THE DEVELOPMENT OF AN ADVANCED MECHANICAL SEAL FOR SLURRY APPLICATIONS

by

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Although currently based in Manchester, Mr. Irons has visited most of the overseas operating companies. He recently spent seven months with Flexibox Pty, Ltd., in Melbourne, Australia, where he worked alongside their own engineers to develop a mechanical seal specifically for slurry applications.

Mr Irons obtained his B.S. degree in Mechanical Engineering from the University of Birmingham. He holds several patents for the design of hydraulic motors and mechanical seals, has authored papers on the design of barrier-fluid systems for double and tandem seals and has served on the Technical Steering Committee of the Energy Industries Council.

INTRODUCTION

The development of a novel mechanical seal specifically aimed at applications where the sealed medium contains a significant proportion of suspended solids is discussed. It follows the project in detail from the initial recognition of an industry need through the various design and development stages leading to field testing and, ultimately, the introduction of a resulting product range.

THE INDUSTRY NEED

In pumping terms, a slurry may best be described as a means of transporting solid particles suspended in a liquid medium. These particles may be large, small or even fibrous and may be hard or relatively soft. In this context, one may also include liquids which contain a high concentration of dissolved solids since, although they are not strictly defined as slurries, their tendency to crystalise does present similar problems to the mechanical seal designer.

In many instances, the slurry is a natural part of the production process resulting from chemical reactions which are carried out in a liquid phase while, in other cases, the slurry is used as a more economical alternative to transporting by hoppers, conveyors, trucks, etc. Industries which pump solids in the form of slurries include mining, ore processing, paper pulp, cement, sewage, dredging, chemicals, fertilizers, and oil exploration. The spread of industries indicates the depth and breadth of the problems that have to be overcome in providing an adequate solution to pump sealing.

The oil refining industry has been familiar with mechanical seals for some forty years and now uses them on about 95 percent of all pumping applications, but slurry sealing is still dominated by soft gland packings. Slurry pumps are necessarily extremely rugged, quite different from those encountered in the oil and petrochemical industries, and they are often required to operate in equally rugged environments. Users have generally believed that mechanical seals cannot survive under these conditions, even though it can be demonstrated that a reliable seal would produce large cost savings, particularly in reduced water consumption and conservation of valuable process fluids which are currently lost in leakage.

Water is a very scarce commodity on many mining sites and mineral processing plants, as they are often found in semi-desert locations. Gland water which leaks out to the environment can generally be collected and recycled but most of the gland water which leaks into the pump is lost for good. This water also causes product dilution which reduces the pumping efficiency and, in cases where the end product is a dry powder, considerable energy costs can be incurred in removing it.

Information in Figure 1 is based on cost information provided by an Australian Nickel Refinery. These figures relate to a single very small pump which consumed only 0.5 gallons per minute of gland water, but the graph shows that a waterless mechanical seal could pay for itself within approximately 2,000 operating hours and, thereafter, would save about $5,000/year in operating costs.

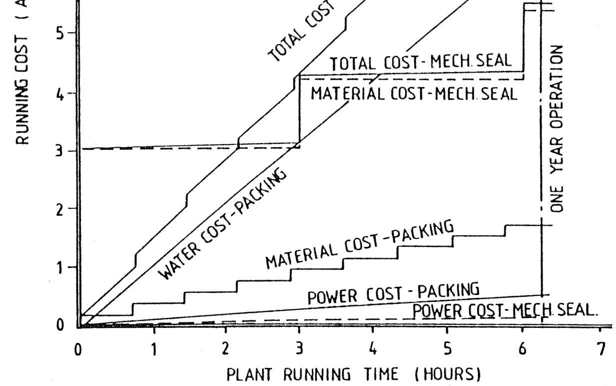

Figure 1. Cost Saving with Mechanical Seals.

PERFORMANCE REQUIREMENTS

Having established the market need for a mechanical seal which would consume little or no water, a survey was carried out of the major slurry pumping industries. This gave rise to the following preliminary performance specification:

Pressure	150 psi
Speed	35 ft/sec. (shaft surface speed)
Temperature	200°F
Solids Content	65 weight %
Shaft Diameter	2″ to 5″

This was seen as a minimum specification which would meet most of the industries' needs but, if possible, it was hoped that it could be exceeded in certain areas. In particular, a higher pressure rating would be required for some pipeline applications and a greater range of shaft sizes was ultimately envisaged.

In addition, it was found that the axial space available in most slurry pumps is very restricted and also the shaft must be axially adjustable to compensate for impellor and casing wear throughout the life of the pump.

FAILURE ANALYSIS

Although it has been said that the slurry pumping industry is dominated by gland packing, sufficient mechanical seal applications were found to permit a meaningful analysis of their modes of failure. This was carried out in order to identify the main areas of weakness and the dominant factors were found to be:

- Clogging of springs.
- Hang-up (i.e., any slurry which does leak across the seal faces tends to dry out and clog on the atmosphere side, thus preventing free movement of the seal components and eventually causing the faces to part).
- Fretting of drive pins, keys, etc.
- Errosion of other seal components.
- Abrasive wear of the seal faces.
- Cracking of brittle seal face materials due to vibration or the presence of abnormally large particles in the slurry.
- Destruction of hard carbide seal faces due to dry running of the pump (blocked suction screens, operator error, etc).

The above modes of failure are not listed in strict order of importance but are grouped in terms of their inter-relationship. Basically, the last three items relate to the durability of the seal faces and can be influenced by materials, shape, size and method of retention.

The first four items, on the other hand, are dictated by the overall configuration of the seal design, and the results of the survey did show that the majority of failures fall into this category. In other words, the mechanical function of the seal is impaired to the extent that it cannot maintain close contact between the all important seal faces, and this often occurs long before failure of the faces themselves. The team, therefore, concentrated first on producing a seal lay-out which would seek to minimise these four problem areas.

DESIGN HISTORY

The general purpose mechanical seal, shown in Figure 2, is clearly very susceptible to all four modes of failure:

- The springs (A) are exposed to the sealed product.
- As the faces wear, the dynamic packing advances onto a surface (B) adjacent to the seal faces where the residue of any leaked product will tend to accumulate and cause hangup.

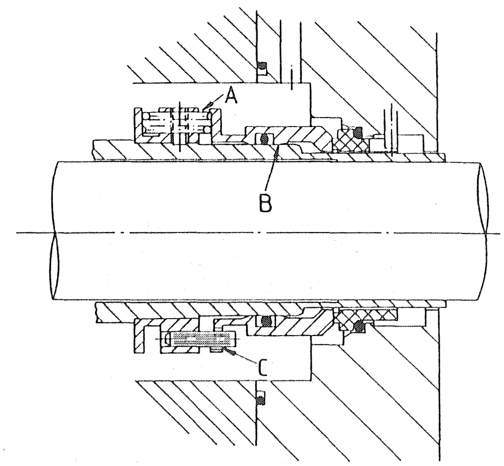

Figure 2. General Purpose Mechanical Seal.

- Any misalignment between the shaft and the pump casing will cause relative movement at the drive pins (C), resulting in rapid wear.
- The irregular contours of the seal will lead to severe erosion.

These problems were addressed more than 20 years ago by designing stationary spring seals, similar to that shown in Figure 3. Here the spring (A), which also functions as the drive mechanism, is located in a chamber outside the sealed product and the dynamic packing advances onto a clean surface (B), which is also protected inside the chamber. Nevertheless, after a period, leakage from the seal faces would travel along the annular space between the shaft sleeve and the gland plate and would find its way into this chamber where it would dry out. In the case of heavy slurries or concentrated solutions, the solid residue would then clog the seal mechanism unless a reliable clean water quench could be provided.

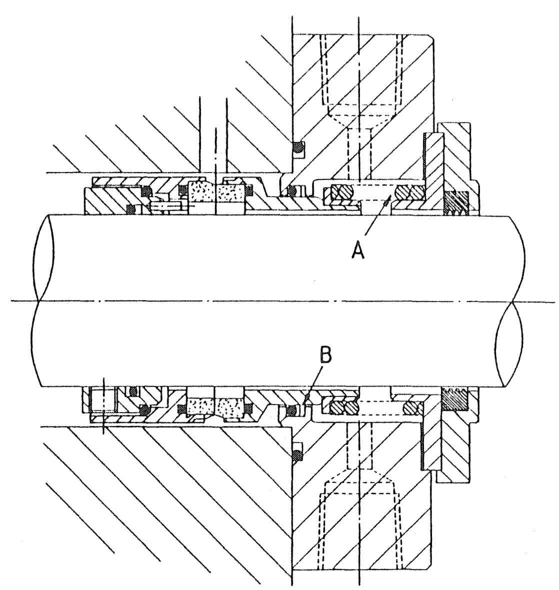

Figure 3. Stationary, External Spring Seal.

Even when a quench was available, the quality of the recycled water was often so poor that it caused scaling in this vital area and, again, resulted in hangup of the mechanical seal.

THE NEW DESIGN

Having considered the past evolution of slurry seal design and having studied the results of the failure analysis, the design team agreed that the principle of isolating the critical seal mechanism from the product was correct; it simply had not been taken far enough. Their proposal, shown in Figure 4, was an extension of the stationary spring design described earlier (Figure 3).

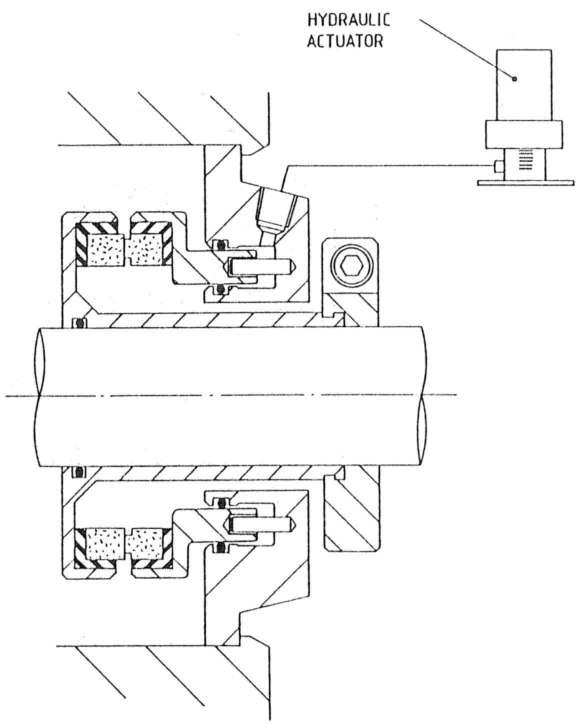

Figure 4. Hydraulically Actuated Slurry Seal.

All surfaces in contact with the sealed product are smooth and free from discontinuities. The drive pins are enclosed in an annular chamber behind the stationary seal ring, which is sealed by two concentric O-rings and is filled with clean oil. This means that the dynamic packings advance onto a surface, which is not only clean but also lubricated, and the reduction in friction more than compensates for the fact that there are now two dynamic packings.

The more novel feature, however, is the complete absence of springs. The oil in the annular chamber is pressurized by a simple weighted piston mounted at any convenient location on the pump and connected to the seal by a flexible hydraulic hose and this provides the initial closing force to the seal faces.

Hydraulically actuated seals are not entirely new; some very elaborate designs have been produced in the past, whereby, the seal face loading could be adjusted to suit varying operating conditions. In contrast, this is a very conventional balanced seal configuration which simply replaces a fixed spring load by a fixed hydraulic pressure of about 4 psi. In fact, the hydraulic actuator gives a more constant face load than a conventional spring since it has zero stiffness. This means that the seal is not sensitive to changes in axial position, such as may be caused by incorrect setting or wear at the seal faces. Furthermore, as the seal faces wear and the stationary seal ring advances, the position of the weighted piston can be seen to move relative to a graduated scale so, with the ratio of hydraulic areas being about 10:1 (depending on seal size), the operator has a clear external indication of the seals condition and is better able to plan his maintenance.

FACE DESIGN

The high hardness and abrasion resistance of engineering ceramics make them well suited as sealing faces, particularly in applications such as this. Unfortunately, they also tend to be fairly brittle so the inserts were designed with relatively large cross-sections to give adequate strength and wear life. In addition, it was decided that there should be no slots or holes which could act as stress concentrations so various methods of retention, such as bonding or shrink-fitting, were evaluated.

As a result, the chosen solution was to mount the ceramic inserts in rubber shrouds, as shown in Figure 4, since it was felt that this would give some degree of resilience to protect against vibration and shock loading. The radial compression of the rubber provides both the sealing and the frictional drive and, as the product pressure increases, this radial compression also increases due to the hydrostatic nature of the rubber. More significantly, however, the hydraulics of the design is such that increasing product pressure generates an axial force which produces increasingly positive sealing and frictional drive between the rubber and the back face of the insert. This method of retention has proved extremely effective and, in subsequent testing, no evidence was found of any inserts having spun in their carriers.

INHOUSE TESTING

Testing in the laboratory fell into three broad categories:

- Initial proving of the design concept (prior to field testing).
- Evaluation of alternative face configurations.
- Evaluation of alternative face materials.

Initial Proving

A second-hand slurry pump was purchased and modified for use as a test bed in Melbourne. Here the prototype seal was run under a variety of conditions to confirm that it could meet the performance requirements, which had been identified at the beginning of the project. The first tests were carried out on clean water. Once the basic integrity of the design had been proved, further tests were conducted on a variety of slurries, which were obtained from mine sites and processing plants all over Australia. In fact, the test bed continued to run long after the seal design had been proved satifactory, since it gave a valuable insight into the individual characteristics of the different slurries.

Alternative Face Configurations

It is well known that two hard seal faces, such as tungsten carbide or silicon carbide, can suffer damage when running together, particularly at very low operating pressures where a stable hydrostatic film of liquid cannot establish itself. This accounts for the wide use of carbon as a counterface in general purpose seals due to its self lubricating properties under marginal operating conditions.

From the point of view of the mechanical seal, slurry pump design often tends to make the situation worse. Many have vanes cast onto the back of the impellor with the intention of keeping the pressure at the gland packing as low as possible and many have axially adjustable impellors, which can be used to regulate the internal clearances and compensate for wear throughout the life of the pump. Thus, on a worn pump operating at low pressure and with its impellor incorrectly adjusted, it is possible to measure subatmospheric pressures in the seal area. For this reason a lot of attention was focused on the performance of the seal faces between -5 psi and $+85$ psi.

It soon became apparent that this type of damage was more repeatable and more severe on clean water than on slurry, presumably because the solid particles in the slurry could hold the faces apart sufficiently to allow the liquid film to enter. The majority of this section of the testing was, therefore, carried out on clean water with only occasional runs on slurry to ensure that the seal face modifications had not introduced any unforeseen side effects.

The temperature at the seal faces was taken as an indication of their performance and was measured by attaching a thermocouple to the inside diameter of the stationary seal ring insert, as close as possible to the running surface. Pairs of test faces were then run through a predetermined cycle of rising and falling pressure, each test being carried out under identical conditions of speed, water circulation rate, etc., and the face temperature was monitored at regular intervals. The seal faces were examined visually after each test and, in cases where damage had occurred, it generally manifested itself as fine radial cracks on tungsten carbide faces or surface "plucking" on silicon carbide faces. The damage was significantly more noticeable at the inside diameter of the contact area, indicating that the liquid film had not fully penetrated between the faces.

As the development progressed, parameters such as face width, convex or concave lapping, shrink-fitting to produce controlled thermal distortion, surface finish and face loading were all examined. The onset of face instability is shown in Figure 5 as the operating pressure is reduced and also shown is how that instability was eliminated by successive improvements to the design.

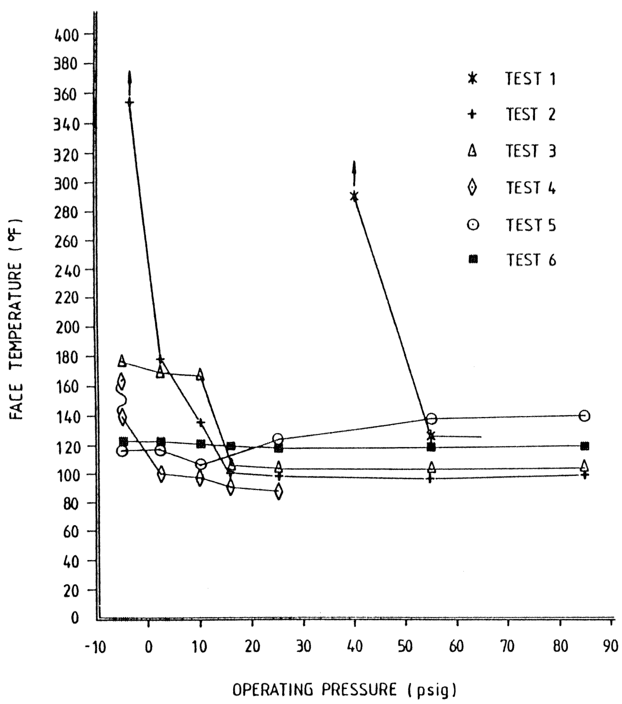

Figure 5. Seal Face Temperature vs *Operating Pressure.*

Only silicon carbide and tungsten carbide seal faces were evaluated during these tests, since it was felt at the time that they offered the best combinations of physical properties and realistic commercial availability. It is also expected that the results of this testing will be directly applicable to other ceramic materials, which may be used in the future.

Alternative Face Materials

The main physical requirements of a face material for slurry seals are hardness, abrasion resistance, toughness, thermal conductivity and tolerance to running under conditions of marginal lubrication. It must also resist attack from as wide a range of chemical products as possible, since many of the applications are in mineral extraction processes where the product liquors are specifically intended to leach out the valuable metal from the crushed ore, but can equally well leach out the metal binder from a carbide seal ring. Furthermore, a single material may not give the optimum solution, since a pair of seal faces in dissimilar materials is less likely to produce galling than a pair of faces made from identical materials. Thus, the number of materials selected for evaluation would have an exaggerated effect on the amount of testing required, due to the increasing number of possible combinations.

The first phase of the material test program concentrated on evaluating the various proprietary grades of silicon carbide and tungsten carbide. A literature search was carried out to identify those materials with the best combination of properties. Sample seal faces were then tested on both clean water and abrasive slurry. This work is still in progress but several carbide grades have now been identified as suitable for use in slurry seal applications.

The second phase of the program is concerned with evaluating some of the more recently developed ceramics for possible use in the future.

FIELD TESTING

It was realized from the outset of the development project that a product of this type could not be proved by laboratory testing alone. Suitable field trials were, therefore, arranged with interested end users in the Australian mining and ore processing industries, and the development team spent many weeks working at these sites.

In general, the results in the field served to confirm the experience that had been gained in the laboratory. The only notable exception was the method of attaching the seal sleeve to the pump shaft. Because the position of the shaft needed to be axially adjustable, the seal sleeve had been designed with a clamping mechanism which could be loosened off to allow the shaft to slide through when adjustment was carried out. The torque and thrust capabilities of the clamping mechanism had been thoroughly tested in the laboratory to far greater loads than could be anticipated in service. Nevertheless, the degree of vibration on some pumps, was sufficient to dislodge the sleeve and a more robust drive collar had to be designed.

One of the most interesting benefits of the fields testing was an improved understanding of the end users attitudes to sealing and the ways in which the equipment was operated. The level of interest in mechanical seals among operations and maintenance personnel was much higher than had been expected, and the most sceptical were often swayed by even a modest success. Initially some engineers believed that the concept of a hydraulically actuated seal was too complicated and would prove unreliable but, having seen the simplicity of the construction and understood the analogy to a car braking system, these fears were generally dispelled. The attitude to the hydraulic actuator itself was also varied. Some felt that it should be installed in a tamperproof enclosure whilst others found that, if a seal leaked slightly on start-up, the hydraulic pressure could be increased by pressing down gently on the piston for a few seconds and, thereafter, the leakage would cease. This ability to control the performance externally was perceived as a great benefit, although it had not been foreseen at the design stage.

Once the initial teething troubles had been cured and seals were generally operating reliably, the majority of failures were caused by the pumps having run dry. Periodically, the sediment on the walls of a settling tank would collapse inwards and block the pump suction pipe or, alternatively, pumps on intermittent batch operation would not be switched off before the level in the tank had fallen below the outlet. Most operators tended to accept these failures as unavoidable, but the frequency with which they occurred on some plants clearly indicated that a solution had to be found. A slurry seal was installed on the test bed in Melbourne, fitted with an auxiliary lipseal to contain a clean water quench (see Figure 6), and a thermocouple was attached to the outside diameter of the stationary seal ring insert as close as possible to the running surface. The seal was then run with no liquid on the product side to simulate dry running of the pump but with about half a gallon/minute of water at atmospheric pressure flowing between the main seal and the auxiliary lipseal. After several hours operation, the seal face temperature had not exceeded 110°F so the quench outlet valve was closed, leaving only a static head of about 3.0 ft water (similar to API 610 Plan 51). The seal was then run for the rest of the day and at no time did the face temperature exceed 130°F. Thus it was demonstrated that the slurry seal could survive dry pump conditions and the use of a static rather than a flowing quench would overcome the scaling problems associated with recycled gland water.

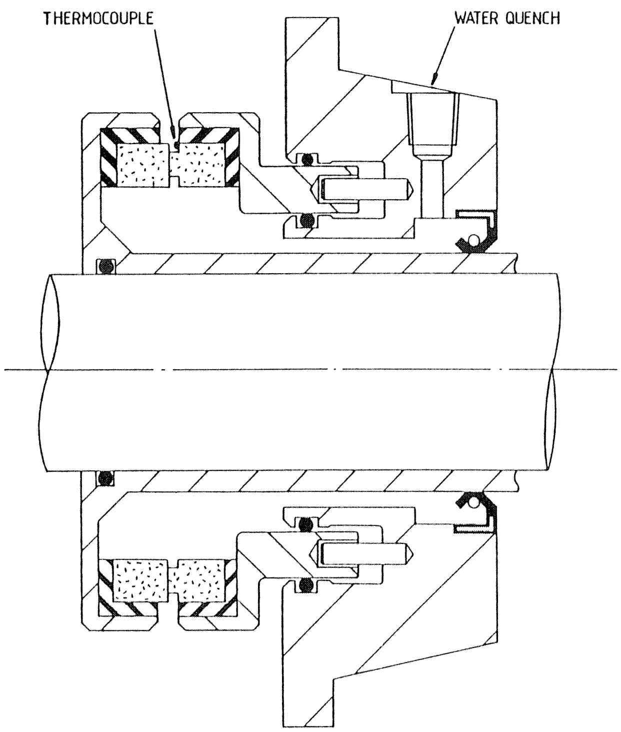

Figure 6. Slurry Seal with Auxiliary Quench Seal.

Although a lipseal was used for the purposes of this proving test, it was realised that the possible eccentricities on a worn slurry pump would make this an unreliable method of sealing. A simple compact mechanical seal has since been designed for the purpose of quench containment.

CONCLUSION

A slurry seal has been designed which consumes no water and which meets or exceeds all the requirements of the original design specification. It has robust carbide seal faces for maximum wear resistance, and these are resiliently mounted to protect them from vibration damage. This method of mounting has the additional advantage that the inserts are easily replaced when the seal is reconditioned. As the faces wear, the dynamic packings advance onto a clean metal surface which is oil lubricated, thus avoiding hangup and the drive pins are also located in the oil chamber to prevent fretting. The seal components in contact with the slurry have smooth contours to minimise erosion, while the large radial clearance between the faces and the shaft sleeve allows any leaked product to escape without clogging. A split drive collar clamps securely onto the existing pump sleeve or shaft, permitting easy axial adjustment of the impellor position, and the overall seal design is axially compact to suit most designs of slurry pumps. In addition to giving an external indication of seal face wear, the hydraulic actuator also gives the opportunity to influence the face loading if required, although this practice is not generally recommended.

Finally the seal can operate without the need for any external services or, if fitted with an auxiliary containment seal and a static water quench, can survive long periods of dry running.