Centrifugal Pump Optimization for Maintenance, Reliability and Operations

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Key objectives:

- Design considerations – inertia bases, variable speed pumping, selecting pumps for BEP and future growth.
- Installation practices – foundation preparation, shaft alignment, and softfoot correction.
- Startup and operation procedures – startup checklists, motor solo's, baseline vibration analysis.
- Troubleshooting – vibration analysis, bearing temperatures.

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Joiner holds a bachelor of science in mechanical engineering from Louisiana Tech University and an master of science in mechanical engineering from Southern Methodist University. He joined Texas Instruments in 1987 and since 1992, has worked in the Worldwide Facilities Group supporting the operation of the DMOS 4 and 5 wafer fabs as well as the design, construction and startup of new wafer fabs around the world. Joiner is responsible for the design and specification of deionized water, wastewater and mechanical systems for sustaining and new wafer fab construction activities. He was elected Member, Group Technical Staff in 1995, ASME Young Engineer of the Year in 1997 and Senior Member, Technical Staff in 1998. He is a registered professional engineer in the State of Texas.

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Prince joined Texas Instruments in 1982 as a journeyman electrician. In 1995, he was assigned to the newly formed Reliability Based Maintenance (RBM) Program after completing a two year millwright training program at Texas Utilities (TU) Electric. Since 1996, he has been wholly responsible for the RBM programs at the DMOS 4, 5 and 6 wafer fabs which includes over 300 pieces of critical rotating equipment supporting over two million square feet of space. His responsibilities include equipment setup, startup and vibration analysis as well as integrating TI's CMMS program (MAXIMO) into these wafer fabs. He is certified as a level 1 vibration analyst.

In May 1930, Texas Instruments Incorporated (TI) was founded as "Geophysical Service," using seismology to find oil. Today, TI is a global semiconductor company and the world's leading designer and supplier of Digital Signal Processing Solutions, the engines driving the digitization of electronics. Headquartered in Dallas, Texas, the company's businesses also include materials and controls, educational productivity solutions, and digital imaging. The company has manufacturing or sales operations in more than 25 countries. TI is well known for its milestone inventions including the first commercial silicon transistors, the first integrated circuit, the first microprocessor, and the first electronic hand-held calculator.

Centrifugal Pump Optimization
Using Technology to Improve Maintenance, Reliability and Operations of Centrifugal Pumps at
Texas Instruments, Incorporated

Provided by

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Introduction

Centrifugal pump reliability is of critical importance to the daily operations of semiconductor manufacturing at Texas Instruments, (TI) Incorporated. Continuous and reliable operation of utility systems utilizing these types of pumps such as process cooling water, chilled and hot water, de-ionized water and industrial waste water systems is essential to provide the manufacturing areas with 100% uptime, 24 hours a day, 7 days a week, 365 days a year. Our facilities support teams which are tasked with building, operating and maintaining these utility systems, frequently compare our responsibility as analogous to performing maintenance and other tasks on a 747 while in mid-flight. Our partners in the semiconductor manufacturing areas require this level of dedication and support, as this industry is highly competitive. Any lost manufacturing time due to an interruption in any one of the 75+ utility systems in each wafer fab equates directly to lost product and more importantly, to lost revenue. Therefore, our staff has adopted very rigorous design specifications, maintenance practices and operations strategies to help us keep our utility systems and ultimately, our manufacturing areas running 100% of the time.

Company Background

Texas Instruments, Incorporated is a global semiconductor company and the world's leading designer and supplier of digital signal processing and analog technologies, the engines driving the digitization of electronics. Headquartered in Dallas, Texas, the company's businesses also include materials and controls, eductational and productivity solutions and digital imaging. The company has manufacturing or sales operations in more than 25 countries. As shown below, figures 1 and 2 provide more information about TI.

Texas Instruments is traded on the New York Stock Exchange under the symbol TXN. More information is located on the World Wide Web at http://www.ti.com.

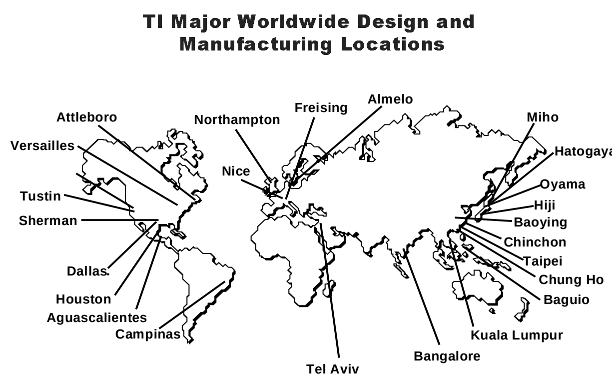
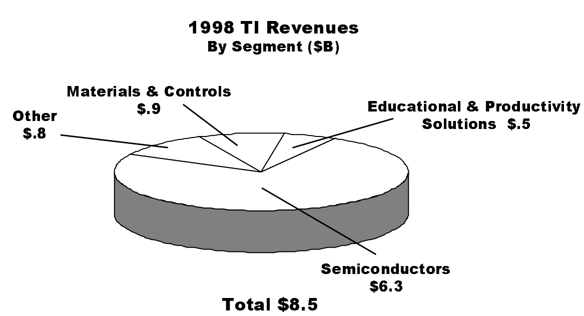


Figure 1 (above) and 2 (below)



Objectives of This Presentation

This paper will discuss the methods and practices utilized at TI's Dallas, Texas facilities to design, select, operate and troubleshoot centrifugal pumping equipment in various applications. Specifically, design considerations such as inertia bases, baseplate selection, piping connections, materials of construction, selecting pumps for parallel pumping utilizing variable speed drives as well as other design factors are critical to the successful installation and operation of equipment. Installation practices such as foundation preparation, inertia base and baseplate setup, shaft alignment, softfoot correction and many other parameters executed by qualified craftsmen ensure longterm reliable operations. And finally, established startup and maintenance practices ensure proper rotation and lubrication requirements are satisfied, as well as provide the template for recording motor solo measurements, vibration data, bearing temperatures, flow, pressures, current and speed for future reference and troubleshooting when necessary. Collectively, these practices provide the backbone of our maintenance programs and ensure the successful and reliable operation of our centrifugal pumping equipment.

Design Practices

Proper design is the basis for all other maintenance and operations strategies to work effectively. Individual areas where design considerations should be comprehended will be discussed in detail.

Pump and Motor Selection

Properly selecting a pump and motor is of utmost importance to meet design requirements. However, not only is capacity and pressure of concern, other parameters such as motor horsepower, efficiency, single or parallel operation, shutoff head and variable speed operation are among the other important points to consider. We typically try to select a pump primarily based on speed and efficiency. The reliability team prefers lower speed equipment such as 1180 and 1750-rpm equipment. However, slower pump speed forces larger equipment, which can be an issue in a cramped mechanical room. Efficiency is also a concern, as we want to minimize pumping horsepower for the given requirements. For fixed speed pumps, we typically select pumps with the operating condition at or near the best efficiency point (BEP) on the pump curve. For variable speed (VFD) operation, pump selection is typically made with the operating point located just right of the best efficiency point. This provides for very efficient operation throughout the expected operating range of the pump. In most cases, the efficiency curve at variable speed allows the efficiency to improve as the pump speed is reduced. Figure 3 shows a typical pump curve.

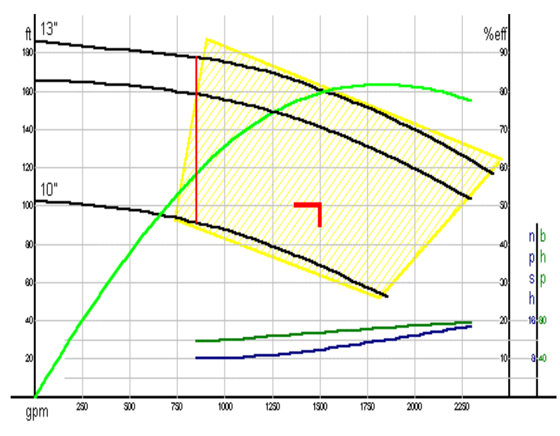


Figure 3

Parallel pumping is another design consideration of extreme importance. Quite often, we select a pump for an application and then purchase and install two. This allows the system to continue to operate while the primary pump is offline for maintenance. This arrangement is known as "N+1", i.e., we need "N" pumps to run the system but install "+1", or a backup, for maintenance purposes. We also have situations when 2 or 3+1 pumps are required. Selecting pumps for parallel operation is important to ensure the pumps are operating within reasonably close conditions. Flat pump curves, or having too many pumps running, can easily deadhead one of the parallel pumps if it is turning slightly slower than a parallel pump. See Figure 4 below.

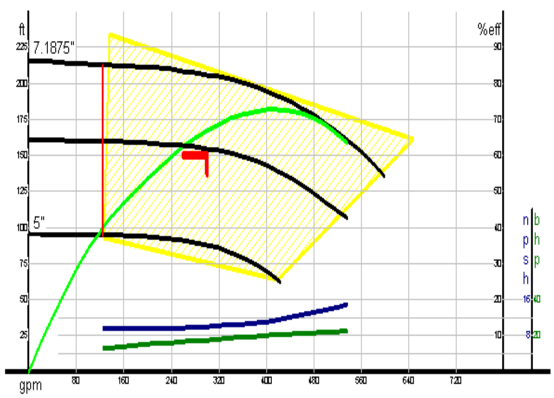


Figure 4

We have experienced parallel pump operation using VFD's and seen two of the three pumps running at 6-8% higher speeds. Motor amperage was another sign of an unbalanced load as the slower pump was drawing 10-12 amps less than the other pumps.

The important point here is to select a pump not only for the capacity requirements, but also considering efficiency, speed and whether or not the pump will be operated in a parallel configuration. Other considerations include the style of pump and the materials of construction. The style of pump is dependent on a number of operating conditions. High purity fluids such as de-ionized water typically call for high purity materials such as 316SS. The ANSI style, horizontal, end suction pumps fit this requirement nicely. Heating and cooling applications are satisfied most commonly with high quality horizontal split case pumps. Specialty applications including industrial waste water pumping require a thorough understanding of the chemistries involved to select the proper pump materials. Manufacturer's recommendations should be considered and adhered to for high purity or wastewater applications.

A brief word on motors should be mentioned here as well. We have standardized on premium efficiency (>95%) motors for all of our rotating equipment applications. We also only utilize open drip proof (ODP) motors unless operating conditions in wet areas such as in cooling tower applications require totally enclosed fan cooled (TEFC) motors.

Foundations

Centrifugal pump foundations must be designed to support the pump and motor. The mass of the foundation should be from 2 to 3 times the mass of the pump, driver, and baseplate. There are basically two types of foundations utilized at TI; housekeeping pads and spring mounted inertia bases.

Housekeeping Pads

TI typically installs four to six (4-6) inch high concrete pads for equipment mounting regardless of whether or not inertia bases are utilized. These pads provide us with the ability to easily clean around equipment and reduce water damage to equipment in the event of a leak or spill. Before pouring a housekeeping pad, the concrete slab on which the pad will sit must have all coatings removed and be roughed up to allow good adhesion of the new concrete. The pad should also be doweled into existing slab and be reinforced with rebar. A properly engineered foundation is essential for long term reliability of rotating equipment.

Inertia Bases

We have been very successful trying to minimize the usage of inertia bases when possible. Our preferred method of mounting any type of rotating equipment is directly on the housekeeping pad. However, in vibration sensitive areas, such as in areas located adjacent to or above or below the semiconductor manufacturing areas, we take baseline vibration data to determine the level of vibration. This data then guides us to determine whether or not we will utilize inertia bases. Other considerations regarding the use of inertia bases include the size and type of pumps or other rotating equipment planned for the area. If we elect to utilize inertia bases, the mass of the inertia base should be from 2 to 3 times the mass of the pump and driver. Inertia base depth should be equal to $1/12^{th}$ the longest dimension of the base, with a minimum of 6" thick, but not necessary to be more than 12" thick unless specifically required. In the past, we have had problems with undersized inertia bases bending and flexing when placed in service. This was primarily due to the insufficient depth of the base. Furthermore, each pump and motor should be mounted on its own individual inertia base. Do not mount multiple pumps on a single inertia base as this again, virtually eliminates the ability to gather accurate vibration readings due to the vibration from the adjacent pumps. Finally, the thrust of vertical discharge end suction pumps should be considered when making spring selections for inertia bases. This style of pump will induce a vertical force on the inertia base, which must be comprehended in the spring selection. Improperly sized springs in this type of pump application will allow the thrust force to cause an unleveled situation at the inertia base. This condition causes unnecessary pipe strain and again, degrades pump alignment.

Baseplate Selection

There are many different types of baseplates in use at TI. Stamped steel, fabricated steel, cast iron, and a polymer concrete mix (polycrete) to name a few. The stamped steel types are very flexible and not worth discussing. Most of the fabricated steel baseplates can be of good quality. These are best described as heavy plate steel with added structural supports for rigidity. This type of base also has machined coplanar mounting surfaces for the pump and motor. Machined surfaces are supposed to be coplanar to within .002 in/foot. In the past we have had some problems trying to level this type of base. You must be careful not to twist this type of base during leveling. The cast iron baseplates are very rigid which helps to resist twisting during leveling and they also come with 0.002 in/ft machined coplanar mounting surfaces. The polycrete baseplate is the type with which we have had the most success. This type of baseplate is made of a solid cast polymer construction that makes it extremely strong and rigid which greatly reduces the chances of flexing. Because this type of base is not machined, you don't get the 0.002 in/ft spec on the coplanar surfaces. These bases typically run around 0.015 in/ft from the factory. We then send these bases out to be ground to within 0.002 in/ft. This type of base is very easy to install. Because it is a solid slab construction, the chance of voids in the grouting and negative impact from voids are virtually non existent.

Installation Practices

A fair amount of detail will be presented on pump installation, as we believe this to be a very important area in the lifecycle of the pump.

Foundation Preparation

Whether utilizing a spring mounted inertia base or installing equipment on a housekeeping pad, the surface beneath the pump and driver baseplate must be properly prepared for grouting. This means chipping the concrete to remove laitance and exposing the aggregate for the grout to adhere to. All dirt and dust must be removed from the working area to ensure proper adhesion.

Baseplate Installation

A properly installed pump baseplate is essential to pump reliability, longevity, and maintainability. When properly installed and grouted, the baseplate is solidly bonded to the foundation, essentially becoming a single monolithic foundation providing a rigid, stable support for the pump and motor. This lowers the natural frequency of the pump baseplate and reduces resonant vibrations, which are damaging to bearings and mechanical seals. The stability and rigidity of the baseplate installation ensure that accurate shaft alignments are attainable and repeatable.

If installing the baseplate on an inertia base, the inertia base needs to be set in the approximate location and up on steel blocks to approximately the same elevation that your springs will be and then roughly leveled. The surface of the inertia base beneath the baseplate must be properly prepared for grouting as discussed previously. Anchor bolts must be protected from the grout so that they will be free to stretch when the baseplate is torqued down.

If using a cast iron or fabricated steel baseplate, make sure the underside where grout will be in contact with is clean and free of debris. Sandblasting is recommended. Again, you want good adhesion from the foundation to the grout to the baseplate. The polymer base and epoxy grouts make a great combination. Also, if using a cast or fabricated steel bases you must drill vent holes anywhere that air might get trapped when grouting. Any air trapped between the grout and baseplate will be a void and can cause a multitude of problems. This is one of the advantages of the polymer base; you don't have to worry about voids.

Once the foundation is prepped and anchor bolts protected, its time to lower the baseplate down into place and begin the leveling process. We try to leave about 2 inches between the foundation and bottom of the baseplate for grout. There are several methods used to level and support baseplates before grouting. These can include wedges, shims and jackscrews. Whatever method is used, provisions should be made for removal after grouting. The intent is to have the baseplate solely supported by the grout. Before starting the leveling procedure, we thoroughly clean the machined surfaces of the baseplate, removing all paint and debris. Using a machinist's level on the machined surfaces of the baseplate, level all surfaces to within 0.002 in/ft, in two directions, 90 degrees apart by raising or lowering each corner of the baseplate. During this process you want to maintain slight tension on the anchor bolts and also maintain the 2-inch clearance between the bottom of the baseplate and foundation. On the polycrete bases we use a piece of ground flat stock and a machinist's level for leveling. Sometimes it is not possible to have the pump mounting surfaces and the motor mounting surfaces level in relation to each other or coplanar, because of baseplate manufacturing methods. When this problem occurs we try to split the difference between the pump and motor mounting surfaces so that neither piece of equipment has too great an angle between its feet and mounting surface (wedge foot). Once level is achieved, pump and motor should be set on the baseplate and a preliminary alignment performed. The intent is to ensure a bolt-bound condition at the motor or pump is avoided. Upon completion of the preliminary alignment, we usually remove the pump and motor from the baseplate before grouting in order to verify the baseplate is still level.

Grouting

"Precision Grouting" is probably the most critical part of the equipment installation; almost everything done to this point has been done in preparation for grouting. Mistakes made during grouting can be very costly down the road. If you are looking to cut corners or reduce costs, do it somewhere else. There are multitudes of different specifications for grouting, many of which can be very intricate and extensive. We contract our grouting services to a few experienced and very thorough suppliers. These suppliers have built positive reputations by performing the job right the first time.

Remember that good surface preparation is essential. If using cement based grouts, the concrete foundation (that was chipped and cleaned) needs to be saturated with water 24 hours prior to pouring the grout. This will keep the concrete from drawing the moisture from the grout during curing. Immediately prior to pouring the grout, removing any excess water is required. When using epoxy based grouts, the foundation must be clean and dry. Be sure to protect anchor bolts and coat jackscrews with something to allow them to be removed after the grout has cured. And be sure to have vent holes drilled in the baseplate to avoid air pockets in the grout. Once the grout has been poured, the curing period often induces shrinkage, which can create voids. If your grout pour is greater than 4 to 6 inches, you may have to make separate pours or add an aggregate to your grout. When pouring, you want to make one continuous pour to avoid trapping air in the grout and never use a vibrator to aid in grout movement. After grout has cured for the recommended amount of time, the jackscrews may be removed and the anchor bolts torqued. If using any baseplate other than a solid polycrete base, now is the time to check for voids. Using a small hammer, lightly tap around on the baseplate listening for a ringing tone. If there are no voids and there is full contact between baseplate and grout, the sound of the hammer tapping the baseplate will be a dull thud. If there are voids present, they will need to be filled with epoxy. Be careful not to pressurize the void with the epoxy, as this can distort the baseplate.

Pump & Motor Installation

At this point, a very solid, level baseplate for mounting the pump and motor should be in place. Before setting the pump or motor, clean all the machined surfaces on the baseplate, pump and motor. Running a file across each surface will ensure there are no burrs and that each surface is flat. After cleaning, lightly coat each surface with blue layout fluid to help prevent rusting. Place the pump on the base first and make sure all mounting bolts are centered in the holes. This will assure flexibility during the shaft alignment should we encounter a bolt-bound condition with the motor, as the pump will be able to move either direction to compensate. Tighten the pump mounting bolts then place a machinist's level on the shaft to check the level of the pump. If the pump shaft is not level, shim the pump feet to bring the shaft to within 0.002 in/ft of level. Once the pump shaft is level, check for a softfoot condition at each of the pump feet. Softfoot is the condition where one or more machine feet are not resting properly on the foundation but are being held down by force with the foot bolts. See Figure 5 below.

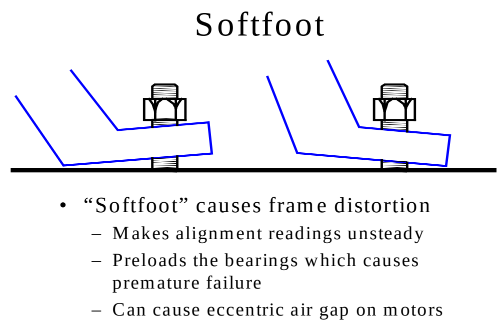


Figure 5

The method we use is to set up a dial indicator from the baseplate to the drive end of the pump shaft, in the vertical, out on the tip of the shaft. Loosen and tighten one foot at a time and record total dial indicator readings at each foot. Any deflection of the shaft greater than 0.002 in/ft must be corrected. Our specification for softfoot is less than 0.002, but we usually try to get less than 0.001 inches.

Next, impeller clearances on end suction pumps must be checked. Quite often, the pump impeller has spun off the shaft during shipment or is lodged against the pump housing. We have had several pumps damaged in the last few years because the impeller was resting against the casing at startup. Follow the manufacturer's recommendations for clearances and procedures. Also, be aware of the type of mechanical seal you have, and how to set the impeller clearance without damaging the seal.

Place the motor on the baseplate and make sure the mounting bolts are centered in the holes. Using a straight edge, perform a rough shaft alignment just to get you in the ballpark. When shimming the motor, it is best to use a good quality, precut stainless steel shim, but steel plates ground flat on both sides can be used for differences greater than 0.25 inches. Also, never use more than five shims under any foot.

For shaft alignments and softfoot corrections, we use a laser shaft alignment system, which reduces the time required to perform alignments, and also allows us to attain much tighter tolerances on our shaft alignments. First pass alignment using the laser system will usually have us within 0.005 inches. A close alignment is required before performing softfoot corrections because shim changes will affect the softfoot. Checking for softfoot on the motor is the same as it was on the pump, unless you are using a laser. Various misalignment conditions are shown in Figure 6.

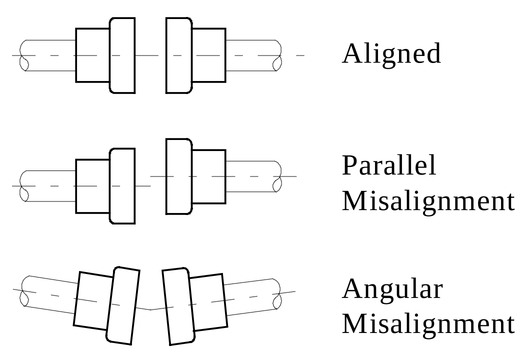


Figure 6

Once a softfoot condition has been corrected, we can proceed with the final alignment. Our alignment spec requires both angular and parallel misalignment to not exceed 0.002 inches for equipment rotating at 3,600 rpm or less. Utilizing the laser, its very easy to obtain a much tighter alignment than specified, we usually align to within 0.0005 inches of our target.

The alignment targets due to thermal expansion are where we have the greatest potential for error. A general rule of thumb is for every inch of shaft diameter, set the motor 0.001 inches high. However, this rule of thumb does not work too well when comparing the thermal expansion of a 42 degree chill water pump to a 180 degree hot water pump. Trial and error often becomes the strategy in this case. More sophisticated alignment equipment exists which can measure actual machine movement due to thermal and dynamic changes. This is something to consider on very expensive or critical equipment, but not cost effective for your average pump installation.

Once the final alignment has been completed we set the coupling gap to the manufacturer's specification, but we don't couple the pump to the motor yet. At this point we check and record the runout on the pump shaft, motor shaft, pump coupling, and motor coupling to ensure there is nothing bent or bored off center. Our specification for runout is less than 0.002 inches.

For pumps installed on spring mounted inertia bases, this is the point where the inertia base is inched into its exact location and floated on the springs. Once the base is resting on the springs it can be brought back into level. Place a machinists level on the pump shaft and level to within .002 in/ft.

Finally, don't forget to lubricate the bearings. On grease lubricated bearings we go ahead and purge the bearings with our brand /grade of grease prior to startup and operation.

Piping Installation

The most important rule of piping is to avoid pipe strain on the pump.

We utilize concentric and eccentric reducers, as well as piping isolators at the suction nd discharge flanges of the pump. Piping isolators have dimensional restrictions so the installation instructions must be followed. Most isolators come with axial restraint bolts to prevent them from over extending. But more often than not, the plumbers install them at their maximum extension, with the restraint bolts tight, defeating the isolation. After the isolators, a check valve is installed in the discharge line and a strainer in the suction line and finally, isolation valves are provided at each end. We use adjustable supports for the reducers that are attached to the pump flanges. These support the reducer right at the pump to eliminate any pipe strain, and they work especially well on the horizontal split case pumps mounted on inertia bases. With the reducers properly supported, the piping properly supported, and a piping isolator properly installed, we can achieve zero pipe strain, and our pump and piping are isolated from each other. This is very important in parallel pumping installations because without proper isolation, damaging vibration can be transmitted from one pump to the other.

Another piping consideration is to avoid piping at right angles into or out of a header or manifold flow. The vibration resulting from the turbulence can cause unnecessary damage to the pump. When several pumps are operating in parallel on VFD's, the right angle discharge into the common header can be a contributing factor to one of the pumps operating in a dead head condition. This is where one of the pumps does not lift its check valve and therefore cannot move fluid. This can double or triple the vibration on that pump and lead to premature failure.

Pipe Strain

Once the piping is complete, we double check for pipe strain. Using two dial indicators, one in the vertical position and one in the horizontal position, read from the motor coupling across to the pump coupling. Zero the dial indicators and begin to tighten the bolts on one of the flanges, only tightening one flange at a time. After the flange bolts are torqued, check the dial indicators to see if the pump has been distorted. We require less than 0.002 inches of movement when the piping is connected or disconnected. Record indicator readings. Using the adjustable piping supports, rezero the dial indicators to remove the pipe strain. Repeat this same procedure for the other flange. If the dial indicators have a reading of greater than 0.002 inches, the piping must be corrected and then re-tested. Another concept we have adopted is to leave the dial indicators mounted on the coupling while filling the system with water. The weight of the water can induce pipe strain which again, can be removed by adjusting the pipe supports at the reducers.

We recheck the alignment to ensure nothing has changed. During construction, a variety of things could have disturbed the pump and motor mounts. Pending any modifications and completion of the piping system, we are ready to proceed with startup.

Startup Practices

Written startup procedures are extremely beneficial to ensure thoroughness. We have adopted a single sheet checklist, which is provided at the end of this article.

Pump Rotation

The first thing at startup is to check the rotation of the motor. Some VFD's have a bypass switch on them, which allow you to bypass the VFD circuitry. If this is the case, motor rotation should be checked in the bypass condition as well. We have had several occasions where the rotation was correct on the VFD but was reversed on bypass.

Motor Solo

A motor solo test consists of taking readings with a vibration analyzer on each bearing location in the horizontal plane, vertical plane, and the axial plane. A motor solo is used to determine if there are any problems with the motor before it is coupled to the pump.

Couplings

After a motor solo, we couple the pump to the motor. We typically use full spacer couplings, especially on end suction pumps. The full spacer allows extra clearance for removing the pump without having to disturb the motor. Check and set the coupling gap to the manufacturer's specifications and record the setting. Once the pump and motor are coupled, check to make sure the shaft rotates freely.

Other Startup Considerations

We double check a variety of items such as proper bearing lubrication, mechanical seal flushing plans, the piping system and pump is full of water,. are air vents properly installed, manual valves are open and pump rotation to name a few.

Pump Startup

After a final check of the pump and piping systems, we commence with startup operations. Typically on new construction, we try to allow a period of time to exercise the pump, i.e., ramp the pump up and down if VFD operated or modulate the discharge valve to see how the pump responds. Data such as motor amperage, voltage, flowrate and pressure is recorded. This data is maintained as it provides a baseline performance criteria for future reference.

Final Vibration Acceptance

The last part of the startup is to perform the final vibration acceptance test. We perform final testing on all pumping systems greater than 20 horsepower and all pumps in critical applications such as de-ionized water, waste water or process cooling water service. We specify a maximum velocity of 0.15 inches/second (peak) under normal operating conditions over the frequency range of 0.4 times the motor synchronous speed up to a maximum frequency of 120,000 cpm. Temperatures are recorded to ensure bearing temperatures do not exceed the manufacturer's specifications. All of this data is then recorded in our startup checklist and stored for future use.

Summary

Careful implementation of these practices has provided Texas Instruments with improved reliability and reduced maintenance costs for our pumping equipment. Our very proactive reliability based maintenance program has helped ensure pumping systems are totally comprehended from design to startup.

In order to keep our staff technically competent, we provide training opportunities which have clearly paid off. Utilization of techniques learned combined with other maintenance technologies such as infrared thermography and ultrasonic flow measurement provides our engineering staff with the facts necessary to identify problems before they occur and decide on the proper corrective action plan.

Finally, we believe keeping these very complex facilities operating safely and at the least cost provides our company with a competitive advantage and therefore, is our primary responsibility.