Fundamentals of Precision Shaft Alignment

Vibration Monitoring System

PREPARED BY
DLI ENGINEERING CORP.
(Jan 2006)
# TABLE OF CONTENTS

Preface and Table of Contents .........................................................................................i
List of Figures and Tables................................................................................................ii
Safety Precautions ............................................................................................................iii
Glossary ...........................................................................................................................vi

1. Introduction To Alignment ........................... .................................................................1
   1.1 Overview ........................................................................................................1
   1.2 Basic Concepts ...............................................................................................1
   1.3 Causes And Corrections Of Misalignment ....................................................3
   1.4 Section 1 Quiz ................................................................................................8

2. Pre-Alignment Procedures .........................................................................................9
   2.1 Outline ............................................................................................................9
   2.2 Trial And Error Alignment Method ...............................................................9
   2.3 Dial Indicator Method ...................................................................................10
   2.4 Section 2 Quiz ................................................................................................15

3. Measurements And Calculations .............................................................................16
   3.1 Outline ............................................................................................................16
   3.2 Three Methods ...............................................................................................16
   3.3 Section 3 Quiz ................................................................................................21

4. Horizontal Machinery Alignment ..............................................................................22
   4.1 Outline ............................................................................................................22
   4.2 Alignment Procedures ....................................................................................22
   4.3 Section 4 Quiz ................................................................................................28

5. Vertical Machinery Alignment ...................................................................................29
   5.1 Outline ............................................................................................................29
   5.2 Alignment Procedure .....................................................................................29
   5.3 Section 5 Quiz ................................................................................................36

6. Supplemental Information .........................................................................................37
   6.1 Rim & Face Method Of Alignment ...............................................................37
   6.2 Case of Obstruction ........................................................................................39

Workbook and Lecture Guide ..........................................................................................41
LIST OF FIGURES AND TABLES

Figure 1-1, Parallel and angular misalignment ................................................................. 2
Table 1-1, Alignment Tolerances .................................................................................... 2
Figure 1-2, Coupling alignment ...................................................................................... 3
Figure 1-3, Assembly of Indicator reverse method ........................................................ 4
Figure 1-4, Dial indicator placements ............................................................................ 5
Figure 1-5, Indicator Sag .............................................................................................. 6
Figure 1-6, Soft foot ..................................................................................................... 6
Figure 1-7, Thermal growth curve ................................................................................ 7
Figure 2-1, Effect of end play on indicator placement ................................................... 11
Figure 2-2, Indicator placement for soft foot check ...................................................... 12
Figure 2-3, Indicator setup for checking sag ................................................................ 13
Figure 3-1, Measurements needed for alignment .......................................................... 16
Table 3-1, Alignment Formulas .................................................................................... 17
Figure 3-2, Graphing the alignment ............................................................................. 18
Figure 3-3, Graphical representation of adjustments ................................................... 19
Figure 3-4, Dial indicator placement for horizontal movement .................................... 26
Figure 5-1, Dial indicator setup for checking alignment ................................................ 29
Figure 5-2, Dial indicator setup for correcting alignment ............................................ 29
Figure 5-3, Measurements for alignment check ............................................................ 30
Figure 5-4, Dial indicator placement for measuring bent flange ................................... 32
Figure 5-5, Numbering the hold down bolts ................................................................. 33
Figure 5-6, Indicator placement for offset adjustment ................................................ 35
Figure 6-1, Setup for rim face method of alignment ..................................................... 37
Figure 6-2, Measurements for rim face method ............................................................ 39
PREFACE

This manual began as a set of paper copy notes at DLI Engineering. The original author is unknown.

SAFETY PRECAUTIONS

Machinery alignment is often accomplished in areas that are hazardous, unless proper precautions are observed. Equipment and materials used must be appropriate to the work area and handled correctly to ensure safety of personnel. Constant vigilance by both workers and supervisors is necessary to eliminate hazardous conditions that could cause a fatal or injurious accident.

1. Ensure that neck chains and loose bracelets are removed or properly secured when working with rotating machinery or in close quarters.

2. Ensure that loose clothing is properly secured when working near rotating machinery.

3. Ensure that appropriate protective items, such as gloves, eye shields, and safety shoes are worn to prevent injury.

4. Ensure that all sources of electrical power have been secured and tagged by qualified electricians before undertaking any repairs.

5. Never bypass any electrical safety or control equipment. When it is necessary that a bypass be made for a specific test or check, only qualified electricians should conduct the test or check. Upon completion of test or check, the safety or control device must be restored immediately.
GLOSSARY

Alignment The process of adjusting a piece of machinery so that its shaft centerline will be in line with the shaft centerline of the machine to which it is coupled.

Angularity Is the angle of the shaft centerline of the machine to be moved (MTBM) in relation to the shaft centerline of the Stationary Machine (SM). The angle amount is expressed in rise over run (Thousandths of an inch per inch), rather than in degrees.

Back Feet Machine supports opposite the coupled end. Sometimes these are referred to as the free end or as the outboard feet.

Cold Alignment This is intentional angularity and offset misalignment entered into the machine to be shimmed, during the cold alignment check, to compensate for thermal growth. Always establish and verify a "Corrected Cold Alignment Specification".

Cold Alignment Specification Some manufacturers provide a cold alignment setting that allows the alignment engineer to know how thermal growth will affect the final running alignment. The manufacturer's technical manual should be consulted to obtain this setting.

Face Reading Readings obtained with a dial indicator as both shafts are rotated when the centerline of the dial indicator stem is set parallel to the shaft centerline.

Front Feet The machine supports on the coupled end, also known as the driven end or inboard feet.

Horizontal Misalignment Misalignment which requires horizontal movement of the machine to be moved (MTBM) for correction. Shims are not typically used to correct horizontal misalignment.

Hot Alignment Check The act of measuring shaft alignment after the machinery has been operated for a period sufficient to allow it to attain its normal operation temperature and therefore undergo thermal growth. This check should be performed as soon as possible after securing the unit.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indicator Sag</strong></td>
<td>The bending of the indicator mounting hardware caused by gravity. It occurs when the shaft is rotated and the dial indicator moves from the “Top” position to the &quot;Bottom” position.</td>
</tr>
<tr>
<td><strong>Jacking Bolts</strong></td>
<td>Bolts on the machine foundation located at each foot used to adjust the horizontal or vertical position of the machine.</td>
</tr>
<tr>
<td><strong>MTBM</strong></td>
<td>Machine to be moved or the machine which will have shims installed under its feet. This will normally be the prime mover (e.g. electric motor, steam turbine). Driven components (pumps, compressors), constrained by pipe connections, are not good candidates for the MTBM.</td>
</tr>
<tr>
<td><strong>Offset</strong></td>
<td>The amount of distance between the centerlines of each machine shaft when measured at the coupling center. Offset is typically expressed in &quot;thousandths of an inch&quot; or &quot;mils&quot;.</td>
</tr>
<tr>
<td><strong>Rim Readings</strong></td>
<td>Dial indicator readings obtained as the shafts are rotated and the centerline of the dial indicator stem is set perpendicular to the shaft centerline.</td>
</tr>
<tr>
<td><strong>Total Run-out</strong></td>
<td>The total radial deflection of a shaft with respect to a fixed point as the shaft is rotated through one complete revolution. Often called TIR for total indicated run-out. This measurement can also be performed in the axial direction when measuring a gear or pulley.</td>
</tr>
<tr>
<td><strong>Skewed Misalignment</strong></td>
<td>Combination of parallel offset, and angular misalignment.</td>
</tr>
<tr>
<td><strong>Soft Foot</strong></td>
<td>The condition which exists when all of the machine's feet are not equally supporting the weight of the machine. Similar to a four legged chair with one of the legs slightly shorter than the other three.</td>
</tr>
<tr>
<td><strong>Stationary Machine (SM)</strong></td>
<td>The term &quot;Stationary Machine&quot; will be used to describe the machine that will not be adjusted, usually the driven machine.</td>
</tr>
<tr>
<td><strong>Thermal Growth</strong></td>
<td>The expansion of a material which occurs when its temperature increases from room temperature to operating temperature.</td>
</tr>
<tr>
<td><strong>TIR</strong></td>
<td>Total indicator reading. This is the total deflection of the dial indicator pointer between the furthest deflection positive to the furthest deflection negative.</td>
</tr>
<tr>
<td><strong>Vertical Misalignment</strong></td>
<td></td>
</tr>
</tbody>
</table>
Misalignment which requires movement of the machine in the vertical direction for correction. Vertical movement is often accomplished with shims.

**Zero (O)**

The process of setting the dial indicator face to "zero" (O).
1. INTRODUCTION TO ALIGNMENT

1.1 OVERVIEW

Upon completion of this lesson, the trainee will be able to:

1. Explain the importance of using proper equipment for alignment.
2. Explain two types of misalignment.
3. Explain and define common alignment terminology, techniques, and tolerances for Pump-Driver alignment.
4. Define the effects thermal growth has on shaft alignment.
5. Explain the use of dowel pins in machinery alignment.

1.2 BASIC CONCEPTS

A. General

This guide will provide the trainee with the information necessary to perform accurate alignment of machinery shafting. The term "accurate" needs to be emphasized. Misalignment is measured in mils, thousandths of an inch. A small alignment error can cause considerable vibration, and accelerated machine wear. Proper alignment plays an important role in the ability of a machine to provide long, reliable, service. Thus, accurate alignment is an important contributor to reduced maintenance and increased machinery plant readiness. The driver and driven machine shaft centerlines (not the coupling halves) must be properly aligned, ideally forming a straight line.

B. Angular and Parallel Misalignment

Shaft misalignment is usually a combination of angular misalignment and parallel offset (refer to Figure 1-1). After alignment, both of these must be within specified tolerances. Adjustment is made in two planes, vertical and horizontal, for horizontally mounted equipment, "Back-Front" and "Left-Right", for vertically mounted units.
C. Alignment Tolerances

1. Misalignment in excess of recommended tolerances will result in frequent repairs to such machinery components as couplings, bearings, sleeves, packing, mechanical seals, etc.

2. Recommended maximum allowable alignment tolerances for pump-driver units are given in Table 1-1. These tolerances are given for units in a hot, i.e. normal operating temperature, condition and are stated in terms of angularity and offset.

Table 1-1, Alignment Tolerances

<table>
<thead>
<tr>
<th>RPM</th>
<th>OFFSET</th>
<th>ANGULARITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEW INSTALLATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-4000</td>
<td>±2.0 mils</td>
<td>±0.500 mils/in</td>
</tr>
<tr>
<td>4000 &amp; UP</td>
<td>±1.0 mils</td>
<td>±0.250 mils/in</td>
</tr>
<tr>
<td>IN-SERVICE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2000</td>
<td>±5.0 mils</td>
<td>±1.000 mils/in</td>
</tr>
<tr>
<td>2000-4000</td>
<td>±4.0 mils</td>
<td>±1.000 mils/in</td>
</tr>
<tr>
<td>4000 &amp; UP</td>
<td>±2.0 mils</td>
<td>±0.500 mils/in</td>
</tr>
</tbody>
</table>
1.3 **CAUSES AND CORRECTIONS OF MISALIGNMENT**

A. **Causes of Misalignment**

1. Misalignment can occur by the loosening of hold-down bolts, mechanical shock, shifting of foundations, etc. This is the reason that periodic alignment checks are recommended especially when the vibration analysis program diagnoses misalignment.

2. Misalignment also occurs during the installation of either or both the driver and the driven units. This is usually the result of inexperience, the lack or proper measuring instruments or tools, and the alignment techniques used.

3. A common alignment error occurs when the shafts are not both rotated during alignment. This wrong method is called "coupling alignment". Several potential errors are associated with simply aligning coupling halves. Aligning the coupling halves doesn't guarantee the alignment of the shafts. Slight misbores, distortion of the coupling diameter, dents, corrosion, and bent shaft ends are all common sources of error for coupling alignment. These errors can result in serious shaft misalignment, even though the coupling halves are aligned. (Figure 1-2).

![Figure 1-2, Coupling alignment.](image)

B. **Correction of Misalignment**

1. Proper alignment methods require the use of dial indicators, a straightedge, a taper gage and a feeler gage.

2. The two units are placed in their approximate installed positions. One unit, normally the driven component, is fixed in place and the other is brought precisely into alignment with the stationary component.

3. Rough positioning is performed by taking straightedge, feeler and taper gage readings on the coupling. The driver unit is then repositioned horizontally or vertically until the shafts are aligned as closely as possible.
4. Dial indicators are then attached in the Reverse Indicator fashion as shown in figure 1-3. Measurements are taken and the adjustments are calculated from the readings.

![Figure 1-3, Assembly of Indicator reverse method.](image)

5. The driver, or machine being moved, is lifted and shifted using shims and dial indicators until specified tolerances for misalignment are met.

C. Alignment Terminology

It is important to understand the definition of terms commonly used in alignment. This helps to remove some of the "mystery" from the language, as well as from what actually occurs during alignment procedures. A few of the most commonly used alignment terms and their definitions are as follows:

1. Angularity.
   a. The angle (expressed as a slope in "thousandths of an inch") between two shaft centerlines.
   b. Angularity occurs in any direction, but is corrected first in the vertical direction, and then in the horizontal direction.
   c. Vertical angularity is corrected by adding or removing shims.
   d. Horizontal angularity is corrected by shifting the machine sideways.

2. Parallel Offset.
   a. Parallel offset is also called "parallel misalignment". It is the distance, (expressed in "thousandths of an inch"), between two shaft centerlines measured at the midpoint of the coupling.
   b. Parallel offset exists to some degree, however slight, if the centerlines of the shafts do not meet at the center of the coupling.
c. Parallel offset can occur in any direction, and like angularity, is corrected first in the vertical direction, then the horizontal direction.
d. Vertical offset is corrected by adding or removing shims in equal amount to both front and back feet.

e. Horizontal offset misalignment is corrected by shifting the unit, equal distances front and back, to the left or right.

3. Machine to be moved (MTBM) and the stationary machine.

a. In most alignment procedures, one of the units, the MTBM, will be adjusted into alignment with the other, the stationary machine.

b. The MTBM will normally be the driver, electric motor, turbine, diesel engine, etc.

c. The stationary unit will normally be the driven machine, a pump, compressor, etc.

4. Skewed Misalignment

a. Skewed misalignment is a combination of parallel offset and angular misalignment.

b. This is the most common way misalignment occurs.

5. Rim Reading

a. Rim reading is a reading obtained on a shaft, as it is rotated with the dial indicator stem placed at a 90° angle from its centerline. (Refer to figure 1-4.)

Figure 1-4, Dial indicator placements.

b. "Top and Bottom" rim readings (0° and 180°) are taken to detect possible vertical offset misalignment.

c. "Left and Right" (90° and 270°) rim readings are taken to detect possible horizontal offset misalignment.
6. Front feet (or foot)
   a. Front feet are the machinery supports nearest the shaft end.
   b. Front feet are also called "inboard feet".

7. Back feet (or foot)
   a. Back feet are the machinery supports that are farthest from the coupling.
   b. Back feet are also called "outboard feet".

8. Indicator sag (figure 1-5.)

   ![Diagram of Indicator Sag]

   Figure 1-5, Indicator Sag

   a. Indicator sag is the bending of the dial indicator mounting hardware caused by gravity. It occurs as the shafts are rotated from the "Top" to the "Bottom" position.
   b. In most cases, this bending will be severe enough to cause a significant error in the readings obtained.
   c. Indicator Sag should be determined prior to the start of alignment and used to adjust readings taken when dial position changes in vertical height.

9. "Soft foot" (Figure 1-6.)

   ![Diagram of Soft Foot]

   Figure 1-6, Soft foot
a. Soft foot is a condition that exists when the bottom of all four component attachment points are not in the same plane and equally supporting its weight.

b. Soft foot can be compared to a four legged chair with one short leg. When the hold down bolts are tightened, the frame of the machinery is twisted. This can result in excessive strains on bearings / seals, and an irregular air gap between the motor rotor and stator.

c. Irregular support loading must be corrected prior to commencing alignment procedures.

10. Jacking bolts

a. Jacking bolts are permanently installed bolts sometimes incorporated into the feet of large components. They are used to raise MTBM feet for inserting or removing shims.

b. Horizontal jacking bolts are sometimes incorporated on the base plate and used to move the MTBM sideways to correct for horizontal misalignment.

11. Thermal Growth.

a. The expansion of the metal of the machine (and its surrounding supports and attachments) which occurs when the temperature of the metal increases from ambient temperature to operating temperature.

b. This expansion causes the relative placement of the shaft centerlines to change thus affecting the alignment of the unit. (Figure 1-7.)

![Figure 1-7, Thermal growth curve.](image)

12. "Cold Alignment Specifications."

a. This is the recommended relative placement of shaft centerlines at ambient temperatures.

b. This placement may include an intentional misalignment of Angularity and Offset (usually only in the vertical plane).
13. "Hot Alignment Checks."

a. Hot alignment checks are used to confirm alignment at operating temperatures.

b. Hot alignment is ideally no angularity and no offset in both the vertical and horizontal planes. The findings of the hot alignment check are applied to the "Cold Alignment Specification."

**NOTE**
*Some manufacturers provide cold alignment settings ("Cold Alignment Specifications") which should compensate for thermal expansion of the metal which occurs as the unit heats up to operating temperature. If the manufacturer gives this information in other than angularity (expressed in "thousandths of an inch per inch") and parallel offset at the coupling "Midpoint" (expressed in "Thousandths of an inch"), the specifications should be converted to these terms before proceeding with the "Cold Alignment".*

**D. Tapered Dowel Pins**

1. Tapered dowel pins are installed through the feet of the machine into the base. They are used as an extra precaution against it slipping out of alignment.

2. Dowel pins are installed after final alignment.

**1.4 SECTION 1 QUIZ**

1. Explain the importance of proper equipment alignment.

2. Describe the two types of misalignment.

3. Define alignment tolerances.

4. Define thermal growth.

5. Describe how tapered pins are used in machinery alignment.
2. PRE-ALIGNMENT PROCEDURES

2.1 OUTLINE
Upon completion of this lesson, the trainee should be able to:

1. Define the difference between "trial and error" and precision alignment methods.

2. Explain why a computational method should be used to determine angularity and offset when doing an alignment.

3. List the three alignment methods that can be used.

4. Explain dial indicator setup for conducting alignment using the Reverse Indicator method.

5. Demonstrate ability to correct for "soft foot" on an actual machine.

6. Demonstrate ability to correct for indicator sag.

2.2 TRIAL AND ERROR ALIGNMENT METHOD

Some alignment methods may be classified as "trial and error". The units are positioned, readings are taken, units are repositioned, and readings are taken and so on. This method can be time consuming and the quality of the alignment job is often suspicious. Proper alignment is measured in thousandths of an inch, the difference between proper and improper alignment often cannot be seen with the human eye or accurately measured without the proper measuring instrumentation and techniques. The final result of trial and error alignment depends on the experience level of the alignment mechanic. This method requires much experience and a certain "feel" to achieve acceptable results. Since the trial and error method is used widely due to its "intuitive approach", there is often a sense of "mystery" to shaft alignment felt by less experienced persons. Equipment is available that makes alignment easier. When properly used, it is relatively easy to make alignments closer than specifications require. There is no real "mystery" in the mathematical formulas used in alignment, or by various computers that are on the market used for alignment.
2.3 **Dial Indicator Method**

Alignment kits that use this method normally include dial indicators, mounting brackets, clamps, rods, and other accessories. If the dial indicators are electronic they normally connect to some kind of computer. For kits with manual dials an alignment computer is normally provided. The purpose of the computer is to automate the mathematics required to solve the trigonometry problem.

**A. Using Manual Dial Indicators**

1. After choosing the method of alignment, the mechanic inputs the measurements required by the prompts. These are the dimensions needed for the calculations. By following the prompts, the information is input in the proper order. After making measurements, the computer will then give the necessary information to correct misalignment. This computer aided approach results in faster alignments, thus reducing maintenance man-hours, material costs, and equipment downtime.

2. The alignment kit can be used on equipment with the coupling connected or disconnected. Routine alignment checks on all components, as well as "hot" checks on steam driven components, will be done with the coupling connected. In cases where one or both of the components are being reinstalled, alignment will be done with the coupling disconnected. Alignment tools such as a straight edge, feeler gage, and taper gage will continue to be used for the preliminary rough alignment.

3. The alignment computers typically can be used with any of three dial indicator arrangements noted below. The technician must select the alignment method best suited for the situation and then use step-by-step measurement procedures.

**B. Alignment Methods**

1. There are three methods that can be used, The Reverse Indicator method, and two variations of the "Rim-Face" method.

2. The "Rim-Face" method is addressed in section 6 "Supplemental Information".

3. Reverse Indicator method. Brackets are mounted on both shafts. Clamps and dial indicator rods are then attached to the brackets. Dial indicators are next attached and positioned to contact the brackets for rim readings on both the MTBM and stationary machine. (Figure 1-3)

**NOTE**
Regardless of the method used, all readings will be taken on the brackets attached to the shaft and not on the actual shaft or coupling.

C. Selection of which Alignment Method to Use

1. The most common mistake made concerning alignment is to attempt to check alignment, or to align two components by taking "Rim" readings on only one of the components.

2. In rare cases, it may be impossible to attach two dial indicators at the same time. In such cases, it is permissible to attach one dial indicator, obtain the required reading, and then mount the dial indicator on the other machine to obtain the other required readings.

3. With different methods available, a decision must be made as to which method to use. One factor that will influence your decision is the amount of "end play" present in either machine. The "Reverse Indicator method is only minimally affected by end play. (Figure 2-1.)

4. "End play" is defined as the amount of axial movement of a shaft. Nearly all machines designed with journal or sleeve bearings will have some "End play", but it may be possible to keep "End play" to a minimum by applying pressure to the end of the shaft during the rotation necessary to obtain reading.

5. In the case of very large machinery or machinery that requires jogging or bumping for rotation, applying manual pressure could be impossible (and dangerous). The Reverse Indicator method should be used in this situation because "End play" has minimal effect on "rim" readings but a large effect on "face" readings. (See figure 2-1)
D. Pre-Alignment Procedures

Before commencing alignment: Check for and correct "Soft Foot" condition. (See section 1.3, C-9). To correct soft foot, proceed as follows:

1. Check stationary (driven) machine for soft foot first. Prepare for soft foot check by removing all dirt, rust, and burrs from the bottom of the stationary machine, mounting feet and the shims to be used. Do the same to the component mounting pads on the foundation.

   a. Install dial indicator on the foot #1 of the stationary machine so that the stem is vertically over, and touching, one foot. (See Figure 2-2.)

   Figure 2-2, Indicator placement for soft foot check.

   b. Compress the dial indicator button approximately half travel, 0.050 inches. Zero the dial and loosen the hold-down bolt for that foot. Note dial indicator deflection, as the bolt is loosened. If the dial indicator shows more than 0.004 inches of movement of the support foot, soft foot may exist. Record the amount for that foot.

   c. Loosen all hold-down bolts. Add shim(s) equal to the recorded clearance beneath the foot as required, use a minimum number of shims of maximum thickness. Note that opposite corners should have the same deflection, but shims to correct soft foot are only placed under one side of the machine.

   **NOTE**
   
   All shims must be made of Series 304 Stainless Steel material.

   d. Repeat procedure for each remaining foot

   e. Ensure that each hold-down bolt is re-torqued after checking each foot.

   f. If mounting bolts are not already numbered, designate one of the coupling end feet on stationary machine as "foot #1". Move to the rear foot on the same side as foot #1 and designate that foot #2. The other rear foot is #3 and the other front foot is #4. Tighten hold-down bolts to torque specifications in an "X" pattern as follows: #1, #3, #4, and #2.
2. Correct for soft foot on the MTBM using the same procedure as described for the stationary machine in step 1.

   a. Conduct a radial run-out test to both the driver and driven unit shafts using a dial indicator. Consult appropriate technical manuals, or manufacturer's technical manual to determine if run-out is within specification. Take action as necessary if run-out is not within specifications.
   b. Place stationary machine and torque the bolts as described in step 1-f.
   c. Place MTBM and check rough alignment at coupling faces using a straightedge, feeler gage and taper gage.
   d. Do not remove the shims put in place during soft foot measurements.
   e. Conduct a preliminary horizontal alignment by moving the MTBM as necessary.
   f. Reposition the MTBM as necessary until the coupling can be connected without difficulty.

4. Determine indicator sag for Reverse Indicator method.
   a. Indicator sag will cause large errors in the alignment procedure if it is not accounted for. Indicator sag is caused by the force of gravity which bends the bar that holds the dial indicator.
   b. Set up the indicator mounting brackets on a straight, round bar. It is important that the brackets and indicators are spaced apart the same as they will be when they are mounted on the shafts to be aligned. (See Figure 2-3)

Figure 2-3, Indicator setup for checking sag.
c. Mount dial indicators, clamps, and rods to brackets as shown in figure 2-3.

d. Hold pipe so that the top indicator is at 000° (pointing straight up), and the bottom indicator is at 180° (pointing to the earth).

e. Zero the top indicator and rotate pipe 180° so the top indicator is now on the bottom.

f. Note and record dial indicator deflection (sag).

g. Repeat procedure for dial indicator that is now on top.

**NOTE**
*During alignment, indicator sag is corrected for by setting the top dial indicator "positive" by the amount of sag when measuring misalignment in the vertical direction.*

5. Install dial indicators and mounting hardware to machine shafts.

a. Remove the brackets from the pipe used to check sag. Do not disturb the attachments that are used to adjust the distance between the bracket and the dial indicator.

b. Attach brackets, clamps, and rods to the shafts of the machines to be aligned. Install each dial indicator such that the indicator button is 90° to the mounting bracket of the opposite dial indicator.

c. Mount the dial indicators close enough to the brackets so that the plungers are about half compressed. The dial indicators are now installed and ready to be set to take alignment readings.

**NOTE**
*Check installation of brackets, hardware, and dial indicators to ensure dial indicators are set as far as possible from the front feet of the MTBM.*

6. Obtain specifications. (Refer to Table 1-1.)

a. Alignment between any two components is never expected to be perfect (0.000). Maximum tolerances measured in thousandths of an inch and total indicated run-out (TIR) are included in the design specifications for all major pieces of equipment.

b. In some cases, design or maintenance information will refer to "Hot" and "Cold" alignment readings. These specifications are intended to allow for metal expansion during operation.
c. Consult manufacturer's technical manuals, equipment drawings, etc. for specifications before undertaking any alignment tasks.

2.4 Section 2 Quiz

1. Define the differences between "trial and error" and precision alignment methods.

2. Demonstrate ability to correct for "soft foot" on actual equipment.

3. Explain the indicator setup for the indicator reverse method.

4. Demonstrate ability to correct for indicator sag prior to actual alignment.
3. MEASUREMENTS AND CALCULATIONS

3.1 OUTLINE

Upon completion of this lesson the trainee will be able to:

1. Explain the various calculation methods for determining angularity and offset for horizontally mounted machinery.

2. Calculate the angularity and offset for horizontal machinery using the graphical method or using mathematical formulas.

NOTE
Vertical machinery is covered in section 5.

3.2 THREE METHODS

A. Required Measurements.

1. Use a ruler and measure the dimensions A, B, C, and D, correctly to 1/8 inch. (See Figure 3-1)

![Figure 3-1, Measurements needed for alignment.]

2. The letter "A" represents the distance between the sensor buttons of the two dial indicators.

3. The letter "B" represents the distance between the coupling center and the dial indicator sensor button on the MTBM.

4. The letter "C" represents the distance from the dial indicator sensor button on the MTBM to the front feet centerline of the hold-down bolts on the MTBM.

5. The letter "D" represents the distance from centerline of the front feet hold-down bolts to the centerline of the back feet hold-down bolts on the MTBM.

6. The letters "PI" (pump side indicator) represent the dial indicator reading on the stationary machine.
7. The letters "MI" (motor side indicator) represent the dial indicator reading on the MTBM.

8. Detailed instructions for obtaining PI and MI readings for horizontal machinery are contained in section 4-B

B. Calculating Alignment Corrections Using Formulas

1. Using the formulas in table 3-1 and the measurements from section A to calculate angularity and offset. All answers should be calculated using whole numbers rounded off to the nearest half thousandth (0.0005) inch for simplicity.

   Table 3-1, Alignment Formulas

   | Angularity | \( \frac{MI + PI}{2 \times A} \) |
   | Offset     | \( (B \times \text{ANGULARITY}) - \frac{MI}{2} \) |
   | Front Adjustment | \( [(C+B) \times \text{ANGULARITY}] + \frac{MI}{2} \) |
   | Rear Adjustment  | \( [(B+C+D) \times \text{ANGULARITY}] + \frac{MI}{2} \) |

2. If the offset or angularity exceeds tolerance, then calculate front and back adjustments using the formulas in table 3-1.

   **NOTE**
   When calculating adjustments, a positive answer means that the feet must have shims added (for vertical alignment), or the machine must be moved to the "right" (looking from the outboard end of the driver) for corrections in the horizontal plane. A negative answer indicates adjustment in the opposite direction.
C. Calculating Alignment Correction Using the Graphical Method

1. A piece of graph paper can be used to determine the angularity, the offset and the amount of adjustment for both front and rear supports. The vertical scale on the graph paper will be in thousandths of an inch, and the horizontal scale will be in whole inches.

2. Using a straight edge, draw a straight horizontal line on the graph paper. This line represents "true alignment". Place four points at properly scaled distances along this line. Start with the location of PI on the left, then MI, then the locations of the front support and the rear support. See figure 3-2.

3. Divide the measurements MI and PI by 2, change the sign of the MI reading, and then plot positive values above the points on the line and negative values below the points on the line corresponding to the indicator locations. See figure 3-2.

4. Draw a straight line through the two measured points PI/2 and MI/2, continue the line until it passes beneath the point that represents the rear supports. This line represents the actual alignment of the driver. See figure 3-2.

Figure 3-2, Graphing the alignment.
5. Determine the offset by measuring the distance between the actual alignment line and the reference line at the coupling center. (See figure 3-3)

6. Determine the angularity by measuring the slope of the actual alignment line. This is done by dividing the amount of rise by the amount of run at any location along the line. (See figure 3-3)

7. Determine the amount of front adjustment required by measuring the vertical distance from the actual line to the point on the reference line representing the front support. (See figure 3-3)

8. Determine the amount of rear adjustment required by measuring the vertical distance from the actual line to the point on the reference line representing the rear support. (See figure 3-3)

![Graphical representation of adjustments.](image-url)

Figure 3-3, Graphical representation of adjustments.
D. Calculating Thermal Growth in an Alignment Procedure

Thermal Growth is expansion of metal in the machine and its surrounding supports and attachments. The expansion occurs when the temperature of the metal increases from room temperature to operating temperature. This expansion causes the placement of the shaft centerlines to change, thus affecting the alignment of the unit.

1. Cold alignment is alignment which is done when the machine is at room temperature. Cold alignment often includes an intentional misalignment (usually only in the vertical plane). This misalignment will compensate for thermal growth so that the offset should be zero angularity and zero offset at operating temperatures.

2. Hot alignment checks are performed immediately after the machine is secured after operating for several hours. It is desired that the alignment be perfect at operating conditions.

3. Some manufacturers provide a cold alignment setting (cold alignment specifications) which is intended to compensate for thermal expansion of the metal as the unit heats up to operating temperature. If the manufacturer gives this information in other than angularity (expressed in "thousandths of an inch") and parallel offset at the coupling "Midpoint" (expressed in "thousandths of an inch"), the placement should be converted to these terms before proceeding with the cold alignment.

4. Thermal growth compensation is usually only needed in the vertical direction. The distance between the shaft center and the bottom of the base will have the largest effect on the shaft's position. When manufacturers' specifications are not available for thermal growth, the amount of growth in can be estimated by using the following formula:

\[
\text{Thermal Growth (mils)} = 0.000006 \times L \times \Delta T
\]

L is the distance from the machine support plane to the shaft center (inches). \(\Delta T\) is the difference between room and operating temperature (°F).

*NOTE*

*Thermal growth calculations are only approximate and should be verified with a hot alignment check as soon as possible after startup.*
3.3 **SECTION 3 QUIZ**

1. Describe the required measurements for determining angularity and offset for horizontally mounted machinery.

2. Calculate the angularity and offset using mathematical formulas and then using the graphical method.
4. **HORIZONTAL MACHINERY ALIGNMENT**

4.1 **OUTLINE**
Upon completion of this lesson the trainee will be able to:

1. Utilize computational methods in conjunction with the Reverse Indicator readings to determine alignment corrections that are required for horizontally mounted machinery.

2. Accomplish necessary alignment corrections by shimming, repositioning, and redoweling components as necessary.

4.2 **ALIGNMENT PROCEDURES**
Alignment procedures must be performed according to a step-by-step procedure. Accomplishing this will normally result in a close tolerance alignment after only one shimming (vertical) and one shifting (horizontal) action.

**NOTE**
A second set of readings is always necessary in order to verify that original readings were accurate. Re-take indicator readings and compare with original readings.

A. **Preparations for the Reverse Indicator Method (M3)**


3. Mount indicators in Reverse Indicator fashion on the machinery shafts.

4. Obtain measurements A, B, C and D. See section 3.2, A
B. Procedure for Determining Vertical Misalignment

1. Obtain the dial indicator readings "MI" and "PI" required for vertical alignment. Accurate "Rim Readings" (Top to Bottom) are necessary to determine the misalignment in the vertical plane.

   a. Rotate the shafts until the dial indicator which is at the driver end of the coupling (MI) is in the top position.

   b. Set MI to compensate for indicator sag, see 2.3.B.4.

   c. Rotate the shafts one full turn (360°) to ensure that the indicator returns to the sag compensation value at the top position. If it does not, check indicator mounting hardware for looseness and repeat steps a, b and c.

   d. Rotate shafts 180° so that the driver end dial indicator is at the bottom position and obtain the "MI" reading.

   **NOTE**
   *Always follow the travel of the dial indicator with an inspection mirror to determine whether the reading is positive or negative.*

   e. Rotate the shafts one full turn (360°) to ensure that the "Rim" reading returns to the same value in the "Bottom" position. If not, repeat steps a through e.

   f. Record the "MI" reading for the vertical plane.

   g. Rotate the shafts until the dial indicator which is on the pump end of coupling "PI" is in the top position.

   h. Set the dial indicator to compensate for the indicator sag.

   i. Rotate the shaft one full turn (360°) to ensure that the indicator returns to the sag compensation value at the "Top" position. If not, check indicator mounting hardware for looseness and repeat steps g through i.

   j. Rotate the shaft 180° (until the dial indicator is in the "Bottom" position) and obtain the "PI" reading.

   k. Rotate the shafts one full turn (360°) to ensure that the "PI" reading returns to the same value at the bottom position. If not, repeat steps g - k.

   l. Record the "PI" reading.
**NOTE**
If a "Bottom" rim reading cannot be obtained due to physical obstructions (such as piping or a shaft which is very close to the base plate), refer to Section 6.2 for the mathematical method of determining the reading.

**C. Procedure for Correcting Vertical Misalignment**

The amount of angularity and offset can be calculated using any one of the three methods described in section 3. Once the angularity and offset are known, they should be compared to the specifications. If the angularity or offset exceed the specification, correction must be performed.

1. All shims which are installed beneath the support feet of the pump or driver shall be made of Series 304 Stainless Steel material.

2. Use of any other materials (such as brass, regular steel, or laminated shim stock) is prohibited. These materials are compressible and tend to "work harden" when subjected to high dynamic loads which occur due to the normal vibration of machinery, as well as potential corrosion and corrosion problems.

3. The shim pack used beneath each support foot shall be composed of the minimum number of shims of maximum thickness. The following design criteria shall be employed for all shims:
   a. All corners of the shims shall be rounded.
   b. A portion of the shim which can easily be grasped by hand shall remain protruding from beneath the support foot after it has been fully inserted.
   c. All shims shall be free of burrs, bends or dents.

4. Place shims between supports and base.
   a. Loosen the hold-down bolts on the MTBM.
   b. Lift MTBM only as high as required to insert or remove shims.
   c. Re-torque hold-down bolts.
   d. Reinstall indicators, and recheck alignment.
D. Procedure for Determining Horizontal Misalignment

To determine the amount of horizontal misalignment, accurate horizontal "Rim readings" (side to side) must be taken. The measurements A, B, C, and D measured in section ‘A’ are the same and do not need to be repeated. In this section, 'right' and 'left' are determined as one looks from the free end of the driver towards the shaft end.

1. Obtain the dial indicator readings "MI" and "PI" required for horizontal alignment. Accurate "Rim Readings" (Right to Left) are necessary to determine the misalignment in the vertical plane.
   a. Rotate the shafts until the dial indicator which is at the driver end of the coupling (MI) is on the right.
   b. Zero the indicator (do not account for sag).
   c. Rotate the shafts one full turn (360°) to ensure that the indicators return to zero. If it does not, check indicator mounting hardware for looseness and repeat steps a, b and c.
   d. Rotate shafts 180° so that the driver end dial indicator is on the left and obtain the "MI" reading.

   **NOTE**
   *Always follow the travel of the dial indicator with an inspection mirror to determine whether the reading is positive or negative.*

   e. Rotate the shafts one full turn (360°) to ensure that the "MI" reading returns to the same value on the left. If not, repeat steps a through e.
   f. Record the "MI" reading for the horizontal plane.
   g. Rotate the shafts until the dial indicator which is on the pump end of coupling "PI" is on the right.
   h. Set the dial indicator to zero.
   i. Rotate the shaft one full turn (360°) to ensure that the indicator returns to zero. If not, check indicator mounting hardware for looseness and repeat steps g through i.
   j. Rotate the shaft 180° (until the dial indicator is on the left and obtain the "PI" reading.)
k. Rotate the shafts one full turn (360°) to ensure that the "PI" reading returns to the same value at the left. If not, repeat steps g - k.

i. Record the "PI" reading for the horizontal plane.

**NOTE**
*If a side "Rim reading" cannot be obtained due to physical obstructions (such as piping), refer to Section 6 for instructions on "In Case of Obstruction."

E. Procedure for Correcting Horizontal Misalignment

The amount of angularity and offset can be calculated using any one of the three steps in section 3. Once the angularity and offset are known, they should be compared to the specifications. If the angularity or offset exceed the specification, correction must be performed in the horizontal plane.

1. **Horizontal Plane Corrections:** Horizontal corrections shall be made only after "Soft Foot" and vertical plane corrections have been made. This order is chosen because horizontal movements do not affect vertical alignments, but vertical adjustments do affect horizontal alignment.

2. When monitoring the movement in the horizontal plane, dial indicators must be placed at the support points that were used when determining the amount of horizontal correction. Do not rely on only one indicator to monitor movements. (See Figure 3-4)

![Figure 3-4, Dial indicator placement for horizontal movement.](image_url)

a. Loosen hold-down bolts.

b. Set both dial indicators at "Zero minus Amount of Movement" so that when the MTBM is moved the desired amount, the dial indicators will be at zero.

c. Commence slowly moving MTBM horizontally while observing dial indicators. Stop moving MTBM when the dial indicators are at zero.
**NOTE**  
*Move MTBM by means of horizontal jacking bolts if installed.*

d. Retorque hold-down bolts.
e. Recheck horizontal alignment.
f. Refer to Table 1-1 for alignment tolerances.
g. If alignment tolerances are not within specification, repeat horizontal procedure.

**F. Installation of Tapered Dowel Pins**

The procedure for installation of tapered dowel pins each time the unit is realigned is as follows.

1. Complete the final alignment for both planes and tighten hold-down bolts to specified torque before installing dowel pins.

2. Do not use old dowel pin holes without "over-sizing" and reaming them to fit larger dowel pins. This is to avoid possible horizontal misalignment due to the dowel pins.

3. Use a standard taper (1/4 inch per foot) reamer to enlarge the hole after the nominal size hole has been drilled through both the support foot and base. The hole should be reamed such that the bottom inside diameter (ID) of the hole is slightly enlarged.

4. Use a tapered dowel pin which, after being "hand fitted" into the hole, protrudes at least a 1/4 inch above the hole.

5. Drive the pin into the hole approximately 1/8 inch to ensure a proper interference fit of the pin to the unit and base plate.

6. Check the final alignment after all the dowel pins have been installed to assure that the unit was not moved during installation of the dowel pins. If the alignment is not within specified tolerances, the dowel pins must be removed, the unit realigned, and the dowel pins reinstalled.
G. Hot Alignment Check

A hot alignment check should be performed on a machine as soon as possible after aligning a machine. Checking the alignment while the machine is still hot will reveal the alignment condition at normal operating conditions. The following paragraphs outline the procedures and cautions associated with the measurements.

1. Machinery must be run several hours before performing a hot alignment check, some machines require as much as 12 hours of operation to reach operating temperature. As a rule, machines should be run 10 to 12 hours before performing a hot alignment check.

2. The hot alignment check should be performed within one half hour after unit is secured.

8. Because of the initial rapid heat dissipation which occurs in metals, it is necessary to obtain hot alignment check readings as quickly as possible after the unit has been secured.

9. Readings obtained from hot alignment checks shall be used to correct the initial cold alignment and cold alignment specifications for the unit.

10. Realign the unit after it has cooled down.
   a. Do not attempt to realign the unit while it is hot.
   b. In the process of cooling down, the horizontal position of the unit will constantly be changing if the bolts are loosened.

11. Repeat the hot alignment check to verify results after cold re-alignment.

4.3 Section 4 Quiz

1. Utilize the mathematical formulas and or the alignment computer in conjunction with the Reverse Indicator method to determine alignment corrections.

2. Accomplish necessary alignment corrections by shimming, repositioning, and redoweling components as necessary.

3. Perform "Cold Alignment Specifications", and conduct "Hot Alignment Checks".
5. VERTICAL MACHINERY ALIGNMENT

5.1 OUTLINE

Upon completion of this lesson the trainee will be able to:

1. Explain the methods for determining angularity and offset for vertically mounted machinery.

2. Calculate the angularity and offset.

3. Correct misalignment on vertically mounted machinery.

5.2 ALIGNMENT PROCEDURE

Vertical machinery alignment is performed differently from horizontal machines. Vertical and horizontal planes are exchanged for left-right and front-back planes. The angularity and offset are found with the dial indicators set up in Reverse Indicator fashion (Figure 5-1). Correction is done with the dial indicators set up in rim-face fashion. (Figure 5-2)

Indicator sag and thermal growth are not considerations for vertical machines. It is not necessary to determine indicator sag. Unless otherwise specified by the manufacturer, thermal growth is ignored in alignments of flexible couplings on vertical machines.
A. Checking the Alignment

1. Check the alignment in two planes, front-back and left-right, using the Reverse Indicator setup as shown in figure 5-1. Angularity and offset tolerances are the same for vertical machinery as for horizontal machinery. If a machine has angularity or offset which exceeds the tolerance, the alignment requires correction.

2. Refer to Figure 5-3. This diagram shows the required measurements that should be taken in inches to the nearest 1/8 inch.

![Figure 5-3, Measurements for alignment check.](image)

3. The letter "A" represents the distance between the sensor buttons of the two dial indicators.

4. The letter "B" represents the centerline between the shaft ends and the dial indicator sensor button on the MTBM.

5. The letter "C" represents the distance from the top indicator "MI" to the point where the MTBM meets the support frame.

4. The letters "PI" represent the dial indicator reading on the Stationary Machine. This reading is thousandths of an inch.

5. The letters "MI" represent the dial indicator reading on the MTBM. This reading is in thousandths of an inch.
6. Check Front-Back alignment.
   
a. Set MI to zero when it is in the front position.

b. Rotate both shafts 180° until MI in the back position, record the reading. Be sure to observe the pointer on the indicator as the shafts are turned to determine which way the indicator needle moves.

c. Repeat these steps and check for repeatability. When repeatable, record front-back MI. If not repeatable, check for looseness.

d. Repeat steps (a) - (c) for PI.

e. Calculate the angularity and offset in the front-back plane. Use the same methods used in horizontal machinery alignment, except for the D measurement which is 0.

7. Check Left-Right alignment next.
   
a. Set MI to zero when it is in the left position.

b. Rotate both shafts 180° until MI in the right position, record the reading. Be sure to observe the pointer on the indicator as the shafts are turned to determine which way the indicator needle moves.

c. Repeat these steps and check for repeatability. When repeatable, record left-right MI. If not repeatable, check for looseness.

d. Repeat steps (a) - (c) for PI.

e. Calculate the angularity and offset in the left-right plane.

B. Correcting Angular Misalignment

Vertical machinery alignment differs from horizontal machinery alignment in that the angular alignment is performed separately from the offset alignment. Angular misalignment occurs because the flange which supports the motor is not allowing the shafts to be parallel. This is the point where angular misalignment is corrected. Angular misalignment must be corrected before correcting offset misalignment.
1. A condition similar to soft foot called "bent flange" can exist between the driver flange and the flange to which it bolts. Check for this condition and correct if necessary before proceeding with an alignment.

   a. Check for soft foot or bent flange by placing a magnetic base indicator holder on the base plate and positioning the stem of the dial indicator against the top of the driver flange near one of the hold-down bolts. (Figure 5-4)

   

   Figure 5-4, Dial indicator placement for measuring bent flange.

   b. Be sure that all bolts are tight and then loosen the bolt near the indicator. If more than 0.004 inch deflection occurs when bolt is loosened, the "Soft Foot" must be corrected by inserting an appropriate amount of shim stock beneath the driver flange.

   c. Repeat this procedure for each of the hold-down bolts.

2. Mount the dial indicators in the rim-face configuration shown in figure 5-2.

3. Determine the "bolt to indicator ratio".

   a. Use a tape measure and measure the radius of the bolt circle to the nearest 1/8 inch. This is the horizontal distance from the motor hold down bolts to the center of the motor shaft.

   b. Use a tape measure and measure the distance from the center of the shaft to the button of the face indicator to the nearest 1/8 inch.

   c. Divide the radius of the bolt circle (from step 3) by the radius of the face indicator travel circle (from step 4). This ratio is called the "bolt to indicator ratio".
6. Number the hold down bolts as shown in figure 5-5.

![Diagram of six numbered bolts](image)

Figure 5-5, Numbering the hold down bolts.

7. Determine which bolt is the reference bolt.
   
a. Turn both shafts until the face indicator is directly beneath hold down bolt #1, record the reading.

b. Repeat step (a) for each of the other hold down bolts.

c. The "highest" bolt is the one with the most negative reading. Select the bolt with the "most negative" number. This is the reference bolt.

8. Obtain face readings for each hold down bolt relative to the reference bolt.
   
a. Turn both shafts until the face indicator is directly beneath the reference bolt. Zero the indicator.

b. Once again, take readings with the face indicator at each hold down bolt and record them. These readings indicate the difference in height between each hold down bolt and the reference bolt.

**NOTE**

The indicator readings which were recorded at each bolt location in step 7 should all be POSITIVE (+) or Zero (0). If a NEGATIVE (-) reading has been recorded, an error was made in selecting the reference bolt and that step should be repeated.

9. Multiply each of the readings obtained in step (7) by the "bolt to indicator ratio". The product of these two numbers is the amount of shimming required at each hold down bolt.

10. Loosen all of the hold down bolts.

12. Add shims to each hold down bolt except the reference bolt.
13. Tighten all of the hold down bolts and check the face indicator run out. Angularity is determined by dividing the indicated reading by the radius of the indicator travel. The face indicator run out should not exceed angularity tolerances specified in section 1.2C.

14. If the run out exceeds angularity tolerance, repeat the alignment steps starting with step 6.

C. Correcting Offset

Offset is corrected by sliding the driver horizontally on the mounting flange. This may be difficult due to the manufacturing practice of placing an alignment groove or rabbet between the flanges. It may be necessary to grind material away from the driver's flange in order to allow horizontal movement of the driver with respect to the support frame.

1. Determine front-back and left-right offset. Take indicator readings using the rim indicator shown in figure 5-2. The following procedure is used to obtain the correct rim readings:

   a. Rotate both shafts until the rim indicator is in the "Back" position.

   b. Set the dial indicator to Zero.

   c. Rotate the shaft one full turn (360°) to ensure that the indicator returns to zero. If it does not, check the indicator mounting hardware for looseness and repeat steps a, b, and c.

   d. Rotate the shaft 180° so that the rim indicator is in the "Front" position and observe the "Front" rim reading.

   e. Rotate the shaft 360° to ensure the "Rim reading" returns to the same value in the "Front" position. If it does not, repeat steps a through e.

   f. Record the "Front" rim reading.

   g. Rotate the shaft until the rim indicator is in the "Right" position.

   h. Set the indicator to zero in this position.

   i. Rotate the shafts one full turn (360°) to ensure that the indicator returns to zero. If it does not, repeat steps g, h, and i.

   j. Rotate the shafts 180° so the rim indicator is at the "Left" position and obtain the "Left" rim reading.
k. Rotate the shaft 360° to ensure the Rim reading returns to the same value at the "Left" position. If it does not, repeat steps g through k.

l. Record the "Left" Rim reading.

**NOTE**

If the "Front" or "Left" Rim readings cannot be obtained due to physical obstructions (such as the pump housing or piping), refer to Section 6.2 and substitute "Back, Front, Right and Left" for Top, Bottom, Right, and Left" respectively for a mathematical method of determining the readings.

2. Calculate the necessary movement to correct offset. The "Front" and "Left" rim readings which were obtained will now be used to determine the necessary amount of movement in the "Back-front" and "Right-Left" planes as follows. **Dial indicator placement is very important in these steps. Right-Left and Back-Front conventions must be followed closely for correct results.**

   a. Divide the "Front" reading by two. This value will be the amount of movement required in the "Back-Front" plane. The direction of movement can be determined by the following rule: If the sign of the reading was POSITIVE (+), the driver must be moved toward the "Front". If it was NEGATIVE (-), the driver must be moved toward the "Back".

   c. Divide the "Left" reading by two. This value will be the amount of movement required in the "Right-Left" plane. The direction of movement can be determined by the following rule: If the sign of the reading was POSITIVE (+), the driver must be moved toward the "Left". If it was NEGATIVE (-), it must be moved toward the "Right".

3. Mount two dial indicators on the mounting base to monitor movement necessary to correct offset.

   a. Magnetically mount two dial indicators on the mounting base, one in the "Back-Front" plane and one in the "Right-Left" plane, in such a manner that their buttons are horizontal against the driver flange and able to monitor the movements in the two required directions (figure 5-6)

   ![Figure 5-6, Indicator placement for offset adjustment.](image-url)
b. Both indicators must be set to Zero before any movement of the driver is attempted. The driver should then be moved horizontally on the base plate until the required movements in both planes are obtained (see Figure 5-6).

5.3 **SECTION 5 QUIZ**

1. Explain the methods for determining angularity and offset for vertically mounted machinery.

2. Calculate the angularity and offset using the alignment computer.

3. Correct misalignment on vertically mounted machinery.
6. SUPPLEMENTAL INFORMATION

6.1 RIM FACE METHOD OF ALIGNMENT

An alternate method of alignment to the Reverse Indicator method is the rim face method. There are two variations to this method. The first variation (M1) calls for the brackets to be mounted on the MTBM with the indicator buttons resting against the shaft of the stationary machine. The second variation (M2) is identical to the first except that the indicators are mounted on the stationary machine with the indicator buttons resting against shaft of the MTBM.

1. The Rim Face method is often not as accurate as the Reverse Indicator method and so should be considered the second choice of method except for the following conditions:

   a. The radius of the "Face" to be measured is larger than the distance from the indicator bracket to the center of the coupling.

   b. Vertical machines require "Face" measurements for correct alignment; therefore Rim Face method will be used.

2. Mounting for the Rim Face method is shown in Figure 6.1.

![Figure 6-1, Setup for rim face method of alignment.](image)

3. After indicators are mounted, care must be taken to ensure that the indicator plunger is perpendicular to the surface it is measuring. Measurements are taken as follows:

   a. Perform the vertical alignment first. This will save time as adding shims will always misalign a machine horizontally.

   b. Take indicator "Rim" and "Face" measurements at two locations per plane of alignment, i.e. top and bottom for vertical plane, left and right for horizontal plane.
c. When using the alignment computer, always zero at the top and read the measurement at the bottom. For horizontal alignment, zero on the right side and read measurements on the left side. The right side will be positive adjustment direction and the left side will be the negative adjustment direction.

d. Sag needs to be compensated on the rim reading only.

e. Ensure that the face indicator is set for largest diameter of travel possible.

4. Determine vertical angularity. The face indicator is used to obtain angularity.

   a. Measure the distance from the center of the shaft to the point at which the face indicator touches the measurement surface. This is distance A.

   b. Place the face indicator at the top, zero the indicator.

   c. Rotate the indicator to the bottom; take the face reading, \( FI \).

   d. Calculate vertical angularity: \( Angularity = \frac{FI}{2 \times A} \).

5. Determine vertical offset. The rim indicator is used to obtain offset.

   a. Place the rim indicator on the top. Set the dial indicator positive to the amount of sag.

   b. Rotate the rim indicator to the bottom. Take the rim reading (RI).

   c. Measure the distance from the center of the coupling to the point at which the rim indicator touches the point being measured. Record as distance B.

   d. Calculate the offset. MTBM is high if offset is positive.

   - For rim face method M1, when dial indicators are mounted on MTBM and measuring the position of the stationary machine, use the following formula: \( \text{Offset} = (Angularity \times B \times 1) + (RI / 2) \)

   - For rim face method M2, when dial indicators are mounted on the stationary machine and measuring the position of the MTBM, use the following formula: \( \text{Offset} = (Angularity \times B) - (RI / 2) \)

6. For horizontal alignment readings using the rim-face method, repeat step 5 while exchanging the top and bottom for left and right respectively.
7. Calculate Adjustments.

a. Use a tape measure to measure the horizontal distance between the center of the coupling to the nearest support. Record this value to the nearest 1/16” as C. (Figure 6-2)

b. Use a tape measure to measure the horizontal distance between the supports. Record this value to the nearest 1/16 inch as D. (Figure 6-2)

c. Calculate front foot adjustment:
   \[ \text{Front Support Adjustment} = (C \times \text{Angularity}) - \text{Offset} \]

d. Calculate rear foot adjustment:
   \[ \text{Rear Support Adjustment} = [(C+D) \times \text{Angularity}] - \text{Offset} \]

8. See Section 4 for horizontal machinery adjustment details.
6.2 **CASE OF OBSTRUCTIONS.**

**A. Obstruction on the Bottom.**

In the case for Reverse Indicator method, sometimes it is impossible to obtain readings from the bottom indicators. If this is the case, proceed as follows:

a. Zero the rim indicator on the TOP at 1/2 the sag value (+).

b. Rotate the shafts to the left, take the reading.

c. Rotate the shafts to the right, take the reading.

d. Add the two readings together, including signs. [For example, left reading = -14, right reading = +6, then sum = (-14 + +6) = -8.]

e. The bottom reading is equal to the sum of the left and right readings.

**B. Obstruction on the Side.**

In the case for Reverse Indicator method, sometimes it is impossible to obtain readings from one of the side positions due to obstruction. Proceed as follows:

a. Zero the rim indicator on the available side.

b. Rotate the shafts so the indicator is on the top, take the reading.

c. Rotate the shafts so the indicator is on the bottom, take the reading.

d. Add the two readings together, including signs. [For example, given that the top reading = -14, and the bottom reading = +6, then by adding the two algebraically, the sum = (-14 + +6) = -8.]

e. The missing side reading is equal to the sum of the top and bottom readings.