Significant improvement in mechanical sealing reliability

Problems with excessive leakage from mechanical seals fitted to high-speed boiler feed pumps were leading to increased maintenance costs and workloads at the Doel 3 and 4 units in Belgium. In search of both an explanation and a solution, the plant's engineers approached Flowserve in the hope that they would provide the answers they needed.

By Gerrit Heyninck, Support Engineer, Electrabel Doel & Gerard van Loenhout, Technical Service Engineer, Flowserve Corporation

The Electrabel nuclear power plant (Group GDF SUEZ) in Doel, Belgium, comprises two 400 mega watt (MW) and two 1000 MW Pressure Water Reactor (PWR) units constructed in the 1970s and 1980s. The last reactors built, Doel 3 and Doel 4, were designed with 3 x 50 percent steam generator feed pumps fitted with mechanical seals as their main shaft sealing solution. With two turbine-driven pumps in operation during normal operation, the third electric driven pump is mainly used for plant start up and redundancy.

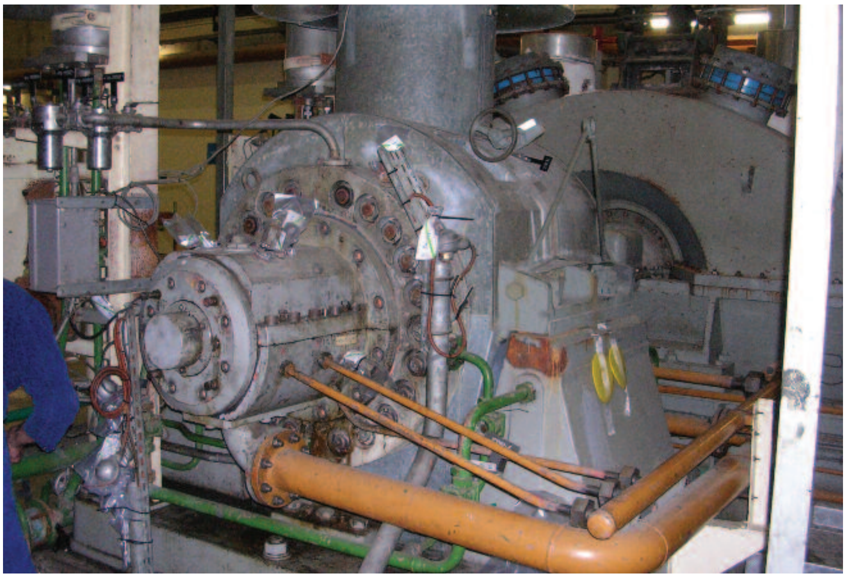
Since the introduction of mechanical seals on high-speed boiler feed pumps in the late 1960s, mechanical seals have proven to be a reliable and cost-effective sealing method compared to alternatives including soft packing, fixed throttle bushing systems using cold condensate injection, and controlled floating ring sealing systems. Many base-load operated power stations manage to get more than 50,000 hours of continuous service out of their mechanical seals.

However, the mechanical seals originally installed in the feed pumps of Doel 3 and 4 only managed to achieve between 9,000 and 16,000 hours of continuous service before overhaul was needed due to excessive leakage. Because a spare pump was installed, this maintenance never resulted in reduced power or an unscheduled outage, but the frequent repairs outside the scheduled outages increased overall maintenance costs and the overall workload for Electrabel's maintenance department.

Searching for a solution

In the summer of 2004, Electrabel's engineering and maintenance department asked Flowserve to find a solution. System engineers generally use leakage as the prime criterion for judging whether a mechanical seal has performed well. In some applications, leakages can be extremely critical, but this is not always the case. Steam generator feed water typically is not dangerous and controlled leakage disposal systems ensure the water is fed into the plant's make-up system for treatment and reuse.

In the case of Electrabel Doel, when fitted with new and refurbished parts, the original seals had almost no visible leakage during the first year of operation. Only after an outage occurred and the feed pumps were re-started, seal leakages would start to increase until the alarms guarding seal-loop temperatures would send a signal to the control room and the pump would be taken out of service for repair. The root cause identified for most of the seal failures at the facility was the lack of the seals' axial movement of its stationary components, caused by burring of the anti-rotation slots, due to hammering damage by the pins. Since both metal parts were made from the same material and hardness, the burring problem



Steam generator feed pump Doel 3.

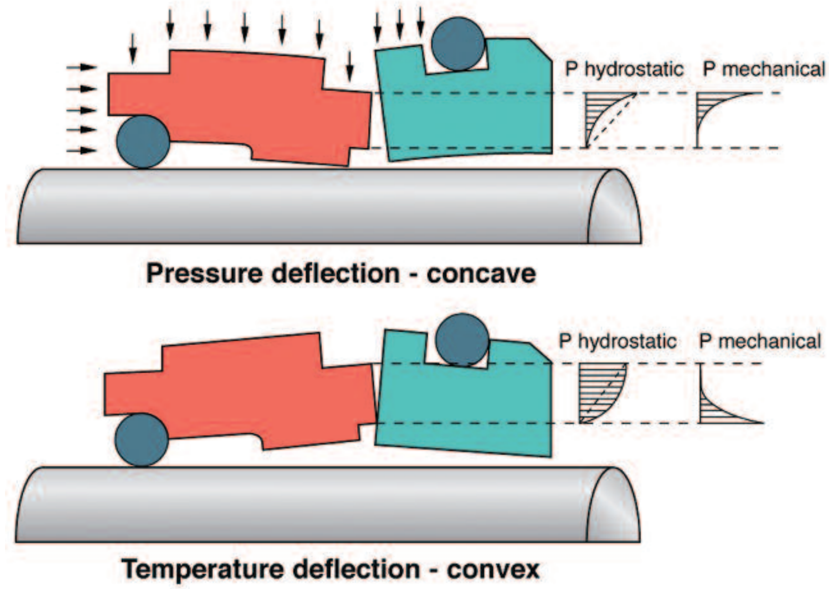


Figure 1: Typical seal face deformations

increased. Once these burrs were removed using a simple file, the seal would typically resume its sealing function when installed back into the pump (Figure 1).

After being presented with all facts and details of pump and plant operation, Flowserve prepared a detailed seal proposal which included a minimum amount of controlled leakage. Since the feed pumps at Doel 3 and 4 are large in size and operate at speeds between 4000 to 4820 revolutions per minute (RPM), the seals' maximum circumferential speed was calculated at 55 meters per second, which is considered high for a pump-type mechanical seal. Designing a slightly higher leakage rate into the seal ensures the seal faces achieve a stable fluid film inside the sealing interface, which reduces the friction and heat generation. Improved lubrication reduces face wear and this in turn lowers any micro vibrations of the internal sealing components.

An agreement was reached that the new proposed Flowserve DHTW mechanical seals would leak 300 cubic centimeter per hour (cc/hour) under ideal test lab conditions. Normally, this value is multiplied by a factor of three to five to estimate actual leakages on the pump during steady operation. Increased pump leakage is related to many external influencing factors including vibrations, transients and operational changes which cannot always be accounted for in the seals' design stage or during the lab testing.

Flowserve's initial design and engineering work for Electrabel started with a first draft of the new sealing solution. To provide Electrabel with the option to use both old and new mechanical seals in these critical pumps, no modifications to the pump hardware were planned, assuring full interchangeability. Once the initial design was completed, advanced computer modeling software was applied to predict the mechanical and thermal deformations of the seal faces and the expected seal leakage value. Years of experience designing high-end mechanical seals, combined with years of lab testing for all kinds of applications, have resulted in the development of finite element analysis models that are accurate and reliable. This precision and knowledge provides engineers with the ability to design mechanical seals for highly demanding applications in a relatively short time frame.

Overcoming seal deformation

Faces in mechanical seals are subject to various forms of deformation. The two major influencing factors are deformations caused by hydraulic pressure (structural deformation) and temperature (thermal deformation). Hydraulic pressure typically causes a concave deformation which closes off the liquid film in the sealing gap and changes the hydrostatic pressure distribution between the faces. This is compensated by the frictional heat generated in the sealing gap, with the temperature distribution causing an opposite convex thermal deformation.

The shape of the sealing gap between the rotating and stationary seal faces impacts the fluid film. As the deformations alter the shape of the seal faces, they automatically change the width of the fluid film and, therefore, the seal leakage rate.

Flowserve is capable of fine-tuning seals to specific operating conditions, which enables stable seal operation at the borderline between the mixed and elasto-hydrodynamic lubrication regime within the Stribeck curve. This curve illustrates the relationship between the coefficient of friction between the seal face and the fluid to be sealed and the separation achieved between the seal faces, as can be seen in Figure 2. Operation in this region of the curve provides a low friction coefficient combined with low seal leakage.

Rigorous testing leads to advances

Prior to manufacturing the new mechanical seals, the new solution was extensively tested in the Flowserve seal laboratory in Roosendaal, The Netherlands, using actual feed water received from the power station to mimic the field conditions as closely as possible. Together with the Electrabel Doel engineering team, a test program was prepared to validate that the new sealing solution would work under all conditions required. The initial test criteria were:

- An average seal leakage rate of 300

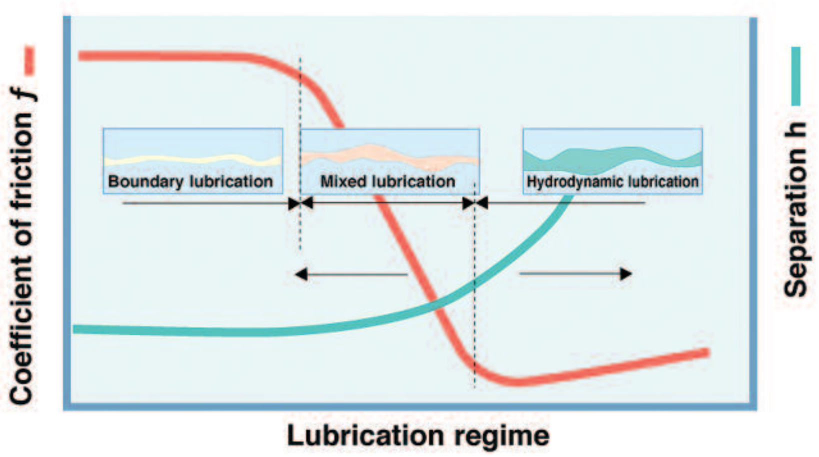


Figure 2: Generalized Stribeck curve.

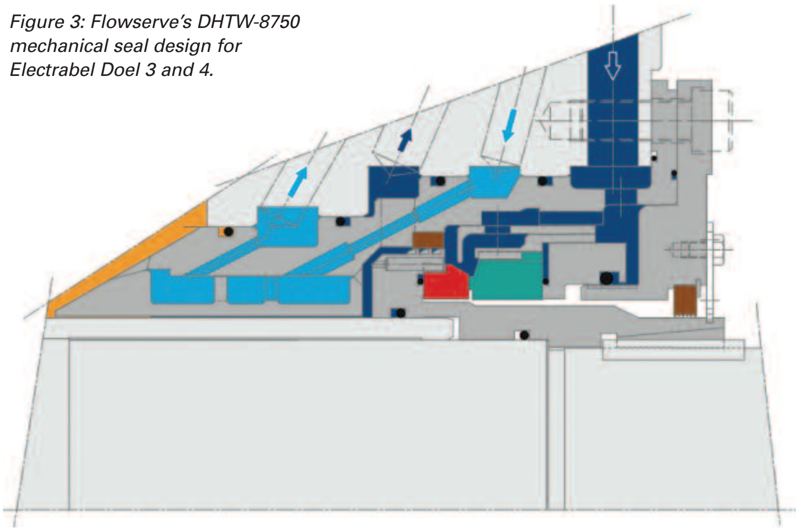


Figure 3: Flowserve's DHTW-8750 mechanical seal design for Electrabel Doel 3 and 4.

cc/hour after run in period

- No evidence of seal face chipping or deterioration of contact surfaces
- A maximum wear rate of the carbon stationary seal face of 25 micrometers per hour (µm/hour)

Electrabel engineering's main objective was to find a sealing solution capable of providing six years of uninterrupted service. The original seals only achieved one to one-and-a-half years of service. Electrabel and Flowserve reached a compromise that the minimum acceptable seal life of the DHTW seal would be 25,000 hours of continuous service, which is slightly less than three years.

The seal design was evaluated for more than 1000 hours on the test stand at operating speeds of 300 RPM, 800 RPM, 2000 RPM and 4400 RPM with 40 bar sealing pressure and input of heat to simulate the flow of water from the hot pump towards the seal. Since speed is a major contributor to thermal deformation of the seal faces, engineers sometimes need to compromise on design. Testing the seal on slow roll speed of 300 RPM showed an increased amount of carbon face wear. After review of the test results with Electrabel Doel, it was concluded that an increase of seal leakage would be required to achieve less wear during slow roll operation. This resulted in agreement on a leak rate of 500 cc/hour under lab conditions.

After completing the lab testing, detailed measurements revealed that with the new leak rate, face component wear was extremely low. By using this design, the seals would have a theoretical life expectancy of eight years, which is two years more than initially requested by Electrabel Doel.

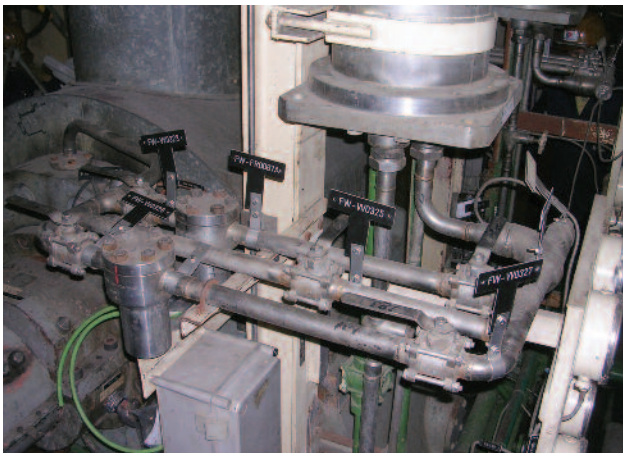
The Flowserve aftermarket philosophy is system-driven, rather than mere component-driven, so detailed recommendations were made to modify the seal's cooling system known as Plan 23. While the original seals operated with relatively high seal loop temperatures, a recommendation was made to install new, extremely efficient seal coolers and exchange all interconnecting seal piping with an increased diameter to reduce flow resistances. To ensure the new seal piping was correctly executed, seal engineers assisted with the final piping process and instrumentation design (P&ID) and isometrics made by the piping contractor.

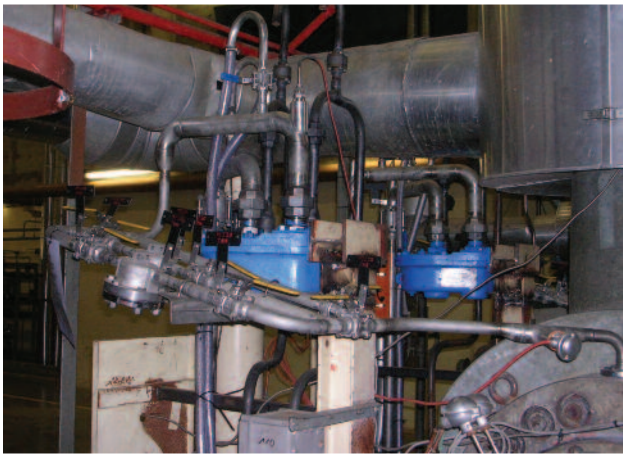
25,000 hours and counting

The first two DHTW-8750 mechanical seals were installed into the turbine driven feed pump, known as pump PP-FW-0064, during the June 2005 outage at Doel 3 (Figure 3). To ensure the installation of the seal was done with the utmost care, extensive checks were conducted by experienced field service engineers.

On June 14, 2005, when the reactor came online again, sufficient steam was available for the turbine driven pump to be placed into service. Electrabel engineers noticed immediately that the seal loop temperatures were much lower, indicating efficient cooling of the mechanical seals. In addition to an overall reduction of seal loop temperatures of 10-15 ˚C, the differential between seal inlet and outlet temperature was reduced from 10 ˚C to about 3-5 ˚C. Since Electrabel Doel had installed a temporary temperature recorder on the seal piping, accurate measurements and recordings could be made, which later became part of a permanent seal monitoring system.

Today, the first two DHTW-8750 seals are still installed and operating, and are as stable as the day they were installed. Although the six year operational goal requested by Electrabel Doel has not yet been fully achieved, the mechanical seals did achieve the agreed 25,000 hours of continuous service. Electrabel Doel intends to keep the Flowserve seals installed for the full six years, after which they will be refurbished.





The original seal cooling system (left) and the new optimized seal cooling system