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K-SEAL TESTS USING DAMAGED SEALS

by

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INTRODUCTION

The proof-test of the K-seal was described in reference (1). The seal was installed in the NRX-A2 reactor actuator ports following the recommendations of subject reference. Damaged seal legs on the NRX-A2 reactor K-seals resulted in a requirement to raise the torque for some of the seals to 120 ft-lb and for others to 240 ft-lb. The torque required was determined by pressurizing the pressure vessel side of the seal with 100 psig helium and tightening until sealing was obtained, i.e., no detectable leak.

The test program conducted here was required to determine:

1. Leakage rate through a K-seal with damaged legs, where the torque had been set for no leakage at ambient temperature and 100 psig with helium.
2. Leakage rate through a K-seal with damaged legs where the torque had been set at 240 ft-lb.

The tests were performed in the same fixture previously employed in WANL-TME-722, and shown on Drawing NT701139, Revision A, except that a solid bolt was used in place of Items 103, 106, 107, and 108.

(1) WANL-TME-722 "Proof Tests For The Bar-X and K-Seal"

TEST METHOD

The K-seal test fixture is shown on Figure 1. The test fixture in the flow loop is shown on Figures 2 and 3. The damaged K-seal which was tested is shown in Figure 4.

The fixture, less the outlet plenum, was checked with the inlet pressurized with helium and the outlet of the seal covered with water. Bubbles indicated leakage. The fixture was then installed in the flow loop. It was purged with helium. The inlet plenum was pressurized with hydrogen from a gas bottle through a pressure regulator. Leakage was measured by detecting a time rate of change in pressure and temperature of a fixed volume. This volume included the discharge plenum, the manometer, the pressure gauge, and inter-connecting lines. At the completion of the test the hydrogen gas was vented to atmosphere and the system purged with helium again before disassembly.

Cooling from ambient to stable cryogenic conditions required only immersing the fixture in the liquid nitrogen bath for 15 minutes or until agitation of the nitrogen ceased. Warm-up to room temperature required heating the fixture with hot water or electric heaters. At best, this took at least an hour for the fixture to stabilize at room temperature.

Fixture sealing consumed considerable time. Comments on this may be found under Discussion.

CALCULATIONS¹

The established maximum permissible hydrogen leakage rate from the reactor to the surrounding area was previously set at 10^{-2} std. cc/sec/in. of diameter of seal. For this seal the figure would be 2.521×10^{-2} std. cc/sec based on the seal internal diameter. It was decided that, for convenience, the change in pressure in the fixed volume of the outlet plenum, etc., would be measured.

The temperature throughout this volume of gas is constant and the leakage rate is small; therefore, the process is isothermal. Here the perfect gas law can be applied:

$$PV = \frac{m R_o T}{144 M} \quad (1)$$

where

P = static pressure in (psia)

V = volume in ft^3

m = mass (lb_m) in volume V

R_o = universal gas constant is $1545 \frac{\text{ft lb}_f}{\text{lb mole } ^\circ\text{R}}$

M = molecular weight of hydrogen is $2.016 \text{ lb}_m/\text{lb mole}$

T = temperature in degrees Rankine

¹ Developed in WANL-TME-722

but since

$$m = Wt \quad (2)$$

where

W = mass flow per unit time (lb_m/sec)

t = time (t) required to obtain mass (m) for flow
rate (W) (seconds)

equation (1) can be written as

$$PV = \frac{W R_o T t}{144 f}$$

or

$$(P_2 - P_1) V = \frac{W R_o T (t_2 - t_1)}{144 f}$$

rearranged we get

$$\Delta P = \frac{W R_o T (\Delta t)}{144 f V} \quad (3)$$

where

$(P_2 - P_1), \Delta P$ = maximum allowable pressure rise in the leakage
plenum (lb_f/in^2)

$(t_2 - t_1), \Delta t$ = period over which the pressure rise is measured
(seconds)

V = leakage plenum volume. This includes the volume
of the pressure lines to gauges and to vent
valve (ft^3)

M = molecular weight of hydrogen is $2.016 \text{ lb}_m/\text{lb mole}$

R_o = universal gas constant is $1545 \frac{\text{ft lb}_f}{\text{lb mole } ^\circ\text{R}}$

T = temperature in $^\circ\text{R}$, the process is assumed to be isothermal, hence the temperature in the seal discharge plenum is assumed to be that of the seal inlet plenum which, in turn, is assumed to be that of the fluid surrounding the test fixture. The surrounding fluid is ambient air or liquid nitrogen.

W = maximum permissible hydrogen leakage rate (lb_m/sec)

With the use of Equation 3, the maximum allowable pressure rise will be calculated for the cryogenic and ambient temperature cases. The values of the parameters are as follows:

V = the leakage volume of h-seal test fixture is approximately 0.0133 ft^3

W = maximum permissible leakage flow based on a 2.521 seal diameter ($4.662 \times 10^{-9} \text{ lb}_m/\text{sec}$)

R_o = $1545 \frac{\text{ft lb}_f}{\text{lb mole } ^\circ\text{R}}$

t = for one hour test period (3600 seconds)

T = 140°R for cryogenic temperature case
 540°R for ambient temperature case

Hence for the cryogenic case, the maximum allowable pressure is:

$$\Delta P = \frac{(4.662 \times 10^{-9} \text{ lb}_m/\text{sec}) (1545 \text{ ft lb}_f/\text{lb mole } ^\circ\text{R}) (140^\circ\text{R}) (3600 \text{ sec})}{(2.016 \text{ lb}_m/\text{lb mole}) (0.0133 \text{ ft}^3) (144 \text{ in.}^2/\text{ft}^2)}$$

$$\Delta P = .971 \text{ psid/hr} = \frac{.971}{.491} \text{ "Hg/hr} = 1.98 \text{ "Hg/hr}$$

and for the ambient case, the maximum allowable pressure is

$$\Delta P = \frac{(.971) 540^{\circ}\text{R}}{140^{\circ}\text{R}} = 3.75 \text{ psid/hr} = 7.6 \text{ "Hg/hr}$$

The K-Seal to be tested first had its legs damaged by crimping with a pair of pliers to be assured that no seal could be achieved with legs of the seal.

Thus a solid metal-to-metal seal would be required. See Figure 4.

At each torque setting the seal was leak-checked in water at 100 psig to 800 psig helium on the inlet plenum, then pressurized on inlet plenum with hydrogen to 100 psig at room temperature for at least 15 minutes, then cold-soaked in liquid nitrogen for 15 minutes, held stable for 15 minutes at 100 psig, while at cryogenic conditions. The hydrogen pressure was raised gradually to 800 psig and held at 800 psig for at least 15 minutes before heating to room temperature.

From the above calculations it can be seen that in a 15-minute period of stability with a Mercury manometer, a change of 0.5" Hg/15 min. period would be readily discernible at cryogenic condition and a figure of almost 2" Hg/15 min. at ambient conditions would be even more so.

DISCUSSION

The tests were initially conducted with a stainless steel sealing nut. At 120 ft-lb torque with 2" Hg pressure drop across leaking fixture seal it appeared that the seal did not leak. The results were not conclusive, fixture seal leakage may have balanced internal leakage. All testing that followed was conducted with an aluminum plug, with a higher pressure drop across the O-ring seal on the outlet plenum, and with frequent surveys to check fixture leakage.

The O-ring (fixture) seals were adequate at room temperature but once down to cryogenic conditions they behaved like metal-to-metal seals. The pressure they exerted against the fixture's mating parts was reduced, so the bolt load was reduced. The initial bolt torque was limited by the strength of the aluminum threads in the mid-fixture section. Early testing, in WANL-TME-722, indicated that an oversized O-ring would more positively seal with this low torque level. Unfortunately the oversize O-ring when compressed by tightening the bolts was pressed into the bolt threads and pieces were extruded and torn off the O-ring as the bolts were rotated. The O-ring so damaged ruptured at cryogenic temperatures. As an interim solution to this problem, without retorquing the fixture, studs, which of course did not rotate, were fabricated from threaded rod. All rubbing surfaces of nuts, studs, and washers were lubricated with a dry lubricant to increase the amount of torque available to load the seal.

Another seal test will employ a test fixture that has the female threads in a stainless steel plenum to permit higher torque and a wider O-ring groove to better accommodate the O-ring.

Table I describes the test conditions and the results obtained.

CONCLUSIONS

The results of these tests on a damaged aluminum K-seal indicate that when the longer flexible sealing leg of the K-seal is effectively eliminated, the solid body of the seal can stop leaks at 240 ft-lb. This pre-supposes that the sealing surface of the port is in as good a condition as on the test fixture, i.e., no radial marks, blemishes, or scratches. A seal that did not leak under 100 psig ambient temperature helium for 120 ft-lb torque, leaked at 800 psig on helium at ambient temperature and beyond the previous recommended maximum at 800 psig on hydrogen at cryogenic temperature. It can be concluded from this last statement that ambient temperature helium may indicate the same leak as hydrogen at test condition if the pressure drop across seal is 800 psig.

Stainless Plug

TEST DESCRIPTION	GAS	TORQUE (ft-lb)	TEMPERATURE	PRESSURE (psig)	REMARKS
Visual leak check with seal immersed in water	Helium	45	Ambient	200	Undamaged seal leakage 2-1/16" bubbles per minute
Visual leak check with seal immersed in water	Helium	120	Ambient	800	Damaged seal, leakage 1-1/16" bubble per minute
Flow Test	Hydrogen	120	Ambient	110	No leakage
Flow Test	Hydrogen	120	Cryogenic	110	Fixture seal leaked excessively
Visual leak check with seal immersed in water	Helium	120	Ambient	700	Leakage-one bubble/10 to 15 minutes
Flow Test	Hydrogen	120	Ambient	100	No leakage
Flow Test	Hydrogen	120	Cryogenic	100	No leakage
Flow Test	Hydrogen	120	Cryogenic	760	No leakage
Flow Test	Hydrogen	120	Ambient	100	.05" Hg/5 min
Flow Test	Hydrogen	120	Cryogenic	100	Fixture seal leaked excessively

Aluminum Plug

Visual leak check with seal immersed in water	Helium	60	Ambient	200	- 11 1/16" bubbles in 3 minutes
Flow Test	Hydrogen	60	Ambient	100	No leaks
Flow Test	Hydrogen	60	Cryogenic	100	.15" Hg/5 min
Flow Test	Hydrogen	60	Cryogenic	450	Fixture seal leaked

TEST DESCRIPTION	GAS	TORQUE (ft lb)	TEMPERATURE	PRESSURE (psig)	REMARKS
Visual leak check with seal immersed in water	Helium	120	Ambient	100	No leakage
Visual leak check with seal immersed in water	Helium	120	Ambient	200	No leakage
Visual leak check with seal immersed in water	Helium	120	Ambient	400	No leakage
Visual leak check with seal immersed in water	Helium	120	Ambient	600	Leak at rate of 9-1/16" dia (approx.) bubbles per 2 minutes
Visual leak check with seal immersed in water	Helium	120	Ambient	800	Leak at rate of 88-1/16" dia (approx.) bubbles per minute
Flow Test	Hydrogen	120	Ambient	100	No leakage in 20 minutes
Flow Test	Hydrogen	120	Liquid Nitrogen	100	No leakage in 15 minutes
Flow Test	Hydrogen	120	Liquid Nitrogen	800	9.3×10^{-2} std. cc/sec for 16 min.
Visual leak check with seal immersed in water	Helium	240	Ambient	800	No leakage
Flow Test	Hydrogen	240	Ambient	100	No leakage in 15 minutes
Flow Test	Hydrogen	240	Liquid Nitrogen	100	No leakage in 15 minutes
Flow Test	Hydrogen	240	Liquid Nitrogen	800	No leakage in 15 minutes

APPENDIX A

Figure 1
K Seal Test Fixture

APPENDIX A

Figure 2

Schematic Seal Test

APPENDIX A

Figure 3

Seal Test Cell Arrangement

Figure 4
Damaged K-Seal

APPENDIX B

The following test record sheets describe the test in detail that is summarized in this report:

<u>TEST RECORD</u>	<u>DATE</u>
K1706790	7-14-64
K1706791	7-14-64
K1706792	7-14-64
K1706793	7-14-64
K1706794	7-14-64
K1706795	7-15-64
K1706796	7-15-64
K1706797	7-15-64
K1706798	7-15-64
K1706799	7-15-64
K1535106	7-15-64
K1535111	7-16-64*

* This sheet was beyond the scope specified in the test program. Its purpose was to determine if any permanent deformation would occur with a new K-Seal when torqued in the test fixture.