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Development of Aluminium Wire as an UHV Compatible Demountable Seal

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A R T I C L E   I N F O

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A B S T R A C T

Aluminium and Copper wire-seals were fabricated and characterized as ultra-high vacuum (UHV) demountable wire-seals for large sized non-circular openings. A vacuum system used to measure integrated helium leak rate over the whole circumference of the wire-seal and the wire compression at particular compression force is described. The results show that the leak rate of the order of 1 × 10 – 10 mbar l/s can be achieved by applying the force per unit length of 258 kN/m to aluminium wire-seal with compression of 25 %, while to obtain the same order of leak rate in copper wire-seal, the force per unit length is 415 kN/m at the compression of 44 %.

Introduction

SST–1 tokamak is a super-conducting steady state tokamak with a major radius of 1.1 m and minor radius of 0.2 m. It is designed for plasma discharge of the duration ~ 1000 seconds to obtain fully steady state plasma [1-2]. The SST–1 vacuum vessel is made up of sixteen vessel modules [3-4]. Each module of vacuum vessel comprises of vessel sector, interconnecting ring, one radial port and two vertical ports. Two vertical ports (top and bottom) are triangular in shape while the radial one is rectangular in shape as shown in figure 1 and figure 2.

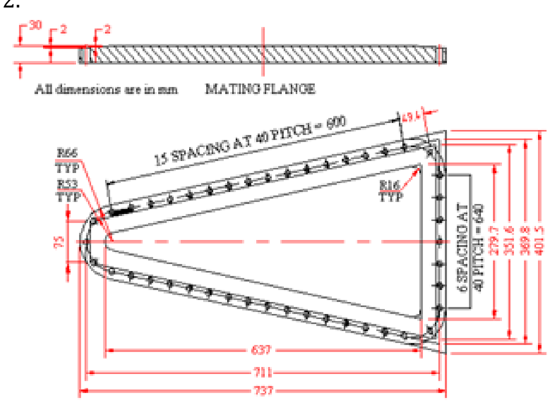

Figure 1: Triangular port blanking flange.

For ultra-high vacuum (UHV) requirement, the selection of de-mountable seal is crucial for non-circular port openings. In selection of UHV non-circular de-mountable seal, one has to consider the leak tightness, easy repair, bake-ability at high temperature, optimum compression and finally the cost. In UHV de-mountable sealing, conflate, helicoflex, wheeler type seal and wire-seal can be used [5-7] out of which wire-seal is found to be suitable. Compression of the wire-seal should be high enough to make up the inaccuracy in machining / planeliness of the flanges. Further the compression should not be too high so that flange-to-flange contact could be avoided and if needed further leak tightening would be possible. As SST–1 tokamak will be baked at 250 °C, the wire-seal should have required leak tightness at this temperature.

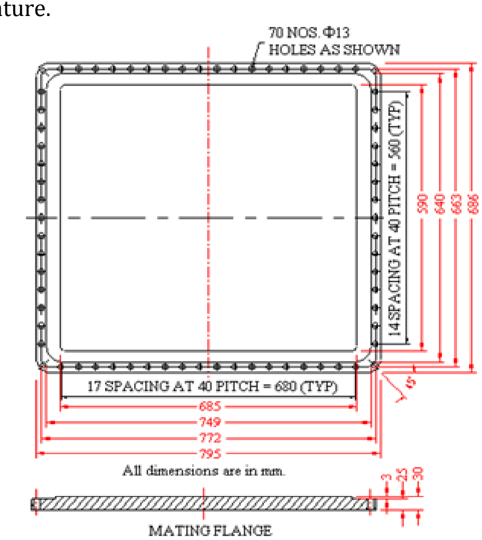

Figure 2: Rectangular port blanking flange.

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Due to easy fabrication of seals, lower hardness, lower out-gassing, easy rectification on sealing faces when they get damaged and very low cost, aluminium wire is selected as a de-mountable seal for SST–1 vacuum system. The hardness test for both aluminium wire and copper wire are conducted by using 'LEITZ' micro hardness tester and the result is shown in the table 1. Aluminium wire-seal of 2.6 mm cross-sectional diameter has been chosen to make up the inaccuracy in machining and to avoid the flange-to-flange contact due to high compression. For comparison, copper wire of 1.65 mm cross-sectional diameter is chosen [8]. This paper presents the results of the experiments carried out to study the performance of aluminium and copper wire-seals. The experimental set-up is described in section– II. Section–III gives the procedure and results. A brief discussion is being done in section–IV.

Table 1: Hardness of Aluminium and Copper.

Material	Process	Diameter (mm)	Hardness (Hv)
Aluminium	As received	2.6	25.09
	Annealed one	2.6	21.92
Copper	As received	1.65	108.20
	Annealed one	1.65	62.59

2. Experimental set-up

Figure 3 shows the schematic of vacuum system used for circular wire-seal test. The circular vacuum chamber was fabricated out of stainless steel tube of 100 mm diameter and 150 mm length. It's one end is connected to MSLD while other end has a test flange with outer diameter of 220 mm. The test flange and its matching flange were polished to smoothness between 0.4 to 0.8 micron.

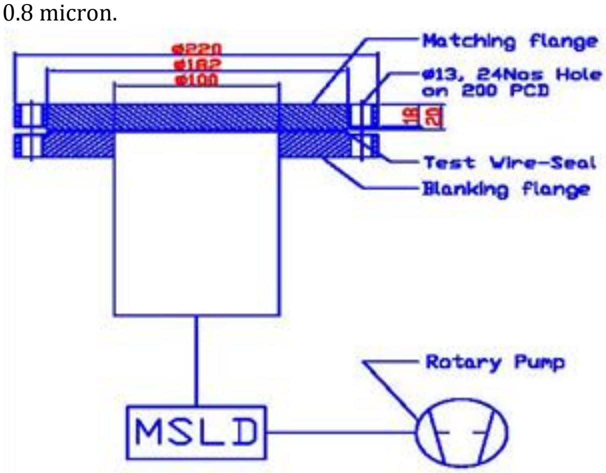

Figure 3: Schematic of the experimental set-up with circular flange.

It has 24 holes of 13 mm diameter at P.C.D. of 200 mm. A test wire-seal of 178 mm diameter is placed between the test flange and matching flange. It is connected to helium leak detector followed by an integrated rotary pump (speed 1.6 m3/h). This leak detector has sensitivity of the order of 1.0 × 10^{-10} mbar l/s. The flange, chamber and seal are baked at 300 °C.

Similar system has been used for the triangular wire-seal test. The vacuum chamber was fabricated out of stainless steel tube of 175 mm diameter and 150 mm length. This chamber test flange has 33 holes of 13 mm diameter with spacing between the adjacent holes to be 40 mm as shown in figure 1.

3. Experimental procedure and results

Aluminium wire of 2.6 mm cross-sectional diameter of required length was cut and the two ends were polished. The wire piece was annealed and then these two ends were fused by using 12 KVA wire butt-welding machine to form a closed loop. A cone was used to shape this loop in circular form of diameter 178 mm. The seal was placed on the system test flange and the port was covered with matching flange. A pre-set type torque wrench was used to tighten the nuts of bolts to the known torque.

Experiments were carried by using 12 alternative bolts of circular vacuum chamber with spacing between adjacent to be 52.3 mm. The torque was increased step by step. Each time the compression of the wire-seal and the local as well as integrated leak rate throughout the seal was measured. This process was continued till the integrated leak rate through the wire-seal was of the order of 1.0 × 10^{-10} mbar l/s. For the leak rate measurements 'spraying of helium' method was used. The average leak rate and the average compression against the applied force per unit length for five numbers of circular aluminium wire-seals are experimentally determined and their average are plotted in figure 4 and figure 5. Figure 6 shows the average leak rate against compression for this aluminium wire-seal.

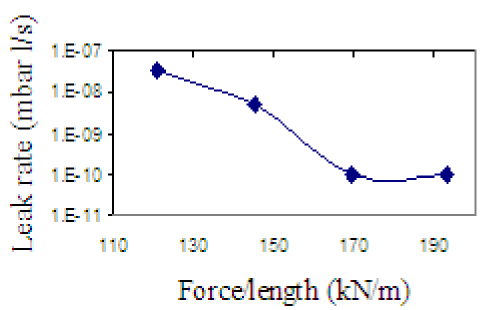

Figure 4: Aluminium circular wire-seal leak rate against force per unit length.

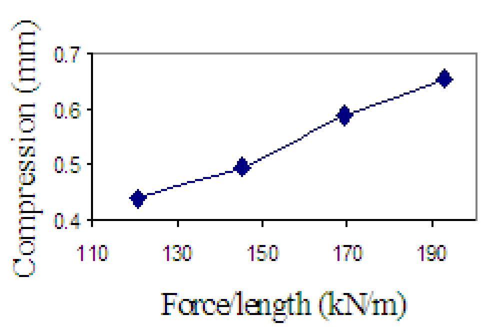

Figure 5: Aluminium circular wire-seal compression against force per unit length.

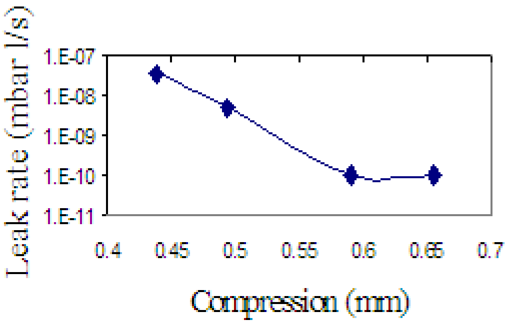

Figure 6: Aluminium circular wire-seal leak rate against compression.

After achieving leak rate of order of 1.0×10^{-10} mbar l/s, the system was baked at 300 °C for 6 h. to see the effect of baking on leak tightness of wire-seal. It was observed that some of the bolts were getting loosed during baking and need re-tightening at the same torque in which leak rate of the order 1.0×10^{-10} mbar l/s have been obtained previously. But by using spring washer, this problem of re-tightening was solved. It was observed that by use of spring washer, bolts have not been got loosed. In the next phase, triangular vacuum chamber was used. Both aluminium and copper wire-seals, three numbers from each were tested for average leak rate and average compression against the force per unit length of wire-seal. Here copper wire of cross-sectional diameter of 1.65 mm is used. Figure 7 and figure 8 show the average leak rate and average comparison as a function of applied force per unit length. Figure 9 shows the leak rate against the compression for aluminium and copper wire-seals.

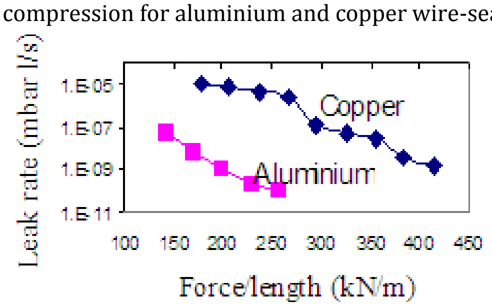

Figure 7: Triangular wire-seal average leak rate against force per unit length.

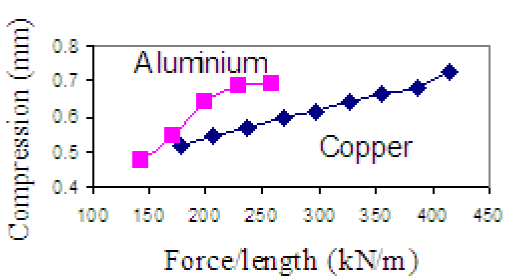

Figure 8: Triangular wire-seal average compression against force per unit length.

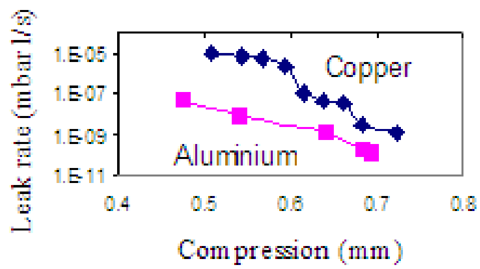

Figure 9: Triangular wire-seal average leak rate against average compression.

4. Conclusion

The force 'F' exerted on the flange by a bolt of diameter 'D' is given by

$$F = \frac{KT}{D} \qquad (1)$$

where 'T' is the torque applied to tighten the bolts and 'K' is a constant dependent on accuracy of threads, smoothness of thread surface and lubrication etc. which is for our case is approximately considered to be 5. Thus the total force acting on a given seal can be calculated using the equation (1) and the average force acting on unit length of seal can be found out from the total number of bolts used during the experiment.

Figure 4 shows that to obtain the leak rate of the order of 1.0×10^{-10} mbar l/s in aluminium circular wire-seal, the force per unit length required ranges from 165 kN/m to 200 kN/m. At this range of force per unit length, the wire gets compressed in the range of 0.5 mm to 0.65 mm out of 2.6 mm total thickness as shown in figure 5. Figure 7 and figure 8 show the comparison between aluminium and copper triangular wire-seal leak rates and compressions against force per unit length. To achieve the leak rate of order of 1.0×10^{-10} mbar l/s for aluminium, the force per unit length ranges from 250 kN/m to 270 kN/m while it is 420 kN/m to 470 kN/m for copper. Similarly average compression for aluminium is 44 %, while for copper is 25 % to achieve the required leak rate of order of 1.0×10^{-10} mbar l/s.

Acknowledgement

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