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# Development of a bellows assembly with an RF-shield for the KEKB

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*Abstract*

A bellows assembly with an RF-shield has been designed for the KEK B-factory (KEKB). The RF-shield suppresses the excitation of the higher order mode (HOM) at the bellows gap and reduces the impedance. Our new-designed RF shield is a usual finger type but has extra spring fingers to ensure the sufficient electrical contact between contact fingers and beam duct. The wearing test is performed using a experimental model over 5000 expansion-contraction cycles with a 20 mm stroke and any mechanical problem is not found except for the dust production due to the abrasion. Since the abrasion depends on the contact force, the heating of the model is measured transmitting 80 kW of 508 MHz microwave in atmosphere for several contact forces and the necessary contact force, 50 g/finger, is obtained experimentally.

## 1. Introduction

The collider of the KEK B-factory (KEKB) consists of two rings, High Energy Ring (HER, for 8.0 GeV electrons) and Low Energy Ring (LER, for 3.5 GeV positrons). The average beam currents for the HER and the LER are 1.1 A and 2.6 A, respectively. The designed bunch length ($\sigma_z$) is 4 mm for both rings, which gives the strict limitation on the impedance of vacuum components [1]. For easy installation and alignment, about 750 bellows assemblies are to be installed in each ring and, therefore, are likely to be one of large impedance sources in the ring. The RF-shield has a role to flow the wall current as smoothly as possible and reduce the impedance [2-4].

The main criteria in designing the RF-shield is to keep a good electrical contact while absorbing the expansion and contraction during the beam operations. Failure to meet this criteria will result in electrical discharge and possible melting on the contact point [5]. Large enough contact force without excess wearing is required, but there has been no practical data for the contact force so far.

A bellows assembly with an RF-shield for the KEKB collider has been specifically designed to meet these requirements. The RF-shield is a usual finger type but has a special spring fingers to press surely the contact fingers on to the beam tube. The wearing test was performed using a experimental model. To find the necessary contact force, furthermore, the heating of the RF-shield was checked transmitting 508 MHz microwave through the model. We report here the structure of the bellows assembly and these experimental results.

## 2. Structure

A schematic drawing of the bellows assembly for the LER is shown in Fig.1. The RF-shield is composed of three parts, a inner tube, a contact finger and a spring finger (slide finger). The contact finger is positioned between the spring finger and inner tube. Since the contact finger is outside of the inner tube, the impedance of the bellows assembly is kept very small. For 1 mm thick inner tube, for example, the calculated broad band impedance (Z/n) and the loss factor (k) of a bellows assembly are $4.23 \times 10^{-6}\ \Omega$ and $2.5 \times 10^{-3}$ V/pC, respectively for the LER. The electrical contact between the contact finger and the inner tube is ensured by the spring finger. Each spring finger is in contact with one contact finger with an appropriate force. The structure can be applied for not only the circular beam tube but the non circular one, such as racetrack or rectanglular shape. Cooling water channels in the drawing should be attached to absorb the heat flux due to the reflected synchrotron radiation power, the joule loss and the higher order mode (HOM) loss [3].

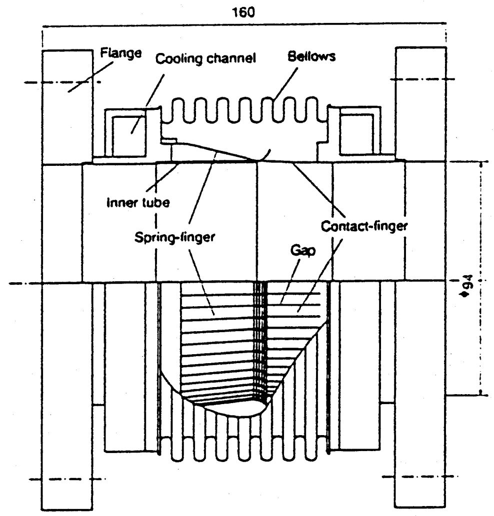


Fig.1. A schematic drawing of the bellows assembly

Figure 2 shows the outlook of an experimental model of the bellows assembly (without bellows). The model is for the LER and has a circular cross section. The inner diameter is 94 mm and overall length is 160 mm. The spring finger and the contact finger have thickness of 0.4 mm and 0.2 mm, and widths of 4.6 mm and 5.5 mm, respectively. The gap between each contact finger is 0.5 mm. In total 50 contact fingers surround the inner tube. RF-shield has a maximum expansion stroke of 20 mm and transverse offset of

1 mm. The inner tube has 1 mm thickness. Good elasticity is required for the spring finger to maintain sufficient contact force. Furthermore, high thermal conductivity is necessary for the thin fingers to avoid excess heating. Both the spring finger and contact finger are therefore made of Beryllium-Copper (C1720). The contact point of spring finger is coated with about 1 μm TiN to reduce wearing. Both the contact finger and spring finger were heat treated at 315 °C. All other parts of the bellows assembly including the inner tube are made of Stainless Steel (SS304).

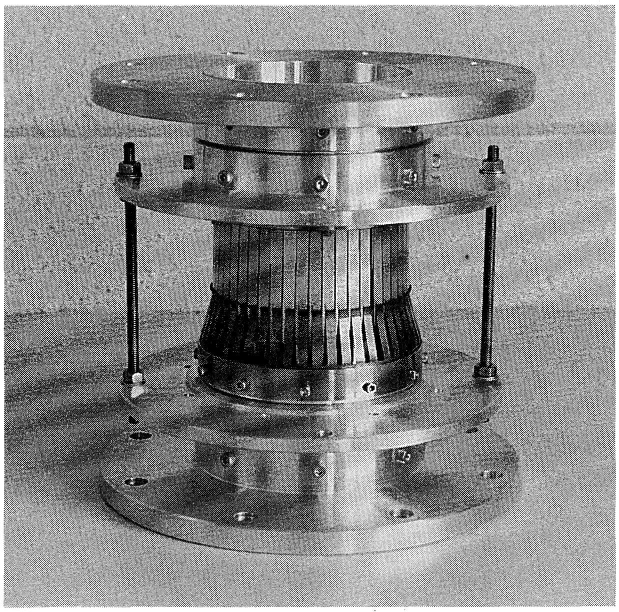

Fig.2. The outlook of an experimental model

## 3. Experiments

### 3.1 Mechanical test

Testing was carried out using a model with the same parameters described above under a pressure of $1 \times 10^{-2}$ Torr. The contact force per finger was set in the range from 150 g to 170 g. The RF-shield was expanded and contracted 5000 times over a stroke of 20 mm, which corresponds to 100000 times with a stroke of 1 mm that will be experienced by the real bellows assembly during 10 years beam operation. One stroke took approximately 10 seconds.

We observed finally no kinking or sticking of contact fingers and found no mechanical problem. However, metal particles due to the wearing of contact parts were observed. The mean size of particles was approximately 50 μm. Such particles have been found to reduce the beam lifetime or broaden the beam size when passing though or trapped to the beam [6]. Since the wearing is inevitable for finger type RF shield, the particle generation is one of the important problems in the present design. An approach to reduce the particle is to choose appropriate combination of the materials or the coatings for the contact finger, the spring finger and the inner tube. The wearing test is now undergoing for several promising materials such as inconel, titanium or hastelloy. The second effective solution is to choose a sufficient but not excess contact force. We have tried to find the suitable contact force experimentally as described in the following section.

### 3.2 Heating test

Excess heating at the contact points was checked by transmitting 508 MHz microwave for several contact forces using the experimental model. The microwave was applied because it can simulate more realistic wall current excited by the bunched beam than the DC current. The CW 508 MHz microwave was supplied from a 10 MW klystron used for the RF cavity of the TRISTAN Main Ring. The average and the peak beam current of LER are 2.6 A and 156 A, which are induced by 14.3 kW and 600 kW of 508 MHz microwave power, respectively. In the experiment the microwave power up to 80 kW was transmitted and was sufficient to investigate the heating due to the average beam current.

Figure 3 shows a schematic diagram of the experimental apparatus. A 50 Ω coaxial transmission line was formed using the model bellows assembly and a brass rod as an inner conductor. The transmission mode is TEM mode. The wall current, therefore, has only axial component that is just the same as the real wall current in the beam tube. The bellows model is similar to that descried in Sec.2 but has the length of 200 mm and the body of Aluminum alloy. Spring fingers under five different loads investigated, that is, load 1 (0 to 3g), load 2 (15g), load 3 (50g), load 4 (90g) and load 5 (160g). The bellows assembly is thermally isolated by a cover to simplify the experimental condition. The input power was increased in step of 10 or 20 kW and maintained at each power level for about 10 minutes. Temperatures were monitored using three thermocouples positioned at the inlet, at the middle and at the outlet of bellows assembly.

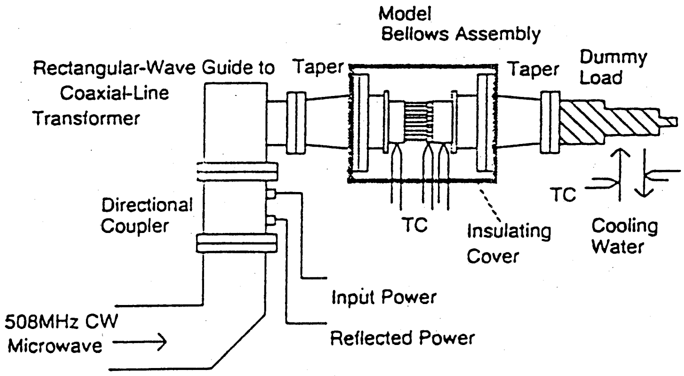


Fig.3. A schematic diagram of experimental apparatus

Figure 4 shows the increase rate of temperature (°C/sec) versus input microwave power. The temperature is the average of three thermocouples. The straight line is the result for the case of the minimum power loss, that is, without any contact resistance, calculated using the surface resistance and the specific heat of the model. From this figure it can seen quite clearly that abnormal heating occurs for the load less than 50 g/finger. To see more definitely the effect of contact force, the power loss per 10 kW input power is plotted versus the average contact force in Fig.5. Observation of the fingers after the experiments revealed arcing spots on the contact fingers with a load less than 50 g/finger.

From the results it can be concluded that the contact force larger than 50 g/finger is necessary to provide the sufficient electrical contact. Considering manufacturing and setting errors, however, the spring finger should be designed to provide the contact force of 100 g/finger at least. This value is much less than that in the mechanical test (170 g/finger), and the problem associated with metal particles may be reduced. Be careful, however, that the experiments were done in atmosphere where the water vapor in the air will work as a lubricant. Furthermore, the frequency of wall current in the experiments is far low compared to those in the real beam tube. The more realistic investigation will be necessary.

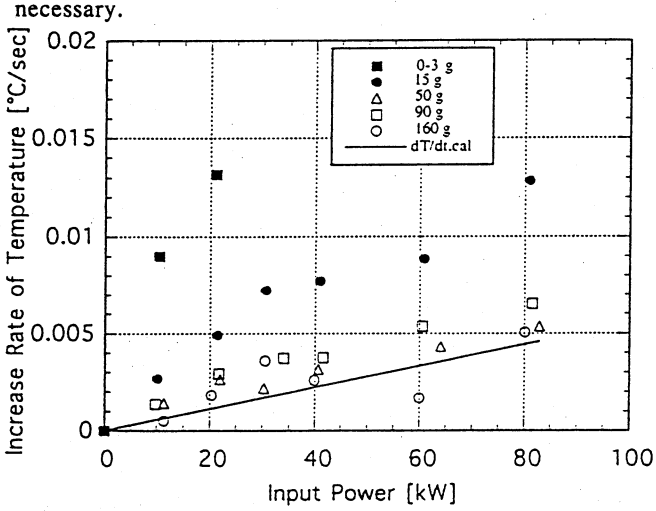


Fig.4. The increase rate of temperature (°C/sec) versus input microwave power. The straight line is the calculated minimum increase rate of temperature.

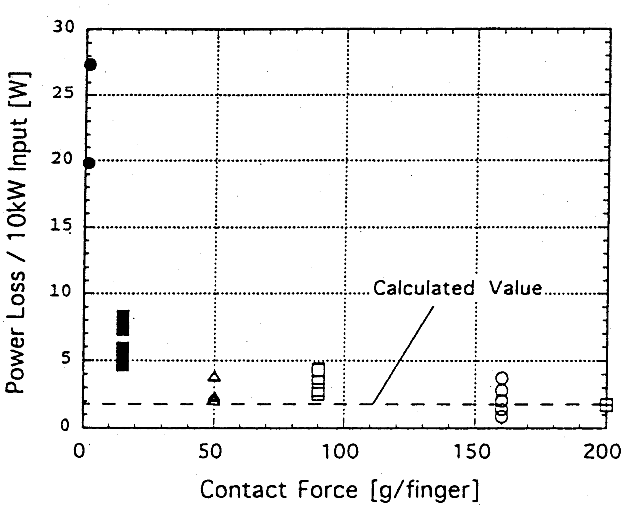


Fig.5. The power loss per 10 kW input power versus the average contact force. The dotted line is the calculated minimum power loss.

## 4. Summary

A bellows assembly with an RF-shield has been developed for the KEKB. The RF shield is a usual finger type but has the special spring fingers to press the contact finger without fail. The minimum contact force was investigated experimentally by transmitting microwave up to 80 kW though the bellows assembly in atmosphere. A contact force above 50 g/finger was found to be necessary to avoid abnormal heating. Considering manufacturing and setting errors, however, the spring finger should be designed to provide the contact force of 100 g/finger at least. A test using 2856 MHz microwave to check the arcing in vacuum is now in preparation. Further tests to find the best combination of finger materials will be also carried out in high vacuum.

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