PUMP RELIABILITY IMPROVEMENTS THROUGH EFFECTIVE SEALS AND COUPLING MANAGEMENT

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ABSTRACT

Market pressures are demanding cost reductions in the process industries. Most operators are seeking to achieve substantial savings through reductions in the maintenance and "real" operating costs of centrifugal pumps of which seals, couplings and sealed bearings are critical elements.

This paper reports on the variable lifetimes being currently achieved, the improvements that are being made through performance surveys and reliability improvement programs and the importance of cooperation between supplier and user.

Data are often very difficult to get and to interpret. The paper discusses how detailed surveys in over 20 operating plants have been carried out and the results analyzed. Special software has been developed for the continuous monitoring and management of pumps, seals, couplings, and bearings in operating plants, and this is described.

INTRODUCTION

One of the major challenges facing operators and maintenance personnel in the process industries is to reduce equipment operating costs. Centrifugal pumps are very significant pieces of rotating equipment that have, traditionally, incurred high "real life" costs. The pump components responsible for much of that cost have been seals, bearings and, to a lesser degree, couplings.

To put that into perspective (Figure 1), it is useful to present some failure data supplied by one refinery, for centrifugal pumps with two or more failures in one year (164 failures from 67 pumps during 1996).

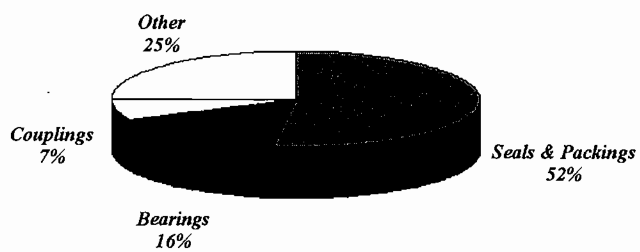


Figure 1. Pump Failure Distribution.

For the seals and packing, analysis of the "failure data" show that the packed pumps are seven times more likely to appear in the problem pump list.

The coupling failures include nonmembrane units. The failure rate for the membrane units is only one to two percent.

It would be absolutely wrong to assume that the fault all lay with the failed components, however. Surveys of pump populations in the USA and reported by A.G.H. Coombs (1988) suggest that the basic cause of seal failure, for example, and their relative importance are as follows:

- Operating problems (flush flow interruptions, etc.) = 40 percent
- Mechanical difficulties (assembly errors, incorrect clearances, poor alignment etc.) = 24 percent
- Faulty circuit design (insufficient suction, deficient flush circuit, pump characteristics unsuitable) = 19 percent
- Seal component selection inadequate (errors in materials or configuration) = 9 percent
- Miscellaneous causes = 8 percent

These figures do serve to illustrate two things. First, seals, bearings and couplings are all important target areas for reductions in pump failures, and secondly, correcting the problems involves much more than just looking at the components.

The component suppliers have made significant advances over the years and these are of direct benefit.

Evolutionary improvements in mechanical seals, bearing seals, and power transmission couplings have led to substantial improvements in the MTBF of pumps and reductions in operating costs. New materials and technologies, and standards such as API 682 offer simple, cost effective ways of improving seal reliability and, interestingly, will also improve emission performance. Membrane couplings can eliminate the maintenance requirements associated with traditional gear couplings, and modern bearing isolator seals can greatly extend bearing life, compared to lower cost lip seals.

Taking advantage of those advances relies on a methodical process of identifying bad performers, generating a reliability improvement program and implementing and monitoring it. The effectiveness of this approach can be demonstrated by the benefits gained in over 20 refinery sites that have undergone such a program and monitored the results.

In all cases where substantial improvements have been made, there has been close cooperation between supplier and user, and a high level of dedication has been evident.

THE METHODOLOGY FOR PERFORMANCE IMPROVEMENT

A productive approach is to measure current performance, identify problem items (bad actors), agree on an improvement plan, and continuously monitor performance as changes are implemented, ideally in close collaboration between user and supplier.

Surveying and Understanding Current Performance

One of the most difficult tasks can be finding the necessary data in a plant with no record of performance monitoring. There are ways and means of making reasonable estimates from which meaningful reports can be produced, failure profiles can be constructed, bad actors identified, and the improvement process started.

MECHANICAL SEALS

Mechanical Seals MTBF

What life should be expected from mechanical seals? Anyone involved in the subject will confirm life span to be variable, dependent on the seal duty, seal design selected, quality of installation and process operation.

Where the seal design ideally meets the application, the seal will last the life of the equipment at 20 years or more, whereas on some applications where an incompatible design for the duty has been installed, life can be counted in days (API 682 is now targeting a minimum of three years).

In evaluating seal performance, a collective site or plant index is the best tool for comparison. The one used mostly in this paper is "mean time between failure (MTBF)" (cost data have historically not been readily available), that is:

$$\text{Mean time between failure} = \frac{\text{Total number of pumps}}{\text{Total number of seal failures in month}} \quad (1)$$

$$= \text{Mean time between failure (months)}$$

A moving average of six months should be used to smooth the curve. Some organizations use a multiplying factor of typically 0.5 to 0.75, the rationale being that all the pumps are not running together. Others use the number of installed mechanical seals. Typically, a refinery will have 15 percent of between bearing pumps with two seals.

Using the total pump index, what is the present achievable MTBF for a refinery site? From the data available, the top quartile is now exceeding an MTBF of six years (no running factor applied) and this should be achievable at any site. It is, however, a moving target upwards and we should also look at the other end of the scale where there are refineries achieving less than two years.

An essential prerequisite of an audit is documented failure data. Human memory is poor over the time scale involved. All refineries visited have kept failure data to various degrees of accuracy and the trend to computerized maintenance management has provided an improved databank. Some refineries have very comprehensive computerized failure record systems, but all tend to be dumping grounds for data with no feedback programs to implement a failure reduction program.

With a large pump population, a reasonably accurate MTBF can be obtained with only a few months' data. A more accurate MTBF is achieved by averaging over a six month period. This will indicate the overall performance of the site or unit and will allow comparison with its peers.

It is normal practice to cross check failure data from spare parts usage, the carbon face being used as the comparative component as it is normally changed at a seal repair. All pump maintenance has to be analyzed, not just seal failures. Typical reporting levels for manually recorded is 80 percent, whereas computer maintenance management gives recording levels above 95 percent.

The MTBF allows evaluation of the site performance but does not provide the data to initiate change. For this, a minimum of one year's failure data are required for a low MTBF site. Additional years improve accuracy but account should be taken of any seal modifications made in the audit period. Where the MTBF is 72 months and above, two or three year's data are required to identify the problem areas.

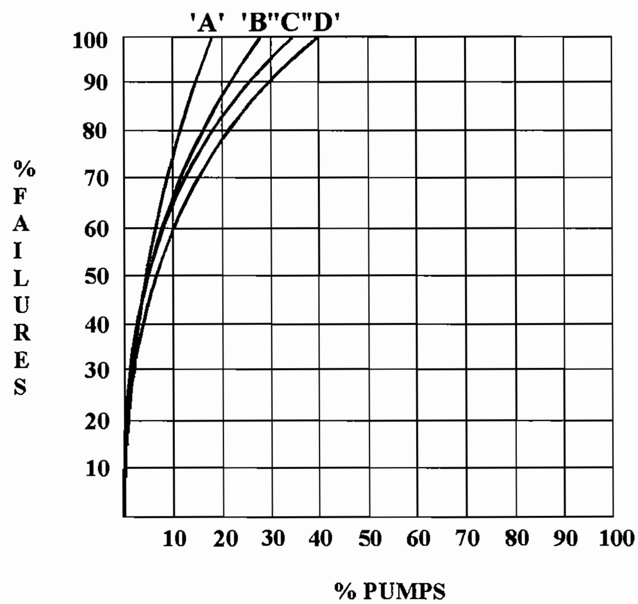
From this failure data, a plot "percentage failure against percentage pump population" can be drawn. The shape of this curve establishes the character of the problem. A steeply rising curve indicates a small percentage of problem seals, whereas a 45 degree line indicates a uniform failure rate. The total shape of the curve is influenced by the number of years of data, but normally this has a minor effect on the slope up to the 10 percent population point, the area of main interest. The curves shown in Figure 2 illustrate the time factor influence on the shape of the curve.

In deciding the course of action to be taken, the failure curve must be considered in conjunction with the MTBF. The following hypothetical examples illustrate the appropriate approach for two different scenarios:

- Example A—An MTBF of 60 months with 60 percent of failures from 10 percent of pump population, only 40 percent of pumps failed in the three year period.

For this pattern of data, the plant has a good baseline performance with a small number of problem duties. The generally accepted method of improving this performance is to correct the deficiencies of the worst 10 percent. Elimination of the problem units will provide the desired step change in seal life.

- Example B—An MTBF of 28 months with 35 percent of failures from 10 percent of pump population, 60 percent of pumps failed in the three year period.



'A'	1990	12 months
'B'	1990/91	24 months
'C'	1990/91/92	36 months
'D'	1990/91/92/93	48 months

MEAN TIME BETWEEN FAILURES (MTBF)

1990	60 months
1991	67 months
1992	69 months
1993	75 months

Figure 2. Effect of Length of Audit Period on Failure Distribution Graph.

For this pattern of data, improving the performance of the worst 10 percent would not achieve the overall objective and a more general review of the site sealing selection is also required.

Planning

The normal practice is to deal with the worst performing pumps first, and this can give dramatic improvements in pump MTBF in a very short time. It is important to construct a prioritized program for continuous long term improvement.

The next phase of an improvement program requires close cooperation between the site engineers and the seal vendor. For Example A, the worst 10 percent group need to be listed and investigated individually. This will require one or all of the following:

- Confirmation of process duty specification
- Confirmation of seal selection against duty specification
- Site inspection of operating seal to confirm that external services, circulation piping, etc., is correct
- Providing the seal vendor with failed seal components for failure analysis

From these data, recommendations can be made to correct the deficiency of the installed seal. It is unlikely that all the problems will be resolved at the first attempt, and good records are essential as it may be necessary to look at time over years. Data on the condition of failed seals must be logged.

Where a general review has been required, the low MTBF has been attributed to old seal technology and low quality seals, usually dating back to the 1960s and earlier. The appropriate action here is to upgrade face materials and elastomers. Where the original seals are of low technology, typically simple unbalanced or elastomeric bellows units, these are replaced. In addition, the worst 10 percent is still listed and investigated as for Example A.

Discussing and Agreeing on How to Cure the Problem Items

Very often, modern materials and designs can be used to provide low cost upgrades of seals supplied many years ago. Most users want simple solutions and not, for example, complicated double seals, which might improve MTBF but have hidden cost disadvantages. Frequently, the environment is to blame, coolers can be blocked or quenches and auxiliary services not operating properly. A cure can normally be found through a process of discussion that is honest, open, and objective!

These surveys have shown vast differences between the seal life for similar plants, dependent on the degree of upgrading and correction of problem seals. Repeat surveys have also shown that it is possible to raise the performance of the plant by pursuing seal life improvement programs.

The oldest seal still in service that these surveys have uncovered was installed in 1949, and more than 50 percent of all seals surveyed were installed before 1970.

There have been significant advances in seal technology over the years and the old and today's technology run side by side on many sites. The whole evolutionary history of seals was found at a number of locations. In the worst case, nine different face combinations were found for the same seal design and size where today's material technology parts could be fitted to the original seal, covering all requirements and improving the performance.

For a number of seal vendors, the basic design of the general purpose seal is unchanged and today's face technology can be retrofitted into the existing seal. The seal design may not conform to API 682 in detail (typically on the design of sleeve and safety bushings), but neither do the pumps in which they are installed comply to the relevant API, and the potential life of the upgraded seal is identical to a new unit of today's standard.

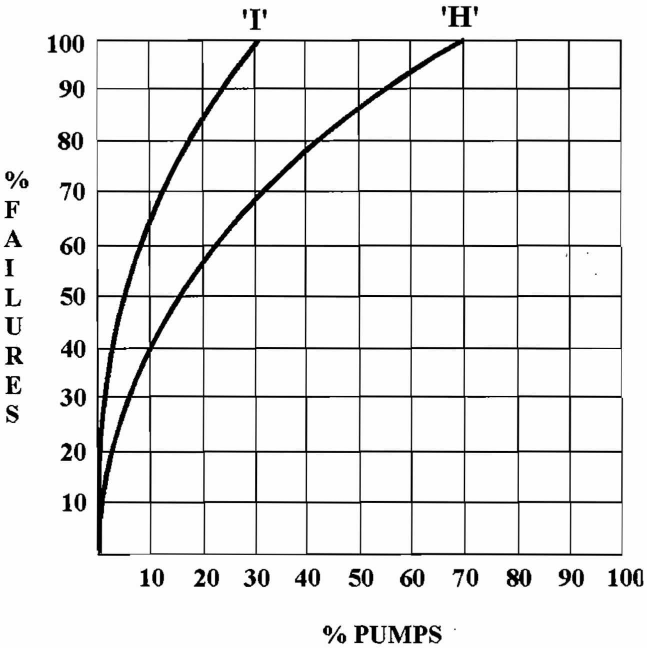
Upgrading of existing seals to the new seal materials and face dimensions is far more acceptable to the owners than the purchase of complete new seals. The cost differential of replacement parts to the original specification or new standard is very low, and in some cases the new components are less costly.

In analyzing the data from plants with predominately stellite or Ni-resist seal faces (installation date prior to 1970), it was found that the MTBF was low and the percentage of pump failures in an audit was high. The upgrading of the general seal population on these sites produced a dramatic improvement in MTBF. Typically, 60 percent to 70 percent of installed seals failed in a three year period, compared with 30 percent to 40 percent for upgraded units (Figure 3).

This is probably predictable when the different face wear capability is considered. Many operators' seals date back to the 1940s, when face materials were commonly carbon versus stellite. Modern counterparts frequently use interchangeable components, but with modern face materials (silicon carbide versus premium carbon grades, e.g., API 682) and a number of other changes to improve seal performance. When this is the case, this provides the customers with a very low cost method of upgrading (no need to replace seal plate and sleeve, etc.) and many performance improvement plans have been based on this possibility.

A typical seal and its increased operating range are illustrated in Figure 4.

The general upgrading can normally take place with little or no disruption to refinery maintenance routine. The warehouse stocking is simply changed and the new parts fitted on the normal maintenance requirement.



Refinery Location 'H' = 3 year period

Refinery Location 'I' = 3 year period

Figure 3. Observed Effect of Low Grade Seal Faces.

The major effort in the seal life improvement program is the correction of the problem sealing duties (worst 10 percent). *Collectively analyzing the problem sealing duties from over 5,000 pumps surveyed, provides a listing of process streams that have proved difficult to successfully seal and where more care should be taken in seal selection.*

A division of product stream for an average refinery follows. There will be variations for individual refineries dependent on the units installed and the sealing policy for nonhydrocarbon services. The 200°C (392°F) division has been selected, as historically this was the upper limit used for O-ring secondary packings.

- Hydrocarbon service above 200°C (392°F): 15 percent of pumping duties
- Hydrocarbon service below 200°C (392°F): 60 percent of pumping duties of which seven percent are light hydrocarbons (vaporizes at atmospheric conditions)
- Nonhydrocarbon service duties: 25 percent of pumping duties—boiler feedwater, clean water, sour water aqueous solutions, etc.

Applying the problem sealing duties to similar oil refinery surveys (Tables 1 and 2) shows the failure distribution against the sealing duties and the overall relationship of duty to failure rate.

Table 1. Problem Seals by Sealing Duty from Survey Reports.

	Locations																		
Sealing Duties	A	B	C	D	E	F	G	H	I	J	M	N	O	P	Q	S	T	Tot	%
HC above 200°C (392°F)																			
- pusher	12		1	5		15	3	3	9	7	8	4	1	11	3	3	1	80	31
- bellows	5	2		7	8				1	1				1				25	
HC below 200°C (392°F)	14	8	5	7	3	2	8	6	8	3	4	9	5	16	8		3	117	34
including: - hot crude 120 to 200°C (248 to 392°F)	1	1		1	1		1		2	1				1		1	1	11	
- LPG	2	2	1	3		1	1	1	4	1		4	2	3	2	1	1	29	15
- light HC	5		3	2		1			1			1	2	4	1	3		23	
Non HC duties	18	2	2	9	15	11	6	2	2	3	3	3	1	11	1	2	2	93	28
including: - sour water	3		2		4	4	2		1		1	2		6		1	2	28	
- clean and BF water	7			3	3	4	1	2		2	2			1		1		26	
- aqueous solutions	8	2		4	8	3	3	1	1	1		1	1	4				37	
	Lubricant plants only																		
Furfural				1		3		2								3	2	11	
Wax and solvents				3		2		3		1						2	2	13	
																	Total	336	

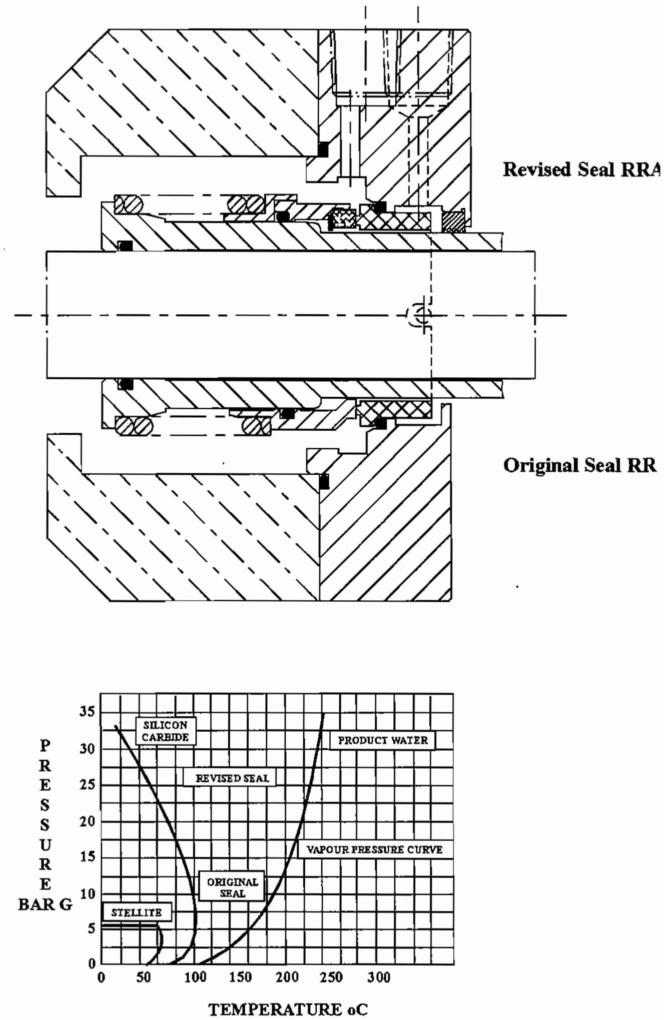


Figure 4. Improved General Purpose Refinery Seal.

Table 2. Relationship of Pump Population to Problem Seals.

	Percentage Pump Population	Problem Seals	Severity Factor Percentage Pump Population
HC duties below 200°C (392°F)	60	34	0.57
HC duties above 200°C (392°F)	15	31	2.1
Non HC duties	25	28	1.1
Sub Groups:			
LPG and light HC	7	15	2.3
HC duties below 200°C (392°F)	53	15	0.28
(not including light HC and hot crude)			

There is poor correlation between individual refineries' failure distribution and the overall profile as the data cover such a wide range of performance (MTBF) and seal technology. An example would be Location F where over 50 percent of problem seals are in the over 200°C (392°F) temperature group. This refinery uses double pusher type seals with a centralized barrier fluid system. Another extreme is Location B where only 11 percent are in the above 200°C (392°F) temperature range and 66 percent are in the hydrocarbon group of under 200°C (392°F). This refinery has metal bellows seals on all high temperature services. Thus, each refinery has to be considered in its own right when specifying corrective action.

Using the relationship of pump population to problem seals (Table 2) a "severity factor" has been calculated:

$$\frac{\text{Percent problem seals}}{\text{Percent pump population}} \qquad (2)$$

This gives an indication of the most difficult sealing duties for refineries that have not been upgraded.

For this index, par is one and LPG and light hydrocarbons come out as the worst area with an index of 2.3, followed by hydrocarbons above 200°C (392°F) at 2.1.

At the other end of the scale, hydrocarbons below 200°C (392°F), not including light hydrocarbons and crude oil above 120°C (248°F), the index is only 0.28.

Hydrocarbon Duties Above 200°C (392°F)

The first group of hydrocarbon seals are those operating above 200°C (392°F). They form only 15 percent of the pump population, but give 31 percent of the problem sealing list.

The majority of problem units are pusher seals using elastomeric secondary packing with the product temperature above the working limit of the elastomers. They work by virtue of the false environment provided by product coolers, external flush or double seal arrangements. Failure is usually due to problems with these secondary systems.

Water cooled product circulation cooling has a particularly bad history with plugging on the product side and fouling up on the water side. As many as 50 percent were found to be not working on any survey. With today's preferred seal selection, coolers are only required in water service above 80°C, and this limit on use has been achieved at one leading refinery where only a small quantity of good quality water was available (general cooling by salt water).

A number of refineries and oil companies have been slow to accept metal bellows seals, some having had poor performance from initial installations. In discussion with plant engineers, some still consider metal bellows as a new product, yet they have been in service for over 20 years, and as with other components, significant development has taken place, particularly in replacing the welded bellows with the formed bellows.

Metal bellows seals, in general, outperform pusher seals in high temperature services, but care must be taken in selecting the seal manufacturer. Table 3 lists the performance on four refineries that give a range of 60 months to only six months from the MTBF of metal bellows seals. The low performance units were the exception not the rule.

Table 3. MTBF for Metal Bellows Seals in Hydrocarbon Service Above 200°C (392°F).

Refinery E - 92 pumps	Seal Vendors 'B' and 'A' 4 years data	MTBF - 60 months
Refinery B - 24 pumps	Seal Vendors 'A', 'B,' and 'C' 3 years data	MTBF - 54 months
Refinery D - 30 pumps	Seal Vendor 'D' 2 years data	MTBF - 12 months
Refinery A - 15 pumps	Seal Vendor 'D' 4 years data	MTBF - 6 months

Hydrocarbon Duties Below 200°C (392°F)

The majority of seals (60 percent) operate in hydrocarbon (HC) service below 200°C (392°F) and only account for 34 percent of problems. If the LPG/hot crude units (120°C to 200°C (248°F to 392°F)) are removed, then the duties below 200°C (392°F) give 53 percent of the pump population against 15 percent of poor performers.

With a number of refineries now achieving over six years' MTBF, the conclusion is that 50 percent or more mechanical seals, in this category on high performance plants, have an MTBF of 10 years and more, some lasting the lifetime of the plant.

The problems of LPG/light HC/hot crude need to be addressed.

Light Hydrocarbons

In sealing light hydrocarbons, the seal is often required to operate with a very low product temperature margin, which can give rise to unstable conditions at the seal faces with the potential of leakage forming a vapor cloud.

The earlier API design condition that the pump vendor provides a differential pressure of 25 psi between the stuffing box and suction pressure to stabilize the product is not normally met, even on the new pump test stand. In service, the neck bush soon wears, dropping the pressure down close to suction pressure.

It should also be noted that the gradient of the vapor pressure curve depends very much on the fluid being pumped and the actual position on the curve (Figure 5) shows the vapor pressure for light hydrocarbons. Thus, the use of differential pressure as a selection concept is dangerous on light hydrocarbons, since it does not truly reflect the product temperature margin that dictates product stability at the seal face.

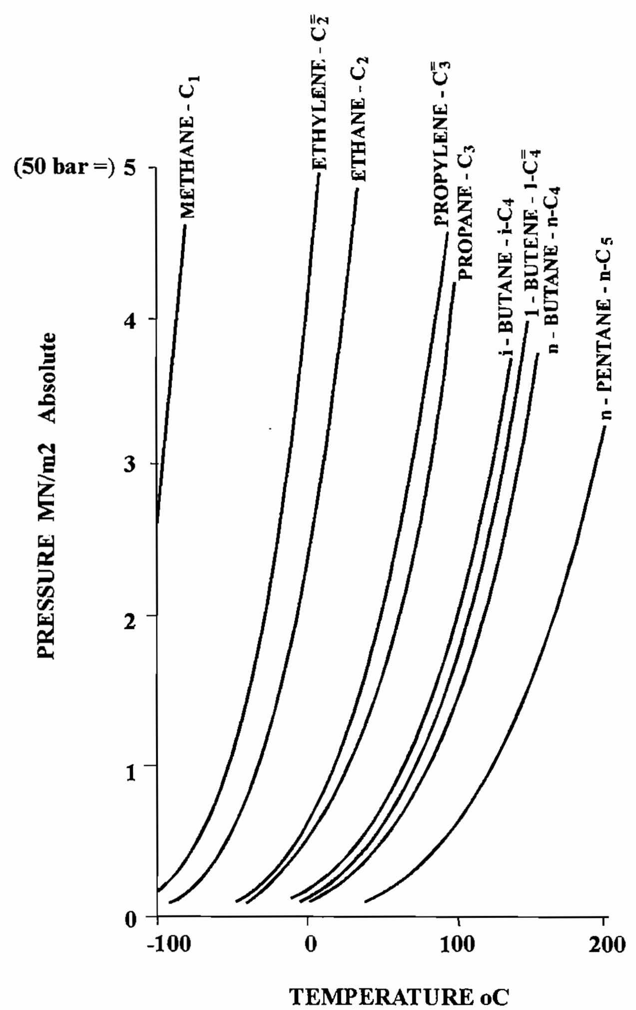


Figure 5. Vapor Pressure Curves for Light Hydrocarbons.

To address this problem, in the early 1970s, our company produced a steam heated seal working on the principle of creating a gas phase at the seal faces. These seals were generally very successful in providing a stable seal, but in some cases, particularly with mixed streams, gave poor performance. In one such case, the average life of the seals was less than two months and actually experienced 24 failures in a period of three years. This was replaced some years ago with a multipoint injection seal, which assures liquid surrounding the main seal with a dry running standby seal outboard. This seal has had only one failure in the past 10 years.

Figure 6 illustrates the arrangement of the light hydrocarbon seal with its noncontacting standby seal.

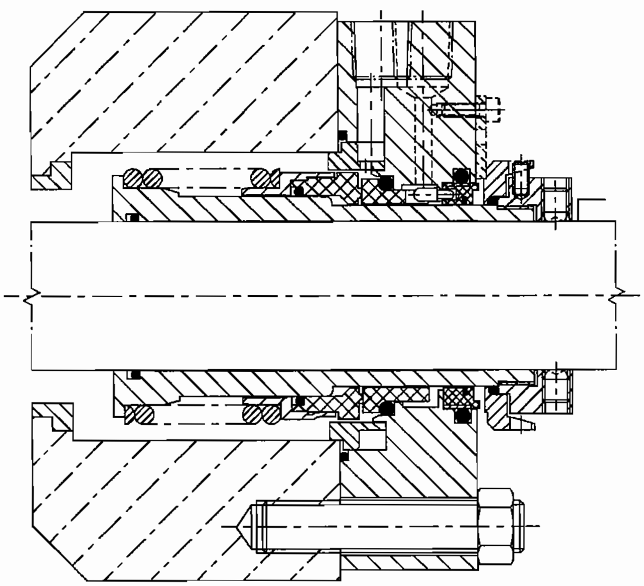


Figure 6. Improved Light Hydrocarbon Seal.

There are a significant number of the vapor phase seals still in service and standard seals that are operating in the gas phase, many with an MTBF of less than one year.

Light hydrocarbons have been the most rewarding area of the upgrading programs. A number of refineries have replaced the existing seals with the above described light hydrocarbon design. Repeat surveys show these seals no longer appear in the problem listing, and the payback on investment has been as low as three months.

Safety aspects are important for these sealing duties where failure of the primary seal can cause a vapor cloud of the escaping product. In the majority of cases, the replacement seal has included a secondary containment seal in the form of a dry running contacting or noncontacting style. The primary seal has also shown from refinery surveys to meet existing emission regulations.

These surveys have highlighted poor safety aspects at some locations. In one instance, unmanned LPG single seals were only 100 yards from residential housing, with a public highway in between.

Preflashed Crude Oil (Above 120°C (248°F))

The preflashed crude oil duty appears in most problem sealing duty lists. Data from 12 refineries (Table 4) and three different seal vendors gave an MTBF for the service of only nine months. Only two refineries gave a "no recorded failures" for a three year period and both use an external seal flush.

Crude oil is a wide boiling range material that is more difficult to successfully seal. Problems with crude oil are normally associated with hangup of the seal due to carbon and/or heavy wax deposits. The seal life is improved with a steam quench, but problems are not fully resolved.

An external flush (Plan 32) solves the problem but at what cost? Rerunning a distilled product is expensive. Injection of cold crude from upstream of preheaters could solve the problem. Product circulation coolers are unlikely to achieve sufficient cooling to make a difference.

Limited data on metal bellows seals in this duty indicate they give improved life. Refinery code B replaced pusher seals with bellows units, raising the MTBF from seven to 48 months.

Table 4. Mechanical Seal Life in Hot Crude Oil Service (Preflashed Crude).

Refinery Code	No. of Pumps	Product Temperature	MTBF	Seal Vendor & Type of Seal	Remarks
A	2	126°C (259°F)	7	'X' - Pusher	
B	2	122°C (252°F)	7	'Y' - Pusher	
Bi	2	122°C (252°F)	48	'Z' - Bellows	Seal retrofit
D	3	131°C (268°F)	9	'X' - Pusher	
E	2	148°C (298°F)	18	'Y' - Pusher	
F	2	287°C (548°F)	NR	'Y' - Pusher	External Flush
G	2	116°C (240°F)	12	'Y' - Pusher	
I	3	208°C (406°F)	11	'V' - Pusher	
J	2	150°C (302°F)	4	'Y' - Pusher	
P	2	218°C (424°F)	8	'Y' - Pusher	
Q	2	168°C (334°F)	NR	'Y' - Pusher	External Flush
S	5	130°C (266°F)	8	'Y' - Pusher	
T	3	140°C (284°F)	6	'Y' - Pusher	Water quench

NR = None recorded

Lubricant Manufacturing Plants

The performance of mechanical seals on lube plants is satisfactory except for the sealing duties involving furfural and the pump seals involved in the wax and solvent duty of the wax extraction from drum filters. These duties appear in all lube plant survey problem seal lists.

Development work on seals to satisfactorily cover these duties is required. Changes to existing seals have not provided a successful seal life.

Nonhydrocarbon Duties

The number of nonhydrocarbon seals in refineries is surprisingly high at 25 percent and they are largely ignored in the API requirements. They play their full part in the problem pump category with 27 percent of problems. In a number of surveys, seals in this category have had the lowest MTBF on the site. These sealing duties are given the least attention, and, in many cases, the lowest quality seals, yet the product pumped can be as dangerous as the hydrocarbons and equally important to the reliability of the plant.

The resolution of the problems tends to be on a "case by case" basis, but there are some groupings possible. Sixty percent of refineries had one or more boiler feedwater pumping duties in the problem list. All were for water at a temperature above 80°C (176°F), and seal failure is similar to that for the LPG duties involving wearout of the carbon face. Typical seal life is six months.

If the correct seal is selected with the necessary secondary service, the seal life can be many years. A product circulation cooler is essential to reduce the stuffing box temperature to below 80°C (176°F). For boiler recirculation pumps, a magnetic filter is required in the seal circulation line. Site surveys usually find no coolers fitted or coolers not effective, low grade seal faces, and no magnetic filter.

For sour water duties, the problem is defining the product. They often contain trace elements that chemically attack the seal components. Failure mode analysis is usually the most profitable approach.

Operating Difficulties

Many seals that fail have been subjected to conditions outside their design envelope, either by maloperation or process requirements. A common problem is dry running, often combined with pump cavitation induced vibration. This occurs on vacuum units or pumping from tankage, and appears in most problem pump lists.

An example is the vacuum distillation column bottom pump working with a negative suction pressure and with normal wear on neck bushes, the seal chamber will be under vacuum conditions. This has been confirmed by site measurements at three locations. Product circulation is often ineffective, because the lines plug unless trace heated and insulated. The seals do not normally leak outward in service, but on shutdown when a positive pressure is established in the stuffing box. Investigation usually shows heavy face damage.

With pumping from tankage, the pump suction pressure is dependent on tank elevation and product level in the tank. The pump will operate down to the vapor pressure of the product, resulting in a vacuum condition in the seal chamber and dry running of the seal. The result can be over temperature damage to seal faces and packings. There are reported cases where the operators use the pump as the tank level gauge, running the unit until flow stops. Seal problems have been resolved by fitting tank level gauging.

One solution to these sealing problems is to fit a simple tandem seal with the barrier fluid at atmospheric conditions. Alternatively, a double seal using a flow from the pump discharge to provide positive pressure sealing can be used. This has proved an effective solution to vacuum duties, including deep vacuum conditions of condensate extraction for steam turbine condensers.

Heavy cavitation or low flow vane passing vibration problems have to be engineered out by the operator, as it is damaging to the seal and pump bearings. Metal bellows seals are particularly at risk where fatigue cracking failures of the bellows have been recorded. The various other maloperations, such as running the pump with valves closed, etc., have to be covered by training.

Seal Services

Ideally, a mechanical seal should operate without any external services; unfortunately, with the present state-of-the-art, this is not practical. A product circulation line (Plan 11) is normally installed. This piping should ideally be a plain length of tube, but for various operating reasons, real and imaginary, we place cyclone separators, valves, flow controllers, strainers, coolers and vent connections to piping or pump body. All of these items can cause premature failure of the pump if not correctly installed and maintained.

- Cyclone separators—Often installed when not required to protect the seal from solid particles. If incorrectly installed in a dirty duty, they will erode through the associated piping.
- Valves and flow controllers—There are no means of measuring the flow and operators just love to adjust valves, usually to the "off" position.
- Strainers—Installed in line with no differential pressure gauge, not normally inspected until seal fails.
- Coolers—Often installed in inappropriate duties, heavy product plugs the unit when cold and fouling of waterside reduces efficiency. If required, they must be regularly checked for differential temperatures.
- Vent connections—With connection to various pressure levels, the seal can be starved of product circulation or supplied with a different product.

All of these appendages to the circulation system have appeared as the cause of seal failure.

Atmospheric Quenches—Water and Steam

Historically, water quenches were common on mechanical seals in hydrocarbon service, being left over from when pumps had packed glands. Refineries in the top half of performance have dispensed with it, but it is still common in older refineries with little upgrading.

The only duties requiring a water quench are products that crystallize on the atmospheric side of the seal. This has been removed on many installations on upgraded units, resulting in premature failure of the seal.

Steam quenches are essential for long seal life and safety for a number of high temperature and heavy hydrocarbon duties. Most problem pump lists include sealing failures associated with inadequate or nonexistence of a steam quench, which is to prevent coke formation and to cool the seal at high temperatures or to heat the seal faces on some medium temperature hydrocarbon residue duties.

Provision of a dry steam flow of 2 to 5 psig is not a simple task when the system pressure is often at 125 psig. Pneumatic controllers or manual valves do not have long term stability. Orifices are the most successful but must be of the correct material to withstand wire drawing. Over pressurization will cause early seal failure. Steam traps and insulation are essential. Site surveys often find a flow of tepid water to the seal, which on hot duties flash off into steam in a dramatic fashion causing pressure pulsation at the seal.

For the heavy fuel oil pumping duties from tankage, sludge bonding damage to the face often appears as the cause of failure in the problem sealing duties due to high viscosity of cold product at the seal faces. Suitable steam heating of faces will usually resolve the problem.

Double and Tandem Seals

Problems with external flush or barrier systems for double seals also form a significant percentage of items in the "poor seal performance" listing. A few refinery locations have a high preponderance of double seals with an external barrier system. The MTBF for these seals is lower than the site average, and the higher capital and running costs of these units does not necessarily provide a better seal performance.

There are very few sealing duties in a typical oil refinery that justify a liquid barrier double or tandem seal. Today's technology can supply alternative seals with a statistically better chance of an acceptable performance.

Implementation

The difficult part is making it happen! Here is where the desire and the dedication are really necessary. The benefits are directly proportional to the input. An example would be where seal lifetimes were taken from an MTBF of 35 months to 82 months in four years and, almost entirely, due to the efforts of the operator.

In any seal life improvement program, the reliability survey is the simple part. To manage the changes, in addition to the normal workload, is the challenge. There is no universal panacea to resolving mechanical seal failures. A dedicated long term commitment is required.

A collaborative effort between the refinery and the seal vendor can work well. "Workshops" or "surgeries" have proved effective where all seal failures are kept and analyzed by a team of engineers from the refinery and the seal vendor. The economic way is to implement any changes when the seals need to be repaired. This extends the program over a number of years.

Recordkeeping is very important if the effects are to be measured and also to correct the deficiencies. Not all the problems are resolved at the first attempt.

The ongoing data being collected show that the objectives of improving seal life is being achieved. The average seal life data over a number of years for the refineries surveyed are summarized in Figure 7 and Table 5. Only the country of locations is given as the surveys are carried out on a confidential basis and is considered to be commercially sensitive. Most of them are improving and the rate of improvement is very much dependent on the commitment of people to change.

The improvement in performance at one medium size UK refinery (location B) shows the MTBF was fairly steady at about 36 months for some years prior to the survey (Figure 8). This was

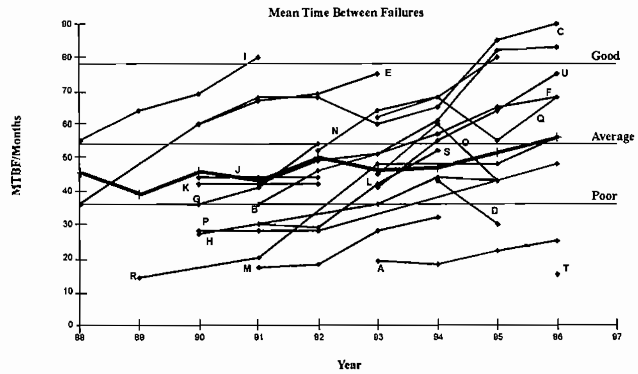


Figure 7. MTBF Curves for 21 Refineries.

Table 5. Mean Time Between Failures for 21 Refineries.

Location	No. of pumps	Year									
		88	89	90	91	92	93	94	95	96	97
A - South Africa	400						19	18	22	25s	
B - U.K.	240				36s	46	51	61	82s	83	
C - U.K.	185			60	68	68s	60	65	85	90s	
D - South Africa	750							43	30s		
E - Middle East	680	36		48	53	55	60s		65	78s	
F - U.K.	530				42s	49	51	57s	65	68	
G - U.K.	370			36s	41	54s					
H - U.K.	275			27s			36	44	43s		
I - Korea	220	55	64	69	80s						
J - Australia	240			44s 3 yr. average							
K - Australia	50			42s 3 yr. average							
L - U.K.	80						42s				
M - U.K.	82				17	18	28s	32s			
N - U.K.	179					52	64s	68	80s		
O - Europe	90						45	60	43s		
P - South Africa	300			28s 3 yr. av.						48	
Q - U.K.	166						62	68	55	68s	
R - U.K.	49		14		20s		48		48	56s	
S - U.K.	280				30s	29	42	52s			
T - South America	184									15s	
U - U.K.	1						41s	55	64	75	

xxs indicates year of survey

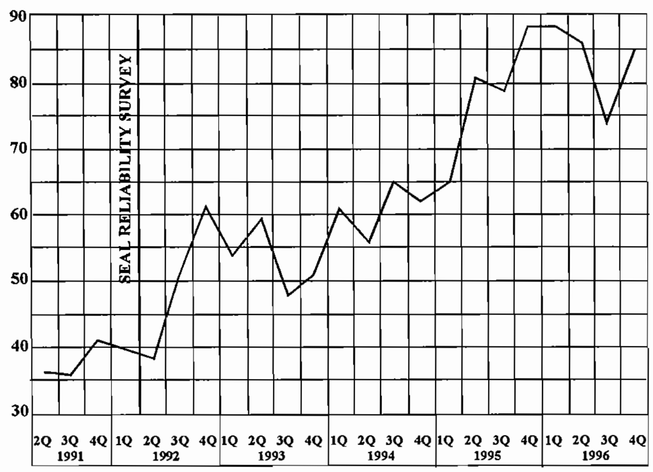


Figure 8. MTBF Improvements in a UK Refinery.

raised to 82 months over a four year period and almost entirely due to the efforts of one dedicated site engineer collaborating with the supplier.

The distribution of MTBF at 21 refineries is plotted in Figure 9. The normally expected Gaussian distribution is not clearly there with two peaks showing. There is, therefore, no distinctive average MTBF, probably due to the sample size of only 21.

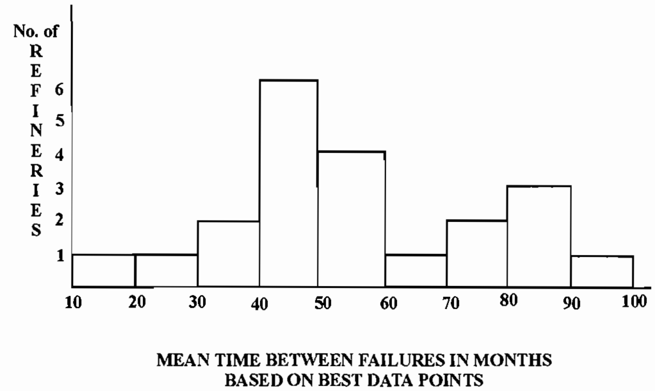


Figure 9. MTBF Distribution for 21 Refineries.

Unfortunately, there are examples of where repeat surveys show only moderate improvements with many of the same problem seals, because no action has been taken to resolve them. There must be a long term commitment of the plant personnel to make any significant improvement. Very few plants monitor their MTBF for seals or other failures even after the initial survey. At one location, personnel considered it a management tool with which to attack them!

Other Performance Indicators

For over a decade, MTBF has been the primary means of assessing mechanical seal reliability, mainly because other data are hard to find. Measuring MTBF on one site in the same way offers an excellent guide to performance, and allows trends and changes to be monitored. To compare different sites, however, requires great care. With that in mind, an additional approach was proposed by a UK refinery engineer to provide a simple "yardstick" with which comparisons could be made and which looked at money; cost reduction being the primary objective.

That "yardstick" was cost per seal installed (CPSI). Cost per seal installed can provide an alternative view that permits an overall appreciation of what is happening at one site, and allows comparison with another site. How accurate are the base data?

- The number of mechanical seals installed? Almost all sites have this logged to an accuracy of 95 percent or greater.
- Annual amount spent on mechanical seals? Virtually all purchasing departments will have this to an accuracy greater than 99 percent.

If we use a very simple equation:

$$\frac{\text{Amount spent on all mechanical seals} = \$250{,}000}{\text{All seals on site} = 500} = \$500 \text{ CPSI} \quad (2)$$

This very simple equation uses readily available data and yields the actual cost of using any manufacturer's mechanical seal (based on the purchased cost of parts and services from the vendor).

Example 1

A survey of 10 refineries' CPSI (Table 6) was carried out using only one seal vendor's mechanical seal data. It showed extremely interesting results and certainly put a cost perspective on the traditional MTBF form of measurement. The fact that all seals in this example are from one vendor makes the comparison between refineries particularly accurate.

At the highest end of the scale, Refinery 1 has a CPSI of $1266 per annum, which in this case equated to an MTBF of less than 30

Table 6. A Survey of 10 Refineries' CPSI.

Refinery	Number of seals	Annual spend $US	Cost/seal installed $US
Ref 1	550	696,390	1266
Ref 2	380	183,700	483
Ref 3	660	584,500	886
Ref 4	250	208,750	835
Ref 5	180	116,900	649
Ref 6	250	183,700	735
Ref 7	90	43,420	482
Ref 8	250	197,060	788
Ref 9	280	116,900	418
Ref 10	500	283,900	568
Totals	3390	2,615,220	771

months. Refinery 9, with the best performance, has a CPSI of $468 per annum and an MTBF of 60 months. Even allowing for the 100 percent improvement in MTBF (which would reduce the CPSI to $633), there is a further 26 percent improvement in cost management.

In this case, those savings had been brought about by using the most suitable, and therefore most cost effective, sealing solution for each application, but closely linked to maximum rationalization.

Example 2

To underline the importance of the part that the site operator plays, it is useful to look at the cost per seal installed for a number of different sites all using the same seal vendor (Table 6).

The range of CPSI is from $1266 to $418, with a mean of $771 (a range of three to one). In this case, one of the major reasons is the relative complexity of the seal configurations used. The user with the highest costs uses dual seals much more extensively than the one with the lowest costs.

Finally, it is interesting to look at the combined results of two sites (same operator) with three different seal vendors (Table 7).

Table 7. Combined Results of Two Sites with Three Seal Vendors.

Vendor	CPSI
A	264 US dollars
B	1013 US dollars
C	897 US dollars

Clearly, it is interesting to compare the results from different vendors, and CPSI can give a meaningful insight when the different vendors' seals are used in similar services. In the above case, the figures are a little misleading, as the vendor with the worst CPSI has all the hot hydrocarbon services (high temperature bellows seals).

CPSI is a useful and meaningful indicator but, as with MTBF, care must be taken.

BEARINGS

The Problem

Experience in the oil refining industry, and other process industries, shows that many mechanical seal failures are, in fact, the result of premature bearing failures; themselves often the result of lubricant contamination. While none of the refineries surveyed maintained separate records of mechanical seal failures occasioned by premature bearing failures, refinery maintenance engineers will recognize the extent of the problem (a problem readily solved by the installation of suitable bearing isolator seals).

Background

Historically, bearings installed in pumps and other rotating process machinery have been protected by external throwers, which rely on centrifugal force, felt or other "soft" rings inserted into the bearing housing or the traditional synthetic rubber lip seal. All of these designs have inherent disadvantages ranging from ineffectiveness of the thrower (which only works in the dynamic condition) to local heat generation, one way sealing performance, and peripheral speed limitations together with the inevitable shaft wear adjacent to the bearing when felt type rings or lip seals are fitted. Some of these disadvantages are illustrated in Figure 10.

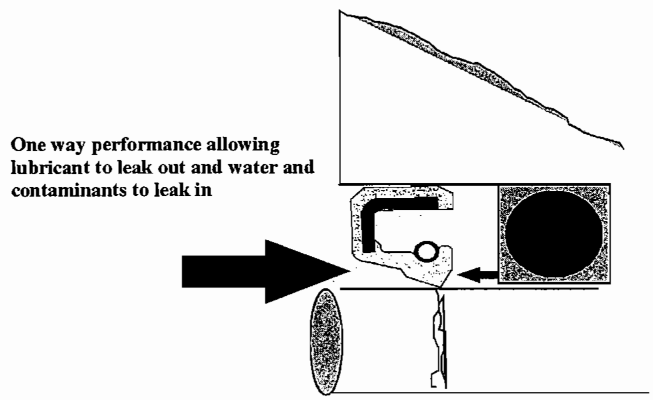


Figure 10. Bearing Lip Seal.

The contamination of the bearing lubricant by water, whether as a result of climatic conditions or washdown, has a dramatic effect on bearing life. For example, as little as 0.002 percent water content in a typical mineral oil reduces bearing life by 48 percent; by 78 percent for 3.0 percent and by a massive 83 percent for 6 percent water content. A significant cost in terms of plant downtime, replacement bearings, and associated mechanical components such as new or reconditioned mechanical seals.

The Solution

While labyrinth seals have existed since Roman times (the archetypal Roman chariot had crude animal fat lubricated wheel bearings sealed with wooden labyrinths), recent developments in nonmetallic, noncontacting labyrinth bearing isolator seals have proved to offer a significant increase in bearing life. Typically, from three or four months to two years on pumps in a paper mill, and from six to twelve months on electric motors in a particularly corrosive atmosphere in a chemical plant. In a relatively "clean" environment, the installation of labyrinth bearing isolator seals extends bearing life by a factor of two, while on plant and machinery subject to "washdown" (e.g., in a cellulose plant), bearing life is typically extended by a factor of six or seven. On typical oil refinery duties, six to 10 years is currently not unusual, provided there are no other external factors affecting the installation (e.g., steam quench allowing water into the bearing). This can be significantly extended for all cases using bearing isolators. A typical nonmetallic, noncontacting bearing isolator seal is shown in Figure 11. Ironically, bearings are also changed from time to time as a consequence of mechanical seal or other failures.

Two-piece nonmetallic, noncontacting labyrinth bearing isolator seals are now widely installed, not only for the protection of bearings on refinery and other process plant rotating machinery, but also in a wide range of machinery including electric motors, turbines, gearboxes, conveyors, contractors plants, etc., and in other industries (e.g., food and drink processing, pulp and paper, power generation, metallurgical plants, mining and quarrying, and water and waste treatment).

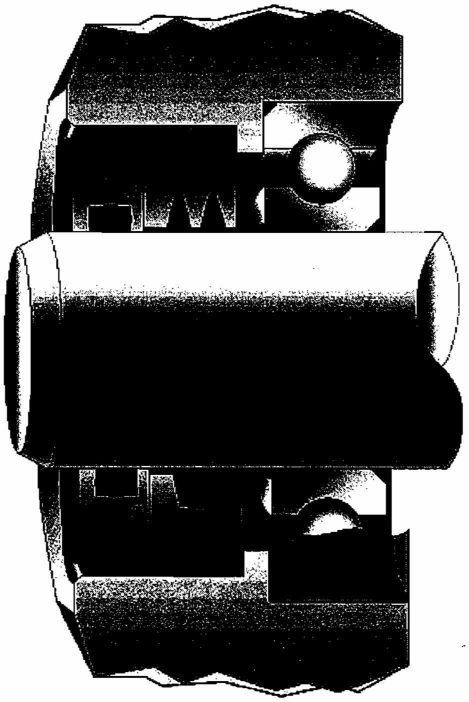


Figure 11. Bearing Isolator Seal.

As will be recognized, the principal features and benefits of a well designed bearing isolator seal are:

• Nonmetallic construction for corrosion resistance and spark resistance.

• Noncontacting design for long life and zero power consumption.

• One piece unitized design for ease of installation.

• High tolerance to axial movement and self aligning capability.

• Self lubricating in case contact between rotary and stationary elements occurs.

• High shaft speed capability to eliminate a weakness of lip seals.

• Reasonable first cost to generate early benefits.

Bearing Isolator Seal Economics

The economics of installing labyrinth bearing isolator seals may be considered from two aspects. First, from the point of view of extended bearing life. Secondly, from the point of view of power savings. In addition, there is the safety aspect, every bearing failure is a potential fire. Many serious refinery fires have been initiated by a bearing failure. Together, these can add up to considerable annual savings on a typical oil refinery installation with say 350 pumps and 50 other oil lubricated rotating machines, i.e., a total of 400 driver/driven machine sets, each machine having two bearings, giving a total of 800 bearing seals required. (This analysis ignores the potential for bearing isolators on the driving machine—typically the electric motor.)

Bearing Life and Associated Machinery Economies

As will be seen from the costs shown below, an investment of $140 in a 2 inch labyrinth bearing isolator seal, which doubles the life of the associated bearing, shows a potential payback of just over one year with subsequent savings of $84,000 per annum for a population of 400 machines. (All assumed to be conventional end suction pumps for illustrative purposes.)

• Typical bearing repair costs comprising: 2 inch bearing, labor, mechanical seal repair, miscellaneous parts (gaskets, etc.): $1500

• Cost of labyrinth bearing seal: $140

A refinery with 400 units and a pump/bearing MTBF of 10 years would have 40 bearing failures per year. Out of these failures, approximately 10 would not be diagnosed by vibration monitoring, resulting in catastrophic failure with subsequent damage to pump shaft and other components. Average repair costs of these units is $10,000.

• Annual bearing repair cost:	10 × $10,000	$100,000
	30 × $ 1,500	$ 45,000
	Total cost	$145,000

• One off cost of installing bearing seals: 800 × $140 $112,000

• Assuming a doubling of bearing life, the annual repair cost reduces to $72,500

Power Consumption Economies

The calculation below shows the smaller, but still very significant, savings in power consumption that can be achieved on plants fitted with labyrinth bearing isolator seals. The same typical oil refinery fitted with 400 machines, each showing a power saving of $58 per annum, offering a potential total power saving of $11,600 (200 machines running).

• Assume friction torque of 10.44 in oz/in circumference (based on 2.25 in results)

• Assume:
  • 2 seals per pump
  • 1.375 in shaft
  • 3600 rpm
  • Electricity cost at 3 cents/kWh
  • Pump usage 3 shifts/day, 7 days/week, 48 weeks/year

• Torque = 45.1 in oz

• Power consumption = 0.2402 kW

• Total power consumed = 1.937 kWh/year

• Total cost = $58.11/year

Summary of Savings

Where Labyrinth Bearing Isolator Seals Are Installed

In summary, for a total investment of $112,000, a refinery with 400 pump/drivers with oil lubricant bearings could save $84,000 per year (maintenance savings of $72,500 and power savings of $11,600). At the same time, there would be a significant reduction in the risk of fires from bearing failures.

However, to return to the principal subject of this paper, the reduction in unplanned maintenance shutdowns due to premature bearing failures eliminates concomitant and unplanned mechanical seal repairs.

Couplings

If significant improvements in MTBF within a plant are to be achieved, then consideration must also be given to the type of coupling used. In a survey carried out in a Middle East refinery, seven percent of reported pump failures were attributed to the coupling.

Another survey carried out in a major UK refinery identified that between 28 percent and 44 percent of couplings fitted on units within the plant were of the lubricated gear type. Gear couplings have been extensively used in the process industries. They have been regarded as rugged and reliable, but they require regular servicing. The disadvantages of gear couplings have created a strong movement toward metal membrane couplings.

One UK operator reported to us that a substantial amount of equipment was being sent to the central workshop with gear or other lubricated couplings fitted. The majority of these on closer inspection, showed extensive wear or had failed catastrophically due to inadequate lubrication.

An ongoing program to change out all lubricated couplings on site through a process of upgrading and rationalizing with metal membrane couplings over a five year period has resulted in the elimination of failures, attributed directly to couplings, with a noticeable reduction in equipment being sent to the workshop.

Another Middle East refinery reported that they had achieved a steady increase in reliability from 36 months to 55 months over a three year period by keeping up to date with technology and upgrading with membrane couplings.

The membrane type coupling has proved to be one of the most reliable couplings in the process industries. Early designs of membrane couplings (1950s, Figure 12 (lower half)) have undergone major development to match the needs of today's pumps. Figure 12 (upper half) illustrates the new revised model. As can be seen, the redesign of this coupling has made significant weight savings. The coupling is now less than 40 percent of the original coupling weight with a 300 percent improvement in power to weight.

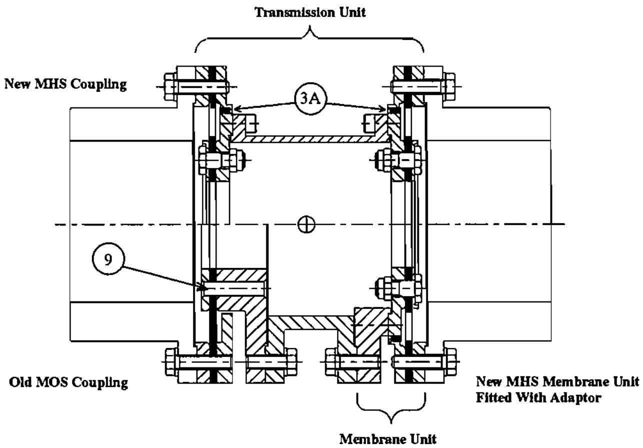


Figure 12. Upgraded "Spoke Form" Membrane Coupling.

Care has been taken to maintain the reliability of the coupling along with the advantages of:

- Fail free operation in the event of membrane failure.
- Low axial stiffness.
- High angular misalignment capacity.

A new standard feature has also been introduced, item 3A (Figure 12) is a nonmetallic safety bushing, which eliminates any risk of sparks being emitted that may cause a fire or even an explosion in hazardous zones. This feature is complemented by the use of nickel copper alloy membranes, nickel copper alloy center fix bolts (item 9, Figure 12) and a high tensile brass outer guard ring for nonsparking application.

The first coupling of this type was supplied to a UK refinery. The refinery had a problem with vibration levels on one particular unit, and this became so severe that failure of the coupling occurred. A major factor was seen as the weight of the coupling, in relation to the size of the shafts. As the majority of the existing metal membrane couplings had given such excellent service, the operators approached the authors' company with the idea of a replacement, but with reduced weight. The new coupling was fitted in 1985 and has been operating continuously since.

In the above example, the shaft separation allowed the use of a standard spacer type coupling. However, when converting from gear couplings to membrane couplings, the shaft separation is usually very small. In one Middle East refinery, the maintenance staff was looking at updating the gear couplings on their refinery as part of their maintenance cost reduction program.

A total of 300 close coupled units fitted with gear couplings were identified and considered for conversion, but the majority were not readily convertible to membrane units because of the short distance between shaft ends available. The requirement for a suitable spacer coupling, which would be applicable to these units, meant it must fit over the shafts. The maintenance staff had very clear ideas of what they wanted and approached the authors' company to provide the engineering solution. The design must:

- Have maximum separation of the flexing elements for maximum misalignment capability.
- Axial length to fit in the existing restrictive space envelope.
- A minimum number of sizes to cover the onsite range of requirements.
- Should allow easy disconnection of the drive.
- Should have high resistance to "flying" in the event of membrane failure.
- Access to the shaft should be available to allow for alignment.
- Costs to be such as to give an acceptable pay back on the basis of accepted savings.

Illustrated in Figure 13 is the split spacer metal membrane coupling that was designed to meet the users requirements. The coupling features "reversed" hubs with the membrane packs attached to the back of the hub flange, rather than over the hub bosses. This offers two distinct advantages:

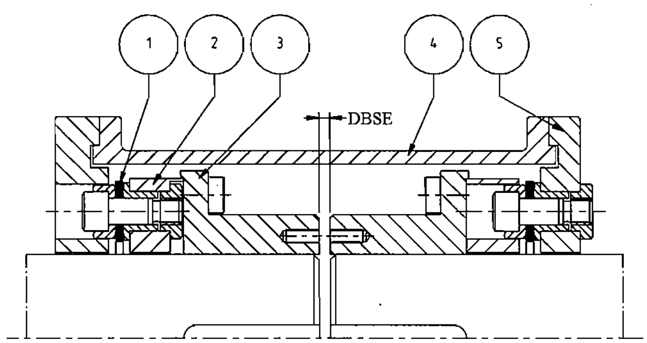


Figure 13. Close Coupled Membrane Coupling. (1. Membrane pack, 2. Inner guard ring, 3. Hub, 4. Split spacer, 5. Outer guard ring)

- Allows the maximum shaft size for a particular membrane size
- The distance between the membranes is maximized for maximum misalignment capability.

The coupling also features a novel split spacer that is spigotted into the guard rings in such a way as to absorb the centrifugal loading. The use of the split spacer allows:

- Easier coupling assembly.
- Inspection of the membranes without disturbing driving and driven machinery.
- Disconnection of the drive for test reasons.
- Easy coupling alignment using the "reverse periphery" method or something similar.
- The spacer overlaps both hubs and gives very high security against flying of the spacer in the unlikely event of membrane failure.

While the coupling was extremely novel, it had the advantage of using tried and tested technology extensively. A range of six couplings covering the range of 11 to 260 kW/1000 rev/min was designed and the first prototype (rated at 27 kW/1000 rev/min) was manufactured and shipped to site.

The fitting staff liked the split spacer and its ease of installation. After a period of satisfactory operation, a further 200 couplings were supplied at this site alone and in all cases vibration levels were lower. The couplings have now been in service for some nine years.

The regreasing of the couplings employed the equivalent of three mechanical fitters at this refinery, with further maintenance time involvement of electrical and process staff in preparing the unit to be worked on. At the start of the program, gear couplings were greased at four monthly intervals. The economics of changing to the described nongreased couplings provided a payback of less than a year for the smaller coupling sizes and was fully justified on cost savings throughout the range of sizes.

MONITORING

It is clearly vital to continuously monitor, both to show that the desired improvements are being achieved, and to provide a basis for ongoing improvements. Many large companies have good software to help in this process, but sometimes it is so complicated and user unfriendly that it is not used. Many smaller or older facilities have no mechanisms at all and find it hard to make a start.

Computer technology has expanded rapidly in our industry with software programs now on the market for the complete design and selection of pumps/seals and couplings, down to the selection of a simple O-ring. There are many software programs available to the plant engineer that will help establish the MTBF and identify the poor performers.

Any good program needs to be flexible in its design. Refineries vary considerably in the amount of data available and on the degree of data they wish to have access to. In some cases, existing operating systems within the plant will perform many of the required tasks.

The program needs to be capable of being used on both existing and new plants. On existing plants, the software is usually used as part of a management agreement with the seal maker. The input of the initial data can be difficult and varies in complexity, from the local engineer entering the data to the electronic transfer of the data from the plant computer system. An effective agreement will provide the resources to perform this task.

A new plant follows a different route with some of the data being entered at the precontract stage, and developed and added to by the supplier during the development of the contract. On the supply of the pump to site, the equipment vendor can then hand over a complete program with all data loaded.

The following summarizes the stages/data screens useful for effective seal and coupling management.

Preinstallation

- Confirmation of site and contract data
- Identification of the units and plant items in the plant
- Pump data
- Ancillary equipment data
- Seal duty and specification
- Coupling duty and specification
- Ability to view seal and coupling drawings
- Spares list

After Startup

- Maintain a pump history
- Log and record an event
- Calculate MTBF for the plant or unit
- Identify poor performers
- Record details on the condition of failed components
- Stock control

Such software has found success in a number of applications where this kind of monitoring and control would not otherwise have been possible. It is important for that reason as one of the essential tools in a reliability improvement program. Such software can be "stand alone" or integrated into existing plant systems. Applications range from refineries to chemical and pulp and paper plants.

Such systems allow events to be recorded and the data to be analyzed to produce failure distribution information and MTBF data for complete plants or individual units.

Whether the data are collected and managed manually or in such a system is not crucial. The important thing is that the right data are available to the right people.

SUMMARY BENEFITS

The improvement process is only worthwhile if the benefits exceed the input. These will include not only reductions in direct operating and maintenance costs, but also the possibilities of reduced energy costs and costs of auxiliary services; factors that are often ignored.

Mechanical Seals

The improvement of seal and coupling performance is only worthwhile to the user if the benefits exceed the input. For oil refineries, reliability does not normally affect unit availability as pumping equipment is covered by a standby unit.

External services of cooling water, barrier systems, or the downgrading of a clean product into a dirty stream to provide an external flush can be expensive in specific cases. The installation of a seal that can work effectively in the environment of the product being pumped can make significant savings.

The repair of mechanical seals installed in centrifugal pumps forms the major part of pump maintenance costs in the oil and many other process industries. Analysis of data at a number of locations has shown that 50 to 70 percent of pump maintenance work is initiated by the failure of a mechanical seal.

The cost of repairing a typical pump is three to four times the cost of the seal components, due to the work involved and the replacement of secondary items such as bearings. A figure calculated as an average cost of a seal repair for a medium size back pull out pump is $2,000, which, in some instances, is the same as a new "state-of-the-art" seal. With problem seals only lasting three to six months, the return on investment is self evident.

Looking at the broader picture, an oil refinery complex will have between 500 and 2000 mechanical seals. One large UK refinery spent $1.9 million on seal repairs in one year, with an MTBF of less than 48 months. For them, there were major incentives to improve.

The capital costs of a failure reduction program is relatively low, since only a small percentage of the installed seals (normally less than 10 percent) will require complete replacement.

It is normal practice to upgrade the existing seal reusing the nonwear components, only changing the faces and secondary packing. The differential costs are very low, in some cases the new component costs less than the spares to the original material specification.

The rationalization of components with upgrading has also provided a return on investment. A typical refinery's spares inventory amounts to over $1000 per installed seal and with ownership costs at 20 to 25 percent per annum, worthwhile reductions in costs can be achieved. Typically, inventory surveys achieve a 30 percent reduction without increasing the risk factor.

Couplings

The trend away from lubricated couplings to metal membrane couplings on a number of refineries has assisted in the improvement to the MTBF at site.

New designs of couplings allow for easy conversion from gear to the membrane type. The upgrade to metal membrane couplings can be carried out over a number of years without impacting production.

The economics of changing to metal membrane couplings can provide a payback within one year.

Bearings

Historically, mechanical seals and soft packings were the focus of attention for operators seeking to reduce real life costs. Major advances have been made in improving seal reliability, and MTBF values of over four years are now commonplace. Additionally, it is accepted that many seal and coupling failures are, themselves, caused by premature bearing failures. Bearing isolator seals are rapidly gaining popularity and, indeed, are being increasingly specified on new projects. The potential maintenance and downtime savings are substantial.

REFERENCES

Coombs, A. G. H., 1988, "Mechanical Seal Practise for Improved Performance," I. Mech E Guides for the Process Industries, Mechanical Engineering publications for the I Mech E.