2.2.4 CENTRIFUGAL PUMP INJECTION-TYPE SHAFT SEALS

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Injection-type shaft seals (sometimes called *packless stuffing boxes)* are designed to control leakage from hot-water pumps. Cool water is injected into each seal to either suppress or regulate the hot leakage, which would otherwise flash upon reaching the outside of the pump.

Injection-type shaft seals provide high reliability and yet require little maintenance. They are used primarily in power plant boiler-feed and reactor-feed pump applications where shaft peripheral speeds are high (3600 rpm and up) and pumping temperatures are greater than 250°F (120°C). Under these conditions, conventional packing or mechanical-seal-type stuffing boxes may not be suitable or desirable.

Injection shaft seals are either *serrated throttle bushings* or *floating ring seal* designs that regulate the flow, temperature, and pressure of the controlled leakage. The flow of the cool injection and of any hot water in the seals depends on operating pressures, but it is restricted by close seal clearances and is regulated by injection control valves.

The operating temperature of the seals is controlled by allowing cool injection water to surround the outside of the seal. Ports in the seal enable the cool injection water access to the shaft to either overcome or mix with hot water in the seal so that the resulting seal leakage is cool.

The seal designs must provide sufficient pressure breakdown between the pump suction or balance device chamber pressures inside the pump and the atmospheric conditions outside the pump. Upon reaching the outside of the seal, the cool leakage is piped away by gravity drain for eventual return to the power plant feedwater system.

SERRATED THROTTLE BUSHINGS

The construction of a serrated (sometimes called *labyrinth* or *grooved)* bushing (see Figure 1) varies from one pump manufacturer to another. However, the serrated designs basically involve a rotating shaft running with a reasonably small clearance, such as 0.002 to

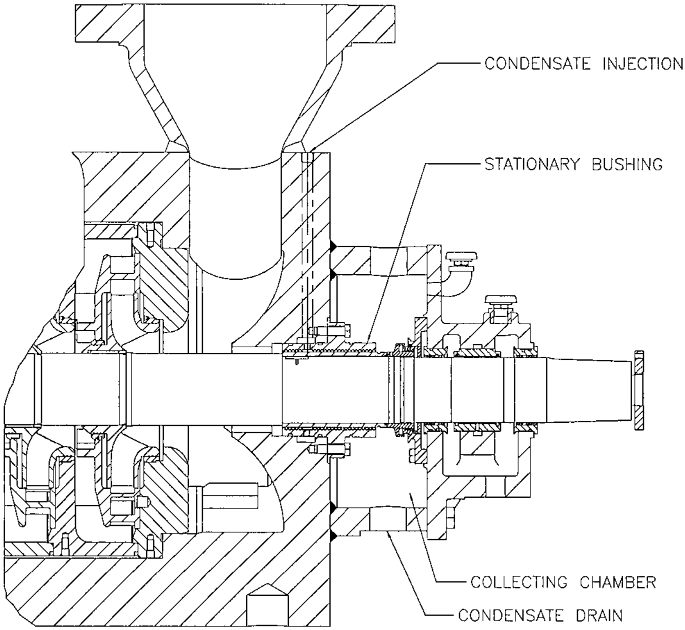

FIGURE 1 ***Author: Replacement caption was not provided***

0.003 in per inch (0.002 to 0.003 mm per millimeter) of the shaft diameter within a solid stainless steel (typically 12 percent chrome) stationary bushing installed in the pump casing end cover. Grooved serrations are applied to the hardened stainless steel rotating surface (usually a shaft sleeve) or to the stationary bushing or to both rotating and stationary surfaces to effect a high throttling action or stuffing box leakage reduction.

The serrations create a more effective pressure breakdown than a smooth axial surface and enable increased running clearances to let foreign particles, such as grit, pass through or flush out in the grooves. The increased clearances also enable more tolerance for any displacement between rotating and stationary components that might result from assembly misalignment or from distortions induced by transient temperatures. The grooved running surface area at clearances is greatly reduced relative to that of a smooth axial surface, and therefore possible metal surface contact between rotating and stationary parts is reduced during transient operations.

Seal leakage could be reduced by decreasing the running clearance in the injection seal, but the smaller clearance would limit the capability of the serrated seal to conform to radial shaft movement. Reduced clearances in any injection seal design may lead to problems with thermal distortions caused by a loss of available cool injection water and may also increase galling by particles trapped in the seal running fits.

FLOATING RING DESIGN

A segmented throttle bushing made of many floating rings will enable conformity with the radial shaft movement and smaller running clearances to reduce seal leakage. The construction of a floating ring stuffing box (see Figure 2) varies from one pump manufacturer

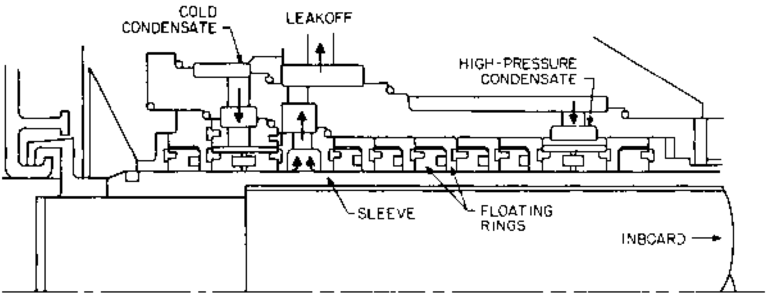

FIGURE 2 Floating ring seal design with shaft sleeve. Pegs prevent rotation of spring-loaded rings but let them float radially. (From *Power,* August 1980, McGraw-Hill, New York, copyright 1980)

to another, but the unit basically consists of a stack of hardened, martensitic stainless steel rings (typically 17 percent chrome), instead of a stationary bushing. The rings run against a smooth, hardened, martensitic stainless steel (typically 12 to 17 percent chrome) rotating shaft sleeve surface.

The separate rings are all contained within a housing installed in the pump casing end cover. Each ring is loaded against an adjacent stainless steel ring spacer so that a stationary seal is produced in the axial direction, but the ring is still able to move radially with the shaft. An axial loading of the rings is provided by hydraulic pressure during operation and by springs during idle pump periods. The rings are locked against rotation usually by pegs and/or a slot arrangement.

A small radial clearance, usually 0.001 to 0.0015 in per inch (0.001 0.0015 mm per mm) of the shaft diameter, is provided between the rings and the shaft sleeve to provide an adequate throttling of seal leakage across the limited number of seal rings. The length of each ring varies with the diameter of the injection-type seal but is generally about 0.50 in (13 mm). The radial clearance enables a reduced injection flow but increases the sensitivity of the seal to foreign particles in the seal leakage.

The individual seal rings are permitted to move radially (float), finding an equilibrium running position relative to the shaft. The capability to float up to .016 in (.4 mm) radially increases the tolerance for shaft misalignment as the shaft passes through the seal area. The multiplicity of seal rings further reduces the effect of any angular displacement between the rotating and stationary components that might arise from errors in the original assembly or from distortions caused by temperature changes during pump load variations.

Some injection-type shaft seal designs use a combination of serrations and floating rings in the same stuffing box. For either type of seal, careful maintenance during the assembly or disassembly requires accurate alignment of the rotating and stationary components as well as careful handling to avoid scratching the components. Cleanliness is of utmost importance with shaft seals.

CONDENSATE INJECTION REQUIREMENTS

Because boiler-feed and reactor-feed pumps normally have high feedwater temperatures, 250 to 500°F (120 to 260°C), with consequent vapor pressures higher than external atmospheric conditions, the seal leakage must be cooled to avoid flashing in the stuffing box or outside the pump. This cooling is usually accomplished by injecting cold condensate from a power plant condensate pump directly into the seal to cool the stuffing box components as well as the seal leakage.

The amount of condensate injection water required will depend on several factors, including (1) whether the design is a serrated or floating ring, (2) the type of seal control system, (3) the diameter, clearance, and rotating speed of the running fit, and (4) the internal pump pressure and temperature. A typical example of stuffing box flows would be a 5500-rpm, boiler-feed pump with a temperature-controlled seal system (described later) and a serrated 5-in (127-mm) diameter running seal with about 0.015 inches (0.38 mm) of diametrical clearance. The approximate flows would be as follows:

1. Total injection per seal: 5 to 15 gpm (0.3 to 1.0 l/s)
2. Leakage from internal pump to seal: 0 to 5 gpm (0 to 0.3 l/s)
3. Drainage from each seal: 8 to 20 gpm (0.5 to 1.3 l/s)

Given a seal with a floating ring design (having typically half the clearance of seals with a serrated bushing design), the previous conditions would require only 50 to 60 percent of the injection water needed by the serrated bushing design with the larger clearance.

During pump standby periods, higher injection and leakage flows are required because of reduced seal throttling caused by low or zero speed, by high internal pump pressures, or by a pump balance device that induces higher internal leakage during standby. The injection flows to both stuffing boxes on a multistage pump may not be the same as a result of pump balance action at one end of the pump.

Cold condensate, 85 to 110°F (30 to 45°C), is usually available from the power plant condensate pump or secondary condensate booster pump discharge. The variation in condensate supply pressure relative to internal boiler-feed pump pressure makes it necessary to use injection control systems for satisfactory seal operation.

Condensate injection systems vary to accommodate the wide range of pressures and temperatures found in different power plant feedwater system layouts. The four basic types of injection flow systems are (1) manual, (2) differential pressure-controlled, (3) differential temperature-controlled, and (4) constant drain temperature control.

Manual System Manual flow control requires setting and readjusting a valve by hand for each stuffing box each time a change occurs in pump operating conditions due to varying plant loads. Although it is possible to use such a control system, it is not usually recommended because of the inability to automatically compensate for rapid changing conditions.

Differential Pressure-Controlled System The differential pressure-controlled shaft seals operate as cold condensate maintained at a pressure greater than boiler-feed pump suction is injected into the central portion of the seal. By maintaining an injection pressure above the pump seal chamber pressure, a small portion of this injection water flows into the pump proper, and most of the injected water flows out of the seal into a collection chamber adjacent to the pump bearing bracket. The leakage in the collection chamber, which is vented to the atmosphere, is drained by gravity for an eventual return to the main feedwater system.

The differential pressure-controlled system has a pneumatic injection control valve. This valve in the condensate injection line is governed by an air signal received from a differential pressure control monitor that maintains the preset pressure differential, 10 to 25 lb/in^2 (70 to 170 kN/m^2), between the injection pressure and the internal pump pressure. This system is not always favored, however, because of a feedback instability tendency resulting from operating pressure changes affecting the valve position, which changes pressure, and so on. Another unfavorable factor for hot-water service is the introduction of cold condensate into a hot pump at all times, including pump idle periods, affecting pump prewarming conditions.

Differential Temperature-Controlled System The differential temperature-controlled system operates by maintaining a seal drain temperature differential of 25°F (14°C) above the injection water temperature. The temperature differential ensures a continuous out-leakage of hot boiler feed water. The hot out-leakage is desirable, ensuring that cold water cannot be injected into the pump and thus eliminating thermal distortions that occur with the differential pressure-controlled system. The valve controllers are identical to the controllers used for the differential pressure-controlled system.

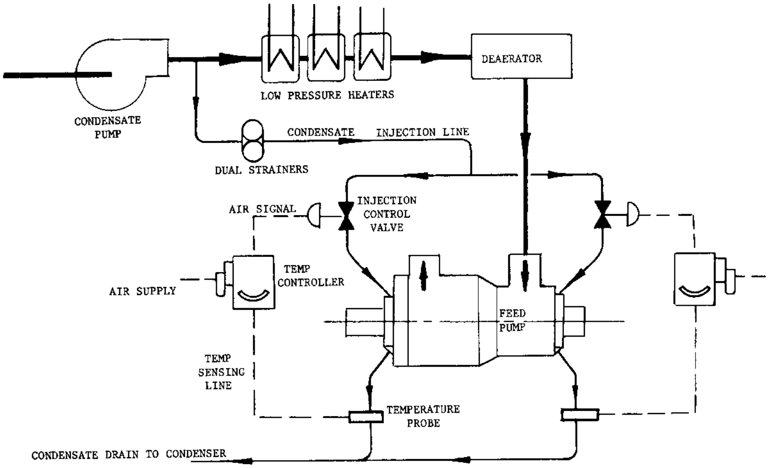

FIGURE 3 Temperature-controlled system regulating condensate injection to feed pump shaft seals

Constant Drain Temperature-Controlled System The constant drain temperature-controlled seal system (see Figure 3) controls hot out-leakage by throttling the injection flow to maintain a preset seal drain temperature. This system has a temperature-sensing probe in each seal drain line. Each probe is connected to an indicating temperature controller, which provides an air signal to a pneumatic control valve in the condensate injection line for control of the seal injection flow rate. Electronic control systems are often used where thermocouples or RTD's sense drain temperatures. The signal output is then processed through an I/P controller that adjusts the position of the pneumatically operated throttle valve as required.

The cold condensate is injected into the stuffing box central portion and allowed to mix with hot water entering the seal from inside the pump. The drain temperature is maintained at a preset 140 to 150°F (60 to 66°C) to preclude flashing in the stuffing box or in the drains. Note that with this system some hot water enters the seal. Therefore, cold condensate does *not* enter the hot pump and does not adversely affect pump warming conditions, especially during extended idle periods. The required condensate injection pressure is at least equal to the internal stuffing box pressure plus interim frictional loss between the condensate supply source and the point of hot-water mixture. Note that this system *may* enable satisfactory operation even when the condensate supply pressure is nearly equal to boiler-feed pump suction pressure. In addition to providing a rapid response to variations in operating pump conditions, this type of control will always supply just enough injection water to maintain the recommended drainage temperature.

Intermediate Leakoff System The intermediate-leakoff shaft seal system (see Figure 4) has many variations but basically uses a bleedoff from a central portion of the stuffing box. This system may be used to reduce internal stuffing box pressure if high boiler-feed pump suction pressure exists. To create a positive leakoff flow, the intermediate bleedoff flow is piped back to a plant feedwater system low-pressure point, such as a plant condenser, heater, or booster pump suction where the pressure is less than the boiler-feed pump suction pressure. However, the back pressure of the leakoff destination must be above the bleedoff vapor pressure to suppress flashing in the leakoff lines. This back pressure may be the leakoff destination pressure or may be created by an orifice or a valve.

Cold condensate injection into the stuffing box is controlled by a pressure differential monitor maintaining a preset pressure above the bleedoff pressure (refer to Figure 4). A

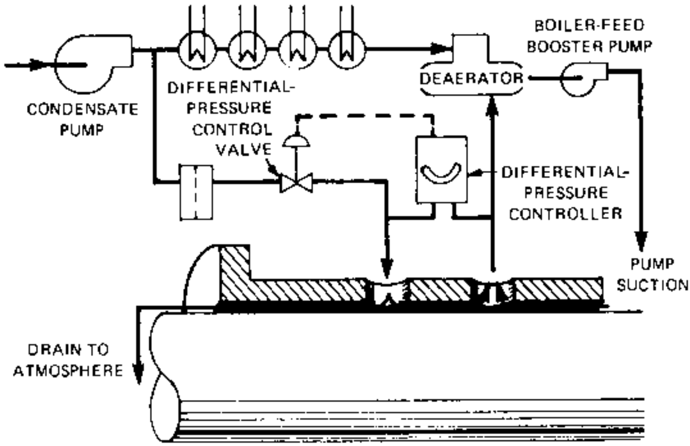

FIGURE 4 Typical intermediate-leakoff shaft seal system. (From *Power,* September 1980, McGraw-Hill, New York, copyright 1980)

stuffing box drain temperature control can also be used. Note that the cold condensate injection pressure need not equal or overcome a high feed pump suction pressure. The condensate injection temperature must still be 85 to 110°F (30 to 45°C) to keep the drain temperature below the flashing condition. Condensate injection shaft seals without an intermediate bleedoff but that are subject to suction pressures in excess of about 250 lb/in^2 (1725 kN/m^2) must be extremely long for a proper pressure breakdown. Longer shaft seals require thicker pump case end covers, affecting pump cost, and a longer rotating element, which could adversely affect rotor dynamics. The intermediate-leakoff shaft seal is effective where there is high feed pump suction pressure imposed by boiler-feed booster pumps or in a closed feedwater system with no deaerating open heater, wherein a condensate pump discharge can be fully imposed on the feed pump at low plant loads.

In plant systems with feedwater heaters between a booster pump and a feed pump, a high pressure condensate from the cooler booster pump is injected into the seal to enable a cooler intermediate leakoff to help prevent flashing (refer to Figure 2).

INJECTION SOURCES

Many power plant feedwater systems with deaerating direct-contact heaters (open cycle) usually have the boiler-feed pump drawing water directly from the deaerator. These open cycles with constant-speed condensate pumps always have cold condensate supply pressures in excess of boiler-feed pump suction pressure because of the increased available condensate pump head at low system flows and the interim system frictional loss at high system flows.

If a boiler-feed booster pump or a closed feedwater system with no open heaters and resultant higher boiler-feed pump suction pressures is used, the pump manufacturer may elect to require condensate injection seal water booster pumps or may use an intermediate-leakoff packless shaft seal with a condensate injection overcoming only the intermediate leakoff pressure. If the condensate pumps are variable-speed units that enable the condensate injection pressure to drop to an equal feed pump suction pressure at low loads with little or no feedwater system frictional drop, then condensate injection seal water pumps are required. In this situation, at least one pump manufacturer offers an optional pumping ring configuration in their packless seal that can increase the seal water pressure in the stuffing box to overcome any pump suction pressure.

AUXILIARY EQUIPMENT

The condensate injection piping should be conservatively sized based on the maximum injection flow requirements to obtain a low pressure drop between the injection source and the seal injection control valve. These control valves may be equipped with limit stops to prevent full closure and enable a continuous cool injection to the seals under almost all operating conditions. In some installations, isolating lines are furnished around the valves to enable a continued injection flow even during control valve maintenance. The valves can also be designed to remain open during a failure, such as a loss of station air to the pneumatic controls, and to close only with an air supply. Injection control systems that are not properly maintained might result in cold water entering a hot pump. Should this problem occur while a boiler feed pump is in the hot standby mode or when turning gears, thermal gradients will occur, leading to contact among the close running fits within the pump. Proper maintenance and operation of the injection control systems is necessary to ensure reliable operation of the pump itself. The air supply filter regulators for each control must be furnished with relatively dry clean air at station supply pressure.

The condensate injection supply to the seals must be clear and free of foreign matter to prevent damage to stuffing box components. It is therefore necessary to install filters in the injection line prior to the control valve. To keep damaging fine mill scale, oxide particles, abrasives, and other materials from entering the small seal clearances, several pump manufacturers recommend 100-mesh (150-micron) dual strainers. If dual strainers with isolating valves are used, each filter can be cleaned without interrupting injection flow during pump operation. Pressure gages should be installed before and after each filter to permit the operator to monitor filter pressure drop. A differential pressure switch and alarm for each filter are preferable to alert the operator to clean the strainer when pressure drop becomes excessive.

The condensate injection shaft seals should always be filled with cool water before and during pump operation, even during reverse pump rotation. Some pump manufacturers stipulate that condensate injection *must* be continuous without any interruption during all operation modes.

The clearances in the condensate injection shaft seal may double over the service life of the internal wearing parts. With double clearances, the leakage will approximately double. This factor should be considered when sizing the return drain piping back to the plant condenser if frictional losses are to be kept to a minimum. The drain line should be pitched at least a quarter-inch per foot (20 mm per meter). The collecting chamber at the pump stuffing box is vented to the atmosphere, and the only head available to evacuate the chamber is the static head between the pump and the point of return. This head must always be well in excess of the frictional losses (even after the leakage is doubled). Otherwise, the drains may back up, the collection chambers may overflow, and the adjacent bearing brackets may flood, with subsequent possible intrusion of water into the pump bearings and lubricating oil.

The seal collection chambers have especially large connections to assure proper drainage, provided no back pressure exists. Two types of condensate drain systems can be used to dispose of the drain coming from the collecting seal chambers. One system uses traps that are piped directly to the plant condenser if sufficient static head exists for positive drain flow. The second system collects the drain in a condensate storage tank into which various other drains (from other pumps shaft seals and so on) are also directed. As this vented storage tank is under atmospheric pressure, it must be set at a reasonable elevation below the pump centerline so that the static elevation difference will overcome frictional losses in the drain piping. A separate condensate transfer pump, under control of the storage tank liquid level control system, can then pump the condensate drains from the storage tank into the plant condenser. The storage tank should have its own overflow protection system that enables outside drainage if, for some reason, proper drainage cannot be achieved. For example, the top of the tank vent pipe should be below the pump centerline to help preclude the possibility of drainage backing up to the level of the pump seal collection chambers. Note that this storage tank should also be large enough for an adequate drainage collection to help prevent backups.

PACKLESS SHAFT SEALS WITHOUT INJECTION

The packless shaft seals that have been so successfully applied to boiler-feed, reactor-feed, and booster pump services are applicable to a number of other services. For instance, they are very suitable for cold-water condensate booster pumps and for high-pressure pumps applied to hydraulic descaling or hydraulic press work. In such services, there is no need to bring in an injection supply water to the breakdown seals (unless the pumped water is not clear and free of gritty material), because the water handled by the pump is already cold with no danger of flashing as it leaves the pump stuffing boxes.