DEVELOPMENT OF A BELLOWS ASSEMBLY WITH RF-SHIELD FOR KEKB

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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 a special spring-finger to press contact-fingers onto the beam tube. The minimum contact force is studied experimentally utilizing microwaves. A contact force of 50 g/finger is found to be necessary. The higher order mode (HOM) power leaked from beam tube into inside of bellows is estimated using measured coupling coefficients of the RF-shield and a computer simulation. The leaked power is expected to be 6 - 18 W and about 16 W, respectively, for the slit length of 20 mm, which are in the allowable range.

1 INTRODUCTION

Parallel to the overall design of vacuum system, a vacuum bellows assembly with RF-shield has been developed for the KEK B-factory (KEKB)[1]. The vacuum bellows absorbs thermal expansion and contraction of the beam tube during beam operation or baking. The RF-shield has to keep a good electrical contact while keeping smooth mechanical moving with high reliability.

The usual RF-shield is a finger-type which consists of many narrow sliding fingers around a beam tube to bridge the gap of bellows[2,3]. One of the key points for the finger-type RF-shield is the strength of the contact force. Each contact-finger should touch a beam tube with an appropriate contact force to keep a sufficient electrical contact against a high current with high frequencies. The leakage of the TE mode HOM from the beam tube into the inside of bellows is an inherent and another important problem of the finger-type RF-shield. The excess heating of contact-fingers due to the leaked power weakens the contact force and will cause arcing.

We developed a vacuum bellows with RF-shield of usual finger-type but having the special spring-fingers to press securely the contact fingers on to the beam tube. To find the necessary contact force experimentally, the excess heating was checked transmitting 508 MHz cw-microwave through a model. Arcing of the RF-shield in vacuum was also observed using 2856 MHz pulse-microwave. The estimation of the HOM power leaked into the inside of bellows was tried using the measured coupling coefficient of the RF-shield at a TE mode. The estimation was cross checked by computer simulation using the MAFIA code.

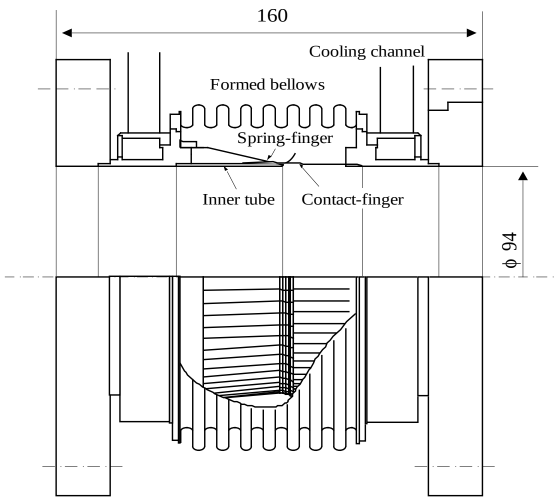

Figure: 1 Schematic drawing of the bellows assembly for the LER of KEKB.

2 STRUCTURE

For the KEKB, the bellows assembly should absorb the maximum stroke of 20 mm and the offset of 1 mm. The design lifetime is 10^5 times' expansion/contraction with 1 mm stroke. The bellows assembly designed for the LER of KEKB is schematically drawn in Figure 1 and the structure of the RF-shield is illustrated in Figure 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. Every spring-finger presses one contact-finger independently.

The contact-finger is 0.2 mm thick beryllium-copper alloy (C1720) and has the width of 5.5 mm and the gap of 0.5 mm. The spring-finger is 0.4 mm thick Inconel-625 and is coated with silver. The tip of the spring-finger has a curvature of 5 mm. The inner tube is 0.8 mm thick stainless steel (the tip is 1.0 mm thick) coated with silver and is surrounded by 52 contact-fingers. Other parts of the bellows assembly are made of stainless steel.

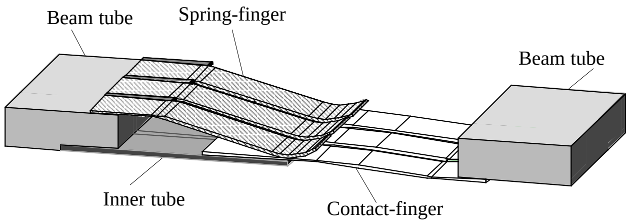

Figure: 2 Structure of RF-shield.

3 NECESSARY CONTACT FORCE

3.1 Heating test

We checked excess heating of contact points transmitting high-power microwave through an RF-shield model[4]. We utilized a 508 MHz klystron as a microwave source. The TE_{10} mode in the rectangular waveguide from the klystron was transformed to the TEM mode in the 50 Ω coaxial line by a coaxial coupler. The coaxial transmission line was formed by an RF-shield model (ϕ 94 mm) and another inner rod (ϕ 40 mm). The contact forces tested are (a) 150-170 g/finger, (b) 80-100g/finger, (c) 30-70g/finger, (d) 0-30g/finger and (e) 0-3 g/finger. The contact force was changed by installing the spring-fingers with different initial bending angles. The input power was stepped up by 10 or 20 kW up to 80 kW. The power was kept for about 10 minutes at each level and temperature rise of the model during it was observed. At 80 kW the RMS current density is larger by 2.3 times than that of the LER.

The power loss at the model estimated from the temperature rise per 1 kW input are shown in Figure 3, where the data are potted at the average contact forces. Abnormal heating was clearly observed for the cases (d) and (e), that is, less than 30-70 g/finger (50 g/finger in average). The broken line in the figure is the calculated power loss for the case without contact resistance. The results indicate that the contact force of 50 g/finger is necessary.

Actually the wall current is induced not only by the beam but also by the HOM inside the tube. We tried the same test at higher input power to check the margin for the contact forces larger than 50 g/finger. We transmitted the power up to 600 kW, where the RMS current density is 6.3 times larger than the case of LER. It was found that the contact force of 100 g/finger has a safety factor of about 6.

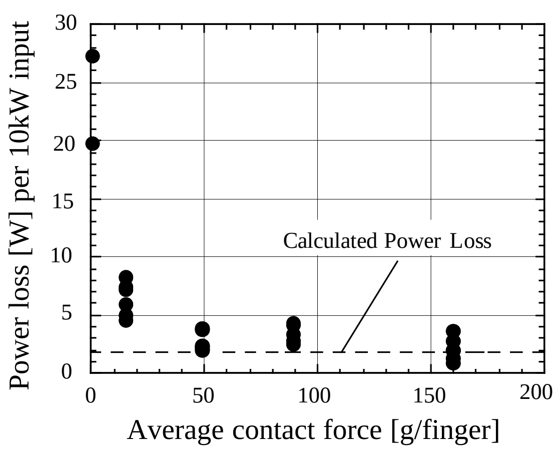

Figure: 3 power loss at the model per 1 kW input for tested contact forces.

3.1 Arcing test

We performed the arcing test in vacuum using a 2856 MHz pulsed microwave. The test stand is the resonant ring in KEK [5]. The RF-shield piece was set on a short waveguide in the ring. The number of fingers was 5. The width, gap and materials were the same as those used in the heating tests. The contact points were observed through a viewing port. The tested contact forces were about (a) 90 g/finger and decreased to (b) 60 g/finger, (c) 30 g/finger and (d) less than 10 g/finger.

We transmitted microwave up to about 10 MW. About 96 kW and 45 kW is enough to generate the equivalent peak current density and the electric field at wall to those in the LER, respectively. No arcing was observed at the contact points for the case (a) - (c). For the case (d) we observed arcing at the contact point at about 5 MW. The results indicate that the minimum contact force of 50 g/finger is sufficient even from the view point of arcing.

4 ESTIMATION OF LEAKED HOM POWER

4.1 Using measured coupling coefficient of RF-shield

The bellows model used has the inner diameter of 100 mm and the nominal length of 175 mm [5]. The length of the bellows section is 105 mm. The outer and the inner diameter of the bellows is 160 mm and 134 mm, respectively. In the measurement, two dummy tubes were connected to both sides of the model and formed a cylindrical cavity with a length of about 850 mm. The coupling coefficient of the RF-shield, β, was calculated from the Q values of the cavity.

At an appropriate bellows length, both the coaxial cavity inside the bellows and the cylindrical cavity had the same TE_{111} resonance frequency, which we call the matching frequency, f_{match}. Using the external Q, Q_{ext}, of the inside of cavity at f_{match} and the unloaded Q, Q_0, of the cylindrical cavity, the β was calculated from $\beta = Q_0/Q_{ext}$. The dependence of the β on the slit length, l_s, we measured by sealing the slits with narrow copper while keeping the f_{match} unchanged. The leaked power, P_{leak}, can be estimated by $P_{leak} = \beta/(1+\beta) \times P_{in}$, where P_{in} is the input power to the cylindrical cavity. The P_{leak}/P_{in} was plotted against the l_s in Figure 4.

For the first approximation, the P_{in} can be reasonably assumed to be the HOM power having the same frequencies with the TE mode resonances inside the bellows, P_{match}. The P_{match} is defined as the sum of HOM power with frequencies in the range $f_{te} \pm f_{te}/(2Q_{match})$, where f_{te} represents TE_{nml} mode resonance frequencies inside the bellows. The P_{match} is found to be about 40 % of the total HOM power for L_b = 60 - 80 mm, when Q_{match}

= 100 is assumed. Since the total HOM power is estimated as 70 Wm^{-1} for the LER, the P_{in} is about 30 W for 1 m beam tube. Otherwise, more safely, P_{in} may be assumed to be P_{match} between adjacent bellows assembly. In this case $P_{in} \approx 30\times3 = 90$ W. At the designed slit length of 20 mm ($P_{leak}/P_{in} \approx 0.2$), P_{leak} can be estimated as 6 W (18 W) for P_{in} = 30 W (90 W).

Care should be taken that following factors had been neglected in the estimation : (1) the real ring is not a cavity, (2) the HOM is not always TE mode, (3) the β of the RF-shield for higher resonance modes are not known and (4) the Q value of matching, Q_{match}, is also unknown for higher resonance modes.

The maximum temperature was calculated to be 64°C (ΔT = 34°C) at the tip of the spring-finger for P_{leak} = 6 W (the cooling water 30°C). The expected temperatures for l_s = 20 mm are in the tolerable range if the maximum allowable temperature is 150°C (= baking temperature).

4.2 Using MAFIA code

To make the estimation of the leaked power in the more realistic condition, a simulation was performed using the MAFIA code. The simulation model is shown in Figure 5.

The model tube has three bellows model ($b^{\#1}$ - $b^{\#3}$) and small dips ($d^{\#1}$ - $d^{\#3}$) as impedance sources. A Gaussian bunch with the length (σ_z) of 4 mm travels at the center of the tube with the velocity of light. The inner diameter of the tube is 94 mm. The bellows length is 80 mm and the outer diameter is 148 mm. The number of slits are 16 and the width is 3 mm, and the total slit width is almost the same as that of the real bellows. The loss factor (total energy loss) due to $d^{\#1}$, $k^{\#1}$, and the electro-magnetic energy inside the each bellows ($W^{\#1}$ - $W^{\#3}$) just after passing the bunch were calculated changing the slit length, where the loss due to $d^{\#2}$ and $d^{\#3}$ is compensated. Figure 6 shows the $W^{\#1}/k^{\#1}$ - $W^{\#3}/k^{\#1}$ for three slit length, l_s = 20, 30 and 60 mm. Although most of the leaked energy is found to leak into the first downstream-side bellows from the dip, the HOM energy leaks also into

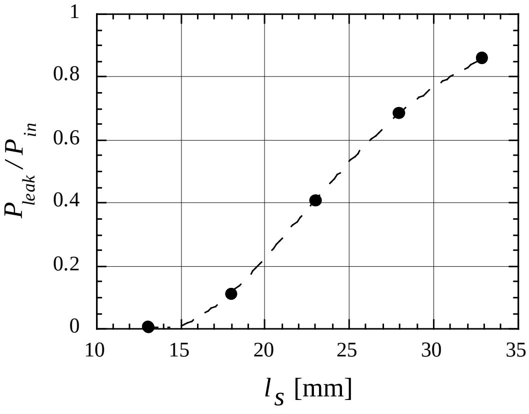

Figure: 4 Change of P_{leak}/P_{in} against l_s

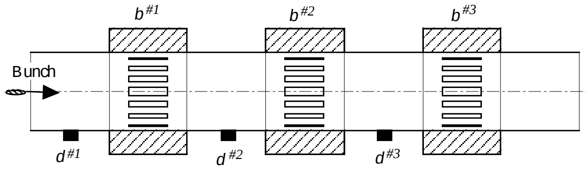

Figure: 5 Model tube for simulation.

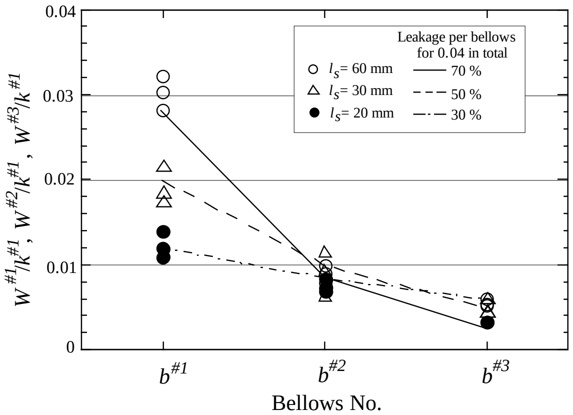

Figure: 6 $W^{\#1}/k^{\#1}$ - $W^{\#3}/k^{\#1}$ for three slit length, l_s = 20, 30 and 60 mm.

the subsequent bellows. The $W^{\#1}$ is larger for longer slit length. The total leaked energy ($W^{\#1}$ + $W^{\#2}$ + $W^{\#3}$), however, does not so depend on the slit length and is about 4 % of the total energy loosed by the bunch ($k^{\#1}$). Considering the bellows at up stream side of the dip in the ring, about 8 % of the total energy loosed by a bunch will be absorbed by bellows.

Since the total HOM power is about 200 kW in the ring and there are about 1000 bellows in the ring, the expected leaked power is about 16 W per one bellows. The estimated power is again in the tolerable range. This estimation was based on the single bunch calculation. However, if almost the leaked HOM energy in the bellows is absorbed during the bunch period (2 ns at minimum) the estimation is a good approximation.

ACKNOWLEDGMENTS

The authors would like to thank the members of TRISTAN Accelerator Division in KEK for their useful discussions and continuous encouragement.

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