High Current RF Shield for PEP-II Vacuum System Expansion Joint*

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ABSTRACT

A novel RF shield was developed for the circular expansion joint used throughout the PEP-II vacuum system straight sections. Existing RF shield designs, used in accelerators/storage rings throughout the world, have been the source of many failures at beam currents much smaller than the 3 amps planned for PEP-II. This RF shield uses a unique spring-loaded finger mechanism to maintain proper electrical contact across the joint, accommodate 1.5 mm transverse and 32 mm longitudinal excursions, while minimizing geometry-driven trapped-mode RF heating at GHz frequencies. Alumina-dispersed, copper alloy fingers are used to maintain desired mechanical properties at higher temperatures instead of the more commonly used beryllium-copper alloys. A prototype expansion joint was assembled, mechanically tested, and subjected to 200% of the expected operational RF load. This RF shield design can be easily adapted to non-circular geometries.

1 INTRODUCTION

The PEP-II Asymmetric B Factory [1], requires approximately 275 circular expansion joints distributed throughout the straight sections in the High Energy Ring and Low Energy Ring. A bellows-type mechanism must provide mechanical decoupling due to thermal expansion while providing continuous RF coupling on the inside wall between the straight section vacuum chambers.

RF shield failures in existing bellows designs are common at beam currents an order of magnitude less than that required by PEP-II. Trapped modes induced by RF shield geometry or inadequate mechanical contact between the two parts of the RF shield used in some designs may induce the failures. The contact point is usually implemented using many individual “RF fingers” which are spring-loaded by the geometry or by using an additional spring element.

Some existing RF finger mechanisms are believed to be fundamentally flawed due to the synergistic effect of bending stresses and resistive heating at the contact point. Commonly used RF finger materials (i.e. Be-Cu) will relax and/or distort over time given a sufficiently high combination of stress at elevated temperature. This may reduce or even eliminate the spring contact force in an RF finger. Distortion in one or more RF fingers may also form an RF cavity producing additional HOM-induced heating. Whether from arcing or HOM heating, further increase of the RF finger temperature promotes further distortions and further heating resulting in a “run-away” failure of the RF finger.

These distortions can be minimized by a carefully designed RF finger geometry using suitably prepared surfaces at the contact point.

2 DESIGN FOR PEP-II

Figures 1 & 2 show the RF finger mechanism designed for use in the PEP-II vacuum straight sections. The unique “Curly-Q” feature at the end of the RF finger improves functional reliability by minimizing bending stresses at the contact point. During installation, any transverse offset induces bending stresses in the RF fingers. Bending stresses are reduced by a counter-acting bending moment induced by pre-loading the Curly-Q with an under-sized retaining band. This also rotates the end of the RF finger away from stub thus minimizing any likelihood of an undesirable secondary electrical contact.

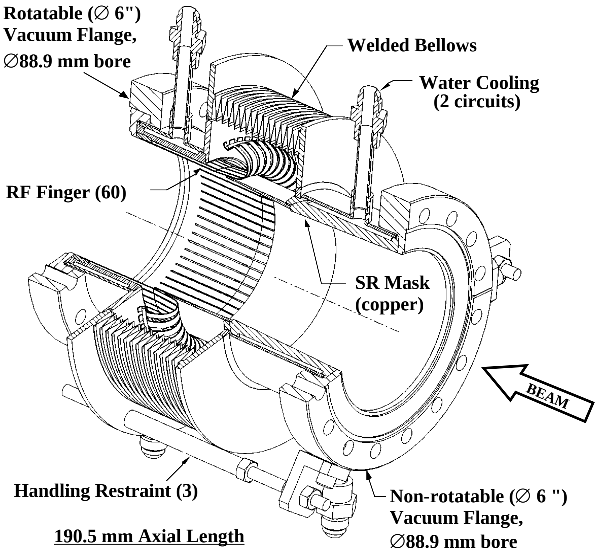

Figure 1: Cut-away of bellows module assembly.

The rigid retaining band is sized to provide a pre-load of 2 ounces (57 grams) minimum at the contact point

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during all operational excursions. The Curly-Q finger geometry keeps the retaining band and stub concentric ensuring even distribution of the load to each finger during axial and transverse excursions of the mechanism.

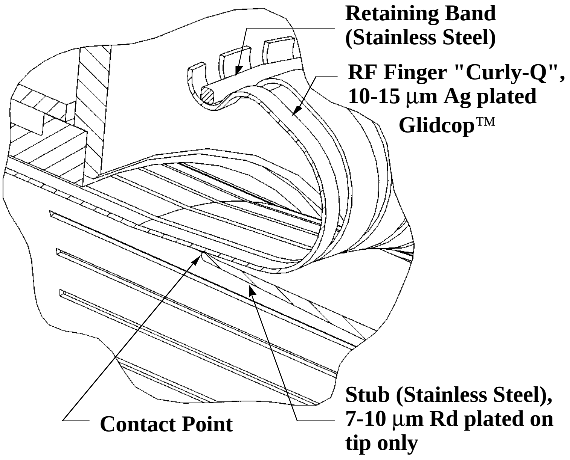

Figure 2: Close-up of RF Shield showing Curly-Q.

Choice of materials is another important factor in the design. The fingers are made from Glidcop™ [2], an alumina-dispersed copper alloy, which exhibits superior mechanical properties at higher temperatures than the more commonly used beryllium-copper alloys. An optimum plating specification has been developed for the contact point in PEP-II bellows used in both the arc and straight sections. The RF fingers (Figure 2) are silver plated while the high duty cycle surface on the tip of the stub is rhodium plated.

A water-cooled mask (Figure 1) shields the RF finger mechanism from synchrotron radiation. The upstream end of the RF finger mechanism is also brazed into the mask. The base of the RF fingers is e-beam welded to a water-cooled copper ring at the downstream end of the assembly.

The bellows module was designed to accommodate the following axial and transverse displacements during assembly, installation, bake-out, and operation:

Assembly and installation tolerance	±1.50 mm transverse, ±6.35 mm axial
In-situ bake @150°C	19.0 mm axial, 10 cycles
Operation Δ=20°C	2.54 mm axial, $2\mathrm{x}10^5$ cycles
Total	**32 mm axial** **1.5 mm transverse**

3 RF FINGER ANALYSIS

Three features of the Curly-Q, shown in Figure 3, control the bending stresses: Curly-Q pre-compression, τ; finger tip flare, ζ; and Curly-Q rollback, α_π. Curly-Q pre-compression is the differential between the ID of the rigid retaining band and the "free state" of the Curly-Q. The finger tip flare occurs between α_bL and L along the length of the RF finger. The Curly-Q rollback defines the location (α_πL) of the rigid retaining band on the Curly-Q.

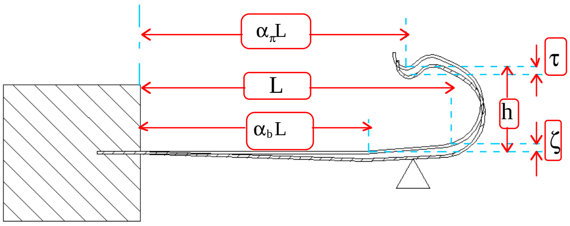

Figure 3: RF finger Curly-Q configuration.

In addition to the constraints described previously, the stress relaxation characteristic of the RF finger material must also be considered. All together, four constraints must be satisfied:

1. the contact force for any individual finger must ≥2 ounces over the operational excursion band;
2. secondary electrical contact must not occur during operation (permitted during bake-out);
3. bake-out bending stresses ≤ 49 ksi[1];
4. operational bending stresses ≤ 40 ksi[2].

The two design stress limits are indicated in Figure 4 along with the thermal excursion bands for both operational and in-situ bake-out modes. (The axial installation tolerance is included in the excursion bands.)

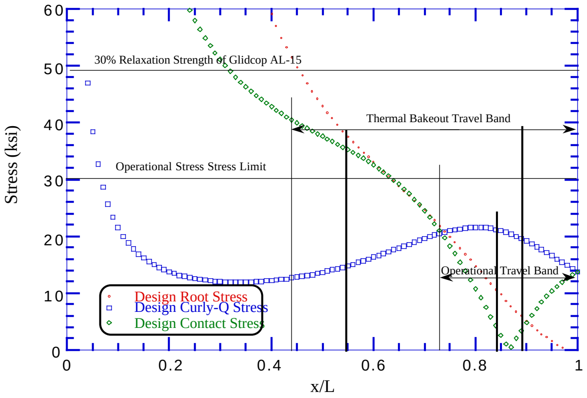

Figure 4: Critical bending stresses in RF finger at the contact point (normalized to finger length).

4 MECHANICAL TESTING

A series of mechanical tests were conducted on prototype components to validate the analytic models and identify any long term affects of extended cyclic loading. In a test conducted on the prototype assembly, only two measurements could be made on the RF fingers due to testing constraints: contact load at the tip of the Curly-Q (near the rigid retaining band) and tip displacement. Experimental measurements for the maximum load at the Curly-Q tip are compared to an FEA model and a beam model in Figure 5.

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[1] Yield strength de-rated 30% at 150°C for 100 hours [2]

[2] Yield strength for infinite exposure at 100°C [2]

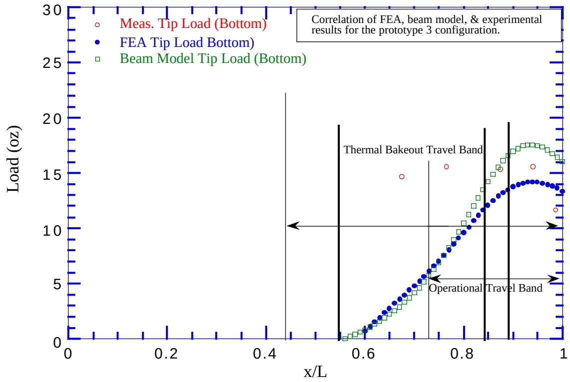

Figure 5: Correlation of experimental and analytic tip load vs. contact position (normalized to finger length).

The Curly-Q geometry in the prototype differed slightly from the "production" design causing secondary contact to occur at a point closer to the end of the RF finger. Nonetheless, the two analytic models predicted the prototype finger behavior very well over the critical operation region prior to secondary contact. Further engagement after secondary contact results in a relatively constant tip load (not included as part of either analytic model).

The RF finger mechanism geometry, materials, and attachments were tested to 200,000 cycles to assess any potential mechanical failure modes. The test fixture distorted during operation inducing transverse offsets greater than the 1.5 mm intended. Nonetheless, the e-beam weld joint at the base of the fingers endured bending stress greater than design requirements with no indication of degenerative wear or micro-cracking. Cyclic testing (in vacuum) of the plated surfaces at the contact point is planned for the "production" design.

5 RF TESTING

An RF test was devised to simulate the maximum RMS power generated at the contact point in the RF finger mechanism. Figure 6 shows the test fixture.

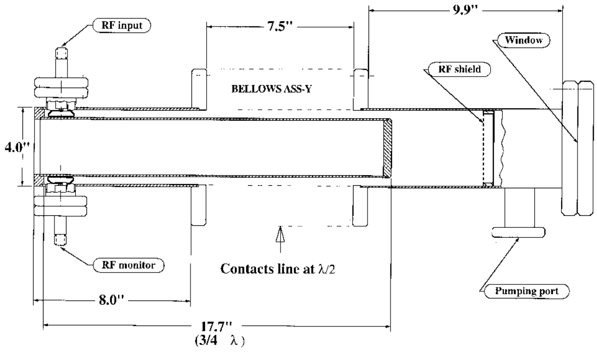

Figure 6: Schematic of RF test simulator.

The prototype bellows is mounted in the test section of a 3/4λ resonate cavity so that the contact point of the RF finger mechanism is located at the λ/2 location. Thus, the contact point is subjected to the peak current generated in the RF test simulator. At nominal test conditions, the simulator supplied 106 W of RF input to achieve the 1.9 W/cm power dissipation expected at the contact point during PEP-II operation for 3 A beam current [3].

The prototype was successfully tested at >200% of the nominal operational load while being articulated through axial and transverse offsets. There was no visual evidence of arcing during more than 200 hours of testing nor was there any damage upon post-test inspection. Future testing at Lawrence Berkeley National Laboratory will look for any potential HOM-excited trapped modes as the prototype is articulated in the axial and transverse directions.

6 CONCLUSIONS

This Curly-Q RF finger concept lends itself to other more complex beam pipe geometries as shown in Figure 7, examples "A" and "B". (Sharp corners are not a problem as long as the RF fingers are carefully arranged around the corner.) However, this design will not work for the re-entrant portion of the beam pipe geometry in example "C; the tips of the RF fingers would interfere with each other.

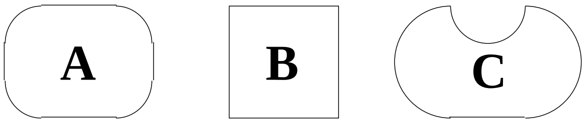

Figure 7: Examples of other geometries.

Analysis, mechanical tests, and RF power tests of prototype components have demonstrated the reliability of a bellows RF shield tailored for the PEP-II vacuum system straight sections. The unique RF finger geometry adopted here should be more resistant to the failure modes seen in some existing RF shield designs.

7 ACKNOWLEDGMENTS

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