Improved Operation In CANDU® Plants with CAN8 PHT Pump Seals

by

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Abstract

The CAN8 PHT pump seal is currently operating in twenty-one pumps, twelve at Bruce A, seven at Bruce B and in both pumps at Grand Gulf Nuclear Station (GGNS). The CAN8 seal has markedly improved performance over the CAN2 seal previously used at the Bruce stations and the SU seals previously used at GGNS. Details of the performance improvements are discussed.

Prior to installation in Bruce B, the CAN8 seal was slightly modified and then demonstrated to be resistant to reverse pressurization failures, since this was a known failure mechanism with the CAN2 seal. Subsequent experience showed that Bruce A was also susceptible to reverse pressure incidents. A review of plant operating procedures at Bruce A showed reverse pressure was likely the initiating factor for several previously unexplained seal disturbances.

The reverse pressure failure mechanism is described, as are the improved system operating procedures designed to prevent it. Preventative procedures have now been implemented across Ontario Hydro Nuclear. The ability to track down seal failure mechanisms such as this is greatly enhanced by the improved system monitoring and data retrieval now in place at Bruce A and Bruce B.

Introduction

The first CANDU installation of a CAN8 Primary Heat Transport Pump (PHTP) seal was in Unit 3 at Bruce A. An historical summary of PHT seal changeouts at Bruce A is shown in Fig. 1 —see Ref. 1 for details up to 1986. Fig. 1 shows a dramatic rise in the number of seal changeouts in 1993 following the 1990 introduction of low pressure running during the plant's start-up sequence. This accentuated the tendency of the stators in the CAN2 seal to rotate in their holders. As a result, symptoms such as rapid wear of the stator back face, overheating, and thermocracking began appearing. This weakness in the CAN2 design led to a decision to change seals. All operating units at Bruce A were converted to the CAN8 PHTP seal design between September 1994 and November 1995.

Although there were some early teething problems related to problems with the chrome oxide coatings on three seal sleeves, Ref. 2, and two premature changeouts in 1996, the seal has performed very well since its introduction at Bruce A. As shown in Fig. 1, Bruce A has now operated for more than one year without a PHTP seal change and if the current CAN8 seal performance continues, 1997 will be Bruce A's first full calendar year without a seal change. This good performance, coupled with a modification that ensures the seal is resistant to reverse pressure, led to the installation at Bruce B in December 1996. At the time of writing, seven PHTP's at Bruce B have had seal upgrades from the CAN2 to the CAN8.

This paper describes the CAN8 seal upgrade, the reason for the 1996 replacements, and actions taken to ensure this type of problem does not recur. The close co-operation between the seal suppliers and Bruce A operating staff has been instrumental in understanding the nature of the problems experienced and in effecting a timely cost-effective solution.

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The Replacement Seal

The CAN8 design, shown in Fig. 2, replaces the AECL-designed, Byron Jackson-supplied, CAN2 PHTP seals in CANDU® plants and the earlier Byron Jackson SU design in Boiling Water Reactors (BWR's). Designed in 1991 for BWR and CANDU® service, the CAN8 seal is capable of operating at high or low pressure with no loss in performance. This capability is achieved through improved control over seal face deflections derived from low hysteresis between the seal rings and their supporting surfaces, Ref. 3.

The stator rotation problem of the CAN2 design has been solved through the use of a resilient elastomer anti-rotation device. The CAN8 design also incorporates improved cooling of the rotating and stationary components. In addition, to facilitate lapping and refurbishment, the CAN8 seal parts have no recessed faces.

Conversion to the CAN8 from the CAN2 is relatively simple and cost effective. Many CAN2 components including seal flanges, pressure breakdown devices, spring assemblies, and shaft sleeves are suitable for use with CAN8 seals. Often all that is required to convert these components is an inspection to verify fit; at most, only minor rework is required.

History and Performance at Grand Gulf and Bruce

The Grand Gulf BWR plant has been using the CAN8 seal since May 1992. The two seals currently installed have been operating without incident. One of the two was installed during their September 1993 refuelling outage. The other was installed in October 1996 to replace a seal that had experienced episodes of temperature cycling giving 5000 to 10,000 cycles in total since the July 1995 fuel outage. These cycles were ~17°C peak-to-peak in amplitude and had a 15 to 20 min. period. The normal expectation is for about 150 slow cycles (2 week period) over a 6-year operating life. The temperature cycles were caused by a problem with the pump's internal heat exchanger, which periodically allowed hot water into the seal cavity. On inspection, the seal's second stage was found to have a shot-blasted appearance on the rotor support and spring assembly. Fine metal flakes of undetermined source were found in the secondary seal cavity. Even in this tough environment of numerous temperature transients, seal face measurements gave an extrapolated seal life of 6 years for both stages. The metal flakes caused no damage to the seal faces.

At Bruce A, four CAN8 seals were installed in Unit 3 in September 1994. As discussed in Ref. 2, three of the sleeves had an excessively rough chrome oxide coating, which resulted in erratic interseal pressure "spiking" problems and some elevated gland return temperatures (up to 70°C) during seal operation. These seals were replaced during outages for unrelated problems in January and February 1995, and April 1996. The Pump 3 seal, installed with a smoother Bruce Central Maintenance Facility (CMF) chrome-oxide-coated sleeve, remains in incident-free operation. A fifth CAN8 seal using a CMF coated sleeve was installed for a trial run in Unit 4 Pump 2 in mid-November 1994 following stator rotation problems with a CAN2 seal during unit start-up.

Bruce A Units 1 and 4 were converted to CAN8 PHTP seals in November and June respectively. The Pump 2 seal previously installed in Unit 4 was also changed at this time so that a normally-operating seal could be inspected. The inspection results showed very low wear, giving an extrapolated seal life in excess of 10 years on the primary stage and 25 years on the secondary.

The first two Bruce B CAN8 seals were installed in December 1996 following an inability to get their CAN2 seals to meet pre-installation leakage test criteria. Since then five more have been installed and all have operated flawlessly.

The 1996 CAN8 Seal Changeouts and Inspections at Bruce A

In 1996, three CAN8 seals destaged during start-up at Bruce A: one with interseal pressure low, the other two with interseal pressure high.

The first of these, from Unit 1 Pump 1 after ~4 months operation, experienced some periods of operation with slightly elevated gland return temperatures (exceeding 50°C) and inspection of the seal revealed that portions of the secondary U-cup had stuck to the chrome oxide coating of the shaft sleeve along the line of contact. This is now thought to be the most likely reason for the seal destaging. At the time, there was speculation that a No. 2 stage O-ring had been displaced during operation. This theory was later dismissed because there was no damage to the O-ring consistent with such a displacement, and because testing showed that no shaft motion or pressure inputs could cause it.

The second of these, a No. 1 stage destaging in April 1996, was the replacement for the Unit 1 Pump 1 seal and did not stage properly during start-up. The seal inspection showed no obvious reason for the seal's destaging.

The third of these was in Unit 3 Pump 4 in August 1996. This seal failed due to U-cup displacement by the reverse pressure mechanism described below.

U-Cup Displacement by Reverse Pressure

Although it was thought that U-cup displacement was not a problem at Bruce A, it was recognized as a frequent means of seal failure at Bruce B. There, it occurred during unit start-up and was accompanied by a sudden depressurization of the PHT system. Two things can happen as a result: one is a small amount of shaft motion <0.5 mm including thrust bearing gaps and deflection of the pump motor support system, the other is reverse pressurization of the primary seal. The first should not cause problems if the U-cup seal slides freely, but the second can cause problems for a standard U-cup design such as used in the CAN2 seal or the CAN8 seal as installed in Bruce A. This reverse pressure mechanism was verified by testing reported in Ref. 4.

Consider the system shown in Fig. 3. This flow schematic is for the two-stage seal system used at Bruce A and B. Normally the gland return valve is open and system pressure is divided about equally across the two seal stages. If system pressure suddenly drops below the interseal pressure, the direction of pressure drop across the primary stage will be reversed. When sufficient energy is stored in the system, e.g. air compressed in unvented instrument lines, gland return lines or the secondary seal cavity, the reverse pressure can be maintained and a reverse flow generated through the primary stage. The reverse flow and pressure act against the back of the U-cup and, in the SU, CAN2 and Bruce A-CAN8 designs, if the force generated is greater than the spring force and flow is large enough, the U-cup can be pushed out of position as shown in Fig. 4. When the reverse pressure is relieved, the springs will act on the U-cup follower to close the gap. The normal result is that the U-cup is caught between the rotor support and the U-cup follower and it fails to reseal. This causes the seal to destage. The rotor support supplied to Bruce B is modified to prevent this from occurring.

Revised Venting Procedures

The August 1996 seal failure by U-cup displacement provided an opportunity to study seal data in detail during the entire incident. The Gateway data retrieval system provided plots which were examined and found to show reverse pressure across the primary stage of the seal. This led to the conclusion that the seal had failed by reverse pressure displacement of the U-cup. This was later confirmed when the seal was examined.

The system venting procedure used during the unit start-up calls for the seal gland return valve to be closed while the PHT system is vented. The result is that if the seal is not leaking appreciably, the interseal pressure rises to near system pressure. In this condition only a small drop in system pressure is required to reduce it below the interseal pressure. Opening valves to vent the PHT reduces the system pressure, possibly quite rapidly depending on how fast the valves are opened. This clearly was a situation with a high probability of causing a reverse pressure across the primary seal.

Accordingly, the PHT and seal venting procedure was revised to include the following in the order given (after checking that the changes would not affect any other systems):

- opening the gland return line valve after seal injection is started and the seal cavity is filled,
- after the system pressure reaches 2 MPa, venting the seals for 30 seconds via the quick vent lines,
- opening the system valves as usual to vent the PHT piping.

This ensures that most of the air is out of the instrument lines and that the gland return line is free of air, and minimizes the size of any reverse pressure energy source. With the system venting done and when the gland return valve is open, the amount the system pressure can be reduced before getting below the interseal pressure is maximized.

Operating History Since the Revision of Venting Procedures

In the thirteen months since the system venting procedures were revised at the end of August in 1996, the operation of the Bruce A CAN8 PHTP seals can only be described as uneventful. There have been 7 unit shutdowns and 4 unit startups without seal problems and no seal changes for any reason.

These procedures have been reviewed with station personnel at both Darlington and Bruce B and station procedures have been modified there as best suits their system configuration. This reduces the likelihood of reverse pressure problems at those stations and neither have reported any problems relating to reverse pressure. Both stations have gone through several start-ups since that time.

At Bruce B, trends of the interseal pressure for CAN8 seals have been very flat and there has only been one small excursion in gland return temperature. This tracked a large increase in pump runout and vibration and returned to normal shortly thereafter even though the vibration levels remained higher than normal, Ref. 5.

Conclusions

The CAN8 PHTP seal, which had its successful introduction in main coolant pumps for BWRs at Grand Gulf, has now shown itself to be a cost effective upgrade for the CAN2 seals in CANDU service. Initial problems associated with excessively rough chrome-oxide-coated sleeves were quickly eliminated.

Although the reverse pressure problem slightly extended two outages at Bruce A, no CAN8 PHTP seal has forced any of the user plants down from full power. This is in stark contrast to the many forced outages caused by the CAN2 seal in the few years between the introduction of low pressure running and the introduction of the CAN8 seal.

The availability of data through systems similar to the Gateway system will pay dividends by providing an accurate sequence of events during system disturbances. Data from this system greatly facilitated the effort to determine the cause of the August 1996 seal failure by reverse pressure. The time required to prepare revised operating procedures was also reduced.

The close co-operation between the user and seal supplier has resulted in a product fully adapted to CANDU PHTP operation.

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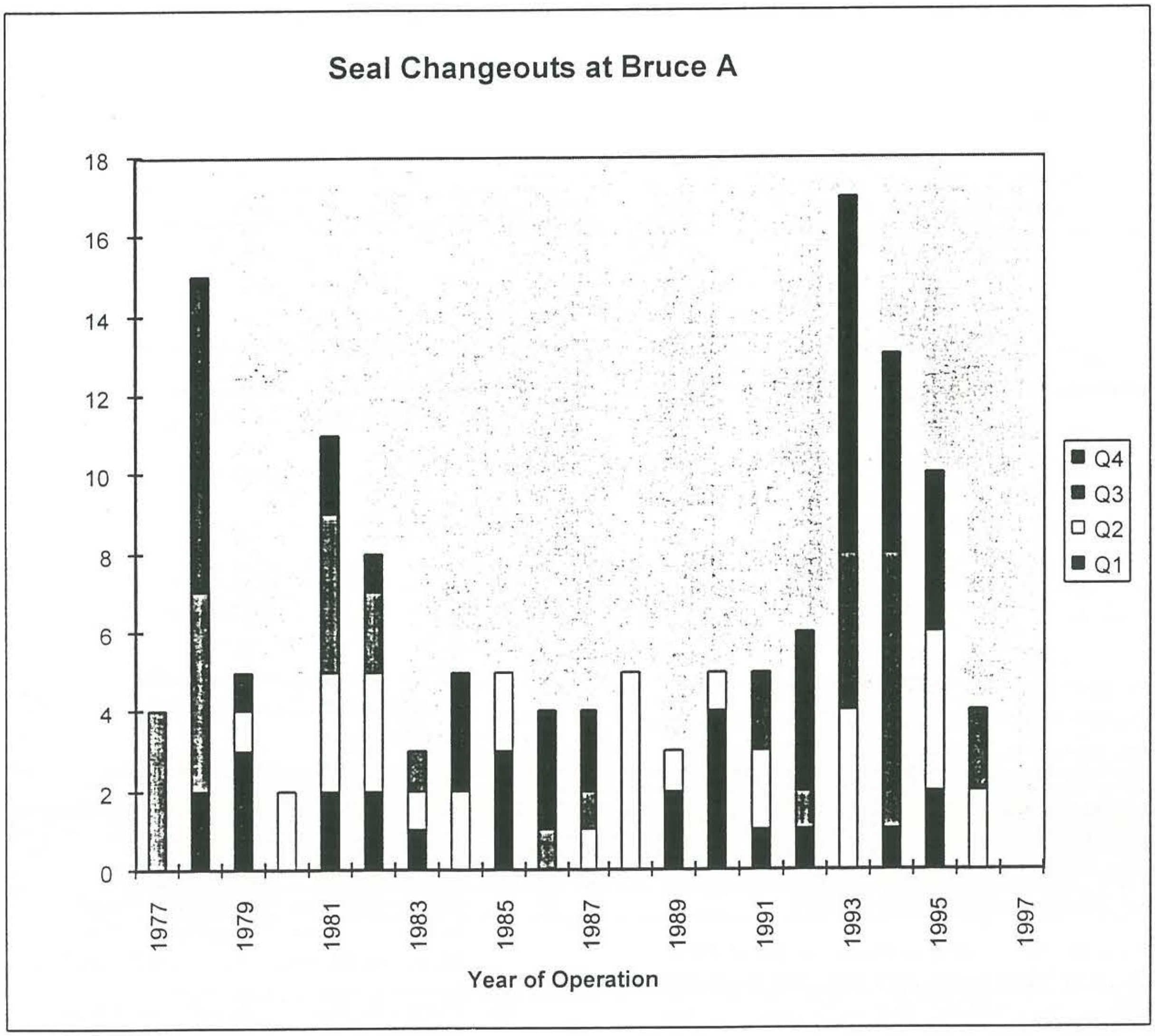

Fig. 1: Seal Changeout History at Bruce A.

1977 to 1981 – mixture of SU and CAN1 seals changeouts

1982 to 1993– changeover from CAN1 to CAN2 and CAN2 to CAN2 changeouts

1994 – 5 CAN2 to CAN8 and 8 CAN2 to CAN2 changeouts

1995 – 7 CAN2 to CAN8 and 3 CAN8 to CAN8 (2 with rough sleeve and 1 trial seal for inspection)

1996 – 4 CAN8 to CAN8 changeouts (1 rough sleeve, 2 reverse pressure induced and 1 sleeve friction related)

1997 – No changes to date

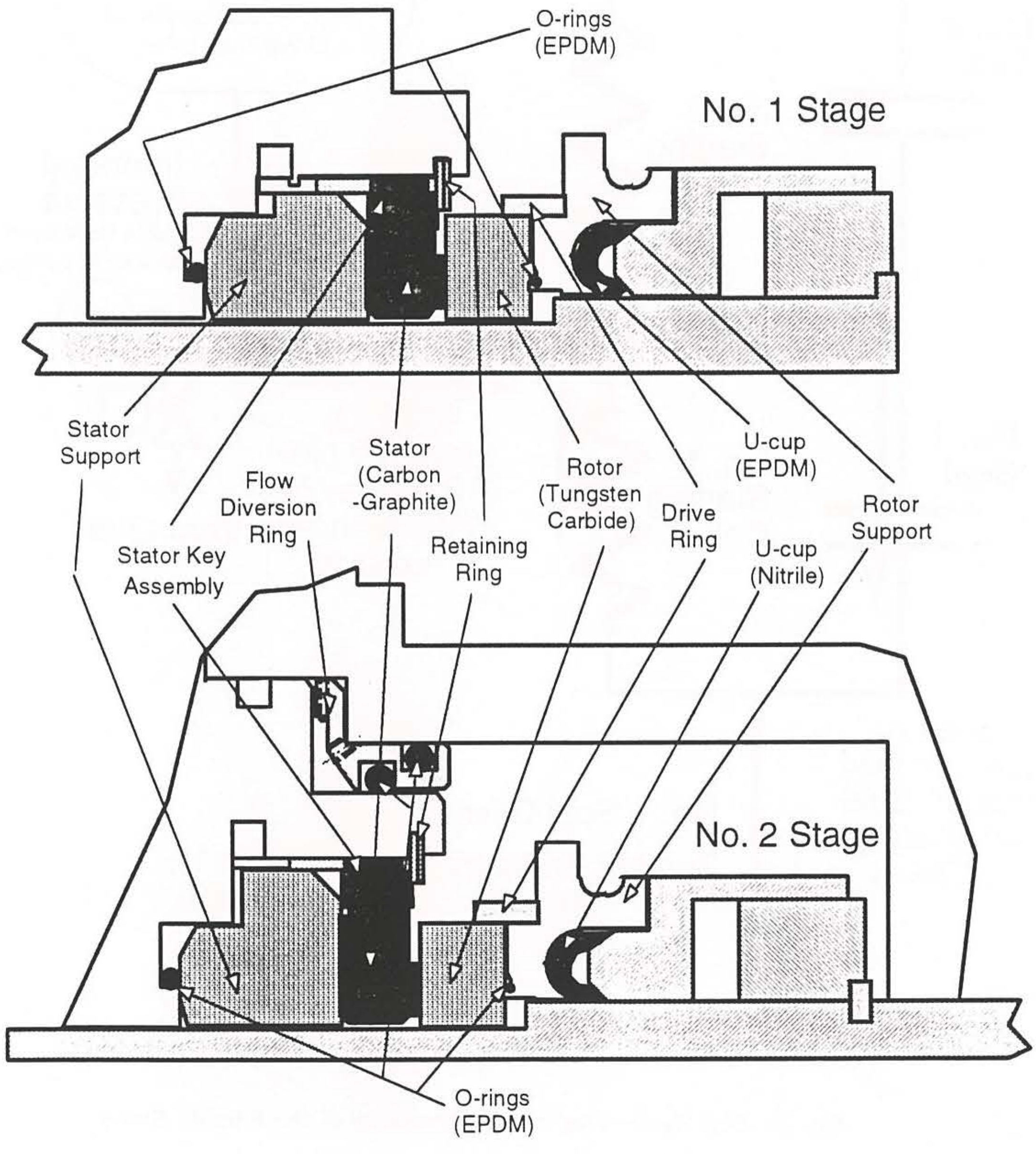

Fig. 2: Two-Stage CAN8 Seal for CAN2 Replacement.

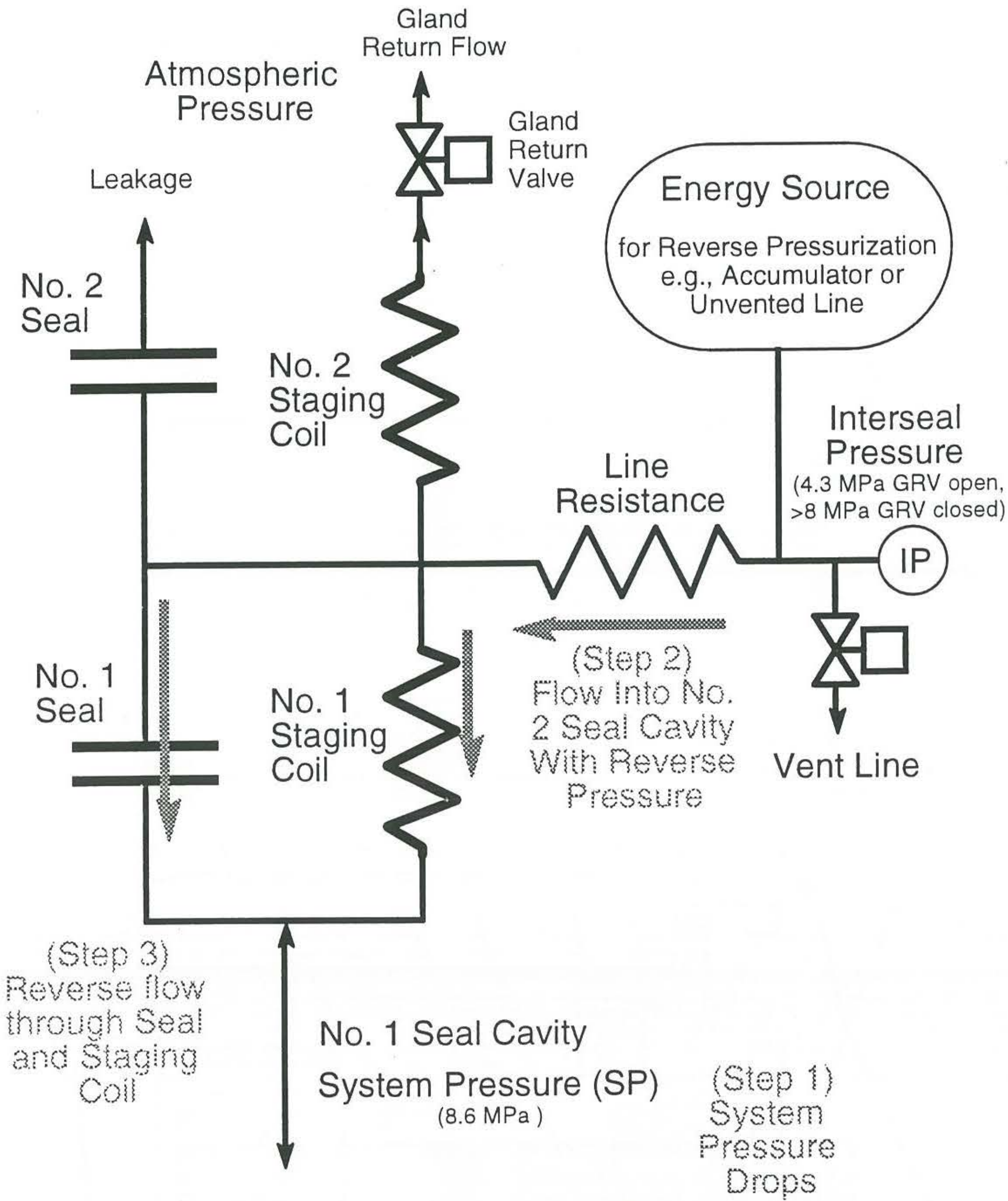

Fig. 3: Seal System for Reverse Pressure of the Primary Stage

Primary Stage Under Reverse Pressure

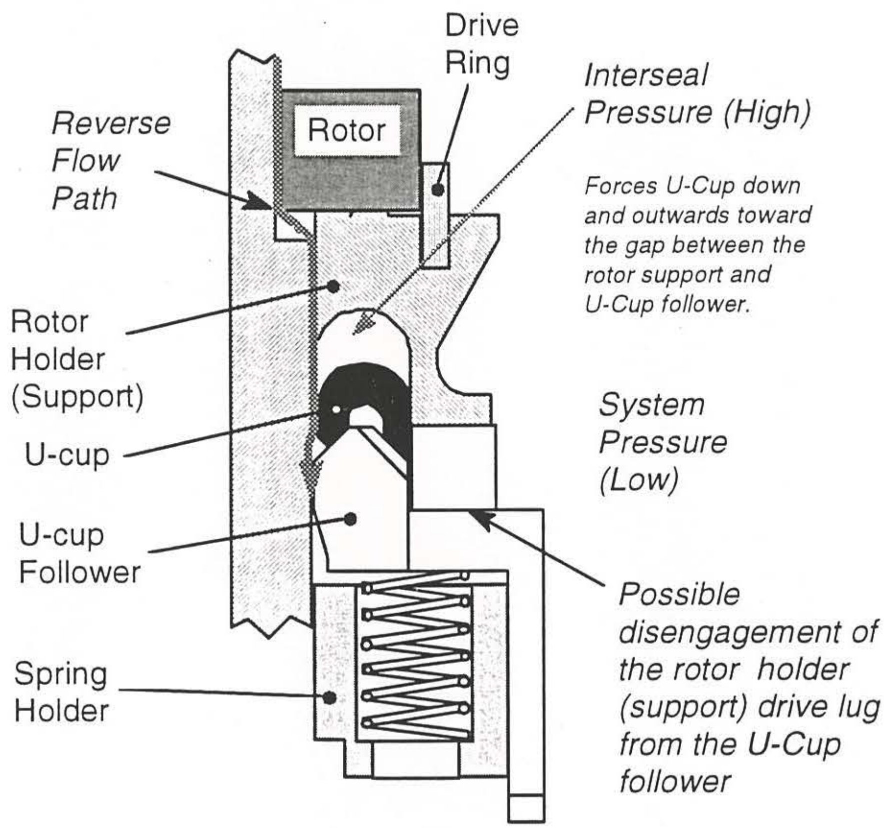

Fig. 4: Effect of Reverse Pressure on Primary Stage with CAN2 Design U-cup Seal.