UPGRADING PRIMARY HEAT TRANSPORT PUMP SEALS

by

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INTRODUCTION

Changes in the operating environment at the Bruce-A Nuclear Generating Station created the need for an upgraded Primary Heat Transport Pump (PHTP) seal. In particular, the requirement for low pressure running during more frequent start-ups exposed a weakness of the CAN2 seal and reduced its reliability.

The primary concern at Bruce-A was the rotation of the CAN2 No. 2 stators in their holders. The introduction of low pressure running exacerbated this problem, giving rapid wear of the stator back face, overheating, and thermocracking. In addition, the resulting increase in friction between the stator and its holder increased stationary-side hysteresis and thereby changed the seal characteristic to the point where interseal pressure oscillations became prevalent. The resultant increased hysteresis also led to hard rubbing of the seal faces during temperature transients.

An upgraded seal was required for improved reliability to avoid forced outages and to reduce maintenance costs. This paper describes this upgraded "replacement seal" and its performance history. In spite of the "teething" problems detailed in this paper, there have been no forced outages due to the replacement seal, and in the words of a seal maintenance worker at Bruce-A, "It allows me to go home and sleep at night instead of worrying about seal failures."

THE REPLACEMENT SEAL

The CAN8 design, shown in Fig. 1, was chosen as the replacement for the CAN2 PHTP seals at Bruce-A. Designed in 1991 for both Boiling Water Reactor (BWR) and CANDU® service, the CAN8 design 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.

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 similar to that used in the successful CAN2A design. 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 inspection to verify fit; at most, only minor rework is required.

PERFORMANCE AND INSTALLATION HISTORY AT GRAND GULF AND BRUCE-A

The first two CAN8 seals were installed in May 1992 in the Grand Gulf BWR plant while laboratory testing was continued. Although there were no mid-cycle problems, these were replaced by the CAN8 "Mark II" version during Grand Gulf's September 1993 fuel outage. These seals then operated flawlessly until the spring of 1995. At this time, the seals were removed for system decontamination and unfortunately one of the pumps was re-assembled incorrectly and destroyed its seal at start-up. This seal was repaired, and both it and the remaining seal from 1993 continue to operate well as of October 1995.

Four CAN8 seals were installed in Bruce-A Unit 3 in September 1994. Existing spring assemblies, seal flanges, and pressure breakdown devices were inspected for conformance to CAN8 design requirements, relapped as necessary and then used in seal assemblies. None of the available shaft sleeves met the surface finish requirement of 0.2 μm Ra nominal. However, the sleeves were coated with flame sprayed chrome oxide in the U-cup areas and at the tertiary seal, and this surface coating had been used successfully with the CAN2 seal despite being much rougher than the CAN8 specification. Coated sleeves were accepted for CAN8 application on this basis. Three of them were new from the pump supplier. These were installed in Pumps 1, 2, and 4. The fourth

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– installed in Pump 3 – had been coated by Bruce Central Maintenance Facility (CMF) during reconditioning. A fifth CAN8 seal using a CMF coated sleeve was installed in Unit 4 Pump 2 in mid-November following stator rotation problems with a CAN2 seal during unit start-up.

In mid-November, the CAN8 seal in Pump 2 of Unit 3 began to exhibit sporadic "spiking" in interseal pressure, accompanied by no other appreciable changes in seal operating parameters (see Fig. 2). Normal interseal pressure at the time was 4.3 MPa. During "spiking" the interseal pressure would rise suddenly, in less than 6 s, to between 5 MPa and 8.8 MPa, and remain at the higher pressure for a random period of time before returning just as rapidly to normal. The periods of high interseal pressure ranged from less than 6 s to several hours in duration. This "spiking" would disappear for several days, and in at least one case for a couple of weeks, before recurring without any discernible initiating event. Note that this behaviour is very different than the more regular pressure cycles that can occur due to high friction between the seal rings and their supporting surfaces [Refs. 1 & 2]. The seal continued in this state for an estimated 10,000 or more pressure cycles, until the unit was shut down for other reasons in mid-January 1995. The faulty seal was then removed, replaced, disassembled, and inspected by AECL and Bruce-A personnel. Excessive roughness of the sleeve coating was the suspected problem.

Following start-up of Unit 3 on February 4, Pump 1 gland return temperature alarmed high at 63°C, but then cleared. Other seal operating parameters remained normal, however, the gland return temperature stayed ~10 to 12°C above normal (i.e., in the 57°C ±5° range) for the next week when the unit was again shut down for other reasons. Although the gland return temperature was not seriously high, examination of the seal trend data showed that the temperature had been trending upwards slowly since around the start of December 1994 and it was decided to change and inspect the Pump 2 seal. Again, sleeve roughness was the suspected cause.

Subsequently, the third CAN8 seal with a similarly rough sleeve (Pump 4), has shown elevated gland return temperatures similar those experienced in Pump 1. This seal remains in service however.

In June 1995, the three remaining CAN2 seals in Unit 4 were replaced by CAN8 seals and the CAN8 seal in Pump 2, though operating normally, was removed for inspection to verify that the wear rate with a relatively smooth sleeve was very low.

INSPECTION AND ASSESSMENT OF SEALS

Visually, the seals removed from Unit 3 Pumps 1 and 2 looked in excellent shape. Rotor and stator seal faces of both stages appeared highly polished, as is consistent with normal operation, and there was no evidence of thermocracking of rotors or cracking or chipping of the stators. Seal support pieces were also in excellent condition. Elastomers were all flexible and appeared to be in almost as-new condition; barely visible on the No. 1 U-cup was a thin shallow groove, ~0.001 in. wide and deep, nibbled where the U-cup bridges the gap between the rotor support and shaft sleeve. The rotor supports, U-cup followers, and spring holders showed no evidence of any rubbing against their shaft sleeves or binding between components. The only manifestation of the interseal pressure spiking of Pump 2 and the high gland return temperature of Pump 1 was in the wear rates of the carbon-graphite stator faces. These are given in Table 1 in terms of the extrapolated seal face life, i.e., the estimated running time till the entire seal face is worn off at the average wear rate up to inspection.

The seal removed from Unit 4 was also in excellent condition visually. Wear rates, also presented in Table 1, are very low.

Table 1: Extrapolated Life and Shaft Sleeve Surface Roughness for Inspected Seals

Seal		No. 1 Stage	No. 2 Stage
Unit 3 Pump 2 *(4 mos. run time*	Life Finish (Ra)	1 a 0.84μm (33 μin.)	10 a 0.79μm (31 μin.)
Unit 3 Pump 1 *(5 mos. run time*	Life Finish (Ra)	2 a 0.91μm (36 μin.)	>10 a 0.91μm (36 μin.)
Unit 4 Pump 2 *(6 mos. run time*	Life Finish (Ra)	10 a 0.33μm (13 μin.)	>25 a 0.41μm (16 μin.)

Based on the operating data and inspection results, the following conclusions were reached.

- For Unit 3 Pump 2, the seal faces separated in response to small downward shaft movements because the friction between the U-cup and sleeve was larger than could be consistently overcome by the spring and pressure forces acting to close the seal. As the No. 1 seal opened, the closing force due to pressure drop across the U-cup decreased because the interseal pressure increased. This left only the spring force to force the No. 1 seal closed. Upward movement of the shaft would close these faces in a similar manner. The No. 2 seal faces meanwhile remained closed since the higher interseal pressure provided increased closing force. The reason this occurred only after several months of operation is postulated to be the loss of lubrication on the rougher surface. The other factor in this is the probability that the pump was operating near the point where the pressure forces acting on the shaft and impeller balanced the combined shaft and impeller weight.

- For Unit 3 Pump 2, the high gland return temperature in this case indicated hard rubbing on the No. 1 stage, since flow routed past the seal faces into the secondary seal cavity would carry heat with it. Hard rubbing causing the more rapid wear was initiated by higher friction associated with the loss of lubrication on the rougher sleeve surface.
- All three CAN8 seals examined from Bruce-A showed more wear on the No. 1 stage seal faces than on the No. 2 stage, whereas in Grand Gulf the No. 1 seal wore less. This is thought to be due to differences between the internal flow patterns around the No. 1 seals from Bruce-A and Grand Gulf. Tests with the Bruce-A flow configuration showed no measurable difference.

RESOLUTION OF THE BRUCE TEETHING PROBLEMS

After inspection of the two seals from Unit 3, a special program was started to address the issues raised. It included the following:

i) Laboratory testing to determine if the CAN8 seal can be made to give high gland return temperature with a stainless steel sleeve polished to specification. These tests, with seal faces lapped to the same condition as those removed from service, did not reproduce the high gland return temperatures seen in the field. This indicated that excessive sleeve roughness was an important ingredient in this problem.

ii) A program to ensure that chrome oxide coated sleeve roughness was as low as reasonably possible. Bruce-A and Bruce CMF personnel have succeeded in reducing the surface roughness of the chrome oxide coatings to the 0.25 to 0.4 μm Ra range. Note that there have been no problems attributed to sleeve roughness with earlier CMF coated sleeves, neither with the CAN8 nor CAN2 seals, and that previously these sleeves typically had surface roughness in the 0.4 to 0.5 μm Ra range.

iii) Measurement and visualization of internal flow in the seal cavity with the goal of improving cooling of the No. 1 seal stage. This program showed that an easy modification would improve the cooling flow in this stage.

iv) A test program to investigate the friction characteristics of U-cups on both CMF and the pump supplier's chrome oxide coatings and on polished 17-4 PH stainless steel. This program has shown that the latter's chrome oxide coatings supplied to Bruce-A are susceptible to loss of lubrication. In a lightly lubricated state, meant to simulate the conditions at the U-cup after the seal has operated for some time, the U-cup did not slide on the sleeve at pressures above 4.3 MPa during 0.05 Hz motions of 2 mm amplitude. All other sleeve preparations tested did slide under these conditions.

The No. 1 stage internal flow modification for improved cooling and the reduced roughness chrome oxide coated shaft sleeves were installed in all four pumps in Unit 4 during the June 1995 outage. Operation of these seals and the three seals with CMF coated sleeves installed in Unit 3 has been trouble-free to date.

EXTENSION TO A THREE STAGE CARTRIDGE

The CAN8 seal design has now been extended to include a third stage, the same as the No. 1 stage used in Bruce-A. This is shown in Fig. 4. It allows upgrade of the CAN2 seals in use at Darlington, Point LePreau, and Wolsong-1. This is accomplished by machining the shaft sleeve to accept a new balance sleeve and adding an axial spacer to the stationary assembly. By avoiding the use of new larger-size seal rings, support rings, and elastomers, any uncertainty in performance of a "new" seal design has been minimized.

CONCLUSIONS

The CAN8 PHTP seal, which had its successful introduction to 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 high wear associated with excessively rough chrome oxide coated sleeves was quickly eliminated. 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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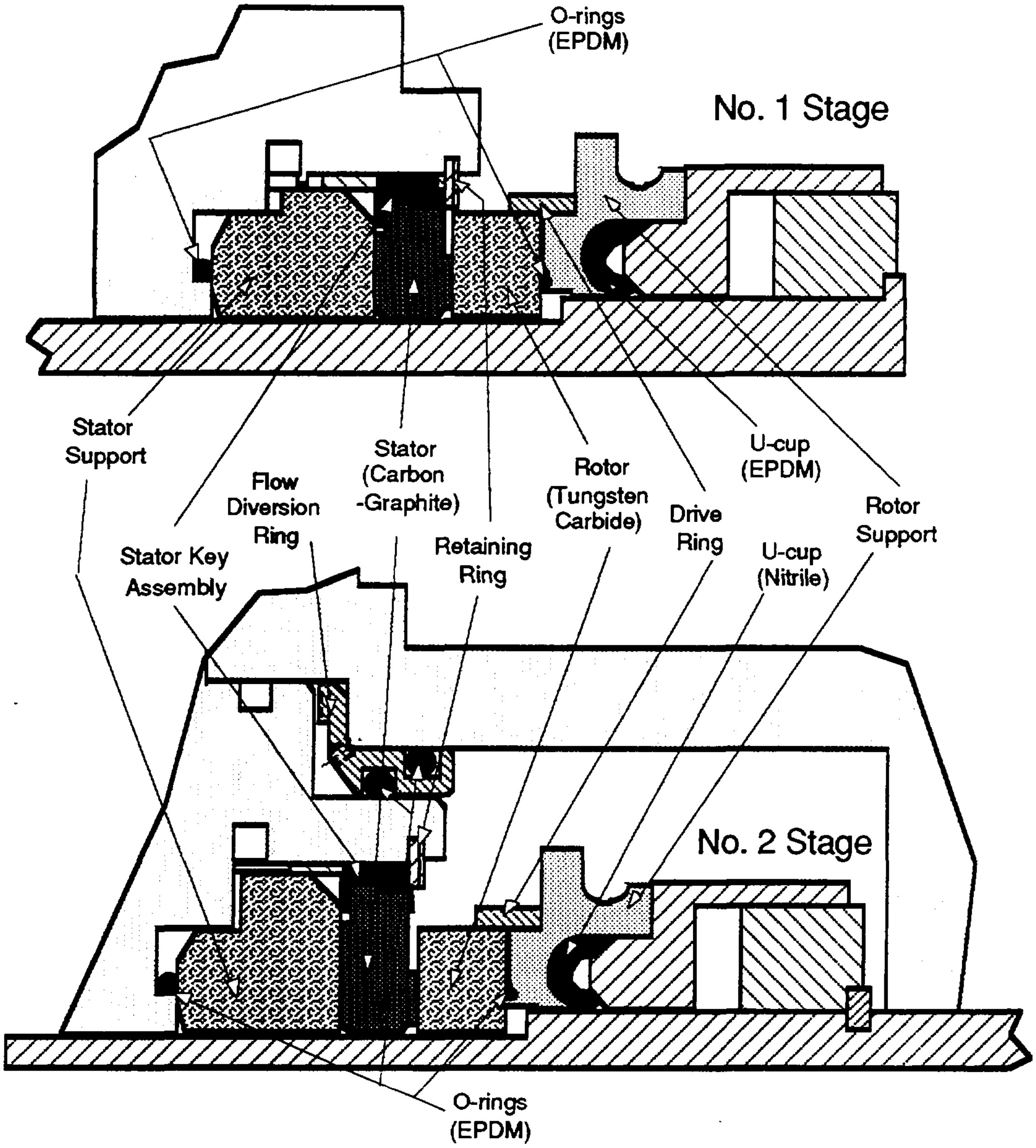

Fig. 1: Two Stage CAN8 Seal for CAN2 Replacement.

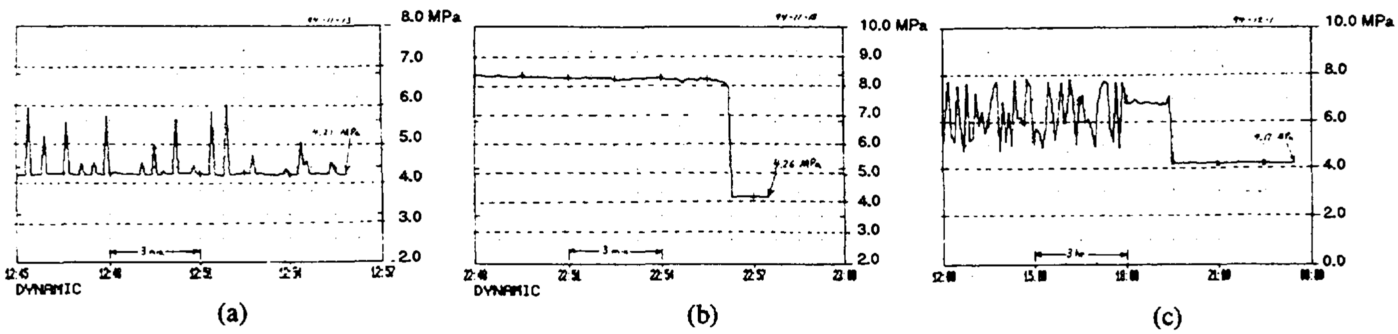

Fig. 2: Interseal Pressure Spiking due to Sleeve Roughness: (a) Trend with "spiking," (b) Trend with step change return to normal, (c) Trend (computed) with "spiking," stabilization, and step change return to normal

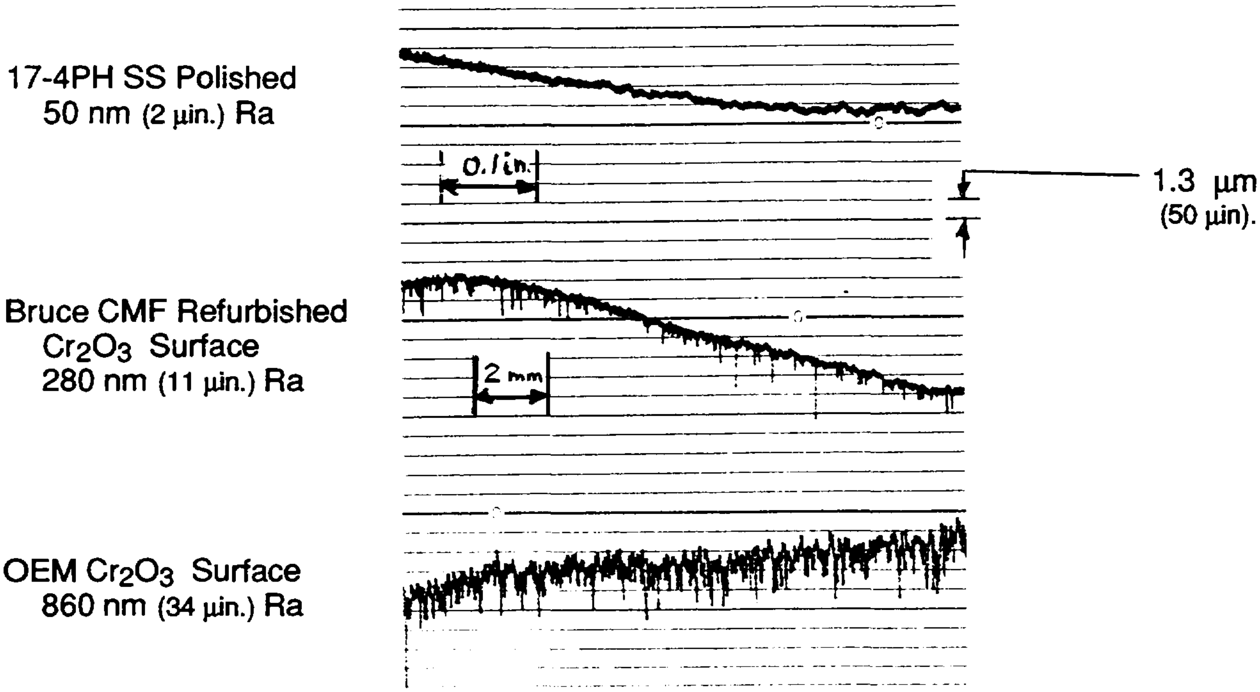

Fig. 3: Surface Profiles for Sleeves used in U-Cup to Sleeve Friction Tests

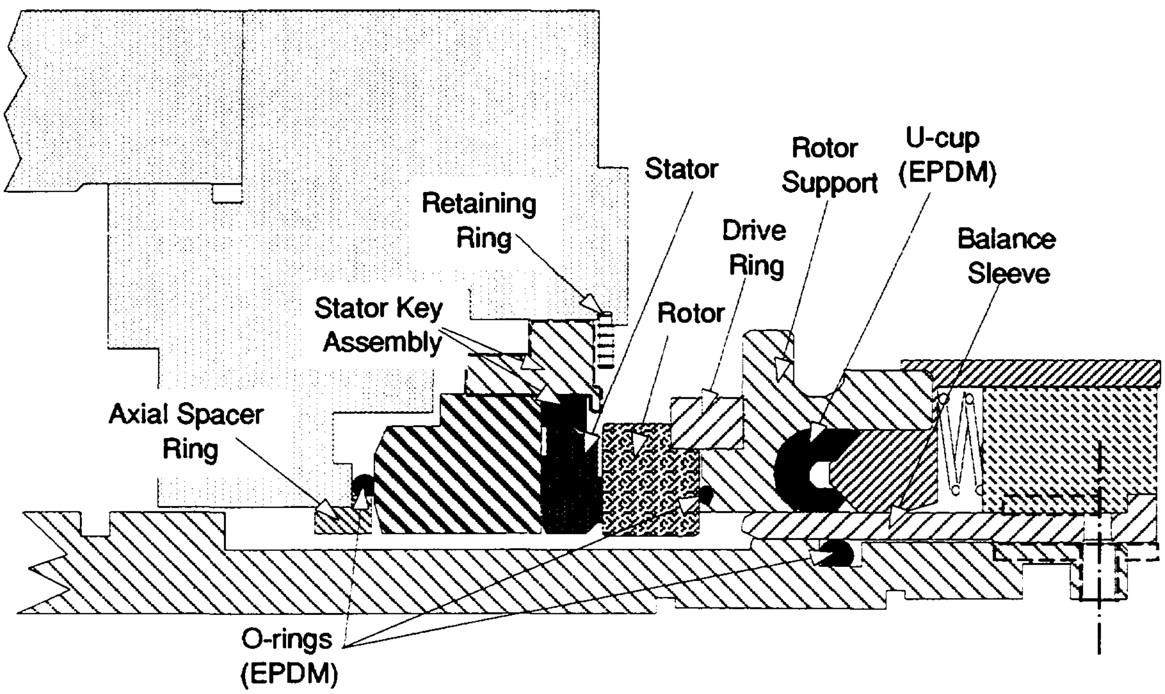

Fig. 4: CAN8 Primary Stage Replacement for Three Stage CAN2 Seals.