FINAL DESIGN AND MANUFACTURING OF THE PEP-II HIGH ENERGY RING ARC BELLOWS MODULE*

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Abstract

An update on the Arc bellows module for the PEP-II High Energy Ring is presented. Final design, manufacturing issues, material and coating selection, and tribological and RF testing are discussed. Performance and operational requirements are also reviewed. The RF shield design has been proven during assembly to allow for large manufacturing tolerances without reducing the mechanical spring force below required values. In addition, the RF shield maintains electrical contact even with large misalignments across the module.

1. INTRODUCTION

A novel RF shield bellows module developed at SLAC has been successfully manufactured and installed in the PEP-II High Energy Ring (HER). Tests indicate that the module meets its performance and operational requirements. The primary function of the bellows module is to allow for thermal expansion of the chambers and for lateral, longitudinal and angular offsets due to tolerances and alignment, while providing RF continuity between adjoining chambers.

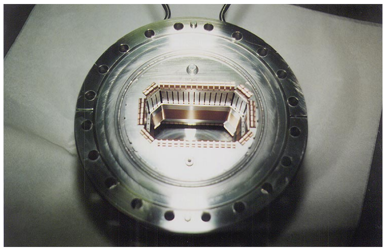

Figure: 1 HER Arc Bellows Module

To make a more robust design and reduce RF shield failure, a “double finger” mechanism was developed. This improves on previous designs by keeping high temperature areas away from high stress areas. The hot RF shield does not provide the contact force, but is held by lower temperature backing fingers. Alumina-dispersion strengthened copper (GlidCop®) and Nickel-chromium alloy (Inconel®) were the materials selected.

2. ARC CELL DESIGN

The HER circumference is 2.2km and stores 3000mA of 9GeV electrons [1]. The HER is hexagonal, with six arc regions 240 m in length and six straight regions 120m in length. A cell consists of two dipole magnets, separated by a quadrupole/sextupole doublet with 16 cells per arc. The dipole and quadrupole chambers are made from octagonal copper extrusions, and the bellows module bridges the gap between the dipole and the quad chamber.

3. DESIGN DESCRIPTION

The design employs a silver plated high conductivity GlidCop Al-15 RF shield finger which slides and makes electrical contact on the outside wall of a Rhodium plated GlidCop Al-25. This assembly preserves the chamber profile to create a uniform beam pipe. A welded bellows maintains vacuum and allows for travel with lateral offset.

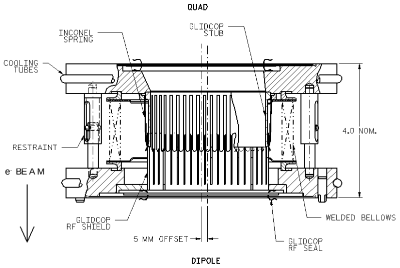

Figure 2: Bellows Module Assembly Drawing

The bellows module is designed to satisfy several key requirements. First, it allows for thermal expansion of an arc half cell. Table 1 lists the different scenarios for thermal motion. It is also requires that the module compress 19mm for installation. The major concern during installation is to consistently seal the flanges and to install the module without damaging the delicate RF seals on each end. In addition, a lateral offset of ±1mm and 25mrad of angular misalignment is required for fabrication and chamber alignment tolerances. Note that the lateral offset is limited by the welded bellows and not the RF shield.

Scenario Description	Travel	Cycles
Max. Compression, Installation	19 mm	100
Max. Extension,	1.3 mm	20
In-Situ Bake (150°C)	11 mm	10
Beam Off/On	5 mm	10,000
Filling	3.8 - 5 mm	200,000

Table 1: Thermal and Installation Travel Scenarios

Another primary function is maintaining a continuous chamber and electrical conduction path to minimize beam instability and impedance. RF shield failure could result in creating a cavity which produces a trapped mode. The RF shield fingers slide on the outside wall of the stub, which ensures that potential failure will not result in the fingers falling into the beam tube. The sliding joint produces an inward 1.5mm step which eliminates the potential for mode trapping. The size of the

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step is driven by two features: the mechanical stability of the stub wall and the rounded contact surface at the tip, which ensures that the shield finger will not make a secondary contact on the stub.

The module also required masking to be from intercepting a synchrotron radiation strike of up to 1170W/cm^2. An offset of 5mm between the Dipole and Quadrupole chamber was used to shadow the module with minimal change to the volume of the beam passage. The offset was produced by tapering the upstream flange. The module produces a calculated 0.061nH inductive impedance [2].

For every RF shield finger there is a mating Inconel 718 spring finger which applies an average of 170g of force to provide sufficient electrical contact. Previous RF shield designs had dual purpose fingers which served as both the spring and the shield. However, this is extremely difficult to implement successfully since conductive materials do not exhibit the mechanical properties of high temperature springs.

The conductivity of the materials used for electrical contact joints are key parameters in its current carrying capacity. Numerous designs in the past utilized Beryllium Copper (BeCu) for the RF shield. The thermal conductivity of GlidCop Al-25 is 90% of copper, and a factor of two higher than BeCu. Also, the mechanical properties of BeCu are extremely sensitive to the precipitation age hardening process conducted after forming. Due to the hardening process, BeCu is also susceptible to overaging, which significantly lowers the strength properties at slightly elevated temperatures. The yield strength of GlidCop is slightly reduced to 448MPa at 1000°C [3], which is the braze temperature for the RF shield sub-assembly. This decrease in yield strength is not sufficient to cause permanent distortion due to lateral offsets across the fingers. Stress relaxation at elevated temperatures does occur in GlidCop, but does not affect the contact force.

4. THERMAL/STRUCTURAL ANALYSIS

4.1 Thermal Loading

There are four primary sources of heat: 0.25 W/cm^2 scattered SR, 0.04W/cm^2 from ohmic losses, 0.07W/cm^2 from HOM Heating and localized heating due to high frequency and large image currents *in vacuo* from contact resistance. The total heat load applied on the inside perimeter is 0.36W/cm^2

4.2 RF Shield/Spring Finger

GlidCop was used for the stub and shield for its high thermal and electrical conductivity, its mechanical stability at high temperatures, and manufacturabilty. The temperature at the tip of the shield finger is balanced against structural loading. Thin shield fingers are stressed by the lateral and angular offsets across the module. Required finger length determined by the total travel of the module is 30 mm. The thickness and width of the RF shield is optimized to decrease tip temperature, keep the bending stress at the base below yield, maintain the force due to operational bending stress below 28g and prevent buckling. ANSYS calculations show that the cooling on the flange will keep the base of the majority of shield fingers at 65°C. The majority of the fingers could reach 91°C based on 0.5W/cm^2 of heat flux, with a few of the tip temperatures slightly exceeding 100°C. Test data indicates minimal stress relaxation in GlidCop at 300°C [3]. The consequences of a high tip temperature are reduced by the independent Inconel spring fingers. These isolate the high-temperature region at the ends of the shield fingers from the high-stress area at the base of the spring fingers.

When the module is fully compressed during installation and has a lateral offset of 1.3mm, the bending stress is only slightly below yield. If handled properly it would be difficult to apply the full lateral offset allowed by the module restraints. A 1.3mm offset during normal operation produces 83MPa stress at the root and less than 10g of force. This bending stress does not significantly affect the contact force because the spring fingers are 15 times stiffer.

Calculations indicate that the critical buckling force for the RF shield is two times higher than the load. Analysis assumed pinned ends and a coefficient of friction of 1 for Silver on Rhodium in vacuum. To confirm that buckling is not a problem in this design, a test at the worst case extension and highest load was performed. Buckling was not observed.

The pre-deflection on the Inconel spring applies 85 to 200g on the shield finger and is relatively insensitive to manufacturing tolerances. The bending stress at the root is nominally 60 percent of yield. Inconel 718 was selected for the spring because of its high strength, high temperature capabilities and ease of manufacture.

4.3 Stub

ANSYS calculations using a stainless steel stub and 1W/cm^2 heat flux produces a maximum temperature of 273°C. GlidCop Al-15 was used instead to increase the conductivity, which reduces the heat flux to 0.5W/cm^2 Calculations for the GlidCop stub produced an acceptable peak temperature of 45°C.

5. TESTING

5.1 Plating

Plating adhesion is critical for solid lubrication and for dust reduction. An acid etch test was used to confirm that the adhesion between the Rhodium and the base material was acceptable. No surface asperities were observed when the plating was brought to 500°C. The adhesion of the silver plating was also verified prior to and during manufacturing by firing the part at 900°C.

5.2 Sliding Joint Tribology

The tribology of the sliding joint *in vacuo* is a concern for three reasons: overheating or galling at the contact joint could cold-weld a finger to the stub, insufficient or excessive lubricity from silver plating could produce excessive dust, and plated surfaces could behave below expectation at elevated temperatures. Initial tests were performed at SLAC using 4.7mm of travel for 200,000 cycles. Forces from 55 to 200g were applied using various silver plating thicknesses at ambient temperature and 200°C. Results indicated that a combination of 5µm of rhodium plating on the stub and 13 µm of silver on the shield and produced an acceptable sliding joint.

Final cyclic testing was performed using the correct geometry, materials, and plating thickness. The fingers were cycled to traverse a distance equal to 150,000 cycles of 1.3mm travel. Qualitative analysis showed no indication of wear to the base metal and negligible dust production. The shield was plated with 13µm of silver and the Rhodium was plated with 2.5µm.

5.3 RF Contact Integrity

The integrity of the RF contact was confirmed for the full lateral, angular and longitudinal motion of the bellows module. No configurations were found where contact was lost between the finger and stub.

5.4 Welded Bellows Cyclic Testing

The lateral offset of the bellows module was limited by the cyclic lifetime of the welded bellows. Calculations indicated that the maximum allowable offset was only 0.76 mm. Results of cyclic lifetime testing found that an offset of 1.3 mm was acceptable.

5.5 Resonances in Bellows Module

Possible resonances of the bellows module were tested at LBNL by studying TE and TM modes propagating along the beam pipe. A poorly coupled TE mode resonance was found at 2.48 GHz. This resonance corresponds to a half-wavelength between the bellows flanges. It was estimated that only 20 percent of the propagating TE mode power will be lost to this resonance. Measurements showed no significant resonances coupled to the TM modes.

5.6 Power Testing

The goal of this test was to determine if the contact load is sufficient to transfer RF current without significant heating due to the contact resistance between the RF shield and the beam pipe. Previous experiments found that conductivity is an important parameter for high current carrying capacity across an RF joint [4]. The higher the conductivity, the lower the contact resistance and the lower the local temperature at the contact. A low temperature at the contact is desired to reduce cold welding of the two materials.

The test apparatus built at SLAC employed the Straight Section bellows module. The materials and contact forces of the RF shield fingers and stub plating were the same for the HER Arcs bellows module. Therefore, the test results pertaining to contact force and current carrying capacity is applicable.

The bellows module was subjected in vacuum to 1.5 times higher current than is expected at 3 A circulating current for PEP-II. The contact showed no signs of damage from this test.

5.8 Residual Gas Analyzer (RGA) Scans/Bake Out

RGA scans were performed to ensure that the part was compatible for ultra high vacuum. After 24 to 48 hours at 200°C, there were no peaks above mass 44. The bellows module showed no indication of mechanical failure or reduction of contact force.

6. MANUFACTURING

Minimal fixturing was necessary during final assembly of the bellows module. The springs were deflected away from the mating stub using dowel pins and the RF shield was inserted. The spring fingers went through numerous inspections during their manufacturing process to ensure that the pre-deflection was in the range needed for the spring force. All forces inspected were greater than 85g and the average was approximately 170g.

7. INSTALLATION

The inner chamber profiles from each end of the module were aligned using precision dowel pins, these pins were also used as datums to align the Dipole with respect to the Quad chamber. Furthermore, the pins aided in mating the RF Seals by reducing any transverse motion while being compressed between the two flanges. To mitigate potential problems during the early stages of installation, approximately 15% of the chambers were boroscoped for RF continuity.

8. FUTURE WORK

The HER Arc RF shield bellows module has been adapted for several different areas of the ring. Bellows for the Interaction Region are similar in design. The design has also been modified for a round chamber in the abort line and is currently being assembled. PEP-II is working on applying this design for the LER Arc bellows and the LER Straight Section bellows which will be installed at the end of this year.

9. REFERENCES

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