SLAC-PUB-95-6993
August 1995
CONF-950512--364

A ZERO-LENGTH BELLOWS FOR THE PEP-II HIGH-ENERGY RING*

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Due to beamline space constrictions and the modular design of the vacuum system. a conventional bellows can not be used everywhere in the PEP-II High-Energy Ring (HER) arcs. A zero-length "Flex Flange" was developed which actually performs better than a more standard bellows. The Flex Flange fits the space available while still preserving the modularity of the system. Furthermore, the design provides for an accurate match-up between adjoining octagonal copper chambers despite the large fabrication and assembly tolerances and high operational loads. Beam chamber continuity is ensured by an integral RF seal ring which is easy to install and fault-tolerant. Heating from synchrotron radiation and higher-order mode trapping is managed to ensure a robust connection despite the 3000 mA beam current of the PEP-II HER. The Flex Flange concept is versatile and adaptable to many applications. yet economical both in space needed and cost.

INTRODUCTION

The HER circumference is 2200 m and consists of six straight sections 120 m in length and six arc sections 240 m in length. Each arc contains 33 quadrupole magnets and 32 dipole magnets to form 16 cells per arc. The HER vacuum system design[1] is comprised of 33 quadrupole and 32 dipole vacuum chambers, made from extruded OFE copper, and positioned in the magnet gaps for each arc totaling 198 quad chambers and 192 dipole chambers.

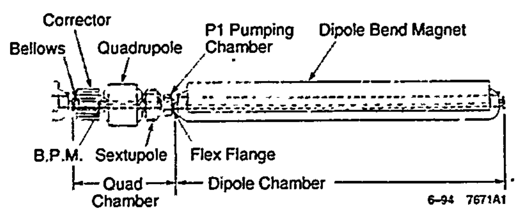

Figure 1. HER Arc Half Cell

The need for the Flex Flange arises from beam line space constraints. cost effective manufacturing tolerances and the overall length of the dipole chamber. The distance between the quadrupole and dipole magnets in the Arcs leaves only 0.31 meters of physical space between the magnet coils. A pump chamber with attached 60 liter per second ion pump occupies the majority of that space including the necessary space for flange bolts. The joint is large enough only for a pair of 8" Conflat flanges. The prototype experience showed that the minimum pratical angularity tolerance for welding a Conflat flange to a chamber is ±4.35 mrad. Without elaborate and costly machining and fixturing. the total angular misalignment of two chambers across a flange pair is 2 x 4.35 = ±8.7 mrad (±0.5°). This angular misalignment would produce a 51 mm offset at the opposite end of the 5.84 m long dipole chamber. The force needed to push the chamber back on beamline would induce bending stresses great enough to yield the EB fillet weld on the flange adapter.

Such attention to tight flange angularity is not necessary for more coventional chambers. A comparison to the HER Straight Section drift chamber is shown below. The drift chamber is a stainless steel tube that can be approximated as 101.6 mm OD x 3.2 mm wall (4" OD x 1/8" wall). A cantilevered beam model is used to estimate the stresses that would result from displacing the free end 51 mm.

	HER Arc Dipole Chamber	HER Straight Drift Chamber
E, Modulus of Elasticity	120 Gpa (17.4×10^6 psi)	207 Gpa (30×10^6 psi)
I, Moment of Inertia	9.87×10^6 mm^4 (23.7 in^4)	1.21×10^6 mm^4 (2.9 in^4)
σ_{yield} , Material Yield Strength	70 Mpa (~10 ksi)	241 Mpa (~35 ksi)
σ_{weld} , Bending Stress in Weld	254 Mpa (37 ksi)	90 Mpa (13 ksi)

Table 1. Comparison of Weld Stress in Copper and Stainless Steel Beam Pipes

The table shows that. while a stainless chamber could endure such lateral offsets and stresses at the weld root, the copper chambers cannot. The material strength of the stainless tubes in the straight section eliminates the flexible joint requirement. A flexible connection, however, is needed in the arcs to avoid the possibility of yielding the vacuum seal joints.

DESIGN REQUIREMENTS

The space limitations and flexibility requirements form a subset of a larger collection of design requirements for the flange joint which include ultra high vacuum

Work supported by Department of Energy Contract DE-AC03-76SF00515

compatibility. low beam impedance, thermal management and chamber support system issues. These requirements were developed as the vacuum system design proceeded from conceptual to final design.

Space Constraints	Minimize Z space
Flexibility	Allow ± 0.5° of Pitch Allow ± 0.5° of Yaw No XYZ Displacement No Roll
Vacuum	Reliable UHV Seal to 1 nTorr
Low Beam Impedance	Accurate XY position Steps ≤ 1.5 mm across flange joint Electrical continuity across joints
Thermal Loads	Maximum of 1 W/cm^2 due to : Scattered Synchrotron Radiation (SR) Resistive Losses Higher Order Mode Heating Contact Resistance Heating
Structural Loads	Gravity, Vacuum and Earthquake Loads Torsion due to Chamber Twist

Table 2. Flex Flange Design Requirements

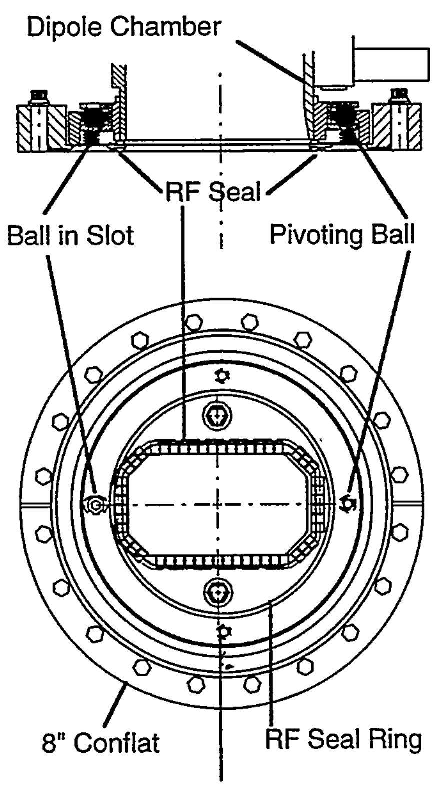

Figure 2. Flex Flange Assembly with Integral RF Seal

DESIGN DESCRIPTION

The design employs a ball bearing that is captured in the Z direction to provide the pivoting motion for the flange. The pivot is at the three o'clock position coincident with the SR stripe. A second ball bearing in a slot at the nine o'clock position sets the minimum and maximum yaw. A pair of pins at six and twelve o'clock in oversized holes sets the minimum and maximum pitch. The assembly contains < 0.12 mm of "rattle" due to tolerances on the ball-bearing-to-slot location fit. A flexible bellows is welded to stainless rings on the mechanical assembly with minimal offset. This assembly, containing all parts except the knife-edge flange and RF Seal, is positioned with tooling and EB welded to the end of the chamber perpendicular to the chamber centerline within 0.25°. An 8" Conflat flange is then welded within 0.25 mm of its ideal location to the end of the chamber. Finally, the RF Seal is accurately positioned with respect to the chamber inner octagonal profile and mounted to the flex flange. A pair of alignment pins locate the flanges accurately during installation to ±0.25 mm. These mechanical assembly tolerances were verified during prototyping.

Mechanical Loads

The Flex Flange assembly is designed to accomodate the structural loadings due to gravity, vacuum, earthquake (EQ) and external support loads.

Axial	Vacuum Load	± 1780 N (± 400 lb)
	Chamber Friction	± 134 N (± 30 lb)
	EQ	± 1691 N (± 380 lb)
Vertical	Chamber Weight	- 267 N (- 60 lb)
	EQ	± 134 N (± 30 lb)
Lateral	EQ Load	± 623 N (± 140 lb)
Twist	Removing Extrusion Twist	± 136 N•m (± 100 ft•lb)

Table 3. Flex Flange Mechanical Loads

The loadings imposed by the external supports are conservative. They include frictional forces and the moment imposed by twisting the chamber as required to rotationally align the octagonal cross-sections of the mating dipole and quadrupole chambers.

The ball bearings experience the highest forces due to the combined vertical loads and chamber twist. These forces are not high enough to cause Brinnelling to occur in the countersink bearing area. Pull-out is not a problem since the bearings are seated in countersunk holes and restricted from large XY deflections by the pins in the assembly.

RF Seal

The integral RF seal ring provides electrical continuity between chambers. Crushable fingers made of GlidCop® (chosen for its thermal and structural properties) are employed to accomodate the variations in gap width between chambers. Sets of finger stock are brazed with 35/65 Au-Cu braze alloy to a stainless plate containing the octagonal inner profile of the vacuum chamber. The seal is positioned within 0.5 mm of the SR impingement surface and fastened with a pair of bolts. The seal is not reusable, much like a knife-edge flange gasket.

It is extremely important that the RF seal is shadowed from direct synchrotron radiation. The seal can conduct the relatively low heat load of 1 W/cm^2, but cannot survive the 2000 W/cm^2 direct SR strike. This extremely high heat flux would cause the seal to fail catastrophically.

Material	GlidCop®
Finger Width	4.06 mm (0.160")
Finger Thickness	0.15 mm (0.006")
Number of Fingers	52
Contact Force per Finger	>200 grams (0.44 lb)
Nominal Gap	5.87 mm (0.231")
Maximum Gap	7.44 mm (0.293")
Minimum Gap	3.96 mm(0.156")
Number of Crushes per Seal	1

Table 4. RF Seal Design Parameters

The gap between the end of the dipole and quadrupole chamber is affected by many tolerances. While the nominal value is 5.87 mm (0.231"), tolerances on piece parts, subassemblies and tunnel installation can cause the gap to vary around the circumference of the octagonal profile by as much as ~3.5 mm (0.138"). The total compression of the seal is divided between the two chambers at about 50%. This means that the seal is precompressed ~1.25 mm when mounted to the inside of the Flex Flange assembly on the end of the dipole chamber. Stacking tolerances during installation may cause the gap to increase or decrease slightly. Even at the largest expected compression, residual contact forces equating to 0.75 mm (0.030") of springback have been verified through testing. This springback ensures that no finger lift-off can develop during normal operation.

Flex Flange Bellows

The bellows are made by MetalFab to their clean specification and may be vacuum fired to meet SLAC's stringent vacuum requirements.

The bellows remains static except during installation to accomodate pitch and yaw of the flange pair. Thermal expansion of the chamber is taken up by the bellows module[2] at the opposite end of the chamber. The only thermal expansion that the Flex Flange bellows must accomodate is the thermal growth of the flange pair, which is negligible. The axial stroke specified reflects the reliability requirement for the UHV seal. The assembly only allows a rotational stroke in pitch or yaw of one bellows end plate with respect to the other. The entire bellows never experiences the full axial stroke during operation.

Outer Diameter	137.2 mm (5.400 ")
Inner Diameter	120.7 mm (4.750 ")
Stroke	3.05 mm (0.120")
Offset	0.13 mm (0.005")
Number of Cycles	5,000
Temperature Range	35 - 150 °C
Convolution Material	SS 304L
End Plate Material	SS 347

Table 5. Flex Flange Bellows Design Parameters

FUTURE WORK

During the ramping to full production, a pre-production module will be assembled and mechanically cycled to ensure performance of the Flex Flange bellows and the RF seal assemblies. The module will be tested to evaluate the impedance contribution of the RF seal and investigate possible higher order mode effects.

CONCLUSION

The Flex Flange design developed for the HER Arcs meets or exceeds the physics and engineering requirements imposed upon it. The concept is adaptable to many applications.

REFERENCES

[1] Vacuum System Design for the PEP-II B Factory High Energy Ring, C. Perkins et al, EPAC94, London, England, June 27 - July 1, 1994.

[2] Bellows Design for the PEP-II HER Arc Chambers, M. Nordby et al., Particle Accelerator Conference, Dallas TX, May 1-5, 1995.