Main Coolant Pump Shaft Seal Guidelines

Volume 1: Maintenance Manual Guidelines

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Main-Coolant-Pump Shaft-Seal Guidelines.

Volume 1. Maintenance-Manual Guidelines

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

This project (RP1556-1) was undertaken as a logical extension of earlier EPRI work to investigate the causes of failure and the state of the art in the design of nuclear main coolant pumps (MCPs). Both the failure history study reported in EPRI Final Report NP-1194 and the design study reported in EPRI Final Report NP-2458 concluded that problems with the mechanical face seal were major contributors to pump unavailability and to plant unavailability.

A project survey to update and augment this earlier work (reported in EPRI Interim Report NP-2611, Volumes 1 and 2) substantiated that a wide spectrum of reliability has been experienced in operating and maintaining "identical" shaft seal systems. The field survey responses were grouped into three general failure-cause categories: system-induced, maintenance-induced, and design-related. For each category, fault trees were constructed to describe how seven or eight events typically lead to the observed failure modes. This data analysis did not reveal a predominant event-failure mode relationship but rather pointed out that corrective actions in each of the three categories are necessary to improve seal and seal auxiliary-system reliability. These findings provided the bases for completing a comprehensive analysis of seal reliability and for developing guidelines with specific recommendations that would lead to improved MCP availability.

PROJECT OBJECTIVE

The overall goal was to develop a composite set of technical guidelines that can be used interactively by the utility, the nuclear steam systems supplier, the architect-engineer, and the pump manufacturer to increase the reliability of both the seal and seal auxiliary systems while at the same time to improve pump performance.

PROJECT RESULTS

This document is one part of the three-volume set of guidelines that has been developed to present the composite of required corrective actions. The volume titles are:

- Volume 1: Maintenance Manual Guidelines
- Volume 2: Operational Guidelines
- Volume 3: Specifications Guidelines

Woven through the specific details of each of these recommendations, a common problem-cause thread is apparent: the lack of an effective communication-response cycle between the pump seal supplier, the system designer, and the operational user. The data indicate that each of these parties has a contribution to add to the total corrective action. History indicates that successful mitigation of seal failure will only come about if these contributions are responded to in a spirit of mutual cooperation.

These guidelines are of interest to pump seal suppliers, system designers, and utility operations and maintenance staffs.

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ABSTRACT

This report presents a set of guidelines and a listing of information and data which should be included in maintenance manuals and procedures for Main Coolant Pump Shaft Seals. The noted guidelines and data listing are developed from EPRI sponsored nuclear plant seal operating experience studies. The maintenance oriented results of the most recent such study is summarized. The shaft seal and its auxiliary supporting systems are discussed from both technical and maintenance related viewpoints.

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SUMMARY

An investigation into main coolant pump (MCP) shaft seal failures in U.S. commercial nuclear power generating stations has been completed. The purpose of this project was to define the means to reduce high-cost, lost-power outages caused by MCP shaft seal failures. The initial effort consisted of a survey of U.S. commercial nuclear plants and led to the grouping of the observed failure modes into system/operational-related, maintenance-related, or design-related categories. A report (EPRI Interim Report NP-2611, Volumes 1 and 2, Main Coolant Pump Shaft Seal Reliability Investigation), containing the results of this survey was published in September 1982. The survey sample was representatively large (27% of total U.S. commercial plant population) and included the three industry seal suppliers (Bingham-Willamette, Byron Jackson, and Westinghouse Electric Corporation). Operationally incurred and/or induced problems and seal redesign parameters were identified. Failure hypotheses in the form of fault trees were developed to describe the failure mechanisms, and recommendations were made for seal reliability improvement.

The results of the survey reaffirm that the primary coolant pump shaft seals are complex and sophisticated devices. As a critical pressure-boundary component in the primary heat transport loop, the seal system is often taxed beyond design limits and forced into a failure mode. Experience shows that the seals have often been subjected to stress conditions exceeding their design capability because of improper operator procedures. In other instances, the overstresses were caused by seal auxiliary-system malfunctions or inadequacies. Problems during maintenance have been aggravated by a lack of appreciation of the component's sophistication and delicacy, and the findings show the severity and frequency of the "built-in" failures resulting from improper maintenance. Included, and synergistically interwoven amongst these field-induced problems, are the failures due to design shortcomings. These problems relate to the inherent parameters that require either a redesign for greater operating margins or alternate design mechanizations to improve the reliability of the shaft seal assembly.

From these results, user-oriented Maintenance Manual, Operational, and Specification Guidelines were generated. Each of the three volumes is written as a stand-alone

document. However, the solution to the seal failure problem will only come from the successful enactment of the recommendations in all three guidelines. These volumes are:

1. Volume 1: Maintenance Manual Guidelines. This volume represents a set of guidelines and a listing of information and data that should be included in maintenance manuals and procedures for MCP shaft seals. The maintenance-oriented results from the project's operating experience study are summarized. The shaft seal and its auxiliary supporting systems are discussed from both technical and maintenance-related viewpoints.
2. Volume 2: Operational Guidelines. This volume presents a set of guidelines and criteria for improving MCP shaft seal operational reliability. The data relating to usage procedures and practices and operational environmental influence on seal life and reliability from the project survey are summarized. The shaft seal and its auxiliary supporting systems are discussed from both technical and operational-related viewpoints.
3. Volume 3: Specification Guidelines. This volume presents a set of guidelines and criteria to aid in the generation of procurement specifications for MCP shaft seals. These guidelines were developed from EPRI-sponsored nuclear power plant seal operating experience studies, from a review of pump and shaft seal literature, and from discussions with pump and seal designers.

The recommendations in these three volumes of seal guidelines, if diligently applied, should enhance shaft seal procurement, operation, and maintenance, thus increasing equipment and plant availability.

MAIN COOLANT PUMP SHAFT SEAL MAINTENANCE MANUAL GUIDELINES

1.0 INTRODUCTION

Mechanical shaft seal reliability surveys sponsored by EPRI have disclosed a need for improving the performance and availability of end-face-type shaft seals used in vertical main coolant pumps (MCP's) and in recirculating pumps (RCP's). Forced plant outages caused by seal failure, identified either by excessive seal leakage, oscillating interstage pressures, or changes in seal cavity pressures, can be costly and are necessarily of concern. Prior shaft seal reliability surveys (see Reference 1 and Reference 2) have identified shaft seal failures caused by maintenance-induced failure modes. Poorly organized and improper shaft seal assembly practices range from faulty assembly, use of defective parts, improper installation, incorrect adjustments, damage in handling, inadequate maintenance training, to the introduction of contaminants during seal assembly or static pressure testing, which are among the major causes for seal failure. Figure 1 identifies the types of the most prominent maintenance-induced seal failures.

In general, all of the plants surveyed identified maintenance as an incipient failure inducing mode. The expressed opinion on the adequacy of training and availability of experienced maintenance personnel varied from an isolated response of total inadequacy to expressions of "highly trained, very experienced." The major portion of the surveyed plants fell between these extremes, thus indicating a definite need to improve personnel performance. Therefore, this document establishes guidelines and criteria that can be used as the basis for a more useful and reliable shaft seal maintenance manual for personnel training.

Some utilities are recognizing the benefits resulting from training and qualifying personnel specifically for pump seal maintenance. They have developed improved seal testing/inspection methods and handling

FIGURE 1 MAINTENANCE-INDUCED SEAL FAILURES

fixtures, and have utilized training aids such as mock-ups, films, and seminars to supplement maintenance manuals and procedures.

These guidelines discuss:

1. Drive system/pump interfaces and required information;
2. Mechanical seal system interfaces and required information;
3. Tools, gages, and test fixtures required for a proper assembly and installation;
4. Sequencing of seal cartridge shutdown, removal, disassembly, inspection refurbishing, and assembly; and
5. Visual training aids and introduction to proper care and handling of seal components and assemblies.

It is recommended that the implementation of the shaft seal maintenance manual guidelines also be directed towards upgrading the manuals now available in the field. The recent survey disclosed several poorly organized, field-corrected manuals that were likely to cause more harm than good. There were examples of manuals and procedures that had been hand corrected, with instructions and sketches made in margins and on loose scraps of paper. These informal corrections or changes had apparently been made by both station personnel and field service men and not followed up with subsequent formal document action. As a result, neither the user nor vendor engineering staff are aware of these changes.

Seal maintenance requires that the reactor be in a cold shutdown state. The pump coupling half must be removed. Most pumps contain a spacer coupling which permits the removal and replacement of seals without having to remove the motor or the motor coupling half. The pump coupling half, in some cases, is a tapered hub which is shrunk fit on the pump shaft and must be removed to gain access to the seal. Some older pumps do not have the spacer and require motor removal prior to seal maintenance.

Access to the seal housing is normally through large cutouts in the motor mount structure, but access to these areas is often constrained by external interferences such as:

- Other reactor system components;
- Containment walls;
- Structural elements;
- Pipe runs;
- Instrumentation lines; or
- Cable trays.

These physical access limitations add another dimension to the seal maintenance tasks and must be accounted for in the development of the total seal maintenance program.

Seal removal and replacement (R&R) requires the use of overhead rail-supported fixtures. Once a new seal is installed, the seal cover and spacer coupling are secured and the pump-motor shaft is aligned. Any disturbance to the balance of the pump-motor rotating assembly may either subject the refurbished seal to undue vibration-induced stresses or require balancing in place.

Two methods are presently used for assembling and installing mechanical seals.

1. The single cartridge method.

The assembly is made up as a self-contained package, including seal faces (rings), back-up rings, elastomers, shaft sleeve, springs, pressure breakdown cells and other ancillary parts, all of which are preassembled with a controlled static seal face loading. After bench testing for hydraulic integrity, the cartridge is installed over the pump shaft with the shaft sleeve properly positioned.

2. The limited shaft seal assembly arrangement.

The installation of this arrangement consists of limited preassembly of seal components and assembly of the remainder at the pump site and over the pump shaft. This method requires extreme care and protection against contamination and calls for careful positioning of critical parts in a confined space.

2.0 EQUIPMENT DESCRIPTION

To gain the perspective of the overall influence of maintenance on the operational integrity of shaft seals, the following sections describe shaft seal operating principles, seal auxiliary systems, system instrumentation, and the pump/primary coolant system characteristics which affect seal performance.

Since the relative merits of hydrodynamic and hydrostatic configurations are not at issue, we describe the general design highlights and their attendant operating and maintenance constraints to support the development of maintenance manual guidelines contained herein.

2.1 Hydrodynamic Seals

Control of the leak rate using a hydrodynamic seal (Figure 2) depends upon the action of mechanical spring forces and fluid pressure on unbalanced areas of a seal ring to provide seal face closure. The sealing surfaces are separated only by a thin fluid film. This film is generated by the hydrodynamic pumping action caused by the rotational velocity of one of the seal faces and the pressure gradient across the sealing gap. Because of the thin-film seal face separation, hydrodynamic seal leakage is normally less than one gallon per hour (gph). These low-leakage seals are, however, sensitive to the level of the closing force. Therefore, balance ratios and spring load magnitudes are very important design-controlled parameters. If the closing force is too high, the seal faces will contact during operation. The wear and heat generation between the rubbing surfaces varies directly with the magnitude of the closing force. Such wear and heat generation can become excessive very rapidly and lead to catastrophic seal failure. If the closing force is too light, the faces will readily separate with attendant high leakage.

Hydrodynamic seals are comprised of two, three, or four tandem stages, as shown in Figure 3. The number of stages depends on the primary coolant system pressure that must be contained. BWR installations operate at a nominal 1100 psi pressure, with each of two sealing stages subjected to approximately 550 psi differential pressure. PWR primary coolant loops operate at about 2150 psi, and three sealing

FIGURE 2 HYDRODYNAMIC SEAL STAGE TYPES

FIGURE 3 A TYPICAL 3 STAGE HYDRODYNAMIC SEAL ARRANGEMENT (WITH A 4TH VAPOR STAGE)

stages are used to divide differential pressure evenly across each stage to approximately 700 psi. The interstage pressure breakdown is accomplished by circulation of water through flow impedance paths between the seal stage cavities, which are series connected. Each such cavity contains the components that comprise a single mechanical seal stage (refer again to Figure 2). It should be noted that a low-pressure fourth sealing stage (referred to as a vapor seal) is utilized in some hydrodynamic seal installations. This fourth stage operates similarly, in principle, to its upstream higher pressure stages but at a differential pressure of less than 50 psi. In the event of a failure of the preceeding stage, this sealing element is designed to contain full system pressure for a limited time.

A typical hydrodynamic mechanical seal stage consists of a rotating flat face ring, driven by the seal shaft sleeve, and a stationary mating face supported by the pump/seal housing. The rotating face has freedom for axial and angular movement to allow for the formation of a thin fluid film of uniform cross section over the mating seal face area. This is accomplished by a spring-loaded flexible seal ring mechanization, as shown in Figure 2. An elastomer is used as a sliding secondary seal between the tandem differential pressure staging cavities. These secondary seals are in the form of O-rings, U-cups, and bellows. The backing springs also serve to provide full seal closure during pump static conditions and aid the hydraulic seal face force balance when the pump is running.

In addition to the rotating and stationary seal rings mentioned above, there are other precision-lapped rings used to maintain squareness and rigidity of the faces/rings in running contact. These are referred to as "back-up rings."

2.2 Hydrostatic Seals

The hydrostatic seal, conceptually represented in Figure 4, is a self-regulating, force-balanced sealing device. The balance is achieved by summing: 1) the axial closing spring and pressure forces behind the stationary seal ring; and 2) the force generated by the opening pressure force in the gap between the rotating collar and the stationary seal ring. The opening force results from the radially inward decreasing

FIGURE 4 TYPICAL HYDROSTATIC SEAL STAGE

gap between the seal faces, which forms a converging film thickness in the sealing interface. This tapered-gap geometry produces a higher film-pressure opening force between the collar and stationary seal faces than that which would exist were the faces flat and parallel. The fluid being sealed flows radially inward toward the shaft in the converging direction of the tapered seal face. If the seal ring tends to close, the interface pressure increases and the ring is forced back to its steady-state operating position. Conversely, if the seal ring tends to open, the interface pressure decreases, which reduces the load-carrying capacity of the film, and the axial pressure/spring force restores the seal to its steady-state position. Thus, the interface film profile serves as a position feedback mechanism to provide a positive restoring force to the seal ring for steady-state gap separation. Because of its relatively large separation gap, leakage through the hydrostatic seal interface is in the range of 3 to 5 gallons per minute (gpm).

Seal assemblies designated as hydrostatic are also multistage devices (see Figure 5). Only the first, high-pressure stage is hydrostatic in nature, with subsequent stages operating on the thin-film hydrodynamic principle. Therefore the assembly may be referred to as hybrid-hydrostatic. The first hydrostatic stage operates with full system differential pressure of approximately 2150 psi. Pressure reduction is to approximately 50 psi for the second stage. The second seal stage is designed to contain the full system pressure for a limited time in the event that the high-pressure stage fails. In this condition, however, seal leakoff rate increases to about 25 gpm.

2.3 Description of the Vertical Centrifugal Pump/Seal and the Motor Interface

Electric-motor-driven, single-stage, vertical centrifugal pumps provide the primary coolant circulation in U.S. commercial nuclear power generating plants. The pump and motor shafts are rigidly coupled and are rotationally guided by two oil-lubricated motor bearings and one pump water bearing. Axial thrust loads are supported by a thrust bearing in the motor assembly. A typical pump and coupling are shown in Figure 6.

FIGURE 5 A 3-STAGE HYBRID HYDROSTATIC SEAL ARRANGEMENT

FIGURE 6 TYPICAL VERTICAL COOLANT PUMP ARRANGEMENT

Proper mechanical alignment between the vertically mounted electric motor (drive) and the pump shaft is critical. Because the coupling between the two vertical shafts is angularly rigid and axially solid, an improperly aligned pump-motor shaft can cause angular and lateral misalignment that may exceed the acceptable design limits set by the seal designer.

These misalignments can interfere with the forming and maintaining of the film (40-400 micro-inches) separation required between the mating seal faces for normal seal operation. Other destructive vibrational forces within the seal assembly can result from pump-motor misalignments. Besides angular and lateral alignment considerations, critical axial stack-up tolerances must also be established and maintained in order to prevent a premature seal malfunction (see Figure 7). The axial position of the coupling forms the reference point for the proper adjustment to locate the seal shaft sleeve within the seal assembly. Meeting the specified axial location of the shaft sleeve is essential in providing necessary seal face unit loading prior to pump startup.

For instance, if an improper stackup or shaft sleeve setting exists, then one of two early failure modes will occur: 1) excessive seal leakage; or 2) excessive face wear.

Another concern that may exist is that of maintaining the cold pump alignment when approaching the hot pump operating conditions. It may be that maintaining the cold alignment is impossible, but awareness of this effect may enable operating personnel to accommodate for the expected thermal changes when establishing the cold pump alignment.

2.4 Pump Shaft Seal Interface

An axial shaft displacement of approximately one-eighth of an inch must be accommodated within the seal assembly. This requirement places stringent operating limits on the back-up springs and on the allowable distortion/displacement of the secondary elastomeric seals. Such axial motions arise from:

1. Downthrust caused by the weight of the rotating assembly;

FIGURE 7 MOTOR/PUMP COUPLING - AXIAL STACKUP

2. Pump shaft length changes because of steady-state and transient thermal variations;
3. Action of the oil lift system when lifting the pump shaft off the thrust bearing at startup to reduce motor starting torque load;
4. The resultant axial thrust loads on the pump shaft; and/or
5. Motion resulting from the motor rotor seeking its magnetic center.

The displacement freedom designed into the seal assembly must not be compromised during seal maintenance activities.

The desired operating fluid film gap between the mating seal faces is on the order of 40 and 400 microinches, respectively, for hydrodynamic and hydrostatic seals. A constant fluid film gap must be maintained, even though the motion to gap size ratio (with a typical 1/8 inch shaft displacement) is approximately 300 to 1 for the hydrostatic seal and 3000 to 1 for the hydrodynamic seal. Because of the very small hydrodynamic gap, face flatness and roughness is critical to seal functional integrity. Hydrodynamic seal faces are precision lapped for flatness within 20 microinches, with comensurate surface finishes. Such stringent seal face flatness and surface finish requirements impose demanding care in rework, handling, assembling and installing main coolant pump seals.

The closeness of the hydrodynamic sealing surfaces requires that materials used for the rotor and stator faces must tolerate continuous low-speed and intermittent high-speed contact without serious wear or galling on either face. A material combination such as titanium carbide for one of the rings and a carbon composite for the mating ring is an example of a compatible set used for hydrodynamic seals. On the other hand, hydrostatic seals cannot tolerate any contact between opposing seal faces, even at low/startup speed conditions. Pressurization of the hydrostatic seal cavity must be completed prior to shaft rotational motion in order to separate the seal faces. Thus, although a larger operating gap is maintained, the tolerance to damage from dynamic contact of the seal faces is much smaller for hydrostatic seals.

Lateral and angular displacements between the stationary and rotating seal faces result from:

1. Motor-pump shaft centerline misalignments;
2. Hydraulic moment unbalance caused by a lack of concentricity between the rotating and stationary seal faces;
3. Thermally induced seal ring deformations that change the size and shape of the gap between the seal faces;
4. Shaft or seal support deflections allowing a shaft tilt which in turn induces a wobble in the rotating face;
5. Steady state and dynamic hydraulic impeller forces; or
6. Shaft loads due to an unbalance in the rotating assembly.

An angular displacement (tilt) of one of the seal faces with respect to the other causes a widening of the gap on one side and closure on the other. Since proper sealing requires a small gap size and since seal ring diameters are large (i.e., 7 to 12 inches typically), very small tilt angles (e.g., 4×10^{-4} degrees) can cause rubbing contact between the sealing faces on one side while concurrently opening up the leakage path on the other. As previously noted, rubbing contact between the mating faces, at the high rotational speeds of operating pumps, accelerates wear and generates considerable heat energy, conditions that reduce seal life drastically and/or rapidly induce catastrophic seal failure.

Lateral displacements of the shaft at the seal assembly cause the secondary elastomeric seal to rub against the mating walls. This causes the fretting often noticed during seal refurbishment. Excessive internal seal heat generation or lack of adequate cooling to the seal assembly further aggravates this problem, since elastomers harden under excessive heat loads. Proper transmittal of seal tracking force requires compliant elastomer properties, and hardening adversely affects the ability of the assembly to maintain the proper seal face gap clearance.

However, some lateral cyclic (orbiting) motion of the rotating seal ring against the mating surface may be beneficial, since it provides an increased seal gap flow that increases the heat removal capability and decreases seal face wear.

Temperature-controlled, pressurized, clean water must be provided for proper and reliable shaft seal operation. Seal water delivery systems may vary in physical configuration and design detail, but they are functionally similar and provide for:

1. Delivery of sufficient flow of water at the required pressure within prescribed temperature limits;
2. Prevent ingress of contaminants to the seal cavity;
3. Collection and return of the seal leakage flow;
4. Collection and return of the controlled staging flow water (leak-off);
5. Pressurization of the seal assembly prior to pump startup to provide adequate staging flow for hydrodynamic seals and to assure separation of hydrostatic seal faces; and
6. Venting of gas voids trapped or carried to the seals by circulating water.

Typical seal auxiliary systems for hydrodynamic and hydrostatic seals operating in MCP's are shown in Figures 8 and 9 respectively. In the case of systems with injection, an independent source provides the high-pressure cooled water to the seal. The injection supply is at a slightly higher pressure than the pump case pressure. As a result, some of the injection supply enters the primary coolant loop and the rest flows through the seal. In this manner the primary coolant is blocked from entering the seal assembly. Water cleanliness is beneficial to seal operating integrity. The introduction of debris into the primary coolant loop during assembly/maintenance and the transport of corrosion products (crud) generated in the primary coolant loop can be avoided by using an independent injection water supply to the seal. If the injection supply is interrupted, seal cooling and lubrication is still available from cooled primary coolant supplied from the pump internals. Thus the use of injection can provide seal water supply redundancy. In the injectionless systems, seal cooling and lubrication is accomplished by circulating the high-pressure primary coolant through heat exchangers and then introducing the reduced-temperature coolant to the seal. The heat exchanger is cooled by low-

FIGURE 8 HYDRODYNAMIC SEAL AUXILIARY SYSTEM

FIGURE 9 HYBRID-HYDROSTATIC SEAL AUXILIARY SYSTEM

pressure, externally supplied component cooling water (CCW). In this case, single-point loss of CCW will adversely affect seal life. Numerous seal failures have been reported subsequent to interruption of the cooling water supply. The use of an independent seal injection does not automatically provide reliable cooling redundancy unless the CCW heat exchanger capacity is adequate to handle the additional heat load imposed on it when the injection supply is lost. Several instances have been noted in which the loss of injection precipitated seal failures because of the thermal transients associated with this event. A cursory review of the various designs disclosed that the seal heat exchangers are not easily removed or dismantled. In general, the heat exchangers are adequately sized but it may be advisable to take preventive measures, by means of proper CCW treatment, to reduce the degradation of heat transfer effectiveness caused by shell-side fouling.

Water contaminants in the form of system corrosion products, wear residue from system components, or foreign materials introduced during assembly, fill, or maintenance can cause seal failure. In the case of hydrodynamic seals, such contaminants may create unequal staging differential pressures by partially or totally blocking the staging flow path. This will cause dry running (zero differential pressure across the sealing gap) in the seal stages that have lost the staging pressure differential. Additionally, small-particle transport to the seal interface will cause accelerated wear through the destruction of the highly polished, lapped, seal faces.

Contaminants are equally damaging to the hybrid hydrostatic seal mechanization. Two of the three seal stages in this assembly are of the hydrodynamic type. Therefore the preceding discussion applies here. In addition, larger particles find easier entrance at the opening of the taper wedge interface and buildup a blocking accumulation that can upset the load-carrying capacity of the seal to the point of collapse of the separating film.

Since water contaminants are detrimental to seal reliability, it is imperative, from a maintenance point of view, that the primary coolant and the auxiliary injection system, when used, be maintained at a high degree of cleanliness. The injection system supply water inlet is located within the lower seal cavity in such a way that the injected

fluid flushes any debris/crud from the primary coolant system downward, away from the sensitive seal faces. Whenever possible, adequate filters and debris alarms should be used to protect the seal.

2.6 The Controlled Bleedoff System and Instrumentation

There are basically two types of controlled bleedoff (CBO) systems. They are pictorially shown in Figure 8, Hydrodynamic Seal Auxiliary System, and Figure 9, Hybrid-Hydrostatic Seal Auxiliary System. Both figures represent vertical MCP's for a PWR plant.

Seal survival is dependent upon maintaining the CBO line free so that there is an equal differential pressure across each cavity. The hydrodynamic seal system uses built-in throttling devices (sometimes coils of tubing), in series from high pressure to low pressure, to obtain the equal differential pressures. The flow through the CBO ranges from 0.7 to 1 gpm. The fluid passing through the CBO line and seal cavities will consist of seal leakage and either injection fluid or cooled primary coolant. It is essential for prolonging seal endurance that the CBO line remain open at all times during normal pump/plant operations. With the proper CBO flow, the differential pressure across each seal face will be maintained at the desired design condition.

When the typical hydrodynamic seal auxiliary system is injectionless, reactor coolant cooled by heat exchangers contained within the pump provides cooling to the seal cavity. These heat exchangers are cooled by low-pressure component cooling water. Annunciating alarms are often provided to alert operating personnel to the incurrence of dangerous staging flow or seal cavity operating temperature conditions. Functional integrity of seal staging is determined by differential pressure sensors across each seal stage.

The sealing system shown in Fig. 9 supports a hybrid-hydrostatic seal assembly (i.e., a hydrostatic first stage followed by two subsequent hydrodynamic seals). Pumps with hydrostatic seals contain a thermal barrier heat exchanger that is cooled by low-pressure component cooling water. Injection supply of about 8 gpm is provided, of which, typically, 3 gpm flows up to the seal, most of which is returned

through the No. 1 leakoff line. The second-stage seal leakoff is approximately 3 gph at a seal cavity pressure of 50 psi. A standpipe riser tank, as shown in Fig. 9, also serves as the leakage collection tank and provides a head of approximately 5 to 10 feet of water to the third-stage seal cavity. If the third-stage leakage exceeds that of the second stage, make-up water is supplied to the third seal cavity from the No. 2 seal leakoff supply.

Means to control and measure injection flowrate to each pump type are provided. These controls, as well as pressure sensors, flow recorders/alarms, and temperature probes in various parts of the circuit, are lumped and schematically shown as the seal supply control system. The first-stage leakoff is measured by flowmeters and the second-stage leakoff, which is below the threshold of normal flow-measuring instruments, is determined by integrating the flow that collects in the standpipe riser collection tank over a period of time. If the third-stage seal leakage is too high, the tank fills until it reaches an overflow level, whence fluid is returned to a central collection/processing area. To aid the operator in assessing the integrity of these seals, second-stage high and low leak flows are detected by level sensors on the standpipe collection tank. The No. 1 seal bypass line is closed during normal operation. This line is normally opened only during startup and venting procedures.

The foregoing discussion provides only a broad, general overview into seal operating principles. It is presented to heighten the reader's awareness of the:

1. Engineering sophistication and tolerance sensitivity of the sealing device;
2. Adverse effects from harsh operating environment;
3. Tight performance demands of typical thermal-mechanical duty cycles; and
4. Sensitive interfaces between the seal and other system components and subsystems on whose proper performance seal reliability and longevity depends.

The maintainability conditions are equal in severity to the operating environment. In some instances, maintenance personnel have complained of the lack of satisfactory access to pump shaft seals. These complaints encompass the tight workspace around the seal and the awkward/difficult to reach aspects associated with seal removal and replacement.

Nuclear power plant maintenance must often be performed under conditions of radiation, temperatures above 100°F, steam leaks, excessive noise, poor illumination, and awkward work access and footing. The problems of servicing equipment under these conditions are compounded by the fact that all too often, emphasis on maintainability was compromised during the plant design phase. It has been demonstrated by the military and numerous complex space programs that maintainability must be a controlled design specification parameter, or the consequences of unavailability and logistics can elevate the life cycle costs to unacceptable levels.

If a conducive seal servicing environment has been provided for by design, maintenance guidelines and criteria can focus only on the serviceability of the seal. Since such servicing conditions are not provided for in many nuclear power plants, effective seal maintenance is compromised. This is visible in the response from utility participants of the seal experience surveys noted in References 1 and 2.

Access

A major complaint voiced by maintenance personnel has often been the lack of satisfactory access and footing around the seal/pump area. Limited access through motor mount cutouts to remove fasteners can be a problem. The situation is even more acute when large torque wrenches (requiring two men to operate) must be used to properly secure fasteners. In such situations, the torque wrench indicator is often not readily visible. Such inaccessibility problems associated with the placement of components in locations that render them difficult to reach or place them beyond visual limits compromise the reliability of the equipment. Such reliability degradations are not the fault of the

maintenance technician but of the designer of the installation. Nevertheless, inaccessibility is a maintenance problem.

Seals are often damaged during the handling/transport phase. Seal cartridges are dropped, have been moved by sliding and bumped/bounced during handling. The necessity to physically handle excessive loads is a matter of inadequate system design from the human factor's point of view. Maintenance personnel must often find ways to overcome these design oversights which neglected to consider the range of human strength capability. Awkward and obstructed provisions for seal cartridge removal and replacement and lack of attention paid to proper handling fixtures have contributed to numerous failures whose root cause emanates from such improper maintenance provisions. It is primarily because of the lack of planning that maintenance personnel are forced to improvise their own solutions. Such solutions vary between individuals and from time to time. Because of these improvisational aspects associated with seal maintenance at many power plants, a seal maintenance procedural review should be conducted.

3.2 Labels

For a variety of reasons many plant components either are not identified or the identification is difficult to read because of size, location, or lack of contrast between tag and lettering. Often identification tags that were originally in place have been removed. Such conditions invariably lead to improper location of components needing repair, adjustment or procedural manipulation. For example, seal problems have been introduced by the use of incorrect vent valve open/close operating sequence. Improper vent valve operation can reverse the pressure on secondary sealing elements such as "U" cups, thus relieving the preload on the "U" cup follower, unseating the "U" cup and/or creating other problems such as drive lug loosening/dislocations. These problems are all real and have occurred. Improper valve sequencing may be reduced by properly labeled valves. The problem of missing identification tags is very great. The literature estimates that anywhere from 10 to 50% of the original labels are now missing. This is complicated by the fact that components are often visually obstructed. Thus, although a pervading general problem is noted here, it obviously impacts on the specific subject of seal maintenance.

3.3 Improper Storage/Warehousing Problems

Numerous instances have been reported where incorrect replacement parts have been installed in seals being refurbished. Many of these incidents may be caused by incorrect part identification or difficult retrieval systems associated with poorly organized stock rooms. Needless to say that the serviceman bears the prime responsibility of identification of correct replacement parts. Identification errors on the part of the warehouse mislead the serviceman and increases the chance of wrong parts usage in seal refurbishment.

3.4 Procedures, Manuals, Maintenance-Related Information

One of the most consistent responses contained in the recent shaft seal reliability survey was associated with the inadequacy of detailed maintenance related information concerning shaft seals. Suppliers were blamed for not providing required data to understand seal operation and seal diagnostic procedures. Detail drawings and detail tolerance and assembly stack-up dimensions are among the data required by seal service personnel. Lack of vendor supplied information is part of the problem, and manuals and procedures in many instances do not contain sufficient detail. However, some of these documents contain hand-written corrections and revisions which are never followed up by review through more formal channels. As a result, the validity of the changes may be questionable. If, on the other hand, the corrections are valid, they may rest only in one book and a desirable change is lost to others. The fact that hand-scribbled revisions in margins exist in seal maintenance documents is indicative of improper inspection/QC associated with these tasks. Good QC practices require that functional organization elements review workmanship procedures and changes thereto.

A Sandia Corporation study (Ref. 3) reviewed all of the Licensee Event Reports over a four-year period and identified 751 personnel error-related problems associated with maintenance, test, and calibration activities. Table 1 reflects these summary findings and indicates that the most frequent cause of error was noncompliance with procedures. Other prominent problems were attributed to inaccurate and incomplete procedures. These data are indicative of the importance of procedures

TABLE 1

RELATIVE FREQUENCIES OF CLASSES OF PERSONNEL ERROR ASSOCIATED WITH THE PERFORMANCE OF
MAINTENANCE, TEST, AND CALIBRATION ACTIVITIES (FROM REF. 3)

<u>Performance Deviations</u>	<u>Frequency of Reported Events (4 yrs)</u>			<u>Percent of Reported Events</u>		
	<u>Maintenance Activities</u>	<u>Test Activities</u>	<u>Calibration Activities</u>	<u>Maintenance Activities</u>	<u>Test Activities</u>	<u>Calibration Activities</u>
Noncompliance with Procedures	132	55	49	39	21	32
Misalignment of Valves, Breakers, Fuses, and Switches	84	95	12	25	36	8
Preparation of Inaccurate Procedures	13	32	49	4	12	32
Preparation of Incomplete Procedures	37	34	20	11	13	13
Inadequate Revision of Procedures to Reflect Changes in Equipment or Specifications	15	22	12	4	8	8
Failure to Inform Others of Necessary Actions Following Completion of Procedure	29	10	1	9	4	1
Misinterpretation of Communications	23	7	2	7	3	1
Misunderstanding of Procedures	3	9	6	1	3	4
TOTALS	336	264	151	100	100	99

in reducing human error in maintenance.

3.5 Preventive Maintenance

MCP and RCP shaft seal reliability has been compromised by a lack of timely attention-getting indications of developing malfunction trends. Seal systems are well instrumented for critical operating parameters of pressure, temperature, flow, and vibration. However, preventive maintenance through trend tracking is not routinely practiced in many power plants. Earlier seal reliability surveys (References 1 and 2) reported opinions that seals have failed during delays in transmission of, or inattention to caution-warning information to operators. For example, the chart recorders used to monitor critical seal flow information are located in remote locations in some operating plants. In addition, many recorders are overloaded and others do not dedicate a channel to critical seal operating data. As a result, seal performance trends (which can be used to prevent major seal-caused outage) are often overlooked.

In this context, it is interesting to note that many of the instrument gauges throughout the various plants are not color banded to give the observer an indication of the normal, marginal, or abnormal status of the measured parameter. Proper coding of such displays would aid in timely alert to a malfunction trend so that maintenance may be instituted at the earliest time. An effective and systematic preventive maintenance program can prevent serious equipment damage, minimize the occurrence of unscheduled outages and reduce scheduled outage duration.

3.6 Training

As previously noted, there is a general feeling in nuclear plants that training efforts for maintenance personnel have not received sufficient attention. Over 25% of the respondents to the recent seal reliability survey identified inadequate training of maintenance personnel as a contributor to the seal problems encountered at those plants. Previous estimates of inadequate maintenance training as a contributor range as high as 60% of the respondents. This change gives evidence that the need for improved maintenance training for nuclear plants is recognized and improvements in this area are in progress. Consistent with this

recognition is the developing interest in training aids. While the value of control room simulators has been clearly perceived in the training of control room personnel, no such general acceptance has crystalized with respect to widespread use of training mock-ups for maintenance purposes.

Shaft seals are complex assemblies of numerous close tolerance parts and require knowledgeable and skilled personnel for accomplishing proper maintenance, both at the pump site for removal/replacement and in the shop for rebuilding. During these operations critical dimensions, adjustments, processes, and procedures must be measured and adhered to. For example, sealing faces must be maintained within the order of 20 microinches of flatness (with commensurate surface finish). Handling during the assembly process must insure cleanliness consistent with such close tolerances. Whereas lubricants are required for the elastomers contained in the assembly, seal face lubricant contamination must be avoided. Additionally, the assembly must provide for specified axial travel freedom to accommodate pump shaft operational displacements. Such a critical assembly procedure is greatly aided by use of training mock-ups, made of clear lucite with color-coded internal parts for easy step-by-step viewing. The training program should include the installation of the mock-up seal cartridge with the installer wearing the required protective garments. It has been reported that making the final critical dimensional settings (in thousandths of an inch) through multilayered gloving is difficult and requires a level of patience which is not always present. Faulty assembly of seals and improper installation of seals into pumps have been repeatedly experienced by 80% of the power plants participating in the recent seal reliability study. The implementation of training aids for maintenance purposes will certainly go a long way in decreasing the incidence of such maintenance induced failure modes.

4.0 MAINTENANCE MANUAL GUIDELINES SUMMARY

Having reviewed pertinent EPRI reports and the results of the recent survey (Reference 1), and after numerous discussions with Byron Jackson personnel, i.e., designers, engineers, and field servicemen, the following MCP and RCP seal maintenance manual guidelines have been generated. The intent of the guidelines is to provide a checklist of

information and data needed by the utilities to specify the contents and requirements of an effective seal maintenance manual. The guidelines may at times appear too detailed and at times rather general in nature. That is because of the difficulty of isolating and identifying the operational boundaries of a typical shaft seal assembly and its system interfaces. It was apparent from the field information gathered that there is 1) a need to upgrade existing plant maintenance manuals and 2) to specify the requirements and contents of newly prepared manuals. The contents of these manuals should contain technical descriptions, engineering-design information, cartridge removal information, assembly/disassembly information, important interfacing dimensions, critical adjustments, cooling water thermal and cleanliness requirements, necessary tools/gages and fixtures, seal operating acceptance criteria, static test acceptance criteria, application of trending instrumentation, parts shipping, receiving inspection and storage conditions.

The guidelines include the following critical areas of concern:

1. Motor/pump interface;
2. Seal system interface;
3. Necessary tools, gages, and fixtures;
4. Servicing the seal assembly/cartridge; and
5. Interface control drawings and critical part dimensions.

4.1 Motor/Pump Interface

Proper alignment of the motor shaft to the pump shaft is essential to successful seal performance. Because the pump/motor coupling is rigid, any angular, lateral, or axial misalignment can cause faulty seal performance. The failure modes are usually excessive leakage, extreme face wear, or broken seal faces.

The following information should be included in a maintenance manual accompanied by detailed instructions and measurement procedures aided by well-labeled drawings.

4.1.1 Motor

- a. Shaft extension ____ + ____
- b. Shaft diameter ____ + ____
- c. Acceptable shaft runout + ____
- d. Shaft end float + ____
- e. Motor flange rabbet fit ____ + ____
- f. Shaft perpendicularity to motor baseline
- g. Static turning torque:
 - Axially loaded ____
 - Axially unloaded ____
- h. Key/keyway fit ____ + ____
- i. Split ring fit ____ + ____
- j. Method for centering motor shaft in bearing
 - Top
 - Bottom
 - Both

4.1.2 Motor Shaft Coupling Half

- a. How installed
- b. Inside diameter ____ + ____
- c. Keyway fit ____ + ____
- d. Location on shaft, distance from end of shaft ____

4.1.3 Spool Piece or Spacer

- a. Overall length ____ + ____
- b. Spacer-hub-to motor coupling hub runout + ____
- c. Spacer-hub-to pump coupling hub runout + ____
- d. Axial pump thrust plate thickness ____ + ____

4.1.4 Pump Shaft Coupling Half

- a. Type of shaft fit:
 - Taper
 - Shrink
 - Curvic

- b. How applied to shaft end:
 - Shrink heat _____ °F + _____ °F
 - Bolted _____ ft-lbs _____ + ft-lbs
- c. In-place location on shaft end:
 - From shaft end _____ + _____
- d. Key/keyway fit _____ + _____

4.1.5 Coupling Assembly

- a. Weight _____
- b. Center of gravity _____
- c. Acceptable runout on spacer:
 - Cold _____ + _____
 - Hot _____ + _____
- d. Acceptable distance from seal flange to pump coupling face:
 - Cold _____ + _____
 - Hot _____ + _____
- e. Torque values (specify critical fasteners):
 - Fasteners _____ + _____
 - Pump shaft nut _____ + _____

4.1.6 Axial Shaft Sleeve Adjustment Plate

- a. Sequence of installation
- b. Extension of mechanical shaft sleeve above seal flange _____ + _____
- c. Acceptable gap clearance between adjustment plate and seal flange:
 - Cold _____ + _____
 - Hot _____ + _____

4.1.7 Manual Pump/Motor Shaft Acceptable Turning Torque Measurements

- a. Breakaway _____ + _____
- b. Turning _____ + _____
- c. Where to grab coupling/shaft

4.1.8 Coupling Disassembly/Assembly Sequence and Match-Marking

- a. Disassembly
- b. Parts wrapping and care
- c. Parts storage
- d. Inspection
- e. Assembly

4.1.9 Pump Shaft Coupling Half Removal

- a. Removal
- b. Replacement criteria
- c. New parts acceptance criteria
- d. Installation

4.1.10 Identified Fixtures and Gages for Checking New and old Coupling Parts

- a. Taper plug gages
- b. Bore plug gages
- c. Curvic teeth gages or blueing-in procedures

4.1.11 Acceptable Mounting, Location, and Calibration of:

- a. Dial indicators
- b. Proximometers
- c. Accelerometers
- d. Shaft Key Phasor Probes

4.1.12 Vibration

Identify allowable levels at specific locations

4.2 Seal System Interface

The mechanical shaft seal assembly system interface boundary includes internal fluid cooling, internal heat exchangers, seal injection water, internal CBO lines and leakoff, venting, leakage collection, and the necessary trending instrumentation.

The following is an outline of maintenance-related information that should be contained in a productive manual.

4.2.1 Internal Cooling Required Information

- a. Working as built schematic of the internal flow circuitry.
- b. Head-capacity of the internal recirculating pump ____ ft,
____ gpm.
- c. Heat exchanger
 - Tube surface area ____.
 - Shell surface area ____.
 - Fouling factor ____.
 - How to clean or reduce fouling.
 - BTU/Hr rating ____.
- d. Acceptable CCW temperature control range and limits.
- e. Acceptable CCW flow range and limits.
- f. Acceptable CCW cleanliness and chemistry:
 - Particle size ____
 - Chemistry ____
 - Type and size of filter, if required ____
 - Filter differential pressure actuated relief valve requirements.
- g. Estimated hours to seal failure after loss of CCW ____.
- h. Internal thermocouples:
 - Where to locate
 - Temperature ranges and limits ____ to ____
 - Alarm setting ____
- i. Effects of thermal shock and thermal soak on the:
 - Carbon seal face
 - Carbide seal ring
 - Backup rings

- Elastomeric seals

4.2.2 Controlled Bleedoff and Leakoff Required Information

- a. Working as built schematic of the CBO and leakoff flow system internal to the pump:
 - Type of pressure-reducing device(s)
 - Head loss vs. flow
 - Temperature effects on flow/pressure
- b. Maximum particle size that system will pass ____
 - Wear or erosion effects on pressure drop.
- c. Effects of plugging.
- d. Effects of a high system back-pressure.
- e. Effects of valving off the CBO or leakoff line.
- f. If a close-clearance throttling device is used (earlier BWR systems), what are the effects of a nonconcentric bushing on pressure drop?
- g. If coils of capillary tubing are used:
 - How to remove and replace
 - When to remove and replace
 - How to change flow resistance for fine tuning
 - How to pressure-check each coil pressure
- h. Acceptable flow range and limits
- i. Should valves be in the CBO/leakoff lines? If so:
 - Should they be manually actuated?
 - Automatically engaged?
 - With remote sensing?
 - When should they be engaged?
- j. Effects of loss of CBO/leakoff flow:
 - On seal cavity differential pressure

- On the face lubricating film
 - On seal face wear
 - On seal life after loss of flow
- k. Effects of CBO and leakage flow on interstage cooling.
- l. Recommended instrumentation for:
- CBO/leakage flow
 - Seal-stage pressure and differential sensing
 - Seal-stage temperature sensing
- m. Interpretation of trending information relating to seal performance forecasting:
- Changing pressure trends
 - Changing temperature trends
 - Changing flow trends
- n. Use of the CBO/leakoff flow lines for venting.
- o. The effects of a pressure transient on the:
- Carbon seal face
 - Carbide seal ring
 - Backup rings
 - Elastomeric seals
 - Shaft sleeve

4.2.3 Seal Injection Water System Required Information

- a. A working as built schematic of the pump internal flow paths:
- Flow impedance per path, if flow is divided within the pump
 - Temperature effects on flow/pressure
- b. Acceptable injection water inlet pressure range ____ to ____
- Permissible peak-to-peak pressure if a piston pump is used ____ + ____
- c. Acceptable water inlet temperature range ____ to ____

- d. Acceptable water cleanliness and chemistry requirements:
 - Particle size ____
 - Chemistry ____
 - Type and size of filter, if required ____
 - Filter differential pressure actuated relief valve requirements
- e. Recommended alarm settings:
 - Pressure ____ to ____
 - Temperatures ____ to ____
 - Flow ____ to ____
- f. A written description of the injection system to include:
 - Its flushing capability
 - Its cooling capability
 - Effects if the injection is lost
 - Estimated length of survival of shaft seal and related components without injection

4.2.4 Required Mechanical Shaft Seal Venting Information

- a. A working as built schematic of the optimum venting system internal to the seal cartridge and pump.
- b. Recommended phase to start venting:
 - At initial installation
 - During partial fillup
 - During partial pressurization
 - At full speed
 - At partial speed
 - At zero speed
 - Run-vent-run
 - At maximum temperature
 - At midrange temperature
 - At minimum temperature
 - With seal injection
 - Without seal injection
 - Allow soaking time at high pressure for several hours
 - Or a combination of the above

- Means to observe/determine that the system is properly vented
- c. Acceptable criteria for completion of venting.
- Length of time at venting
 - Visual amount of aeration
 - Chemical analysis of vented fluid
- d. The effects of improper venting on:
- Seal cooling and unequal temperature distribution
 - Seal face film lubrication
 - Instrumentation readouts
- e. The effects of high fluid velocity venting on:
- Seal component erosion
 - Water hammer reaction on components
- f. The possibility of setting up a negative pressure transient when rapidly venting and its effects on:
- Thin film gap and leakage
 - Secondary elastomers
 - Carbon seal face when in tensile loading
 - Instrumentation
- g. The effects of low pressure seal operation.

4.2.5 Seal Leakage Collection System Required Information

- a. Working as built schematic of the seal leakage path through and out of the shaft seal assembly.
- b. Shaft seal leakage rate criterion:
- Normal rate ____
 - Abnormal rate ____
- c. Suggested method for determining intercavity leakage changes.
- d. Method for evaluating the change in seal leakages based on
- Pressure

- Temperature
 - CBO flow or leakoff flow
- e. Acceptable method for measuring seal leakage:
- Continuous flow rate
 - Volumetric/weight within a discrete period of time.
- f. A written discussion on leakage rate vs.:
- Differential pressure changes
 - Temperature changes
 - Hours in service
- g. Recommended leakage collection system:
- Standpipe type
 - Minimum-maximum back pressure _____ to _____

4.3 Necessary Tools, Gages, and Fixtures

This section of the maintenance manual guidelines addresses the requirements for the necessary tools, gages, and fixtures for successful removal, repairs, and replacement of the many components of the shaft seal assembly (cartridge).

The identified tool, gage and fixture recommendations should be considered as minimum requirements needed to do a proper maintenance job. The items listed should be made available to the maintenance crew prior to the designated time for repairs. The listing will briefly cover the need for a data sheet when taking alignment and parts measurements, motor/pump turning torques and initial setting measurements on the coupling and the shaft sleeve. The list shows the need for various types of static testers and lapping equipment.

4.3.1 Required Tools, Gages, Fixtures, and Related Information

- a. The maintenance manual should itemize the necessary tools required to dismantle the seal cartridge and related components:
- Wrenches, sockets, spanners, and Allen head types
 - Torque wrenches
 - Snap ring pliers

- Spiral-lock retaining ring removal tools
 - Installation and removal tools for carbon faces, seal rings, and backup rings
 - Measuring devices
 - Lifting lugs
 - Lifting slings and material type
 - Pneumatic tools and couplings
 - Wiping tissues (types and material)
- b. The maintenance manual should list the required gages:
- Tapered plug gages or blueing if practical
 - Ring and bore gages
 - A pyramidal O-ring gage
 - Feeler gages
 - Height gages
 - Dial Indicators
 - Scales and calipers
 - Micrometers and size ranges ____ to ____
 - Optical flats and monochromatic lights
- c. The following is a partial list of required fixtures:
- Fixtures to center motor shaft in bearings
 - Fixture for indicating motor shaft to seal cavity (Figure 10) runout when motor shaft is centered
 - Fixture to measure motor shaft to seal flange runout (Figure 11) with motor shaft centered
 - Fixture to measure runouts up and down the solid (rigid) coupling (Figure 12)
 - Fixture to measure motor shaft end float (Figure 13)
 - Motor turning fixture (Figure 14) with adaptors for turning completed coupling assembly with motor oil lift on. The fixture should also include a torque measuring device.
 - Seal housing and subassembly upending fixture
 - Fixture for measuring shaft sleeve extension when seal assembly is complete
 - Fixture for pressure and flow testing of pressure-reducing coil

INDICATOR NO.	READINGS			
	0°	90°	180°	270°
1				
2				
3				
4				

FIGURE 10 MOTOR SHAFT TO SEAL CAVITY RUNOUT FIXTURE

INDICATOR NO.	READINGS			
	0°	90°	180°	270°
1				
2				
3				
4				

FIGURE 11 MOTOR SHAFT TO SEAL FLANGE RUNOUT FIXTURE

FIGURE 12 COUPLING RUNOUT FIXTURE

GAGE PRESSURE	TOTAL LOAD ONE CYLINDER

FIGURE 14 MOTOR TURNING FIXTURE

- Fixture for static pressure and flow-testing a complete seal assembly when not in pump

4.4 Maintenance Needs for Servicing the Seal Assembly/Cartridge

The shaft seal maintenance manual should detail the assembly and disassembly procedure of the seal cartridge once it is removed from the pump unit. Where there is no integrated seal cartridge assembly, the maintenance manual should clearly describe the component-by-component removal and replacement of the internal seal parts at the pump site. This arrangement can be more susceptible to inaccuracies of assembly than the cartridge concept. The majority of the shaft seal configuration used in the surveyed power plants are of the cartridge or semicartridge type.

There may be as many as 80 internal seal components within a four-stage MCP seal cartridge. The parts range from very small pins and springs to large and cumbersome staging partitions and flanges. They may be damaged if improperly stored or abused during inspection, cleaning, and assembly. These parts must be protected from O-ring age-hardening, surface scratches, nicks, chips, dings, blockage of pressure-reducing devices, improper preassembly lubrication on elastomers, fingerprints on lapped faces, and the use of incorrect wiping tissues.

Disassembly, repair, and reassembly must be accomplished according to the best practices, following the recommended sequencing and procedures obtained from the vendor-prepared maintenance manual. An excellent example of an assembly sequence for a multi-stage shaft seal can be found in Reference 4. The following is a list of several of the causes of maintenance-related seal failures.

1. Excessive prelubrication on O-rings and U-cups
2. U-cups installed backwards
3. Damage to U-cups and O-rings, nicks, and cuts
4. Plastic film found in seal assembly
5. Parts not to print
6. Dirt between sealing faces
7. Cocked seal faces and rings

8. Partial blockage of capillary tubing used for pressure reducing
9. Hairline cracks, scratches, or chips on sealing faces
10. Improper hookup of injection lines
11. Wrong size O-rings - too large
12. Damaged teflon backup rings
13. Dropped seal assembly (cartridge) after pressure/flow testing
14. Wrong size seal faces

4.4.1 Required Training Aids

- a. Design-related films
- b. Maintenance-related films
- c. Full-size seal and cartridge assembly models of clear lucite housing with color coded internal parts.
- d. Training seminars for all levels of maintenance personnel
- e. Maintenance supervisory trips to vendor's plant

4.4.2 Exploded Views of all Seal Parts, Subassemblies, and Final Assemblies

4.4.3 A Parts List Cross-Referencing Seal Parts to Items and Instructions in the Maintenance Manual

4. 4.4 Drawings of Each Seal Part with Critical Dimensions and Specifications

- a. Dimensions (see Figures 15 and 16)
- b. Surface finishes
- c. Flatness requirements
- d. Parallelism requirements
- e. Material properties
- f. Acceptance criteria for reuse or replacement
- g. Brief description of the parts' importance

4.4.5 A Listing of all Necessary Tools, Gages, and Fixtures

4.4.6 Drawings of all Tools, Gages, and Fixtures, Including:

- a. Critical fixture dimensions

1. FLATNESS ON $\sqrt{A}$: _____ LIGHT BANDS
2. MATERIAL:
3. SURFACES MARKED $\oplus$ TO BE PARALLEL WITHIN _____.

FIGURE 15 SIMULATED SEAL FACE DRAWING

1. FLATNESS SPEC ON $\sqrt{A}$: _____ LIGHT BANDS
2. MATERIAL:
3. SURFACES MARKED $\oplus$ TO BE PARALLEL WITHIN _____.

FIGURE 16 TYPICAL BACK-UP RING DRAWING

- b. Center of gravity
- c. Weights and lifting points
- d. Procedures for using, cleaning, and care of fixtures

4.4.7 List of All Applicable Procedures

- a. Lapping carbon faces
- b. Lapping carbide faces
- c. In-place lapping of backup ring and support
- d. Use of optical flats and monochromatic lights
- e. Pressure and flow testing of pressure-reducing cells (coils)
- f. Pressure and flow testing of assembled seal cartridges
- g. Packaging and storing critical seal components and assemblies
- h. Cleaning and inspection of parts received for stores and vendors

4.4.8 Shaft Seal Cartridge or Seal Component Required Removal Information

- a. Tagging and removal of pressure, leakoff, and bleedoff lines and related sensors and instrumentation lines
- b. Installation of shaft sleeve locator plates in preparation for seal cartridge removal
- c. Lowering of the pump shaft and spacer coupling removal
- d. Recommended sequence for removing the pump shaft locking nut and coupling half
- e. Recommended use of shaft seal cartridge removal tool and/or fixture
- f. Where the cartridge concept is not used, a seal component-by-component removal procedure is required; more on this later
- g. Estimated required extraction force when removing the cartridge
- h. Procedures for freeing a jammed/frozen seal cartridge

- i. Protection or removal of shaft-to-shaft sleeve drive pins or keys
- j. Recommended data or information sheets for recording each procedure and significant event
- k. Recommended use of signoff check list as each event is complete

4.4.9 Required Packaging or Wrapping for Transportation to Service Repair Area

4.4.10 Required Care/Protection of Exposed Pump Shaft End and Seal Cavity

- a. Protection of shaft threads or taper
- b. Cleaning and preparation of shaft sleeve fits and shoulders
- c. Protection of shaft O-ring fits

4.4.11 Plugging and Protection of all Exposed:

- a. Sensor openings and pressure taps
- b. Seal injection inlets and outlets
- c. CCW inlets and outlets
- d. Controlled bleedoff and leakoff inlets and outlets

4.4.12 Maintenance Manual Requirements for Shaft Seal Disassembly and Assembly

- a. Subsequent to the detail procedures for the part-by-part removal of the fourth-stage vapor seal, if applicable, and also to the removal and transportation of the seal cartridge to a working area, the manual should address the use of the necessary fixtures for holding and upending the seal cartridge for internal component removal and repair
- b. The manual should also cover:
 - Pertinent subassembly and assembly drawings
 - Pertinent seal part drawings and nomenclature

- Required tools and fixtures
- Use of data sheets and signoff logs
- Need for covering the work bench, table, or floor with clean paper
- Necessary inspection tools, mandrels, and gages

4.4.13 Disassembly Instructions Should Cover:

- a. Seal flange removal
- b. O-ring removal and care
- c. Backup ring removal and handling
- d. Seal rings and face removal and handling
- e. Drive key(s)/pin(s) removal and care
- f. Retainers, spiral lock rings, and fasteners removal
- g. Spring holder and spring removal
- h. Secondary seals, bellows, O-ring, U-cup removal and handling
- i. Interstage pressure-reducing devices removal

4.4.14 Each seal component should be placed in a logical array on the clean-paper-topped working bench. The manual should pictorially display the recommended layout.

4.4.15 The manual should refer to the appropriate procedure for such items as:

- a. Parts cleaning and handling, including appropriate cleaning fluids for each part
- b. Inspection of the fragile seal ring and faces
- c. Inspection and handling of O-rings, U-cups, and bellows

4.4.16 Each seal stage should have its own set of instructions, with part identification, layout space, and arrangement

4.4.17 The instructions within the manual should list the necessary criteria for reuse, repair, or replacement of:

- a. O-rings, U-cups, and bellows
- b. Carbon seal faces and rings
- c. Carbide seal faces and rings

- d. Shaft sleeve, spacer sleeves, and sleeve nuts
- e. Interstage pressure-reducing devices

4.4.18 With the completion of the above and the identification of those parts to be replaced or refurbished, the manual should then discuss:

- a. Inspection and acceptance of refurbished parts
- b. Inspection and acceptance of new parts from either stores or the vendor
- c. Possibility of relapping of lapped surface that may have changed with time and shipment
- d. Various inspection tools, gages, and mandrels should be referred to and used when checking:
 - Turns
 - Bores
 - Flatness
 - Parallelism
 - O-ring sizes
 - O-ring shore hardness
- e. Use of good cleaning procedures in preparation for parts installation and assembly

4.4.19 The step-by-step assembly sequence should be clearly written. The manual should contain:

- a. Ample illustrations and exploded views
- b. Critical stackup tolerance and check points on assembled seal cartridge (see Figure 17)
- c. Intermediate static test points
 - Spring rates and forces
 - O-ring sliding force
 - Face flatness checks
 - Pressure/flow checks on coils of capillar tubing pressure-reducing devices
- f. Upending fixtures should be referenced and used for rotating

FIGURE 17 FINAL ASSEMBLY DIMENSIONAL CHECK

end-for-end heavy cartridges and subassemblies

- g. All lifting slings and aids referenced and used on flanges, staging partitions, and subassemblies
- h. The maintenance manual should contain warnings at appropriate stages of assembly against:
 - Excessive prelubrication of O-rings
 - Lubricant and fingerprint contamination of lapped surfaces
 - Improper hand lapping of supporting surfaces in flange cavities
 - Dirt or foreign objects entering the seal subassemblies and final enclosure

4.4.20 Safety Wiring of Critical Fasteners and Assemblies

- a. It is very important that a section of the manual be devoted to the use of safety wiring techniques along with the identification of the cap screws to be wired, the amount required wire, and the necessary tool(s).

Note: The safety wiring should be completed only after the final assembly dimensional check (figure 17) and the completion of the pressure and flow tests.

4.4.21 Final Assembly Dimensional Check

- a. This section of the manual will define and illustrate what overall dimensions are acceptable for a dimensionally correct assembly (see figure 17). The section should contain at least the following information:
 - Overall length (A) _____ + _____
 - End of shaft sleeve to floating face follower (B) _____
+ _____
 - Free gap between floating face follower and spring holder (C) _____ + _____
 - End of shaft sleeve and adjusting plate (D) _____ + _____
 - Upper seal flange and face of adjusting plate (E) _____

- Nose of exposed rotating seal face and end of shaft sleeve (F) ____ + ____
- b. The seal assembly (cartridge) should also be checked for maximum shaft sleeve travel when the assembled sleeve is axially forced to move relative to the seal flange. The measured amount of travel and the force to cause the movement should be as specified by the vendor.
- c. If the entire seal assembly is completed at the pump site, then the vendor should provide the necessary intermediate staging dimensional checks for assurance of a properly assembled unit (see Figure 18).
- d. Minimum required dimensions when seal is assembled at the pump site (See Figure 18):
- Rotating face (middle seal) to face of middle seal flange (A) ____ + ____
 - Flange to end of middle seal sleeve (B) ____ + ____
 - Flange to a step in the pump shaft (C) ____ + ____
 - The vendor should be asked to provide check dimensions for any subassemblies prior to installation (see Figure 19).
 - There may not be a viable method for checking the axial end float of the semi assembled seal components relative to the fixed flange face.

4.4.22 The Required Final Assembly Pressure and Flow Test Method and Acceptance Criteria

- a. With the successful assembly of the seal cartridge and the completion of the dimensional checks, the instructions should include the necessary means for pressure and flow testing the seal cartridge. An acceptance criteria should also be included.

FIGURE 18 AT PUMP ASSEMBLY DIMENSIONAL CHECK

ACCEPTABLE RANGE		
	MAX	MIN
A		
B		
C		

FIGURE 19 SUBASSEMBLY DIMENSIONAL CHECK

- b. The static test fixture should be able to:
 - Accept the final assembly without dismantling or modifying the seal components
 - Accept the seal cartridge in a vertical attitude
 - Use quick disconnect couplings for the pressure/flow lines
 - Check the seal chamber venting system
 - Have means for measuring and indicating the various bleedoff/leakage flows and differential pressures
 - Have means for observing and measuring seal leakage flow.
 - Axially stroke the assembled shaft sleeve through the normal working length of the springs
- c. The manufacturer should recommend test fluid cleanliness and a means for obtaining the required fluid flow and pressure.
 - Type of filtration
 - Compatible fluid chemistry
 - Acceptable pressure pulsation
- d. A recommended flow/pressure test procedure should include acceptance criteria along with symptoms and causes for a malfunctioning seal assembly. The list should include:
 - Acceptable bleedoff and/or leakoff flow
 - Acceptable interstage pressure differentials
 - Acceptable seal leakage at operating pressure
 - Leakage flow with changing axial locating seal shaft sleeve
 - What to look for if there is excessive seal leakage, bleedoff and interstage pressure differentials
- e. The instructions should also contain a method for purging and rinsing the internal cavity of the assembled seal cartridge if the test fluid is not compatible with the pumping system.

4.4.23 The finale to a well constructed and meaningful maintenance manual should include a section on reinstalling the seal cartridge and the required care in attaching the motor/pump solid coupling.

- a. Installing the seal cartridge, final enclosure and vapor seal if applicable. Instruction should include:
 - Removing plugs and other protecting devices
 - Cleaning of the pump seal cavity
 - Wiping down of the pump shaft end
 - The proper use of the seal assembly installation fixture (removal fixture)

4.5 Interface Control Drawing and Critical Parts Dimensions

The complexity, sensitivity, and operational importance of the current shaft seal design and configuration demands more detailed maintenance-related support information from the seal designer and system supplier than what has been provided in the past. Installation, maintenance, and operational manuals were previously designed and assembled with good engineering practices and intentions, but were often lacking in indepth supportive information regarding a) system interface data and control and b) seal part drawings and critical dimensions. In general, the manuals reviewed did cover the basic requirements for seal assembly and disassembly in a logical manner with the necessary warnings and precautions. Missing from the documents reviewed were the system interface control drawing and sufficient seal part interface dimensions.

It is essential that the following be included in the maintenance manual.

4.5.1 Interface Control Drawing (ICD) Requirements

- a. Seal injection interface:
 - Inlet location
 - Line sizing
 - Flow/temperature/pressure limits
- b. CCW Interface:
 - Inlet and outlet locations
 - Line sizing
 - Flow/temperature/pressure limits
- c. Pressure and temperature probe interfaces:

- Locations and identification
 - Expected operating range and accuracy
- d. Controlled bleedoff (CBO) and leakoff interfacing:
- Line size and location
 - Maximum permissible back-pressure
 - Expected flow range
 - Warnings not to impede flow
- e. Seal leakage and collection system interface:
- Line location and sizing
 - Expected flow range and alarms
- f. Motor shaft and coupling interface information:
- Acceptable shaft/coupling runouts
 - Axial displacement no load to full load
 - Maximum expected motor/coupling vibrations
 - Breakaway and turning torque limits
 - Refer to Section 1.0 and referenced figure for complete requirements

4.5.2 Seal Part Drawings and Related Dimensions

- a. Seal part drawings and related dimensions for inspection before assembly use
- b. Refer to Section 4.4 and figures for complete requirements

5.0

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