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PRELIMINARY DESIGN OF RF-SHIELDED BELLOWS

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Abstract

A new design of RF-shielded bellows is proposed for the TPS to alleviate wake field effects and Joule heating resulting from contact resistance at the contact interface of sliding two dissimilar metals. Most efforts are put into controlling corrosion which is regarded as the main cause of electrical contact degradation. Rh-Au is chosen as a mating interface because they are stable under high temperature condition. Experimental tests are made to find an effective plating thickness of Rh and Au and to determine a suitable normal load applicable on the Rh-Au interface. A preliminary design of RF-shielded bellows that can sustain thousands of cycles during their lifetime is under testing.

INTRODUCTION

RF-shielded bellows are used to absorb thermal expansions during vacuum baking and to adjust for mismatches during vacuum chamber installation. Without RF shielding, charged particles would see cavity-like structures or abruptly changing wall dimensions which can trap electromagnetic fields around this imperfect location [1][2]. In addition, these electromagnetic fields, also called wake-fields, will act back on following charged particles possibly causing instabilities. Generally speaking, wake fields are harmful to stored beam quality and beam life-time and it is important to expose a smooth surface to the image currents of the charged particle beam rather than a corrugated structure when it comes to RF-shielded bellows (see Fig. 1). The structure of RF-shielded bellows must be flexible and hence a sliding contact configuration is used to preserve electric continuity. Sufficient force must be applied to the sliding contacts providing a contact resistance as low as possible and should not be affected by changes in the surface condition even after hundreds of relative motions. Based on the original structure, we propose a new design that changes the outside shell from formed bellows to welded bellows, reduces wake fields by lengthening the transition lengths and enhances electric sliding contact reliability through multiple contact points. Here, we address some key parts and main concepts for the design of RF-shielded bellows as shown in Fig. 2.

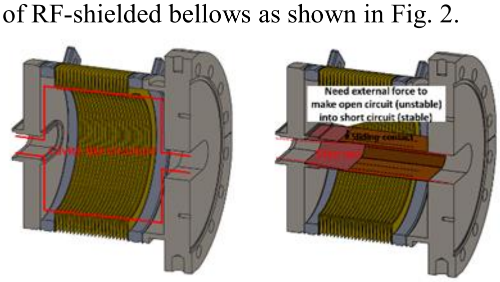

Figure 1: left without shielding; right with shielding.

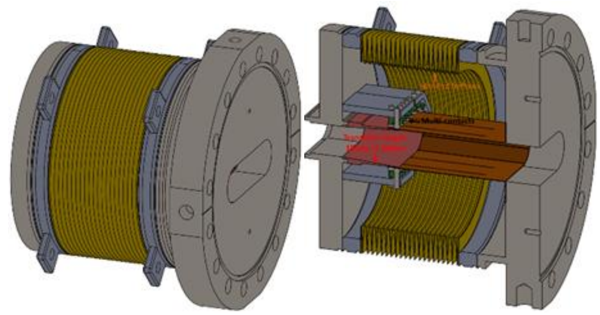

Figure 2: left outer view; right inner view.

RF-SHIELDED BELLOWS PARTS

Both welded bellows and formed bellows are usually used as an outer shell for RF-shielded bellows. The spring rate for welded bellows is about one order of magnitude lower than for formed bellows but formed bellows are more robust. Given the greater compressibility under limited space, we choose welded bellows since its compression could be as high as 20mm. For the RF-shielded structure, we double the transition length from 15mm to 30mm so as to reduce wake fields as seen in Fig. 3. The image current distribution is uneven because of the racetrack like vacuum chamber shape with an aspect ratio of about 4. Most of the image currents are concentrated directly on the top and bottom as shown in Fig. 4. A normal force (or pressure) is applied via a 3-4 mm ball which is connected to a spring and user-defined force to be adjusted by changing the spring length while the spring constant is about 150-200g per mm. Some special RF-fingers, especially on the higher current top and bottom, where considered to have more than one contact point, which can lower the contact resistance in addition to providing an insurance for continuing electric conductance when contact of one point deteriorates. The stainless steel stub is electroplated with Rhodium and the Copper based RF-fingers are Gold plated to obtain a reliable mating interface because Rhodium and Gold seldom bond to each other even at high temperatures. The detailed structure is shown in Fig. 5.

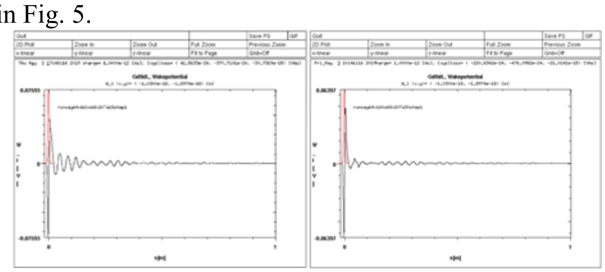

Figure 3: Wake field computation for 15 and 30mm taper length for the transition from 68x20 to 64x16 mm chamber cross section

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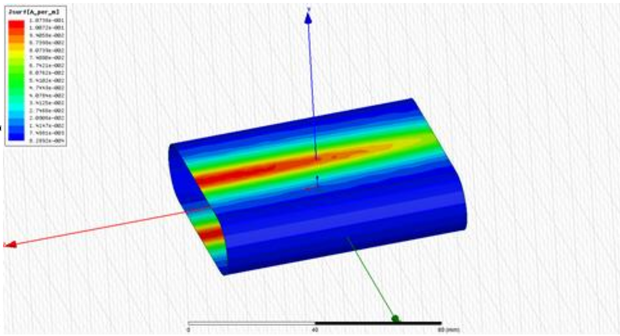

Figure 4: surface current distribution of a 68x20 mm chamber under 500MHz.

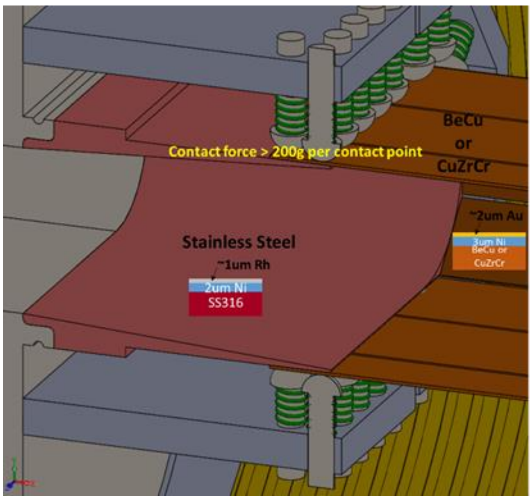

Figure 5: detailed view of the mating surfaces. The SS316L stubs are plated with Rhodium and the Copper fingers are plated with hard Gold.

CONTACT RESISITANCE AND TESTS

Low contact resistance is the major design criterium, especially for interfaces where large currents flow. Ohmic heating can degrade device performance and once that happens, it will never recover. The electric interface properties depend much on surface conditions. Applying forces (or pressure) could break oxide layers covering conductor surfaces and cause a decrease of contact conductance. Although large forces decreases contact resistance, it is not desirable for sliding contacts because large forces give only short-term stability instead of long-term reliability [3][4]. Plating can alter surface properties. For example, plating the base conductor with hard materials can enhance abrasion resistance and plating with high conductivity materials can improve contact resistance [5]. In our design, RF-fingers are plated with 2um hard Gold onto of a 3um thick Nickel underlayer which avoid the Copper atoms diffusing into the Gold matrix. The stainless steel stubs are plated with 1um Rhodium on a 2um Nickel underlayer. The small contact resistance could be measured via a four-wire method and instruments HIOKI RM3458 and Keithley 2450. First, the contact resistance under static conditions and applying varying forces is measured. Table1 shows the results. The absolute values of contact resistance depend on the mating geometry, machine capability and outer environment and therefore relative values are more meaningful. Although forces larger than 100g give an acceptable contact resistance, forces less than 180g are less reliable and, as a precaution, forces larger than 200g per contact point are therefore preferred. In the next step, contact resistance with relative movement is tested. Forces of 200g, 300g, and 400g per contact point are applied and recorded during 1000 back and forth stroke cycles as seen in Fig. 6; Although larger image currents could be tolerated by a smaller contact resistance, ohmic heat losses may determine the actual value of contact resistance. Usually, the thickness of RF fingers is about 0.3-0.5mm and they are made of high conductivity materials, so that a current of less than 1A would not cause overheating. If the stored beam current is higher, say several amperes, the issue of contact resistance is much more serious and one should take the thickness of the RF-fingers into consideration to prevent ohmic heating which might result in heat induced mechanical deformation. Thinner fingers are useful to compensate vacuum chamber assembling tolerances but they are likely to become deformed especially due to relative movement from external forces.

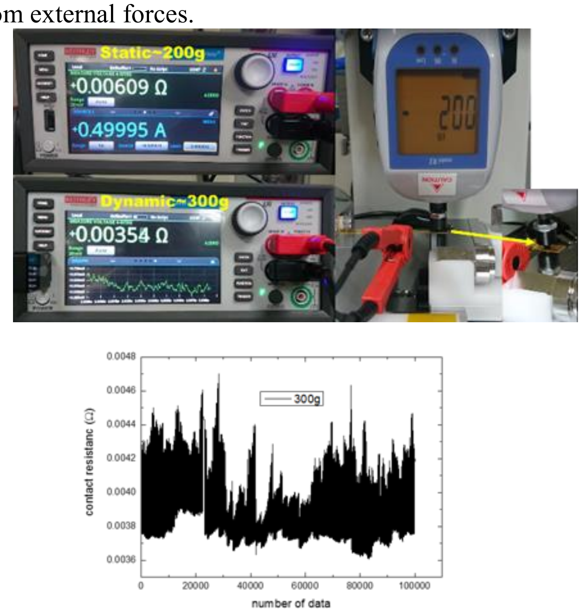

Figure 6: The top figure shows the experimental equipment and the lower graph shows the measured data when the devices are in continuous dynamic motion.

Table 1: Contact Resistance for Different Forces

mΩ	Run1	Run2	Run3
Free*	55	37	53
100g	11	12	14
200g	6.4	8.3	8.3
300g	3.5	3.6	3.9
400g	2.4	2.3	2.5
* : Sensitive to External Disturbance			

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DISCUSSIONS AND SUMMARY

The goal for the stored TPS beam current is 500mA. Serious wake field problems can be avoided as long as we avoid unwanted cavity-like geometries and preserve a smooth path for image currents inside the bellows. An increase of contact resistance in Rf-bellows by ageing can result in Ohmic heating which in turn can burn the electrical component. Detachable terminals, such as sockets, motors, connectors, etc., are rated by specifying safe currents and contact resistance for long term use. The sliding contact of RF-shielded bellows is something like a detachable terminal but is used in an ultra-high vacuum environment. The most important thing for the designer to know are the extent of the axial stroke, possible radial offset, maximum image current, and desired service life-time. Generally speaking, 10mΩ per contact point is very acceptable for a beam current bellow 1A. The question is how to maintain that 10mΩ through the whole service time of the RF-shielded bellows. Plating is an effective method, and creating as many contact points as possible is another way. However, increasing the contact points means increasing the overall force exerted on RF-shielded bellows and that impedes the flexibility of bellows. Based on current distribution, the high current density region is considered a high-risk region which can easily lose contact resistance especially in a dynamic state so multiple contacts are applied in such places. In our present design, 200-400g contact force per contact point is acceptable but more experimental checks should be made to choose more reliable values. In addition, the finger is 10-11mm wide in high current density regions and five contacts are made directly on the top and bottom instead of 1-2 contacts in other low current density places. The thickness of fingers is 0.3mm; BeCu 17410 and CuZrCr C18140 are selected as finger materials and plated with 2um thick hard Gold after they are shaped into RF-fingers. The mating stub is made of 316L stainless steel and plated with a 1um thick layer of Rhodium. Up to now, we've used some components and tested RF-finger sliding on the stub with different normal forces while monitoring the changes in contact resistance both under static and dynamic conditions. Although these tests give optimistic results, the mechanical strength of the fingers, having been through thousands of motion cycles and the artificial way to place the spring-loaded balls on the right place, are not very clear. Many studies and tests are still necessary to verify long term reliability.

Table 2: Specification of TPS Straight Section RF-Shielded Bellows

Axial Stroke	+5/-15 mm
Radial Offset	+ /- 1mm
Bend Angle	< 1 degree
Expected Life-time	> 1000 times

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