Mechanical seals: service experience

B.S. Nau*

During recent decades, a considerable amount of research has been carried out in an attempt to understand how mechanical seals work. However, to understand the relevance of the different concepts put forward from time to time, it is necessary to examine the behaviour of seals working in real applications: on centrifugal pumps, mixers, etc., on process plant, and in all the other diverse applications where mechanical seals are to be found. Only in this way is it possible to assess which mechanisms are the really significant ones from a practical point of view.

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Whilst having some similarities to bearings, mechanical seals are subjected to an extraordinarily diverse range of working environments. The 'lubricant' is necessarily the fluid which is to be sealed, and this may be contaminated with other materials — liquid, gaseous and solid. Similarly, temperatures and pressures vary over wide ranges.

To illustrate the diversity of fluids, the following are some of those to which seals are commonly exposed:

- water
- light hydrocarbons
- heavy hydrocarbons
- salt solutions
- polymer melts
- acids
- alkalis
- steam
- gases

In process plants, temperatures range from cryogenic to values over 300°C, although most lie in the range 20–200°C. Pressures are less easily defined. What the seal sees is a pressure somewhere between pump discharge and pump suction pressure. Discharge pressures range up to 20 bar, commonly, and sometimes even higher. Most however are below 10 bar.

The aspects of performance with which the seal user is usually concerned are leakage-rate and life. When sealing non-hazardous fluids, life is the prime consideration, though it is not easily defined. A 'failure' is usually considered to have occurred if the leakage rate has risen to a level which is unacceptable in the particular circumstances of sealed fluid, equipment and environment. Wear is rather uncommon as the reason for removal of a mechanical seal.

It is difficult to obtain quantitative data on seal life in service, as opposed to rig test data. On the one hand, the practicalities of the situation are that the personnel involved are too busy to find the time to record the event; they have different priorities. On the other hand, a pump is often not running continuously, hence, there is uncertainty about both the cumulative time run and the number of starts, which are also of interest.

In recent years, BHRA has been collecting quantitative information on mechanical seal performance in process plants. This has been under several headings:

(i) What values of leakage and life are presented by the best and the worst of mechanical seals?
(ii) How much leakage escapes unseen, in the vapour phase?
(iii) What are the causes of premature failures?

During the same period, workers in several companies, around the world, have taken an interest in mechanical seals and have addressed such questions as:

(i) What is the cost of seal failure in terms of: lost production, maintenance costs, capital tied-up in standby pumps, etc.?
(ii) How does seal performance compare with that of related devices, such as bearings?
(iii) What can be deduced from statistical patterns of failures?
(iv) Is it possible to correlate life with composite dimensionless parameters based on known operational variables?

Addressing this second group of questions first, the published information indicates that the costs of seal failure are very high indeed. Buck studied refinery seals and concluded that 'most seals fail prematurely'. Only 10% of his sample had 'worn out'. Will stated that his company spends 15 million dollars a year on pump maintenance, and 75% of this was attributed to seal failure. In the UK, companies have reported not dissimilar levels, e.g. in 1970 BP Chemicals reported that 60% of plant breakdowns were due to mechanical seals.

Statistical analyses, using Weibull methods, point to a random distribution of life rather than a wear-out situation, due to old-age, which would be preferred. Summers-Smith and Berthele have published Weibull plots, and MTBF data. The former has compared the resulting L10-life values adversely with those for rolling bearings in process plant applications. The latter presented similar data but emphasized the need for caution in interpretation when there are some early failures and a large number of unfailed units at the end of the analysis period, as can happen. This can unduly bias the results.

The statistics indicate that seal life is typically randomly distributed. This conclusion is supported by the widely held view that mechanical seals are unpredictable. One may last
a year or more, whilst another, apparently identical and subject to the same duty, may fail within a few weeks. Accepting this, the question becomes: what causes random failures?

In rolling bearings, fatigue is responsible for such behaviour, but in mechanical seals this has never been clearly identified as a significant factor. More often it has been assumed that random deviations in the operating environment of the seal are responsible, but this is not easy to verify. Again, it has been argued that if the seal is routinely exposed to such perturbations, then its design should adequately cater for these.

Operational transients can include short-term fluctuations, and other changes, of pressure and temperature; transient vapour phase or gas entrainment; structural deflections of the pump — caused by pipe loads, thermal expansions, etc; vibration due to impeller wear or pump-operation away from the best efficiency point. Obviously, the risk of some of these transients is greater when operating under certain conditions. For instance, vaporization is more likely with volatile fluids, at higher temperatures or lower pressures. Thermal deflections are more likely in high temperature applications. By examining life data in relation to various groups of dimensionless parameters, Buck hoped to develop a tool for identifying potential problem applications. Fig 1 illustrates some examples of his results, based on plant-life data in oil refining duties. In the event he was not able to come up with any clear-cut parameters. BHRA studies have pointed to some particular problem areas: stop/start running and vibration being the most severe.

Some indication of the wide range of installed-life achieved by mechanical seals is provided by the BHRA plant data in Fig 2. Mechanical seal lives of several years are not infrequent, occasionally extending to as much as twenty years in isolated documented instances. Most seals, however, have a much shorter life, perhaps 6–12 months; and quite a number have a very short life, of the order of a few days or weeks.

Fig 1 Effect on mechanical seal life of various parameters:
(a) pressure x velocity, (PV factor); (b) face material thermal stress resistance with no pressure differential (SDF = 0); (c) as (b), but non-zero pressure differential SDF; (d) vaporization factor, proportion of film in liquid phase (LDF): (●) stable; (○) unstable
The variation of leakage-rates is just as wide. Fig 3 presents BHRA data from a number of process plants in the UK. For seals with no liquid-phase leakage, the BHRA work revealed that there was always a measurable, if sometimes small, leakage of vapour even from stationary seals. Typically, the vapour mass leakage rate was comparable to that of liquid phase leakage from many ‘good’ seals.

Conclusions

In conclusion, the question of the causes of premature failure is returned to. In some cases, this results from a failure to apply the best available engineering practice. A situation that can result from slavish adherence to the minimum requirements of such standards as API 610, a widely used pump standard in process plant. An attempt to remedy this situation is in hand. The Mechanical Seal Working Party of the Institution of Mechanical Engineers’ Process Division is currently preparing a code of practice to help users achieve the best results within the state of the art.

A more direct approach to investigate the problem of premature failure has been applied by BHRA. A part of this program involved running large numbers of commercial seals under conditions of controlled perturbation from standard reference conditions. One of the findings of this work was that the carbon material, almost universally used as one seal face, can play a critical role in failure under certain conditions, particularly when there are adverse transients. More importantly, the good and bad carbons could not be distinguished by the conventional physical tests used in quality control.

A fuller discussion of the state of the art is to be found in Nau³. It remains to be seen whether there are other unexpected factors operating.

References

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