GRUNDFOS

WHITE PAPER

ALIGNMENT

by Greg Towsley

With requirements of organizations to cut costs and manage operation and maintenance budgets better, minimizing equipment downtime has become increasingly important. An aspect of trouble-free operation is the alignment of rotating equipment.

Alignment should be completed on any equipment that has a driver and driven equipment. It should not be standard practice to only align “high energy” or high-speed pumps. ALL pumps should be considered for alignment.

To provide an overview of alignment, the discussion in this article applies primarily to horizontal centrifugal pumps that are operating in a general service and driven by a separate driver through a flexible coupling on a common baseplate.

Many of the terms and techniques described can be used for other types of pumps and rotating equipment, but the installation and operation instructions should be followed as required by the manufacturer.

This article is meant to be used as a primer only. Extensive training and practice should be completed prior to aligning equipment that is in service.

GENERAL

The lack of alignment, or misalignment, is a condition where the rotating centerlines of two or more machinery shafts are not in line with each other. This is not easy to detect when machinery is running. The rotating equipment is aligned following a series of detailed steps of a few alignment techniques.

It can be said that the goal of alignment is to position the equipment so that any deviations of the shaft centerlines are below specified or required criterion. Further, the objective is to minimize equipment downtime and maximize the operating life of the rotating equipment.

Misalignment of rotating equipment can have many affects on the equipment and the entire system. As can be seen in *Figure 1*, the greater the misalignment, the greater the reduction in time the equipment can continuously run until failure; the lower the misalignment, the greater the length of time between failure due to the effects of misalignment.

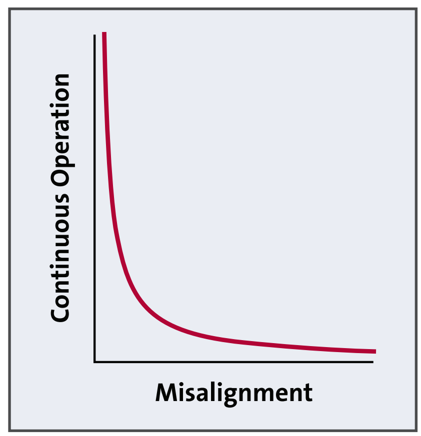


Figure 1. *Impact of Misalignment on Continuous Operating Life*

Some of the affects of misalignment include:

- Bearing life of the pump and the driver can be reduced due to misalignment causing high temperature or oil leakage.
- Although flexible coupling manufacturers advertise that their design can compensate for misalignment, mechanical seals can fail due to alignment that is not within the mechanical seal manufacturer’s recommendations.

- Shaft failure or breakage can occur if the equipment is grossly misaligned.
- Excessive misalignment can cause the most durable and best-designed couplings to wear quickly or even fail. Damage to a coupling insert can be seen in *Figure 2*.
- Other components with internal clearances within the pump, such as impellers, wear rings, and casings can wear prematurely.
- Misalignment may cause the pump and driver to operate with excessive or unusual noise.
- Vibration may also be observed due to misalignment. However, the vibration data must be carefully analyzed before the blame is put on misalignment. Misalignment may still be present but not seen in the vibration data if forces of the rotating equipment are acting in the same direction to dynamically balance the unit during operation.

Some failures that are initially attributed to physical setup misalignment may actually be caused by other mechanical deficiencies. Bent shafts going unnoticed can cause the equipment to be misaligned.

Deficiencies in the coupling components, such as a distorted hub, an eccentric hub bore, or an out-of-square hub bore may also cause the equipment to be misaligned. If the equipment is not aligned with the consideration of temperature change, the equipment may "grow" during operation and become misaligned.

Although the equipment is typically aligned or the alignment is checked at the factory prior to shipment, proper final alignment is the responsibility of the installer and user of the unit. Those with final responsibility cannot allow the flexible coupling to compensate for misalignment.

The installing technician or contractor should be made aware of and understand the specification and the alignment goals before beginning the work. In addition to understanding the alignment goals, the installation instructions for the pump, driver, and coupling should be reviewed.

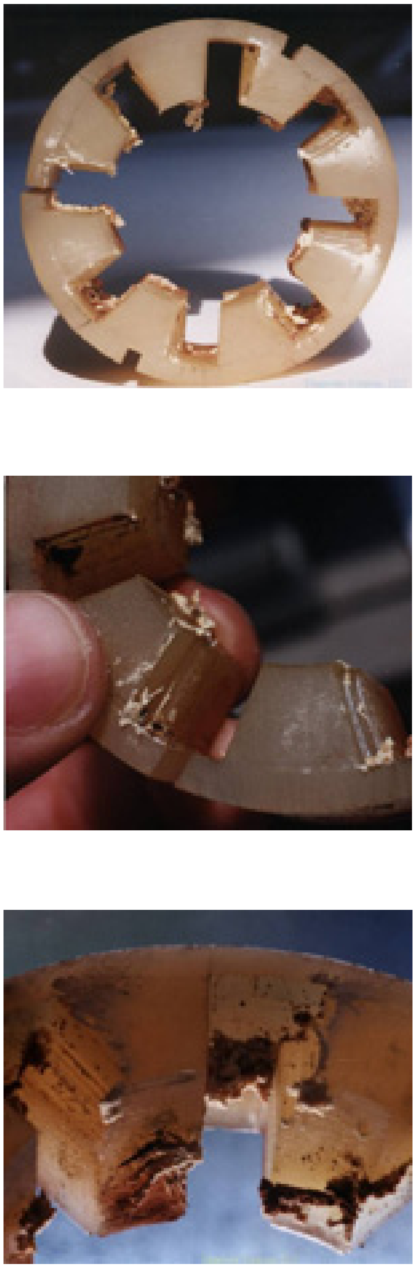


Figure 2. *Coupling Insert Damaged by Misalignment*

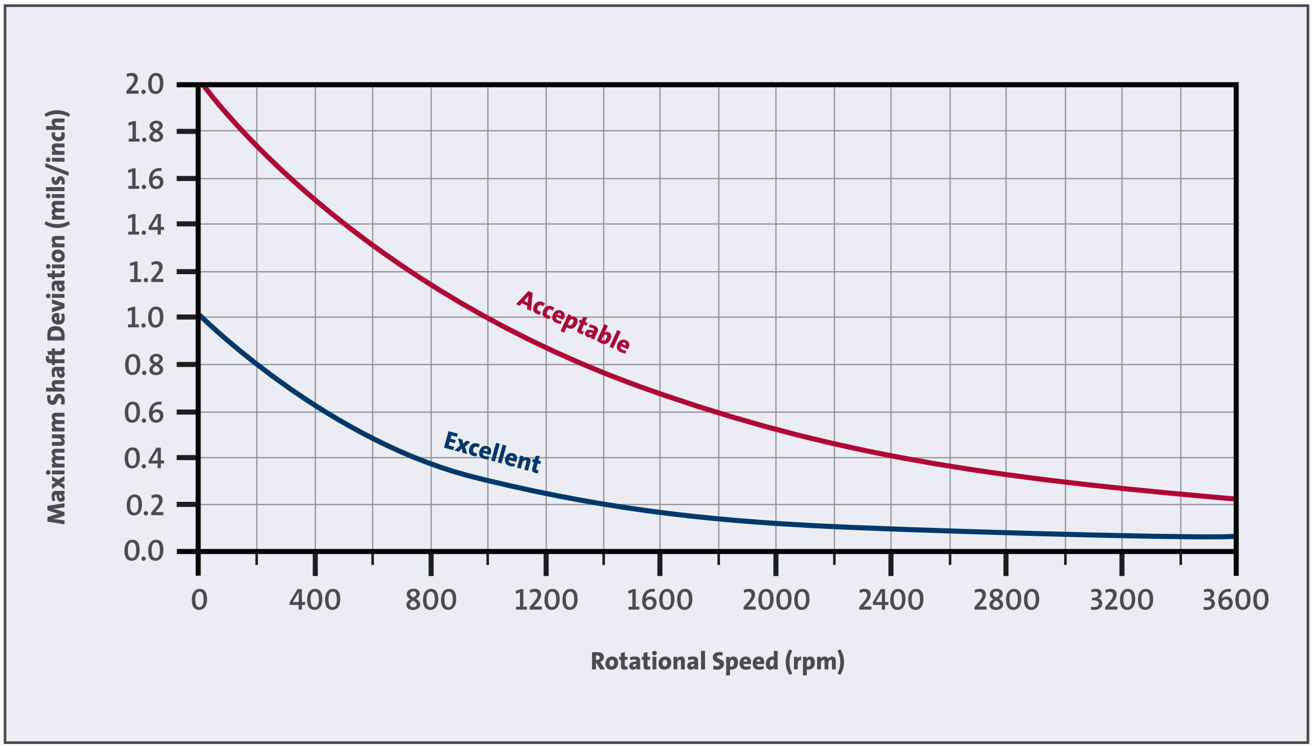


Figure 3. *Alignment Tolerance Chart*

If using hired contractors for alignment, a clause in their contract may be considered that requires them to provide initial alignment data, soft foot conditions, corrections made to the equipment, runout of the equipment shafts, final alignment data, and any moves made on equipment.

The equipment user must establish a specification for acceptable alignment that will provide a guideline for those installing rotating equipment. A chart, similar to that shown in *Figure 3*, can be developed to provide alignment guidelines.

The specification must include a dependable and repeatable process that will insure a reliable installation. The alignment tolerance that is included in the specification should consider the shaft operating speed, shaft length, and the severity of the installed service.

Included within the procedure should be information on documentation. This documentation should include, at a minimum, alignment forms and diagrams of the before and after alignment data. This information should be filed with the equipment file for future reference.

An important part of alignment is having the proper training and the proper tools. No matter what method of alignment is used, the dial indicators and lasers do not do the alignment – human beings do the alignment.

With proper extensive training and practice, and the correct tools for the job, equipment alignment can take less than 60 minutes. Because of the criticality of alignment to rotating equipment, an organization should not skimp on costs of the necessary tools and training.

ALIGNMENT TERMS

There are a few basic terms used in alignment that should be reviewed. The specific terms discussed in this section are important to a successful installation.

ANGULAR MISALIGNMENT

Angular misalignment is the term used when two shaft centerlines are at an angle to each other, as shown in *Figure 4*. Angular misalignment can occur in the horizontal or vertical plane of the shafts. A typical objective is to obtain angular misalignment to less than 1°.

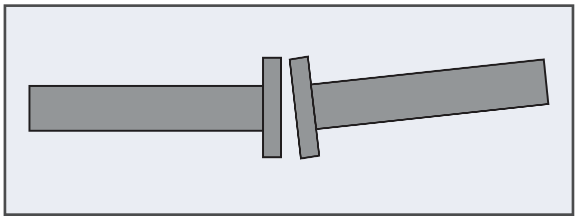


Figure 4. *Angular Misalignment*

PARALLEL MISALIGNMENT

When the equipment shaft centerlines are parallel, but are offset from each other, as shown in *Figure 5*, it is called parallel misalignment. This type of misalignment can also occur in the horizontal or vertical plane.

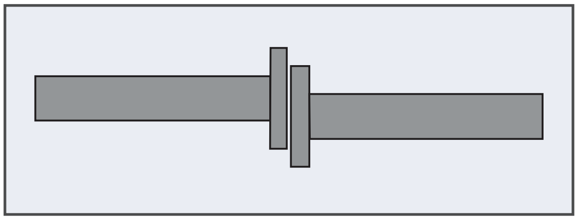


Figure 5. *Parallel Misalignment*

It is important to note that equipment shafts can have angular and parallel misalignment simultaneously. Both must be considered for a successful installation.

BOLT BOUND

The term "bolt bound" is used to describe a condition that occurs during the alignment process, where the driver or pump cannot be moved any further. The best method to resolve this problem is to fill-weld the existing bolt hole, redrill in the proper location, and retap. This problem can also be resolved by removing the problem equipment and increasing the diameter of the mounting holes in the feet.

SHIMS

Shim stock or precut shims are used to raise the driver during the alignment process. The proper shimming of the driver should occur only after the installation of the baseplate has been finalized and the connection of the piping to the pump is completed.

Typical of the baseplate manufacturers, a minimum of 0.125" shim under the driver feet will allow for proper alignment. Although a minimum is recommended, it must be noted that too many shims may make the installation "springy". A stack of the same size of shims, as shown in *Figure 6*, should have five or fewer shims of the same size. The precut shims should be sized to fit the bolt of the equipment feet. The stack should also have the thinner pieces of shim sandwiched between the thicker pieces.

The use of homemade carbon steel shim is not recommended. In addition to the possibility of rusting, the cut carbon steel may have inconsistency in its thickness, thereby causing a soft foot.

Precut shim of 304 Stainless Steel material is available. These precut shims usually have the thickness measured and the exact thickness is etched on the shim. Although the thickness may be marked on the shim, the thickness should be double checked before installation.

Figure 6. *Precut 304 Stainless Steel Shim*

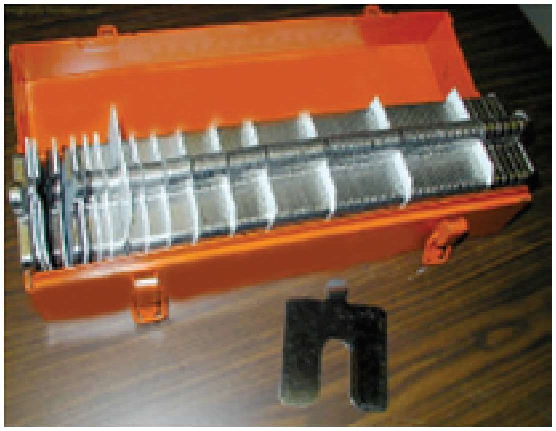


Figure 7. *Field Box of Precut Shim*

These precuts shims may come in a convenient box that contains many sizes, as seen in *Figure 7*. Besides 304 stainless steel, precut shim is also available in Mylar for pumps that are in chlorine or hydrochloric acid services.

For proper use and installation of the shim, the mounting pad and the equipment feet must have a smooth surface, free of burrs, and milled flat. The shim is inserted until contact is made with the bolt, and then moved back away from bolt to insure proper clearance.

SOFT FOOT

Soft foot is a condition that occurs when one or more equipment feet are not firmly on the sole-plate or baseplate. With a soft foot condition, the equipment will have a tendency to move during operation. Soft foot should be corrected before final alignment and operation.

There are a number of different types of soft foot. It is important to identify the type of soft foot condition that is present. The method to correct the soft foot depends upon the cause of the soft foot. Using the wrong method to correct the soft foot may intensify the problem and make it worse.

Soft foot can initially be found using feeler gauges. Prior to tightening the equipment feet down or shimming, feeler gauges should be used to measure the gap under each corner of the same foot. The readings at each location under each foot will provide information about the type of soft foot condition.

Parallel Air Gap or Short Foot

The most common soft foot condition is a parallel air gap, or short foot. This condition is identified when there is an equal gap at all four corners of a foot. A short foot can occur when one leg of the driver is too short, when the foot mounting pad is not in the same plane as the other(s), or the foot has an inadequate amount of shim under it. If the alignment process has been started, and an accurate or consistent alignment cannot be obtained, it is likely that there is a soft foot condition present.

To check for the parallel air gap, set up the dial indicator on a foot and loosen mounting bolt. If the foot moves more than 0.002", or the soft foot standard defined by the user, the foot is considered soft and needs to be corrected. This should be done for all feet and documented.

The following example is typical for correcting parallel air gap or short foot. *Figure 8* shows a view of a motor with various parallel air gap measurements at each foot. It should be assumed that the gap shown is the same under each corner of the foot.

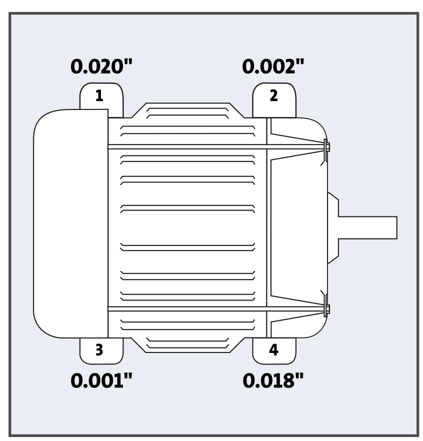


Figure 8. *Soft Foot Elimination Example*

To calculate the amount of shim to add to compensate for the short foot, the sum of the smaller gap values are subtracted from the sum of the larger gap values.

This amount is divided by two. Use 80% of the quotient as the amount of shim that should be added under each foot to remove the parallel air gap. The equation can be shown as:

$$\text{Shim to add under Foot \#1 and Foot \#4} = \left[\frac{(gap_1 + gap_4) - (gap_2 + gap_3)}{2}\right] \times 0.80$$

$$= \left[\frac{(0.020" + 0.018") - (0.002" + 0.001")}{2}\right] \times 0.80$$

$$= \mathbf{0.014"}$$

Shim, in the amount of 0.014”, should be added under Foot #1 and Foot #4. Recheck by following the same procedures initially described.

Bent Foot

A bent foot is a type of soft foot that occurs when the bottom of foot is not coplanar, meaning that the foot slopes from one corner to another. The best way to correct bent foot is to remove the equipment and machine the foot, the baseplate, or possibly both.

If the correction must be made in the field, then the shims used in alignment must be stepped to correct the slope. Depending upon the size of the foot and the amount of slope in the bent foot, 4-6 shims may be stepped to match the slope of the foot. Additional modifications to shim may have to be made for the proper slope.

If rise of foot is from the outside going in, all of the equipment feet must be machined coplanar. This type of bent foot cannot be fixed in the field. Unless the feet are machined, it will always deform when tightened.

Squishy Foot

A squishy foot occurs when dirt, grease, paint, rust, or other foreign materials are on the shim, the base, or the equipment foot. The only solution to squishy foot is to clean the parts and materials.

DIAL INDICATORS

Dial indicators are used to measure the amount of misalignment between the equipment. A dial indicator (*Figure 9*) can assist in determining alignment within ±0.001”. The dial indicators come from the manufacturer pre-calibrated, and must be rechecked on a regular schedule.

Shaft alignment kits are available starting at approximately $600.00. These kits will contain two

Figure 9. *Dial Indicator With Alignment Fixture That Clamps to a Shaft*

(2) alignment frames, roller chain, two (2) dial indicator assemblies with swivel joints and mounting rods, tubing of varying lengths, instruction manuals, alignment worksheets, and a sturdy carrying case with handle. This type of kit will handle the vast majority of shaft alignment situations.

When initially getting ready to use a dial indicator, make sure that it works properly and can travel the full range of the indicator.

Upon installation of the indicators and at the beginning of the process, note the direction that the indicator travels. The indicator should be adjusted to start at zero (0.000").

The indicator needle traveling clockwise is considered positive, while counterclockwise is considered negative travel.

During the alignment process and a full 360° sweep, the summation of the left and right side readings should equal the summation of the top and bottom readings.

In addition, the indicators should have read the same reading (0.000") when it reaches the original position.

BAR SAG

Bar sag is a deflection that occurs in the overhung indicator bar due to the bar's weight and the weight of the indicator. Because of the precision that is required for alignment, the bar sag must be compensated for.

To determine the amount of bar sag, mount the indicator on a pipe in same approach, distance, etc. as it will be mounted on equipment shaft. Next, zero the indicator on top. Then roll the dial indicator 180°, so that it is located at the bottom. Read the indicator.

During the alignment process, this bar sag amount must be included in your alignment calculations. Instead of zero on the top of the dial indicator, dial in the positive value of the bar sag reading. During the alignment process, the dial indicator should read zero when rolled to bottom.

ALIGNMENT BASICS AND PRELIMINARY CHECKS

There are a number of different tasks to complete and check prior to doing the actual alignment. The preparation for alignment can be as important as the alignment itself. Approximately 85% of the time spent in aligning equipment is with preliminary checks, repositioning the equipment and post alignment documentation. The alignment basics and preliminary checks apply to all alignment methods.

To insure accuracy and speed of the alignment, the equipment should be aligned three times. The first time should be during the installation process (preliminary).

Next, the equipment should be final aligned after it is piped and before the start up of the equipment. Finally, the alignment should be checked when the equipment is hot, after running for a time.

Safety of personnel is important during any part of the alignment process. The first step is to lock out and tag all driver controls and isolation valves. Other safety regulations required at the installation site must be followed.

As people are doing the alignment of the critical equipment, it is imperative to make sure that they have the proper training to complete precision alignment.

A properly trained technician in the fundamentals of alignment will not only provide a quality alignment, but also should do it in a timely fashion, exceed the recommended standards, and do it right the first time.

The tools used in alignment are also important. If using dial indicators to align, calibrated indicators are required with the additional equipment used to hold the indicators in place. Laser alignment kits are typically complete with all the necessary alignment diagnostic equipment.

Additional alignment tools include a straight edge, a feeler gauge and a taper gauge. Of course, the necessary tools to loosen and tighten bolts, clean parts, and move equipment are also required.

Information about the equipment should also be reviewed before the alignment begins. This includes the recommendations of the manufacturers, as well as technical information on the equipment that may have been taken previously.

Preliminary checks of the equipment, including soft foot, pipe stress, and equipment condition should be taken to insure that these would not cause the equipment to become misaligned.

Measurements of the shaft positions should be taken. The pump and driver shafts should be checked for runout. The shaft runout should not exceed 0.002" T.I.R. The clearance in bolt holes in equipment feet should be adequate to allow movement of the equipment.

Pipe stress can have as much or more affect than soft foot on misalignment. When installing piping in a system, the piping must start at the pump connections and be erected away from the pump. Pipe stress on a pump can prevent a pump from being properly aligned. This problem can be prevented during the original construction.

A preliminary alignment check should be done before grouting to ensure alignment can be obtained. This can be done during fabrication or at the installation site. The equipment feet must be free of dirt and scale. Confirm that the driver can be adjusted by being lowered or moved side to side. The check must be made with the equipment at ambient temperature. The pump must also be disconnected from all pipe during this preliminary alignment check.

The pump and driver must be installed on a good baseplate and the proper foundation. Final alignment should be completed only after the grouting has cured during the unit installation. This is to ensure that no changes have occurred during the grouting process.

The pump and driver coupling hubs should then be installed with the proper gap per the coupling manufacturer's installation instructions.

Each shaft must turn freely with hubs installed on the shaft. Confirm that the face and outside diameters of the coupling hubs are square and concentric with the coupling bores.

Spacer type couplings are aligned with the spacer element removed from the coupling. Gear type couplings are aligned with the same alignment methods, except that the coupling covers must be moved back out of the way of the alignment work.

A preliminary check of the angular measurement of the coupling gap should be made with a feeler or taper gauge, or other tool. In lieu of a feeler gauge, a measurement of the distance can be taken between the hubs.

The clearance that is being confirmed is shown in Figure 10. For this preliminary check, do not rotate either shaft. The check should be made at 90° intervals in four places, typically at 0°, 90°, 180°, and 270°. If possible, adjust the alignment of the equipment until within 0.002" T.I.R. or less at all four locations.

The preliminary check of the parallel alignment is next. A straight edge can be used to check parallel offset as shown in *Figure 10*. Again, do not rotate either shaft, and check the parallel alignment in four places at 90° intervals. Check the alignment on the horizontal axis first, then the vertical axis.

During preliminary alignment or final alignment, always recheck alignment after any alteration. Movement in one direction may alter alignment and modifications made in another direction.

The parallel offset should be rechecked if any adjustments are made to the angular alignment. The angular alignment should be rechecked after any adjustments are made to the parallel alignment.

After the preliminary alignment is completed, the piping, ductwork, etc. can be attached. Any stress found at the pipe connections should be removed. The horizontal stress in the piping should be relieved first. This can simply be done by loosening all bolts at the pump flanges and looking for movement. Make adjustments to pipe hangers and supports as necessary.

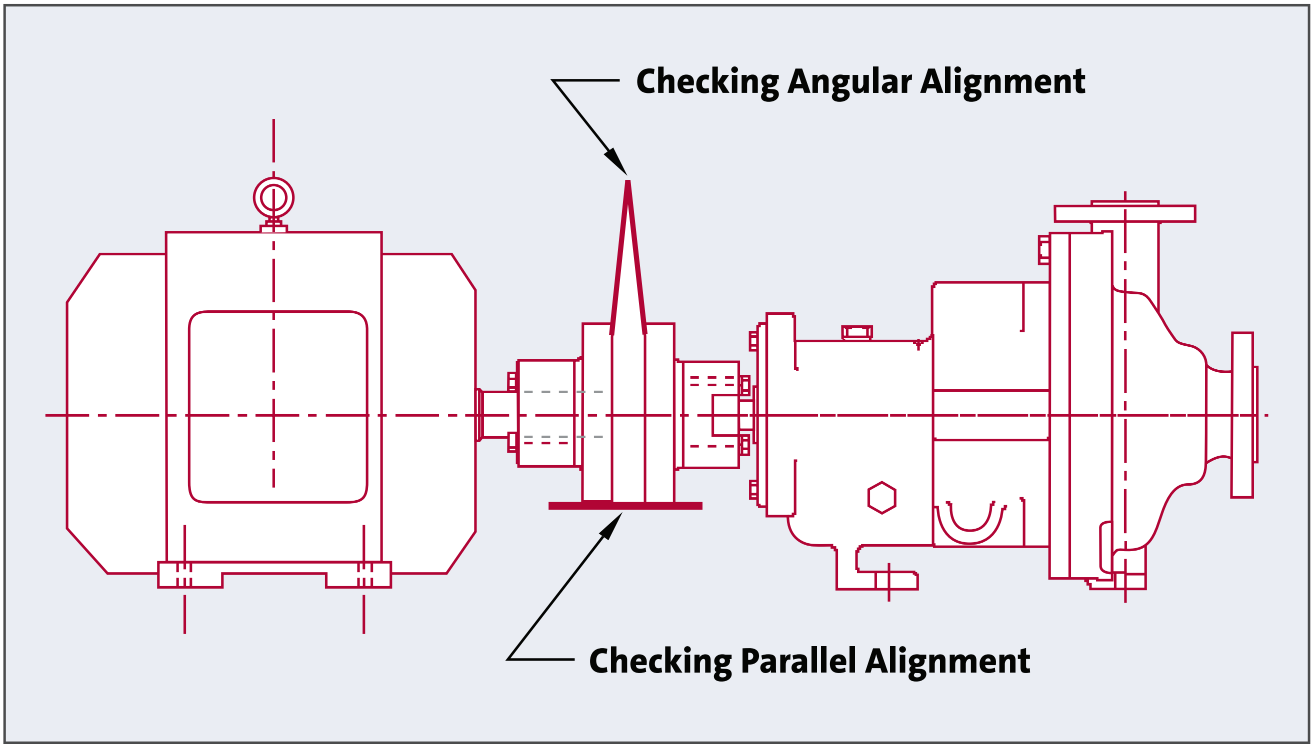


Figure 10. *Preliminary Alignment Checks*

The vertical piping stress should be relieved next. Make any modifications to relieve the horizontal or vertical stresses in stages. The stresses are only partially relieved the first time. Additional modifications should follow.

The final alignment of the equipment is done after the grout is set, the piping is in place, and the baseplate bolts tightened to the foundation.

Although the coupling installation instructions may allow for greater misalignment, the alignment should be within 0.004” in all directions, or as required by the manufacturer or user specification.

Methods for final alignment include Rim and Face, Reverse Dial Indicator, and Laser. The Rim and Face method can be used with the simplest of installations.

It is recommended that the Reverse Dial Indicator or Laser Alignment methods be used when the shaft separation between the equipment is greater than 50% of the outside diameter in which the dial indicators contact the coupling hub rim. A summary of each of these methods is described below.

RIM AND FACE METHOD

The Rim and Face alignment method is typically used when it is not possible to rotate both shafts or if there are space limitations.

A disadvantage of this method is that the dial indicators are running on the surface of the coupling hub. The hub may have flaws, such as surface defects or eccentricity that may make alignment difficult.

The goal for Rim and Face alignment is 0.002” T.I. R. or less when the pump and driver are at operating temperature.

This method will obtain an offset reading on the outside diameter (rim) of the driver coupling hub and an angular reading at the coupling hub face, and will use these readings to mathematically or graphically adjust the driver to the required location for alignment.

Figure 11 provides a view of the set up of the Rim and Face Method. The indicator bar can also be mounted on the pump shaft if room allows.

Figure 12 shows the dimensions and readings that are required for alignment using the Rim and Face Method. Following are definitions used with the Rim and Face Method.

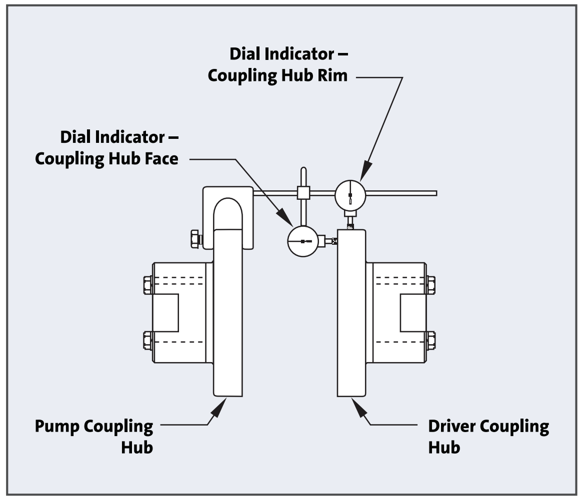


Figure 11. *Rim and Face Indicator Setup*

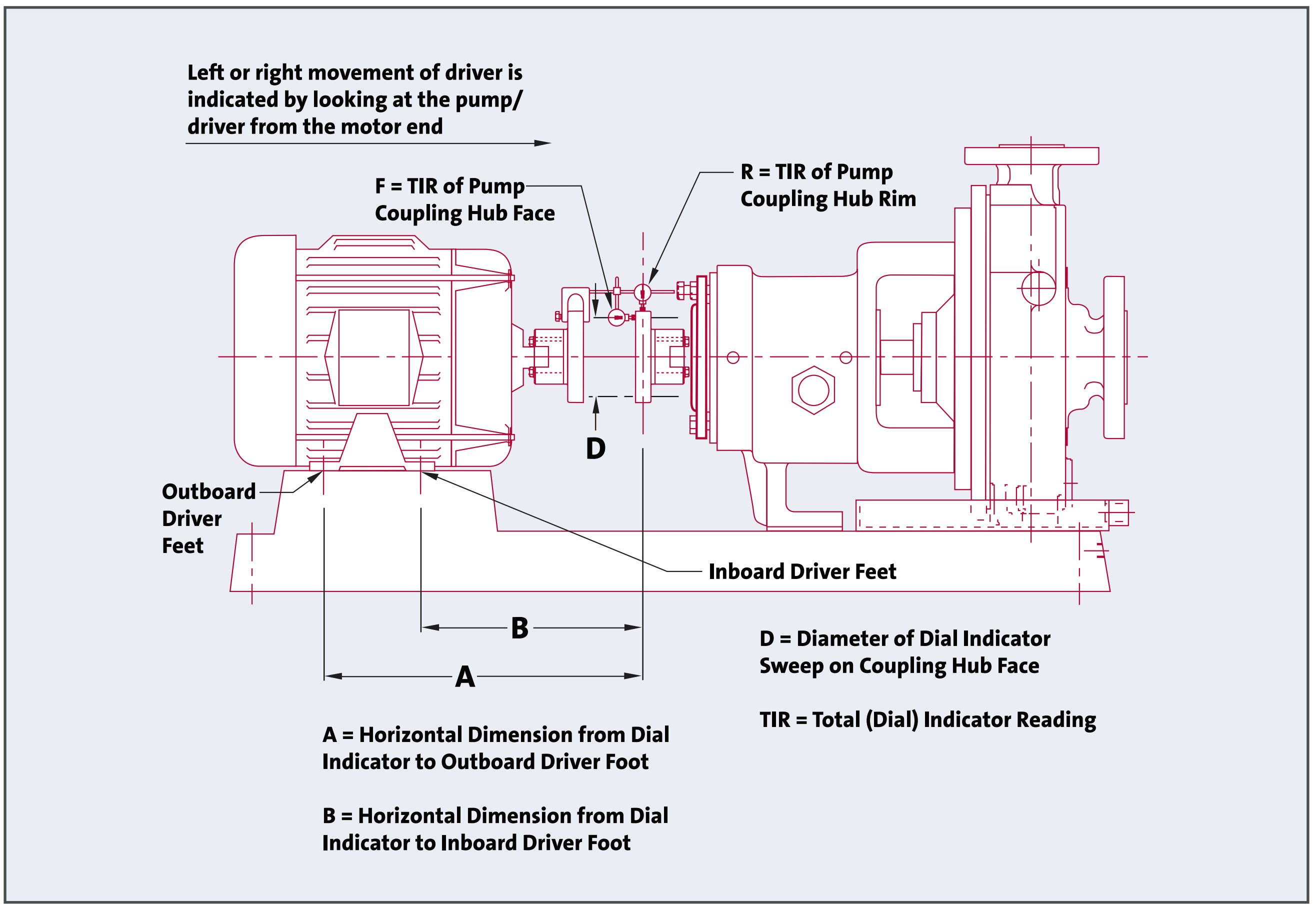


Figure 12. *Rim and Face Method – Layout*

DEFINITIONS

IB	Inboard (towards pump) driver feet
OB	Outboard (away from pump) driver feet
A	The horizontal distance from the rim dial indicator location to the centerline of the bolt for the outboard driver feet
B	The horizontal distance from the rim dial indicator location to the centerline of the bolt for the inboard driver feet
D	The diameter of the dial indicator sweep on the pump coupling hub face
TIR	Total Indicator Runout
F	The TIR of the pump coupling hub face
R	The TIR of the pump coupling hub rim

Two formulas are used in determining the movement required of the driver. Equations 2 and 3 define the adjustments needed for the inboard (IB) and outboard (OB) driver locations. These formulas will be used for horizontal movement, using the horizontal dial indicator readings, and for the vertical movement, using the vertical dial indicator readings.

$$\text{IB Movement} = \frac{F \times B}{D} - R$$

Equation 2. *Inboard Driver Movement*

$$\text{OB Movement} = \frac{F \times A}{D} - R$$

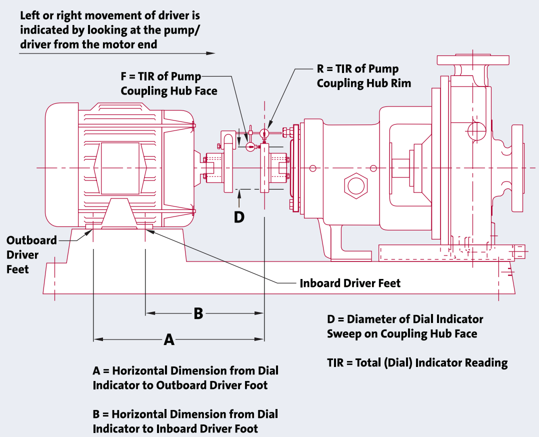
Equation 3. *Outboard Driver Movement*

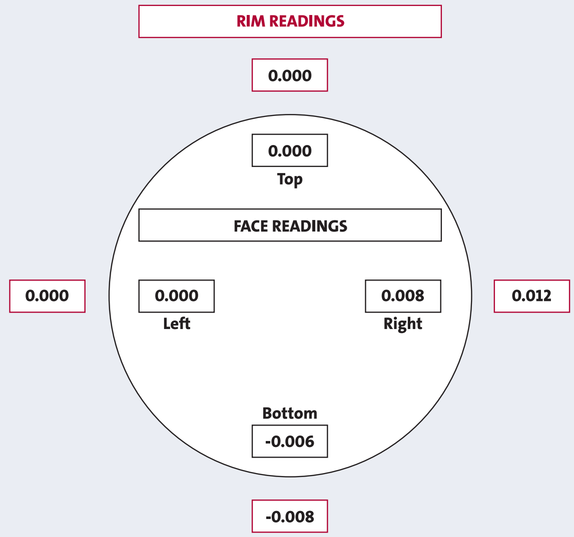
When considering horizontal movement of the driver, the movement to the left or right is based on the view from behind the driver, looking towards the pump.

RIM AND FACE ALIGNMENT PROCEDURE

Following is the procedure to align equipment utilizing the Rim and Face Method.

1. Eliminate Soft Foot
   a. Determine if a soft foot condition is present. Follow the procedures to remove the soft foot condition if it exists.
2. Confirm Bar Sag
3. Align Driver from Left to Right
   a. Set up the dial indicators as shown in *Figure 11*.
   b. Record measurements “A”, “B” and “D” as shown in *Figure 12*.
   c. “Zero” the rim and the face dial indicators to 0.000” at the 9 o’clock position of the couplings, as viewed from the motor end. Reference the dial indicator diagram in *Figure 13*.
   d. Rotate the indicators on the driver shaft 180° until they are in the 3 o’clock position.
      i. Note the direction of the movement of the needles on the indicators.
      ii. Clockwise movement of the needle is considered positive (+).
      iii. Counterclockwise movement of the needle is considered (-).
   e. Determine the amount of horizontal movement of the IB and OB of the driver
      i. Make adjustments to the readings with respect to the Bar Sag.
      ii. Utilize *Equation 2* and *Equation 3* to determine the amount of movement.





	Inches
A =	26
B =	16
C =	4

Horizontal Driver Movement	Positive (+) = Left Negative (-) = Right
$IB_{Horizontal}$ =	0.026
$OB_{Horizontal}$ =	0.046

Vertical Driver Movement (Add or Remove Shim)	Positive (+) = Add Negative (-) = Remove
$IB_{Vertical}$ =	-0.020
$OB_{Vertical}$ =	-0.035

IB = Inboard

OB = Outboard

$$IB_{Movement} = \frac{(FaceValue)xB}{D} - (Rim\ Value)$$

$$OB_{Movement} = \frac{(FaceValue)xA}{D} - (Rim\ Value)$$

Figure 13. *Rim and Face Alignment Worksheet*

iii. A positive (+) value of the $IB_{Horizontal}$ or $OB_{Horizontal}$ requires the driver to be moved to the left, as looking toward the pump from behind the driver.

iv. A negative (-) value of the $IB_{Horizontal}$ or $OB_{Horizontal}$ requires the driver to be moved to the right, as looking toward the pump from behind the driver.

f. Make adjustments to the driver. Tighten all motor bolts using a torque wrench. The same torque on all mounting bolts reduces the influence of deformities in the motor feet.

4. Align Driver Vertically

a. The dial indicators should still be set up as shown in *Figure 11*.

b. "Zero" the rim and the face dial indicators to 0.000" at the 12 o'clock position of the couplings, as viewed from the motor end. Reference the dial indicator diagram in *Figure 13*.

c. Rotate the indicators on the driver shaft 180° until they are in the 6 o'clock position.

i. Note the direction of the movement of the needles on the indicators.

ii. Clockwise movement of the needle is considered positive (+).

iii. Counterclockwise movement of the needle is considered (-).

d. Determine the amount of vertical movement of the IB and OB of the driver

i. Make adjustments to the readings with respect to the Bar Sag.

ii. Utilize *Equation 2* and *Equation 3* to determine the amount of movement.

iii. A positive (+) value of the $IB_{Vertical}$ or $OB_{Vertical}$ requires the driver to be raised, utilizing additional shims as required.

iv. A negative (-) value of the $IB_{Vertical}$ or $OB_{Vertical}$ requires the driver to be lowered, by removing the unnecessary shims as required.

e. Make adjustments to the driver. Tighten all motor bolts using a torque wrench. The same torque on all mounting bolts reduces the influence of deformities in the motor feet.

5. Recheck the horizontal alignment to insure that all alignments are acceptable.

6. Document the final readings on an alignment form or data sheet, and file accordingly.

REVERSE DIAL INDICATOR METHOD

The Reverse Dial Indicator method of alignment is the most common type of alignment, and is recommended for most all installations.

The reverse dial indicator method uses the relative measurement of the centerlines of two opposing shafts. This method acquires two indicator readings across the coupling.

These readings are used to mathematically or graphically assist in determining the required adjustments and shimming for each foot of the driver, or moveable unit.

Measurements will be taken in the horizontal and vertical planes of the shafts. The indicators will be set up in a similar fashion as shown in *Figure 14*.

One indicator is mounted on each shaft and mounted 180° opposite each other. When reading the indicators, it is important to watch the direction from "zero" that the needle travels.

Travel to the right, or greater than zero (0), is considered positive (+). Travel of the needle to the left, or less than zero, is considered negative(-).

As graphing is one method in determining the alignment of the equipment in the Reverse Dial Indicator method, it is important to have consistency between the installation, pictures and the graph paper.

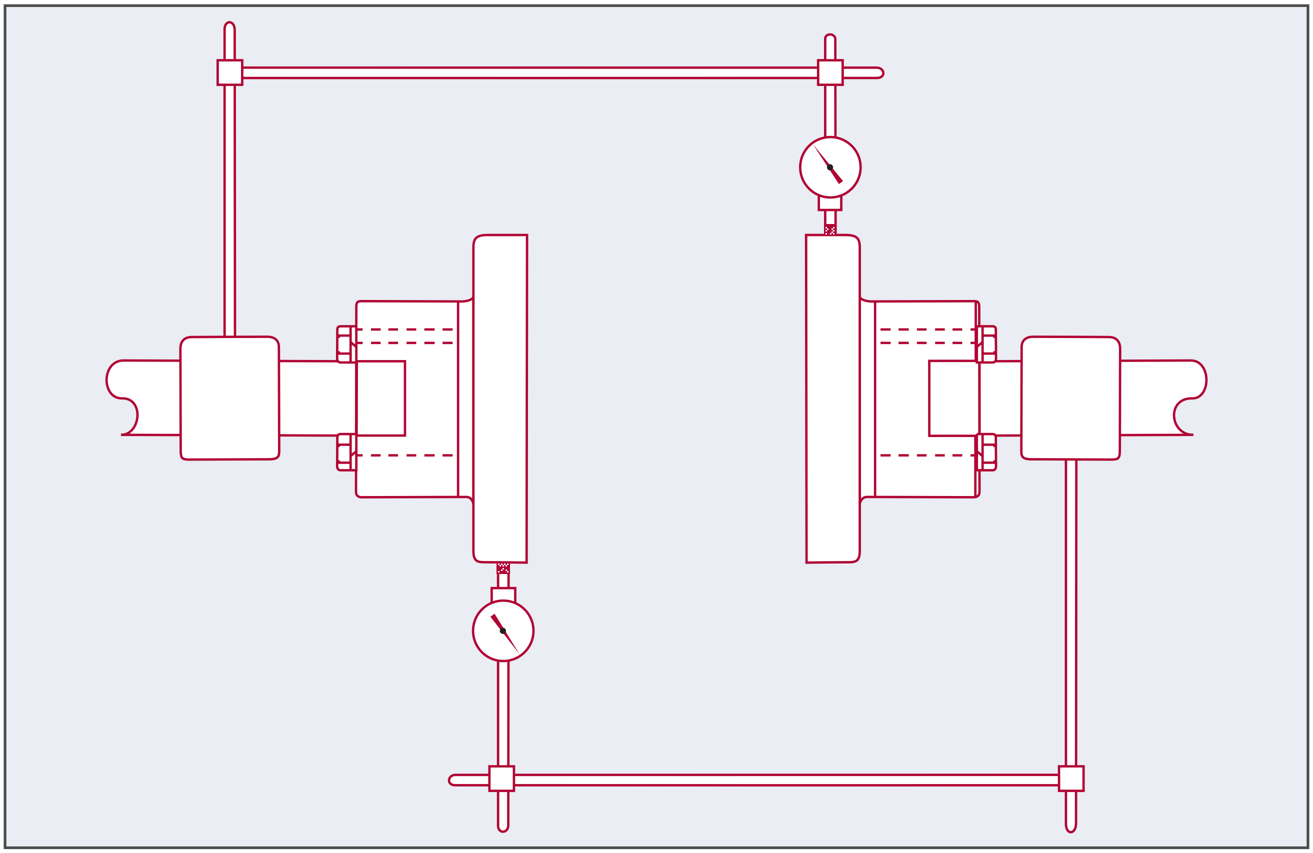


Figure 14. *Reverse Dial Indicator Method*

For this article, the moveable (driver) unit is considered to be on the right side of the installation, pictures and graph paper.

Plain graph paper can be used for plotting the information. A worksheet, as shown in *Figure 15*, can be set up to show the installation and allow for graphing the solution.

The slope method is used to determine the required adjustment. The three equations below are used in the calculations of the adjustments.

$$m(\text{slope per inch}) = \frac{[\text{Stationary Unit Reading} + \text{Movable Unit Reading}]}{2A}$$

Equation 4. *Slope*

$$\text{IB Foot Change}_{\text{Vertical}} = [m \times (A + B)] + (\text{Stationary Unit Reading})$$

Equation 5. *IB Foot Vertical Adjustment*

$$\text{OB Foot Change}_{\text{Vertical}} = [m \times (A + B + C)] + (\text{Stationary Unit Reading})$$

Equation 6. *OB Foot Vertical Adjustment*

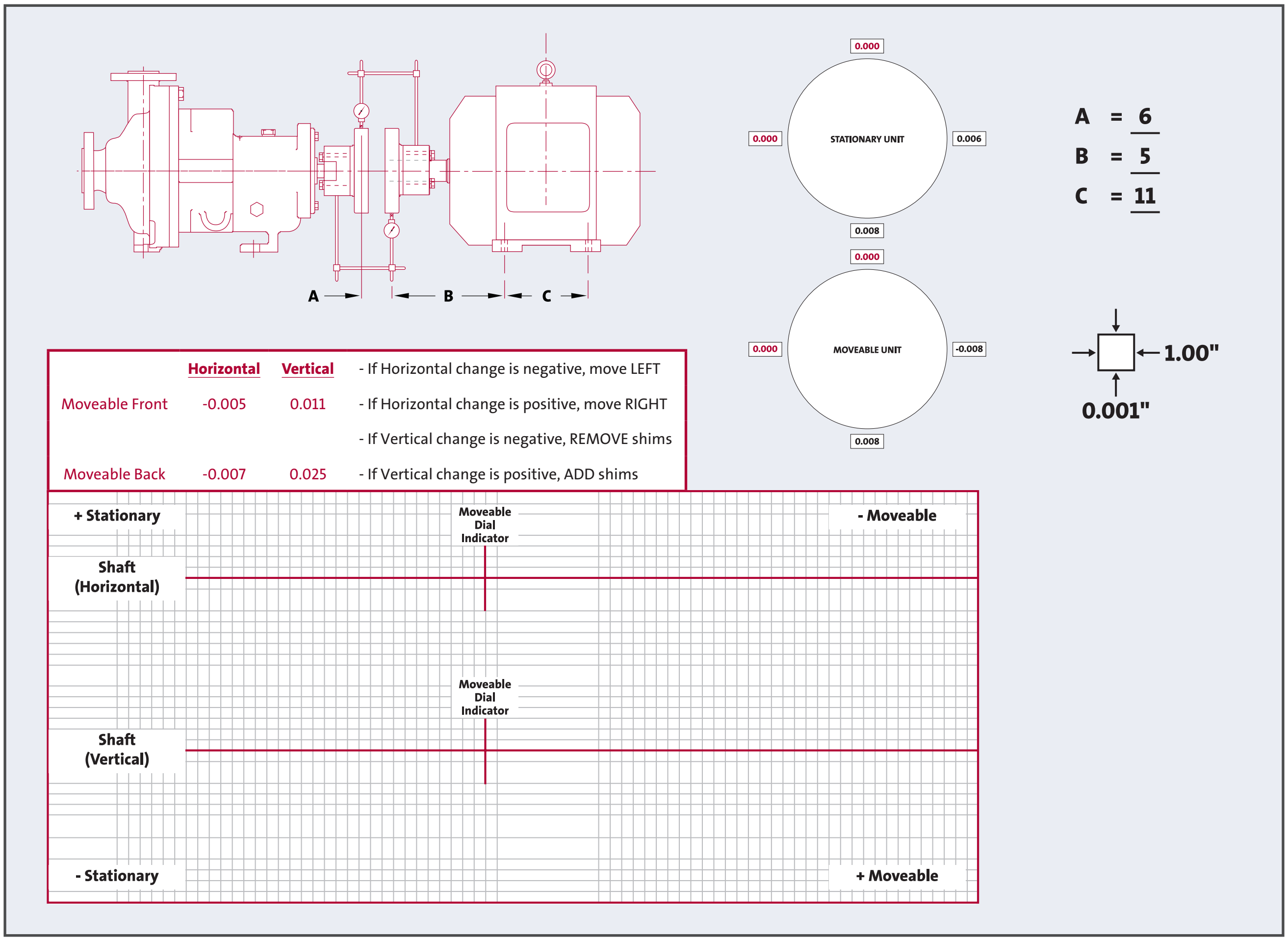


Figure 15. *Reverse Dial Indicator Alignment Worksheet*

REVERSE DIAL INDICATOR ALIGNMENT PROCEDURE

Following is the procedure to align equipment utilizing the Reverse Dial Indicator Method. Note that some steps are identical to the Rim and Face Method.

1. Eliminate Soft Foot
   a. Determine if a soft foot condition is present. Follow the procedures to remove the soft foot condition if it exists.
2. Confirm Bar Sag
3. Align Driver from Left to Right (horizontal)
   a. Set up the dial indicators as shown in *Figure 16*.
   b. Record measurements “A”, “B” and “C” as shown in *Figure 16*.
   c. Using graph paper with square grids, utilize the width of a square as 1 inch, and locate the dial indicator locations and moveable feet on the shaft line accordingly.

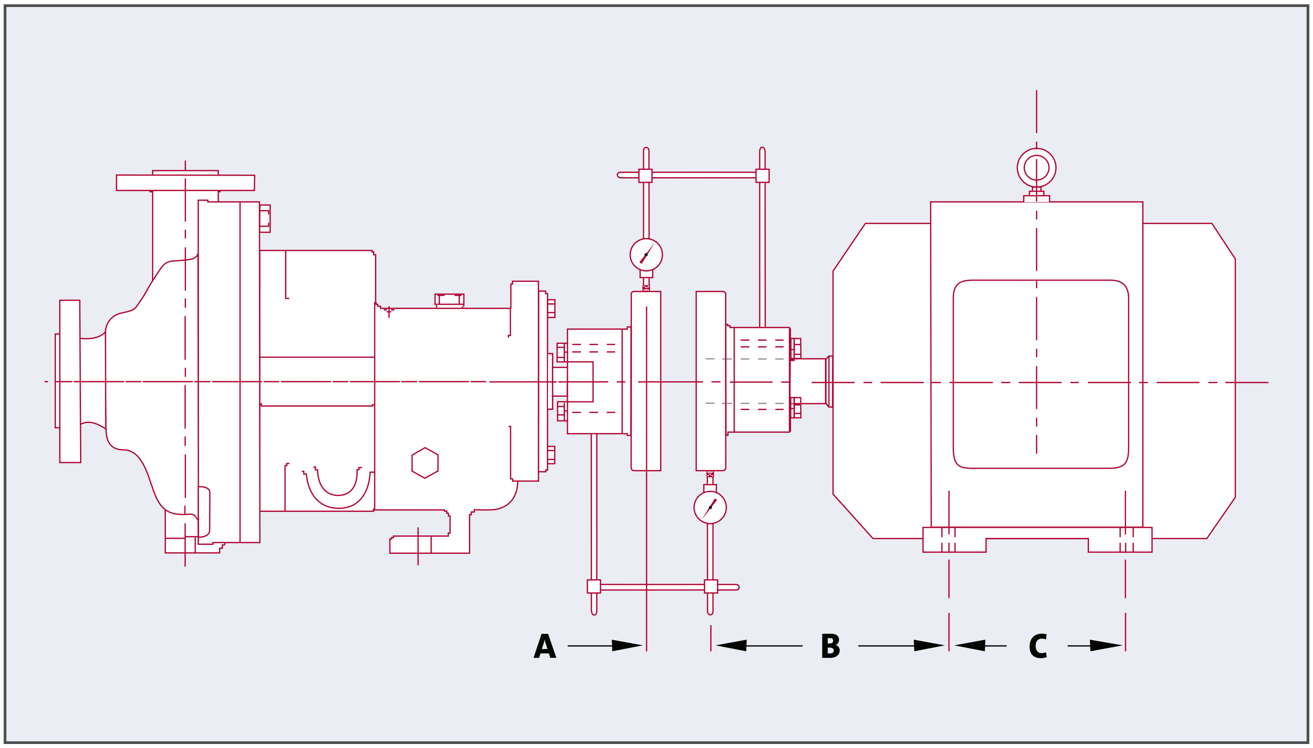


Figure 16. *Reverse Dial Indicator Setup*

d. "Zero" the rim and the face dial indicators to 0.000" at the 9 o'clock position of the couplings, as viewed from the motor end. Reference the dial indicator diagram in *Figure 15*.

e. Rotate the indicators on the driver shaft 180° until they are in the 3 o'clock position.

    i. Note the direction of the movement of the needles on the indicators.

    ii. Clockwise movement of the needle is considered positive (+).

    iii. Counterclockwise movement of the needle is considered (-).

f. Determine the amount of horizontal movement of the IB and OB of the driver.

    i. Utilizing the Reverse Dial Indicator graph, mark the points that are half the indicator readings under their positions. A vertical square should be considered 0.001".

    ii. Draw a line connecting these two points, and extending to a point below or above the moveable feet positions.

    iii. The graph will show how much the feet will be required to move, based on a vertical square being considered 0.001".

    iv. The graphed points below the shaft position (+) will require the feet to be moved to the right.

    v. The graphed points above the shaft position (-) will require the feet to be moved to the left.

g. Make adjustments to the driver. Tighten all motor bolts using a torque wrench. The same torque on all mounting bolts reduces the influence of deformities in the motor feet.

4. Align Driver Vertically
   a. The dial indicators should still be set up as shown in *Figure 16*.
   b. "Zero" the rim and the face dial indicators to 0.000" at the 12 o'clock position of the couplings, as viewed from the motor end. Reference the dial indicator diagram in *Figure 15*.
   c. Rotate the indicators on the driver shaft 180° until they are in the 6 o'clock position.
      i. Note the direction of the movement of the needles on the indicators.
      ii. Clockwise movement of the needle is considered positive (+).
      iii. Counterclockwise movement of the needle is considered (-).
   d. Determine the amount of vertical movement of the IB and OB of the driver. Note that *Equations 4*, *5*, and *6* are used in calculating the slope and the required shim removal or addition. The steps are similar to those for horizontal movement.
      i. Utilizing the Reverse Dial Indicator graph, mark the points that are half the indicator readings under their positions. A vertical square should be considered 0.001".
      ii. Draw a line connecting these two points, and extending to a point below or above the moveable feet positions.
      iii. The graph will show how much the feet will be required to move, based on the a vertical square being considered 0.001".
      iv. The graphed points below the shaft position (+) will require shim to be added.
      v. The graphed points above the shaft position (-) will require shim to be removed.
   e. Make adjustments to the driver. Tighten all motor bolts using a torque wrench. The same torque on all mounting bolts reduces the influence of deformities in the motor feet.
5. Recheck the horizontal alignment to insure that all alignments are acceptable.
6. Document the final readings on an alignment form or data sheet, and file accordingly.

LASER ALIGNMENT METHOD

The laser alignment method is considered a precision-based performance technique that provides a faster, more accurate way to align equipment.

It is ideal for alignment of equipment over long distances, and it is less prone for user error. Because of the range of technology between various manufacturers, the steps for laser alignment are not discussed in detail in this article.

The laser alignment equipment consists of a transducer system. *Figure 17* provides a view of a

Figure 17. *Setup of Laser Alignment Equipment*

laser alignment system installed on a pump and electric motor. The system contains a laser diode and position sensor on one mounting bracket.

The diode emits a pulsating, non-hazardous, laser beam that is directed at the opposite bracket. The opposite bracket contains a prism that redirects the laser beam back to the position sensor. Like other shaft alignment techniques, the shafts are rotated to determine the vertical and horizontal readings for angular and parallel misalignment.

The shaft positions and readings are automatically provided to a small computer. The computer then calculates the relative movement required at the feet of the moveable machine. *Figure 18* provides a view of the diagnostic computer.

A major advantage of the use of laser alignment is the precise measurement of misalignment. Laser alignment can detect misalignment to ±0.00004”. In addition, with the use of laser alignment, bar sag concerns are eliminated.

However, there are drawbacks and limitations to the laser alignment method. Laser alignment equipment typically costs more than $10,000. Service companies or those companies with many pumps or large pumps are the primary buyers of laser alignment equipment.

The environment in which the laser alignment equipment is used is also a limitation. The atmospheric temperature must be between 32° and 131° Fahrenheit for the use of laser alignment. The environment must also be free of steam, dust, or air currents.

These detractors will prevent the reading of the laser beam properly. However, it is possible to use a plastic pipe to shield the beam from the steam, dust, or air currents.

FINAL CHECKS AND WORK CLOSEOUT

After the equipment has been aligned, some additional tasks and checks should be performed.

- Make sure that each shaft turns freely with the coupling hubs installed.

Figure 18. *Laser Alignment Diagnostic Equipment*

- The safety equipment should be removed and the equipment energized.
- The driver should be “bumped” to check for proper rotation.
- Reinstall the safety precautions and complete the assembly of the coupling per the installation instructions.
- Rotate the coupled shafts to ensure they turn freely.
- Install the coupling guards per OSHA or applicable requirements.
- The safety equipment should be removed and the equipment energized.

Once the pump is ready to operate, the pump and piping that has been drained should be filled. As the pump and the system piping is filled, observe for any piping distortion due to improperly supported piping. Poorly supported piping may cause misalignment.

After the piping is installed, the pump unit is operated under normal conditions and is thoroughly warm, stop the pump unit to recheck alignment while it is warm. This also ensures that there is no additional pipe strain.

If additional alignment is required of more than 0.002” from the pipe free condition, the additional piping strain should be corrected. Additional discussion on piping installation can be found in another article.

For high energy and petroleum pumps, the pump and driver feet are drilled and doweled at two locations, near the thrust bearing end, after the final alignment is complete and meets the specifications.

Documentation of the alignment is important to the installation and operation of the equipment. Make a record of the final alignment tolerance on an alignment form or data sheet. This should be placed in the equipment’s history file. This provides not only proof of final condition, but allows a starting point and historical data for the future.

For work done in the future, this information will allow for the alignment to be done quicker and smoother, saving set up time. In will also provide a basis to allow for measurement of operational time.

Reporting or recording sheets can be developed to include information on soft feet, pipe stress and strain, coupling and shaft runouts, installation conditions such as bolts being found loose, and specifying the initial, desired, and final alignment information.

The sheet should also provide a location for identification of the persons completing the work to be documented. This places responsibility of quality work on individuals, and provides learning opportunities if a failure occurs.

Reported data allows for troubleshooting and root cause analysis of equipment failures. The data can be used to compare the “as discovered” condition and the “as completed” condition. This can be particularly useful for equipment with chronic abnormal behavior.

Another useful tool for recording data are digital photos. Pictures of the shaft, coupling, base, and foundation conditions can be stored. These could be used in the future during set up to determine any special needs or how the installation was left.

Although alignment should not be scheduled to be rechecked with the frequency of preventative maintenance procedures, it should be rechecked when observations are made in regards to the settling of the base, foundation, or soils, changing of the piping system, process changes, or seasonal temperature changes.

For a new installation, the alignment should be scheduled to be rechecked 3-6 months after the initial installation and alignment.

SPECIAL SERVICES

HIGH TEMPERATURE

Abnormally high temperatures can affect the alignment of a pump and its driver. These temperature changes can be caused by friction in the bearings or change that occurs with a process liquid.

The thermal growth can occur on pumps in a hot service, such as in the petroleum industry or power plants. When the pump is the equipment in the hot operation, the pump is set and aligned lower than the driver. This is called “cold setting”. This will allow for the thermal growth.

The pump manufacturer will typically have a chart available to assist in the proper alignment. The manufacturer’s recommendations should always be followed for the exact piece of equipment.

If the driver is the high temperature equipment, such as with a steam turbine, the driver shaft should be set lower than the pump shaft to compensate for vertical expansion of that equipment. After the equipment reaches normal operating temperatures, alignment should be verified.

VERTICAL PUMPS

For services located in process plants, alignment of vertical pumps must be considered. This is especially true if the driver thrust bearing carries the load of the driver and the pump.

Because of the importance of the driver thrust bearing in this pump and driver configuration, accurate radial and angular alignment between driver and the pump is essential.

As part of the precision alignment process of vertical pumps, the driver shaft runout and concentricity with the mounting fit must be reviewed. This should always be done prior to the assembly or reassembly of the driver on the pump.

As a rule of thumb, the process industry recommends that the shaft runout and the concentricity of the mounting fit should be within 0.002" total indicator runout (T.I.R.) per foot of rabbet fit diameter of the motor mount. In addition, the mounting face must be perpendicular to the shaft within 0.002" T.I.R. per foot of rabbet fit diameter.

The driver shaft runout should not exceed 0.002" T.I.R. or 0.001" T.I.R. per inch of shaft diameter, whichever is greater. For a solid shaft motor, the shaft end float must not exceed 0.010" T.I.R., and 0.005" T.I.R. is recommended if the pump has a mechanical seal.

These requirements may be more stringent than the National Electrical Manufacturers Association (NEMA) [1], but they are essential for solid shaft drivers and 2-pole motor speeds. Typical NEMA tolerances are acceptable for deep well turbines and 4-pole rpm or lower speeds.

Some manufacturers and models do not use a rabbet fit between the pump and driver, but align the driver shaft to the pump stuffing box. This practice is also acceptable to use if the rabbet fit is not concentric with the shaft.

When final aligning vertical pumps, the driver should be within 0.0005" per inch of stuffing box bore for pumps with mechanical seals, and 0.001" per inch of stuffing box bore for packed pumps.

For large motors, the use of jacking bolts may be required to move the motor.

ALIGN EQUIPMENT TRAINS

There are occasions when more than two pieces of equipment are installed in a "train" for a service. An example would be a pump, gear reducer, and a driver. The alignment of a train can become more demanding due to an additional variable.

It is important to understand the equipment involved. As previously mentioned, the installation and operation manuals for all of the equipment in the train should be reviewed. A consistent procedure should be developed to provide a sequence of alignment that will be used for each time the equipment is aligned.

A guideline used in the industry is the fixing of the middle piece of equipment, usually the gearbox, and move the other equipment – in other words, start in the middle and move outward. Rough readings should be taken to insure none of the equipment would be bolt bound.

If the equipment is bolt bound, the position of all equipment should be graphed to determine optimum position. This technique is acceptable if piping has not already been installed. If the piping is already installed and fixed, then additional care should be taken to insure that pipe stress is not put on the pump.

REFERENCES

1. National Electrical Manufacturers Association (NEMA), 1300 North 17th Street, Suite 1847, Rosslyn, VA 22209; http://www.nema.org.

ACKNOWLEDGEMENTS

Figures 2, 6, 7, 9, 17, and 18:
Diagnostic Solutions, LLC.

BE > THINK > INNOVATE >

Being responsible is our foundation
Thinking ahead makes it possible
Innovation is the essence

USA
GRUNDFOS Pumps Corporation
17100 West 118th Terrace
Olathe, KS 66061
Phone: (913) 227-3400
Telefax: (913) 227-3500

USA
PACO Pumps – National Headquarters
Grundfos CBS Inc.
902 Koomey Road
Brookshire, TX 77423
Phone: (800) 955-5847
Telefax: (800) 945-4777

CANADA
GRUNDFOS Canada Inc.
2941 Brighton Road
Oakville, Ontario
L6H 6C9
Phone: (905) 829-9533
Telefax: (905) 829-9512

MEXICO
Bombas GRUNDFOS de Mexico S.A. de C.V.
Boulevard TLC No. 15
Parque Industrial Stiva Aeropuerto
C.P. 66600 Apodaca, N.L. Mexico
Phone: 011-52-81-8144 4000
Telefax: 011-52-81-8144-4010

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