MAG DRIVE PUMPS: WHY THEY WORK–HOW THEY FAIL

by
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ABSTRACT

As the use of magnetic drive pumps become more popular and sometimes demanded, knowing how to install, operate and troubleshoot mag drive pumps becomes essential. System design, purchasing, installing, and commissioning mag drive pumps can be an experience. The intent is to share with users and manufacturers the problems and successes associated with mag drive pump design, installation, and operation. Exploring problems in the design and installation of pumps and safety systems should give insight to those planning on installing new pumps. The detailed review of pump failures will give everyone an opportunity to see failures associated with mag drive pump operation. The experience was gained during the startup and operation of 20 mag drive pumps in ethylene oxide service over a four year period.

MAG DRIVE PUMP APPLICATION AND SELECTION CRITERIA

The installation of 20 magnetic (mag) drive pumps in the ethylene oxide (EO) unit at the Clear Lake plant resulted in many lessons learned. Those lessons are explored in the mag drive pump failures section below. Several factors should be explored before specifying, purchasing, installing, and commissioning a new mag drive pump.

Before purchasing a mag drive pump the project engineer must obtain the normal pump design criteria for the following conditions.

- Startup conditions
- Normal operating conditions
- Transient operating conditions
- Shutdown conditions

The list above looks like a normal project checklist, however the EO installation did an inadequate job of looking at all the necessary criteria before purchase. Normally, process engineering designs for normal operation, and that flow is used by project engineering to purchase a pump. Although this is a widely accepted method for sizing and purchasing a pump, it will not necessarily be successful when sizing and purchasing a mag drive pump. A mag drive pump is somewhat more sensitive to changes in pumping conditions than an ANSI designed pump. Take, for instance, startup conditions. How many operating units start up with the same fluid at the same pressure, temperature, specific gravity, and viscosity, as specified on the datasheet? How many operating units start up with the same fluid as will be pumped when at normal operation? How many pumps are used for two different operations? How many pumps stay at one flowrate during a unit startup/operation/shutdown cycle?

Pumps are not always operated the way the project/process engineer intended. The pump system is supposed to be designed for bep (best efficiency point) operation. However, real world installations demands more from a pump than single bep operation. A pump may be used to transfer fluid from tower to tower before the unit startup to achieve a normal tower operating level. A pump could be used to clear the unit in case of a unit trip. A pump may be a spare for a completely different service via a jumper line. All these scenarios must be explored before the installation of a mag drive pump.

MAG DRIVE PUMP DESIGN CONSIDERATIONS

It seems that every manufacturer currently building ANSI pumps has now introduced a mag drive pump design. There are even some new manufacturers that have emerged with mag drive pump technology. The introduction of new mag drive designs is good in that a wide variety of experience and technology is being utilized. Each manufacturer claims the best design. However, there are several design issues that should be explored to ensure a reliable mag drive pump installation. Below is a discussion of the different sections of a mag drive pump that should be reviewed before deciding upon a particular pump manufacturer.

Roller/Ball Bearing/Drive Magnet Section

The roller/ball bearing/drive magnet section of mag drive pumps are all similar in design. It is, however, a good idea to look at the overhung weight compared to the bearing span and shaft diameter. Some of the drive magnets are quite large, and the bearing span normally does not change, especially in pumps built to ANSI dimensions. Specifying or at least verifying the manufacturer's balance tolerance is recommended. The drive magnet must also have a safety ring that will contact the bearing frame/housing, protecting the containment shell from contact with the magnets in case of a roller/ball bearing failure.

It is important to look at the lubrication scheme for the roller/ball bearings and the shaft seal that keeps the lubricant from entering the drive magnet section of the pump. When using wet sump lubrication, if the shaft seal fails and allows an oil level to build in the drive magnet section, heat will be generated. Normally the pump will start making noise and begin vibrating, which can be detected by periodic vibration monitoring. If the oil level buildup is not detected by vibration, the temperature of the drive magnet section of the pump will increase, eventually resulting in a roller/ball bearing failure. The problem of oil in the drive magnet section has not been evident when using pure oil mist lubrication.

It is recommended that the inside of the roller/ball bearing/drive magnet section of the pump be painted with an oil resistant paint. The paint will prevent rust formation. Rust formation is particularly a problem when the pumpage is cold, allowing condensation. Light surface rust is not a problem. When the rust scale becomes heavy enough to flake off and adhere to the drive magnet it can build up to the point where it contacts the containment shell. Abrasion of the containment shell is a problem, since it cannot be detected without disassembly of the pump. Some means of purging the drive magnet section is preferred, however this could prevent the drive magnet section from being classified as secondary containment in some pumps.

Driven Magnet/Bearing Section

The driven magnet/bearing section is the most critical design aspect of the mag drive pump. Everything from the bearing material to bearing design to thrust loading to assembly should be considered when specifying a mag drive pump. The driven magnet/bearing section is where the bulk of the engineering is incorporated. If the engineering is done properly, the result is a reliable pump, provided the application is adequately specified.

Internal fluid flow design should be seriously reviewed before purchasing a mag drive pump. The fluid that circulates through the driven magnet/bearing section is the only means of lubrication and heat removal. Once the fluid has circulated from the discharge of the pump through the driven magnet/bearing section, heat has been added. The fluid must then be discharged into the pump's main flow to either the suction or the discharge. Once heat has been added, the vapor pressure of the fluid changes. If the pump has been applied in a service where the ratio of vapor pressure to suction pressure of the pumpage approaches one, and the internal fluid flow is discharged in to the suction, flashing may occur. Flashing should be avoided in the driven magnet/bearing section of the pump. Flashing in the bearings results in essentially dry running, and thus, possible premature bearing failure. Flashing in the suction results in thrust reversals, and thus, possible premature bearing failure. The fluid used to lubricate the bearings and remove heat should be discharged into the pump's main discharge flow path, reducing the chances of flashing and the possibility of premature bearing failure.

Sleeve/journal bearings are used in every mag drive pump to support the rotor. The rotor includes at least a driven magnet, journal or sleeve bearings, thrust runner, and impeller, and (in most cases) a shaft, lubrication passages, spacers, etc. Sleeve/journal bearing design are critical to reliable pump operation.

Pump manufacturers supply two main bearing materials; carbon and silicon carbide. Carbon will wear over time and must be monitored to ensure the driven magnet rotor does not contact the containment shell. Silicon carbide has excellent wear properties and will withstand most thermal shock without failure. The sleeve bearings used in mag drive pumps should not wear quickly. If wear is a concern, some means of predicting the life or measuring the wear should be investigated. Silicon carbide is the material used most often by manufacturers. Some manufacturers diamond coat the silicon carbide journal bearings to allow brief episodes of dry running without bearing failure.

The sleeve bearings should be mounted to the shaft, so that they will not slip and rotate about the shaft during operation. The preferred method of securing the sleeve bearing to the shaft is to press the sleeve over tolerance rings creating an interference fit. A tolerance ring is a wavy ring with waves running parallel to the axis of the shaft. The waves create a slight interference fit of the sleeve bearing to the shaft. Tolerance rings also allow the shaft and bearing sleeve to grow independently, without stressing the bearing sleeve. The sleeve bearing should not be located and secured using a key (round or square), due to the stress riser created in the silicon carbide part. Stress risers in silicon carbide parts have proven to be a source of sleeve bearing failures.

Thrust bearings are used to locate the rotor and carry thrust loads generated by the pumping end design. The thrust bearing should be engineered so that, when installed, full-face contact between the bearing and thrust runner is achieved. If full-face contact is not achieved, point loading is created, resulting in premature bearing failure. There are basically only two designs in the marketplace; a) fixed faces (Figure 1) and b) floating faces (Figure 2). A floating-face spherical-seated thrust bearing design could be acceptable if there were some way to secure the floating-face at all times. The spherical-seat must be a true full spherical contact surface, not line contact. The spherical-seat contact surface is one of the only instances where fretting of silicon carbide against silicon carbide has been observed (Figure 3). It has been determined, by the manufacturer, that the spherical-seat thrust bearing design performs unsatisfactorily.

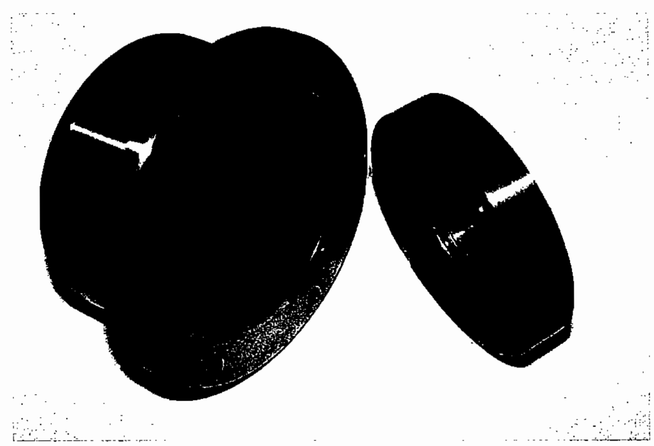

Figure 1. Fixed Face Geometry Thrust/Journal Bearing Pressed into a Housing (L), and the Rotating Fixed Face Geometry Thrust Bearing (R).

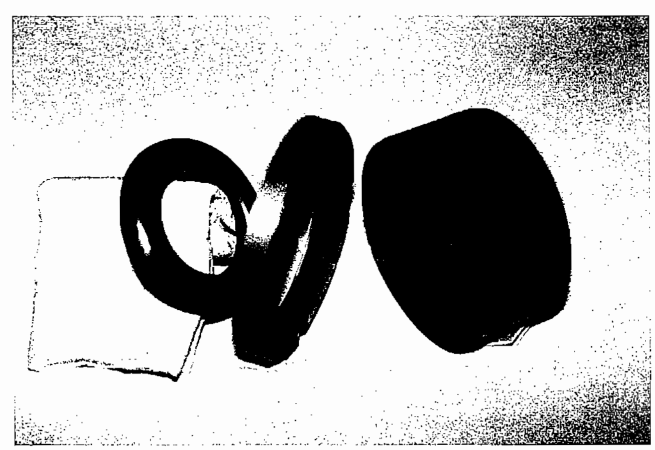

Figure 2. Rotating Spherical Seat (L) and Thrust Bearing (C), Floating Face Design, with Mating Thrust/Journal Bearing (R).

The load on the thrust bearing is directly affected by the pumping end design. Open impellers introduce higher thrust loads than closed impellers. Thrust loads must be either offset by thrust balancing the impeller or absorbed by the thrust bearings. Experience has shown that lower thrust loads translate into increased reliability.

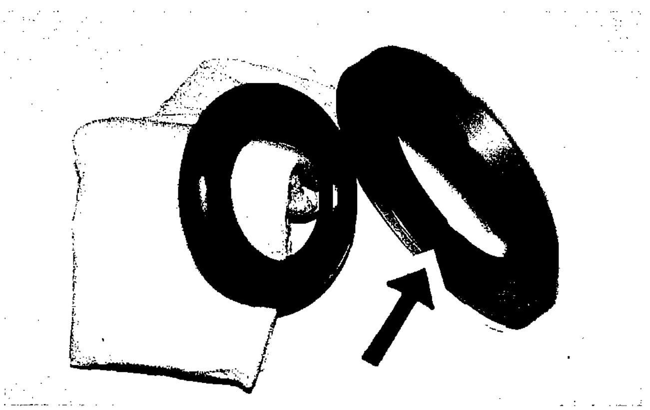

Figure 3. Fretting of the Spherical Seat.

Assembly of the bearing section can also pose some problems. Experience has shown that journal bearings that are prefit into a carrier are easier to install and remove than those bearings that must be carefully pressed into a bearing frame. When a pump is disassembled, it is advantageous to be able to completely disassemble the pump for inspection without destroying the sleeve/journal and thrust bearings. Silicon carbide as a bearing material does not wear in most applications. Therefore, if the bearings are in good condition before removal and can be successfully removed during maintenance, the bearings can be reused reducing repair costs.

Most shaft assemblies (sleeve bearings, thrust runners, driven magnet rotor, and impeller) are secured by one or possibly two shaft nuts. The shaft nuts compress the shaft assembly assuring all parts rotate as one unit. Looseness occurs when, for instance, the shaft grows axially due to thermal expansion more than the assembled parts on the shaft. The result is a loose sleeve or a sleeve bearing rotating relative to the rotor assembly causing premature failure. Wavy tolerance rings, graphoil spacers, and nuts capable of expansion are all used to ensure the shaft assembly remains compressed. Wavy tolerance rings under sleeve bearings and graphoil spacers between parts have proven to be a reliable means of ensuring that sleeve bearings do not rotate relative to the rotor assembly.

Minimum Flow–Thermal or Stable

Magdrive pumps, unlike ANSI pumps, have two minimum flow requirements. Thermal minimum flow is the pumps main flow necessary to assure the heat generated in the driven magnet/bearing section is removed. Stable minimum flow, the same minimum flow specified in ANSI pumps, is the flow required to assure proper operation of the pump. Meeting the requirements of both minimum flows is imperative for good reliability. In most cases, the thermal minimum flow is higher than the stable minimum flow. In any case, protection must be employed to assure the higher of the two minimum flows is met at all times.

INTERNAL HEAT GENERATION

In a mag drive pump, bearings are not the only forces generating heat. As a matter of fact, most of the heat is generated by eddy current losses between the driven and drive magnets. With a permanent magnetic coupling, the driven rotor turns at the same speed as the drive rotor. The two magnets are separated by a containment shell. The containment shell is normally 0.040 in to 0.100 in thick with about 0.070 in clearance between the magnets and the containment shell. The containment shell cuts the magnetic flux lines, termed eddy current losses, created by the permanent magnets. The amount of heat generated is a function of the pump rotation speed and material and thickness of the containment shell. Containment shell materials such as 316 stainless steel generate more heat than Hastalloy C, and Hastalloy C generates more heat than high performance plastics. The magnetic properties of the material has a direct effect on how much heat is generated due to eddy current losses.

A pump rotating at 3600 rpm can generate a lot of heat during dry running with no fluid in the pump. Literature [1] suggests that the temperature of the containment shell directly between the two rotating magnets (Figure 4) rises above 750°F within 30 sec of the onset of dry running. A spring loaded thermocouple on the containment shell (Figure 5) measured an increase in temperature of only 40°F in the same 30 sec. (Figure 6). The temperature *vs* time curve can change, depending on pump design. Note that the 750°F temperature is not measured with a spring-loaded thermocouple on the shroud. It is measured between the two rotating magnets using a thermocouple welded to the containment shell. The bulk of the heat generated is due to eddy current losses directly between the two rotating magnets. Internal fluid flow between the driven magnet rotor and the containment shell is necessary to remove the heat.

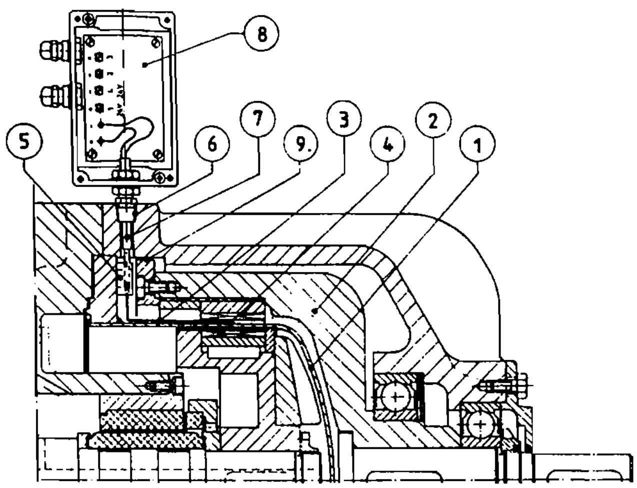

Figure 4. Containment Shell Temperature Measurement Directly between the Magnets.

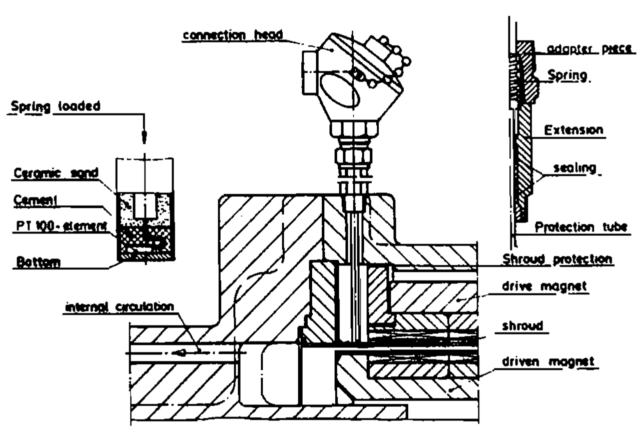

Figure 5. Containment Shell Temperature Measurement Using a Spring Loaded Thermocouple/RTD.

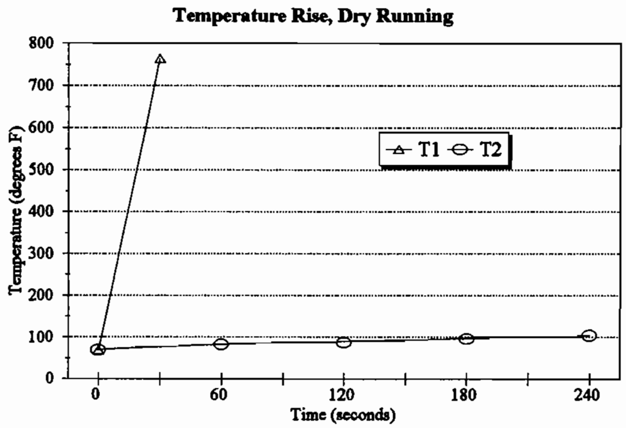

Figure 6. Containment Shell Temperature. T1 Is Measured Directly between the Drive and Driven Magnets. T2 Is Measured Using a Spring Loaded Thermocouple/rtd.

MAG DRIVE PUMP PROTECTION/INSTRUMENTATION

Mag drive pumps were designed to eliminate fugitive emissions. They do eliminate fugitive emissions, however, mag drive pumps have created new and different problems. Safe and reliable operation of a mag drive pump depends on, not only the pump selection and installation process, but monitoring of pump condition. The author's plant protects all of its mag drive pumps with shutdown instrumentation. The way a pump is protected against damage, and to what extent, is a decision that must be made during the pump system design and installation process. Below is a list of the types of instrumentation that has been used at the author's plant. Some pump systems dictated more than one monitoring method to assure adequate protection.

Monitoring Methods

Temperature of the containment shell, using a spring loaded contacting thermocouple/RTD (resistance thermal device) or temperature of the fluid leaving the containment shell measured in a thermowell are ways to monitor pump condition. Both methods monitor the temperature resulting from heat generated by eddy current losses in the magnetic coupling and bearing friction. These are commonly suggested temperature measurements by mag drive pump manufacturers.

Temperature measurements of the heat generated in the driven magnet/bearing section can be used as an absolute or differential temperature. The differential temperature measurement would be referenced to the pump suction fluid temperature. A differential temperature would result in a direct measurement of the heat input to the fluid by the pump.

The pump manufacturer should be able to calculate the temperature rise of the fluid that lubricates the bearings and cools the driven magnet rotor. The calculation is very sensitive to specific heat of the fluid, therefore, the number should be used as a starting point in choosing alarm setpoints. The alarm setpoints will most often need adjustment after startup and as historical data becomes available. Note when choosing alarm setpoints that the vapor pressure of the fluid must be taken into account, or the fluid could be vaporizing in the containment shell before the alarm setpoint is reached, resulting in dry running bearings and less heat removal.

There are problems associated with these temperature measurements. When a pump condition results in heat generation that is not removed by fluid circulation, the heat generated must be conducted to the thermocouple/RTD. The time required to conduct the heat varies for many reasons. The main reason is thermodynamics. The heat generated must be conducted to the point where the measurement is being taken, and there is a finite time required to conduct the heat. Another, more serious reason, is dry running. The heat transfer medium is normally liquid. During dry running, the heat transfer medium is vapor. The heat transfer time increases when the heat transfer fluid is vapor as opposed to liquid. An extreme case occurs during dry running when magnet temperatures can reach 750°F before the temperature at the thermocouple/RTD on the containment shell reaches 40°F. Therefore, the slow response time of the pump protection/shutdown system normally results in a damaged pump.

Pump condition can be monitored indirectly by monitoring the containment shell temperature or fluid leaving the containment shell temperature. A trending increase in containment shell or fluid leaving the containment shell temperature, keeping all pumpage conditions the same, is a good indicator that something is wrong in the driven magnet/bearing section of the pump. The temperature can increase due to plugged internal lubrication ports, bearing damage, solids on the magnet, etc.

Temperature monitoring of the containment shell or fluid leaving the containment shell should not be the only means of pump protection/monitoring. The bulk of the heat is generated directly between the magnets; therefore, for an accurate and timely temperature measurement the temperature must be measured between the rotating magnets (Figure 4). The responsiveness of the containment shell temperature or fluid leaving the containment shell temperature measurement is not adequate for a pump protection system, especially if the pumpage is volatile.

Minimum flow protection is accomplished by installing a flowmeter normally in the discharge line of each pump. The minimum flow to protect against is either the thermal or the stable minimum flow, which ever is higher. Flow is a straight forward measurement; however, it can be taken for granted that it provides adequate protection when it really does not. A flow measurement is a good and reliable protection method, provided only one pump is operating in a two pump system. Suppose for instance, that a flowmeter is installed in a common discharge line downstream of a pair of pumps, primary and spare. Suppose that both the primary and spare pump are operating at the same time. The primary pump is stronger than the spare pump, e.g., due to a speed difference, turbine drive, impeller trim, pump blocked in, etc. The minimum-flow protection is satisfied. However, the weaker pump may have little or no flow forward, thus is not protected by minimum flow. Therefore, both pumps must be individually protected if minimum flow is the only means of shutdown protection provided.

Low suction vessel level protection is a means of protecting a pump from dry running. This form of protection is applied in many tank loading and off loading applications. It is necessary to have some form of protection to ensure the pump will not run dry or have inadequate NPSH. A low suction vessel level is a good and reliable means of pump protection. If a tank must be completely empty after an unload operation, then a mag drive pump would not be recommended for the service. However, a mag drive pump may be used to unload to a specified level, and the remainder of the product may be pressured out, e.g., rail car unloading. If the pump is allowed to cavitate because of low level, it will surely fail the thrust bearings and possibly the sleeve bearings.

Power monitors are the most widely accepted method of monitoring a mag drive pump for shutdown protection. The power monitor can only be applied to pumps driven by electric motors. Power monitors provide the broadest range of protection of any of the above monitoring methods. A power monitor can protect against low flow, high flow, magnetic decouple, and dry running, which all lead to mechanical damage. Power monitors also provide startup bypass capability when specified. The power monitor measures the power consumed by the motor and, therefore, responds quickly to changes in load. Changes in process conditions and how they affect the pumps power usage can also be monitored, trended, and used as a predictive maintenance tool.

Periodic vibration monitoring has been used to monitor the pumps mechanical condition. However, the sleeve bearings run so smoothly, typically less than 0.1 in/sec overall, that periodic vibration monitoring has, for the most part, been unsuccessful in predicting sleeve bearing failures. Periodic vibration monitoring is very successful in predicting the failure of the drive magnets support bearings, normally roller or ball bearings. This monitoring is important to ensure the drive magnet does not contact the containment shell due to a support bearing failure.

Recommended Minimum Mag Drive Pump Protection

Minimum mag drive pump protection should include a temperature measurement of the containment shell or fluid leaving the containment shell and a power monitor. The power monitor, if set properly, can be used to protect against low flow, high flow, magnetic decouple, and dry running. The temperature measurement of the containment shell or fluid leaving the containment shell, if trended, can give some indication of the pump's driven magnet/bearing section internal condition.

MAG DRIVE PUMP FIELD EXPERIENCE

Plant personnel replaced 20 pumps containing ethylene oxide (EO) in various concentrations in February 1991. The decision was made to change the pumps to mag drive from single-sealed ANSI pumps, due to fugitive emissions concerns. The replacements were to be done during a unit shutdown. The entire installation, not just the pumps, is a key part of realizing reliable system operation.

The plant has had mag drive pumps running in EO service since 1986. Two pumps were installed in tank circulation service as a trial. This trial was used as justification to install mag drive pumps in EO service. Only one of the two trial pumps has failed to date. The failure was the result of starting the pump before gas was purged from the pump.

The replacement project could not begin until the unit was shut down. The pumps being installed are not standard ANSI dimensions, therefore, the existing pumps, motors, and bases had to be removed. The foundations had to be chipped down and new pump bases leveled and grouted to the existing pads. New spool pieces had to be fabricated for each pump's suction and discharge. Existing minimum-flow lines were removed, eliminating the dead leg of EO in the minimum-flow lines. Minimum-flow line removal necessitated the installation of minimum-flow protection.

Each pump was protected by at least two different pump shutdown protection methods. Each pump had two temperature shutdowns. The temperature measurements were the containment shell temperature and the fluid leaving the containment shell temperature (each referenced to suction fluid temperature). Each pump also had a minimum flow shutdown. A few pumps also had a low suction vessel level shutdown. The shutdown protection methods are described in more detail in the following discussion.

The pumping conditions for each pump are different during startup, operation, and shutdown. Several pumps are used to clear towers, transfer water from tower to tower ensuring proper tower levels for startup, and wash towers after a shutdown. The pumping conditions are different during any one of the above operations, not to mention normal unit operation. Not taking all these conditions into consideration, turns out to be a costly mistake.

Much time and effort was spent to correctly size, specify, purchase, and install the pumps. A concerted effort was made to train operations on the new mag drive pumps and the differences between the mag drive pumps and the ANSI pumps.

The pump installations went well; it was the startup that caused all the problems. The plant wrecked nine pumps on startup, and delayed the unit startup two weeks. During this two week commissioning phase, they learned many valuable lessons. Several failures encountered during and since startup are discussed in detail in the following section.

Improper Application

The first nine failures came during unit startup as two pumps were being used to flush the purification section of the unit. The pumps were running on water and transferring it from one tower to another. The pumps are 600 gpm pumps running at 3600 rpm. The pumps would operate fine until the tower level got low, but not as low as it would be during normal unit operation. Each time the level got low, the pump would cavitate and wreck. The pumps were rebuilt, and given particular attention on each successive restart. All the while, maintenance engineering was checking the pump specification sheets with the manufacturer. The manufacturer verified cavitation was a problem.

It was thought the pump had enough NPSH. The NPSH available was recalculated. The pumps had 13 ft of NPSH available. The pumps required 18 ft of NPSH. The original pump specification sheet, used to purchase the pumps, stated an available NPSH of 26 ft. It was now evident why the pumps cavitated and failed nine times.

After nine failures, and two weeks delayed startup, the decision was made to put the old ANSI pumps with single seals back in service.

The NPSH problem was traced to the project. After the new mag drive pumps were approved for the project,by maintenance engineering, the project engineer decided that a good cost-saving measure would be to reduce the size and cost of these two pumps by changing the speed from 1750 rpm to 3600 rpm. The 1750 rpm pump required 9.0 ft of NPSH, and probably would have worked fine. The 26 ft of available NPSH must have been an error transposed from a calculation sheet, because no one was ever able to recreate that number.

Motor Rotation

The pump startup procedure required the pump to be bump started, on off. During the bump, Operations was to look for increasing discharge pressure. If the discharge pressure did not increase, the pump should not be started, and the operator should look for valve lineup problems, check tower levels, etc. If discharge pressure does build, then start the pump.

In this case, the discharge pressure did build, and the pump was started. The pump ran well for about 10 sec. The discharge pressure was not as high as it should have been, and the pump started making noise. The pump was shut down, and tower level and valve lineup was verified. The motor rotation was checked, and it was running backwards.

The pump was pulled and disassembled. The thrust bearing was found chipped but not destroyed. The radial sleeve bearing looked as though it had exploded, splitting from the inside diameter (Figure 7) and seizing in the journal bearings. The radial shaft support, after the sleeve bearing split, was provided by the shaft rotating within the sleeves. The remaining pumps were uncoupled and motor rotation was checked, again. Two more pumps were found to have incorrect motor rotation.

Pump Shutdown System Testing

The pump shutdown system incorporated on most of the mag drive pumps included two temperature shutdowns and a low flow shutdown. The temperature shutdown system included two differential temperature measurements. First, a differential temperature of the containment shell was measured with a contacting thermocouple, referenced to the suction fluid temperature. The second measurement was a differential temperature of the fluid leaving the containment shell measured with a thermocouple inside a ther-

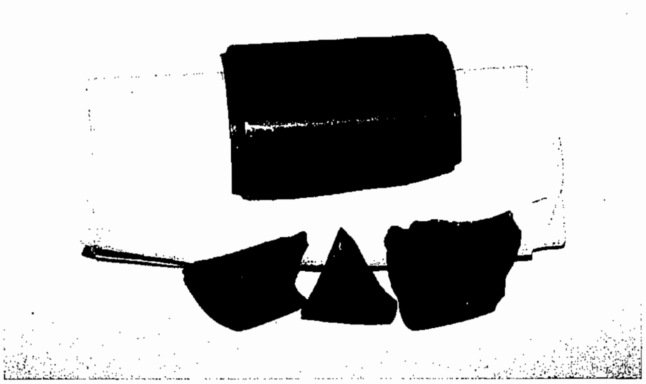

Figure 7. Sleeve Bearing Failure.

mowell in the pump, referenced to the pump suction temperature. Either of the two temperature measurements or the flow measurement can shut down the pump.

Operations, without maintenance engineering involvement, decided to test the temperature shutdown system. Operations started the pump, on water, and blocked the discharge, which should never be done for any length of time. During a normal pump startup the shutdown system must be bypassed for a few seconds to allow the minimum flow shutdown to be satisfied. Therefore, the start switch is a shutdown system bypass switch, when depressed. The operator had to hold the start switch to keep the pump running. The temperature alarm never sounded. The pump casing reached temperatures in excess of 200°F. The operators allowed the pump to shut down and contacted maintenance engineering. As a precaution, the pump was pulled and disassembled for inspection. As it turned out, this test was an excellent way to verify the design of the differential temperature shut down system.

The differential temperature measurement will give a direct measure of the heat input to the fluid circulating in the driven magnet/bearing section. The problem was the location of the suction temperature reference thermowell. The thermowells were located in the suction spool piece, inches from the pumps suction flange. As the pumpage temperature increased, with no flow, the heat migrated through the fluid up the suction line. Heat migration coupled with the thermowell location kept the differential temperature in an acceptable operating range. The problem was solved by moving the suction temperature thermowells several feet upstream of the pump suction. The new thermowell location prevented the suction fluid temperature measurement from being affected by heat generated in the pump.

This test can also be used as an argument for a shutdown based on absolute temperature of the containment shell. The shutdown setpoint could be chosen based on the autoignition or decomposition temperature of the fluid stream. An absolute temperature shutdown could serve as a last resort pump shutdown in the event other shutdown systems failed.

Flowmeter Installation

Flowmeters were installed to provide minimum flow protection for each pump. The flowmeter was placed between the pump discharge flange and the discharge block valve. A target type (drag force) flowmeter was installed on each pump. In theory, the installation made good sense, each pump has its own minimum flow protection. However, the flowmeter was extremely inaccurate, due to the location of the target type flowmeter. The flow turbulence in the discharge piping was such that the flowmeters did not read flow accurately or consistently.

The flowmeter must be relocated so a valid flow measurement can be obtained. The decision was made to use existing process flow measurement points. The existing points currently used for process flow measurement are of the orifice plate type. A tee was placed on each flange tap allowing the installation of additional dedicated flowmeters, one for each pump. The concern being, that if more than one pump is online at a time, the flowmeter will not provide protection for both pumps since only one pump is required to satisfy the minimum flow requirements.

The minimum-flow shutdown flowmeters were sized such that the low flow shutdown would be about 70 percent of full span. This means the flowmeters, during normal pump operation, are running well above 100 percent span. There was some concern that the flowmeter may not work when required due to continued operation above 100 percent span. To date, this has not caused a problem. The flowmeters have been recalibrated after each shutdown and have never been more than 10 percent out of calibration.

Minimum flow pump protection arrangements similar to the above are not adequate if more than one pump is allowed to operate at the same time in the same system. Currently, a project is under way to remove all flowmeters and replace them with power monitors. A power monitor, if properly set, can provide the same minimum flow protection as a flowmeter. Some means of ensuring the required minimum flow is recommended with the installation of mag drive pumps.

Shutdown System Vs Pump Failure

A pump shutdown on minimum flow due to a tower dump valve malfunction. The dump valve on a tower base drain opened, which was also the pump suction line, starving the pump for suction. The pump shutdown on minimum flow immediately. Operations discovered and repaired the malfunctioned valve and tried to restart the pump. During the restart, noise was noticed and maintenance engineering was notified.

The outboard, drive end, thrust bearing was found to be destroyed, Figure 8, and the sleeve bearings chipped and scored. The failure of the outboard thrust bearing is indicative of a failure caused by cavitation. The onset of cavitation results in the sleeve bearings essentially running dry causing chipping and scoring of the sleeve and journal bearings. During cavitation, the thrust balance of the impeller is disturbed resulting in thrust reversals of the rotor. The impacting caused by thrust reversals tend to crack the silicon carbide thrust bearings. Once the bearing is cracked, the failure proceeds rapidly due to silicon carbide particles in the lubrication fluid (Figures 9 and 10). If the particles can be flushed from the damaged bearing quickly, bearing damage can be minimized.

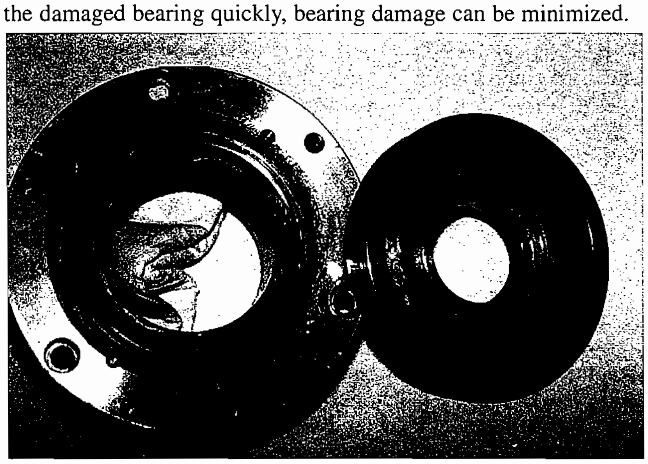

Figure 8. Thrust Bearing Failure.

The shutdown system immediately shut the pump down on loss of flow. However, the thrust reversals damaged the bearings almost immediately. During each case of documented cavitation, the thrust bearings have been chipped and sometimes catastrophically failed.

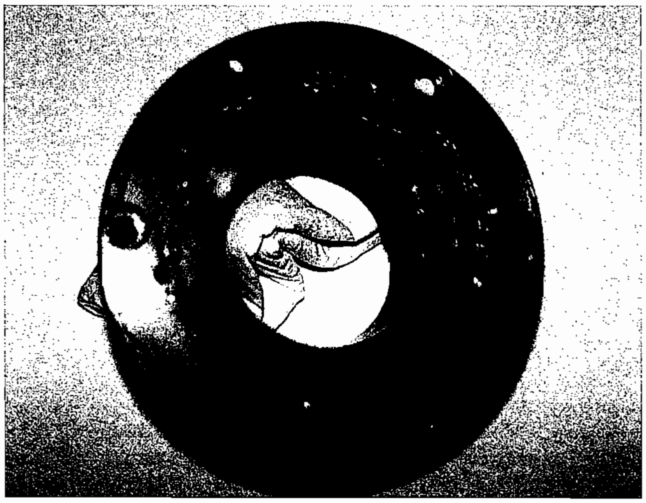

Figure 9. Thrust Bearing Failure.

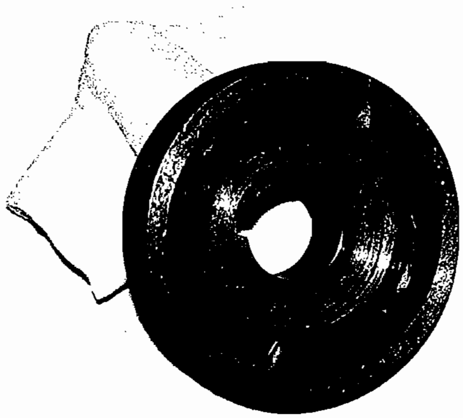

Figure 10. Severe Silicon Carbide Particle Damage.

The pumps will continue to operate with failed bearings with little or no increase in overall vibration amplitude. Pumps have been removed from service where metal to metal contact was the thrust bearing. Sleeve bearings have been completely split with the shaft rotating within the sleeve. The major concern with this situation is the silicon carbide chips must pass between the driven magnet and the containment shell before exiting the pumps driven magnet/bearing section. The silicon carbide chips can do severe damage to the containment shell (Figure 11). The plant has not breached a containment shell due to silicon carbide chips, but several containment shells have been replaced after silicon carbide chip damage.

Magnetic Particle Erosion

Magnetic particle erosion is the result of having ferrous/magnetic particles in the pumpage. These magnetic particles make their way back through the lubrication ports to the driven magnet/bearing section of the pump. The small magnetic particles eventually have to pass between the driven magnet rotor and containment shell. As the particle passes over the driven magnet it is attracted to the driven magnet, and it adheres to the driven magnet. Fluid passing between the driven magnet and containment shell pushes the particle to one end of the magnets and rotation forces the particle to the trailing edge of the magnets. The net result is a buildup of ferrous

Figure 11. Silicon Carbide Particle Damage to the Containment Shell.

particles at one corner of each individual magnet in the driven magnet rotor. These particles flutter during pump operation and eventually erode a hole in the driven magnet rotor (Figures 12, 13 and 14), and groove the containment shell (Figure 15).

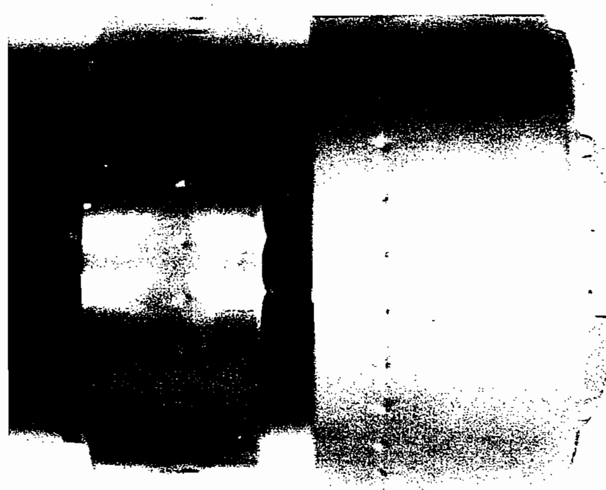

Figure 12. Magnetic Particle Erosion Damage (Magnified 4×)

Figure 13. Magnetic Particle Erosion Damage (Magnified 4x).

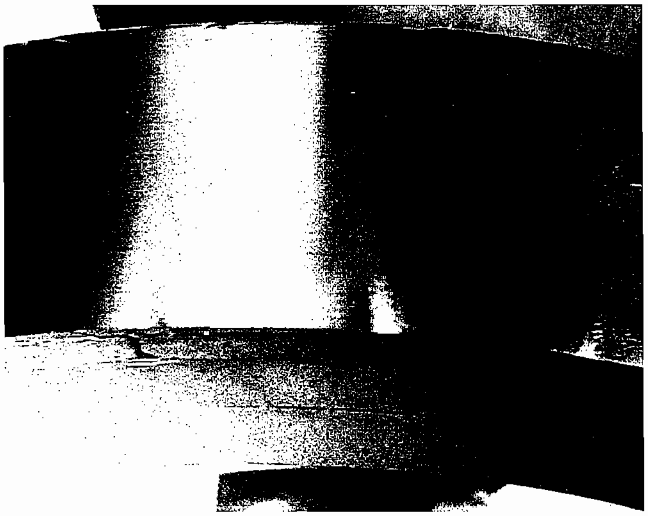

Figure 14. Driven Magnet Magnetic Particle Erosion Damage Cross Section (Magnified 2x).

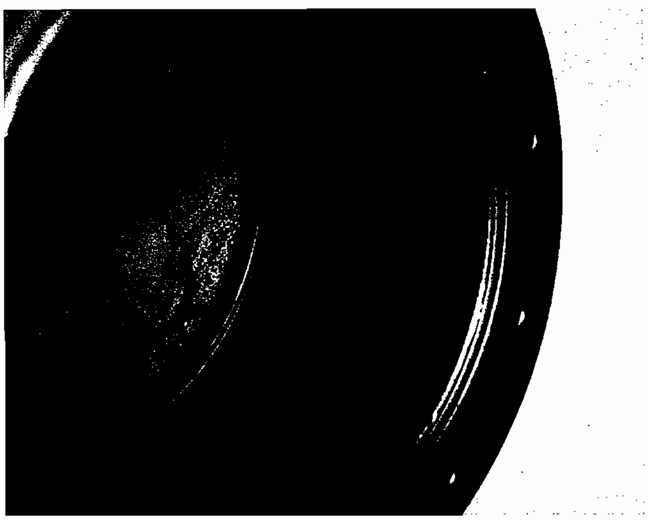

Figure 15. Magnetic Particle Erosion of the Containment Shell.

Magnetic particle erosion cannot be detected directly by temperature, low flow, power, etc. The failure is internal erosion. If the situation goes undetected, the ultimate failure could be the breach of the containment shell.

During a recent unit shutdown, three mag drive pumps were pulled for inspection. Of the three pumps, two required replacement of the driven magnet rotor and one required replacement of the containment shell. Holes eroded in the driven magnet shroud ranged from 0.002 in deep to 0.06 in deep, exposing the magnet.

When the magnetic particle buildup on the driven magnet becomes excessive, the containment shell can also be eroded. The containment shell, of the driven magnet that was eroded 0.06 in deep, was also grooved 0.015 in deep (Figure 15).

A magnetic filter arrangement can be incorporated to filter only the fluid that passes through the driven magnet/bearing section. Magnetic particle erosion has been experienced in three different manufacture's pumps. If the pump system has ferrous materials of construction, then the possibility exists for magnetic-particle erosion.

Preventative Maintenance Inspection

Twelve pumps were pulled for inspection after four years of installation, translating into about two years of actual operation of each pump in spared service. Operations switches the pumps after one week of operation to ensure the spare pump is viable. Eight of the 12 pumps had not been worked on in the four years since installation.

Of the 12 pumps pulled for inspection, only four pumps had problems that needed correcting. Three of the four required the replacement of the outboard thrust bearing. A thrust bearing failure is normally the result of cavitation, loss of suction, or vapor in the suction line on startup. One pump required the replacement of the containment shell due to magnetic particle erosion.

The remaining eight pumps were inspected thoroughly and assembled using all the parts that were removed. The silicon carbide bearings showed some signs of dry running, probably from startup. However, the dimensions of the bearings had not changed due to wear. Because of this inspection a new inspection interval has been set, with more frequent inspection for those pumps where magnetic particle erosion is a concern.

When designed and installed properly, the reliability of the mag drive pumps have proven to be much greater than the single-sealed ANSI pumps removed from service. In four years of operation, only eight pump repair jobs have been required. Not one of the eight repair jobs has been the result of a pump failure but rather the operating environment failing the pump. There have been no fugitive emissions reported as a result of the mag drive pumps since installation.

CONCLUSIONS

Mag drive pumps definitely have a place in the petrochemical industry in the future. Each potential user should thoroughly investigate the pump design and the application before applying a mag drive pump. This presentation was not intended to discourage the use of mag drive pumps, rather to encourage the thorough design considerations necessary to ensure a reliable installation. In the four years of operation in the author's company, every mag drive pump failure has been the fault of some system design or operation upset. The mag drive pumps, when operated properly, have been very reliable. The conclusions below detail a list of considerations for reliable pump system installation, operation, and troubleshooting.

- Mag drive pumps are different than the standard ANSI pump and can cause more problems than they were intended to solve.
- A close examination of all operating conditions (e.g., unit startup, normal operation, unit shutdown) should be a minimum requirement for installation.
- Protect the pump by providing both a temperature sensor of the fluid leaving the containment shell and a power monitor. These two monitors should provide adequate pump protection and indication of pump condition.
- Maintenance engineering should be heavily involved in the specification, selection, installation, and commissioning of mag drive pumps. Maintenance engineering should also assist in the training of operations before startup of a new mag drive pump application.
- Maintenance engineering should verify the final pump selection as stated on the purchase order.
- Coat the inside of the roller/ball bearing/drive magnet section of the pump with an oil resistant paint to prevent rust formation.
- Motor rotation must be correct. Motor rotation must be verified before coupling the pump and motor. Reverse rotation of a mag drive pump will almost certainly result in a driven magnet/bearing section failure.

• The suction temperature thermowell location should be far enough upstream that heat generated by the pump does not affect the temperature measurement.

• Investigate thoroughly the minimum flow protection design before installation. Proper system design, before installation, will save time and money.

• The shutdown system may not protect a pump from failure. Therefore, if the shutdown system is activated and shuts down a mag drive pump, the potential for damage should be assessed before the pumps is allowed to continue operation.

• Periodic inspection of mag drive pumps for magnetic particle erosion is necessary if ferrous materials of construction are used anywhere in the pump system.

• Periodic vibration monitoring is recommended to possibly predict and avoid catastrophic roller/ball bearing failures.

REFERENCE

1. "Mag-Safe®, Multi-Monitoring on Sealless Magnetic Driven Pumps," Dickow Pumpen KG, pp. 1-4 (1994).