[1)] For example residual radioactivity could not be detected by a 3" NaI crystal detector in the vacuum beam pipe the of 20 MeV beam transport line.[2)] Aluminium is preferred as a material for vacuum chambers for high-intensity electron synchrotrons and electron storage rings because of its good thermal conductivity, its low material ease of manufacture with respect to complicated profiles by extrusion, low residual radioactivity, and the fact that it is completely nonmagnetic. The vacuum chambers currently used are of aluminium with conventional stainless-steel bellows and conflat stainless-steel flanges. An aluminium-stainless-steel transition has been used in the construction of the electron storage ring,[3),4)] but an all-aluminium vacuum system including beam ducts, bellows, flanges, gaskets, and bolts and nuts would be preferable. Since aluminium flanges and metal gaskets are not available commercially, a suitable aluminium flange/gasket combination had to be designed and fabricated.[5)]

Aluminium flange and gasket

The composition of the aluminium flange and metal seal pose a problem since the surface hardness and the mechanical strength at bakeout temperatures are insufficient in ordinary aluminium alloys. However, a special aluminium alloy 2219-T87,[6)] developed for space rocket components, has been found to be have the necessary mechanical properties. Recently a new type of metal seal-Helicoflex[7)]-appeared on the market. Basically on Helicoflex is a flexible metal O-ring with an elastic core which supplies the sealing force. Anodized aluminium alloy (2219-T87) bolts and nuts were used to tighten the flange, and the flange was also anodized. The thickness of the anodized layer was about 30 μm. The O-ring and its sealing surface on the flange were not anodized. The aluminium alloy vacuum chamber (6063-T6), bellows (5052) and the alloy flange (2219-T87) were welded by an alternating current (50 Hz) TIG process using aluminium alloy fillar wire (4043). Distortion after welding was negligible and remachining was not necessary. Decrease of the surface hardness on the O-ring groove could not detected.

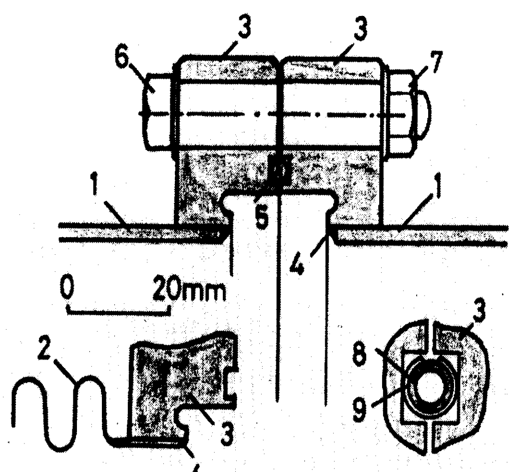

Fig.1 Aluminium alloy (2219-T87) vacuum flange and pure aluminium Helicoflex O-ring composition. 1. aluminium alloy chamber (6063-T6), 2. aluminium alloy corrugated bellows (5052), 3. aluminium alloy flange (2219-T87), 4. welded by AC TIG, 5. Helicoflex aluminium O-ring, 6. anodized aluminium alloy bolt (2219-T87), 7. anodized aluminium alloy nut (2219-T87), 8. elastic core (nickel base super alloy inconel 750) coil spring, 9. pure aluminium (1050)

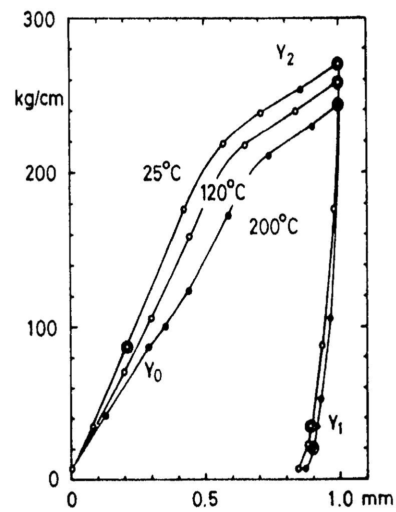

Fig.2 Sealing characteristics of the Helicoflex O-ring in room and bakeout temperature. Y_o = initial sealable tightening force along the O-ring, Y_1 = minimum sealable tightening force along the O-ring at decreasing the tightening force and Y_2 = maximum sealable tighening force along the O-ring.

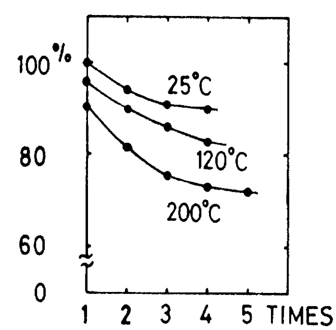

Fig.3 Tightening force vs. sealing times in room and bakeout temperature. Origin is Y_2 = 270 kg/cm at room temperature.

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Aluminium alloy (2219-T87) vacuum flange and pure aluminium Helicoflex O-ring composition is shown in Fig.1 The sealing characteristics of the Helicoflex O-ring, whose diameter was 4.5 mm and the flanges were measured using a compression tester and a helium leak detector at room temperature as shown in Fig.2 and Fig.3. The tightening force of the flanges ranged from 100 to 250 kg cm^{-1} along the O-ring. The normal tightening force was 200 kg cm^{-1}. The width of the touching surface of the aluminium O-ring is about 2 mm, so the surface pressure from the O-ring to the aluminium flange does not take such a high value. No surface defect of the aluminium flange due to the aluminium O-ring appeared after many tightening cycles at the bakeout temperature 150°C. The fixed depth of the O-ring groove was made to correspond to the compression distance of the O-ring and the flanges were tightened until the flange surfaces touched. A torque wrench was not required. A used Helicoflex O-ring viewed with an optical microscope shows a surface which has grooves like a photograph record.

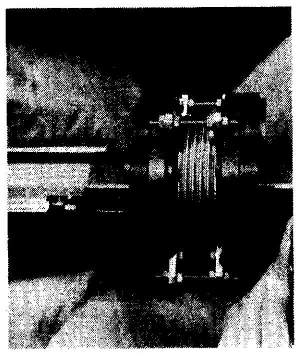

Fig.4 An aluminium alloy corrugated bellows with an aluminium alloy vacuum flange inserted two long aluminium vacuum chambers.

Aluminium bellows

A bellows between these aluminium chambers is necessary for ease in assembly in order to absorb mechanical tolerances, misalignments of the machine components and thermal expansion. An aluminium alloy bellows element produced a hydraulic expansion 0.5 mm wall thickness is no more difficult to construct than a stainless-steel corrugated bellows element. The application of the weldable and bakeable aluminium alloy flange and metal gasket combination makes it easy for an aluminium alloy tube to be replaced by an aluminium alloy corrugated bellows as shown in Fig.1 and Fig.4. After 7 convolutions the active installed length is 100 mm permitting the required 10 mm lateral offset, including some plastic deformation acceptable under static conditions. If the purpose of this aluminium bellows is not dynamic motion, a long life-time can be expected.

Vacuum testing

The test vacuum chambers were two PETRA[3] type profile, 300 mm long chambers with 150 mm diameter flanges. The bellows was inserted between two chambers as shown in Fig.5. The pumping system consisted of a 220 l s^{-1} turbomolecular pump and 160 l s^{-1} sputter ion pump. The following cleaning procedure was adopted: degreasing in toluence at room temeprature and an ethylalcohol rinse at room temperature. Leak testing after repeated cycling to 150°C was carried out. The leak rate of the flange and metal seal combination was measured with a helium leak detector and found to be less than 10^{-11} atm cm^3s^{-1}. The ultimate pressure in the system was 3×10^{-10} torr. Typical outgasing rate was approximately 2×10^{-12} torr l $s^{-1}cm^{-2}$. The residual gas mass spectrum at the ultimate pressure shows mainly hydrogen, carbon monoxide and carbon dioxide. The special aluminium alloy (2219-T87) is not suitable for extrusion. Practically, the bakeout temperature is limited to approximately 170°C by the aluminium alloy pipe (6063-T6).

Fig.5 PETRA type profile aluminium vacuum chamber. Ultimate pressure is 3×10^{-10} torr.

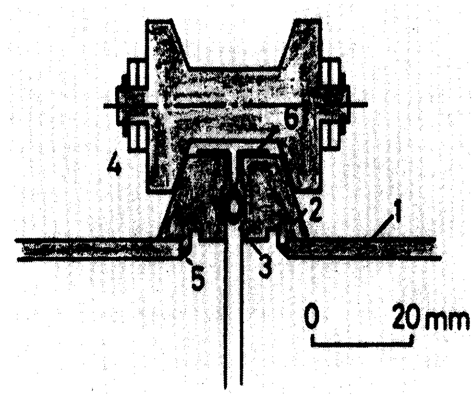

Fig.6a An aluminium alloy quick coupling flange, an aluminium O-ring with retainer ring and roller chain coupler. 1. aluminium alloy chamber (6063-T6), 2. aluminium alloy flange (2219-T87), 3. Helicoflex aluminium O-ring, 4. roller chain coupler, 5. AC-TIG welding, 6. retainer ring.

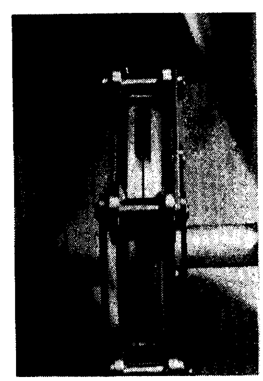

Fig.6b Aluminium alloy quick coupling flanges and roller chain coupler.

CrN treatment on the gasket groove

Practically, we have problem with the surface of the gasket groove. The special aluminium alloy (2219-T87) is suitable for using an Helicoflex O-ring but the aluminium surface is weak for scratching. Cromium-nytride coating by the ion-plating method[8] was carried out on the aluminium surface of the gasket groove. The thickness of the CrN layer was about 16 μm. The surface hardness of the CrN was very high and its micro Vickers (100 gr) was about 1800. The CrN treatment on the aluminium was a perfect protection against scratching. CrN treatment has no problem for surface on ultrahigh vacuum. This CrN treatment can be replaced the ordinally anodized treatment on the aluminium flange in atmospheric side.

Quick coupling flange

A quick coupling system was developed. The structure of the quick coupler is the different as an EVAC-type quick coupler as shown in Fig.6. This new type of coupler is a roller chain type. The roller chain type coupler system has low friction between the coupler and the anodized aluminium flange, uniform tightening force along the metal gasket and the extension upto large size coupler. Just same as the EVAC type quick coupler system. It is was also possible as shown in Fig.7. However, small defects caused by the EVAC type coupler occurred on the anodized aluminium flanges. In this case, lubrication such as molybdenum-sulphite was necessary to reduce the friction between the coupler and the flanges.

Large size flange

It was also possible to use large size flanges of upto 625 mm in diameter flanges and 625 mm × 625 mm for square flanges as shown in Fig.8. Large size bakeable aluminium chambers such a kicker magnet chamber, a septum magnet chamber and a bump magnet chamber can be made for injection and extraction.

Aluminium driving mechanism

Bakeable driving mechanisms for the beam profile monitor and the slow scraper were made by aluminium as shown in Fig.9. A dynamic bellows, a ball screw and a ball bush were used ordinally parts. The weight of this driving mechanism was reduced to one half of that of ordinary stainless steel mechanism.

Conclusion

Thus a complete aluminium vacuum system for ultrahigh vacuum has been developed. The resulting assembly is compatible with ultrahigh vacuum operation and is resistent to hard radiation. This aluminium vacuum system was widely used in the straight section of the KEK proton synchrotron, the extracted beam line of the KEK synchrotron, and the beam transport line between the KEK booster and the KEK main ring, and the KEK booster and the KEK linac. The new aluminium vacuum system may be widely used in electron storage ring such a Photon Factory,[9] PETRA, PEP and CESR, a proton storage ring such a TRISTAN,[10] ISABELLE, POPAE and CERN.

Acknowledgement

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Fig.7 An aluminium quick coupling flange and EVAC type coupler

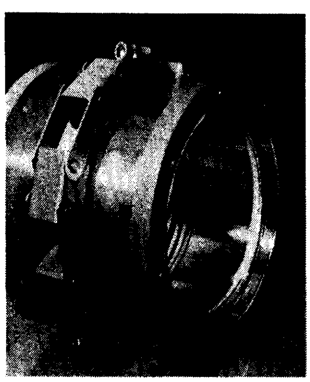

Fig.8b A large size aluminium flange up to 625 x 625 mm and squear type Helicoflex aluminium O-ring.

Fig.8a A large size aluminium flange up to 625 mm in diameter and Helicoflex aluminium O-ring.

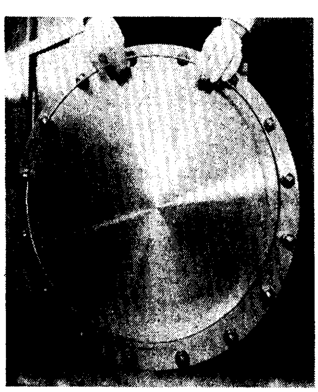

Fig.9 A bakeable aluminium driving mechanism.