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CRYOGENIC PRESSURE TESTING OF DEMOUNTABLE SEALS FOR LARGE-COIL PROGRAM APPLICATIONS*

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INTRODUCTION

Instrumentation leads on the General Dynamics and General Electric Large Coils will be brought out of the coil cases through vacuum-tight cryogenic electrical feedthroughs. To allow access to the connections inside, these feedthroughs will be installed on demountable flanges. The coil manufacturers have proposed that these flanges be sealed with Sierracin/Harrison K-Seals.[†] These seals must be leak-tight in vacuum against liquid helium at pressures up to 10 atm generated during a magnet quench.

A rich literature exists on cryogenic demountable seals using packings such as soft metal wire or gaskets;[1-6] plastics, elastomers[9] and even soap-glycerin mixtures.[10] Many of the methods used suffer from various disadvantages. For example, indium gaskets have been known to cold flow and may require tightening after a few thermal cycles. Indium is also difficult to remove from the flange surfaces when a joint is reassembled. Very careful cleaning and polishing of the flange surfaces is required in most cases, no

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[†] Reference to a company or product name does not imply approval or recommendation by the Union Carbide Corporation or the U.S. Department of Energy to the exclusion of others that may be suitable.

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matter what the gasket material. Sealants which are applied in a liquid or molten state require time to cure or cool and solidify. In addition, liquid sealants can only be installed with the flanges in a certain orientation. Relaxation of the clamping force on the gasket due to differential thermal contraction is often a problem and can sometimes lead to very complicated and expensive flange designs. Finally, most of the seals described in the literature are user-fabricated and require some degree of skill and experience to ensure reliable operation. For applications such as the Large Coil Project (LCP), where many seals will be installed by craft personnel in an industrial environment, a commercially produced seal which can be installed like a common rubber O-ring is preferable. However, relatively few commercially produced seals have been qualified for cryogenic applications.[6,11,12] In this paper we report favorable cryogenic test results with one version of the Sierracin/Harrison K-Seal.[13]

TEST SAMPLES

A cross section of the K-seal is shown in Fig. 1. The stainless steel body of the seal has two flexible metal lips which press against the mating flanges and maintain sealing force over the whole temperature range. The seal takes its name from the way these lips suggest the arms of the letter "K" in cross section. A softer coating can be applied to the seal to enhance sealing against surface microirregularities.

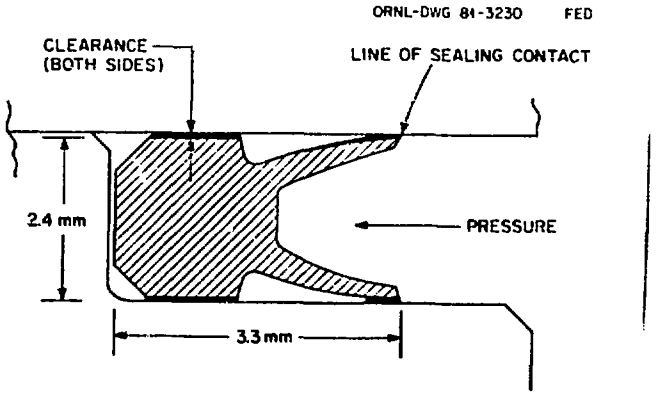

Fig. 1 Cross section of K-seal in installed position.

The seal requires only a cavity of matching diameter to locate it in one mating flange. The flange surfaces must be machined smooth to 0.8 μm (32 μ in.) and parallel within 50 μm (0.002 in.) in the lip contact area. The cavity is machined 0.4 mm (0.016 in.) shallower than the seal thickness to provide the interference which compresses the seal when the flanges are made up. For high pressure applications, the working pressure should be applied from the direction of the lips to make the seal self-energizing. Approximately 100 nt/cm of circumference (60 lb/in.) of bolting force is required to fully compress the seal.

A total of four sample seals was used in the tests. Two were 57 mm (2.25 in.) in outside diameter and coated with lead, and two were 48 mm (1.88 in.) in outside diameter and coated with Teflon.

APPARATUS AND TEST PROCEDURE

The apparatus and instrumentation are shown schematically in Fig. 2. The seal under test was mounted in a cavity between two stainless steel containment flanges. Six 6.3-mm (0.25-in.) stainless bolts on a 66.6-mm (2.62-in.) bolt circle compressed the flanges and test seal together. The flanges were 12.7 mm (0.50 in.) thick and were thus quite rigid. The cavity was pressurized with helium to 10 atm through a 1.4-mm-ID capillary. An evacuated chamber surrounded the flanges and was connected to the leak detector via a 10.9-mm- (0.43-in.-) ID stainless tube. The chamber was sealed by a closure weld which was ground away to change samples. The vacuum chamber was in turn immersed in a 4.2 K liquid helium bath. Temperatures were monitored by Au-Fe vs Chromel thermocouples mounted on the vacuum chamber and containment flanges. The thermocouples were referenced at 77 K in an external liquid nitrogen bath. Test pressures on the seal were measured with a 0-14-atm absolute Bourdon gauge with a precision of better than 0.02 atm. Most of the tests were conducted with a full-scale helium leak detector sensitivity of 3 x 10^{-9} atm-cc/s.

Prior to testing, the K-seals and flanges were examined under a microscope at magnifications up to 70, and any defects which might affect sealing properties were noted. The test seal and flanges were cleaned with alcohol before assembly. The bolts were lubricated with Molykote 321^{+14} and torqued to 7.5 N-m (66 in.-lb) in steps of 1.1 N-m. Before tightening the bolts, the clearance between flanges was measured to verify that sufficient seal compression was applied. This clearance was taken up by the time the torque reached 2.2 N-m (20 in.-lb). After a preliminary leak check, the vacuum chamber was welded on, and the apparatus was installed in the dewar. The high pressure line was evacuated and backfilled with clean helium gas several times to prevent blockage

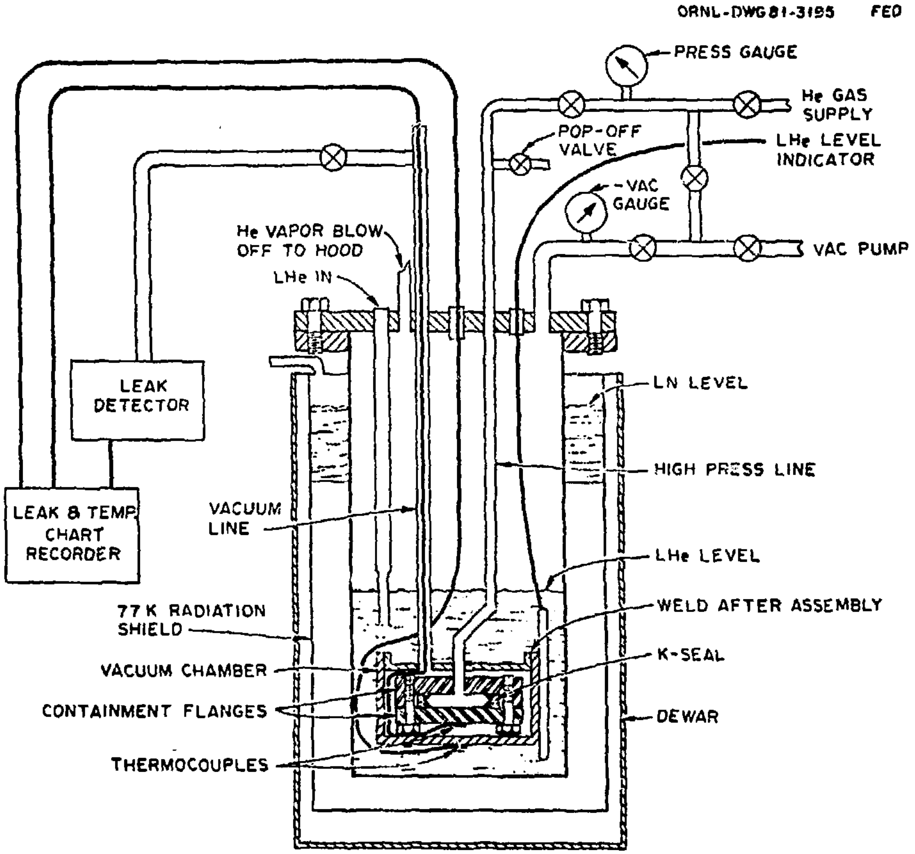

Fig. 2 Schematic of apparatus and instrumentation.

by contaminants, and the chamber was cooled down overnight by radiation and gas conduction to the 77 K radiation shield in the dewar. When the test seal reached 80 K, it was pressurized to 3 atm, and liquid helium was transferred into the bath. Because it was insulated by the surrounding vacuum chamber, the seal did not reach 4.2 K until about an hour after the bath was filled. When helium began to condense in the seal cavity, the pressure in the high pressure line suddenly fell to 1 atm. This fall in pressure verified that the high pressure line was not blocked and that the test pressure was in fact reaching the seal. The flange temperature also rose a few tenths of a degree when the pressure was raised. All blowoff vapor from the helium dewar was piped to a vent hood to prevent spurious drifts in the leak detector background due to high ambient helium levels in the laboratory. After completion of the tests, the cryogens were removed, and the apparatus was warmed up overnight.

Pressure tests were carried out at room temperature, 80 K and 4.2 K. Before each run, the leak detector calibration was checked with a standard leak. At each temperature, the leak detector output was plotted on the chart recorder as the helium pressure inside the seal was raised to 10 atm in 1-atm steps. Full pressure was held for 5 min before the line was vented. The pressure was cycled up and down several times to verify seal integrity under changing loads. If possible, the seal was subjected to two complete temperature cycles to 4.2 K and back. After testing, the seal was removed and again microscopically examined.

RESULTS AND CONCLUSIONS

Before any seals were tested, tightness of the pressure line joint to the upper containment flange was checked in a separate run. For this experiment, the helium passage was drilled only partway through the flange, so that the line was dead ended. The apparatus was cooled to 4.2 K and the line and joint were verified leaktight to 10 atm. After warmup, the helium passage was drilled through the flange from below.

The results of the pressure tests at various temperatures are summarized in Table 1. In some cases, the leak detector background was drifting slowly during seal pressurization. Passing the test was defined as the absence of any observable change in the background drift rate on the 3×10^{-9} atm-cc/s scale which could be correlated to the changes in pressure on the seal. Both lead coated seals survived two complete cycles from room temperature to 4.2 K and back on this basis. The first Teflon coated seal survived the initial cooldown to 4.2 K but failed during warmup. The second Teflon coated seal was not even initially leaktight at room

Table 1. Results of K-Seal Pressure Tests

Temperature (K)	Lead No. 1	Lead No. 2	Teflon No. 1	Teflon No. 2
300.0	P*	P	P	F
80.0	P	P	P	-
4.2	P	P	P	-
300.0	P	P	F	-
80.0	P	P	-	-
4.2	P	P	-	-
300.0	P	P	-	-

*P = Pass; F = Fail.

temperature. Failure of the Teflon seals was easily determined by sharp changes of direction in the leak detector output plot vs time. A typical plot for the first Teflon seal is shown in Fig. 3. Obvious leak indications were seen even with only 1 atm inside the seal.

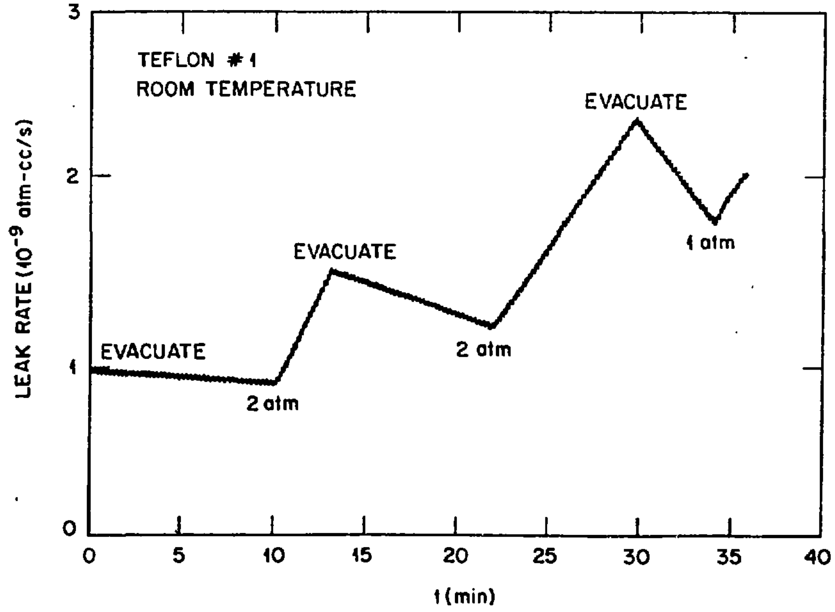

Fig. 3 Leak rate vs time, Teflon No. 1, room temperature.

In another test, the second lead seal was reinstalled to assess its reuse capabilities. The seal leaked at room temperature. However, it was found that if it was coated lightly with Apiezon "N" grease, it performed perfectly over the whole temperature range.

Figure 4 shows typical photos of the sealing lip region of the seals, both before and after compression. Various defects, dents, and bubbles in the coatings were noted as shown in 4(a) and 4(b). The Teflon coated seals tended to pick up dust readily and were much harder to keep clean than the lead coated ones, probably due to charge buildup on the dielectric coating. In Fig. 4(c), the degree of flattening of the edges of the seal lips after compression of the seal is apparent. In Fig. 4(d), the bubble shown in 4(b) is similarly flattened for the Teflon coated seal. Some small dust particles can be seen nearby, and these might have played a role in failure of the seal.

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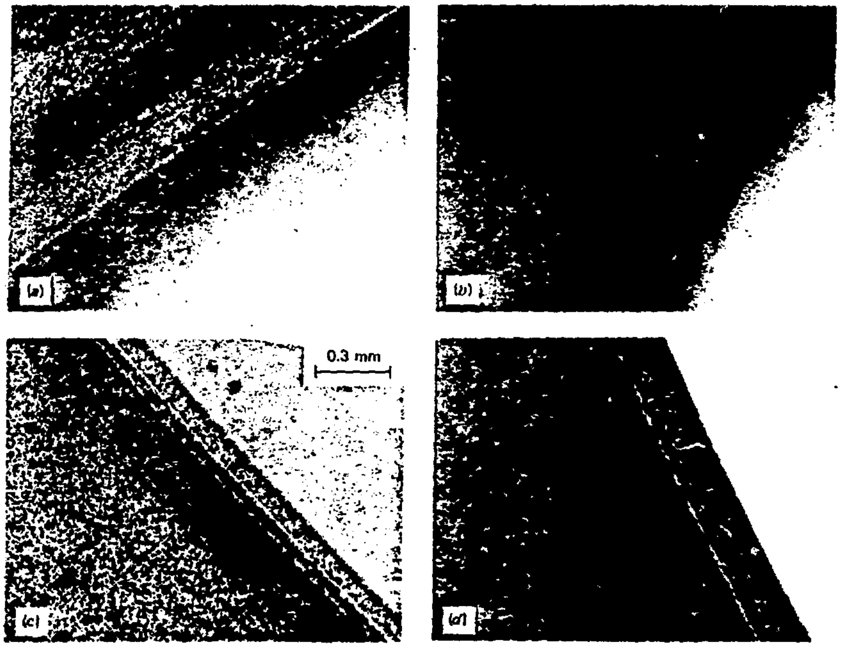

Fig. 4 Photographs of lead and Teflon coated K-seals. Approximate scale is shown. (a) Lead No. 2 before run; (b) Teflon No. 2 before run; (c) Lead No. 2 after run; and (d) Teflon No. 2 after run.

The results indicate that lead coated Sierracin/Harrison K-seals should perform reliably in LCP applications if reasonable care is used in their installation. The seals may be reused if coated with a film of vacuum grease. They provide significant advantages in ease and simplicity of installation over many other cryogenic sealing methods.

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