Mechanical seals must be designed to meet a host of challenging conditions
Credit: EagleBurgmann

Sealing the deal

Mechanical seals sit at the heart of the myriad of pumps and other rotating machinery within a thermal power plant and huge emphasis is placed on their reliability. David Appleyard explores key industry trends as manufacturers work to extend the operational lifespan of their seals.

In almost every pump there exists a mechanical seal which separates the pumped fluid from the atmosphere while allowing efficient operation of the rotating shaft which drives the pump impeller.

Of course, within a thermal power plant there are countless applications. They are found in just about every rotating piece of equipment and thus mechanical seals are a critical component in the process pumps of coal, gas and nuclear plants.

Tom Evans, power generation market manager for seal manufacturer John Crane Group, explains that mechanical seals are found, for example, in the main heat cycle – pumping raw feedwater, boiler feedwater, condensate and the cooling water that supports the condensate system. They are also found in secondary pumps, fire suppression systems, and service and wastewater applications. In coal-fired installations, mechanical seals are also used in sludge pumps and systems such as fly ash, coal slurry, limestone slurry for the flue gas desulphurization (FGD) scrubber system and fuel oil.

Although many of the applications are in the hot water and steam cycle, the range of duties and service conditions goes from the fairly benign – with a lower temperature and minimal amount of solids or abrasives in the fluid – to the other extreme where there are very high temperatures and pressures, fluids containing significant volumes of suspended solids, or hazardous or potentially corrosive liquids like ammonia or volatile organic compounds (VOCs).

Mechanical seal design

A mechanical seal comprises a stationary seating element which is fixed within the pump housing and a rotating element fixed to the shaft. Precisely machined, these two components are pressed together, meeting at a wear face, while the extreme tolerances between the two elements minimizes leakage.

In fact, mechanical seals rely on a certain amount of 'leakage' to lubricate the moving surfaces. In use, the rotating element is supported on an extremely thin lubricating film, typically some 0.25 μm thick. This film is developed through a combination of hydrostatic pressure – the difference between the pump operating pressure and atmosphere – and hydrodynamic pressure as a result of the motion between the surfaces.

The first commercially successful mechanical shaft seals were developed in the 1930s and 1940s as an alternative to the braided packing 'stuffing box' seals which had previously been used. They became steadily more sophisticated until today a shaft seal typically also includes elements such as a spring to keep the wear faces pressed together plus a number of supplementary O-rings or bellows and their torque transmission components.

Given the various duties and service conditions of the mechanical seal, reflecting the diversity of the pump industry itself, there are countless variants.

However, the challenge for seal designers is to maintain this ideal tolerance between the rotating and stationary elements. Too wide a gap and the pumped fluid will leak, too narrow and frictional losses increase

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Tom Evans, power generation market manager, John Crane

and excessive heating could see the seal fail prematurely. At high velocities the hydrodynamic pressure separates the parts through the formation of a full-fluid film, while at lower velocities or higher loads a mixed lubrication regime exists. Here, some of the load is supported by contact points on the two surfaces and it is in this mode that mechanical seals typically operate. As a result, seal face materials must be able to withstand the friction generated by both high loads and high relative velocities.

Consequently, one of the main areas of investigation concerns the materials used in the wearing faces of the fixed and rotating parts. Ideally, seal face materials have a low friction coefficient, coupled with hardness, good corrosion resistance and high heat conductivity.

A number of materials are commonly used depending on the application, including aluminium oxide, carbon graphite, cemented tungsten carbide, silicon carbide and, more latterly, even diamond, which has the highest hardness and thermal conductivity of any known material, as well as corrosion resistance and a low friction coefficient.

There is also a choice in pairing materials against each other. In any event, the selection of the facing material is critical to the lifespan of the seal.

For example, while graphite is well known for its low-friction properties, its softness means that it is used in combination with a harder form of carbon and often further impregnated with metals such as antimony, tin or lead. It is commonly paired with tungsten carbide as the combination can withstand dry running for several minutes without causing damage. Furthermore, the favourable lubricating properties of carbon graphite mean the seal is suitable for use in poor conditions, such as in hot water where a lower viscosity as well as evaporation in the seal gap can have a negative impact.

Mechanical seal failure modes

A mechanical seal is dramatically influenced by numerous factors over which its manufacturer has no direct influence, such as operating temperature, transients from start-stop operations or mechanically induced vibrations resulting from poor pump shaft alignment, for example.

As already indicated, one of the key failure modes of the mechanical shaft seal is dry running. Without the lubricating film, friction can elevate seal temperatures to several hundred degrees Celsius in minutes. This can cause failure of the elastomeric elements of the seal such as the O-rings.

Dry running may be caused by excessive loading or contamination of the fluid film, for example, but low viscosity of the pumped medium or a temperature well above the boiling point at atmospheric pressure can exacerbate potential issues with dry running and a phenomenon in which localized heating and cooling occurs can cause thermal fatigue in the seal faces.

Another significant factor is the presence of suspended and dissolved solids, as Evans explains: "A coal-fired plant does have some fairly difficult service conditions for a mechanical seal. Services entail water of varying temperatures, pressures and shaft-speeds of the pump, but coal-fired plants in particular have a lot of services that contain abrasives and solids within the fluid which are hard for the mechanical seal because it creates additional abrasion and erosion of the components."

Furthermore, as the lubricating film in the sealing gap is subjected to large gradients in temperature, pressure and velocity this increases the likelihood of precipitation and sedimentation there.

Evans adds that contamination can also 'hang up' the seal, meaning the seal is no longer flexible. "The particles can get into the mechanical seal's O-rings and springs and cause them to go rigid, where the seal is no longer able to move with the shaft movements and pressure deflections. It can be difficult to have a seal operate correctly under these circumstances."

Andreas Kretschmer, head of global business segment power for EagleBurgmann, echoes this point, adding boiler feedwater pumps: "These pumps have quite challenging operating conditions with regards to mechanical seals because they are large-diameter and operate at very high speed."

Aside from suspended solids, seal performance can also be dramatically influenced by other aspects of the water quality of the pumped fluid.

For example, two decades ago many thermal plants changed their feedwater treatment system from all volatile treatment (AVT) of boiler feedwater to combined oxygen treatment (COT) to resolve a number of technical issues such as precipitation in the boiler tubes and ammonia extraction. However, this change in combination with these high-speed applications resulted in a significant shortening of the lifespan of mechanical seals.

Kretschmer explains: "In some cases where we had mechanical seals which had a lifetime of 40, 50 or 60,000 hours, they in some cases lasted only 2000 hours.

"We made an intermediate and pragmatic solution. These mechanical seals have a cooling circuit from the seal to a small heat exchanger and back. Into this circuit we injected a little water and ammonia mixture to imitate the AVT as far as the mechanical seals were concerned. Of course, most users have not been happy to introduce a little dosing system and a little chemical plant, using ammonia which is hazardous, in front of their monster pump."

Inevitably this prompted the industry to invest more in research.

Kretschmer continues: "The problem we faced is most commonly known as electro-corrosion."

In these high-speed applications and under particular conditions, when using silicon carbide for example, minute arcs cause electrical corrosion. Under such circumstances the material of the seal itself becomes degraded. This failure mode only affects large, heavy-duty feed pumps, but the result, depending on the sliding velocity, is a very short lifespan.

Following decades of research into the root cause of the phenomenon, in 2010

Boiler feed pumps present several challenges for mechanical seal manufacturers
Credit: EagleBurgmann

EagleBurgmann arrived at a solution using a proprietary electrically conductive diamond coating.

"It's a derivative of our basic diamond face coating," says Kretschmer. "We made a slight modification to the coating itself, which is proprietary. This diamond coating has electrical conductivity. Having this coating on the mechanical seal, we are able to dissipate or balance all electrical differences and loads between the rotating part and the ground.

"Some pump manufacturers have tried to install, let's say, grounding brushes to help discharge, but this only partly helped. It brought some improvement, but you cannot put the brush directly on the seal," he adds.

Kretschmer is optimistic, saying: "In power plants, abrasion and physical wear is basically well covered by normal, standard mechanical seals which are designed and engineered using different materials so that they can address all the different challenges within a power plant. No matter whether it's nuclear or fossil – it can be radioactive, it can be abrasive – there is a solution."

The consequences of failure

While Kretschmer's optimism may be well placed, there is no doubt that failure of the mechanical seal is the primary cause of pump failure. Given that, typically, the more modern thermal power stations in Europe have a single large pump supplying all the boiler feedwater, a failure has dramatic repercussions. As Evans observes: "The boiler feedwater pump is the heart, the core of any thermal power generating plant. If that pump fails for any reason, it could be a seal, a bearing or a power shaft, that whole generating unit comes off line, and there's a whole load of people that know about that real quick."

Inevitably, operators have to stop the main pump for maintenance on the seal, which typically means decoupling the pump. Furthermore, the mechanical seals of such a multistage pump are installed between bearings. So before finally gaining access to the seals, the bearings have to be removed, the lubricating oil must be drained and the unit must be cooled sufficiently for service personnel to work on the unit – a main boiler feedwater pump typically has an operating temperature on the order of 180°C.

Seals can be partly refurbished and elements such as the steel gland which closes the pump casing, shaft leaf and seal face carriers can usually be reused, but the seal faces themselves are wearing parts.

Overall, though, breaking down a pump to the point where a seal can slide off the shaft and be replaced, together with reassembly, takes two or three days, depending on the number of maintenance shifts. Inevitably, this is very costly given that such pumps are extremely critical in terms of availability.

One option that is being explored by the industry is the use of split seals that allow the seal to be replaced without decoupling the pump and drive. Evans highlights a recent product along these lines: "A few years ago we launched a new product, the Type 3740 split seal. This allows the plant personnel to completely eliminate the need to disassemble that piece of equipment and to rebuild it for the sake of a leaking non-split seal. The idea of having a split seal that can eliminate several days of equipment outage and get the turnaround for repair to, in some cases, less than 30 minutes, is a huge incentive for power plants to look at split seals for some of their pumping applications."

Industry trends

Extending the so-called Mean Time Between Failure and Mean Time Between Maintenance is a key driver for the industry, but general power sector trends are also pushing the limits of mechanical seals still further.

Evans says: "We're forever spending time and effort in our R&D labs to create products that can operate at increasingly higher temperatures, higher pressures and faster shaft speeds because that is the direction that the pump OEMs are going."

Referring to a general trend towards higher boiler temperatures and pressures as more modern power plants move to supercritical and ultra-supercritical steam conditions, he continues: "The companies that manufacture these pumps are developing new pumps that are larger or operate at higher pressures and temperatures because that increases the power plant efficiency. We, in turn, have to provide mechanical seals for those pumps that can withstand those higher temperatures and pressures."

Similarly, Kretschmer highlights R&D investment and testing of new products. For example, in nuclear installations safety requirements are becoming more stringent and designers are considering pumps and mechanical seals which can operate without cooling.

As Evans says: "We know the trends, what direction the power industry is going in and what the pump OEMs are developing. Then we in turn, as a supplier to the power industry and to the pump OEMs, know what is required of the seals – we are actively developing products."

Kretschmer, though, argues that few major challenges remain for mechanical seals, where even in the harshest environments service lifespans are approaching that of other mechanical components such as bearings. He concludes: "As an engineer I say 'job done'; as a seal manufacturer, I am concerned."

David Appleyard is a freelance journalist specialising in the energy and process sectors.

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