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DEMOUNTABLE VACUUM SEALS FOR FUSION REACTOR APPLICATIONS

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Abstract

Demountable vacuum seals for fusion reactor applications must be compatible with the reactor environment, easily scalable, very reliable and readily maintained by remote handling methods. We are investigating gate valves as well as flanges in our efforts to provide such seals. They are all metal and scalable without becoming massive and require no axial fasteners. Preliminary tests on an initial 30 cm aluminum flange using no soft metal coatings or gaskets have given several vacuum tight closures. Weld fatigue of this preliminary design caused degradation of the seal with further cycling to leakage levels of 10^{-8} Tl/sec, which is acceptable with differential pumping for either valves or flanges. Additional flange pairs using slightly altered geometry, fabrication techniques, and seal plating materials will be tested and reported on.

INTRODUCTION

Demountable vacuum seals for fusion reactor applications must be compatible with the reactor environment, readily scalable, highly reliable, and easily handled by remote methods. Currently available flange seals have serious limitations that must be considered in developing a reactor-compatible sealing system:

- Very high gasket loads (> 2000 lbs/in. are required to make a metal seal.
- Scaling to large sizes is not predictable, and the flange cross section becomes massive.
- Limited success has been achieved in non circular applications.
- Thermal excursions and gradients are not tolerated well.
- Installation and maintenance are not compatible with remote handling.

Large gate valves, which are essentially remotely operated seals, currently suffer the same limitations. The sealing system that we are developing addresses all these limitations with the goal of eliminating them.

Figure 1 shows one of several radially loaded fluid-pressurized seal arrangements that we are testing. A pocket is machined in the male flange, which is closed off with a welded ring leaving a volume that can be pressurized. A thin wall (0.050 in.) is then machined on the enclosure. This thin wall, which is parallel with the inner pocket surface, has an angle of 4° with the vertical. The three other sides of the enclosure are very thick compared to the 0.050 in. side in order to withstand several thousand psi with very low stress and deflection. The outside wall of the enclosure is machined parallel to the centerline and acts as a guide when assembling the male and female flanges. The 4° angle on the thin wall prevents contact with its mating wall during assembly to minimize marring the sealing surfaces. For a flange with a nominal I.D. of 12 in. the dia-metral clearance between the male and female guide diameters is about 0.004-0.006 in. as is the diametral clearance between the 4° tapered walls.

The seal is accomplished by pressurizing the cavity and driving the thin wall elastically into the mating flange wall. The mating flange sealing wall is essentially a rigid constraint to the motion of the thin-walled sealing surface. Thus, if the contacting portion of the thin wall is within the elastic strain range of the material, it will retract when the pressure is released. Further, if a seal load in excess of 2000 lbs/in. is generated, a vacuum tight seal can be accomplished.

For a nominal 12-in. diameter flange the thin wall should bulge, elastically, about 0.018 in. on the diameter for aluminum and about 0.007 in. on the diameter for stainless steel. Since the maximum movement is limited to < 0.006 in. by the mating flange constraint, either material should behave elastically. 6061-T6 aluminum was chosen for our initial tests.

To generate sealing loads of 2000 lbs/in. or better without using fluid pressures greater than 2500 psi, we modified the sealing surface of the thin wall as shown in Fig. 2.

Figure 1. Flange Crossection

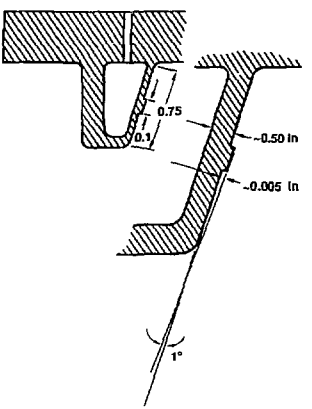

Figure 2. Seal Surface Detail

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This modification provides a pressure amplification up to 7.5 times the cavity pressure. Thus, at a cavity pressure of 1000 psi, we can achieve a seal load up to 7500 lbs/in. of seal. This load is much greater than the 2500 lbs/in. successfully used in aluminum foil seals.

SEAL TEST

The test arrangement is shown in Fig. 3. The initial test procedure was to assemble the mating flanges (both of which were blanks), evacuate the cavity between them with the leak detector pumping system, and measure the pressure and leak rate as the fluid pressure to the seal cavity is applied. This procedure was later modified because the seal pressure would not center the flange pairs once they were evacuated, which resulted in a nonuniform sealing pressure. Thus, on the last flange pair we tested for this report, the seal cavity pressure was brought up to 1000 psig prior to evacuating the cavity between them.

The first flange pair tested is shown in Fig. 4 and is designated flange "A". Flange "A" is of a top-entry-type flange where the pressure cavity is machined from the top and closed by a welded ring. The flange "A" diaphragm is 0.05 in. thick and 0.625 in. wide. It is machined as shown in Fig. 2 and moves radially inward to seal. Two runs were made, and the results are shown in Fig. 5. The minimum leak rate for both runs of about 3 x 10^{-6} millibar l/s occurred at the arbitrarily set pressure limit of 2500 psi. The nonlinear character of run two indicated plastic deformation of the diaphragm near the heat-affected zone. This deformation resulted in the loss of pressure amplification on the sealing ridge, thus terminating the tests.

Following the two tests, measurements were made to determine the elastic recovery of the diaphragm of flange "A". A plot of pressure versus deflection is shown in Fig. 6. Full elastic recovery occurred at 1000 psi cavity pressure and 0.006 in. deflection. At

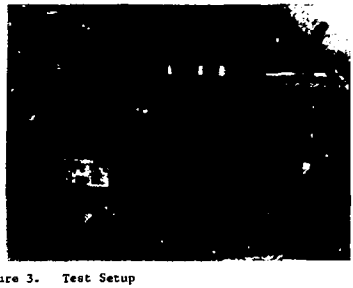

Figure 3. Test Setup

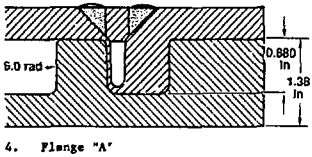

Figure 4. Flange "A"

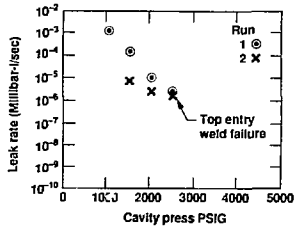

Figure 5. Flange "A" Results

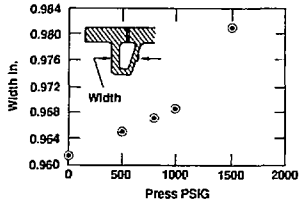

Figure 6. Flange "A" Deflection Test

1500 psi and 0.018 in. deflection there was 0.007 in. of plastic deformation. From simple elasticity considerations, the stress for a 12-in. diameter flange was 10,000 psi for 0.006 in. deflection and about 18,000 psi when yielding occurred. The low yield for 6061-T6 is probably due to the proximity of the weld zone to the diaphragm. However, the 0.006 in. elastic deflection is twice that needed for the diaphragm to contact the rigid mating seal surface, but insufficient to support pressure amplification of the seal.

The second flange tested is shown in Fig. 7 and is designated Flange "B". Flange "B" is essentially identical to Flange "A", except the closure ring was placed on the O.D. of the cavity (Fig. 7) to minimize the weld effect on the diaphragm. Figure 8 shows the results of ten runs. Between each run the flanges were disassembled and rotated relative to each other. All ten runs reached the background of the leak detector (LH ultratest F) with the flanges bagged at 1 atm of helium. In other words, all ten runs were vacuum tight at 2500-psi cavity pressure.

The third, and final flange pair tested to date is Flange "C" (Fig. 9). The only change from Flange "B" was that the insertion depth was increased from 0.9 in. to 1.5 in. and the diaphragm width from 0.625 in. to 0.875 in.. The intent was to increase the pressure amplification of the diaphragm. Further, Flange "C" was the first flange pair tested using the modified procedure of pressurizing to 1000 psi prior to evacuation to ensure flange-pair centering. Ten runs were made on 3/9/87 using the unmodified procedure. On 4/10/87 the flange was remachined to remove scratches on the seal land, and the flange pair was pressurized to 1000 psi before evacuation. Figure 10 shows the results.

DISCUSSION

Multiple vacuum-tight closures can be made with gasketless radial-pressure-sealed flanges. Also, the

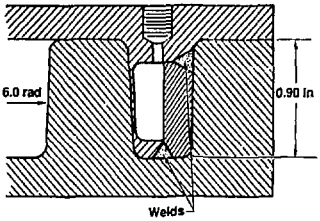

Figure 7. Flange "B"

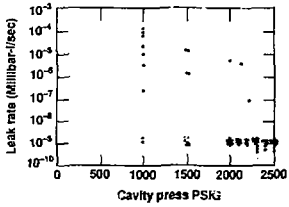

Figure 8. Flange "B" Results

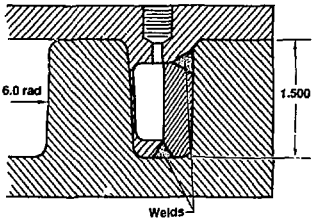

Figure 9. Flange "C"

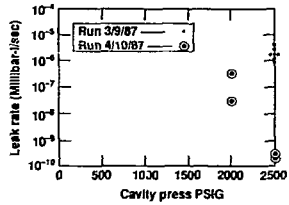

Figure 10. Flange "C" Results

multiple cycling of the seal, including disassembly, degrades the seal surfaces, thus increasing the leak rate by several orders of magnitude. This was anticipated and our intention is to gold- or copper- or silver-plate the seal land to provide a material that is less susceptible to work hardening and scratches. We intend to use a portable brush-plater for this purpose. To get an indication of what soft-metal plating would accomplish, we applied a very light coat of Apiezon L to Flange "B" and "C" after they had degraded to about a 10^{-6} millibar l/s leak rate. Both flanges responded to multiple cycles with leak rates less than 10^{-9} millibar l/s at 2500 psi.

CONCLUSION

We have a high level of confidence that a radial-pressure sealing system can be developed that will provide:

- Reactor compatibility.
- Remote handling (no bolts, no gaskets).
- Very large, all-metal sealed valve application.
- High tolerance for thermal excursions and gradients (with intermetallic diffusion considered).
- A good possibility for noncircular configurations.
- A flange cross section that does not become massive in large diameters.

Acknowledgements

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