EVALUATION OF LIQUID FILM SEALS, ASSOCIATED SYSTEMS AND PROCESS CONSIDERATIONS

by

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Gerald Lesiecki is supervisor of the Compressor Systems Section at Allis-Chalmers. He has been associated with the design and development of seals and their systems for compressors in toxic or combustive services from very low pressure service such as plant refrigeration to high pressure service such as hydrocracking and very toxic service for heavy water plants. He also has been associated with the design and development of control, monitoring, and lube systems for compressors which supply air for such services as plant air, soot blowing, blast furnaces, air separation, fluid cat cracking and nitric acid plants; and exhaust air from wind tunnels, jet engine test cells, and paper machines.

Mr. Lesiecki received his BSME degree from the University of Wisconsin in 1960 and has been close to seals and their systems since then.

ABSTRACT

Buffered bushing liquid-film seals have been in existence for some time and have proven to be quite reliable for most centrifugal compressor applications. However, industry has been demanding more from seals and their associated systems over the years. While expecting better performance in terms of lower inner sealant leakage, which means tighter clearances or lower differential pressures, or both, industry primarily wants reliability. Therefore, manufacturers were forced into alternate seals, among which is the pumping type liquid-film seal.

This paper will deal with one company's approach to meet industry's many seal requirements with a pumping type liquid seal. Pertinent process considerations will be brought out which establish the proper seal variation as well as the proper associated system for best operation.

INTRODUCTION

Shaft seals are furnished in horizontally split, barrel type and single-stage centrifugals and axial compressors when positive process gas sealing is required. Typically, they would be utilized in compressors used in hydrocracking, catalytic reforming, refrigeration, methanol, ethylene, ammonia synthesis and other gas compression processes. Seals are required on shafts ranging from 4 to 10 inches and operating at 2,000 to over 20,000 RPM at pressures from sub-atmospheric to well over 3000 PSIG.

Owing to the variety of seal types used, compressor seals have ranked high on the list of causes for "down time" in the process industries. The simple buffered bushing liquid-film seal, however, has been quite reliable when used with generous clearances, but it is difficult to make a liquid-film seal comply with industry's latest requirements of very low inner sealant leakages and continuous full-load duty for a minimum of three years. Since fulfilling one requirement jeopardized the other, a new seal had to be developed.

Through the course of fifteen years, three phases of development, the occasional field problem and continuous customer feedback have brought about the evolution of a pumping type liquid-film seal which fulfills the following seal objectives.

A. LONG-TERM OPERATION

1. Large clearance — similar to those in a journal bearing for comparable reliability.
2. Low inner leakage (oil exposed to gas) — nominal five gallons per day or less.
3. Compact design — allows shorter bearing spans for higher critical rotor speeds.
4. Operates at all pressure levels, from atmospheric through compressor design pressure, without bushing change.
5. Floating bushing — maintains near concentric operation with shaft as shaft position changes in bearings relative to speed — minimizes pressure patterns.
6. Positive under all operating conditions — even with oversize clearances (assuming the sealant flows are within the system pump capacity).
7. Insensitive to temperature or pressure axial shifts between stator and rotor parts.
8. Automatic shutdown when required for special process applications such as refrigeration cycles.

B. LOW MAINTENANCE

1. Complete interchangeability of parts — eliminates complete seal assembly replacements.
2. No special field fitting — seal optimized once at initial assembly.
3. Sleeve with interference fit under bushing — requiring no heat for assembly and disassembly.
4. Non-galling materials — occasional exposure to finite amount of foreign particles will not cause catastrophic failure.

SEAL OPERATION

It is not the intent of this paper to evaluate all the design parameters of a pumping type liquid-film seal, but merely to expose the reader to the seal. A pumping type liquid-film seal is best understood by knowing exactly how it operates.

Static Operation

Under static conditions a pumping type liquid-film seal, as shown in Figure 1, operates like any other buffered bushing seal. A sealant (normally the oil from the lubrication system) is supplied at a nominal 10 gallons per minute to the seal at a positive pressure above the process gas being contained. The sealant flow flows three separate ways.

1. A relatively small portion of the sealant buffers the process gas in the clearance area between the inner portion of the stepped dual bushing (4) and the seal impeller (2), as shown in Figure 1. This inner leakage rate normally varies from one to five gallons per hour, depending primarily on the size of the seal, but is relatively independent of the pressure level of the gas being contained. The spent sealant enters the inner drain and ultimately is bled down to atmospheric pressure by way of a trap.
2. A larger portion of the sealant takes a pressure drop to the atmospheric outer drain, between the outer portion of the stepped dual bushing and the impeller. This outer leakage rate is primarily a direct function of the pressure level of the gas.
3. The excess sealant passes through the stator (3) cooling passages and out of the seal, as shown in Figure 1, where a 5-foot head of sealant is maintained above the process gas by a level control. The level controller (LC) modulates a level control valve (LCV) to provide the pressure drop for the sealant's return to the reservoir.

   Other than the fact that sealant is passed through the stator, this operation is typical of a buffered bushing liquid-film seal, except that a simple buffered bushing could have its control and bypass upstream.

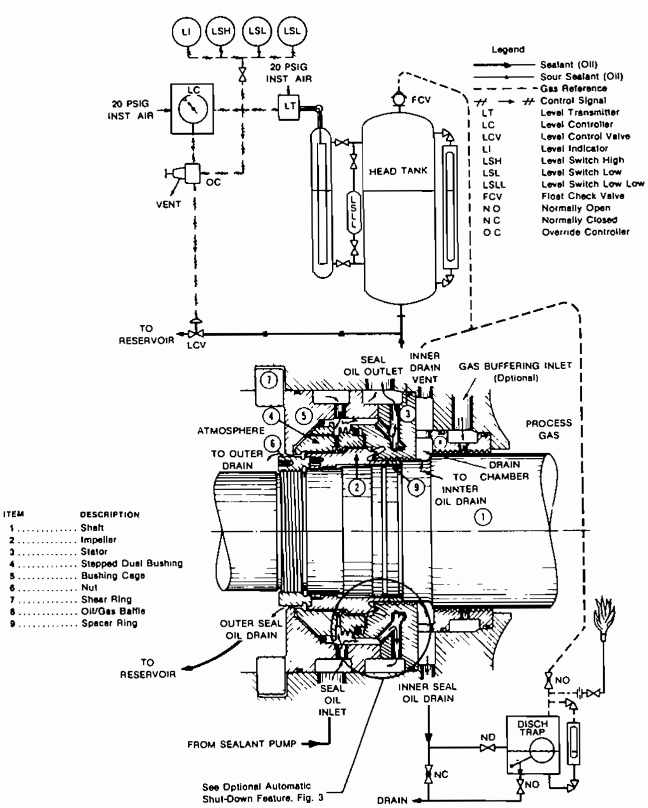


Figure 1. Pumping Type Liquid-Film Seal and Control.

Dynamic Operation

The pumping section of the pumping type liquid-film seal consists of two viscous pumps operating against one another during dynamic operation.

1. The step within the stepped dual bushing works in combination with the outer shoulder of the rotating impeller as a pump, to insure that the entire clearance between the inner portion of stepped dual bushing and the impeller is at a positive pressure level with respect to the process gas. Pressure patterns in this area are similar to those in lightly loaded journal bearings.
2. The portion of the stator that meshes with the inner portion of the rotating impeller acts as a dead-ended pump without a suction source. The pumping action just balances the head of the pumping action of the outer shoulder of the impeller plus the 5-foot head maintained in the head tank; hence, there is no pressure drop through the clearance between the inner portion of the stepped dual bushing and the impeller. The pressure drop is essentially zero, and without a pressure drop the inner leakage is theoretically zero. In actuality it normally is less than 5 GPD, as shown in Figure 2.

Transition Operation

A dramatic transition between static operation and dynamic operation occurs wherein the pumping just balances off the 5-foot head of the head tank, as shown in Figure 2. This point of transition can be adjusted to as low as 50% of design speed on higher speed compressors, but somewhat less on the lowest speed compressors. However, the lower the transition speed, the higher the horsepower loss at design speed. The initial increase in inner leakage is due to temperature effect from the shear and pumping of the oil, which causes the oil viscosity to decrease the bushing to impeller (or shaft) clear-

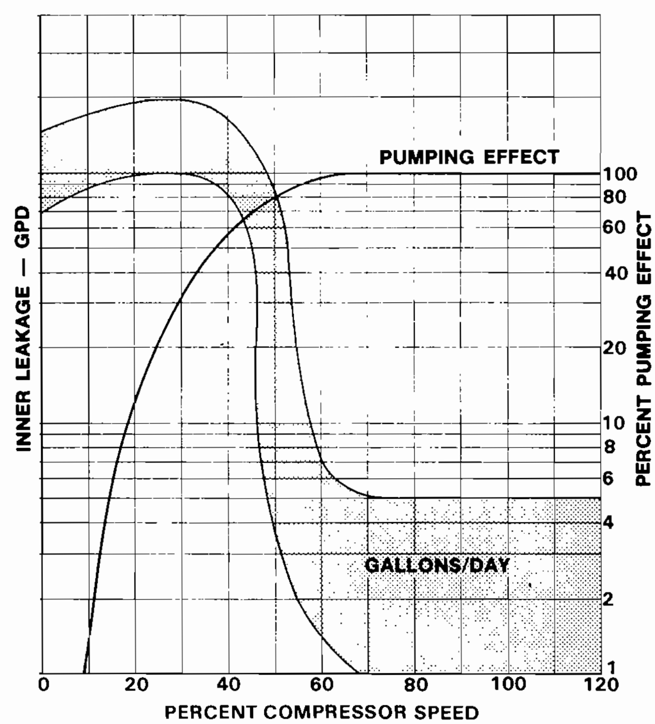


Figure 2. Typical Inner Leakage vs Pumping Effort.

ance to open up, to insure a fail-safe condition between the bushing and impeller (or shaft). The bushing coefficient of expansion is larger than that of the impeller (or shaft) by design. However, the differential between the coefficient of expansions cannot be too great or the outer leakage will become excessive at high speeds and pressures.

Theoretically, after the transition to a balanced condition, the inner leakage should be zero, but due to variation in the sealant-gas interface and wetting of parts there is some leakage. The sealant-gas interface variations can be minimized with the proper sealant system.

SEALANT SYSTEM

The sealant system maintains the sealant at a constant pressure above the gas pressure and is usually combined with the lube system if oil is the sealant as in Figure 3. A separate system is required if the finite amount of gas that ultimately ends up in solution in the sealant could be injurious to the lube system.

The required 2 PSI differential of sealant above gas within the seal is best achieved with a head tank. The sealant is held at a constant 5-foot level with a level control. The level control system, including its valve, should be downstream of the seal and referenced to the gas pressure at the discharge seal of a multi-stage compressor, as opposed to upstream with a deadened seal, to insure that:

1. The seal always receives a constant flow of sealant from atmospheric pressure through its entire operating pressure range, thereby eliminating high temperature operation at low pressures.
2. The seal always has a positive sealant pressure with respect to the gas — all of the pressure drops are ahead of the head tank as opposed to after, which could result in a "seal blow."

The level control cannot be set for speed of response, but must be set for stability. Therefore, the level control should incorporate an override control, as shown in Figure 1, which can quickly "block-in" the head tank, should one or all of the sealant pumps be lost, to preserve the maximum amount of sealant for compressor coastdown, block-in, vent, and purge. The time available can be increased by increasing the size of the head tank. Head tanks with 300 gallons of sealant capacity are not uncommon. However, for processes which do not have block-in valves to isolate the compressors or reliable power sources for the drivers of their lube and sealant pumps, a seal with an automatic shut-down feature is desirable.

There are two common ways of isolating the process gas under static conditions when the sealant pumps are lost:

1. A "boot" fixed to the compressor casing is blown up with an external source of pressure to constrict the shaft and contain the gas within the compressor.
2. An annular piston with a soft seat incorporated in the compressor casing is pressurized from an external source to stroke the piston against the shaft shoulder, thereby containing the gas in the compressor.

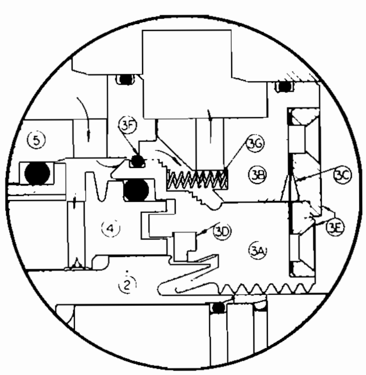
A drawback with these shut-down devices is that both require an external source of gas pressure for actuation and for the duration of the shut-down plus an isolation valve on the head tank.

AUTOMATIC SHUTDOWN

A pumping type liquid-film seal is quite adaptable to the incorporation of an automatic shut-down feature. Simply, the stator (3) can be broken up into several parts, as shown in Figure 4, with the inner portion taking on the role of an annular double seated check valve which operates as follows:

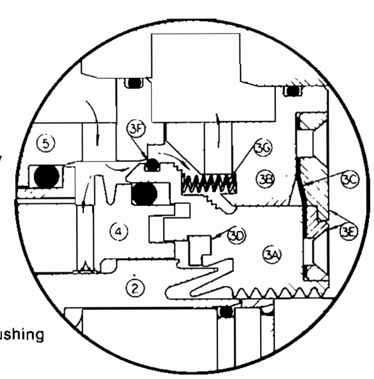
Static Operation

Under static conditions, without a sealant supply, the seal is in the shut-down mode. The springs (3G) force the stator (3A)



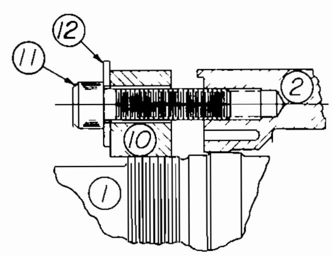
A. At Shut-down

Item	Description
2	Impeller
3	Stator Assembly
	A. Stator
	B. Stator Adaptor
	C. Diaphragms
	D. Soft Seat
	E. Diaphragm Retainers
	F. Secondary Seal
	G. Springs
4	Stepped Dual Bushing
5	Bushing Cage



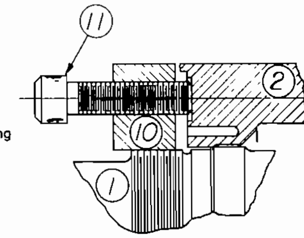
B. Dynamic Operation

Figure 3. Automatic Shut-down Feature Pumping Type Seal (Optional).



Removing Impeller

Item	Description
1	Shaft
2	Impeller
10	Jack/Puller - Bolt Ring
11	Cap Screws
12	Washer



Replacing Impeller

Figure 4. Seal Impeller being Removed and Replaced on its Shaft Intereference Fit.

toward the impeller (2) until the shaft seat (3D) makes absolute contact, preventing gas leakage. Simultaneously, the secondary seal (3F) makes contact with the bushing cage (5), preventing oil and subsequently gas from leaking from the head tank. When a sealant is supplied to the seal at a pressure which exceeds the gas pressure, the stator (3A) is partially forced back, similar to a check valve, which allows the normal circulation of sealant, bringing the head tank up to the 5-foot level. Upon any loss of sealant the stator would immediately move to the shut-down mode.

Dynamic Operation

Under dynamic conditions the impeller (2) pumps up enough head to force the stator (3A) away from the impeller (2), compressing the springs (3G) until the two diaphragm retainers fully mesh. In this condition the seal operates exactly like a standard pumping type liquid-film seal. If the sealant supply is lost while the compressor is at speed, the seal continues to operate normally on the runback from the head tank until the compressor is tripped with the loss of head tank level. During deceleration, the head from the impeller diminishes, allowing the stator to come into the shutdown mode at low speed to prevent a "seal blow." A trip circuit prevents start-up until the sealant level in the head tank is restored.

PROCESS CONSIDERATIONS

Many reasons could be cited why some processes cannot tolerate sealant vapor from the inner drain chamber. The sealant could poison the catalyst or, in an extreme case, create an explosive mixture. One of two positive approaches can be taken to prevent the diffusion of sealant vapors into the process.

1. A fixed amount of process gas can be vented off through an orifice to a low pressure point in the process which is not affected by sealant vapor or, as a last resort, to flare. Venting must be sufficient to create a flow rate greater than the oil vapor back diffusion flow rate through the oil/gas baffle (8) clearance area, as shown in Figure 1, to prevent oil contamination of the process gas.
2. If the process gas is extremely corrosive, toxic, or is not expendable, the oil/gas baffle can be buffered with a gas that is compatible with the process gas in excess of the process gas diffusion rate. However, the buffer gas must be supplied at a positive flow rate toward both the process gas in excess of its diffusion rate and the inner drain chamber in excess of the sealant vapor diffusion rate. These flow rates become critical on high head multi-stage centrifugal compressors because the inner seal is inherently exposed to a lower pressure than the discharge seal and the oil vapor could be aspirated directly into the process.

If the diffusion of sealant vapors must be minimized but not absolutely eliminated, a more economical way of buffering is to use the compressor discharge gas. However, the flow rate must be sufficient to elevate the inner drain chamber to provide the desired flow rate through a trap, a demister, an orifice, and back to the compressor inlet.

If the process is a refrigeration cycle and the compressor has a low inlet temperature, consideration must be given to heating the inner drain chamber to provide adequate gravitational draining of sealant from the chamber. The inner drain chamber can be heated in several ways:

1. If the inlet temperature is in the range of normal ambients, the seal itself supplies enough heat.
2. If the inlet temperature is as low as −40°F (−40°C), the oil/gas baffle is buffered with a warm gas, usually directly from the discharge of the compressor.
3. If the inlet temperature is below −40°F (−40°C), an inner sealant drain heater is required.

MAINTENANCE

Because of its journal bearing clearances in the bushing area and five times journal bearing clearances in the pumping area, as well as ten times the float of a common thrust bearing, a pumping type liquid-film seal is virtually maintenance free as long as the sealant system is clean.

The seal can be disassembled for inspection with standard tools, except for a jack/puller bolt ring and four (4) cap screws which are used to pull the impeller off or push it on its interference fit without heat. Interchangeability of parts eliminates the need of carrying complete seals as spares. Only potential rubbing parts and "O" rings are recommended spares.

The pumping type liquid-film seal can be adapted to accommodate almost any type of compressor application. Given the care that is usually given a common journal bearing, it will provide many years of trouble free service and virtually disappear from the list of causes for "down time."