

The Power of Wear Rings

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The Power of Wear Rings, Part 1

Understand the Lomakin Effect

Reliability leaders view every repair as an opportunity for improvement. After all, most process plants in Europe and North America are more than 20 years old. It makes little sense to assume that the original equipment supplied in the 1970s is up to the task of increasing requirements for reliability, efficiency, environmental protection and safety.

One simple upgrade that can be performed at the time of repair is the installation of nonmetallic wear rings with reduced clearance. With modern composite materials, wear ring clearance can be reduced to 50 percent of the API recommended minimum standard. This change increases pump reliability, efficiency and safety.

Part 1 of this series will address the reliability benefits. Part 2 will address efficiency gains, and Part 3 will address safety. This upgrade is not new, but during the past few years, installing nonmetallic wear rings has become a standard upgrade for many process plants. After nearly two decades of field experience, nonmetallic wear rings have become part of the industry standard. API 610 11th Edition (ISO13709:2009), Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries, recognizes the use of nonmetallic wear rings with reduced clearance.

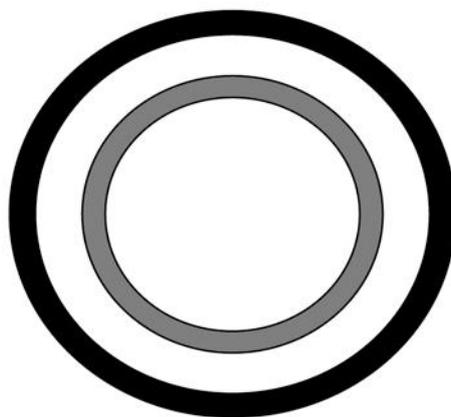


Figure 1a. Concentric rotor end view

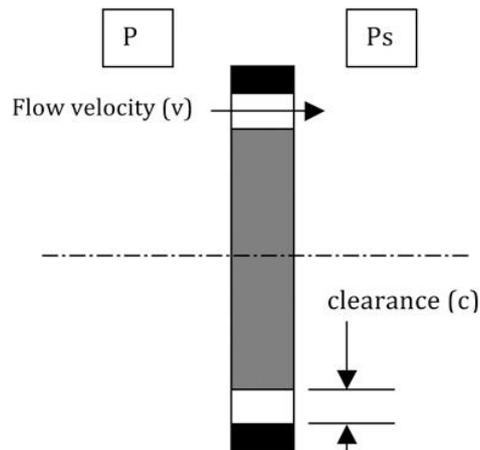


Figure 1b. Concentric rotor side view. Differential pressure from discharge pressure (P_d) to suction pressure (P_s) produces an axial flow of liquid across the wear rings.

The Lomakin Effect

Reducing the wear ring clearance in a centrifugal pump is a significant reliability upgrade because it increases rotor damping and stiffness in the pump. In more practical terms, reducing wear ring clearance decreases vibration and shaft deflection.

The relationship between shaft deflection and reliability is clearly known. Unfortunately, that wasn't always true. The pump designs of the 1960s, 1970s and 1980s did not anticipate current standards for reliability and mechanical seal performance. The main problem with these older pumps is that the shafts are typically too long, too thin and too flexible. This results in excessive shaft deflection and inadequate mechanical seal life.

The members of the API 610 committee recognized the flaws of older designs and from API 610 7th Edition onward have implemented design requirements to minimize shaft deflection. For new single and two-stage pumps, API 610 11th Edition recommends: "To obtain satisfactory seal performance, the shaft stiffness shall limit total deflection...to under 0.05 millimeters (0.002 inches) at the primary seal faces." (American Petroleum Institute)

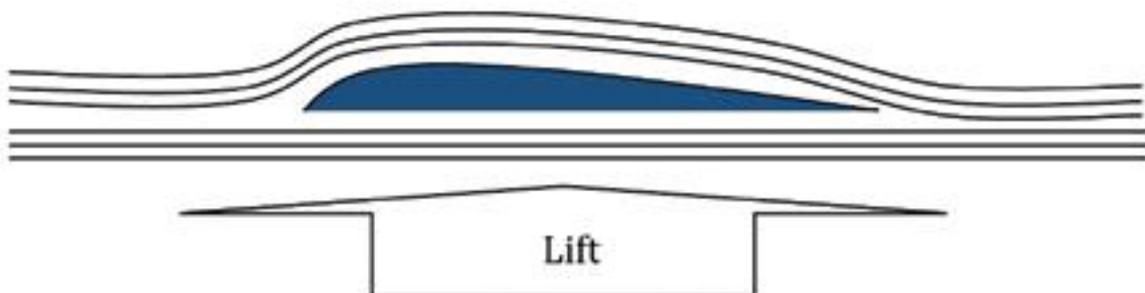


Figure 2. The airplane wing. Higher velocity over the top of the wing results in an area of relatively lower pressure. Lower velocity under the wing results in a relatively higher pressure. The result is upwards force (lift) that allows the airplane to fly.

For older pumps, the major pump manufacturers sell upgrade packages that replace the bearing housing, seal chamber and shaft of the pump. The marketing material for these products inevitably touts increased shaft stiffness and improved mechanical seal life as advantages.

Certainly, both new pumps and retrofits are excellent solutions to the problem of excessive shaft deflection. Unfortunately, most process plants have hundreds of older pumps that would benefit from an upgrade, and these options are often economically viable for only a small segment of the pump population.

The good news is that shaft stiffness comes from two factors—rotor design and wear rings. An older plant can use the power of the wear rings to increase the shaft stiffness for hundreds of pumps.

The stability generated by the wear rings is generally referred to as the Lomakin Effect, which is driven by the differential pressure across the rings. The wear ring is a barrier between discharge pressure (P_d) and suction pressure (P_s). The differential pressure across this interface creates an axial flow velocity as shown in Figures 1a and 1b.

The Lomakin Effect can sometimes be confusing because it encompasses two separate phenomena that occur at the wear rings: damping and stiffness. Damping does not directly prevent shaft deflection, but minimizes rotor response to excitation forces—much in the same way that shock absorbers result in a smooth ride in a car. Reduced clearance increases damping and results in a more stable rotor (Mancini).

Reduced clearance also increases shaft stiffness. The additional stiffness is derived from a positive corrective force which occurs whenever the rotor becomes eccentric. It works similar to an airplane wing (Figure 2), where the difference in relative velocities creates a force due to differential pressure.

A similar situation occurs when a centrifugal pump experiences shaft deflection. The pump rotor is exposed to multiple loads such as the weight of the rotor, hydraulic forces and unbalance to name a few. The result is shaft deflection and a rotor that runs off-center (Figure 3a and 3b). When this happens, the axial flow across the wear ring changes, with higher flow and velocity on the side with larger clearance and lower flow and velocity on the side with less clearance. The stiffness generated from these forces is known as the Lomakin Effect.

Perhaps most important, the stiffness and damping are located at the impeller where the pump has no bearing support. This strategic location gives the Lomakin Effect a great deal of power in minimizing shaft deflection (Figure 5).

Combine the increased damping and stiffness, and a pump with reduced clearance runs with lower vibration, less shaft deflection and a longer life than a pump with standard clearance.

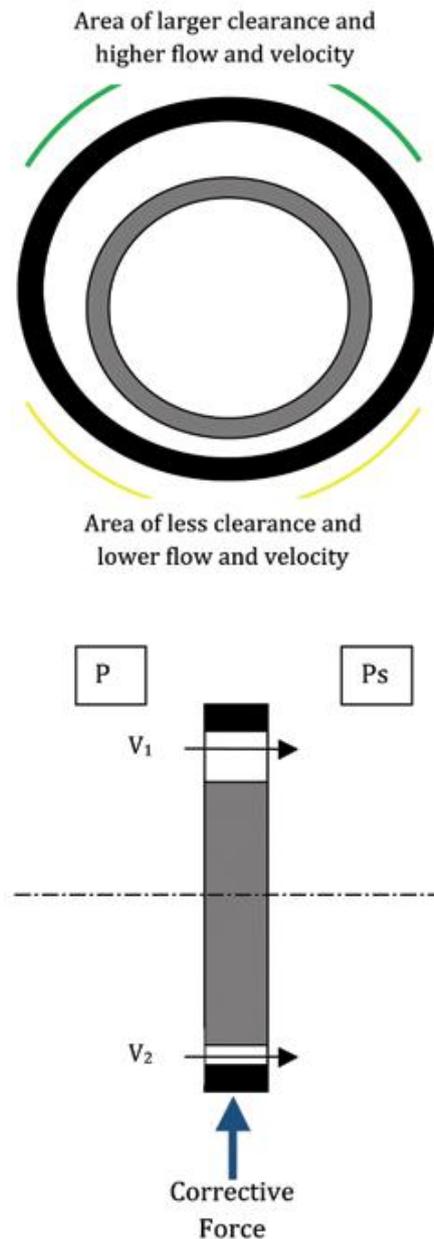
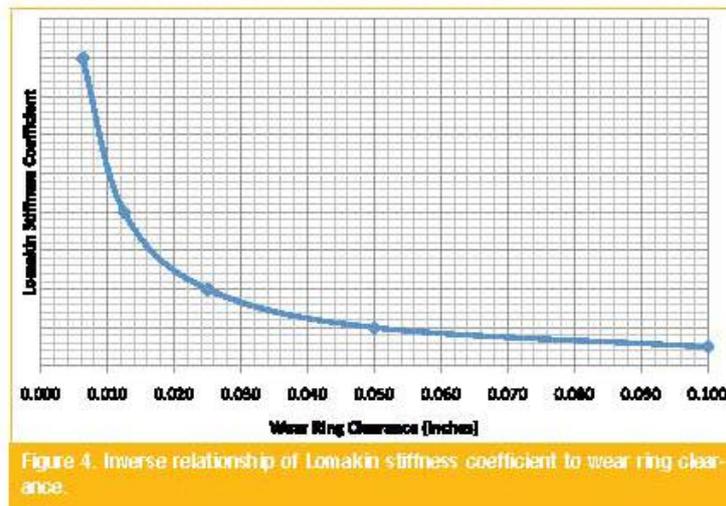


Figure 3a. (top) Non-concentric rotor and view. Higher axial flow will occur in areas with more clearance; lower axial flow will occur in areas with less clearance. Figure 3b. (bottom) Non-concentric rotor side view. The relative difference in velocity ($V_1 > V_2$) results in a net corrective force on the rotor - i.e. The Lomakin Effect.

Case Studies

The reliability impact from reduced wear ring clearance has been documented in numerous case studies during the past two decades. A recent study looked at repair data, vibration data and seal leakage data for 61 pumps installed in a North American refinery. The data was compiled for several years before the installation of composite wear rings with reduced

clearance and for an equal period after the conversion (Aronen, Boulden, Russek). The results are shown in Table 1.



After the conversion to composite wear rings with reduced clearances, the pumps were significantly more reliable, ran with lower vibration and experienced fewer seal leaks. Several other individual case studies have shown similar results. Studies of older pumps have shown overall vibration levels reduced by as much as 90 percent (Komin, 1985). Other studies have shown increased life and/or reduced vibrations in hydrocarbon (Pledger), boiler feed water (Aronen, Plaizier, Sinclair) and condensate services (DuPont).

This upgrade can be of particular benefit with older designs. A 1997 paper highlighted the upgrade of several two-stage overhung pumps. The results from these upgrades showed increased performance, reduced vibration and increased mean time between repair (MTBR) (Pumps and Systems). Even though the two-stage overhung design is now considered obsolete, many of these pumps continue to operate because replacement with a betweenbearings design is cost prohibitive.

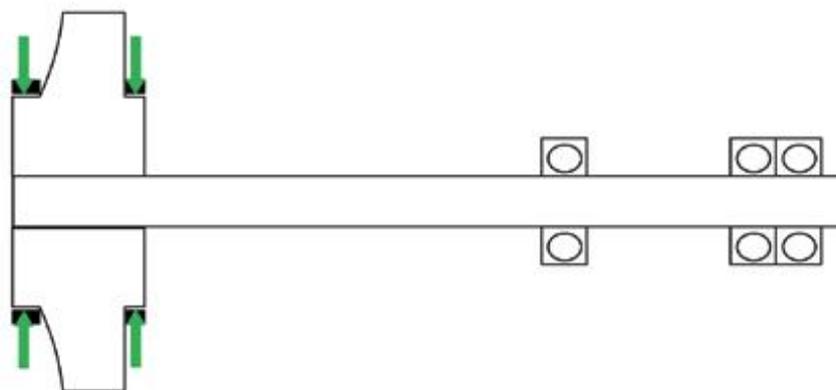


Figure 5. Lomakin-induced stiffness is located at the impeller where the pump needs it.

Cost of Upgrade

Upgrading with composite wear rings is possibly the most costeffective way to improve the reliability of existing pumps. The upgrade can be performed as part of a standard repair, does not typically require additional machinery modifications and should not add substantial time or complexity to the repair

Factor Considered	Change
Annual Repairs	45 percent decrease in repairs
Average Overall Vibration Level	25 percent decrease in overall vibration
Annual seal leaks (VOC services)	67 percent decrease in recorded seal leaks

Table 1. Results from Refinery Study of 61 Pumps

The upgrade cost of composite wear rings is primarily the added expense of an advanced composite material in place of a traditional material, such as 400 series stainless steel, cast iron or bronze. The cost varies widely based on the type and size of the pump. For example, the added cost of composite material for a small, singlestage pump should be less than \$1,000. Whereas, for a large, multi-stage pump, a composite material upgrade can cost more than \$15,000.

Keeping in mind this huge variation, experience suggests that the average cost of a composite wear ring upgrade is in the range of \$3,000. At this price, a large process facility, such as a refinery or petrochemical plant, could upgrade 50 pumps per year for about \$150,000. After a few years, the facility will have upgraded several hundred pumps and have much more reliable pumping capability.

Compare this to the price of the other upgrade options that can increase shaft stiffness, new pumps or major mechanical retrofits (typically provided by the OEM or a qualified independent pump shop). These other alternatives can substantially increase pump reliability and in certain situations they are absolutely necessary. Unfortunately, they cost much more than an upgrade with composite wear rings, limiting the number of services where these upgrades are justified.

Conclusions

Upgrading centrifugal pumps to composite wear rings with reduced clearance is a major reliability upgrade that can be executed at the time a pump is repaired. The reduction in clearance results in increased shaft stiffness—addressing one of the major problems with many pumps, particularly older designs. Case studies have shown this upgrade to result in fewer repairs, lower vibration and fewer mechanical seal leaks.

Compared to other upgrade methods that improve rotor stiffness, composite wear rings offer a cost-effective method of improving reliability for a large population of pumps. Furthermore, this investment pays off not only in terms of reliability but in reduced energy consumption. The efficiency benefits of this upgrade will be the topic of Part 2.

References

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The Power of Wear Rings Part 2: Efficiency

With a 50 percent decrease in clearance, efficiency is increased by 2 to 4 percent.

Part One of this series discussed how wear rings impact pump reliability by increasing rotor stability—reducing vibration and shaft deflection—thereby increasing the life of the mechanical seals. Part Two examines the impact of pump wear ring clearance on pump efficiency.

For decades, pump designers have known that increasing wear ring clearance leads to a loss of efficiency. However, with metal wear rings, even the minimum clearance as specified by API610 is substantial. Because the clearance cannot be reduced between two metal rings without an increased risk of pump seizure, metal wear rings limit pump efficiency.

Using non-metallic wear rings, the metal-to-metal interfaces within the pump can be eliminated, and wear ring clearance can generally be reduced by 50 percent. This change produces a significant improvement in pump efficiency.

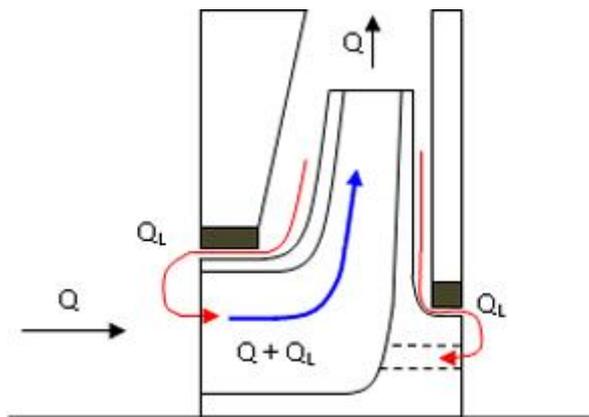


Figure 1. Leakage across wear rings back into the impeller

Pump Efficiency Impact

Wear rings act as a seal between the high-pressure and low-pressure regions within a pump. Leakage past the wear rings (Q_L) recirculates within the impeller as shown in Figure 1. The operators only see the flow coming out of the pump (Q). The total energy consumption of the pump, however, is a function of $Q + Q_L$ —the total flow through the impeller (Lobanoff, Ross).

Obviously, if we reduce the wear ring clearance, we reduce Q_L and therefore reduce the power required to obtain the same flow (Q) from the pump. As we will see, Q_L is often a substantial percentage of the total flow within the impeller.

The relationship between Q and QL is a function of the pump specific speed (NS), which describes the hydraulic performance of a pump. The calculation is:

$$Ns = \frac{RPM \times \sqrt{GPM}}{H^{.75}}$$

Where:

RPM =rotations per minute

GPM =gallons per minute flow at best efficiency point (BEP)

H =Pump head in feet at BEP

Pumps with low specific speed values are said to have "radial flow" impellers. These pumps put up high heads at relatively low flow rates—such as boiler feed water pumps. Conversely, pumps with high specific speed values are said to have "axial flow" impellers. These pumps put up low heads with large flow rates—for example, cooling water pumps.

The relationship between efficiency, wear ring clearance and specific speed has been well documented. In 1946, Stepanoff published a chart showing the efficiency loss for a single-stage, double-suction pump with a doubling of wear ring clearance as a function of specific speed. In 1985, Bloch published a similar chart for a single-suction pump showing the efficiency loss when wear ring clearance increased for pumps of various specific speeds.

If we take this data and use it to estimate the efficiency gain from a 50 percent reduction in clearance, we can plot the data on a curve (Figure 2).

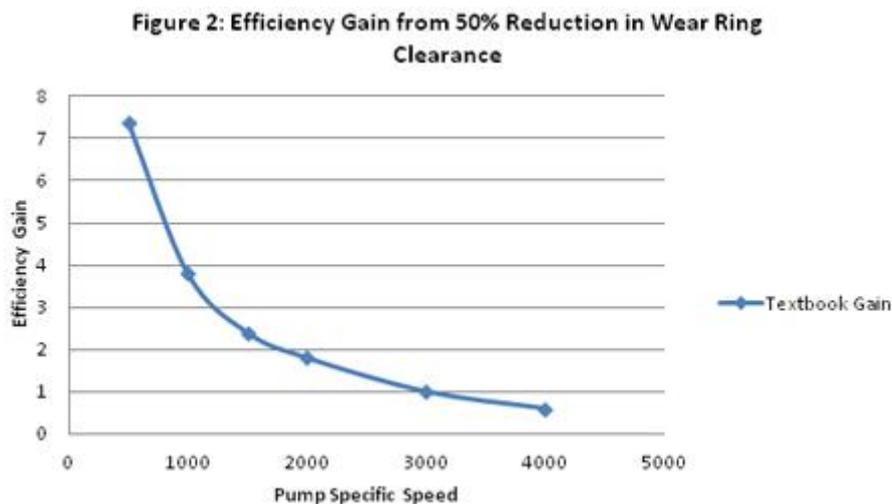


Figure 2: Efficiency Gain from 50% Reduction in Wear Ring Clearance

Source	Pump Specific Speed	% Reduction in Clearance	% Efficiency Gain
Field Study A	1,000	50%	5%
Field Study B	1,500	50%	2.2%
Test Stand 1	1,500	60%	2.5%
Test Stand 2	1,000	27%	2.0%
Test Stand 3	500	78%	10%

Table 1. Field studies and test stand data of efficiency gain versus wear ring clearance

Next, we can compare test data and field studies to the chart. Several studies provide enough information to calculate the pump specific speed, show the degree to which the clearance was reduced and quantify the efficiency gain. Some of these studies are field case studies, and some are from pump test stands. The data is shown in Table 1.

To compare this data to the plot shown in Figure 2, the last three values must be adjusted to approximate what would occur with a 50 percent reduction in clearance. Because leakage flow is mostly linear with clearance, we can approximate the efficiency gain at a 50 percent reduction in clearance by using a linear extrapolation of the efficiency gain. For example for the data point Test Stand 2, a 50 percent reduction in clearance should produce nearly double the efficiency gain of the 27 percent reduction in clearance which was used in the actual test. Making these adjustments, the curve from Figure 2 matches quite well with the field and test stand data (Figure 3).

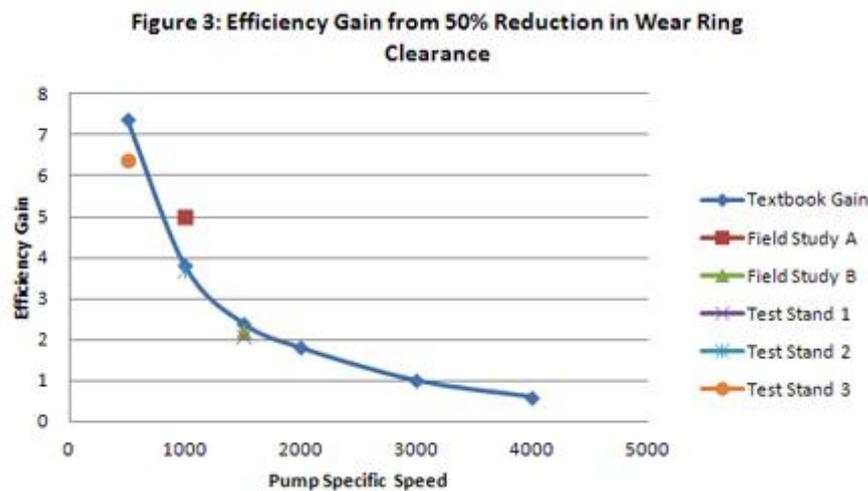


Figure 3. Efficiency gain from 50 percent reduction in wear ring clearance

Bear in mind that Figure 3 shows the efficiency gain from a 50 percent reduction in wear ring clearance compared to the API minimum clearance for a pump running at BEP. Several other situations exist in which efficiency gains will be substantially larger, such as:

- Multistage pumps, which have multiple leak paths in addition to the wear rings, and closing the clearance at all of the leakage paths will increase the efficiency gain
- Pumps for which the wear ring clearance can be reduced by more than 50 percent
- Pumps for which reducing the clearance also mitigates cavitation

Savings

Reducing the wear ring clearance to 50 percent of the API standard will save a plant a substantial amount of money. Consider a population of pumps with total online horsepower of 25,000 horsepower—typical for a 100,000-barrels-per-day refinery. A 3 percent efficiency gain over the entire pump population will decrease power usage by 4.9 million kilowatt hours. Annual savings will be a function of the local cost of power (Table 2).

These savings do not include local incentives for reducing power consumption or other savings, such as avoiding the need for a new substation.

\$/kwh	Annual Savings
\$0.05	\$245,000
\$0.075	\$367,000
\$0.10	\$490,000
\$0.125	\$612,000

Table 2. Annual Savings from 3 percent efficiency gain on 25, 000 horsepower of pumping capacity

Cavitation

Reducing the internal leakage within the pump also reduces the net positive suction head required (NPSHR). Therefore, pumps with reduced wear ring clearance are less likely to cavitate. This was the topic of an entire article in *Pumps & Systems*, July 2009, (Henshaw). The article included a complete pump curve showing the impact of reduced clearance on all aspects of pump performance (Figure 4).

At BEP, the NPSHR was almost 10 feet lower after the wear ring clearance was reduced. For most pumping systems, the only other way to create such a large amount of additional NPSH margin is to increase the height of the suction vessel.

Conclusions

For typical process pumps, reducing wear ring clearance by 50 percent will produce an efficiency gain in the range of 2 to 4 percent. The exact gain will be related to the pump's specific speed, the pump type, how much the clearance can be reduced and where the pump operates on the curve. In addition to the efficiency gain, the pump will also have a lower

NPSHR at most flow rates, reducing the risk of cavitation, which will provide additional reliability and efficiency improvement.

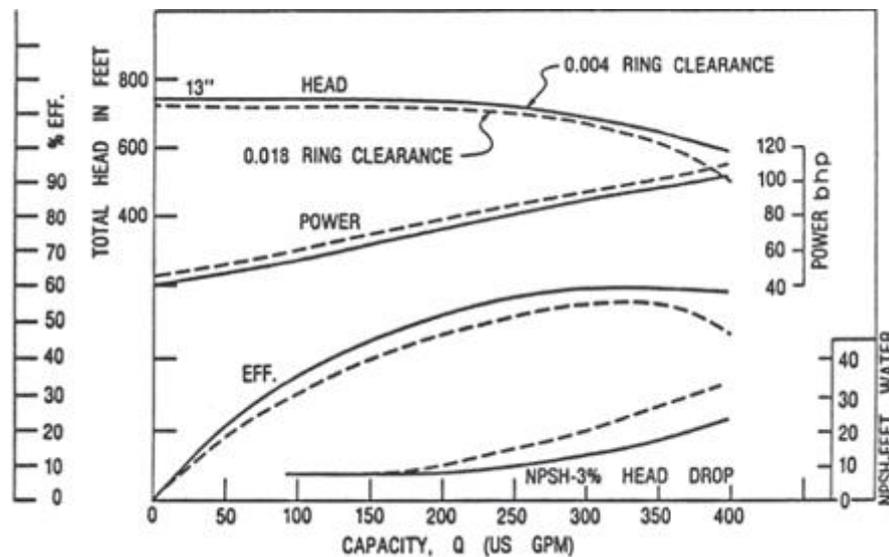


Figure 4. The impact of reduced wear ring clearance on pump performance Source: Pumps and Systems, July 2009

So far, this series has explored the reliability and efficiency benefits of using non-metallic wear rings with reduced clearance. Next month, Part Three (the last installment) will examine the safety aspects of upgrading pumps with non-metallic wear rings.

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The Power of Wear Rings Part 3: Safety

Part One of this series addressed potential reliability improvements from using nonmetallic wear rings with reduced clearance. Part Two evaluated the efficiency gains from reduced clearance. In this final look at pump wear rings, the safety impact of nonmetallic rings with reduced clearances is examined.

Whether a plant uses metal wear rings or nonmetallic wear rings, it has a responsibility to have the necessary safeguards in place to ensure safe operation. This obligation does not go away with nonmetallic wear rings. However, under certain circumstances, nonmetallic wear rings can mitigate the damage from off-design events.

Pump Seizure

Wear rings are the primary interface between rotating and stationary parts in the pump. Under normal operating conditions, little contact occurs at the wear rings. However, hard contact can occur at the wear rings when the pump experiences off-design conditions such as dry running, zero-flow operation or an external event—such as a failed bearing. These circumstances can expose the difference between metal and nonmetallic wear rings. Metal With metal wear rings, an inherent risk of seizure exists—high-speed contact between rotating and stationary parts, welding the parts together. Seizure is an uncommon failure mode but is highly undesirable. When a pump seizes, the rotor often stops abruptly. This can cause broken shafts, failed seals, broken couplings, release of product to atmosphere and all the other negative consequences that can stem from product release. To avoid seizure with metal wear rings, API610 recommends minimum clearances and “a difference in Brinell hardness number of at least 50 unless both [wear] rings have a Brinell hardness number of at least 400.” These guidelines reduce but do not eliminate the risk of seizure.

Nonmetallic

With the use of nonmetallic wear rings, the ordinary metal-to-metal interfaces within the pump can be eliminated, and clearances can be reduced. Extensive industry experience has shown that nonmetallic materials do not seize in the same manner as metal parts. Therefore, a rapid stopping of the pump rotor is highly unlikely.

Example:

Consider the impeller shown in Figure 1 (below).



Figure 1. Impeller after incident

A foreign metal object entered the process stream and lodged itself inside the impeller. The event created very high vibrations and extreme impact loads on the wear rings. Fortunately, this pump was fitted with stationary composite wear rings as shown in Figure 2 (below).



Figure 2. Composite material case wear ring after incident

The operators heard the noise, shut the pump down and put the spare pump into service without incident. The pump did not seize. No damage to the major pump components occurred except for the impeller, and hazardous product was not released to the atmosphere.

Wear Ring Clearance

With metal wear rings, a common practice when faced with pump seizure is to increase the wear ring clearance. As discussed in the first two parts of this series, increased clearance reduces the reliability and efficiency of the pump. Increased clearance can also lead to "excessive vibration, driver or pump bearing failure, shaft breakage, driver overloading and possible total pump destruction." (Bloch & Geitner, p. 35) Conversely, with reduced wear ring clearance, as discussed in Part One of this series, the pump rotor will benefit from additional stiffness and damping, which can reduce vibration; shaft deflection; and the related loads on the critical pump components such as the bearings, drivers and seals.

Material Selection

When selecting a nonmetallic wear ring material, users should consider what happens to the wear rings during off-design operation. Heavily loaded contact between rotating and stationary parts is likely. As in the example above, the rings could experience impact loading. If the pump runs dry, heat will be generated, and potentially, thermal shock may occur when the liquid flow is restored. To withstand these forces, some of the material properties to consider are wear resistance, impact resistance, thermal shock resistance and the coefficient of thermal expansion. No material is indestructible, but with consideration of the above factors, nonmetallic wear rings should remain intact during all but the most extreme off-design events.

Conclusions

Centrifugal pumps are generally safe. However, off-design operation can sometimes lead to extensive damage due to seizure at the metal wear rings. With metal wear rings, the traditional solution has been to increase the clearance at the expense of reliability, efficiency and rotor stability. Nonmetallic materials allow the user to eliminate the metal-to-metal interfaces within the pump and reduce the clearance. This upgrade improves reliability and efficiency, while minimizing the risk of seizure and mitigating damage to the pump during off-design events. Conversely, if a plant avoids one major event through the use of nonmetallic wear rings, the savings from that one event can easily justify the upgrade of hundreds of pumps.

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