Section TECH-I
Pump Operation and Maintenance

TECH-I-1 Pump Safety Tips

Maintenance personnel should be aware of potential hazards to reduce the risk of accidents...

Safety Apparel:

- Insulated work gloves when handling hot bearings or using bearing heater
- Heavy work gloves when handling parts with sharp edges, especially impellers
- Safety glasses (with side shields) for eye protection, especially in machine shop areas
- Steel-toed shoes for foot protection when handling parts, heavy tools, etc.
- Other personal protective equipment to protect against hazardous/toxic fluids

Couplings Guards:

- Never operate pump without a coupling guard properly installed

Flanged Connections:

- Never force piping to make a connection with a pump
- Use only fasteners of the proper size and material
- Ensure there are no missing fasteners
- Beware of corroded or loose fasteners

Operation:

- Do not operate below minimum rated flow, or with suction/discharge valves closed
- Do not open vent or drain valves, or remove plugs while system is pressurized

Maintenance Safety:

- Always lockout power
- Ensure pump is isolated from system and pressure is relieved before disassembling pump, removing plugs, or disconnecting piping
- Use proper lifting and supporting equipment to prevent serious injury
- Observe proper decontamination procedures
- Know and follow company safety regulations
- Never apply heat to remove impeller
- Observe all cautions and warnings highlighted in pump instruction manual

TECH-I-2 PRO Services® Centers: An Economical Alternative

Goulds offers an economical alternative to high maintenance costs. Goulds PRO Services® Centers are experienced with reconditioning all types of pumps and rotating equipment, restoring equipment to original specifications. Users continually utilize PRO Services® Centers for economical repair versus replacement, decreased downtime, reduced inventory of replacement parts and the advantage of updated engineering technology.

Benefits/Services:

- Factory trained service personnel
- 24-hour emergency service
- Machine shop facilities
- Inventory of replacement parts
- Repairs to all makes and manufacture of pumps
- Pickup and delivery service
- Pump installation supervision
- Technical advisory services
- Turnkey field service capability
- Vertical turbine rebowling
- Condition monitoring
- Predictive solutions

Contact your nearest Goulds sales office for location of your nearest PRO Services® Center, or visit PRO Services® website at *www.ittproservices.com*.

TECH-I-3 Symptoms and Causes of Hydraulic and Mechanical Pump Failure

Cause	Hydraulic Failure					Mechanical Failure				
	1	2	3	4	5	6	7	8	9	10
	Pump does not deliver liquid	Pump does not deliver sufficient capacity	Pump does not deliver sufficient pressure	Pump delivers flow intermittently	Bearings run hot and/or fail on a regular basis	High rate of mechanical seal failure	Packing has short life	Pump vibrates at higher-than-normal levels	Pump is drawing too much power	Wear of internal wetted parts is accelerated
Pump not primed or prime lost	■	■	■	■						
Suction and/or discharge valves closed or clogged	■	■	■					■		
Suction piping incorrect	■	■	■							
Insufficient NPSH available	■	■	■			■		■		■
Excessive air entrapped in liquid	■	■	■	■						
Speed (RPM) too low	■	■	■							
Incorrect rotation		■							■	
Broken impeller or bent vanes		■	■		■			■		
Incorrect impeller or impeller diameter		■	■							
System head too high		■								
Instruments give erroneous readings		■	■							
Air leaks in suction line				■						
Excessive shaft misalignment					■	■		■		
Inadequate lubrication					■					
Lubricant contamination					■					
Inadequate lubricant cooling					■					
Axial thrust or radial loads higher than bearing rating					■					
Improper coupling lubrication					■			■		
Suction pressure too high					■	■				
Bearing incorrectly installed					■	■		■		
Impeller out of balance					■	■		■		
Overheating of seal faces						■				
Excessive shaft deflection					■	■		■		
Lack of seal flush at seal faces						■				
Incorrect seal installation						■				
Pump is run dry						■				
Pump run off design point					■	■	■	■	■	
Shaft/shaft sleeve worn						■	■			
Packing gland not properly adjusted							■		■	
Packing not properly installed							■			
Impeller clogged	■							■		
Coupling out of balance					■	■		■		
Baseplate not installed properly					■	■		■		
Pump operating speed too close to system's natural frequency								■		
Bearing failing					■	■		■		
Piping not properly anchored					■	■		■		
Pump and/or driver not secured to baseplate					■	■		■		
Specific gravity higher than specified					■	■			■	
Viscosity higher than specified					■	■			■	
Internal clearances too tight								■	■	
Chemicals in liquid other than specified										■
Pump assembled incorrectly			■		■	■	■	■		■
Higher solids concentration than specified										■

TECH-I-4 Troubleshooting Centrifugal Pumps

Problem	Probable Cause	Remedy
No liquid delivered.	Pump not primed.	Reprime pump, check that pump and suction line are full of liquid.
	Suction line clogged.	Remove obstructions.
	Impeller clogged with foreign material.	Back flush pump to clean impeller.
	Wrong direction of rotation.	Change rotation to concur with direction indicated by arrow on bearing housing or pump casing.
	Foot valve or suction pipe opening not submerged enough.	Consult factory for proper depth. Use baffler to eliminate vortices.
	Suction lift too high.	Shorten suction pipe.
Pump not producing rated flow or head.	Air leak through gasket.	Replace gasket.
	Air leak through stuffing box.	Replace or readjust packing/mechanical seal.
	Impeller partly clogged.	Back flush pump to clean impeller.
	Worn suction sideplate or wear rings.	Replace defective part as required.
	Insufficient suction head.	Ensure that suction line shutoff valve is fully open and line is unobstructed.
	Worn or broken impeller.	Inspect and replace if necessary.
Pump starts then stops pumping.	Improperly primed pump.	Reprime pump.
	Air or vapor pockets in suction line.	Rearrange piping to eliminate air pockets.
	Air leak in suction line.	Repair (plug) leak.
Bearings run hot.	Improper alignment.	Re-align pump and drive.
	Improper lubrication.	Check lubricate for suitability and level.
	Lube cooling.	Check cooling system.
Pump is noisy or vibrates.	Improper pump/driver alignment.	Align shafts.
	Partly clogged impeller causing imbalance.	Back-flush pump to clean impeller.
	Broken or bent impeller or shaft.	Replace as required.
	Foundation not rigid.	Tighten hold down bolts of pump and motor or adjust stilts.
	Worn bearings.	Replace.
	Suction or discharge piping not anchored or properly supported.	Anchor per Hydraulic Institute Standards Manual recommendation.
	Pump is cavitating.	System problem.
Excessive leakage from stuffing box/seal chamber.	Packing gland improperly adjusted.	Tighten gland nuts.
	Stuffing box improperly packed.	Check packing and repack box.
	Worn mechanical seal parts.	Replace worn parts.
	Overheating mechanical seal.	Check lubrication and cooling lines.
	Shaft sleeve scored.	Remachine or replace as required.
Motor requires excessive power.	Head lower than rating. Pumps too much liquid.	Consult factory. Install throttle valve, trim impeller diameter.
	Liquid heavier than expected.	Check specific gravity and viscosity.
	Stuffing packing too tight.	Readjust packing. Replace if worn.
	Rotating parts bind.	Check internal wearing parts for proper clearances.

TECH-I-5 Abrasive Slurries and Pump Wear

THE EFFECTS OF OPERATING AT DIFFERENT ZONES ON THE PUMP CHARACTERISTIC CURVE

The rate of wear is directly influenced by the system point on the characteristic curve. These condition points can be divided into four significant zones of operation (Fig. 1).

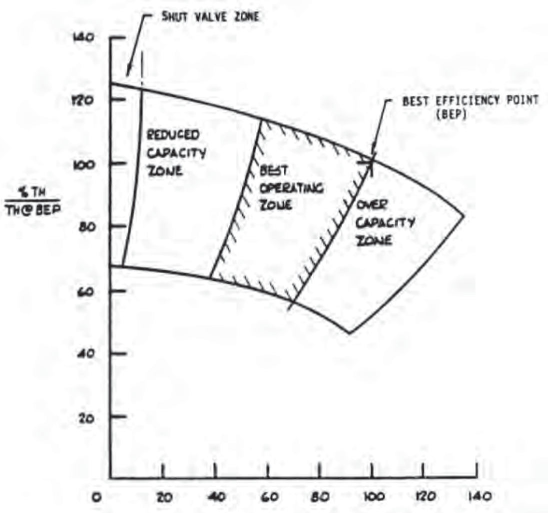


Fig. 1 Slurry Pump Characteristic Curve

Overcapacity Zone: The velocities within the pump are usually very high and recirculation occurs causing excessive wear. The radial hydraulic loads on the impeller increase.

Recommended Operation Zone: The velocities within the pump are reduced (but not enough to cause settlement). Recirculation is minimal and the flow in the suction nozzle should be axial (no induced vortex). The radial hydraulic loads are minimized.

Reduced Capacity Zone: The velocities within the pump are low, separation and recirculation occurs, causing excessive wear. Reducing the capacity should be limited because a certain minimum velocity must be maintained to avoid settling out; with the consequence of increased wear and clogging. The hydraulic radial loads will increase and the pump efficiency will decrease.

Shut Valve Zone: This is the point of zero flow, and pump should not be operated at this point for any length of time. Wear and tear will be rapid due to separation and recirculation, the hydraulic forces will be at their highest, and settlement and plugging will occur. The pump will rapidly heat up, which is particularly serious in rubber constructed pumps.

PRINCIPAL WEAR AREAS

As the abrasive mixture passes through the pump, all the wetted surfaces which come in contact will be subject to varying degrees of wear. It is very important to note that the performance of a conventional centrifugal pump, which has been misapplied to a slurry service, will be significantly effected by a relatively small degree of abrasive wear.

The areas most prone to wear, in order of increasing severity, are:

1. Suction sideplate, particularly at the nozzle region.
2. Impeller, particularly at the eye vane inlets, suction side impeller shroud, and the vane tips.
3. Casing cutwater and side walls adjacent to the impeller tip.
4. Stuffing box packing and sleeve.

NOTE: In the case of a conventional pump with radial wear rings on the impeller, this is where the worst wear occurs.

On severely abrasive services where there are high concentrations of hard, larger, sharp particles, the suction side liner life can be increased if it is rotated periodically to equalize the effects of wear.

In hard iron pumps applied to severely abrasive service, the relative wear rates of the suction side liner, casing, and impeller are in the order of 3 to 1.5 to 1, e.g. the life of the casing is three times that of a suction side wear plate.

Recognizing that due to the nature of the mixtures being pumped, the complete elimination of wear is impossible, the life of the parts can be appreciably prolonged and the cost of maintenance reduced by a good pump design and selection, e.g.:

- Construct the pump with good abrasion resistant materials
- Provide generous wear allowances on all parts subject to excessive wear
- Adopt a hydraulic design which will minimize the effects causing wear
- Adopt a mechanical design which is suitable for the materials of construction and has ready access to the parts for renewal
- Limit the head to be generated and select a low speed pump

TECH-I-6 Start-Up and Shut-Off Procedure for Heated and Unheated Mag Drive Pumps

(This procedure does not replace the instruction operation manual.)

A. CHECKLIST BEFORE START-UP

1. The nominal motor power must not exceed the pump's allowed maximum capacity (compare rating plates of motor and pump).
2. Check direction of rotation with disconnected coupling.
3. Check alignment of coupling.
4. Check ease of pump operation by hand.
5. Attach coupling protection.
6. Connect thermocouples, dry run protection, pressure gauges, etc.
7. Connect heater for heated pumps.
8. Connect cooling system (if required).
9. Attention: Insulation must not cover roller bearings.

B. START-UP

1. Preheat heated pumps for a minimum of 2 hours.
2. Open pressure valve.
3. Open suction valve completely and fill pump.
4. After 2-3 minutes close pressure valve.
5. In case of external cooling, switch on coolant flow.
6. Start motor.
7. Subsequently open pressure valve slowly until pump reaches specified performance level.

C. SHUT-OFF

1. Close pressure valve.
2. Shut off motor. Allow pump to slow down smoothly.
3. In case of external cooling, shut off coolant flow.
4. Close suction valve.

NOTE:

- Throttling must not be done with the suction valve.
- Never shut off the pump with the suction valve.
- Pump must never run dry.
- Never run the pump against a closed pressure valve.
- The pump motor unit must run vibration free.
- Temperature of roller bearings must not exceed tolerated limit.

TECH-I-7 Raised Face and Flat Face Flanges (Mating Combinations)

Pumps of cast iron construction are furnished with 125 or 250 lb. flat face (F.F.) flanges. Since industry normally uses fabricated steel piping, the pumps are often connected to 150 or 300 lb. $^{1}/_{16}$" raised face (R.F.) steel flanges.

Difficulty can occur with this flange mating combination. The pump flange tends to pivot around the edge of the raised face as the flange bolts are tightened. This can cause the pump flange to break allowing leakage at the joint (Fig. 1).

A similar problem can be encountered when a bronze pump with F.F. flanges is connected to R.F. steel flanges (Fig. 2). Since the materials are not of equal strength, the bronze flange may distort, resulting in leakage.

To avoid problems when attaching bronze or cast iron F.F. pump flanges to R.F. steel pipe flanges, the following steps should be taken (refer to Fig. 3).

1. Machine off the raised face on the steel pipe flange.
2. Use a full face gasket.

If the pump is steel or stainless steel with F.F. flanges, no problem arises since materials of equal strength are being connected. Many customers, however, specify R.F. flanges on steel pumps for mating to R.F. companion flanges. This arrangement is technically and practically not required.

The purpose of a R.F. flange is to concentrate more pressure on a smaller gasket area and thereby increase the pressure containment capability of the joint. To create this higher gasket load, it is only necessary to have one-half of the flanged joint supplied with a raised face - not both. The following illustrations show 4" steel R.F. and F.F. mating flange combinations and the gasket loading incurred in each instance.

Assuming the force (F) from the flange bolts to be 10,000 lbs. and constant in each combination, the gasket stress is:

$$P\ (Stress) = \frac{Bolt\ Force\ (F)}{Gasket\ Area}$$

$$P_1\ (Fig.\ 4) = \frac{10{,}000\ lbs.}{49.4\ sq.\ in.} = 203\ psi$$

$$P_2\ (Fig.\ 5) = \frac{10{,}000\ lbs}{} = 630\ psi$$

$$P_3\ (Fig.\ 6) = 15.9\ sq.\ in.$$

It can be readily seen that the smaller gasket, used with a raised face flange, increases the pressure containment capability of a flanged joint. However, it can also be noted that there is no difference in pressure capability between R.F.-to-R.F. and R.F.-to-F.F. flange combinations.

In addition to being technically unnecessary to have a R.F.-to-R.F. mating combination, the advantages are:

1. The elimination of the extra for R.F. flanges.
2. The elimination of the extra delivery time required for a non-standard casing.

Fig. 1

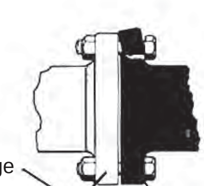


Fig. 2

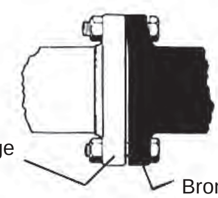


Fig. 3

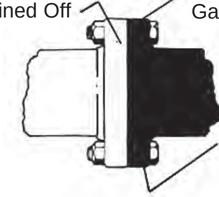


Fig. 4

Gasket Area 49.4 sq. in.

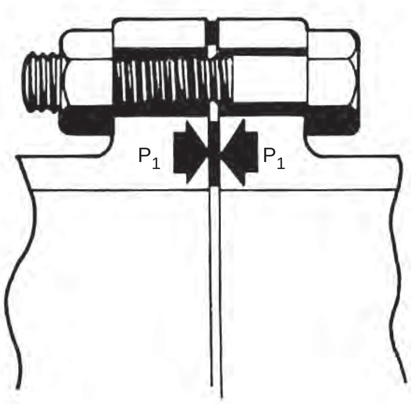


Fig. 5

Gasket Area 15.9 sq. in.

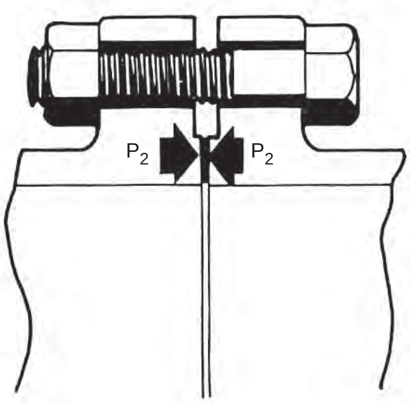
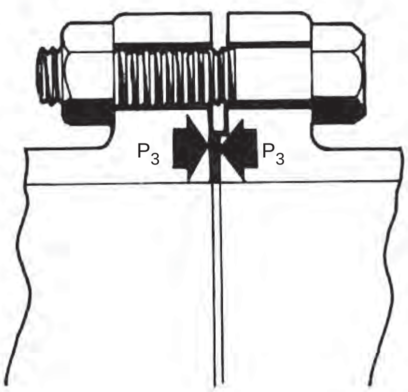


Fig. 6

Gasket Area 15.9 sq. in.



TECH-I-8 Keep Air Out of Your Pump

Most centrifugal pumps are not designed to operate on a mixture of liquid and gases. To do so is an invitation to serious mechanical trouble, shortened life and unsatisfactory operation. The presence of relatively small quantities of air can result in considerable reduction in capacity, since only 2% free air will cause a 10% reduction in capacity, and 4% free air will reduce the capacity by 43.5%.

In addition to a serious loss in efficiency and wasted power, the pump may be noisy with destructive vibration. Entrained air is one of the most frequent causes of shaft breakage. It also may cause the pump to lose its prime and greatly accelerate corrosion.

Air may be present in the liquid being pumped due to leaky suction lines, stuffing boxes improperly packed, or inadequately sealed on suction lift or from other sources.

Refer also to Section TECH-D-7, Pumping Liquids with Entrained Gas.

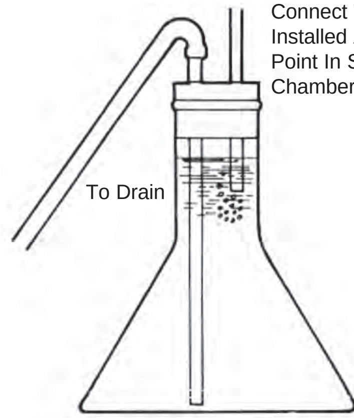
On the other hand, very small amounts of entrained air (less than 1%) can actually quiet noisy pumps by cushioning the collapse of cavitation bubbles.

TESTING FOR AIR IN CENTRIFUGAL PUMPS

The amount of air which can be handled with reasonable pump life varies from pump to pump. The elimination of air has greatly improved the operation and life of many troublesome pumps. When trouble occurs, it is common to suspect everything but air, and to consider air last, if at all.

In many cases a great deal of time, inconvenience, and expense can be saved by making a simple test for the presence of air. We will assume that calculations have already been made to determine that there is sufficient NPSH Margin (2 - 5 times the NPSHR) to insure that the noise is not due to cavitation. The next step should be to check for the presence of entrained air in the pumpage.

When the source of suction supply is above the centerline of the pump, a check for air leaks can be made by collecting a sample in a "bubble bottle" as illustrated. Since the pressure at the suction chamber of the pump is above atmospheric pressure, a valve can be installed in one of the tapped openings at the high point in the chamber and liquid can be fed into the "bubble bottle." The presence of air or vapor will show itself in the "bubble bottle."



This test can also be made from a high point in the discharge side.

Obviously, the next step is to eliminate the source of air since quantities present insufficient amount to be audible are almost certain to cause premature mechanical failure.

NOTE: The absence of bubbles is not proof that the pumpage doesn't contain air.

TECH-I-9 Ball Bearings – Handling, Replacement and Maintenance Suggestions

Ball bearings are carefully designed and made to watch-like tolerances. They give long, trouble-free service when properly used. They will not stand abuse.

KEEP CLEAN

Dirt causes 90% of early bearing failures. Cleanliness is a must when working on bearings. Some things which help:

1. Do not open housings unless absolutely necessary.
2. Spread clean newspapers on work benches and at pump. Set tools and bearings on papers only.
3. Wash hands. Wipe dirt, chips and grease off tools.
4. Keep bearings, housings, and shaft covered with clean cloths whenever they are not being worked on.
5. Do not unwrap new bearings until ready to install.
6. Flush shaft and housing with clean solvent before reassembly.

PULL BEARINGS CAREFULLY

1. Use sleeve or puller which contacts just inner race of bearing. (The only exception to this is some double suction pumps which use the housing to pull the bearing.)
2. Never press against the balls or ball cages, only against the races.
3. Do not cock bearing. Use sleeve which is cut square, or puller which is adjusted square.
4. When using a bearing housing to pull a bearing, pull evenly, do not hammer on housing or shaft. With both races locked, shock will be carried to balls and ruin bearing.

INSPECT BEARINGS AND SHAFT

1. Look bearing over carefully. Scrap it if there are any flat spots, nicks or pits on the balls or races. Bearings should be in perfect shape.
2. Turn bearing over slowly by hand. It should turn smoothly and quietly. Scrap if "catchy" or noisy.

3. Whenever in doubt about the condition of the bearing, scrap it. Five or ten dollars worth of new bearings may prevent serious loss from downtime and pump damage. In severe or critical services, replace bearings at each overhaul.
4. Check condition of shaft. Bearing seats should be smooth and free from burrs. Smooth burrs with crocus cloth. Shaft shoulders should be square and not run over.

CHECK NEW BEARINGS

Be sure bearing is of correct size and type. For instance, an angular contact bearing which is dimensionally the same as a deep groove bearing may fit perfectly in the pump. However, the angular contact bearing is not suitable for end thrust in both directions, and may quickly fail. Also check to see that shields (if any) are the same as in the original unit. Refer to the pump instruction manual for the proper bearing to use.

INSTALL CAREFULLY

1. Oil bearing seat on shaft lightly.
2. Shielding, if any, must face in proper direction. Angular contact bearings, on pumps where they are used, must also face in the proper direction. Duplex bearings must be mounted with the proper faces together. Mounting arrangements vary from model to model. Consult instruction manual for specific pump.
3. Press bearing on squarely. Do not cock it on shaft. Be sure that the sleeve used to press the bearing on is clean, cut square, and contacts the inner race only.
4. Press bearing firmly against shaft shoulder. The shoulder helps support and square the bearing.
5. Be sure snap rings are properly installed, flat side against bearing, and that lock nuts are tight.

6. Lubricate properly, as directed in instruction manual.

TECH-I-10 Impeller Clearance

IMPELLER CLEARANCE

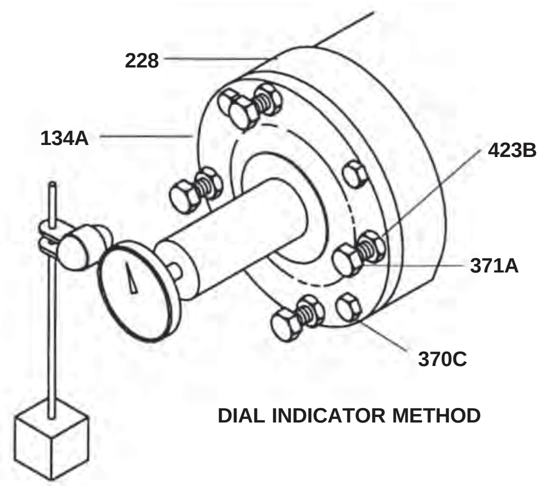
Open impeller centrifugal pumps offer several advantages. They're particularly suited but not restricted to liquids which contain abrasive solids. Abrasive wear on an open impeller is distributed over the diametrical area swept by the vanes. The resulting total wear has less effect on performance than the same total wear concentrated on the radial ring clearance of a closed impeller.

The open impeller permits restoration of "new pump" running clearance after wear has occurred without parts replacement. Many of Goulds open impeller pumps feature a simple positive means for axial adjustment without necessity of disassembling the unit to add shims or gaskets.

SETTING IMPELLER CLEARANCE (DIAL INDICATOR METHOD)

1. After locking out power, remove coupling guard and coupling.
2. Set dial indicator so that button contacts shaft end.
3. Loosen jam nuts (423B) on jack bolts (371A) and back bolts out about two turns.
4. Tighten each locking bolt (370C) evenly, drawing the bearing housing toward the bearing frame until impeller contacts casing.
5. Set indicator to zero and back locking bolt about one turn.
6. Thread jack bolts in until they evenly contact the bearing frame. Tighten evenly backing the bearing housing away from the frame until indicator shows the proper clearance established in instruction manual.*
7. Evenly tighten locking bolts, the jack bolts keeping indicator at proper setting.
8. Check shaft for free turning.

*Established clearance may vary due to service temperature.



DIAL INDICATOR METHOD

TECH-I-11 Predictive and Preventive Maintenance Program

This overview of Predictive and Preventive Maintenance (PPM) is intended to assist the pump users who are starting a PPM program or have an interest in the continuous improvement of their current programs.

There are four areas that should be incorporated in a PPM program. Individually each one will provide information that gives an indication of the condition of the pump; collectively they will provide a complete picture as to the actual condition of the pump.

PUMP PERFORMANCE MONITORING

There are six parameters that should be monitored to understand how a pump is performing. They are *suction pressure* (P_s), *discharge pressure* (P_d), *flow (Q)*, *pump speed* (N_r), *pumpage properties,* and *power*. Power is easiest measured with a clip on amp meter but some facilities have continuous monitoring systems that can be utilized. In any event, the intent is to determine the BHP of the pump. When using a clip on amp meter, the degree of accuracy is limited.

It should not be used to determine the efficiency of the pump. Clip on amp meters are best used for troubleshooting where the engineer is trying to determine the operating point of the pump.

The most basic method of determining the TDH of the pump is by utilizing suction and discharge gauges to determine P_S and P_d. The installation of the taps for the gauges is very important. Ideally, they should be located normal to the pipe wall and on the horizontal centerline of the pipe. They should also be in a straight section of pipe. Avoid locating the taps in elbows or reducers because the readings will not indicate the true static pressure due to the velocity head component. Avoid locating taps in the top or bottom of the pipe because the gauges can become air bound or clogged with solids.

Flow measurements can be difficult to obtain but every effort should be made to do so, especially when troubleshooting. In some new installations permanent flow meters are installed which make the job easier. When this is the case, make sure the flow meters are working properly and have been calibrated on a regular schedule. When flow meters are not installed, pitot tubes can be used. Pitot tubes provide a very accurate measure of flow, but this in an obtrusive device and provisions must be made to insert the tube into the piping. The other method of determining flow is with either a doppler or transitime device. Again, provisions must be made on the piping for these instruments, but these are non-obtrusive devices and are easier to use than the pitot tube. Caution must be exercised because each device must be calibrated, and independent testing has shown these devices are sensitive to the pumpage and are not 100% accurate.

An accurate power measurement reading can also be difficult to obtain. Clip on map meters are the most common tool available to the Field Engineer who is troubleshooting a pump problem. In most cases this has proven to be accurate. However, as previously mentioned, this tool must be used and applied properly. Clip on map meters are not accurate enough to determine the actual efficiency of a pump. If accurate horsepower readings are necessary, a torque shaft must be installed but is not very practical in an actual field installation and lends itself to use in a laboratory environment much better. In some critical installations where the user has provided a permanent power monitor, these have varying degrees of accuracy and they must be understood up front.

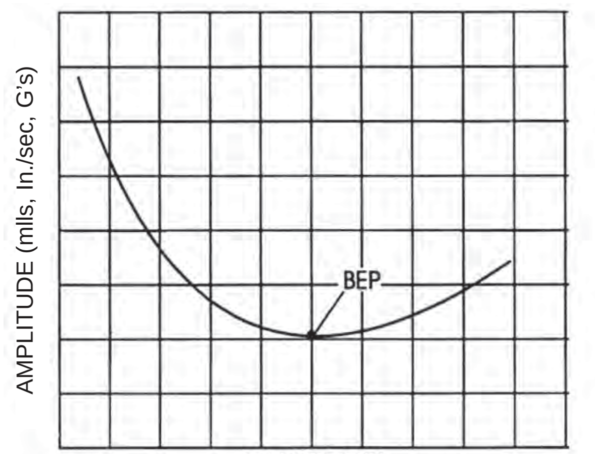
Finally, the properties of the pumpage must be known to accurately determine the actual pump performance. Pumpage temperature (T_p), viscosity, and specific gravity (S.G.), must be known.

When all of the above parameters are known, it becomes a simple matter of calculating the pump performance. There are instances when it proves to be a very difficult if not an impossible task to determine all of the above parameters in the field, therefore, the Field Engineer must rely on his or her ability to understand where a compromise must be made to get the job done. The basic document the Field Engineer must have is the pump performance curve. With this it can be determined where the pump is performing in some cases without all of the information.

PUMP VIBRATION AND BEARING ANALYSIS

Vibration analysis is the cornerstone of all PPM programs. Perhaps the question asked most often is "What is the vibration level that indicates the pump is in distress?". The answer is that there is no absolute vibration amplitude level that is indicative of a pump in distress. However, there are several guidelines that have been developed as target values that enable the analyst to set alarm levels. Also many users have developed their own site criteria that is used as a guideline. Institutions such as the Hydraulic Institute and API have developed independent vibration criteria. Caution should be exercised when applying the published values...each installation is unique and should be handled accordingly. When a machine is initially started, a baseline vibration reading should be taken and trended over time.

Typically, readings are taken on the motor outboard and inboard bearing housings in the vertical and horizontal directions and on the pump outboard and inboard bearing housings in the vertical and horizontal directions. Additionally, an axial vibration measurement is taken on the pump. The inboard location is defined as the coupling end of the machine. It is critical that when the baseline vibration measurement is taken that the operating point of the pump is also recorded. The vibration level of a pump is directly related to where it is operating and in relation to its Best Efficiency Point (BEP). The further away from the BEP, the higher the vibrations will be. See the following chart for a graphical representation of vibration amplitude-vs- flow.



Typical Vibration Level Characteristic vs. Capacity

The engineer must also look at the frequency where the amplitude is occurring. Frequency identifies what the defect is that is causing the problem, and the amplitude is an indication of the severity of the problem. These are general guidelines and do not cover every situation. The spectrum in the chart is a typical spectrum for a pump that has an unbalance condition.

Bearing defect analysis is another useful tool that can be used in many condition monitoring programs. Each component of a roller bearing has its own unique defect frequency. Vibration equipment available today enables the engineer to isolate the unique bearing defects and determine if the bearing is in distress. This allows the user to shut the machine down prior to a catastrophic failure. There are several methods utilized but the most practical from a Field Engineering perspective is called bearing enveloping. In this method, special filters built into the analyzer are used to amplify the repetitive high frequency signals in the high frequency range and amplify them in the low frequency part of the vibration spectrum. Bearing manufacturers publish the bearing defect frequency as a function of running speed which allows the engineer to identify and monitor the defect frequency. Similar to conventional vibration analysis, a baseline must be established and then trended. There are other methods available such as High Frequency Detection (HFD), and Spike Energy but the enveloping technology is the latest development.

It is a common practice to monitor bearing temperature. The most accurate method to monitor the actual bearing temperature is to use a device that will contact the outer race of the bearing. This requires holes to be drilled into the bearing housings which is not always practical. The other method is the use of an infrared 'gun' where the analyst aims the gun at a point on the bearing housing where the temperature reading is going to be taken. Obviously, this method is the most convenient but there is a downside. The temperature being measured is the outside surface of the bearing housing, not the actual bearing temperature. This must be considered when using this method.

To complete the condition monitoring portion of a PPM program, many users have begun an oil analysis program. There are several tests that can be performed on the lubricant to determine the condition of the bearing or determine why a bearing failed so appropriate corrective action can be taken. These tests include Spectrographic Analysis, Viscosity Analysis, Infrared Analysis, Total Acid Number, Wear Particle Analysis and Wear Particle Count. Most of these tests have to be performed under laboratory conditions. Portable instruments are now available that enable the user to perform the test on site.

PUMP SYSTEM ANALYSIS

Pump system analysis is often overlooked because it is assumed the system was constructed and operation of the pumps are in accordance with the design specifications. This is often not the case. A proper system analysis begins with a system head curve. System head curves are very difficult to obtain from the end user and, more often than not, are not available. On simple systems, they can be generated in the field but on more complicated systems this can't be done. As has been stated previously, it is imperative to know where the pumps are being operated to perform a correct analysis and this is dependent on the system.

A typical system analysis will include the following information; $NPSH_A$, $NPSH_R$, static head, friction loss through the system, and a complete review of the piping configuration and valving. The process must also be understood because it ultimately dictates how the pumps are being operated. All indicators may show the pump is in distress when the real problem is it is being run at low or high flows which will generate high hydraulic forces inside the pump.

CONCLUSION

A PPM program that incorporates all of the topics discussed will greatly enhance the effectiveness of the program. The more complete understanding the engineer has of the pumping system, the more effective the PPM program becomes.

TECH-I-12 Field Alignment

(This procedure does not replace the instruction operation manual.)

Proper field alignment of pumps and drivers is critical to the life of the equipment. There are three methods used in industry: rim and face, reverse dial indicator, and laser alignment.

RIM AND FACE

This method should not be used when there is no fixed thrust bearing or on pumps/drivers that have axial shaft movement.

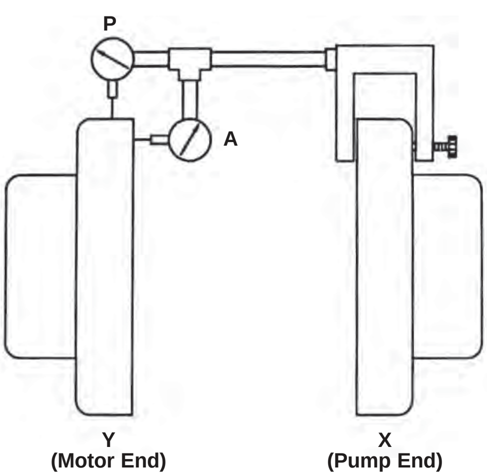


Fig. 1 Rim and Face Dial Indicator Alignment
(Criteria: 0.002 in. T.I.R. rim and face reading)

REVERSE DIAL INDICATOR

This method is the most widely used and is recommended for most situations.

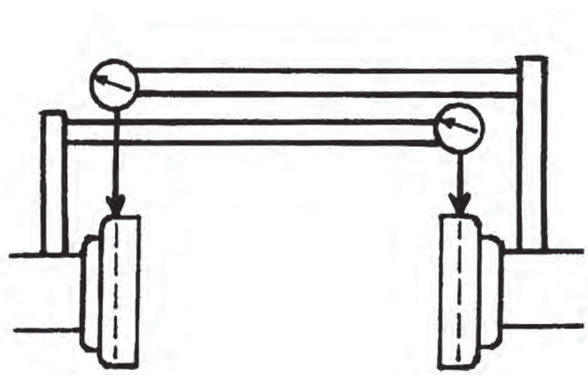


Fig. 2 Reverse Dial Indicator Alignment
(Criteria: 0.0005 in. per inch of dial indicator separation)

LASER ALIGNMENT

Although a popular method, it's not any more accurate than either dial indicator method. Instruments are expensive and require frequent calibration.

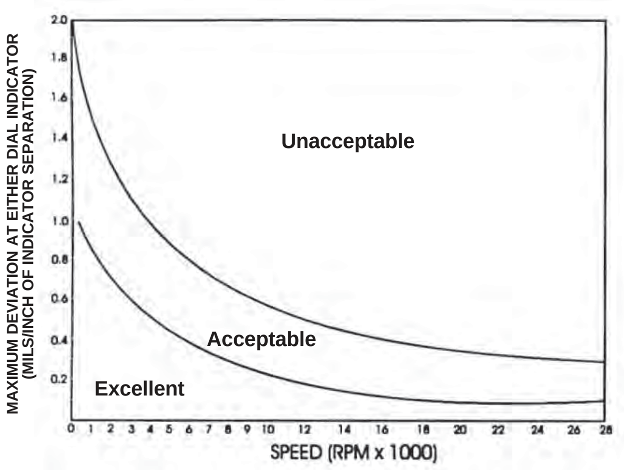


Fig. 3 Guideline for Alignment Tolerances

MECHANICAL ALIGNMENT PROCEDURE

This procedure assumes the presenter knows how to align a pump and has a basic understanding of pump baseplates and piping installation. There are many alignment systems available. We will be using the plotting board with dial indicators developed by M.G. Murray. The plotting board is as accurate as any method available today and gives the best representation of the actual position of the machines that are being aligned. The actual procedure that will be discussed is the reverse dial indicator procedure because it is the most versatile and widely used alignment procedure used today.

PREPARING FOR ALIGNMENT

A. Baseplate Inspection

1. Inspect all mounting surfaces to make sure they are clean and free of any paint, rust, grime, burrs, etc.
   a. Thoroughly clean mounting surfaces. Debar using a honing stone if necessary.
   b. At this point, it is assumed that the baseplate has been installed correctly and is level.

B. Pump and Driver Inspection

1. Inspect all mounting surfaces to make sure they are clean and free of any paint, rust, grime, burrs, etc.

C. Shim Inspectlan

1. Inspect all shims to make sure they are clean and free of any paint, rust, grime, burrs. etc.
2. Dimensionally inspect ALL shims to be used and record the reading on the individual shims.

DO NOT ASSUME THAT THE SHIMS ARE TO THE EXACT DIMENSIONS THAT ARE RECORDED ON THEM.

SETTING EQUIPMENT

A. Pump

1. Set pump on pump mounting pads. Insert pump hold-down bolts but do not tighten.
   a. If there is existing piping, line up pump flanges with pipe flanges. DO NOT CONNECT THE PIPING AT THIS POINT.
2. Level the pump off of the shaft extension. Do not level off of the pump casing flanges. Remember, the piping must come to the pump. You are aligning the pump shaft and the driver shaft. Shafts are the datum, not flanges.
   a. Use a STARRET No.135 level to level the shaft.
   b. Leveling the pump should be accomplished by shimming under the bearing frame foot.

B. Motor

1. Set the motor on the baseplate.
2. Using a straight edge, approximate the shaft alignment.
   a. This will require setting shims of the same thickness under the motor feet; you are just trying to get close so you can use the dial indicators. Get the rough alignment within 0.0625".
   b. If the motor is higher, there is something wrong or it is a special case. This situation must be inspected. Do not shim the pump. The pump is connected to the piping and it will present difficulties with future work on the installation.
   c. Make sure you have the proper shaft separation.
3. Remove soft foot.

C. Alignment. (Reverse Indicator Method)

1. Install reverse dial indicator tooling on shafts.
2. Measure and record the following dimensions on a worksheet, SA, Al, IO. These parameters are defined as follows:
   a. SA = Distance between the dial indicators which is located at the respective planes of correction.
   b. Al = Distance between the adjustable plane of correction and the inboard foot of the adjustable machine.
   c. IO = Distance between the inboard foot and outboard foot of the adjustable machine.
2. Correct for dial indicator sag.
   a. Remove dial indicator tooling from the unit.
   b. Install reverse dial indicator tooling on a pipe or piece of round bar stock in the exact configuration that you removed it from the unit that is being aligned. The dial indicators must be set to the SA distance.
   c. Zero the dial indicator while they are in the vertical up position.
   d. Rotate the entire set-up 180° and record dial indicator readings. This is the sag, the correction will be made when you take the alignment readings.
3. Reinstall the reverse dial indicator tooling back to the configuration it was in Step 1.
   a. The SA dimension must be held.
4. Establishing the datums.
   a. You must take readings from the same position relative to the fixed machine or the moveable machine. Choose the position that is the most comfortable. DO NOT CHANGE THE ORIENTATION ONCE YOU BEGIN TO TAKE READINGS.
   b. All dial indicator readings must be taken 90° apart from each other and at the same relative position each time. Either mark the couplings in 80° increments or use a two dimension bubble level with a magnetic pad. The level is the most accurate method.

c. The shafts must be rotated together and readings taken from the same exact locations every time; therefore, if the coupling spacer is removed, the stationary and adjustable machines coupling hubs must be marked in 90°. increments.

5. Take the initial set of readings.
   a. Zero the dial indicators at the 0° position.
   b. Rotate the shafts simultaneously taking readings every 90°, (0°, 90°, 180°, 270°). Record readings
6. Determine if the initial readings are good.
   a. Add top (T) and bottom (B) together for both planes and the two side readings (S) together for both planes.
   b. Take the difference of the two readings. If the difference exceeds 0.002", there is something wrong with the readings. Inspect the set up and make any necessary adjustments.
7. Algebraically zero the side readings. Be consistent on which side you zero; it is usually easier to zero the 90° side.
8. Make dial indicator sag correction on worksheet.
   a. Dial indicator sag only effects vertical readings. Since the dial indicator is going to read negative on the bottom, add the sag to the dial indicator reading on the bottom.
9. Divide all corrected readings by two because they are TIR readings taken on the outside of a circle.
   a. Remember, when the dial indicator reads positive, the probe is being pushed in. When it reads negative, the probe is extended.
10. Determine shim change.
    a. Lay out the machine dimensions on the plotting board transparency.
       1. Once the scale is determined you must be consistent and use only that particular scale.
    b. Referring to our example, you must use the "C" scale on the bottom horizontal axis. The bottom horizontal axis represents the physical dimensions of the machine.
    c. The left vertical axis represents the misalignment/shim correction scale.
    d. Locate S, A, IB, OB,
       1. S is located where the vertical and horizontal axis of the overlay intersect. S represents the location of the stationary reference plane.
       2. A is marked on the horizontal axis and represents the location of the adjustable reference plane. In our example, it is marked at 7" on the C scale.
       3. B is marked on the horizontal axis and represents the location of the inboard foot of the adjustable machine. In our example it is marked at 15" on the C scale.
       4. OB is marked on the horizontal axis and represents the location of the outboard foot of the adjustable machine. In our example it is marked at 36" on the C scale.
       5. Mark reference on the plotting board transparent vertical scale.
11. Plot shim change for vertical correction first.
    a. Transform worksheet data to the plotting board.
       1. Set S at 0.009" low mark based on the E vertical scale
       2. Set at 0.0035" high mark based on the E vertical scale
    b. Draw vertical lines from the lB and OB locations on the red line to the horizontal zero line on the plotting board.
    c. Count the vertical distances from the lB and OB marks to the horizontal zero line using the correct scale, in our case the E scale, these values are the shim changes at the inboard (lB) and outboard (OB) feet of the adjustable machine.
12. Make shim change.
13. Repeat Step 11 for horizontal correction.
14. Check alignment.
    a. The machines should be aligned at this point; if not, repeat Steps 11 and 12.
15. Inspect final alignment and record all results.