NATIONAL OILWELL VARCO

Trouble Shooting Centrifugal Pumps

by
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Centrifugal pumps are used for a variety of applications and are available in a multitude of styles and configurations. This article focuses on National Oilwell concentric style single stage centrifugal pumps. Thousands of these pumps have been sold since the original design and have proven to be extremely reliable when properly applied and maintained.

As with any piece of equipment the design, manufacturing methods, tolerances, material quality, machining procedures and assembly methods all combine to ensure the dependability and functionality of the equipment. Many companies have tried to duplicate the National Oilwell designed centrifugal pump line; however, only National Oilwell's engineering department knows the exact dimensions, tolerances, load capacities and design parameters necessary to provide high quality pumps that ensure the longest run times and peak performance.

National Oilwell centrifugal pumps feature a rotating assembly housed by a stationary assembly that work in unison to transfer fluid. The rotating assembly consists of a shaft, bearings, mechanical seal (when equipped) and impeller. The stationary portion consists of the frame, stuffing box and casing. Figure 1 will assist in identifying the major components of a centrifugal pump.

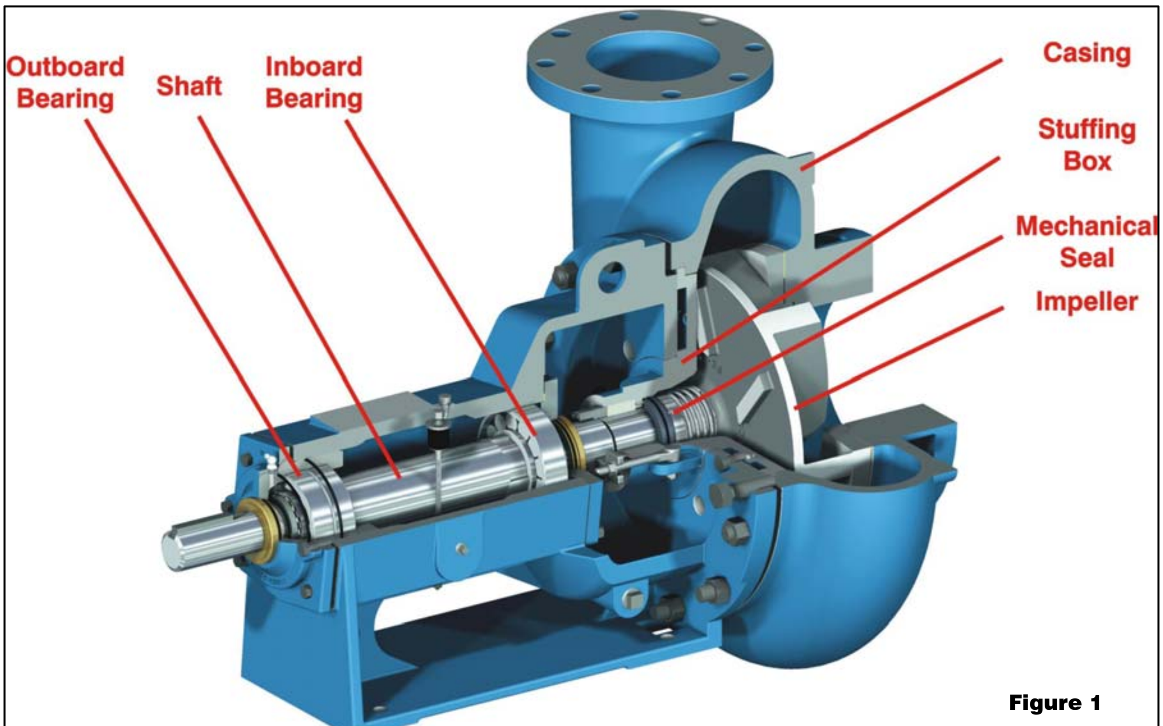

Figure 1

The impeller is the key component of the pump and imparts a centrifugal force on the fluid that results in fluid acceleration. Once the casing is filled with fluid and the pump driver is activated the rotating assembly of the pump begins to spin. When the impeller is spinning, a low pressure zone develops at the eye of the impeller that is relieved by atmospheric pressure on the surface of the fluid in the supply tank. Atmospheric pressure, being greater than the low pressure

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zone, pushes the fluid into the pump; the pump does not suck fluid. Centrifugal force drives the fluid from the eye of the impeller to the OD of the impeller. This accelerates the fluid to a velocity determined by impeller diameter and RPM. The casing harnesses fluid velocity and converts velocity to pressure head. The shaft is simply the device used to transmit the required power and rotational speed to the impeller. If the casing, impeller or shaft fails to work the pump will not perform as designed.

Centrifugal pumps are a simple mechanical device but they can be applied in a manner that causes failure, decreased effectiveness or self destruction. Pump problems generally fall into one of the following categories:

2) Inadequate Suction Conditions / Air Infiltration
2) Insufficient Flow Rate
3) Mechanical / Wear
4) Open Ended Discharge Lines

Inadequate Suction Conditions

Inadequate suction conditions can result in severe damage to a centrifugal pump and in some cases result in zero pump discharge. This can be caused by vapor locking which occurs when air is trapped in the casing. Remember, when the pump is activated and the impeller is spinning, a low pressure zone forms in the eye of the impeller. If air is in the casing or fluid, it will move to the low pressure zone and block fluid from entering the impeller. In order for non-self priming centrifugal pumps to operate properly they must be free from air. Air can enter the pump in a variety of manners. If the pump does not prime properly check for the following:

1) Completely fill casing and suction line with fluid and purge all air prior to activating pump.
2) Is the casing discharge flange oriented above the suction flange? Air travels upward not down. If the discharge flange is positioned below the suction flange air can become trapped in the top of the casing. When the pump is activated the air will move to the low pressure zone and prevent fluid or reduce the amount of fluid that can enter the pump.
3) Ensure the suction piping leads up from the supply tank to the pump suction. Air can become trapped in suction lines that travel up over and back down. When the pump is activated, air bubbles can be pushed from this trap zone into the low pressure zone. Eliminate the trap zone or install a bleed valve to bleed all air prior to activating the pump.
4) Is an air vortex forming on the surface of the supply tank? If the suction line is not adequately submerged an air vortex can form and air will enter into the suction of the pump. To eliminate the air vortex increase the depth of fluid in the supply tank, utilize a larger suction line, reduce GPM transferred or install a baffle plate.

   Figure 2 is a table showing the submergence above the suction line that is required to prevent a vortex. The submergence required is based on the velocity of the fluid as it enters the suction pipe. Fluid velocity is affected by the volume and pipe diameter and can be determined by referring to piping friction loss tables under the velocity column.

   For example, 1000 GPM through SCH 40, 8” pipe will have a line velocity of 6.4 feet per second. A suction line with a velocity of 6.4 feet per second will

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require approximately 3 feet of fluid level above the suction line entry. In this example, if the supply tank's surface level falls below 3' above the suction line entrance an air vortex can form and result in pump vapor lock. To prevent the vortex the tank level must be maintained above 3', the line velocity reduced, or a baffle plate can be installed as shown in Figure 3.

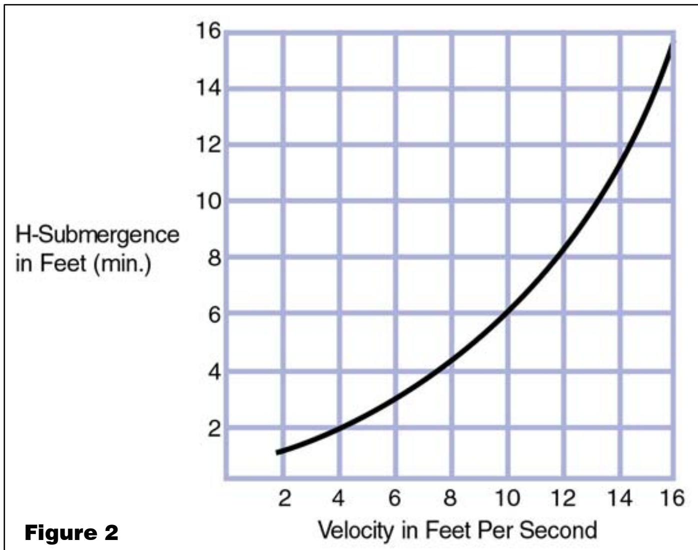

Figure 2

For suction lines that elbow down toward the tank bottom a plate can be fitted around the suction line in a horizontal orientation to achieve the same result.

By installing a baffle plate the fluid velocity is lowered around the edge of the plate. This allows the tank to be drawn to a lower level prior to the formation of an air vortex. If 1000 GPM is being transferred and an 18" baffle plate is installed, the fluid velocity at the edge of the baffle plate would be 1.26 feet per second. This would allow the tank to be drawn to within 1 foot of the plate before a vortex would form.

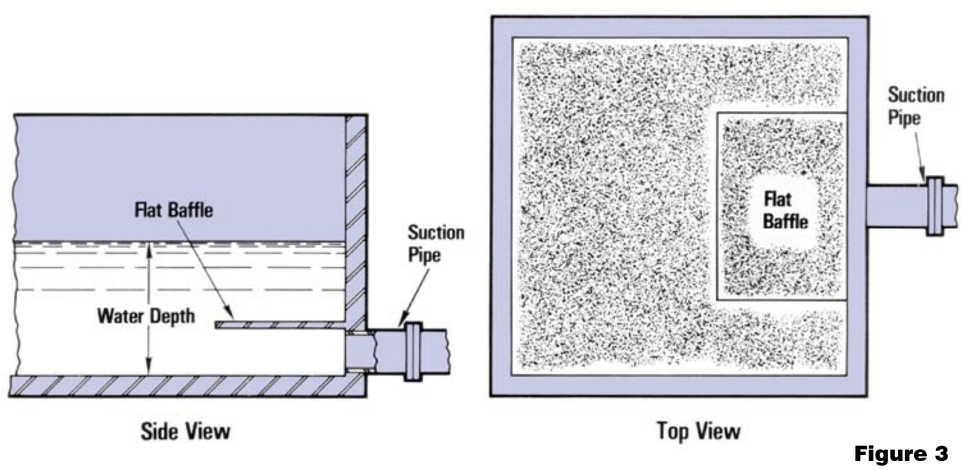

Figure 3

5) Ensure all suction flanges are tight. Loose flanges can allow air to enter the system even when they are not leaking fluid.

6) Ensure adequate Net Positive Suction Head is available (NPSHa). The pump curve contains the minimum value required for proper operation of the pump. Insufficient NPSH values will lead to cavitation and possibly complete failure of the pump. NPSHa values can be affected by friction losses, elevation of supply tank in reference to pump centerline, fluid temperature, elevation of

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jobsite (ie. 1000 feet above sea level) and Specific Gravity of the fluid. Details on cavitation and calculating NPSH values can be found in the National Oilwell article *Sizing Centrifugal Pumps* copyright 2004.

7) The pump suction line should always be equal to or greater than the pump suction flange. Select the proper size suction line that will maintain a fluid velocity between 5-8.5 feet per second.

8) Ensure suction valves are completely open and never throttle the pump volume by adjusting the suction valve.

9) Ensure the suction line expansion joint interior tube has not collapsed. The exterior tube can appear normal while the interior tube has collapsed and is restricting flow to the pump. For oil based fluids a Nitrile tube expansion joint should be used rather than a Neoprene tube.

10) Ensure no foreign objects have lodged in the pump impeller. Flange covers, blue jeans, rags, wrenches and other objects are commonly found in pumps.

11) Verify the pump is turning in the proper direction. A rotation arrow can be found on the casing near the suction flange.

12) Ensure the fluid is free from entrained air or gas. Entrained air will migrate to the low pressure zone at the eye of the impeller and join together with other bubbles to form a large bubble that will impede fluid flow. Make sure the return line is below fluid surface and located away from pump suction as shown in Figure 4.

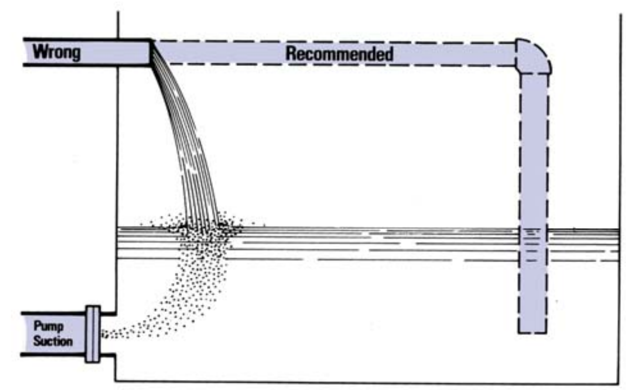

Figure 4 To minimize air entering the mud, return should be away from the suction and below liquid level.

Insufficient Flow Rate

If the pump is transferring fluid but the volume is less than expected the cause can be from inadequate suction conditions as aforementioned, insufficient pressure head, excessive pressure head, blocked lines, cavitation, pump wear or equipment wear.

While insufficient suction conditions can result in zero discharge they can also be less severe and result in decreased flow rates. If inadequate flow rates exist be sure to check the conditions described previously under the inadequate suction conditions section.

If the pump is not sized with the correct impeller diameter or driven at the proper RPM it may not produce adequate discharge pressure head to overcome system friction losses and elevation. Centrifugal pumps are a constant pressure head, varying volume device. This is opposite of positive displacement pumps that produce constant volume, varying pressure. The

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flow from a centrifugal pump is limited by the back pressure it encounters. When the system back pressure and pump pressure head equalize the volume produced by the centrifugal pump stabilizes. If the pump produces more pressure head than can be absorbed by the system it will continue to increase in volume until it reaches the end of its flow curve. Once it reaches the end of the flow curve cavitation begins to occur and can result in a pulsating flow rate. If the cavitation is severe it can destroy the pump fluid end and may result in a drastically reduced volume output. When selecting a centrifugal pump it is necessary to determine the system friction losses and elevation and to choose an impeller diameter and speed that will equal the system friction loss, elevation, and required head at the flow rate desired.

A friction curve can be plotted on a pump curve to determine the flow a pump will produce. Assume a system exists that has a desired flow rate of 1000 GPM. System friction and elevation losses can be determined at multiple flow rates. In this example the elevation is 20 feet, there is 100 feet of new SCH (40) 6" pipe and there is (1) 3" nozzle at the end of the line. These systems parameters create elevation loss, friction loss and nozzle head loss. For this example the operating points of 0, 600, 800, 1000, 1200 and 1400 GPM will be plotted.

Friction loss tables and nozzle loss tables can be referenced to determine the loss values. These can be found in pump handbooks and National Oilwell centrifugal pump catalogs. For this exercise the values are provided in Figure 5.

GPM	Elevation	Pipe Friction Loss	Nozzle Loss	Total System loss
0	20	0	0	20
600	20	4.7	12	36.7
800	20	8	23	51
1000	20	12.1	35	67.1
1200	20	16.9	46	82.9
1400	20	22	68	110

Figure 5

The total system loss values can be plotted on a pump curve to determine the proper impeller and speed for this system. In this example a constant speed curve will be used with varying impeller diameters (a variable speed curve with maximum impeller diameter could also be utilized). Refer to Figure 6 and the friction loss curve.

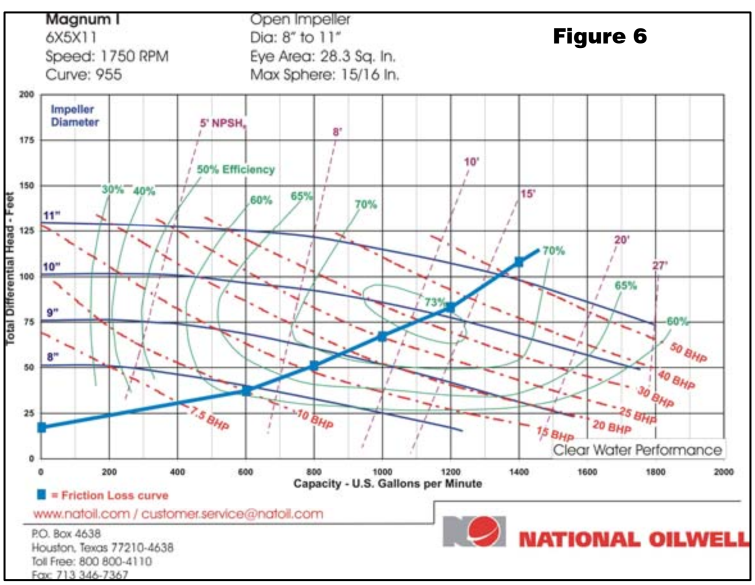

Figure 6

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The friction loss curve shows how different impeller diameters will affect the pump discharge volume. If 1000 GPM is required simply read the intersecting impeller diameter where it crosses the friction curve. For this scenario, a 9.5" impeller would deliver 1000 GPM. If an 8" impeller was utilized the pump would produce 630 GPM. By plotting a friction loss curve an individual can determine if the incorrect flow rate is a result of an improper impeller or speed selection.

Mechanical / Wear

Mechanical related problems in a centrifugal pump are generally related to the impeller, casing, bearings, mechanical seal or packing. The impeller and casing can be affected by wear, corrosion or cavitation (even though the casing is stationary it can affect the performance of the impeller). Bearings can be affected by alignment, lubrication, contamination, exceeding HP limitations and speed. Mechanical seals can be affected by the installation method, corrosion, heat, and lubrication. Packing can be affected by the installation method, abrasion, lubrication and impeller clearances resulting in high stuffing box pressures.

Wear - The impeller is in contact with the fluid being transferred and is rotating at high speed. Accordingly, this is the part most subject to erosion. Figure 7 shows extreme impeller wear, but notice that the wear is smooth and equal across all vanes. Impeller wear causes decreased pressure head and reduced flow rates. Replace worn impellers.

Figure 7

Note: For extremely abrasive applications fluid end parts are available in premium materials such as Magnachrome™ and Supreme Hard™. Fluid end life can also be extended by running maximum diameter impellers at lower speeds. Pump speed can be matched to the application using belt drive configurations.

Impellers are available as full open, semi-open and closed. National Oilwell centrifugal pumps are available with either full open or semi-open impellers. Open and semi-open impellers are dependent on the casing wear pad to act as the impeller front. The impeller should be positioned within .025 inch of the casing wear pad. This will produce the greatest pressure head and operate most efficiently. As the casing wear pad and impeller front begin to wear the gap between these parts increases. This allows some fluid to circulate back to the low pressure zone (eye of the impeller). When the impeller and casing gap wears to an exaggerated level fluid recirculation increases. This increase in fluid recirculation causes lower discharge pressure heads and decreased pump efficiency. Impeller adjustments can be made to overcome the front wear but this will increase the gap behind the impeller. An increased gap behind the impeller will create higher pressures in the stuffing box area which can cause premature packing failures. Replace worn parts when the drop in performance affects system operation.

Figure 8

Corrosion – Corrosion can be caused by incompatibilities between the fluid and metal and air entrained fluids. The fluid weakens or destroys the metal and results in premature pump failure. Figure 8 shows a stuffing box that failed from corrosion. Notice the metal has been destroyed in a non-uniform pattern. Select a fluid end material that is compatible with the fluid being transferred. Various fluid end parts are available in corrosion resistant materials such as 316SS, Aluminum Bronze, and Magnachrome™. In some instances corrosion erosion occurs and will expedite the loss of the part.

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Cavitation - Cavitation can be caused by improper suction or discharge conditions, improper pump selection, high fluid temperatures or a combination of factors. Cavitation severely reduces life of the pump. As fluid enters the pump the pressure at the eye of the impeller drops. If insufficient inlet pressure ($NPSH_A$) is available or insufficient system back pressure exists, fluid transforms from a liquid state to a gas (boils). This gas forms vapor bubbles and as these bubbles travel from the ID of the impeller to the OD of the impeller the pressure increases. Eventually the pressure increases enough to collapse the vapor bubble. When this occurs, the bubble implodes and space once occupied by the bubble fills with fluid. Fluid fills this space with such force that it actually fractures adjacent metal. Figure 9 shows a collapsing bubble. The water dagger at the center of the bubble can smash into metal at speeds up to 560 miles per hour. As this process repeats, it will knock out sections of the fluid end and can even knock a hole through the stuffing box, impeller or casing. Cavitation damage can be seen during pump inspection and in severe cases can be heard. Severe cavitation will sound as if the pump is pumping rocks.

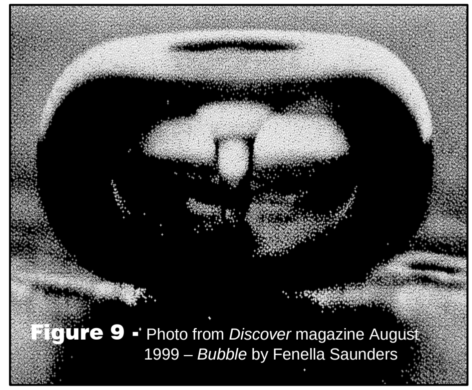

Figure 9 - Photo from *Discover* magazine August 1999 – *Bubble* by Fenella Saunders

Figure 10 shows cavitation damage that occurred in a pump transferring a clear fluid. Notice the jagged edges of the voided areas caused when metal fracturing occurred. This damage can occur on the impeller, casing, and/or stuffing box.

Figure 10

Figure 11 shows cavitation damage that occurred in a pump transferring an abrasive fluid. After the fracture occurs sharp corners are worn smooth by abrasive fluid. The damaged part will look as if a spoon was used to scoop sections of metal from the part. Cavitation can destroy a pump fluid end and simply replacing the parts will not correct the problem. When cavitation is occurring the pump and system have not been sized to work in harmony and the pump will continue to consume parts until the system has been reviewed by a qualified engineer or sales person and the negative system condition rectified or pump reconfiguration has occurred. For assistance in identifying the cause and solution for cavitation refer to the National Oilwell article *Sizing Centrifugal Pumps* copyright 2004.

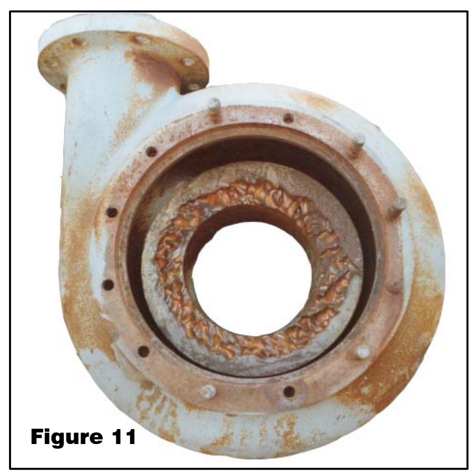

Figure 11

Alignment & Piping – Improper pump and driver alignment can result in pump and/or driver bearing failure. Units assembled at the factory are properly aligned prior to shipping. However, handling during shipment and unit installation normally will cause a misalignment to occur. **It is extremely important to align the units after installation and piping is complete**. Piping should be independently supported. The pump should not bear the weight of the suction or discharge piping.

It is recommended that expansion joints be installed on the suction and discharge side of the pump. Expansion joints simplify the alignment of the piping to the pump flanges and provide compensation for piping expansion and contraction caused by temperature changes. Expansion joints with a Nitrile tube are recommended for oil based fluids to prevent the collapse of the inner tube. A collapsed expansion joint can cause flow restrictions and pump cavitation.

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The recommended procedure for coupling alignment is by the use of a dial indicator, as illustrated in Figures 12 and 13. The dial indicator is attached to one coupling half with the indicator button resting on the O.D. of the other coupling half to measure offset misalignment. To measure angular misalignment, the indicator is positioned so that the button rests on the face, near the O.D., of the other coupling half. Rotate the shaft and dial indicator one full revolution while the other shaft remains stationary and note the T.I.R. Unless otherwise specified by the coupling manufacturer, offset misalignment should be limited to 0.010 inches T.I.R. (Total Indicator Run out) and angular misalignment should be limited to 0.005 inches T.I.R or the levels specified by the coupling manufacturer. Adjust misalignment by loosening driver or pump mounting bolts and re-tightening or shimming as required.

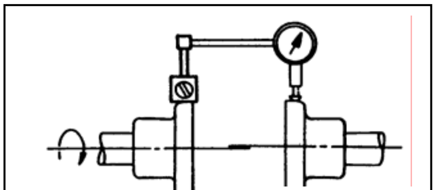
Figure 12

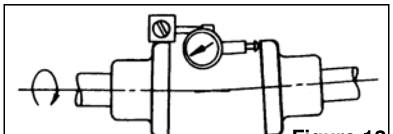
Figure 13

Figure 12 – Measuring Offset Alignment **Figure 13 – Measuring Angular Alignment**

In areas where a dial indicator arrangement is not available, an adequate job of alignment can be done with a straight edge. This method is especially useful if the coupling used contains a rubber drive element.

To check offset misalignment, lay the straight edge in line with the shafts on the O.D.'s of the coupling halves. There should be no gaps under the straight edge. Check two locations 90º apart. Angular misalignment can be checked by measuring the gap between coupling half faces. There should be no more than 1/64" gap under the straight edge or 1/64" variation in the gap between coupling halves. See Figures 14 and 15.

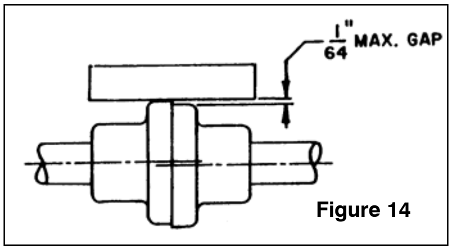

Figure 14

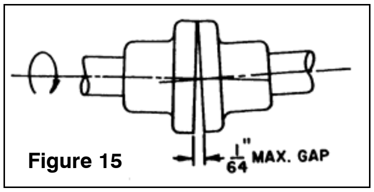

Figure 15

NOTE: Further reference on coupling alignment can be found in Hydraulic Institute, 13th Edition, Pages 117 and 120.

Lubrication – Factors that affect lubrication are inadequate lubrication, excessive lubrication, lubrication type, lubricant compatibility, temperature and contaminated lubricants. A proper lubrication schedule should be established and recorded. National Oilwell Mission centrifugal pump bearings (operating less than 2400 RPM) are fully grease packed during assembly and the bearing cap is packed 1/3 to 1/2 full during pump assembly. The bearings are lubricated with Chevron SRI-2 grease at the factory.

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When re-lubricating, the Chevron grease would be the best choice since mixing greases sometimes causes incompatibility problems. Texaco Premium RB, Shell Dolium-R, Amoco Rycon Premium Grease and Mobilux EP multi-service grease are also acceptable. These have not been accessible in tubes. Greases that are available in tubes and acceptable, in order of preference are: EXXON Unirex N2, Chevron Polyurea EP 2, Texaco Marfac Multipurpose 2, Shell MP (Alvania) 2 and Amoco Rycon Premium 2 EP. [Footnote 1- Appendix]

When using the bearing grease listed above or its equivalent, 5 shots of grease with a standard size hand operated grease gun in each bearing monthly will be sufficient in a 24 hour per day operation. Reduce for lesser operation. Failure to grease the bearings could lead to inadequate lubrication of the bearings and failure. Excessive lubrication of the bearings can result in the frame filling with grease. When the frame is full of grease, heat generated by the bearings cannot be dissipated and could result in bearing failure. Ensure that the grease is free from dirt, water or other contaminants prior to injecting into the bearings.

When cleaning the pump with a high pressure sprayer avoid injecting water under the bearing cap lip seal. If possible allow the pump to cool prior to wash down. Spraying a warm pump with cool water and causing a quick change in temperature can cause a vacuum to occur inside the pump frame and result in water being sucked through the bearing cap lip seals. A breather is installed on the pump frame to help prevent this from occurring and the breather should be inspected to ensure it is not clogged.

The supplied grease is suitable for temperature ranges from -5 to 260˚ F. Contact the factory for temperatures outside this range. Although, the bearings are suitable for operating temperatures up to 250˚ F. Bearing temperatures in excess of 185˚ F should be investigated. Check lubrication, pump and driver alignment and for indications of bearing wear.

Pumps with intended operating speeds above 2400 RPM should be ordered as oil lubricated. Non-detergent 10W30 oil is recommended. The pump must be maintained in a horizontal and level position. Oil levels should be checked regularly and changed every 1-2 months of operation or 1000 hours. Do not overfill the pump as high oil levels could cause churning and overheating of the bearings.

Horsepower Restrictions - It is important to stay within the bearing's rated HP range. The maximum HP rating for a 1 1/8" pedestal is 40 HP, for a 1 7/8" pedestal is 100 HP and a 2 1/2" pedestal is 200 HP. For belt driven 2 1/2" pumps the HP rating should be limited to 150 HP. Belt driven loads are not recommend for 1 1/8" and 1 7/8" pumps.

Mechanical Seals – Mechanical seals are not recommended for 1 1/8" and 1 7/8" pumps transferring fluids with a Sp.Gr. greater than 1.05. The shaft deflection that occurs on these smaller pumps can cause the seal to wear in an irregular pattern and normally results in an insufficient seal life. For applications exceeding this recommendation requiring mechanical seals, Magnum or 2500 Supreme 2 1/2" pumps are recommended.

The seal faces of a mechanical seal require a constant supply of liquid to lubricate the seal faces. A fine film of liquid enters the seal at the OD of the seal face. As it passes across the seal face it lubricates the seal and evaporates by the time it reaches the ID of the seal face. If this liquid supply is interrupted the seal faces can be destroyed in a matter of seconds.

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Failed seals can be examined under magnification to determine the cause of failure. A seal face that is chipped or cracked can be caused be the seal faces separating and then slamming back together. This can happen when cavitation is occurring. A seal with groves worn into the seal faces indicate that the seal faces separated and were contaminated by solid particles and then closed, as seen in Figure 16. Note, the wide groove is a normal wear pattern but the bright grove within the wear pattern is caused by solids contamination. This is also a sign that cavitation is occurring. Cavitation is detrimental to the life of the seal and the pump. The cause of the cavitation must be identified and eliminated.

Figure 16

A seal face that shows large cracks can indicate the seal was run dry, heated up and then was flooded with a cooler fluid creating a thermal shock. Galling, heat checks or a burn odor indicates the seal was allowed to run dry. Figure 17 is an example of heat checks. Only operate the pump when the casing is full of liquid and free from air and air entrained fluids. If it is not possible to run the pump full of liquid at all times a National Oilwell Olympia double mechanical seal is recommended.

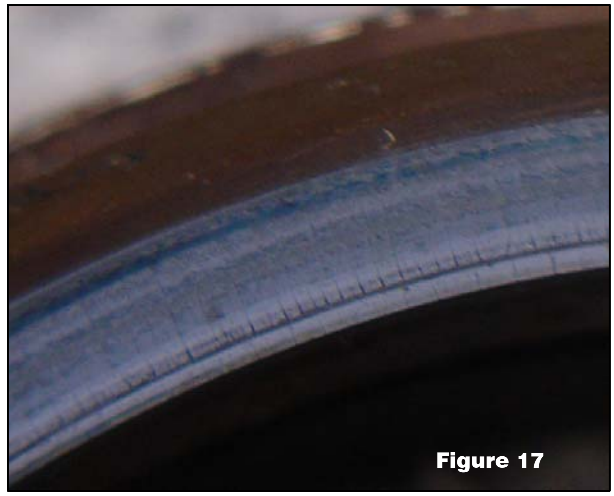

Figure 17

If signs of running dry are present and the pump operator insists the pump has not been run without a flooded suction other factors could be the cause of the problem. When running oil based muds it is important to use a diesel fuel with an aniline point greater than 165. If the aniline point is below 165 the diesel fuel will have a tendency to flash when traveling across the seal face. If the fuel flashes prior to traveling to the ID of the seal then the seal faces run dry. This can also occur when transferring oil based muds with elevated temperatures. Have the aniline point of the diesel fuel checked and ensure that the fuel being utilized has an aniline point greater than 165. If a fuel with an aniline point above 165 is not available or if elevated mud temperatures are unavoidable than an Olympia Double Mechanical seal with barrier fluid reservoir is recommended.

To obtain the maximum life of a mechanical seal avoid the aforementioned problems and ensure the seal is installed properly. Mechanical seal installation instructions are available from National Oilwell. Adjust the impeller to within .025 of the casing prior to installing the mechanical seal. Adjusting the impeller toward the casing after seal installation will cause the bellows to expand. If the bellows is expanded it will not be able to expand further when the seal faces begin to wear and a reduced seal life will occur. When installing the seal ensure the bellow is completely compressed.

National Oilwell's Olympia double mechanical seal is lubricated by the fluid in the barrier fluid reservoir and not by the fluid being transferred. This seal will not be damaged by running the pump dry, oil based muds with low aniline points or high temperature muds.

Shaft Packing – Packing is lubricated in a variety of manners. The packing is grease lubricated, lubricated by the fluid being transferred and in some installations is lubricated by a water flush line. If the lubrication system fails the packing will run dry, heat up, become brittle and fail. Failure can also occur from improper installation methods.

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Packed pumps are equipped with a grease fitting on the side of the stuffing box. The packing should be grease lubricated with quality water based grease every 24 hours of operation. This can be performed manually or a spring loaded grease cup can be installed.

Follow the installation instructions when installing packing. The packing rings should be installed with the split 180 degrees apart from the previous ring of packing with the position of the final ring in the down or 6:00 o'clock position. Therefore with a 6-ring set of packing the first ring of packing should be installed with the split in the up or 12:00 o'clock position, second ring in the down position, third ring in up position and continue until the last ring is in the down position. This configuration helps to prevent excessive leakage and ensures the fluid drips into the pump drip pan and does not run down the shaft towards the bearing cap.

Fluid must be allowed to drip from the packing at a rate of 8-10 drops per minute. This helps to lubricate the packing. When packing is installed the packing gland must only be finger tight. Allow the pump to run for thirty minutes while ensuring the packing continues to drip. Once the packing has reached operating temperatures the packing gland can be slowly adjusted until the pump leakage is reduced to 8-10 drops per minute. Failure to follow these procedures will cause the packing to heat, swell and seal off. If the packing seals off the packing will no longer be lubricated by the fluid and will heat up to a level that it will smoke and burn up. If the packing burns it becomes brittle and will no longer be able to properly seal the pump. When installing packing ensure that the shaft or shaft sleeve is not deeply grooved or pitted. Replace these parts if necessary.

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Appendix

Chevron, Texaco Premium RB, Shell Dolium-R, Amoco Rycon Premium Grease, Mobilux EP, EXXON Unirex N2, Chevron Polyurea EP 2, Texaco Marfac Multipurpose 2, Shell MP (Alvania) 2 and Amoco Rycon Premium 2 EP are trade marks of their parent corporations. This list is a sampling of compatible greases and is not all inclusive. Brands are not ranked in any particular order and National Oilwell does not suggest that any brand is superior to the other.

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