Development of A Bellows Assembly with RF-Shield for KEKB II : Abrasion and Pumping down Tests

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Abstract

A bellows assembly with RF-shield has been designed and developed for the KEK B-factory (KEKB). The RF-shield is a usual finger-type but has special spring-fingers to press contact-fingers (shield-fingers) surely onto inner tube (beam tube). In a chain of design studies an abrasion test of the contact-fingers was performed in vacuum. A quantity of generated metal particles was estimated and expected to have little harm on the beam lifetime if the inner tube is coated with silver. The gas desorption rate and the residual gas components of the bellows assembly were also measured as a final bench test. The gas desorption rate of 1 - 1.5×10^{-10} Pa·l/s/cm^2 was obtained after a bake at 150 °C for 24 hours.

1 Introduction

Parallel to overall design of vacuum system, a vacuum bellows assembly with RF-shield has been developed for the KEK B-factory (KEKB)[1-5]. The bellows assembly absorbs thermal expansion and contraction of the beam tube during beam operation and baking. The RF-shield inside it has to keep a good electrical contact to flow smoothly the wall current induced by the beam while preserving smooth mechanical moving with high reliability. We developed a bellows assembly with RF-shield of a usual finger-type but having special spring-fingers to press securely contact-fingers (shield-fingers) on to inner tube (beam tube). In the R&D so far, necessary contact force, optimum finger length, HOM (Higher Order Mode) power leaked into inside of bellows have been investigated experimentally or by calculation[3-5].

In a chain of the design studies, an abrasion test of the contact fingers was performed in vacuum in relation to the dust trapping problem in electron storage rings[6,7]. In the experiment the quantity of generated metal particles was measured and the influence of it on the beam lifetime was estimated. The effect of silver coated spring-fingers and inner tube on the quantity of particles was also investigated. As a final bench test, a pumping down test of the bellows assembly was carried out to estimate the gas desorption rate and to see the residual gas components. The results of these experiments are presented here.

2 Structure

We briefly reviews the structure of the bellows assembly at first[3-5]. For the KEKB, the bellows assembly should absorb a maximum axial stroke of 20 mm and an offset of 1 mm. The design lifetime is 10^5 times' expansion/contraction with 1 mm stroke. A typical bellows assembly designed for the KEKB is schematically drawn in Fig.1 and the cut-model is presented in Fig.2. The main components of the RF-shield are the contact-finger, the spring-finger, and the inner tube. The contact-fingers are pressed on to the inner tube from outside by the spring-fingers. The electrical contact is kept at the edge of inner tube. The contact force is set to be larger than 100 g/finger at the nominal position. Even for the case of 1 mm offset, the contact force is kept larger than 70 g/finger.

The contact-finger is 0.2 mm thick beryllium-copper (Be-Cu) alloy (C1720) and has the width of 5.5 mm. The gap of slit between adjacent fingers is 0.5 mm. The slit length is 20 mm at the nominal position. The number of contact-fingers is 52 for the model in Fig.1. The spring-finger is 0.4 mm thick Inconel-625 and is coated with silver (10 μm). The tip of the spring-finger has a curvature of 5 mm. The inner tube is 0.8 mm thick stainless steel (the edge is 1.0 mm thick) coated with silver (10 μm) to improve electrical contact. Other parts of the bellows assembly are made of stainless steel. The every component of bellows assembly was degreased and then cleaned by acid before assembly. To prevent contamination during handling, assembling of the bellows was done in a clean room of a class less than 10000.

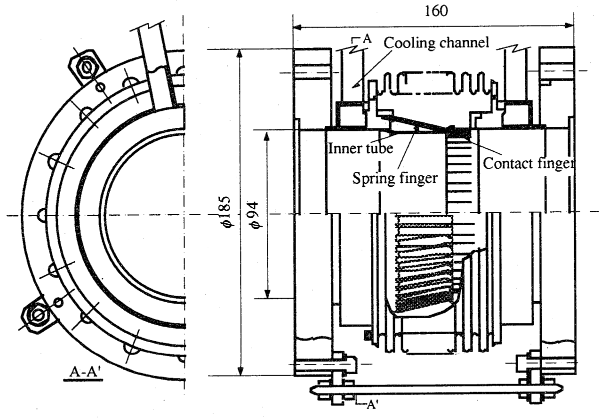

Fig. 1 Typical structure of bellows assembly for KEKB.

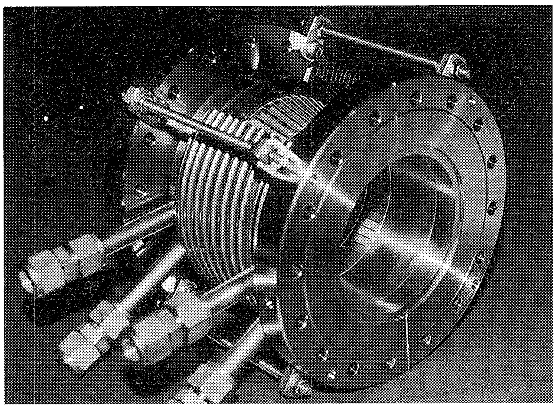

Fig. 2 Cut-model of bellows assembly drawn in Fig.1.

3 Abrasion test

It is well known that small particles (dust) inside a beam tube have a great concern with the dust trapping problem in electron storage rings[6,7]. The metal particles due to the abrasion at the contact point of the RF-shield could be a possible particle source and should be controlled carefully.

The experimental setup for the abrasion test is shown in Fig.3. A test piece of the RF-shield is installed in a vacuum chamber which is evacuated down to less than 1×10^{-4} Pa by a turbo molecular pump. The test piece has five fingers and is fixed to vertical position as shown in the figure. The materials of the contact-finger, the spring-finger and the plate (i.e., inner tube) is the same as the real ones except for silver coating. The contact force is set to about 100 g/finger. The contact-finger performs reciprocating motion with a stroke of 20 mm. The time for one cycle is about 7 seconds. The time is on the same order with that necessary for molecules to cover one layer on a clean metal surface (about 3 seconds). The condition is similar to the real ring where the average pressure will be in the order of 10^{-7} Pa and one stroke during beam operation will take more than several thousands seconds.

The particle counter used is M-25s (Ushio Co. Ltd., Japan) that can count particles by a laser scattering method in vacuum (6.8 atm - 1×10^{-6} Pa). The wave length of the semi-conductor laser is 780 nm. The minimum detectable particle size is 0.27 μm. The size of particle can be classified into 5 ranges between 0.27 and 2.0 μm. The particles dropped from the test piece are gathered by a cone and pass the detector of the particle counter as drawn in Fig.3.

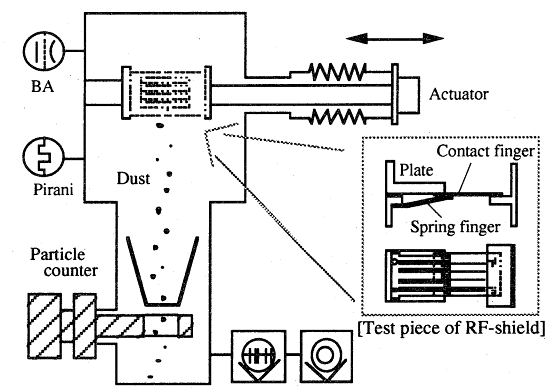

Fig. 3 Experimental setup for abrasion test.

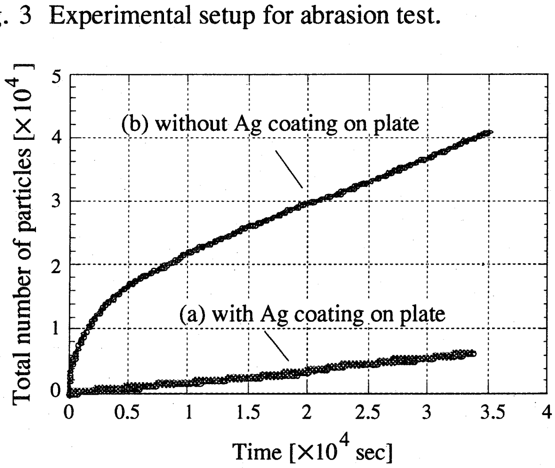

Fig. 4 Total number of generated particles (≥ 0.27 μm) for (a) with and (b) without silver coating on plate.

Fig.4 is a typical result of the time variation of the total number of measured particles (≥ 0.27 μm). The line (a) and (b) are for the case with and without silver coating on the plate, respectively. The spring-fingers were coated with silver. For both cases the quantity of particles increased rapidly at the first stage (≤ 3000 sec.). That is because the metal surface is initially covered by an oxide layer formed in air and the scratched metal particles detach easily from the surface during mechanical motion. The quantity of particles for the case (a) was, however, much less than that of the case (b). The reduce of particles should be due to the silver coating on the plate. It was interesting that the silver coating on the spring finger, contrary to the plate, seemed to have little effect on the quantity of particles since the results for the case without silver coating on both the spring finger and the plate were almost same as (b) in Fig.4. That may be because the spring-finger touches the contact-finger in a point, or a pair of Inconel and Be-Cu alloy is intrinsically a good combination on reducing metal particles generated due to abrasion. Further investigations are now undergoing on this point.

Here we estimate the influence of the particles on beam life time. At first we assume that 2 particles drop during one stroke of 20 mm considering the case of (a) in Fig.4. In the real ring, the stroke during one operation cycle is about 1 mm and the number of fingers just above the beam orbit is one at most. Since about 300 bellows assemblies in one ring will expand and contract during an operation cycle, the possible number of particles (N_p) that may be trapped for one operation is

$$N_p \approx 2\times\frac{1}{20}\times\frac{1}{5}\times300=6.$$

The material of the particle is assumed to be silver (the density is 10.5 g/cm^2). The mass number (A_{atom}) is 108 and atomic number (Z_{atom}) is 47. For the particle with a diameter of 0.5 μm, which was the most dominant size, the mass number (A_p) of the particle is 4.1×10^{11}. If the beam lifetime is determined by the Bremsstrahlung due to the nuclei of the particle, the lifetime, τ [sec], can be calculated by[7]

$$\frac{1}{\tau}=\left\{\frac{16r_e^2}{3\times137}\ln\frac{E}{\Delta E}\ln\frac{183}{(Z_{atom})^{1/3}}\right\}(Z_{atom})^2\times \frac{A_pN_p}{A_{atom}}\frac{c}{2\pi\sigma_x\sigma_yC}\ [\mathrm{sec}^{-1}],$$

where $r_e=3\times10^{-15}$ m is the classical electron radius, $\Delta E/E$ is the RF bucket height ≈ 0.01, $c=3\times10^8$ m/s is the speed of light, $C=3000$ m is the circumference of the ring, $\sigma_x=1$ mm and $\sigma_y=50$ μm are the width and the height of the beam, respectively. Now if all particles are completely trapped in the beam at the same time ($N_p=6$) for the worst case, τ is about 10000 seconds. The lifetime is almost the same order as designed one determined by the pressure with beams[1,2]. On the other hand, the experiment at the TRISTAN AR indicated that the metal particles would melt and evaporate immediately in the beam and should not be trapped[6]. Then if the particles effect on the beam only during crossing the beam (about 1×10^{-4} sec), which may be the most optimistic case, the beam loss is negligible. In summary, if the plate (inner tube) is coated with silver as our design the generated particles at the contact-finger will have little harm on the beam lifetime. Without the silver coating, however, the short lifetime less than one hour may be observed for the worst case ($N_p \approx 20$).

4 Pumping down test

As seen in Fig.1, the bellows assembly has a very complicated structure and has a large surface area. For the typical one with the length of 160 mm and the diameter of 94 mm, the inner surface area is about 2500 cm^2 which is about 5 times larger than the normal beam tube with the same length. The gas desorption rate, therefore, should be sufficiently lower than that necessary for the usual beam tube. The nominal residual pressure without beams should be less than 5×10^{-8} Pa for the ring[1,2]. That requires the gas desorption rate of less than about 1×10^{-9} Pa·l/s/cm^2, where an average pumping speed of 80 l/s/m was assumed. The goal of gas desorption rate of the bellows assembly, therefore, was set to 2×10^{-10} Pa·l/s /cm^2 in N_2 equivalent.

The experimental setup for the pumping down test is presented in Fig.5. The test chamber is evacuated by two turbo-molecular pumps in series. The chamber is separated to two chambers (Ch-1 and Ch-2) by an orifice with a conductance of C_{ori} = 4.9 l/s in N_2 equivalent. The surface area

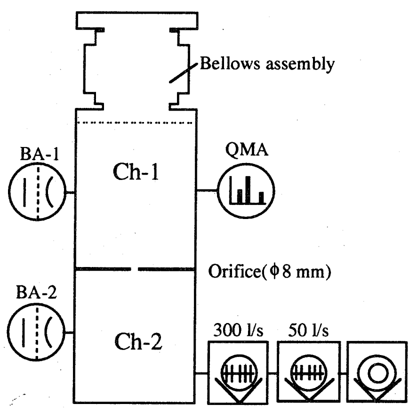

Fig. 5 Experimental setup for pumping down test.

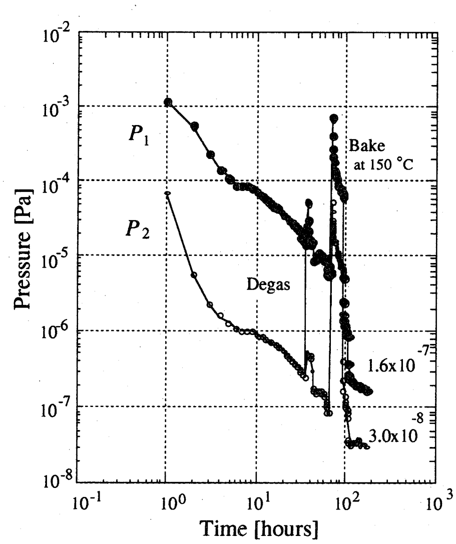

Fig. 6 Pumping down curves for Ch-1 (P_1) and Ch-2 (P_2).

of the upstream side (Ch-1) and downstream side (Ch-2) are about 3100 cm^2 and 3400 cm^2, respectively, without the bellows assembly. Two BA gauges (BA-1 and BA-2) are set to each chamber. The bellows assembly and a quadrupole mass analyzer (QMA, surface area ≈ 900 cm^2) are attached to Ch-1. The gas desorption rate of Ch-1 (q_1) was obtained by the through-put method, i.e., q_1 can be calculated by

$$q_1 = \frac{C_{ori}}{S_1}(P_1 - P_2) \quad [\mathrm{Pa}\cdot l/\mathrm{s/cm^2}],$$

where S_1 [cm^2] is the surface area of Ch-1, P_1 [Pa] and P_2 [Pa] are the pressures of Ch-1 and Ch-2, respectively. The gas desorption rate of Ch-1 without the bellows assembly (q_0) was about 6.6×10^{-11} Pa·l/s/cm^2 after a bake at 200 °C.

Fig.6 is the pumping down curves for Ch-1 (P_1) and Ch-2 (P_2) with the bellows assembly. The bake was at 150 °C for 24 hours. The P_1 and P_2 at 100 hours after the bake were 1.6×10^{-7} and 3.0×10^{-8} Pa, respectively. Then the gas desorption rate of Ch-1 including the bellows assembly was about 9.8×10^{-11} Pa·l/s/cm^2 (S_1 = 6000 cm^2) from the equation above. For reference, considering the q_0 obtained previously for Ch-1 without the bellows assembly, the gas desorption rate of only the bellows assembly was estimated as about 1.5×10^{-10} Pa· l/s/cm^2. In any case the measured gas desorption rate was found to be less than the aimed one.

The residual gas components were also measured after the bake and the most dominant gas component was H_2. Other main gases were H_2O, CO and CO_2 and any significant contamination was not detected.

5 Conclusions

The abrasion test of the contact-fingers indicated the quantity of metal particles generated during mechanical motion would have little harm on the beam lifetime if the inner plate was coated with silver. Silver coating was found to be effective on not only keeping good electrical contact but also reducing particles due to abrasion in vacuum. The gas desorption rate of the bellows assembly was 1 - 1.5×10^{-10} Pa· l/s/cm^2 after a bake at 150 °C for 24 hours and the bellows assembly showed a good vacuum performance.

References

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