APS SR FLEXIBLE BELLOWS SHIELD PERFORMANCE *

J. Jones#, S. Sharma, D. Bromberek
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439 U.S.A.
J. Howell, Fermi National Laboratory, Batavia, IL 60510 U.S.A.

Abstract

The Advanced Photon Source (APS) storage ring (SR) consists of long rigid vacuum chambers connected by flexible formed bellows components. These SR bellows and additional diagnostic chambers are designed with leaf spring beryllium-copper (Be-Cu) alloy contact fingers that insert into mating rigid sleeves to function as electromagnetic shields. The shields protect the bellows convolutions from particle beam image currents and rf energy and reduce beam-induced rf resonances in the diagnostics chambers. The beam aperture of the shields is approximately the same as that of the beam chambers so that the beam impedance of the SR is minimized.

The bellows shields systems' thermal performance has been tested and is monitored during APS SR beam operations. Testing included infrared radiometer camera imaging and thermocouple instrumentation of the rigid sleeve. Direct results indicate that the liners perform well under all stored beam fill loadings through and including 100-mA, 8-bunch operations. Maximum temperatures of the bellows liner systems are typically 35-50° Celsius during standard 100 mAmp stored beam fills and 50-70° Celsius during fills, producing both maximum peak and total current simultaneously. The indirect observations of ring vacuum levels support the temperature data.

1 INTRODUCTION

The APS SR interchamber bellows and diagnostic components are protected from particle beam image currents with Be-Cu alloy contact fingers. These fingers function as leaf spring contacts where the contact force is generated from the deflection of the fingers as a flexible liner is inserted into a mating rigid sleeve. The contact fingers typically span the bellows convolutions, and during bake-out the fingers flex and slide within mating rigid sleeve liner components to accommodate the temporary chamber expansions. The contact fingers are of various lengths, widths, and thicknesses. The rigid sleeve components' outer surfaces are either exposed to atmosphere and convection cooled (see Figure 1) or contained completely within the ring vacuum (see Figure 2). This paper discusses the bellows shield systems' design, testing, monitoring, and performance during APS SR beam operations.

2 BELLOWS SHIELD DESIGN

In selecting the contact finger material, both operational performance and process temperature compatibility were considered. For the APS, the Be-Cu spring alloy UNS number C17200 was chosen for its relatively high electrical and thermal conductivities and for its very high yield strength that is not affected by the APS bakeout temperature of 150° Celsius.

The flexible bellows shields are fabricated from quarter-hard Be-Cu sheet that is easily worked in the pre-hardened condition. The Be-Cu sheet is partially slit into contact fingers by either wire electrical discharge machining of the 0.036-inch-thick material or chemical etching of material up to 0.020 inch thick. The cut finger

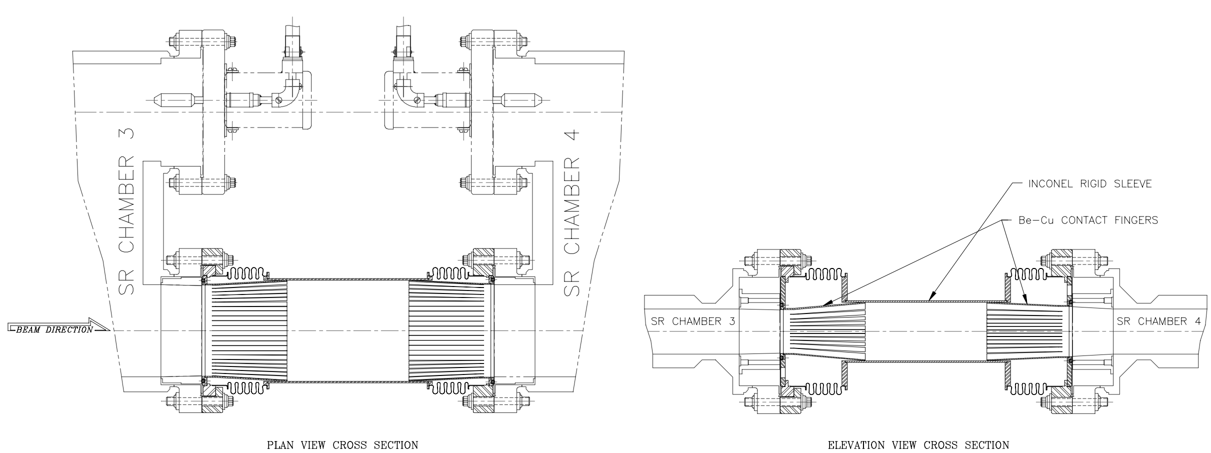

Figure 1: APS SR convection-cooled shield and bellows assembly

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# Email: jones@aps.anl.gov

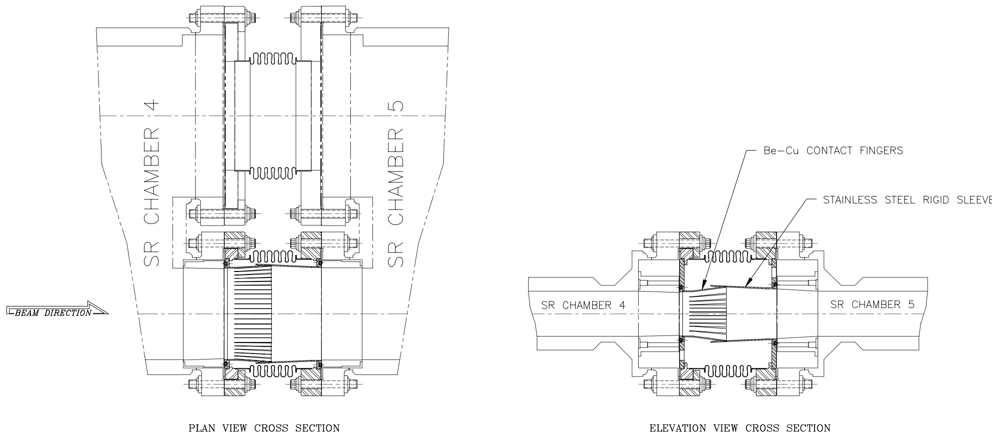

Figure 2: APS SR in-vacuum shield and bellows assembly

stock is then formed to the shape of the APS SR beam tube aperture. A similar aperture is machined into a copper disk that is used both to support the contact fingers and to capture a Be-Cu coil-spring gasket that ensures contact between the bellows shield assembly and the adjacent ring vacuum chamber component within the vacuum chamber flange enclosure. The two items are vacuum furnace brazed to form the typical flexible bellows shield assembly. After brazing, the Be-Cu contact fingers are fully solution hardened by heating at a temperature of 315° Celsius for two hours.

Specialized flexible shield assemblies employ 304 stainless steel mounting disks with the flexible shields attached by welding or screw fasteners. The mating rigid sleeve components are fabricated from Inconel® 625 or 316 stainless steel. The Inconel® rigid sleeves are an integral part of the ring bellows vacuum enclosure assemblies. As such, the exterior of the Inconel® rigid sleeves is in direct contact with air and is convection cooled. The stainless steel rigid sleeves are enclosed completely within the vacuum of the APS SR, and are primarily employed in the shortest bellows applications.

3 TEST AND MONITORING

The performance of both of the bellows shield designs has been monitored during SR beam operations. However, due to limited cooling, the vacuum-enclosed liner systems have been extensively tested and are continuously monitored during APS SR beam operations.

Testing included infrared radiometer camera imaging and thermocouple instrumentation of the rigid sleeve. The test set-up is shown in Figure 3. The infrared radiometer, an Inframetrics PM200, is capable of both thermal imaging of the contact fingers and rigid sleeve, and collecting and storing actual temperatures of the items in the image. A calcium fluoride, (CaF_2), infrared-transparent window is used to allow the imaging of the in-vacuum bellows shield components. The view into the window is shown in the inset of Figure 3. The Be-Cu fingers are coated with graphite to increase the emissivity of the metal surface to approximately 0.8. The radiometer is protected from radiation damage by a lead brick enclosure.

The optics include two front-silvered mirrors in a periscope arrangement in addition to the CaF_2 viewport. The thermocouples are type K, consisting of Chromel® and Alumel® wires. The thermocouple junctions are welded to the exterior of the rigid sleeve. Ten thermocouple junctions are evenly distributed across the lower perimeter of the rigid sleeve at the approximate location of the spring finger contacts. The individual thermocouple wires are insulated with binder-free fiberglass insulation. Two five-pair type-K thermocouple feedthroughs are employed to extract the thermocouple voltage, and an ion gauge is employed to measure local vacuum levels. The infrared radiometer set-up was used during one maximum peak current operation studies period, while the thermocouple instrumentation is a permanent installation.

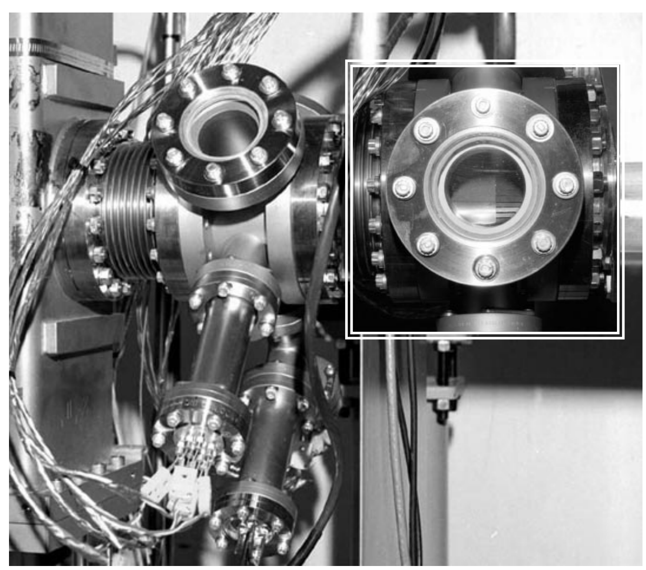

Figure 3: APS bellows shield test assembly

4 RESULTS

Results indicate that the liners perform well under all stored beam fill loadings through and including 100-mA, 8-bunch, 7-GeV operations. During the maximum peak current studies period, the operating mode was primarily high currents singlets fills. The highest observed temperatures were observed on the rigid sleeve components between the spring finger contacts location and the base of the sleeve. This was observed in the infrared imaging of the bellows shield assembly through the CaF_2 viewport. Also observed is the expected result that the peak heating occurs at the minor axis of the "elliptical" bellows shield assembly where the beam image currents are the largest.

Maximum temperatures of the vacuum-enclosed bellows shield systems are typically 35-50° Celsius during standard 100-mA stored beam fills, and 50-70° Celsius during fills producing both maximum peak and total current simultaneously. Plots of the bellows shield thermocouple data for the typical APS SR singlets 100-mA fill operations are shown in Figures 4 and 5; the reference beam-off cold temperature for this data is 28° Celsius. This data shows that the thicker 0.036-inch-thick Type I contact fingers run approximately 15° Celsius cooler than the 0.020-inch-thick Type II contact fingers under the same operating conditions. The difference is a function of both the finger contact force and the finger heat conduction area. Previous thermocouple measurements of the temperature of the convection cooled Inconel® rigid sleeve showed no significant heating. Ion pump ring vacuum monitoring supports the temperature data.

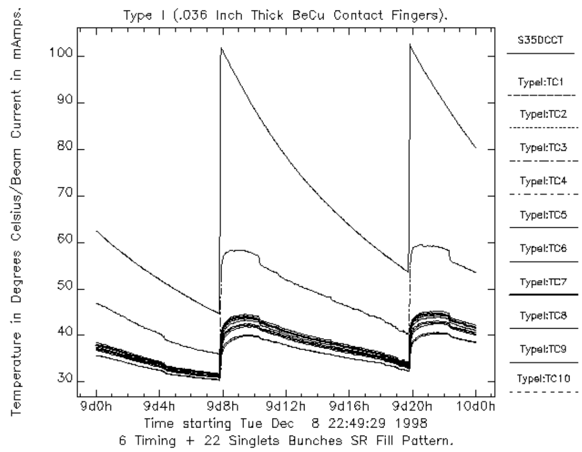

Figure 4: APS Type I bellows shield performance

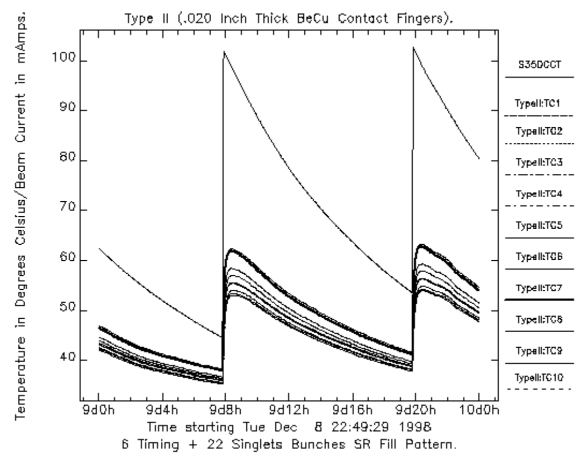

Figure 5: APS Type II bellows shield performance

5 CONCLUSIONS

First and foremost we conclude that the bellows shields are working very well under the present APS SR 100-mA current operations. The maximum operating temperature of 70° Celsius is well below the minimum annealing temperature of 176° Celsius of the Be-Cu alloy. At this temperature the contact fingers can be expected to provide positive contact force for an indefinite period of time. The indirect vacuum level monitoring and beam lifetime projections support this conclusion.

The future operating goals of the APS SR include continuous stored beam top-up and higher stored beam currents of up to 300 mA. As such, some improvements in the bellows shield design are being considered. The proposed rigid sleeve modification is to copper plate the stainless steel surface to reduce the electrical resistance. The thickness of the copper plating will be 0.0003-0.0005 inch, which is more than two times thicker than the 0.00014-inch copper skin depth of rf electrical currents generated by the fundamental frequency of the 352-MHz APS SR rf power system. All beam image current and rf resonant current resistive heating energy is expected to be deposited well within this skin depth.

The proposed modification to the flexible shield is to fabricate the spring contact fingers from Glidcop, which is alumina dispersion strengthened copper. Glidcop has nearly twice the electrical and thermal conductivity of Be-Cu and is much less susceptible to thermal aging and annealing. These improvements are being implemented in an ongoing machine development effort.

Finally, it must be stated that the convection-cooled bellows shield design is the preferred system but, due to SR real estate constraints, it is not always an option.

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