ALUMINUM ALLOY DC SEPARATORS USING HEAT PIPES FOR A e^+e^- COLLIDER, TRISTAN

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Abstract

16 DC separators are installed at both sides of the 4 colliding points. The separator chambers (A6063-T5) are made by a special extrusion technique and the inner diameter is 300 mm. The electrodes (A6063-T1) are 145 mm wide and the gap is 80 mm. On the chambers and the electrodes, N_2 gas discharge processing is applied to make holding time longer. The bushings consist of a ceramic-aluminum alloy seal using vacuum brazing. The estimated parasitic mode loss is on the order of 100 W for 7 mA × 7 mA and single bunch mode. Copper/water screen wicked heat pipes, 19 mmϕ and 850 mm long, are fitted to the electrodes horizontally. After 4 days operation with 2 mA × 2 mA and 2 bunch mode, a temperature rise of about 3.5°C was observed at an electrode. During beam operation one of the separators deteriorated because of an influence of rf current due to bunched beam. The deterioration was triggered by a discharge in the connecting part of the electrodes which consists of a spring and an anti-corona cover. This defect can be eliminated by taking off the spring and the cover or by changing the two piece electrode to a one piece electrode.

1. Introduction

An electron positron colliding storage ring, TRISTAN, 1 km in diameter, uses an ultra-high vacuum system made of aluminum alloys[1]. The required beam life time is about 10 hours. Therefore the required pressure in the beam chamber is on the order of 10^{-7} Pa. The ultra-high vacuum system was accomplished using aluminum alloys having low thermal desorption rate achieved by applying a special extrusion technique[2]. All the beam chambers and vacuum components are basically made of aluminum alloys. DC separator chambers and electrodes are also made of aluminum alloys. A ceramic aluminum alloy seal using vacuum brazing is used for high voltage bushings.

In DC separators in a storage ring, heat due to parasitic mode loss[3] is generated. To eliminate this heat, a cooling system is needed. Electrodes in the separator are difficult to cool because high voltage is applied and the electrodes are isolated thermally and electrically from the chambers. Under these conditions the use of a heat pipe is one of the simplest methods available for cooling. Cu/water screen wicked type heat pipes are used. They are equipped with high voltage bushings.

2. Design and Structures

2-1 Power estimation

The beam current of TRISTAN is 7 mA for electrons and positrons. The power of parasitic mode loss[3] can be estimated using loss parameters (k) as

$$P = 2 i_o^2 k T_b \quad , \qquad (1)$$

where k; volt/coulomb, i_o; maximum beam current, Ampere, T_b; time interval between bunches, sec. Using $T_b = 10^{-5}$ for single bunch and $i_o = 7 \times 10^{-3}$, P is on the order of 100 W, where k is on the order of 10^{-11} [3].

2-2 Cooling material

Though there is no precise explanation, it is estimated that heat is localized and is very close to the discontinuity in structure, especially around the end of the electrodes. To prevent localized heating, a cooling system is needed. A heat pipe structure is adopted because of its simplicity and reliability. Because of high intensity X-ray radiation in TRISTAN, the good coolant of aluminum heat pipes was not obtained. Therefore heat pipe type electrodes were not used.

A Cu/water heat pipe system was selected for heat elimination from electrodes to the outside of the chamber. Copper is suitable for welding to Kovar. Kovar can be soldered to metalized ceramics.

2-3 High voltage bushings, chambers and electrodes

There are two types of bushings. One has an aluminum center conductor and the other one has a heat pipe type center conductor (Fig. 1). The former is used to support electrodes and the latter to eliminate heat and to support electrodes. These bushings are assembled on to the DC separator chambers (Fig. 2). The inner diameter of the chamber is 300 mm. The chamber is made of A6063-T5 by a special extrusion technique. The thermal gas desorption rate of the aluminum chamber is on the order of 10^{-13} Torr·ℓ/s·cm^2 after 24 hour baking. An electrode is 10 mm thick and 145 mm wide. Electrodes are made of A6063-T1. The gap between the electrodes is 80 mm.

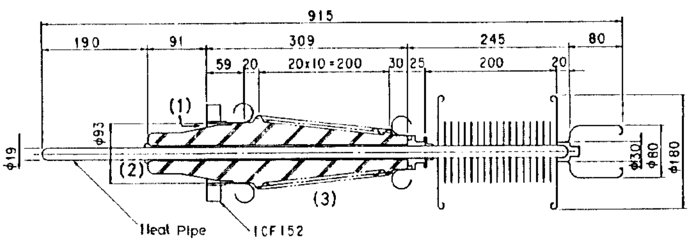

Fig. 1 High voltage bushing equipped with a heat pipe.

There are two types of separator chambers, L type, 5435 mm long (Fig. 3(a)) and S type, 3800 mm long. As it is estimated that heat is generated around the end of the chambers and the electrodes, heat pipe type bushings are set close to the both ends. To obtain good heat transfer between the electrode and the heat pipe, the heat pipes are tightly connected to the electrodes using two aluminum blocks. In addition, heat pipe type bushings are fixed to the chamber as shown in Fig. 2. Therefore both ends of the electrodes are also fixed to the chamber.

To absorb thermal expansion of the electrodes, the electrodes are divided into two pieces near the center of the chamber as shown in Fig. 3(b), (C and H). Aluminum type bushings are used to make movable supports using bearings suitable for operation in vacuum. The divided electrodes are electrically connected using a spring (Be-Cu), as shown in Fig. 4.

At the movable support of L type, bearings are also used. All these springs and bearings are covered with an anti-corona cover. The outside of the heat pipe has 24 fins made of aluminum (100ϕ × 0.6t) pressed to the central conductor to obtain good heat transfer efficiency. Cockcroft Walton high voltage power supplies and high speed breakers are set as shown in Fig. 3(a).

3. Characteristics of the DC Separators

3-1 Tests of high voltage bushings

Before assembly each bushing was tested at 120 kV

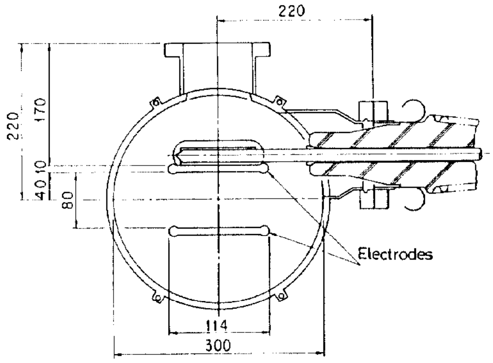

Fig. 2 Assembly of electrodes, heat pipe type bushing and a separator chamber.

whether 1 min holding time was obtained or not. The test was made after DC discharge cleaning (DCDC) which was applied to the bushings at 4 Pa of N_2 gas. The ion dose of about 10^{19} ions/cm^2 of the DCDC has the effect of increasing the conditioning efficiency[4]. At the same dose, holding time at 120 kV increased.

The heat transfer efficiency of a heat type bushing set horizontally was measured under natural convection. A heater was set on two aluminum blocks tightly connected to one end of a heat pipe. The whole bushing was exposed to an atmosphere at room temperature. The heat transfer efficiency was 0.5°C/W.

3-2 Test of DC separator chambers

After the electrodes and the bushings are assembled, a DC separator chamber is evacuated using a 200 ℓ/s turbomolecular pump and DCDC on the order of 10^{18} ions/cm^2 is applied to the electrodes and chamber surfaces. The unit is then subjected to a high voltage test and is required to hold off ± 80 kV for a time exceeding several hours.

After the test the separator is carried into the tunnel and installed in the ring. In the ring L and S separators are evacuated by a 200 ℓ/s turbomolecular pump. DCDC on the order of 10^{18} ions/cm^2 is again applied to both electrodes and chamber. Then the separators are baked for about 24 hours at 100°C. Holes in the electrodes have a surface made in an ordinary extrusion atmosphere. Therefore the thermal desorption rate of this surface is higher than that of the special extrusion. In addition the surface area of the holes is 1/4 of the total area of the separator. To improve the thermal desorption rate baking is necessary. After baking the obtained pressure is on the order of 10^{-7} Pa. Again high voltage of ± 80 kV is applied. All separators exhibited a several hour holding time.

Just after baking, heat transfer efficiency between an electrode and a heat pipe was evaluated by measuring the temperatures of an electrode and the heat pipe fins. It is about 0.02 W/°C cm^2. This is nearly the same as the result from measurement of the contact in an atmosphere.

3-3 Test of DC separators during beam operation

Without beam several hour holding time at ± 80 kV was obtained for all the separators. During beam operation 80 % of the separators were operated at ± 80 ∿ 50 kV and therefore 1.0 ∿ 1.9 mm beam separation was obtained. However in several separators, unwanted discharges between the electrodes occured, discharge current increased, and holding time decreased. Two cases are described below.

3-3-1 Deterioration of bushings by the beam

As operating time increased, the holding time of a separator (S type) decreased. Even if no beam was present, the holding time decreased to 30 min at ± 60 ∿ 70 kV. In addition X-ray radiation was observed from a negative electrode. Without beam, as applied voltage increased from ± 50 kV to ± 70 kV, X-ray intensity increased from ∿ 60 μR/h to ∿ 3 mR/h. It was found that X-rays were emitted from 2 bushings of the negative electrode. Furthermore at ± 45 kV with beam discharge occured very often. Discharge also increased during beam injection.

Holding time and applied voltage were much improved by exchanging the two bushings for new ones.

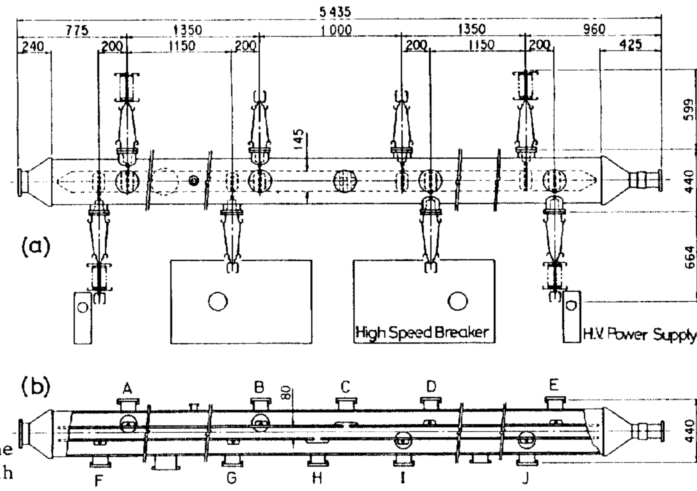

Fig. 3 (a) Assembly of high voltage bushings (L type), (b) Arrangement of electrodes.

3-3-2 Deterioration by rf current due to beam

This problem was observed to cause beams of 1.5 mA to 2.5 mA to suddenly decreased to zero at an applied voltage of ∿ ± 50 kV. The fact was correspondent to the current increase in one separator (L type). The current increase of ∿ 500 μA (normally ∿ 60 μA) corresponded to a beam current larger than 1.5 mA. At ± 30 kV, 2.4 mA beam decreased to 1.6 mA very often, correspondingly, a pressure rise was observed. This is shown in Fig. 5(a), compared with a normal separator (Fig. 5(b)). In addition, at ± 40 kV, X-ray intensity close to the connecting part of a negative electrode was about 30 times larger than that of a positive electrode, where the latter was almost background level. From these facts it was estimated that rf current flowed through the spring at the connecting part and a discharge was occuring between the two pieces of an electrode. The discharge triggered a further discharge between the electrodes and electrons at 80 kV hit the positive electrode. Therefore X-rays were observed.

3-3-3 Temperature rise during beam operation

A thermocouple was mounted in a heat pipe type bushing of a separator (S type) to measure the temperature of an electrode. After 4 days operation of 2 mA × 2 mA at two bunches for electrons and positrons, the temperature was about 21°C compared to 17°C in an atmosphere.

For two bunch operation for only electrons, 1.65 mA × 1.65 mA, temperature difference between electrodes and the end of the heat pipe was 2.4°C. Using the datum of 0.5°C/W estimated input power is 5 W.

4. Discussions

4-1 High voltage bushings

During high voltage test at ± 120 kV for a bushing, checking point was 1 min holding time because bad bushings normally showed holding time less than 10 sec. Weak places for discharge are (1) coaxial gap between ceramics and aluminum cylinders, (2) end of the ceramics in the vacuum, (3) outer surface of corrugated ceramics as shown in Fig. 1. At place (1), and (2) the electric field is concentrated and X-rays can be easily excited. At place (1), a small bright spot was often observed. An air leak occured at the brazing part of an aluminum cylinder after discharges occured several times at higher than 120 kV. Field concentration can be reduced by making the gap and diameter large. X-ray intensity was reduced by setting an aluminum ring, 10 mm thick (= 5 R) and 60 mm in diameter, at location (2). Corona discharge at location (3), can be decreased by anti-corona covers having larger curvature and dimensions. Although the reasons why the two bushings deteriorated during operation are not clear, a possible one is a mixture of (1) and (2). Therefore the high voltage test for a bushing must be set at a longer holding time. Structural defects of bushing should be also reduced.

4-2 Rf current due to beam

All the separators have been exposed to atmosphere after a long shut down began. Fixed and movable supports were checked by removing anti-corona covers.

For the deteriorated L type separator, the stain of an unwanted discharge was observed inside the surface of the covers at the connecting part of the two pieces of an electrode. In addition, on the inside surface of the covers at two movable electrode supports a similar stain was observed. At the connecting part thre was evidence that traces of the spring remained with some material evaporated. Therefore heating as well as discharge could have occured. It can be estimated that rf currents equivalent to 1 Amp. of direct current, heat the spring and the discharge was amplified. At the movable supports, a discharge at the gap between the cover and the electrode can have occured.

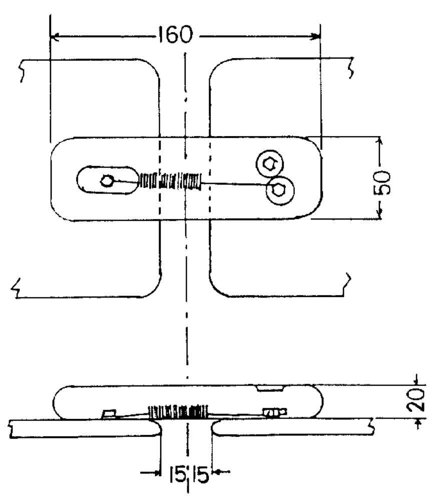

Fig. 4 Connecting part between two pieces of an electrode. Fig. 3(b), (C and H).

A similar stain was also observed at the connecting part of S type separators where this part supports part of the electrodes.

To avoid the discharge in the connecting part, the spring has been eliminated and the two pieces of the electrode are going to be connected outside the chamber using cable (L type). For the S type, since the connecting part is also a supporting part of the electrodes, the electrode is going to be changed to a single piece electrode.

The anti-corona covers are set not to touch the electrodes with a gap of 3 mm. In addition electrodes and central conductors are tightly connected.

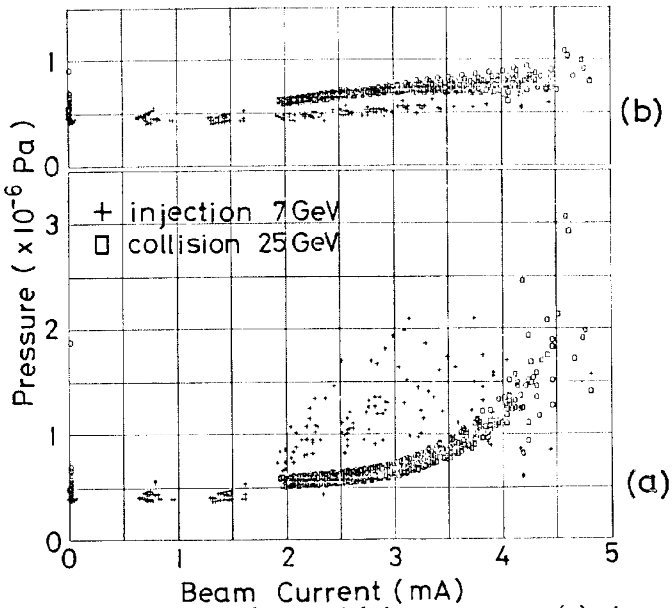

Fig. 5 Pressure change with beam current, (a) the deteriorated, and (b) normal separators.

4-3 Parasitic mode loss due to beam

Since the required beam intensity is 7 mA × 7 mA, the power ratio to the present beam intensity, 2 mA × 2 mA, is about 12. Then the estimated required power is about 60 W per one piece of an electrode for L type. The estimated temperature rise is about 40°C, therefore, the electrode temperature will be 60°C.

For the S type, an electrode will be changed to a single piece electrode. Estimated required power is 120 W, then the temperature rise is estimated to be about 80°C and electrode temperature 100°C. This heat pipe has 4 times the heat capacity required. Therefore the heat pipe can function for a one piece electrode.

5. Conclusion

16 DC separators of TRISTAN, made of aluminum alloys functioned as an ultra-high vacuum system. Heat pipes equipped with high voltage bushings to eliminate parasitic mode loss functioned at a power level of magnitude lower than that eventually required (∿ 100 W). The separators without beam have several hour holding time but deteriorated during beam operation. The dominant structural defect is in the connecting part between two pieces of an electrode. There unwanted discharges were generated. Defects have been improved by changing from two piece electrodes to one piece electrodes.

Acknowledgements

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