ULTRA-HIGH VACUUM SEAL FOR LONG CHAMBERS USING WIRE SEALS*

H. Fernandes#, P. Cappadoro, T. Corwin, D. Harder, P. He, C. A. Kitegi, W. Licciardi, M. Musardo, G. Rakowsky, J. Rank, C. Rhein, and T. Tanabe,
National Synchrotron Light Source II, Brookhaven National Laboratory, Upton, NY 11793, USA

Abstract

As the length of insertion devices (ID's) increase for synchrotron light sources, so does the need to have larger ultra high vacuum (UHV) sealed chambers, which in turn necessitates the use of creative ways of sealing these large chambers in the UHV range (10^{-11} torrs).The method specified below was used to seal a 4-meter test vacuum chamber successfully in the ultra high vacuum range. This method could be used for sealing ID chambers of lengths larger than 4 meters in the UHV range due to its simplicity and reduced cost advantage. This test chamber was also baked for 3 cycles to check for the integrity of the seals and final vacuum levels.

INTRODUCTION

The ultra high brightness NSLS-II storage ring is under construction at Brookhaven National Laboratory. It will have 3GeV, 500mA electron beam circulating in the 792m ring, with very low emittance (0.9nm.rad horizontal and 8pm.rad vertical). Significant increases in brightness requirements for the third generation ID has led to increased length of ID and hence increased length of vacuum chambers. The wire seal method outlined below depicts a way of sealing these long vacuum chambers in a cost efficient way. Other sealing methods for chambers such as Helicoflex ™ seals, metal gaskets, metal O-ring seals and differential pumping methods were studied as potential sources for sealing large vacuum chambers (>2.5 meters) [4]. Of these methods, only the wire seal made it to manufacturing, testing and optimization; the other methods were ruled out due to their high cost, difficulty in manufacturability by vendors due to low production quantities, or failure to meet UHV requirements in terms of operational efficiency and difficulty in installation. The wire seal was able to seal a 4-meter-long vacuum chamber in the UHV range and was also able to maintain the same vacuum specifications during and after baking. Here, we outline the procedure used to seal a 4 meter test vacuum chamber, specify the test results for this chamber, and mention possible methods to improve the wire seal.

TEST CHAMBER CONSTRUCTION SPECIFICATIONS

The seal was tested on a 4-meter test chamber that had a modular design. This design reduces the cost of the R&D chamber to a minimum, as it consists of mainly steel plates. The modular design of the vacuum chamber consists of a base plate as shown in Figure 1. A spacer plate has grooves cut for o-ring seals, which are placed between the front plate and the back plate. The distance between the front plate and the base plate is 0.75". This is maintained to a minimum in order to keep just enough room for bowing of the chamber inwards.

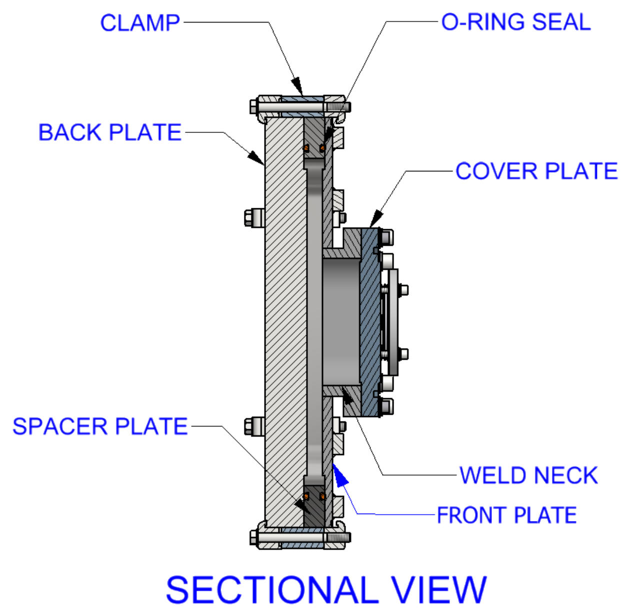

Figure 1: Construction details of test chamber.

O-ring seals were used on either side of the spacer plate to seal the spacer plate with the front plate and back plate. A weld neck was welded onto the front plate. During the first phase of the testing procedure, the top surface of the cover plate and the mating face of the weld neck were polished to 32 micro-inches surface finish because a wire seal would be placed and tested on this surface. During the second phase of the testing procedure, the two mating surfaces were polished to a 16 micro-inch surface finish. The length of the testing surface for the wire seal is approximately 3.6 meters. The entire vacuum chamber from end to end is 4 meters, as shown in Figure 2 below. Stiffening ribs were welded onto the surface of the front plate toward the cover plate. The main reason for the stiffening ribs was to have a chamber with adjustable stiffness which could be either increased or decreased by inserting stiffeners along the length of the stiffening ribs.

ISBN 978-3-95450-138-0

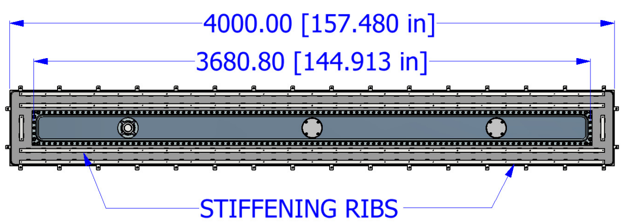

Figure 2: Construction details of test chamber.

In order to seal the face, it is essential to have a regular bolting pattern for the sealing face. 3/8 inch socket head cap screws along with washers were used with spacing between the bolts of 1.457 inches [2], as shown in Figure 3 below. At each of the corners of the cover plate, two set screws were used in order to prevent the cover plate from coming in contact with the wire during initial alignment. The set screws were loosened initially, so as to maintain a gap of more than 1 mm, which is the thickness of the wire.

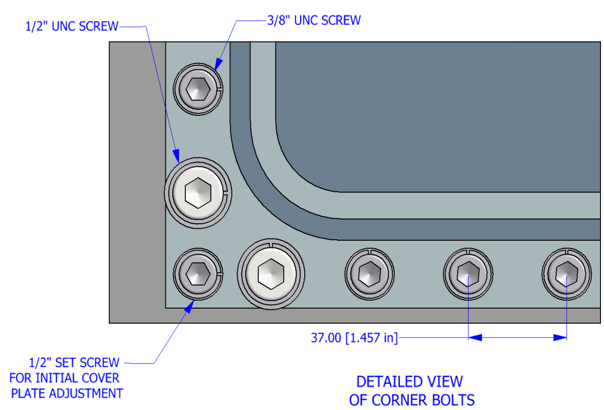

Figure 3: Corner bolt configuration.

Four wire seal adjusting fixtures are set at each end of the cover plate. The wire fixtures are designed such that the tension in the wire as well as the position with reference to the wire placed on the cover flange is adjustable using spring-held linkages, as shown in Figure 4. This design is a novel idea to adjust the tension in the wire seal, which in turn helps reduce sag in the wire, as well as positioning it as close as possible to the bolting pattern. This is a critical component in the installation and testing process, as the position of the wire has direct effects on the attainable vacuum pressure within the chamber.

Two annealed wire seals (aluminum) of different purity were tested on this chamber. Pure aluminium (99.95% pure and 1 mm thick), as well as pure aluminum (99.995% pure and 1 mm. thick, and much softer than the former) were tested.

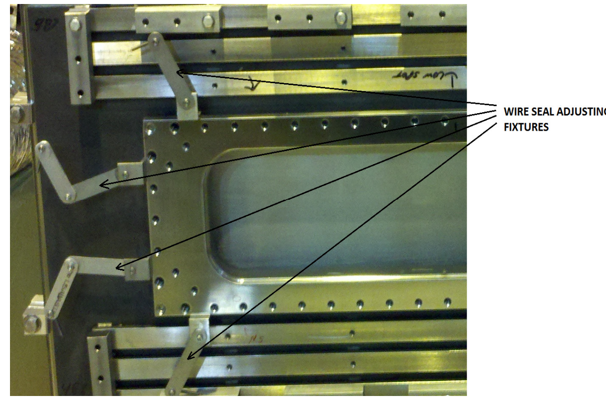

Figure 4: Wire seal adjusting fixtures.

TESTING PROCEDURE

The chamber was tested in the vertical position in order to replicate the actual ID chambers sealed while in operation. This also helps in determining the effect of sag of the wire, which is maximum at the center of the 3.6-meter sealing face.

The O-rings were placed in the spacer plate groove and the corresponding back plate and front plate were aligned with the spacer plate. Clamps were then installed to seal the back plate, spacer plate, and front plate. The cover plate was then aligned with the bolting pattern of the mating bolting pattern of the weld-neck flange. Wire seal adjusting fixtures were then installed with the wires and their position was adjusted with the linkages. It is critical to have the wire not more than 1/8 of an inch away from the edge of the center bolting hole.

Figure 5 illustrates the wire position with reference to the cross bolting hole pattern. Since the maximum sag in the wire is at the center, the wire would be further away from the edge of the center bolting hole. It is absolutely essential to adjust the tension and position in the wire, which in turn helps in keeping this distance to a minimum. Observations have shown that this is the critical position where vacuum leaks occur in the UHV range, if the wire seal is not aligned well during installation. The custom-designed dual linkage Wire Seal Adjusting Fixtures help in aligning and tensioning the wire to the correct tension and position.

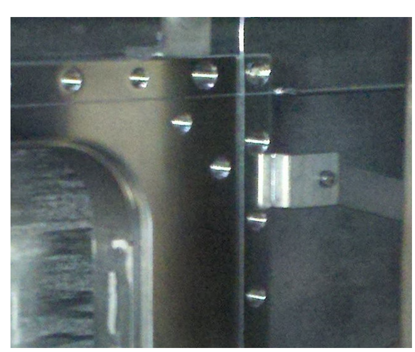
Figure 5: Cross wire configuration at the corner.

At the cross point of the wire seal, as shown in Figure 5, ½-inch bolts were used to provide the required torque necessary to bolt the chamber at the cross point seal . A definite bolting pattern was followed, as mentioned by Savino [2]. The bolting sequence mentioned by Savino [2] helps in moving the crushed wire material away from the center and towards either end of the chamber. This is essential to maintain a uniform seal. The chamber was then pumped down to the UHV range through pump ports on the cover plate. A leak test was done to determine if the chamber was UHV compatible. This was followed by three baking cycle tests.

BAKING PROCEDURE

The chamber was then baked in an oven to 150 degrees C. This was done to replicate the actual baking procedure for all ID vacuum chambers at NSLS-II and study the effect of baking on the wire seal. During the baking process, the temperature was ramped to 150 degrees C in steps of 10 degrees per minute from a room temperature of 25 degrees C [1]. The pressure within the chamber was monitored during the entire baking process. The chamber was baked for a period of approximately 4 hours at 150 degrees C. The chamber was then left to cool down in the oven for a day. The vacuum chamber was then removed from the oven and tested for leaks. Three bake cycles were carried out on this chamber.

RESULTS AND CONCLUSION

Softer annealed aluminum wire seal which is 99.995% pure gave the same results as 99.95% pure wire. An important factor for UHV seals for large vacuum chambers was the surface flatness. The first test was conducted on a 32 micro-inch surface finish, which sealed the chamber. Chambers were leak tested to approx. 1.9×10^{-10} Torr Lit/sec. However, there were a few leaks observed at critical points, mainly around the center of the chamber where the sag in the wire was maximum, as well as around surface imperfection where the 32 micro-inch surface finishes were not maintained. These leaks were negotiated by increasing the torque on the bolts in this area and testing for leaks [5]. These leaks spots would seal if this process was used. However, on polishing the surface to 16 micro-inch, better results were obtained wherein the chamber was leak tested to 6.9×10^{-11}Torr Lit/sec, an improvement of ~ 64 %, compared to the 32 micro-inch surface finish.

It was also observed that the vacuum chamber pressure reduced from 2.15×10^{-5} Torr to 8.7×10^{-6} Torr, as seen in Figure 6, when the surface finish was reduced from 32 micro-inches to 16 micro-inches. This value is dependent on the elastomer O-ring seal. The position of the seal from the bolt edge also affects the seal. For optimal results, it was observed that the wire seal should not be placed any more than 1/8" away from the edge of the sealing bolt. Bolts used for sealing should have washers, and it is advisable to have bolts with maximum permissible torque (>250 inch-lb),; in case of a leak at certain spots, torquing down the bolts around the leak spots would mostly seal the leak. Vacuum levels of 10^{-6} torrs were obtained, as shown in Figure 6. After the first baking cycle, a few leaks were noticed at the edges; these were eliminated by progressively tightening the bolts in sequence. On doing so, vacuum level was maintained to the 10^{-6} torr range after the second and third baking cycle.

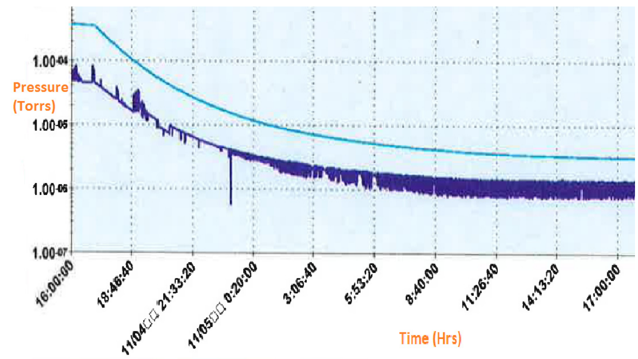

Figure 6: Pressure measurement.

ACKNOWLEDGMENT

The authors are grateful to key personnel at GNB, mainly Eric Raymond(Production Manager), Ken Harrison(President) and Larry Gilbert of Vacuum Solutions Group for manufacturing and conducting preliminary tests on the vacuum chamber as well as machining it to the specifications required by BSA.

The authors are also grateful to Jim Savino from CHESS for all the valuable support and feedback in designing and testing the vacuum seal test system.

The work at Brookhaven Nationals Laboratory was supported by the U.S. Department of Energy, Office of Science under contract 171565.

REFERENCES

[1] Michal Moraw et al., "Analysis of outgassing characteristics of metals", Pergamon Journals Ltd. Vol. 36, p. 523-525, 1986.

[2] J. Savino et al., "Inexpensive, reliable sealing of large UHV enclosures utilizing a progressively-deformed wire", MEDSI, 2010.

[3] J. Roth, "Vacuum Sealing Techniques".

[4] P.V.Head et al.,"Sealing techniques for large Ultra-high vacuum systems", Vacuum, Vol 32, p. 639-640, 1982.

[5] P.Lutkiewicz et al.,"Micro-damage propagation in Ultra-high vacuum seals"International Journal of Pressure Vessels and Piping, Vol 87, p. 187-196. April 2010.

ISBN 978-3-95450-138-0