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Sulzer White Paper

Enhanced efficiency and reliability

Upgrading pump design for control rod drive systems in nuclear power stations

The control of a nuclear reactor and the ability to shut it down safely rate as some of the most important tasks in the world of power generation. At the heart of every reactor are the control rods and the drive system that enables the core reactivity control to be maintained. The hydraulically powered drive mechanisms move the control rods to adjust the power output of the station.

The control rod drive (CRD) system is powered by a pair of centrifugal pumps – one running in duty operation, the other on stand-by. The design of these pumps must clearly meet all the stringent specifications of the nuclear industry, but beyond that, there are a number of areas that should be considered when the ongoing maintenance and repair of these pumps are examined.

Planned maintenance periods can be used to determine potential upgrades or retrofits to the pumping assets to improve both efficiency and reliability.

Legacy CRD pump designs

In this paper, the two common pump designs that are used in CRD service will be compared and contrasted, the WT pump, and the MN pump. The former is a diffuser style pump with inline impellers, while the latter is a volute style pump with opposed impellers.

The common characteristics between the pumps are their axial split design and the bearing positioning of the multi-stage rotor. These are important features that enable the pump to meet the criteria of the CRD application. The axial split of the pump body means that both the suction and discharge nozzles are located in the lower half of the casing and can therefore remain in place during the removal and installation of the internal elements.

In order to develop sufficient pressure for this application, the pump rotor has more than two stages and is referred to as multi-stage. It is positioned between the inboard and outboard bearings with the exact arrangement of the impellers the most significant differentiator. The speed of the pump is determined by the ratios in the gearbox, which is positioned between the drive motor and the pump.

Volute vs diffuser

The volute casing of the MN pump resembles a curved funnel such that it increases in size towards the outward discharge side. As the water flows in at high speed from the suction side, it slows down when it reaches the wider discharge side. The loss in velocity leads to an increase in pressure. This is because of a higher mass of liquid passing over the cross-sectional area of the discharge outlet. A single volute has one passageway, a double volute has two passageways. The latter is the better of the two as the radial loads created on the periphery of the impeller cancel each other out. The volute passageways are cast within the casing of the pump, which is not the case in the diffuser pump.

The WT design uses a diffuser, which is a set of divergent passageways located around the circumference of the impellers. The diffuser blades do not return the fluid to the next impeller eye, this is achieved by the return guide vanes.

In this configuration, where the pump's impellers discharge the fluid to a ring of nozzles, the radial load is balanced by the rotational force generated on the impeller by the water. This leads to a zero radial load on the pump's impellers whenever the fluid is moving, an element that optimizes fluid flow.

The diffuser blades and return guide vanes can be part of the same component. The inter-stage cover is the one component that the diffuser pump has, and the volute pump has not. Therefore, the WT pump has a much simpler casing design than the volute pump. However, inter-stage sealing is required in the WT, whereas this is achieved on the MN pump by bolting the two casing halves together.

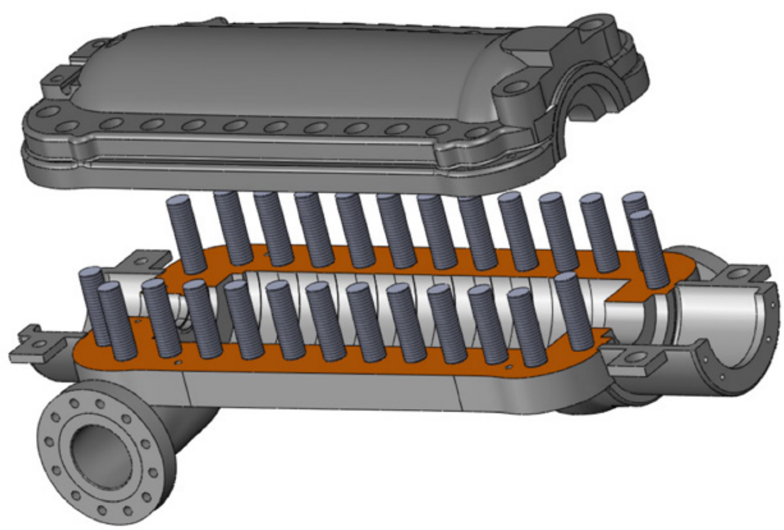

Figure 1: A diffuser style pump with a uniform bolting pattern

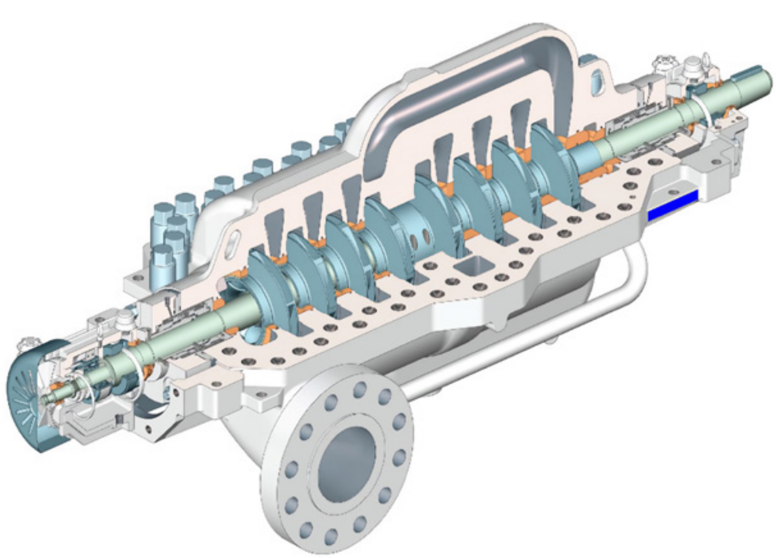

Figure 2: The volute casing has a more complex design

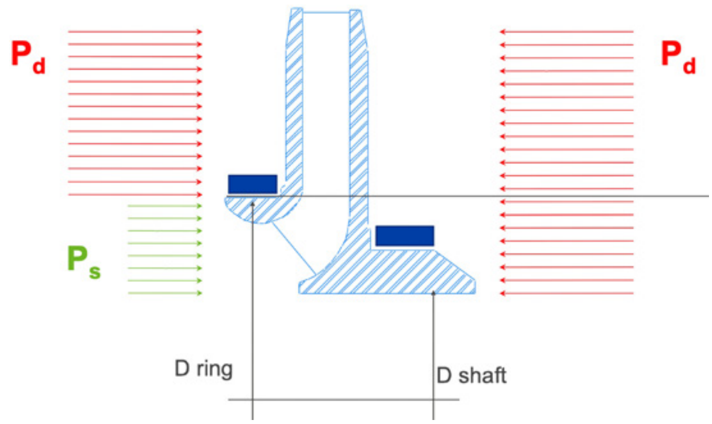

Figure 3: Identifying suction and discharge pressures

Referring to Figure 1, the discharge pressure acts on both the eye shroud and the hub shroud. The thrust created on both shrouds, therefore, is balanced. However, the pressure below the ring diameter is unequal on either side of the impeller and therefore creates a thrust towards the impeller eye.

Thrust compensation - disc

Clearly, the final thrust figure generated is governed by the design of the pump and each one needs a bearing system that is capable of handling it. However, in many applications, especially those involving inline WT pumps, it is not possible to find bearings large enough to cope with the thrust created. It is necessary to include a balancing device in the pump design to offset the thrust generated by the impellers.

In the case of the WT design, the balancing disc is fixed to, and rotates with, the pump shaft, and is separated from the stationary balancing disc head by a small axial clearance. The liquid from behind the pump impeller can leak through this clearance to the balance chamber, from where it can flow back to the pump suction.

The pressure in the balance chamber will therefore act on the whole of the rear face of the balance disc and full pump discharge pressure will act on the smaller exposed area at the front of the disc. Small axial movement of the rotor shaft will adjust the clearance between the balancing disc head and the balance disc thus altering the flow through the clearance as well as causing the pressure in the balance chamber to vary. Altering the pressure in the balance chamber will change the axial force on the back of the balance piston.

The advantages of a balance disc design include reduced internal recirculation (better volumetric efficiency) and the ability of the disc to compensate for wear and the amount of thrust that requires balancing. The disc is referred to as a self-compensating balancing device and may exclude an axial thrust bearing in certain designs, thereby reducing initial cost and simplifying rotor construction and assembly.

Thrust compensation – drum

A balancing chamber at the back of the last stage impeller is either keyed or screwed to the shaft and therefore rotates with the shaft. A small radial clearance, approximately 0.005 inch (0.13 mm), separates the rotating drum from the static casing. Therefore, it needs springs in the bearing housing such that the springs become totally compressed when the two rotating disc and stationery face are approx. 0.005 inch from each other.

The pressure in the balance chamber situated behind the drum is maintained at pump suction pressure by interconnecting pipework. Thus a differential pressure exists across the drum creating an axial end force on the shaft. If there is impeller wear and the thrust alters, it also changes on the inboard and outboard impellers and therefore the drum still maintains good thrust balance.

Optimizing and extending asset service life

Pumping equipment destined for the nuclear industry is designed to last for the expected lifetime of the power station, usually around 30-40 years. During that time periodic maintenance will be required, but at the same time, it is possible to introduce upgrades to the design that will deliver increased performance and reliability.

One of the opportunities to improve the CRD system involves updating the pump design. This includes the removal of the gearbox, and its associated systems, from between the motor and the pump. This change eliminates any gearbox maintenance as well as simplifying the alignment of the skid components and removes the lube system and its piping.

For the pump itself, the design can include impellers with an increased diameter, which allow the pump to operate at 3'600 rpm, and a back-to-back impeller layout that balances the axial thrust. These improvements are matched with a sleeve and ball bearing construction that eliminates the existing lube system and fan cooling of the bearings, which removes the more complex water cooling system.

Meeting the needs of the industry

At the heart of any component upgrade within a nuclear power facility is the ability to complete the project to the strict industry standards and deliver it within the planned project window. Using the example of the CRD pump, this can be accomplished by engaging an experienced and well-qualified maintenance partner, such as Sulzer, which has wide-ranging experience in the design, manufacture and build of complete pump skids, ready for installation in the nuclear industry.

This process enables the replacement system to be completely assembled, tested and proven before it is installed. As with any equipment that goes into a nuclear facility, it must have undergone extensive testing and certification before entering service.

Upgrading a pumping system ensures continued reliability for the operational life of the power plant, while also improving efficiency and often reducing operating costs. The new design will incorporate the proven upgrades over the original features and be delivered in a skid that will "drop in" with the existing equipment to the same footprint.

Updated systems can also correct historic issues surrounding best efficiency points and the pump performance curves. These generally relate back to the original specifications, which were designed to ensure optimum efficiency when operating in an emergency situation where the diesel back-up generators are used to safely shutdown the plant.

However, for the vast majority of the time, during normal operation, the pumps will be running at higher speeds with lower flow requirements. An upgraded design can address these issues, as well as others, to improve maintenance, efficiency and reliability.

Proven pump design upgrades

One example of a pump that has been optimized for the nuclear sector, and especially the CRD application, is Sulzer's MSD pump. Its design and construction reflect the needs of the industry and ensure compliance with current specification. ISO 13709 requires the pump rotor to be stable with two times normal wear ring clearances. The MSD has a center bushing that makes a very effective bearing and provided there is pressure at the discharge nozzle, there is fluid in the center bushing. This design is well-proven with over 10'000 MSD pumps operating with this design.

The center bushing provides maximum support as well as damping for the rotating elements and balances the axial trust. At the same time, the bushing has a split construction that allows the rotor to be dynamically balanced and assembled into the pump without being disassembled.

The impellers themselves are arranged in a back-to-back design, individually dynamically balanced and secured to the rotor. They are supported by wear rings with a tongued construction as well as being pinned at the split line to prevent rotation.

Supporting the rotor are a range of bearing designs that are specified to suit the application. Ring oil lubricated ball bearings with INPRO bearing isolators are used as standard on most pumps that operate up to 3'600 rpm, with both fan and water cooling available. As pump sizes increase and in higher speed machines, sleeve radial and ball thrust bearings are utilized. Together, these upgrades offer a significant improvement in performance and enable pumping systems to deliver better efficiency and reliability.

Conclusion

All pumps in power plants need to be maintained on a regular basis to ensure continued reliability. However, there is also an opportunity to upgrade legacy pumping systems in nuclear power stations to extend their service life and improve efficiency.

By reviewing the existing arrangement, alternative designs can be proposed that use modern engineering capabilities and processes, such as computational fluid dynamics (CFD). Pump specifications, such as flow and head, can be maintained but without the need for gearboxes and lubrication systems.

These improvements can only be achieved if the solution provider has the technical expertise and the facilities to test and prove the upgraded pump assembly meets all the required standards. Such a commitment is a significant undertaking but one that Sulzer takes very seriously. With decades of experience in supporting the nuclear power industry, Sulzer's expertise continues to deliver an unparalleled service to the sector in North America.

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