

THE COOLING TOWER GEAR DRIVE DILEMMA:

*WHY APPLYING COMMODITY PRODUCTS TO
AN ENGINEERED SOLUTION CAN CAUSE
PREMATURE FAILURE*



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The material presented here was primarily based on the research, development and design work done by Jules De Baecke, Vice President of Engineering for Philadelphia Gear.

THE DILEMMA

The cooling tower application presents a unique dilemma for the customer or user. Larger cooling tower assemblies are made up of multiple motor, gearbox, and cooling fan assemblies, collectively viewed and treated as a mass produced product consisting of several identical drive systems. The focus of this investigation is primarily on the larger multiple fan systems that employ double reduction enclosed gear drives to reduce motor speed to fan speed such as those found in power plants and refineries. These gear drives typically consist of a first reduction bevel gear set and a second reduction parallel shaft gear set. This gear drive configuration transmits motor power from a horizontally oriented motor to a vertically oriented fan shaft. However, many of the concepts and ideas discussed are also applicable to single reduction cooling tower enclosed gear drives consisting of a single reduction bevel gear set that transmits motor power from a horizontally oriented motor directly to a vertically oriented fan shaft.

The cooling tower application is demanding and often requires unique component capabilities to meet a variety of environmental and operational challenges. As a result, the supplier's purchasing function will often pursue a low cost quick fix product solution, which is in direct contrast with the users' or customers' need for a reliable long-term solution.

THE OPERATIONAL CHALLENGES

Fan drive systems usually reside at the top of the cooling tower assembly high above ground level, with the gearbox located central to the tower directly under the large fan, a location that is not necessarily conducive to the performance of normal gear drive maintenance. A simple event such as checking the oil level in the gear drive can become difficult. The oil cannot be checked while the fan is operating, and even if the fan is stopped the drive system is still difficult to access.

Another operational challenge that the product must face is driving the fan blades that may be covered with ice because of their outdoor location. Any additional load due to increased

weight and/or unbalance caused by ice formation on the fan blades must be borne by the gear drive. The same gearbox that was designed to be a cost competitive solution now must withstand operating conditions that are beyond normal conditions.

Below is a closer examination of the consequences of not being able to safely get to the gear drive for normal maintenance.

VISUAL DETERMINATION OF SHAFT SEAL INTEGRITY

Commodity gear drive designs operating at the relatively low speeds experienced (900-1800 RPM input speeds and double digit output speeds) will usually contain lip type shaft seals on both input and output shafts. A typical lip seal cross section is shown in figure (1). The inside diameter tapers to a point where the stationary rubber lip rides on the rotating shaft. A circumferential spring is employed to exert pressure on the rubber to seal against the shaft. The key to obtaining maximum lip seal life is to ensure that it is always lubricated. Lip seals are cost effective, and when properly applied, they can supply up to several years of life, but they are susceptible to several possible failure modes. If they do not receive a constant minimum amount of lubrication oil that follows shaft rotation or grease that must be applied externally, the seals will wear and begin to leak. If the leak is not rectified, the gear

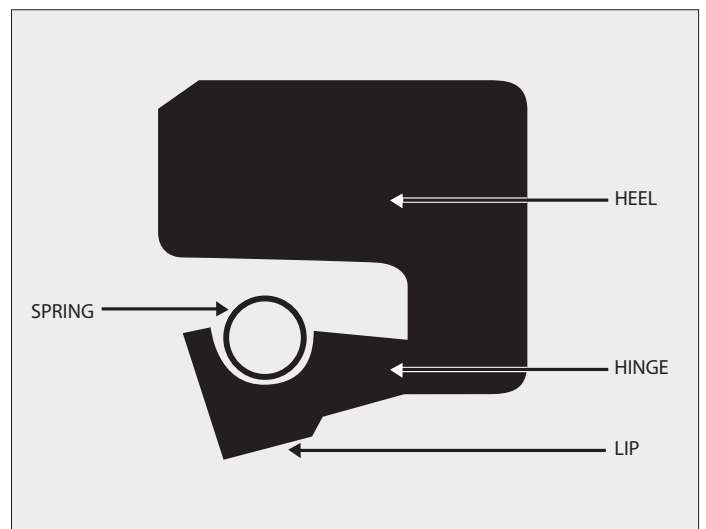


Figure 1. A typical lip seal cross section.

drive oil level will drop. If the lost oil is not replaced in a timely manner, gear and bearing failures will occur. If the leaking shaft seal cannot be seen from ground level or from the drive motor location, a lack of lubrication will only be determined as a root cause of a gear or bearing failure after the fact.

OPERATING WITH DIRTY OIL

Low speed commodity gear drive designs are often splash lubricated, that is, a gear element or a flinger attached to a rotating shaft dips in the sump oil and either directly throws oil to bearings and gear meshes or splashes the oil into a series of oil troughs or flow paths that lead to bearings and gear meshes. Commodity gear drives also typically are not supplied with lubrication oil filters. All submerged bearings need no further special attention other than maintaining lubrication oil in the gear housing because the rationale is that seals and breathers will keep out dirt, and periodic oil changes will remove any contamination generated within the gearbox. Based on experience, typical lip seals will only function as designed if they are properly lubricated with clean oil. Failure to change gear oil on a regular basis will not remove contamination in the lubrication oil. Due to the commodity gear drive's location, changing oil becomes a difficult task. Dirty oil will in time abrade the lip seal material and begin the leaking process discussed above. The lack of oil will deteriorate the lip seals even sooner.

WATER IN THE LUBRICATION OIL

Water in lubrication oil can generate a multitude of problems. It can adversely affect the lubricant's ability to effectively perform its lubricating function by reducing viscosity and thus preventing the oil from generating sufficient oil film thickness between gearing and bearing components. The potential for rust formation during downtime and temperature changes (which promote moisture condensation on gearing, bearings and housing internal surfaces) are potential contamination generators that become destructive forces contributing to a drastically reduced gear drive life. There are several other conditions that if combined with the presence of water, can shorten the lifespan of a gear drive. If water is present with elevated operating temperatures in conjunction with an extreme pressure (EP) additive oil, there are many devastating possibilities. Typical EP additives are phosphorous and sulfur. If the operating environment becomes hot enough to break down a typical EP mineral oil,

it may create a solution of water (hydrogen and oxygen), loose sulfur and phosphorous, and a high temperature to encourage molecular activity and ionization. Even a little salt water has the potential to generate different kinds of corrosive acids and compounds that can ruin a gear set in a period of only a few hours to a couple of days.

NOISY OPERATION

Operators who are consistently around the same operating equipment can often hear even subtle changes in gear drive operating noise signature. However, the operator has to be in reasonable proximity to the unit to hear the change. If the operator is not next to the gear drive when it operates because it is four stories above ground level and operating under a set of whirling fan blades, then any attempt to monitor the noise would be fruitless. In fact, unless the fan blades stop turning or the motor trips out on overload, the assumption is that the gearbox must be okay.

REMOTE EQUIPMENT MONITORING

Remote equipment monitoring is perhaps one of the best ways to assess equipment condition by pre-warning of impending problems and allowing the operator the opportunity to fix a small problem before it turns into a big one. However, remote monitoring requires monitoring equipment, vibration probes, temperature probes, etc., and the ability to read the measured parameters at a remote and safe location. Unfortunately, most cost competitive commodity gear drives come with little to no monitoring equipment- no vibration pickups, no temperature probes and no pressure sensors. Another disadvantage to instrumentation of cooling tower gear drives is the cost associated with the instrumentation of several fan drive modules and maybe more than one piece of monitoring equipment per module.

We have discussed some of the more obvious challenges posed by the cooling tower application. Some of the remedies are costly and may not be good investments for the long term. However, there are many cost effective actions that can be taken during the initial purchase of the cooling tower system, and some that can improve operation of units already purchased and presently in service.

HOW TO MAKE THINGS BETTER WITH EXISTING COOLING TOWER GEAR DRIVES

PROPER ENCLOSED GEAR DRIVE BREATHING

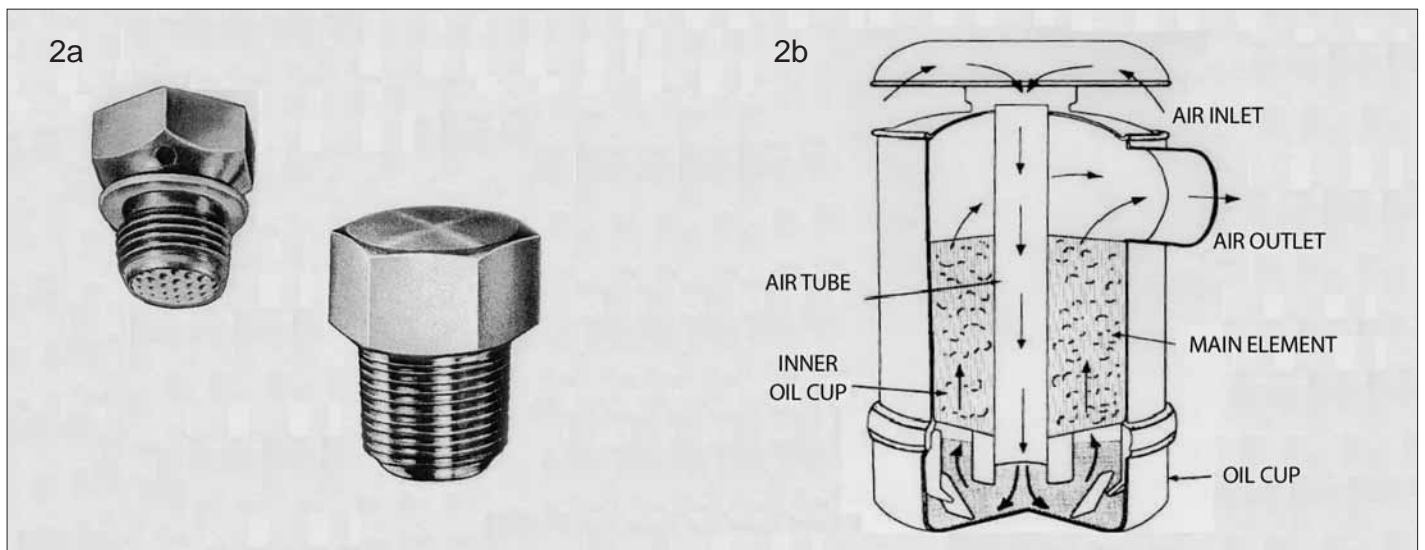
Like humans, enclosed gear drives need to breathe on a regular basis to attain their full lifespan. Most enclosed drive scopes of supply include some sort of breather to permit internal gear casing pressure to equalize with atmospheric pressure when the gear drive's operating temperature causes the air in the gear housing to expand. If the expanding air volume cannot equalize with the ambient atmospheric pressure, the heightened internal gear case pressure can cause shaft seals to leak. To avoid this condition, the breather allows continuous pressure equalization to occur so oil leakage does not become a problem. The type of oil breather chosen and how it is installed can make a significant difference in gear drive long-term health.

In most cases, a commodity type gearbox comes with a commodity type breather. The breather does the minimum job of permitting air pressure between the inner gear drive housing and the surrounding atmosphere to equalize. Any moisture in the air is permitted to enter or exit the gearbox based on prevailing conditions. Once moisture is in the gear housing, it may condense on bearings, gear elements, housing surfaces, and into the lubrication and cooling oil itself. An upgrade from the commodity type breather is the oil bath breather, which forces the atmosphere through a small volume of oil, in a mesh located at the bottom of a gooseneck, that retains the

moisture and prevents it from entering the gear drive housing. Refer to figure (2) for illustrations of both the simple and the oil bath breathers. The oil bath breather works well as long as the oil does not build up and spill back into the gear drive housing. Because of the gearbox housing's location, it is difficult to comfortably perform scheduled breather cleaning maintenance. There is, however, a simple piping arrangement that can make breather draining of moisture a simple and safe task. As can be seen in figure (3), by piping the breather through a pipe Tee and angling a pipe run to drain from the unit directly under the fan out to an accessible area near the drive motor, a small petcock can be opened periodically near the vicinity of the drive motor to drain accumulated moisture that collects in the breather and drains into the angled pipe. The long pipe acts as both a reservoir for moisture collected by the breather and a gravity conduit to remove the moisture from its access to the gear drive. Since the pipe run is fairly long, several days or weeks worth of moisture can be collected and stored by the pipe before the water backs up and enters the gear drive housing.

MAINTAINING LUBRICATION OIL IN THE GEAR DRIVE

Operating the gear drive with dirty, low, or no lube oil can reduce or drastically shorten gear drive service life and increase the chances of a possible surprise catastrophic



Figures 2a and 2b. Typical Breather and Typical Oil Bath Breather.

failure that results in unscheduled downtime. Figures (4a) and (4b) demonstrate Murphy's Law in action. The failure was due to the upper cooling tower gear drive output shaft bearing. Chances are that the upper bearing that failed was splash lubricated by either a flinger attached to a rotating element or a dipping gear that was no longer throwing or dipping because of low levels or no oil at all.

How can we ensure that checking oil levels and replenishing lost or consumed oil is safe and practical? Figure (3) demonstrates one method by which this can be accomplished. By running another pipe from a cooling tower gear housing tap in the bottom half of the housing out to the drive motor area,

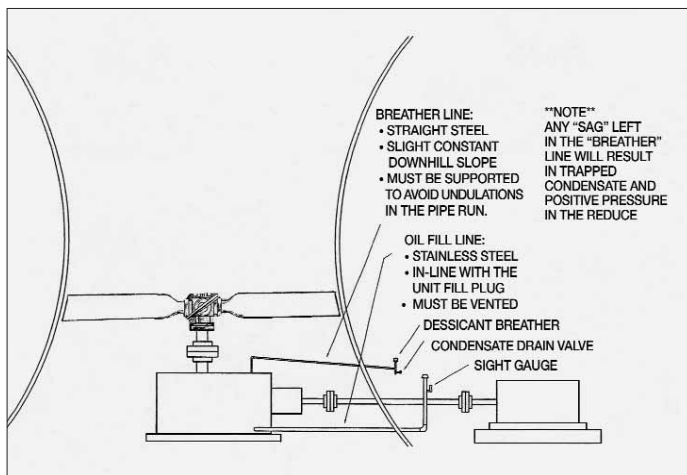


Figure 3. Cooling Tower Gear Drive Breather and Oil Level Sight Glass Modifications.

a remote oil sight gage and fill tap can be located in an area remote from the rotating fan blades where oil level can be checked and restored. With only minor piping modifications, operators can drastically reduce or at least partially neutralize two major causes of cooling tower gearbox failure modes- lack of lubrication and lubrication water contamination.

USE OF SYNTHETIC LUBRICANTS

Synthetic lubricants offer several key advantages over typical refined mineral oil products, whether they are rust and oxidation inhibiting or extreme pressure (EP) additive mineral oil formulations. Synthetic oils are man made compounds that are extremely difficult to break down due to their strong synthetic bonds. Ordinary mineral oils lose their structure and decompose at relatively low temperatures, as low as 325 degrees Fahrenheit. For today's state-of-the-art high power density gear drive designs that run hotter by design, mineral oils are not as good a choice as synthetic oils because of their relatively low breakdown temperatures. Mineral oils have a considerably reduced delta between maximum operating temperature and oil breakdown temperature. High temperature operation and lubrication oil breakdown can lead directly to both shaft seal leaks and inadequate bearing and gear element lubrication. These leaks can lead to a shortened gear drive service life or catastrophic gear and bearing failure.



Figure 4. Canted Output Shaft Due to Upper Output Shaft Bearing Failure.



Figure 4. Collateral Damage to Fiberglass Motor Shaft and Fan Blades.

Another plus to using synthetic lubricant is a more favorable viscosity index as compared to those of corresponding mineral oils. Viscosity index defines the relationship of oil viscosity change with a change in temperature. Synthetic oils possess flatter viscosity indices. That is, the synthetic oil viscosity does not reduce as much as the mineral based oil viscosity with the same corresponding increase in temperature. In other words, one type of synthetic oil can provide an acceptable operating viscosity range over a wider temperature range without sacrificing lubrication capability. Mineral oils that perform satisfactorily at 40 degrees Fahrenheit will often be too thin to operate at a temperature of 125 degrees Fahrenheit and still support an oil film in bearings and gearing tooth meshes that will be sufficient to prevent metal-to-metal contact. Metal-to-metal contact relates directly to accelerated bearing and gear wear and a drastic reduction in service life. To guarantee long gear life, two different viscosity mineral oils would have to be used, depending on whether the temperature was 40 degrees Fahrenheit or 125 degrees Fahrenheit.

The price for synthetic oil can approach four to five times as much as a corresponding mineral based oil. However, as with all products, one must weigh cost versus value. Although synthetic oil is extremely resistant to high temperature breakdown, it is still susceptible to particulate and water contamination, and often the most expeditious way to remove that contamination is via an oil change unless sophisticated centrifuging and filtration equipment is available.

CASE HISTORY

Some of the techniques that can help the user better cope with existing equipment have already been discussed. Below is a brief look at a case study, which represents several techniques that a resourceful user employed to keep very old cooling tower gear drives operating well beyond their expected service lives. This particular user was located in South America, far away from convenient technical support. The personal safety conditions in this particular area were also in serious question. Necessity being the mother of invention, this user became very adept at gearbox maintenance.

In this particular refinery, there was a large bank of double reduction cooling tower gear drives, about 20 units. These units were originally supplied with independent sumps and shaft driven lubrication oil pumps.

While walking through the repair shop, one would notice several low speed output shafts and gear assemblies lying about. The gearing was all single helical, and both gear faces on many of the low speed gear assemblies exhibited significant usage contact patterns on both gear faces. Cooling tower drives typically spend the majority of their time turning in one direction. These gear patterns indicated many hours of logged operation on both gear faces. This user had discovered the trick of removing the single helical gear from its shaft, turning the gear over and re-installing it back on the shaft again to use the gear face that previously was the coast side. This can be risky, especially if both gear flanks are not machined identical. The chance this user took was that the flipped gear would not make sufficient contact with its mating pinion. However, given the situation surrounding this user, the risk was warranted. The user was fortunate in that the original gear supplier was a quality supplier, and gear element loaded and coast side flanks were fairly consistent, so, flipping the low speed gears was successful most of the time. The result- service life extension and not enough spare part orders for the gear manufacturer. What was also remarkable was the knowledge acquired by the refinery maintenance. They became proficient to the point that they knew the proper shrink fit between the low speed gear and shaft. They determined acceptable run out tolerances between low speed gear and shaft, and so on.

If someone inspected the cooling tower proper, it was evident that the refinery crew had used their knowledge to work on the lubrication oil supply system to all 20 gear units. The original units were each individually lubricated by their own shaft driven lubrication oil pump, but there was a large centralized cooling tower lubrication system servicing all of the drives. This common cooling system was conveniently located at ground level and was complete with multiple pumps, coolers and filters, which supplied all units with cool and clean lubrication oil. The remote location of the system permitted easy access for maintaining clean filters and properly operating pumps, coolers, relief valves and other critical lubricating system components.

WHAT IS POSSIBLE WITH A COMPREHENSIVE DESIGN AND BUILD SPECIFICATION

This paper has explored some positive actions that the user can apply to existing cooling tower gear drives that are already in service. Now let us examine some things that can be done if an operator is fortunate enough to be able to start with new equipment. In this perfect world, the user's Maintenance Department is permitted to spend a little more first cost money to significantly reduce equipment lifecycle cost. There will be no bonuses awarded for obtaining an additional 5% discount off the lowest bidder's best and final price. The Maintenance Department will have the luxury of generating a cooling tower gear drive purchasing specification not a commodity product designed and manufactured to make it through the warranty period.

What should such a specification address? Below we explore some of the more desirable cooling tower gear drive value added features that have the potential to significantly reduce unit life cycle cost with only a modest up front cost.

GEAR HOUSING ANTI-CORROSION PROTECTION

The cooling tower enclosed drive operating environment is typically one of the worst. It is almost always unusually hot based on the cooling function the tower performs. The process usually involves water as the heat transfer media, which means the operating area is going to be moist the entire time the tower is operating.

A stainless steel housing might be the ultimate answer if an unlimited budget were available, but a better value proposition might be utilizing a self-curing inorganic zinc paint system to avoid gear drive externals from rusting. For a reasonable premium, a three-part paint system consisting of a zinc primer coat (two to three mils thick), an intermediate epoxy coat (four to six mils thick), and an epoxy finish coat (three to four mils thick) can be applied to provide many years of protection.

AVOIDANCE OF EXTERNAL PIPING

External piping invites breakage and bending, especially in the cramped space immediately under the cooling fan. Small tubing incapable of supporting the weight of a human being or an errant blow of a hammer makes the absence of any fragile external protuberance from the gear drive extremely desirable. If the proper thought is placed into a cast housing design, all bearing and gear mesh lubrication and cooling oil paths can be contained within the housing with no external lines required. The design cost of such a housing is a one-time

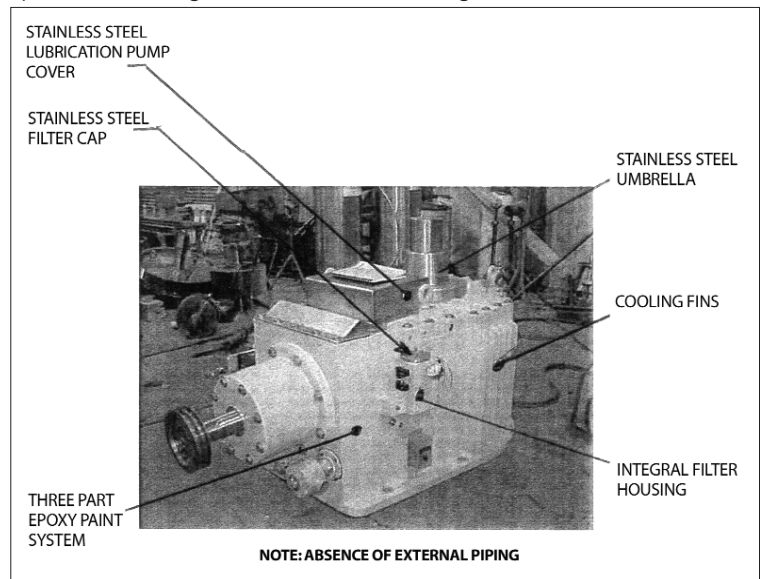


Figure 5. State-of-the-Art Double Reduction Cooling Tower Drive

charge. Once the design exists, the added cost of internal ported oil passages is relatively small. If a particular cooling tower has several tower cooling assemblies as most do, the additional engineering development cost amortized over the total number of assemblies becomes insignificant. Refer to figure (5) to view a cooling tower design that exhibits no external piping. Note the cast in filter housing.

REDUNDANT LUBRICATION AND COOLING OIL SYSTEM

Generally, low speed gear drives are splash lubricated. A gear element or an oil flinger located on a rotating shaft dips in the sump oil and either directly throws oil to bearings and gear meshes or flings oil into a series of oil troughs, pockets or flow paths that lead to bearings and gear meshes as we previously explored under the Operating With Dirty Oil discussion. Other, often larger, gear drives utilize a shaft driven pump to force feed oil to bearings and gear meshes. For a nominal cost, the cooling tower gear drive lubrication system can be made redundant by employing a dual system consisting of dipping gears and/or flingers and a shaft driven oil pump supplying oil under pressure. This set up could one day save the life of a cooling tower gear drive. If the pressure pump is properly plumbed so that the oil suction port is at the extreme bottom of the housing sump, a receding oil level, which would normally prevent gear elements and flingers from dipping in oil that unexpectedly was not there, would not starve the pump until almost all the oil in the gear housing was lost. Since leaking seals are the primary culprits when it comes to oil loss, the lowest level oil can fall within a housing is usually somewhere just below the lowest point of the lowest rotating shaft. If this ever happens the redundant pump system will avoid catastrophic failure by continuing to supply oil to all critical components even though dipping gears and flingers are no longer operating.

FILTRATION

Filtration is one good way to keep your oil clean. We previously explored the eventualities of operating with dirty oil under The Operating With Dirty Oil discussion. Since the user has the opportunity to design the perfect cooling tower gear housing, they also have the opportunity to incorporate in the housing casting a built-in filter housing and associated oil ports with a stainless steel cover plate accessible from the top of the housing for quick changing purposes. Additionally, they have the opportunity to make the filter size large enough so that a periodic changing can be accomplished during scheduled tower maintenance. In addition, in case the filter does get dirty, they can install a filter with bypass capability. Dirty oil is certainly better than no oil at all. Refer to figure (5), which shows the cast in filter cartridge.

COOLING FINS

Users should consider one more enhancement beyond those mentioned above. Today's state-of-the-art enclosed drive gear designs are of the high power density variety. Use of highly loaded case carburized and precision tooth ground gearing in a housing sized to match the gearing means that everything is operating up to maximum limits, whether it be tooth bending and contact stresses or housing operating temperature. A smaller housing means that there is less surface area to dissipate heat generated by working gears and bearings, and less surface area brings about higher housing skin temperature. Higher housing skin temperature leads to hotter lip seals and shorter lip seal life. Higher temperature also means mineral based oils have a much better chance of breaking down prematurely and coking. For a few extra dollars, cooling fins can be added to the cast housing design. With a minimum addition of material, gear housing skin temperature can be reduced significantly, thus reducing the probability that the lip seals and lubrication oil will not realize their respective expected service lives. Refer to Figure (5) and note the cast in cooling fins.

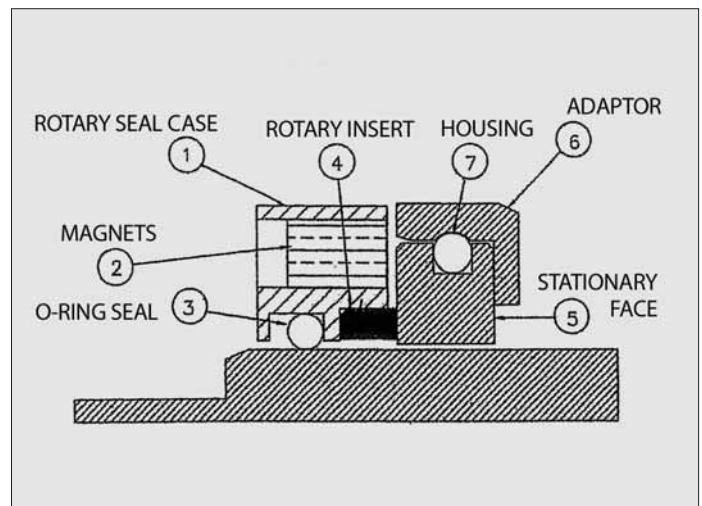


Figure 6. A typical face type seal arrangement.

HIGH END SHAFT SEALS

In the Visual Determination of Shaft Seal Integrity discussion, lip seals were profiled as being cost effective but susceptible to several possible failure modes. On today's market, there are several mechanical face type seal alternatives that have the potential for a considerably longer service life and are significantly more tolerant of misalignment. In addition, they can seal where a positive head of oil exists or where oil is directly impinging on the seal. For a few hundred dollars, these seals can be easily incorporated, not only in new designs, but they can also be back fitted into designs originally containing lip type shaft seals.

A face type seal typically consists of rotating and static members that are separated by an oil film. Usually one member is held against the other by a spring or magnetic force, the two members being separated by only the oil film. Refer to figure (6) for a typical face type seal arrangement.

The last type of seal to be discussed is a different type of labyrinth seal, which uses the same isolating technique to keep out external atmospheric contaminants and to keep in the oil. A series of labyrinth spaces and changes in direction of escape or entrance routes create pressure differentials and fluid turbulence to restrict flow and control leakage. This type of seal relies on gravity, the weight of the fluid, and centrifugal force to create the sealing function. Refer to figure (7) for a typical cross-section of this type of seal.

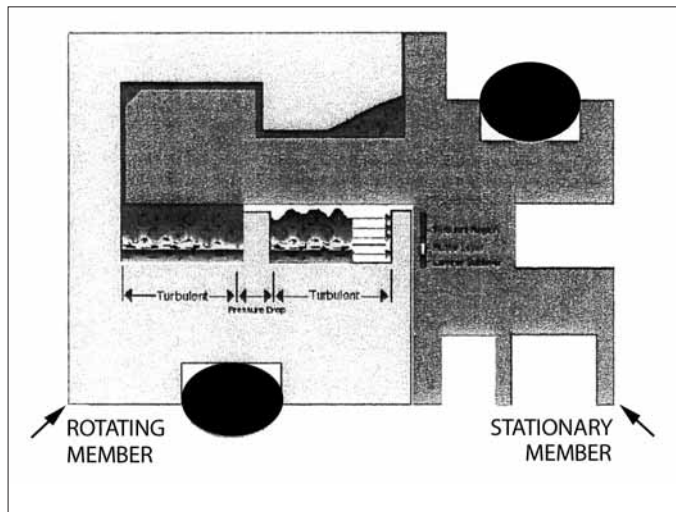


Figure 7. Isolator Type Seal With Multiple Labyrinths

OUTPUT SHAFT UMBRELLA

Another design enhancement of relatively low cost is the incorporation of an output shaft umbrella. The umbrella rotates with the output shaft and shrouds the output shaft seal from any direct fluid impingement, whether it be hot and dirty air circulated by the cooling tower fan, water spray from the cascading cooling water blown by the fan, or hose water from an exuberant equipment cleaner. Figure (8) illustrates a typical umbrella design.

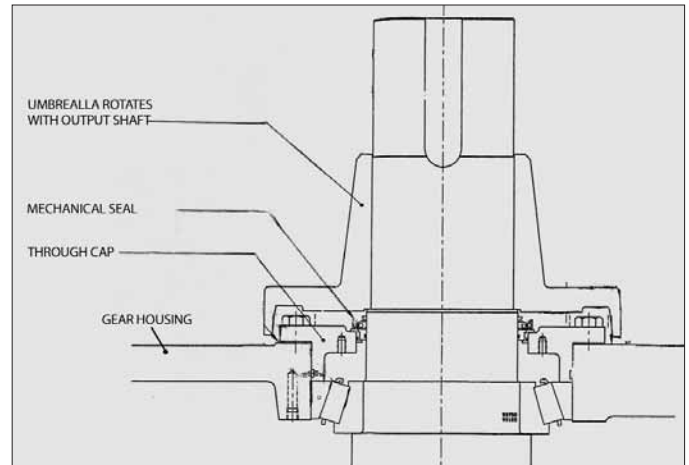


Figure 8. Output Shaft Umbrella

SUMMARY

This paper has examined several of the operational challenges of the cooling tower gear drive application and related them to specific aspects of the cooling tower enclosed drive design. Will a commodity design suffice for the application? Does the particular application require an application-engineered solution, or is the answer somewhere in between? Operational enhancements were discussed for reasonable value-added design upgrades, some of which can be implemented after original gear drives are placed in service. Also discussed were gear drive features representing value-added design improvements that, when built into a purchase specification for new units, can result in significant equipment life-cycle cost reduction and longer and more reliable life-cycle operation. Every enhancement discussed in this paper might not be for everyone or every particular application, but some of these ideas can be of benefit to operators in the never ending pursuit of a cooling tower gearbox that is economical to operate, reliable, and generates little or no life-cycle surprises.



ABOUT PHILADELPHIA GEAR

Philadelphia Gear was founded over a century ago with a simple but profound mission – to provide state-of-the-art gearing for the fast-growing industries of Pennsylvania. From those modest beginnings in 1892, Philadelphia Gear has earned a globally recognized reputation for expertise in power transmission engineering and manufacturing. Our world-class engineering and technical staff provides our extensive customer base across the globe with a full-range of solutions for their power transmission needs – from the installation of new units, to the inspection and repair of older equipment.

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