Why Misalignment Continues to Rank as the Primary Source of Premature Rotating Machinery Failures

- Michael L. Snider

Introduction

There is no question about the progress that has been made during the past twenty years in methods and systems available for performance of shaft alignment tasks. Studies in the early 1980's that revealed 50% to 70% of premature machinery failures were related to misalignment generated a lot of attention and most major industries seriously took on the task of addressing the challenges associated with resolving misalignment related machinery failures. Such efforts have included use of better alignment tools, providing better training, and establishment and implementation of improved alignment standards and tolerances.

While there remains room for improvement in each of these areas, some of which will be addressed herein, there is a significant list of other items which are scarcely given consideration that contribute to costly misalignment-related machine repairs. And the majority of these items have nothing to do with the portion of the alignment task that typically gets the most attention…using the laser or dials to achieve specified tolerances. Another source of misalignment is a lack of understanding of fundamental machine concepts, such as bearing clearances and mechanical seal requirements. Finally, misalignment is frequently the rule rather than the exception as a result of several misconceptions, including such issues as the "flexibility" of flexible couplings or "forgiveness" of self-aligning bearings.

Consider the procedure often followed during an alignment check when vibration analysis or another condition monitoring technology indicates misalignment. Tag out the machine, pull the coupling guard, attach the laser or dial indicator fixtures, take a set of readings, compare results to tolerances, remove the fixtures, replace the coupling guard, remove the tags. Sound familiar? Hopefully not! So, what's wrong with that or similar procedures?

To answer that, let's first make a list of the major sources of misalignment symptoms.

- Poor Alignment Methods
- Good Alignment Methods, But Poor Practices
- Inaccurate Readings
- Pipe Strain
- Thermal Growth
- Bent Shafts
- Cocked Bearings
- Poor Shimming Practices
- Soft Foot
- Poor Bases and Foundations and Improper Grouting
- Excessive Coupling Runout, Poor Coupling Condition
- Move Limitations…Base Bound or Bolt Bound Conditions
- Poor Tolerances

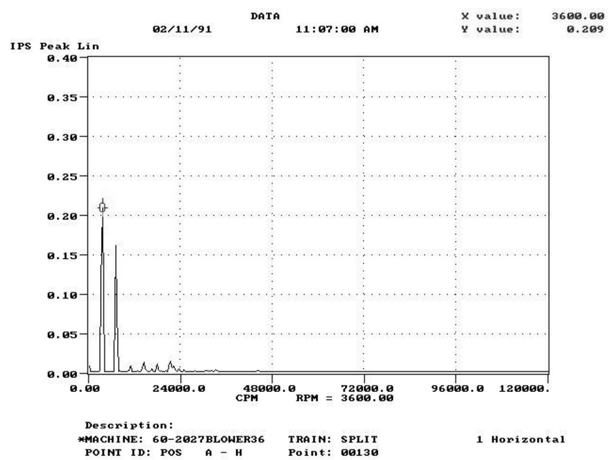
How many of these items are addressed in the simplified procedure above or in the alignment procedures used at your facility? Each of these misalignment sources is discussed in detail in this article.

Detection and Analysis of Misalignment

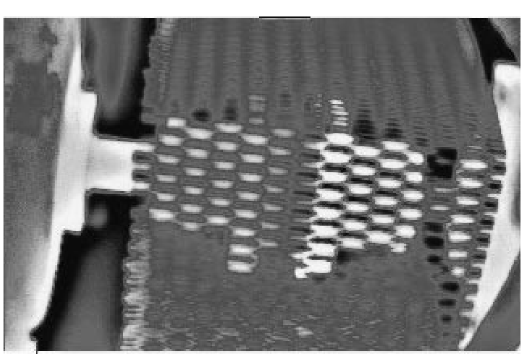
Prior to addressing each of the items listed above, let us first address how we can accurately determine that misalignment is indeed the source of failure. There are many methods and technologies available to detect misalignment, each with advantages, disadvantages, and varying degrees of complexity.

One primary condition monitoring technology used is vibration analysis. While vibration analysis is not able to pinpoint the specific type, cause, or severity of misalignment, there are key symptoms that should be understood and evaluated when misalignment is suspected. While a detailed discussion of how to detect misalignment using vibration analysis is beyond the scope of this paper, the general symptoms are:

- Amplitudes are higher in one particular direction, vertical or horizontal.
- Axial amplitudes are greater than 50% of radial amplitudes at a specific bearing.
- End-to-End and Vertical-to-Horizontal phase relationships are 0 or 180 degrees.
- Vibration spectral data show a 2 X RPM peak higher than 1/3rd the amplitude of the 1 X RPM peak.
- Motions between vertical and horizontal directions are different.



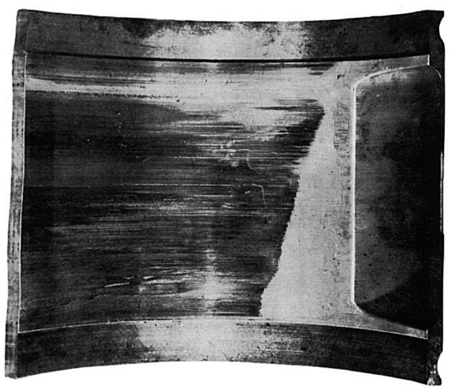
As with any analysis process, when using vibration analysis to detect misalignment care should be taken to gather and analyze a sufficient amount of data, including spectral data, amplitude data, phase data, and time waveform data. It should also be noted that all misalignment problems do not reveal the clear symptoms listed above. Some misaligned machines simply do not react vibration-wise according to these textbook symptoms.



Infrared thermography is another condition monitoring technology that is useful in detecting misalignment. Misalignment frequently results in higher than normal bearing operating temperatures, particularly at the drive-end bearings. Coupling temperatures are also often higher than normal. While simple temperature measurements can be used, infrared data offers a visual confirmation of misalignment. In this illustration, note the “hot spots” at the drive-end bearings and the coupling.

A primary advantage of using condition monitoring technologies such as vibration analysis and infrared thermography to detect misalignment is that the problem can be detected while the machine is still operating. This permits better job planning to further analyze and correct the root causes of the problem.

Other means of detecting misalignment include examination of bearing wear patterns. In rolling element bearings, misalignment often results in a wear track that is skewed across the raceway.



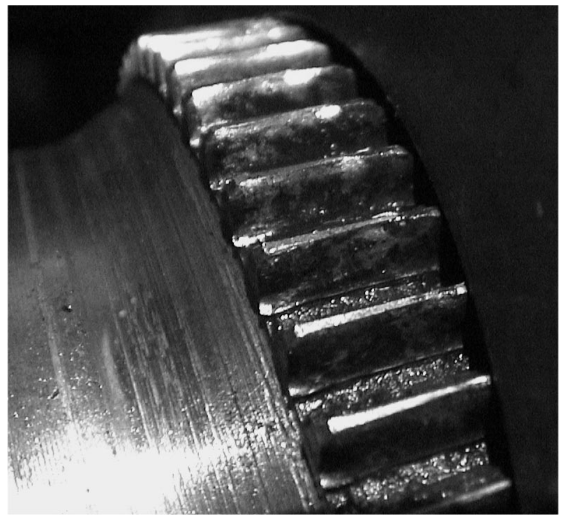
In plane or sleeve type bearings, misalignment often results in either an angular wear track of a pattern referred to as “cross-cornering.”

While misalignment is also a major contributor to premature mechanical seal failures, compared to bearing failures, seal failures don’t typically provide as clear an indication of the specific cause of the failure. From a seal perspective, a primary issue with misalignment is the excessive shaft deflection that results. One challenge in seal failure analysis is determining the specific cause of shaft deflection. Unbalance, poor seal installation, shaft runout and several other problems also result in excessive shaft deflection. General symptoms of misalignment in failed seals include:

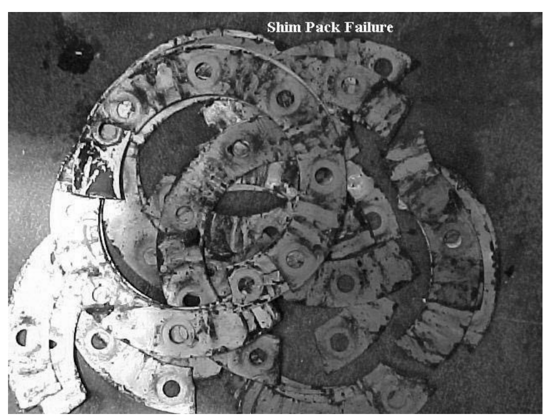
- Excessive wear on secondary seals
- Fatigue failure of bellows type seals
- Wider than normal wear tracks on the stationary primary seal face due to excessive shaft deflection
- Possible eccentric wear track on stationary seal face

Misalignment can also be detected through examination of the coupling itself. In a majority of cases, misalignment will not lead to actual failure of the coupling. The bearings and seals generally fail prior to the coupling; however, examination of the coupling often provides information to confirm the analysis. On elastomeric couplings, misalignment often results in fatigue of the elastomeric element. This includes failed spiders, rubber inserts, rubber boots, etc.

On flex-grid and gear type couplings, misalignment often results in angular wear of the coupling teeth.



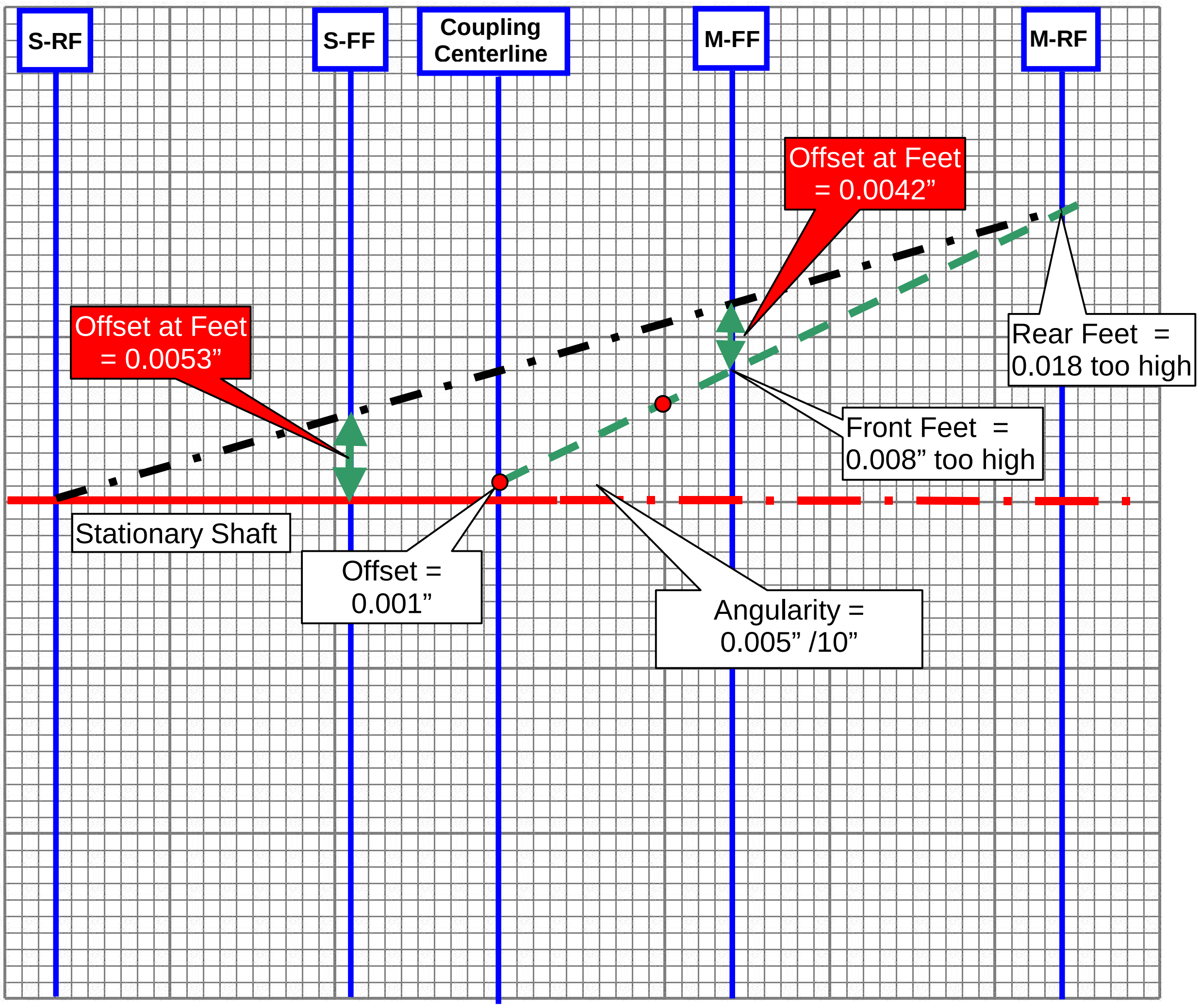
On shim-pack couplings, misalignment often results in shims breaking adjacent to the washer face with fretting corrosion present in the area of the cracks.



What fails due to misalignment and why?

Studies in machinery failures overwhelmingly confirm that the vast majority of rotating equipment failures involves the seals and the bearings. For example, for machines such as pumps, some companies report that as many as four out of five failures include a seal or bearing failure. Obviously, not all these seal and bearing failures are due to misalignment, but significant percentages certainly are. How does misalignment contribute to such failures?

First, let's take a graphical look at misalignment. Consider the illustration below.



It is important to note that the misalignment illustrated here is a combination of only 0.001" offset and 0.0005"/" angularity. In terms of rim-face alignment readings, this would be only 0.002" TIR on the rim of the coupling and 0.002" TIR on the face of a 4" diameter coupling. These values fall within what most would consider "precision" or "excellent" tolerances. But, let's take a closer look. Though the misalignment in terms of offset and angularity appear minimal, the offset at the rear feet of the right machine is 0.018".

Even more important is to look at the offset at the drive end feet (near the drive end bearings and the mechanical seal!) What must be understood is that all shafts attempt to run on a common axis of rotation. **That is, regardless of the type of bearings, or seals, or couplings…they still attempt to run on a common axis.** This common axis is drawn on the graph between the position of the stationary shaft at the rear feet and the misaligned position of the movable shaft at the rear feet. In this example, the distance between the actual shaft position and the common axis is about 0.005" at the front feet of the stationary machine and about 0.004" at the front feet of the movable machine.

Again, those numbers may appear minimal at first glance…slightly larger than a piece of paper. However, let's look at those numbers with regard to mechanical seals and bearings. Mechanical seals are designed to operate with minimal shaft deflection, a maximum of 0.002" is generally recommended. If the misalignment creates a shaft deflection of more than that, it is contributing to premature seal failure.

And what about the bearings? A properly installed rolling element bearing on for example a 2" diameter shaft has only about 0.001" radial internal clearance after it's installed; and it has minimal clearance between the outside diameter and the bearing housing. If the misalignment at the location of the bearing is such that the internal clearance is lost or even reduced, the oil film thickness is reduced, the bearing experiences additional dynamic loading, and misalignment is at least contributing to premature bearing failure.

A common argument to the perspective presented here is that these forces are not truly transmitted to the bearings and the seals, that the flexibility of the "coupling" prevents bearing and seal damage. To rebut those arguments in detail is an argument of its own. However, not only in practical experience, but also in laboratory tests, it has been proven that forces on bearings and seals are almost 100% independent of the type of coupling used. For more information, contact our office or visit our website and review an article entitled "Study Shows Shaft Misalignment Reduces Bearing Life" published by Maintenance Technology magazine in its April 1999 issue.

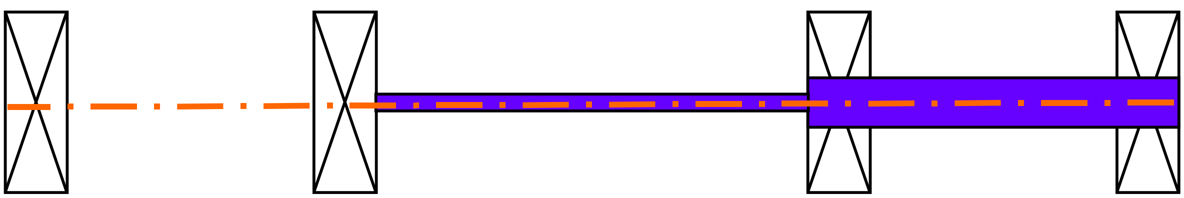
Precision Alignment Standards and Tolerances

Part of the solution to reducing the adverse impact of misalignment on bearing and seal failures is to establish and implement precision alignment standards and tolerances. While these standards and tolerances are comprehensive and will unfold throughout this article, the first two issues relate to standards for alignment methods that are permissible and maximum values that are allowed.

Generally, companies establish alignment tolerances in terms of offset and angularity at the centerline of the coupling. While this may be commonplace, it leaves much to be desired. As was hopefully illustrated in the graph above, even though the offset and angularity values at the coupling may be minimal, the resulting offset at the feet may be significant. If our goal is to minimize loads on the bearings and seals, then the alignment tolerances must specify allowable misalignment at or near the location of the bearings.

Based on the improved bearing life, seal life, and overall machinery reliability achievements of several companies throughout several major industries that have implemented the alignment tolerances shown below, the following represents our recommendation:

Machine Speed	Maximum Offset at Machine Feet	Maximum Offset at Coupling Centerline
< or = to 1800 RPM	0.002” (0.050 mm)	0.001” (0.025 mm)
> 1800 RPM	0.001” (0.025 mm)	0.0005” (0.013 mm)



While these are strict tolerances and may not be achievable for all companies overnight, they are based on practice and experience of companies that have successfully implemented these standards. The primary advantage of this method of specifying alignment tolerances is two-fold.

1. This method minimizes offsets at the bearings, thereby dramatically reducing the impact of misalignment on bearing clearances and on shaft deflection at the seal location(s).

2. This method dictates what precision alignment methods are permissible. For example, it the specified tolerance calls for a maximum of 0.002” at the machine feet, then the method used must be capable of displaying what the offsets truly are at the feet.

    - All laser systems on the market have the capability to display offset and angularity values at the coupling and offsets at the machine feet, and are therefore permissible alignment methods.

- Dial indicator methods are also permissible as long as standards require determination of offsets at the feet by either calculation of graphical methods.
- Traditional single dial rim-face methods are not permitted, since the method generally relies only on values at the coupling.
- Straight edges, calibrated eyeballs, and thickness gauge methods are also obviously not permitted.

Good Alignment Methods, But Poor Practices

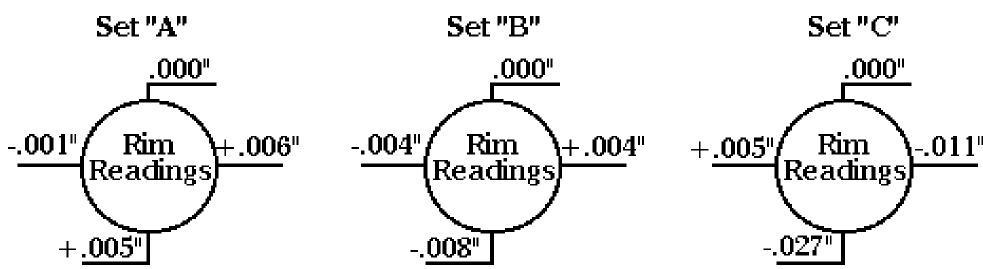
Even when using approved precision alignment systems and methods, there are a variety of poor practices that often yield poor results.   Among them are the following:

- Inaccurate alignment data
- Lack of repeatability
- Misused computer functions and alignment processes

Regardless of whether laser systems or dial indicator methods are used, the entire precision alignment process and all the calculations that are made are dependent on the accuracy, repeatability and validity of the readings. Most personnel who use dial indicators are familiar with the validity rule, which applies to both rim and face type readings:

Validity Rule: The sum of the top and bottom readings must equal the sum of the side and side readings.

Consider the following sets of offset readings:



Set "A"

Note that the sum of the top and bottom, 0.000" + (+0.005"), is equal to 0.005". And the sum of the side to side readings, -0.001" + (+0.006"), is also equal to +0.005". Since these sums are equal, we can conclude that the readings are indeed valid.

Set "B"

Note that the sum of the top and bottom, 0.000" + (-0.008"), is equal to -0.008". And the sum of the side to side readings, -0.004" + (+0.004"), is equal to +0.000". Since these sums are NOT equal, we can conclude that the readings are not valid.

Set "C"

Note that the sum of the top and bottom, 0.000" + (-0.027"), is equal to -0.027". And the sum of the side to side readings, +0.005" + (-0.011"), is equal to -0.006". Since these sums are NOT equal, we can conclude that the readings are not valid.
When a set of readings is NOT valid, we must determine why they are not valid. Included amongst the precautions for using dial indicators are the following:

1. Ensure all fixtures are properly installed, tight on the components, and not rubbing on the machine casings.

2. Take readings at the true clock positions: 12:00, 3:00, 6:00, and 9:00. It is recommended that an accurate level of some type be used after the fixtures are attached to establish the true clock positions. Once these positions are determined, some mechanism (such as marks on the bearing housing or shaft) should be utilized to ensure all readings are taken at these points.

3. All readings should be checked for repeatability. This includes ensuring the dial comes back to zero at the first measurement position and double-checking all readings for consistency.

4. Watch indicators throughout the rotation of the shafts to ensure the proper amount and sign of the reading is determined and documented.

5. Eliminate error due to coupling backlash. This can be achieved by holding opposing pressures on the shafts while they are rotated.

It should be noted that in order to ensure dial indicator readings are valid, we must obtain and evaluate readings at all four clock positions, 12:00, 3:00, 6:00, and 9:00. Most personnel who use dial indicators use this process and rotate both shaft 360 degrees. While in theory, by applying the validity rule, the fourth value could be calculated based only on three readings and 180 degrees of rotation, most people obtain the fourth reading in order to perform the validity check.

While the discussion above may appear to apply only to dial indicator alignment methods, much of it also applies to laser systems. How do we know that a set of laser readings is accurate, repeatable, and valid? While some laser systems provide readings at the four clock positions in thousandths of an inch that can be compared to dial values, others do not. Some systems have several different modes for measuring misalignment. While laser systems offer many advantages over dial indicator methods especially in reducing human errors, they are subject to some of the same sources of error as dial indicators, plus a few more. When using lasers, it is extremely important to observe certain precautions when gathering data:

1. Always rotate both shafts as much as possible during each measurement; 360 degrees is desired and at least 180 degrees if at all possible.

2. Minimize coupling backlash and its adverse impact on reading accuracy.

3. When using longer support rods to hold laser components, if anti-torsion bridge assemblies (rod stiffeners) are provided, use them.

4. Always gather multiple sets of readings and check for repeatability prior to evaluating data or making moves.

5. Keep cables tight and lenses and apertures clean.

6. Have calibration checked as recommended by the manufacturer.

Following these precautions will assist in ensuring that alignment data is accurate and that all the calculations based on that data is accurate as well.

An additional issue related to bad practices relates to misused computer functions and alignment processes. In particular, methods that are provided in most laser systems and with some dial indicator alignment methods for "measuring soft foot" are often misunderstood and misused. Whether using a laser system or a dial indicator mounted from one machine to the other, these methods do not provide accurate soft foot measurements. Though the systems on the market are somewhat different, essentially they function based on shaft deflection that may occur as a result of soft foot. With the laser components or dial indicator(s) set up on the shafts, the user loosens a hold down bolt and observes either the dial indicator or laser's computer display. Dependent on the system being used, either a direct value or a calculated value will appear.

Regardless of the system being used, it is important to understand that these values DO NOT reflect a measured gap between the bottom of the foot and its supporting surface. At best, the displayed values are calculated estimates of what might be going on under the foot. If using these functions, it is extremely important to check the actual condition between the bottom of the foot and the supporting surface to verify whether there is a gap and if so the size of the gap. The preferred method is use of thickness gauges under the feet; dial indicators mounted on the feet are another alternative.

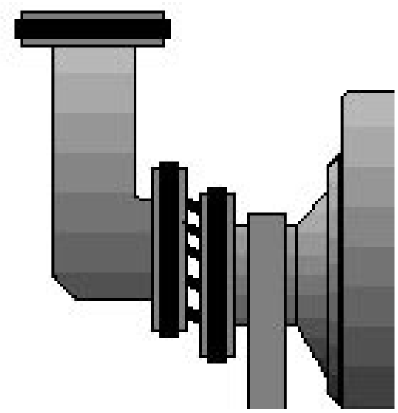
A detailed discussion of this concept will be provided upon request; however, in general the major factors that influence the limitations of such soft foot "measurements" based on shaft deflection are as follows.

- Base stiffness and base deflection
- Bearing internal clearances
- Bearing housing clearances
- Angular foot deflection

More information on soft foot, its causes, effects, and solutions is provided below.

Pipe Strain

Perhaps one of the most significant issues that impacts shaft alignment tasks and contributes to misalignment-related machinery failures is pipe strain. Two major types of pipe strain exist, static pipe strain and dynamic pipe strain. Static pipe strain exists when the machines are not at operating conditions. Dynamic pipe strain exists when the machines are operating, when the piping is full of product and at operating temperatures.



Static pipe strain and its effects are relatively simple to measure. One method is to disconnect the pipe flanges and measure the piping misalignment. When using this method most companies use the standard that there should be no more than 1/64" difference in distance between the flanges. Furthermore, the bolts should go freely through the holes without use of a come-a-long to align the pipe flanges. To check for the effects of pipe strain on the machine, dial indicators should be mounted vertically and horizontally at each bearing. The dials are set to zero and rechecked as each flange is connected or disconnected. Any movement at the bearing of more than 0.002" should generally be considered excessive.

Dynamic pipe strain is much more difficult to check since it is present only after the machine and piping are at operating conditions. Much of this type of pipe strain is due to thermal expansion of the piping, the weight of system fluid, combined with inadequate piping and piping support design. This type of pipe strain is most often detected by using a measurement device to check for machine movement between off-line and on-line conditions. Examples include the Acculign™ system, Dodd Bars, or Permalign™ system.

How does pipe strain cause misalignment-related failures? Like soft foot, pipe strain results in distortion of the machine frame. As the machine frame or casing is distorted, so are the bearing housings, the shaft, and other components. As discussed above, anything that leads to shaft deflection or reduced bearing clearances can quickly lead to catastrophic failure, particularly of bearings and seals.

Thermal Growth

In addition to or combination with pipe strain, another major challenge that complicates the alignment process is how to determine and deal with shaft movement due to thermal growth. It should be understood that a major goal of the alignment process is to ensure the shaft centerlines are collinear when the machines are at operating conditions. If the shafts move between the time the alignment is performed and when the machines are at full operating conditions, then the alignment process should be such that the shafts are misaligned by the proper amount to compensate for the movement that will occur.

The first challenge is how to determine how much thermal growth will occur. There are three basic alternatives to making this determination:

- Manufacturer's Recommendations
- Thermal Growth Calculations
- Actual Measurements on the Machine(s)

In practice, all three of these are often used to make the decision. While manufacturer's literature often provides a good starting point, it is not always accurate. Generally, manufacturer's recommendations are based on engineering data and experience with the machine, but does not take into account your specific operating conditions. Their recommendations also assume that no pipe strain is acting on the machine, potentially impacting the amount and direction of actual movement.

Thermal growth calculations also provide insight into the amount and direction of movement. One advantage this method has over manufacturer's recommendations is that your specific operating conditions and temperatures are factored in. However, this information is again theoretical and assumes no pipe strain or other factors that influence machine movement.

The most accurate information is generally provided by actually measuring movement of the machines themselves. As mentioned earlier, systems available in the market today for this purpose include the Acculign™ system, Dodd Bars, and Permalign™ system. Each of these systems has advantages and disadvantages and should be evaluated based on machine size, machine location, environmental conditions, complexity of setup and use, etc. The advantage each of these systems offer over manufacturer's recommendations and thermal growth calculations is that they do provide actual physical measurement data of movement itself.

Once the amount of movement is determined and reconfirmed, the next challenge is how to compensate for the anticipated movement. After offsetting machines to compensate for dynamic movement, the shafts are obviously not aligned. If using dial indicators, the task can become quite confusing to those without advanced alignment training due to the desired indicator values NOT being zeroes. One major advantage of most laser systems on the market is that they allow the user to input thermal offsets or movement either at the feet or at the coupling, and then the computer compensates for these values throughout the task.

Bent Shafts

When shafts are bent, forces within rotating machinery create symptoms that are somewhat like unbalance and somewhat like misalignment, particularly if evaluating the problem using vibration analysis. However, from the perspective of the bearings and the seals, the problem is similar to that described above, additional dynamic loading, reduced oil film clearances, and shaft deflection. Furthermore, the time to detect that a shaft is bent outside specified tolerances is often during the alignment process.

Several problems contribute to bent shafts not being detected during an alignment check. One is that with most precision alignment methods in use today, both shafts are rotated throughout the alignment process. By rotating both shafts while obtaining alignment readings, the effects of one or more bent shafts <u>on the alignment process</u> is eliminated.   However, bent shafts remain a problem of which we need to be aware.

Cocked Bearings

Earlier in this article, we discussed that misalignment often creates a skewed or angular wear track within the bearing raceway. When a failed bearing is examined and these symptoms are noted, the almost immediate conclusion is that the problem is due to misalignment. And the temptation is usually to conclude that the problem is shaft misalignment; however it should be noted that a cocked bearing will create identical symptoms to shaft misalignment.

Common causes of cocked bearings that should be identified and corrected include:

- Burrs on shaft shoulders
- Non-square spacers
- Non-square shaft shoulders
- Improper bearing installation
- Improper seating of bearing housings and bearing caps

Excessive Coupling Runout & Poor Coupling Condition

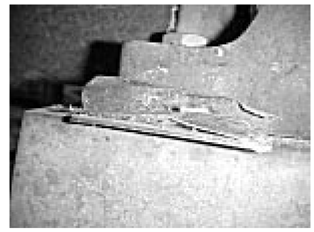
As mentioned during the discussion above on bent shafts, excessive coupling runout often goes undetected, especially because most current alignment practices include rotating both shafts throughout the alignment process. Furthermore, though it is an unacceptable practice, in many cases couplings aren’t even disassembled, cleaned and inspected during the alignment process.

It should be understood that though most couplings in use today are considered “flexible,” there are several common problems with couplings that transmit forces directly to the bearings and adversely impact seal performance. Inspections should not only include cleaning the coupling and inspecting it for excessive wear, but also checking rim and face runout and determining and correcting the source of the runout. Common sources or excessive coupling runout include poor fits to the shaft, eccentric bores, and skewed bores.

Poor Shimming Practices

Improper shimming techniques come in many forms and cause a wide variety of problems. Common shimming errors include:

- Too many shims
- Incorrect shim size
- Dirty shims
- Painted shims
- Bent shims
- Hand-cut shims
- Unequal shims



These errors result in two primary problems:

- Soft foot
- Difficulty achieving alignment tolerances

Tips to avoid these problems include:

1. Check the thickness of all shims and shim packs with an outside micrometer.
2. Ensure the size of the shim matches the size of the foot.
3. A maximum of four (4) shims is recommended per foot.
4. Discard all shims that are dirty, bent, painted, corroded, or hand-cut.

Poor Bases, Poor Foundations, and Improper Grouting

There are several sources of premature machinery failures related to the base problems, including:

- Flexible Bases
- Dirty Bases
- Warped Bases
- Resonant Bases
- Cracked Bases and Foundations
- Burrs & Foreign Material
- Improper Grouting

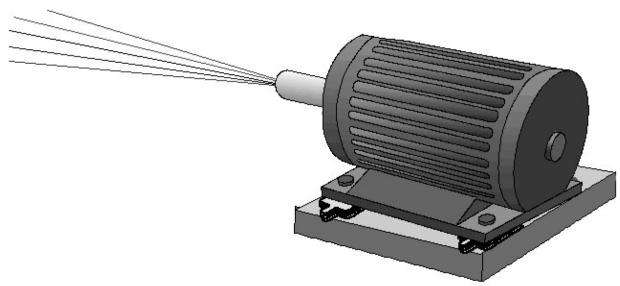
Prior to attempting precision alignment, the entire base should be carefully inspected and thoroughly cleaned.

Soft Foot

Of the many machinery support issues that exist, the problem that often gets the most attention is soft foot. Studies conducted by several companies indicate that up to 40% of their misalignment problems relate to soft foot. Soft foot is defined many different ways, and the concept is much too frequently misunderstood. There are many different types of soft foot, but essentially we can say that a soft foot condition exists any time a machine foot isn't providing support as designed.

Base and foot problems have several adverse effects on machinery operation and on performance of alignment tasks. To understand the reason base and foot problems make alignment tasks more difficult, consider the illustration below. During the alignment task we are measuring the relative position of shaft rotational centers. With soft foot present, the shafts move as the machines "rock" on one or more soft feet.

As a result of soft foot, precision moves become very difficult. Often, one set of readings will indicate that the movable machine should be raised, then the next set indicates it should be lowered, etc. Horizontally, as bolts are tightened, the machines tend to move dramatically side to side.



In addition to making alignment tasks more difficult, there are many machinery reliability problems directly related to base and foot problems, including:

- Bearing Stress
- Machine Frame Distortion
- Electrically-related Vibration
- Improper Motor Air Gap

There are three main types of base and foot related problems, static soft foot, dynamic soft foot, and foot-related resonance. To minimize premature machinery failures caused by base and foot problems, each of these should be understood, though only static soft foot will be addressed herein. A static soft foot condition exists any time one or more feet not make full contact with the machine base when a machine is not operating. When a soft foot condition exists, the feet of a machine do not equally share in properly supporting the weight of the machine. Soft foot conditions occur when the machine feet or the base pads are NOT in a common flat plane.

In order NOT to have a static soft foot, what conditions must exist?

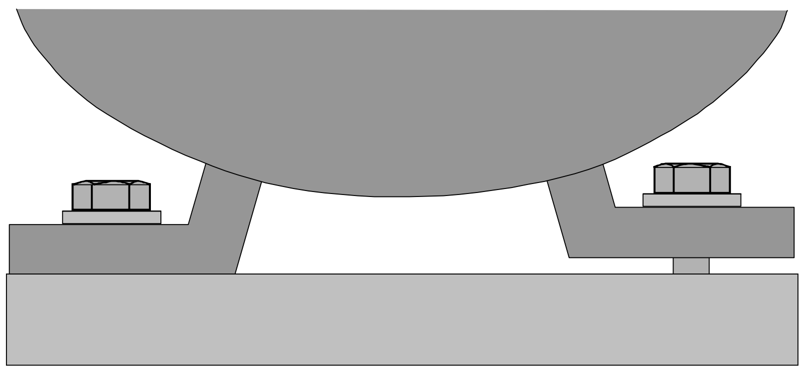
- The base or mounting pads must all be perfectly flat and in the same plane.
- The feet must all be flat and in the same plane.

How often do such ideal conditions exist? Almost never.

Several conditions, some of which are not specifically related to the base or foot, can cause problems that show up as static soft foot. While true soft foot is caused by one or more feet or mounting pads being too short or angled, soft foot can also be induced by shimming errors, pipe strain, etc.

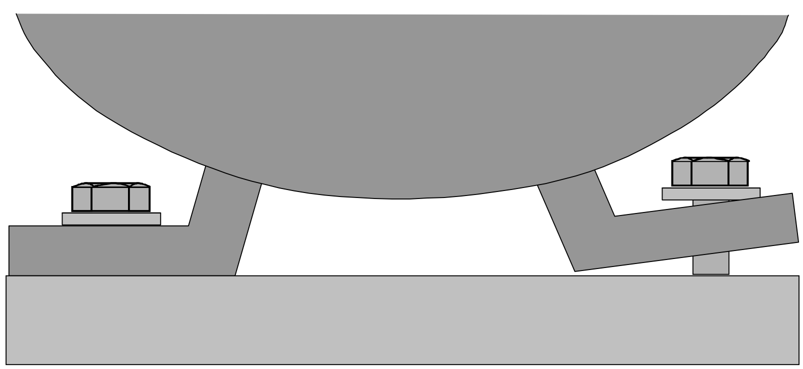
Short Foot

One type of soft foot is called "short foot." When the machine feet and the base pads are flat, but do not all lie in the same plane, the condition creates the effect of a short foot. This type of soft foot is corrected by simply adding the correct thickness of shim material under the short foot/feet.



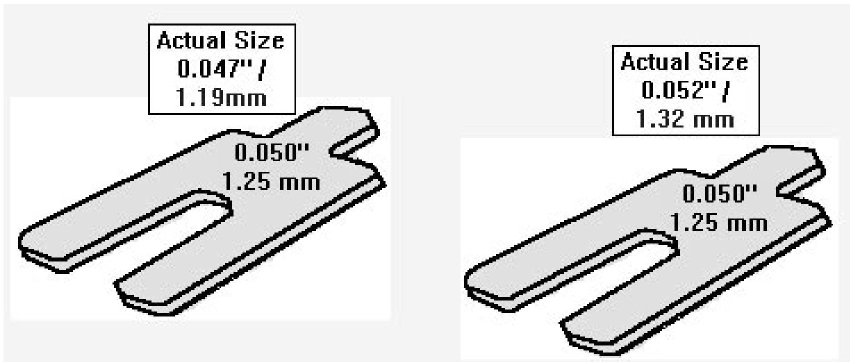
Angled Foot/Mounting Pad

When the machine feet and/or the base pads are not flat, the condition creates the effect of an angled foot. This condition frequently results from improper use of pry bars, dropping machinery, etc. Correcting this type of soft foot usually involves either machining or step shimming.



Shim Induced Soft Foot

Suppose you determine that 0.050" (1.25 mm) of shims need to be added to both rear feet. If two precut shims of unequal thickness are added, a soft foot condition has been induced.



Misalignment and Piping Induced Soft Foot

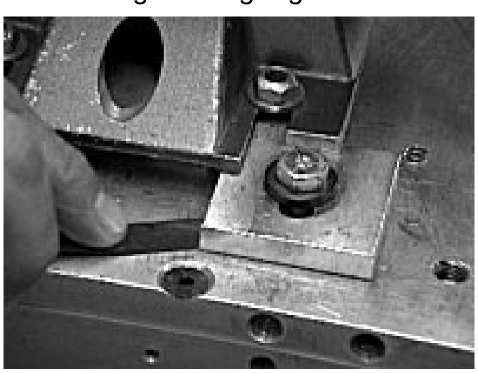
If a soft foot check is performed prior to an adequate "rough alignment" being achieved, and with the coupling assembled, binding in the coupling can lift small machines, and create what appears to be a soft foot. In addition, if a soft foot check is performed on a machine that is subject to pipe strain, the pipe strain can lift, push, or twist the machine as bolts are loosened, creating the appearance of one or more soft feet.

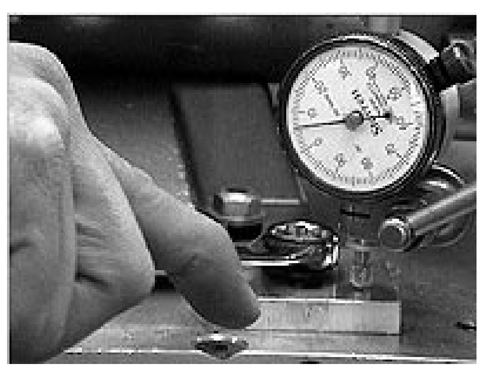
Performing a Precision Soft Foot Check

Before performing a final soft foot check you should know that:

1. A final soft foot check should be performed ONLY after gross vertical angular misalignment has been corrected.

2. Accurate soft foot checks can be made using a dial indicator mounted on the each foot or using feeler gauges or shims.

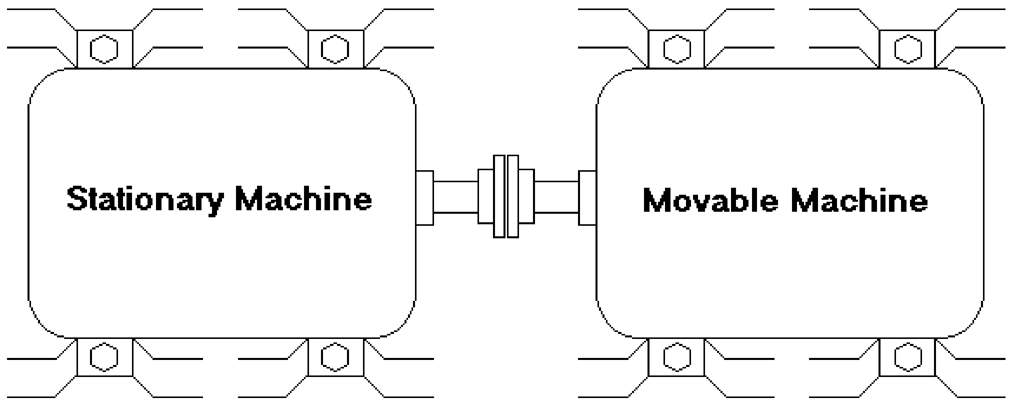




3. **A precision soft foot check should be completed before and after precision alignment has been performed.**

Final Soft Foot Check Procedure

A final soft foot check can be performed using dial indicators or thickness (feeler) gauges. Three to four positions on each foot should be checked and documented. **These checks should be performed on all machines. A common misconception is that soft foot checks are only required on movable machines.**



To perform a final soft foot check using feeler gauges, follow these steps:

1. Loosen a foot hold down bolt, measure and note the gap between the foot and the base. Check 3-4 locations per foot.

2. Retighten the hold down bolt.

3. Repeat steps 1 and 2 until all feet have been checked.

Correcting Soft Foot

Soft foot conditions exceeding 0.002” at any point on any foot should be corrected by performing the steps below:

1. Start by adding shims to correct the foot with the largest soft foot value.

NOTE: Be careful NOT to add too many shims; over correcting will result in increased soft foot at the adjacent feet.

2. After correcting the foot with the largest amount of soft foot, re-check other feet and make corrections as needed.

3. Excessive amounts of angular soft foot conditions must be correcting be either machining the feet or using shims to fill the angular gap.

Conclusions

The progress that has been made in providing major industries with better tools to perform routine shaft alignment tasks is significant. However, despite these tools, the problem appears to be chronic in its nature. If our goal is not simply performing alignment tasks as quickly as possible, but resolving machinery failures due to misalignment, we have many challenges that must be addressed. Hopefully, the most significant of these challenges has at least has been identified here, along with some recommendations on how to resolve them.

Key to the success of our efforts is proving that the failure is indeed misalignment-related. In the detection and analysis section above, we outlined some ways to accomplish this. Once we have determined the problem to be misalignment, we need to take a broad approach and ensure technicians who perform alignment tasks are aware of the many issues raised in this article, and that they have been trained in how to resolve them. This applies to both internal company employees and contractors who install and align equipment as well.

Finally, once the steps have been taken to make the corrections needed, we must take the time to verify that the misalignment problem has indeed been resolved. This is often accomplished through collection and analysis of post-repair vibration and infrared data, tracking additional bearing and seal life, calculation of amperage reduction and energy savings, etc. It is only through these sorts of verification steps that we can indeed see the value in such efforts. These results can then be shared with those who manage the budget.