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PRECISION ALIGNMENT STARTS AT THE BASE

AGENDA

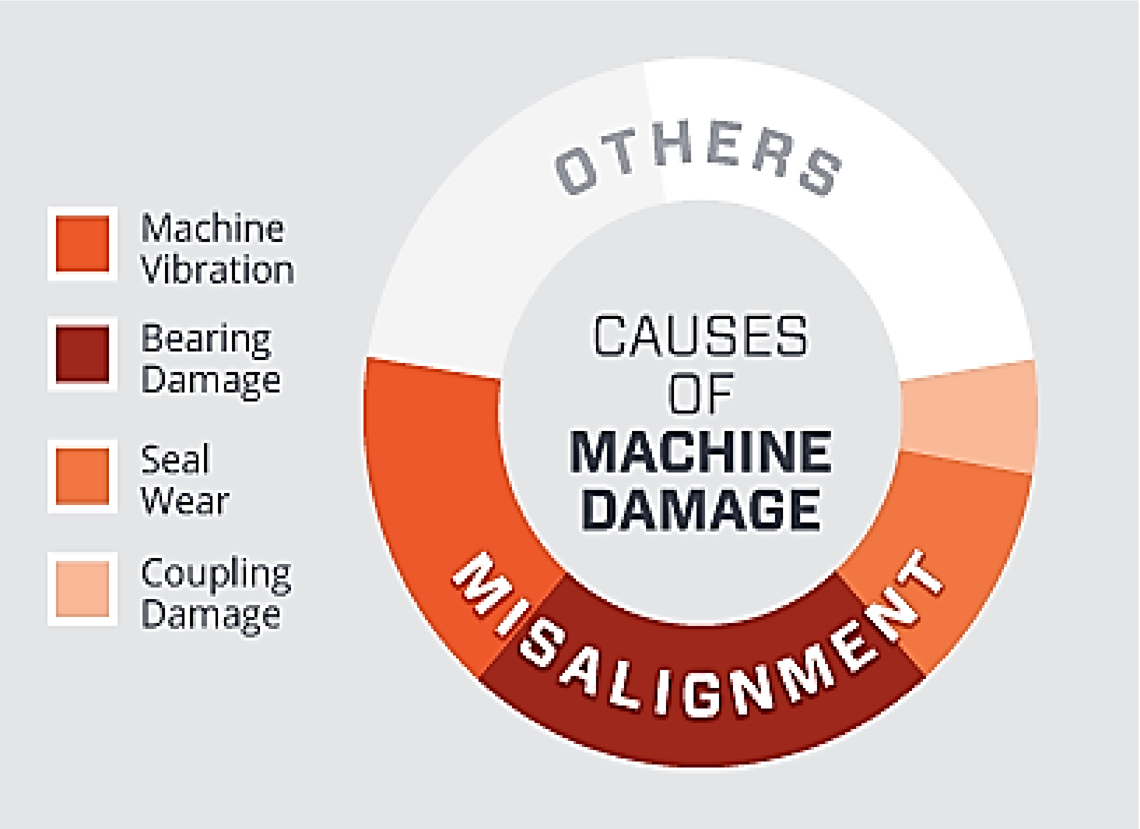
- Precision Alignment
- Fundamentals
- Bearing installation
- Machine installation
- Jack bolts
- Soft foot

WHY PRECISION ALIGNMENT?

Up to

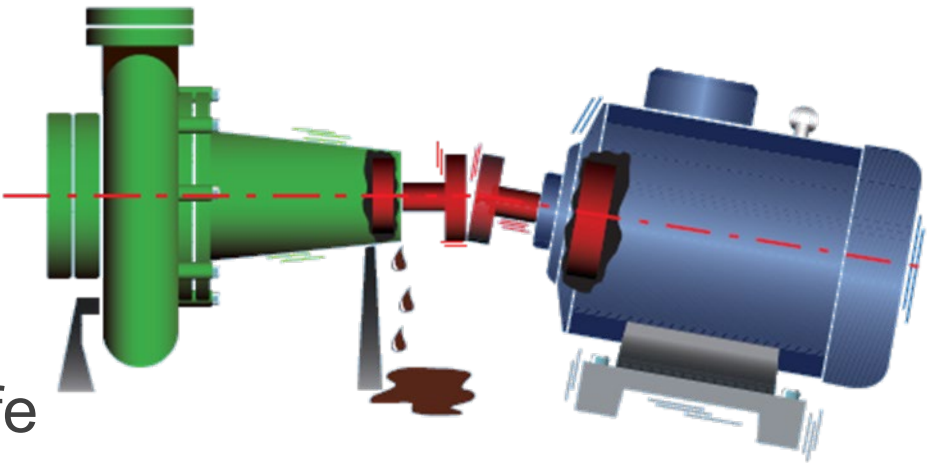
50%

of damage to rotating machinery is directly related to misalignment



Not aligning shaft centerlines to precision tolerances has a substantial impact on:

- Seal failures
- Bearing failures
- Shaft failures
- Coupling wear
- Decreasing component life
- Excessive energy consumption.
- Excessive heat and vibration



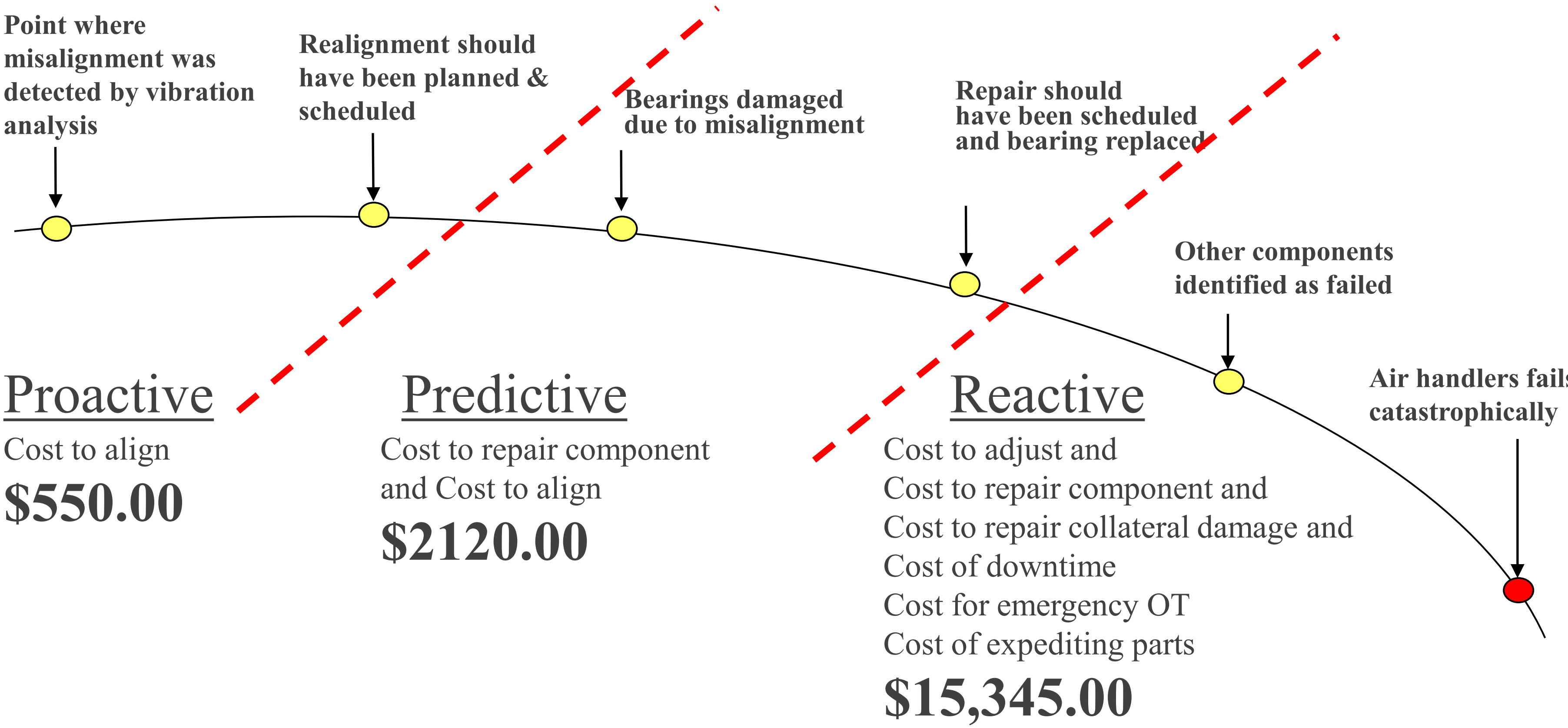
"Vibration analysis just tells you that you have an issue. Alignment keeps your equipment running."

—John Upchurch
Reliability Manager
Holcim Inc.
St. Genevieve Plant

ALIGN YOUR MACHINES!

BE PROACTIVE!

WHY ASSET CONDITION MAINTENANCE



Increased Reliability - Decreased Costs **Decreased Reliability - Increased Costs**

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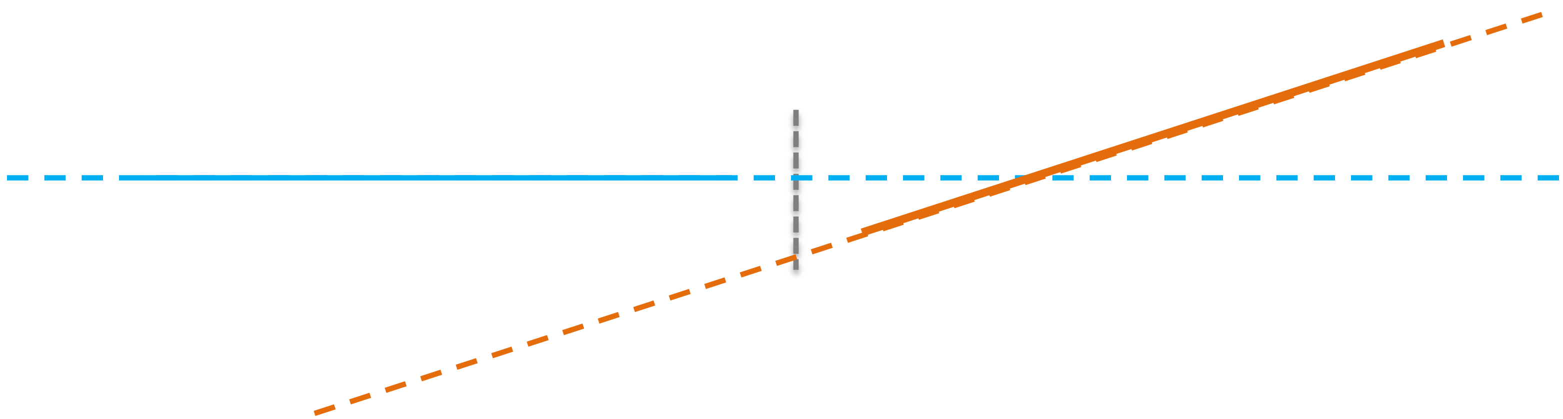
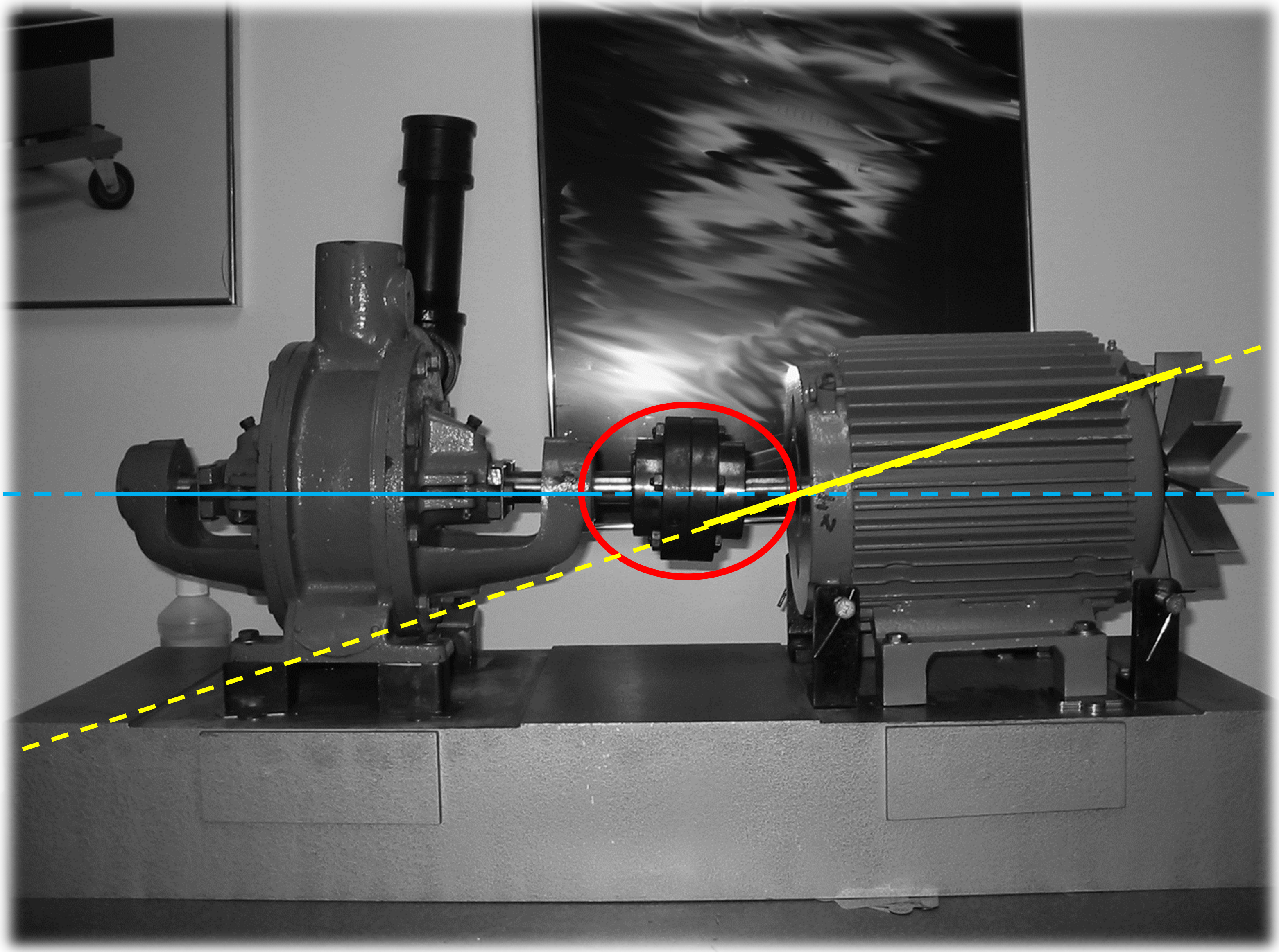
FUNDAMENTALS

- Definition of shaft alignment
- Shaft preloads

DEFINITION OF SHAFT ALIGNMENT

- Positioning two or more machines so that their rotational centerlines are collinear at the coupling point under operating conditions.
  - “rotational centerline”
  - “collinear”
  - “coupling point”
  - “under operating conditions”





The term shaft alignment also implies that the bearings and shafts are free from preloads.

WHAT CAN CAUSE THESE PRELOADS?

- Bearing not installed properly
- Base not flat
  - Manufacturing
  - Installation
- Pipe stress
- Coupling strain

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Bearing installation

- Failures
- Pre-installation
- Conventional Methods

COMMON BEARING FAILURES

- Lubrication Failure
- Contamination
- Improper Mounting
- Misalignment
- False Brinelling
- Improper Storage and Handling
- Poor bearing design

- Fatigue (Spalling)
- Overheating
- Excessive Loads
- Corrosion
- Fit
- Electrical Damage (Fluting)

ROLLER ELEMENT BEARING FAILURE PATTERNS

Bathtub
Pattern A = 4%

Wear Out
Pattern B = 2%

Fatigue
Pattern C = 5%

Initial break-in period
Pattern D = 7%

Random
Pattern E = 14%

Infant Mortality
Pattern F = 68%

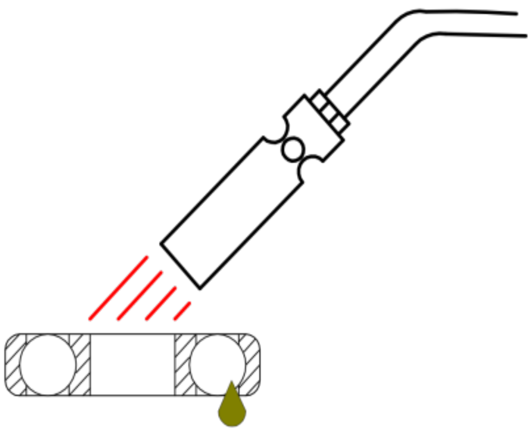
PRE-INSTALLATION CHECKS

- Safety procedures
- Remove old bearing
- Clean-up of shaft: remove grease, nicks, and burrs.
- Do not unwrap bearing until ready for installation
- Ensure shaft diameter is within tolerances
- Check bearing clearances

- Do not remove factory lubricant
- Ensure that bearing is the exact replacement
- Ensure once again that shaft is clean

Blow Torch

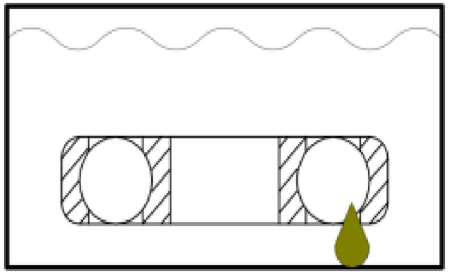
- No Temperature control
- Risk of over heating
- Grease Leaks out of bearing
- Tension in material



CONVENTIONAL HEATING METHODS

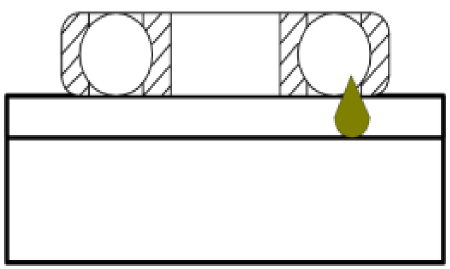
Oil Bath

- Slow Heating process
- Grease cooks out of bearing
- Dangerous (Hot oil)
- Environment unfriendly



Hot Plate

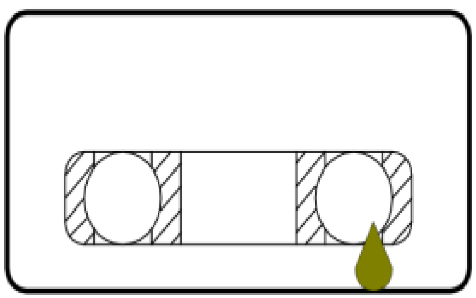
- Risk of over heating
- Grease Leaks out of bearing
- Tension in material



CONVENTIONAL HEATING METHODS

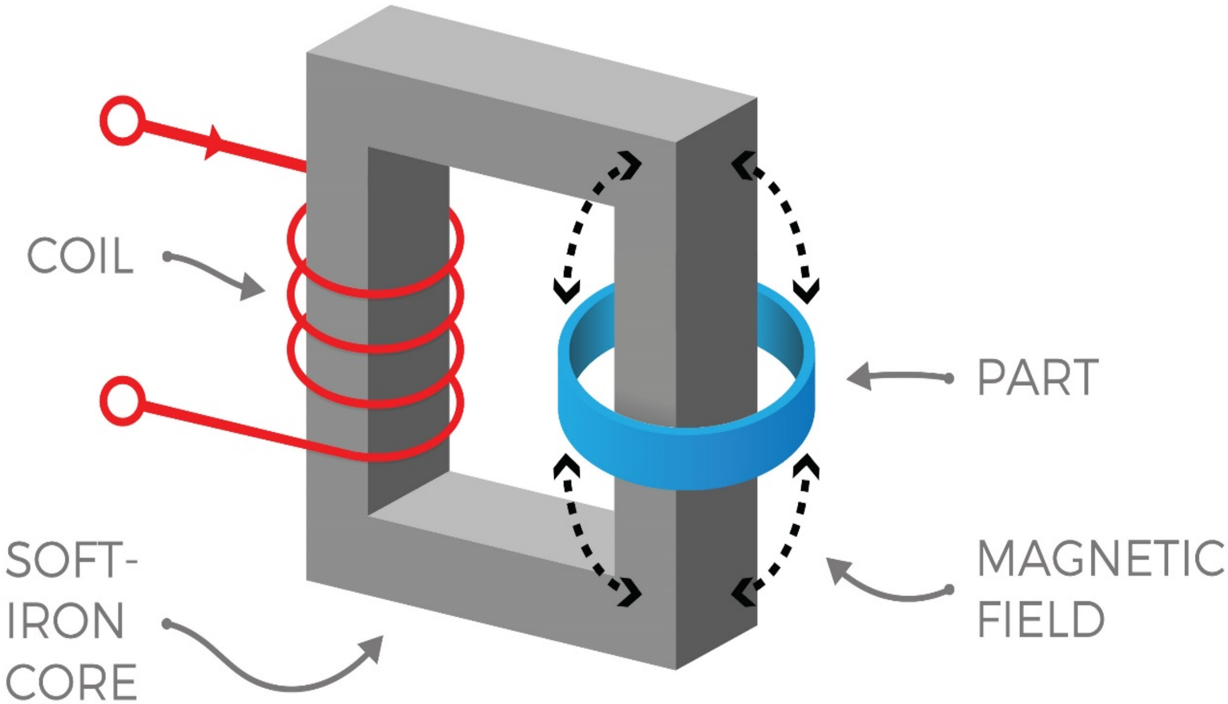
Oven

- Slow heating process
- High energy consumption
- Grease leaks out of bearing



SLEDGEHAMMER

LOW FREQUENCY INDUCTION HEATING



A low frequency induction field affects the complete part.
The part heats equally.

ADVANTAGES OF INDUCTION HEATING

- High speed
- High efficiency
- High cleanliness
- High safety
- Easy control
- Consistent temperature control of bearing
- Reporting

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Machine Installation

- Effects
- Components
- Baseplates

- Machinery Installation is just not new equipment installs
- Machinery Installation includes:
  - Rebuilds
  - Replacements
  - Overhauls

EFFECTS OF POOR MACHINE INSTALLATION

Mechanical

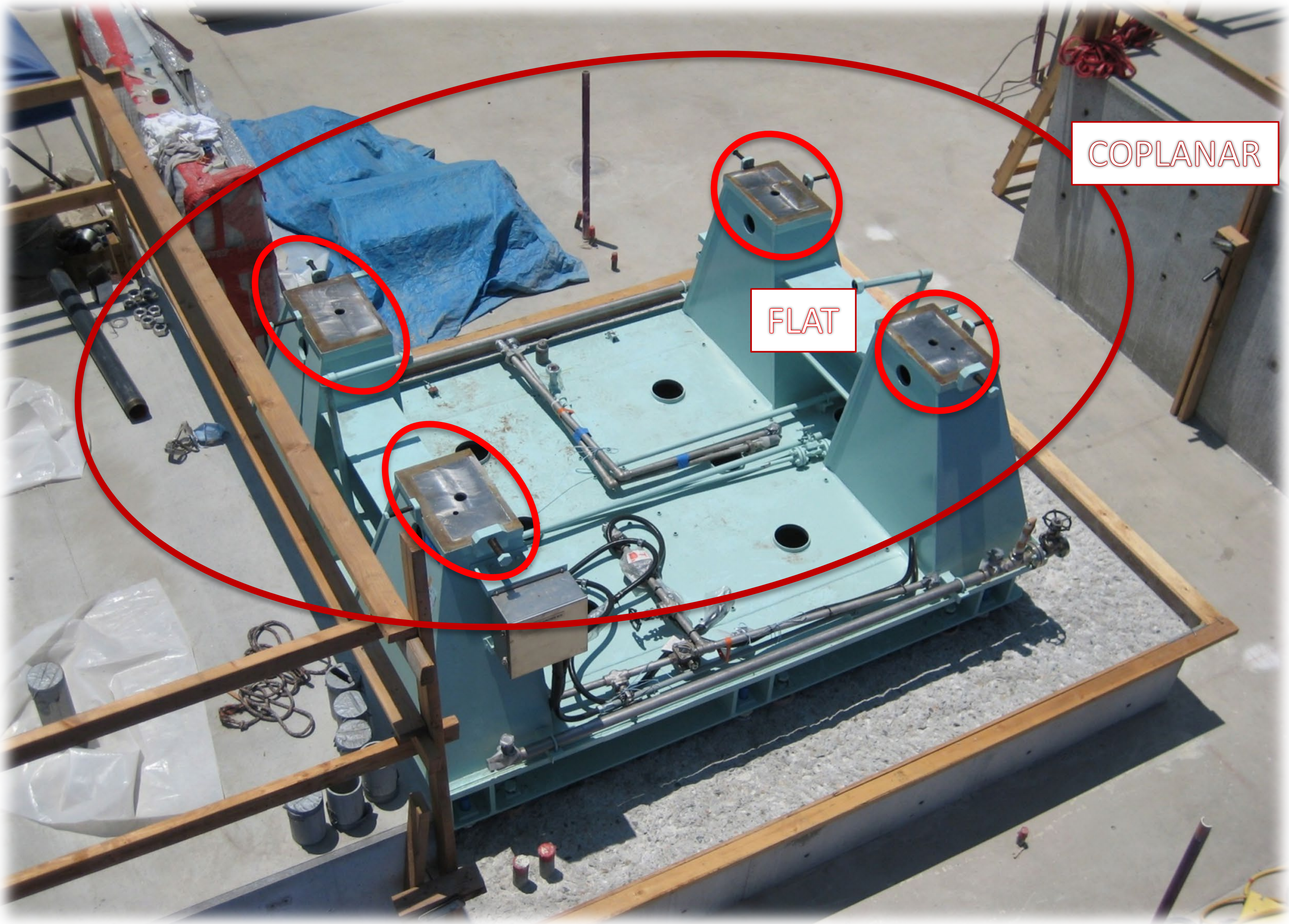
- Misalignment
- Twisted or distorted bases
- Soft Foot
- Unbalance
- Static Stress
- Dynamic Stress
- Coupling/Shaft runout
- Mechanical Looseness

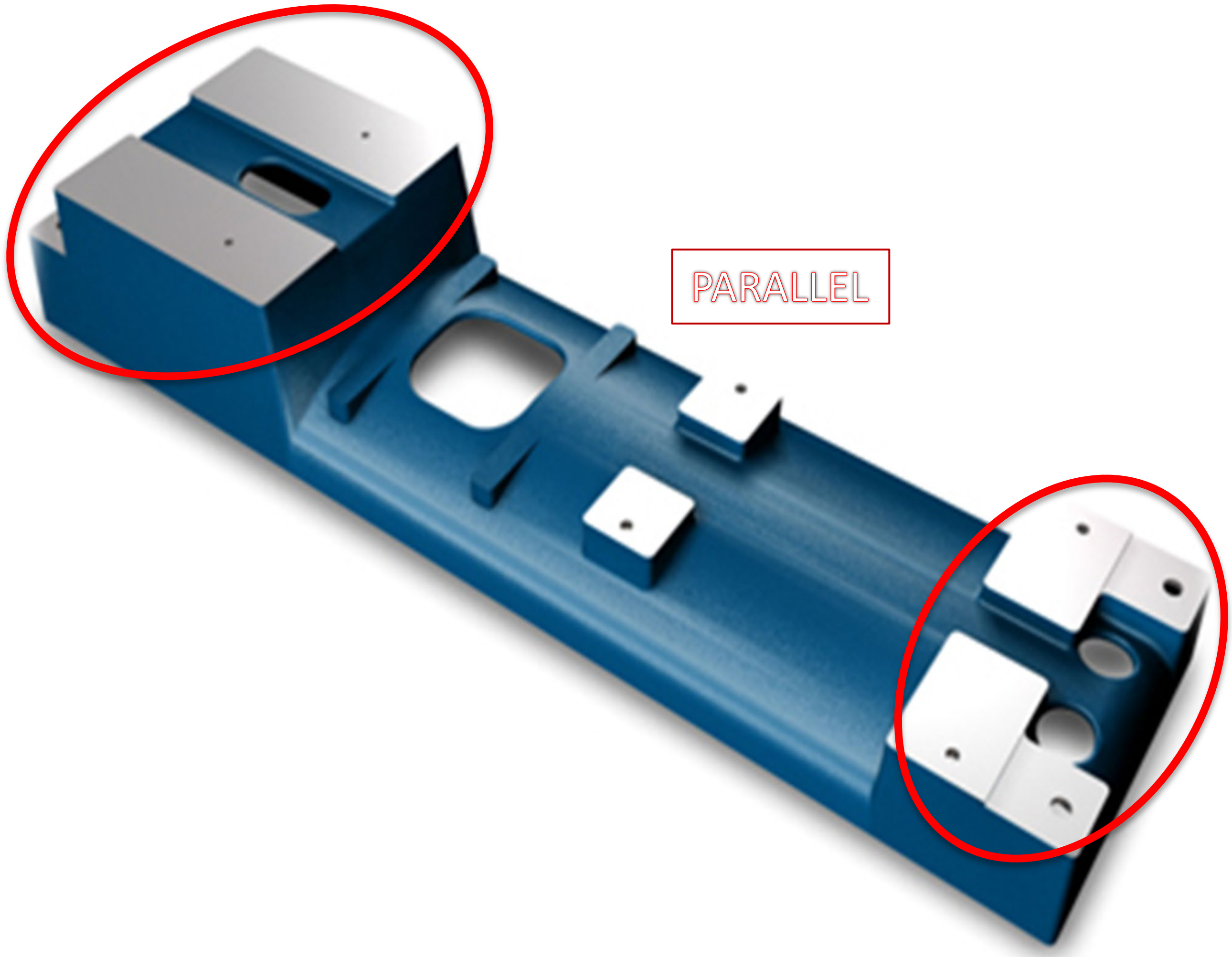
Financial

- Downtime
- Poor product quality
- Lower Capacity
- High operating costs

- Foundation
- Anchoring
- Isolation
- Rigid, level, and flat
- Alignment

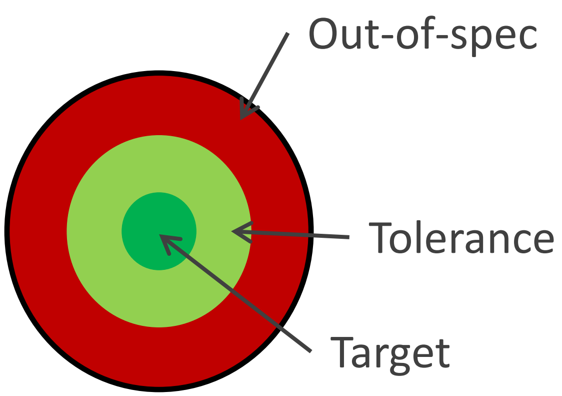
- Bases or Mounting pads must be:
  - Rigid
  - Level
  - Flat
  - Coplanar
  - Parallel to the other machine bases on the train


COPLANAR
FLAT


PARALLEL

PROCEDURE BASED INSTALLATION

- If performing machinery installation, the installations should follow a procedure.
- Procedures reduce the possibility of start-up and premature failures by ensuring repeatability and consistency of activities.
- Procedures should follow the 3T process.
  - Target
  - Tolerance
  - Test



James Kovacevic
HP Reliability Inc

- Machine should be installed centered on the baseplate
- Equal number of shims under all feet prior to alignment
- Inspect base for:
  - Cracked concrete
  - Broken welds
  - Warped surfaces
- Define standards for acceptance

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Jack Bolt Installation

- Jack Bolts
- Bolt Torque
- Best practices

WITHOUT JACKING BOLTS

Accurate?

Safe?

DEFINITION OF JACKBOLT

A bolt or screw attached to the base or foundation used to move or position the movable machine horizontally

Jack bolts should be installed so that they are:

- Parallel to the baseplate
- Perpendicular to the foot surface
- Aligned with the hold down bolt
- Leaving enough space to add and remove shims

- Bolts experience torsion and tension
- Over-torquing creates high bolt tension
- Rusted bolts can be under-torqued due to high friction
  - Torqued bolt may not be tight.
  - Lube bolts

- Most bolts are designed to be torqued at 75% of Proof Load

- Properly sized hold-down bolts to allow movement of machine
- Make provisions for horizontal jacking bolts
- Apply proper torque to hold down bolts

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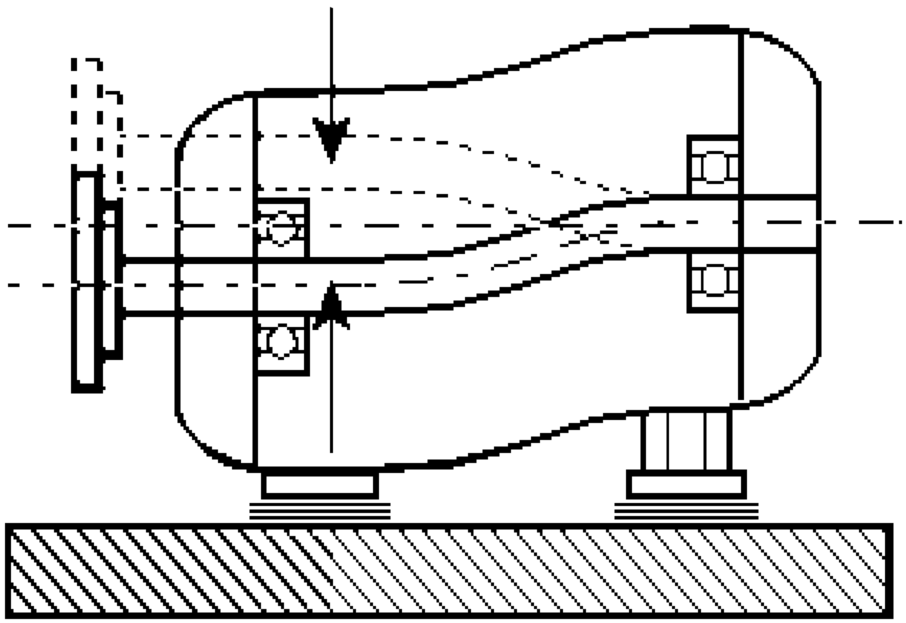
SOFT FOOT

- Definition
- Importance
- Causes of soft foot

SOFT FOOT - DEFINITION

Soft foot means the ***machine frame distorts*** as the foot's bolt is tightened or loosened. An example is a condition where the machine feet do not make solid contact **(at least 80%)** with the soleplate surface or external forces are acting on the frame.



180° later

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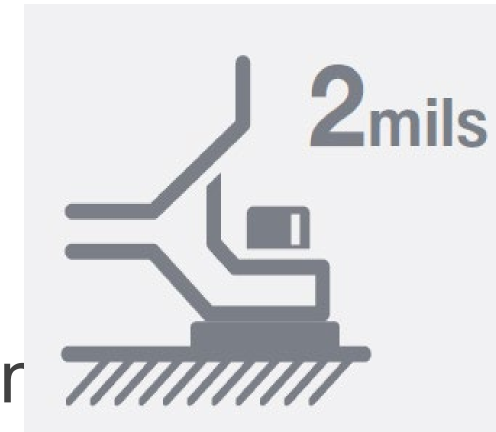
IMPORTANCE

Soft foot needs to be detected and corrected to within .002″ because:

- Destroys bearings and seals.
- Causes internal shaft misalignmer eventually result in shaft failure.

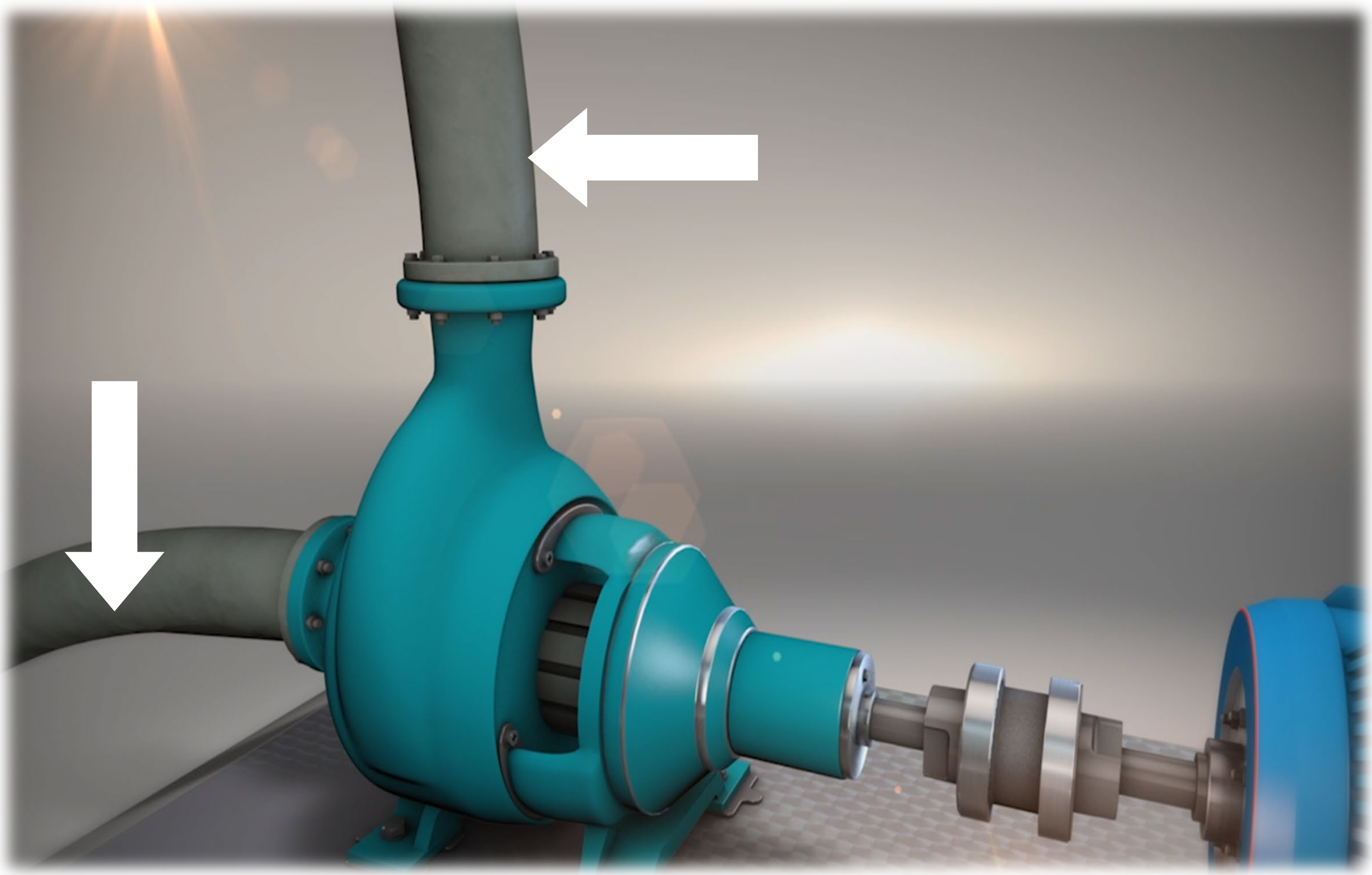


- Makes shaft (coupling) alignment difficult.

- Bad bases
- Bad motor feet (uneven, bent)
- Bad shim pack (bent, dirty, too many shims)
- Dirt, rust under motor feet

- All of the previous considerations apply for the other machines in the train.
- So what else can cause defects on the ‘Driven’ machine?

PIPE STRESS



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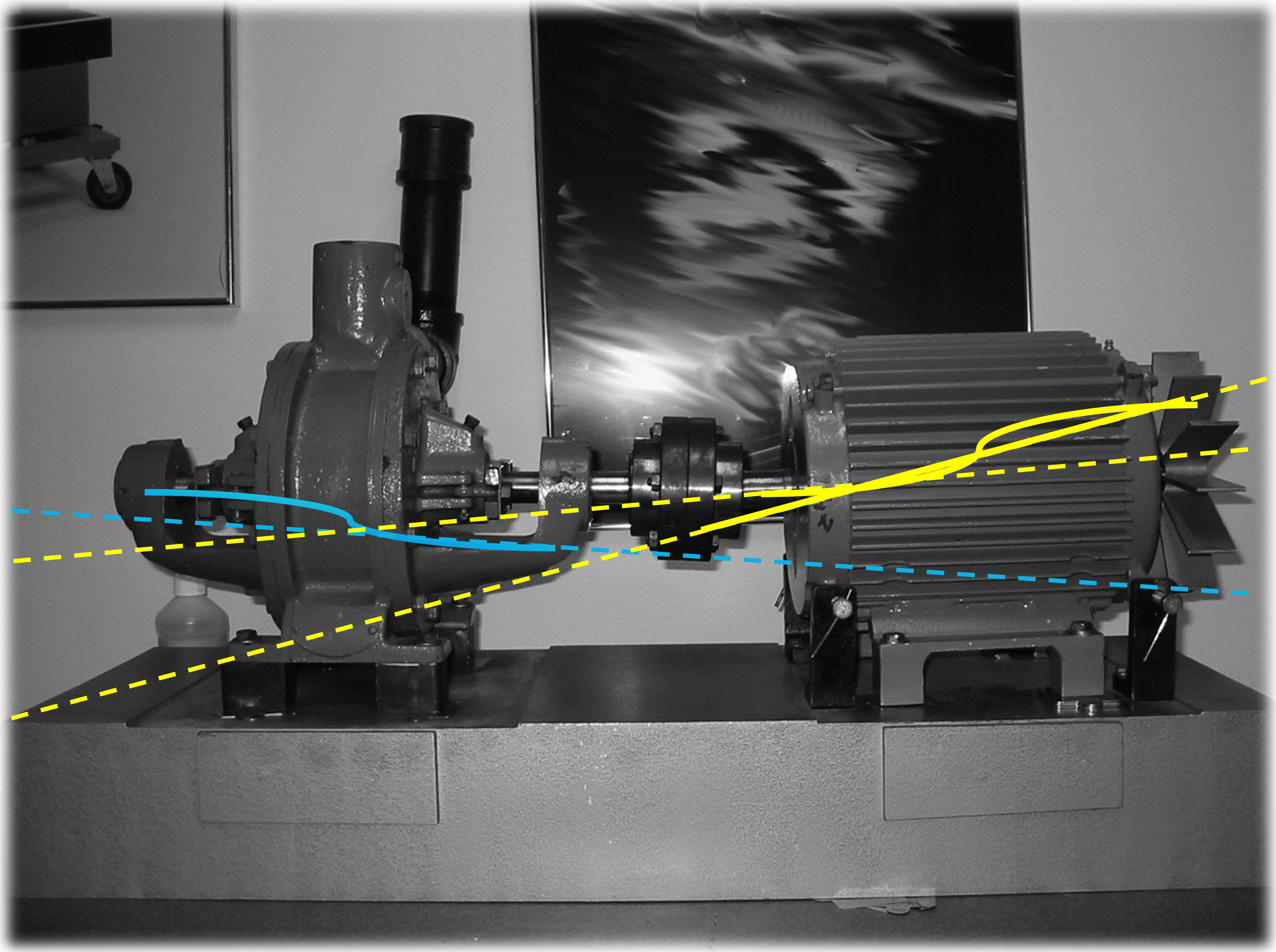
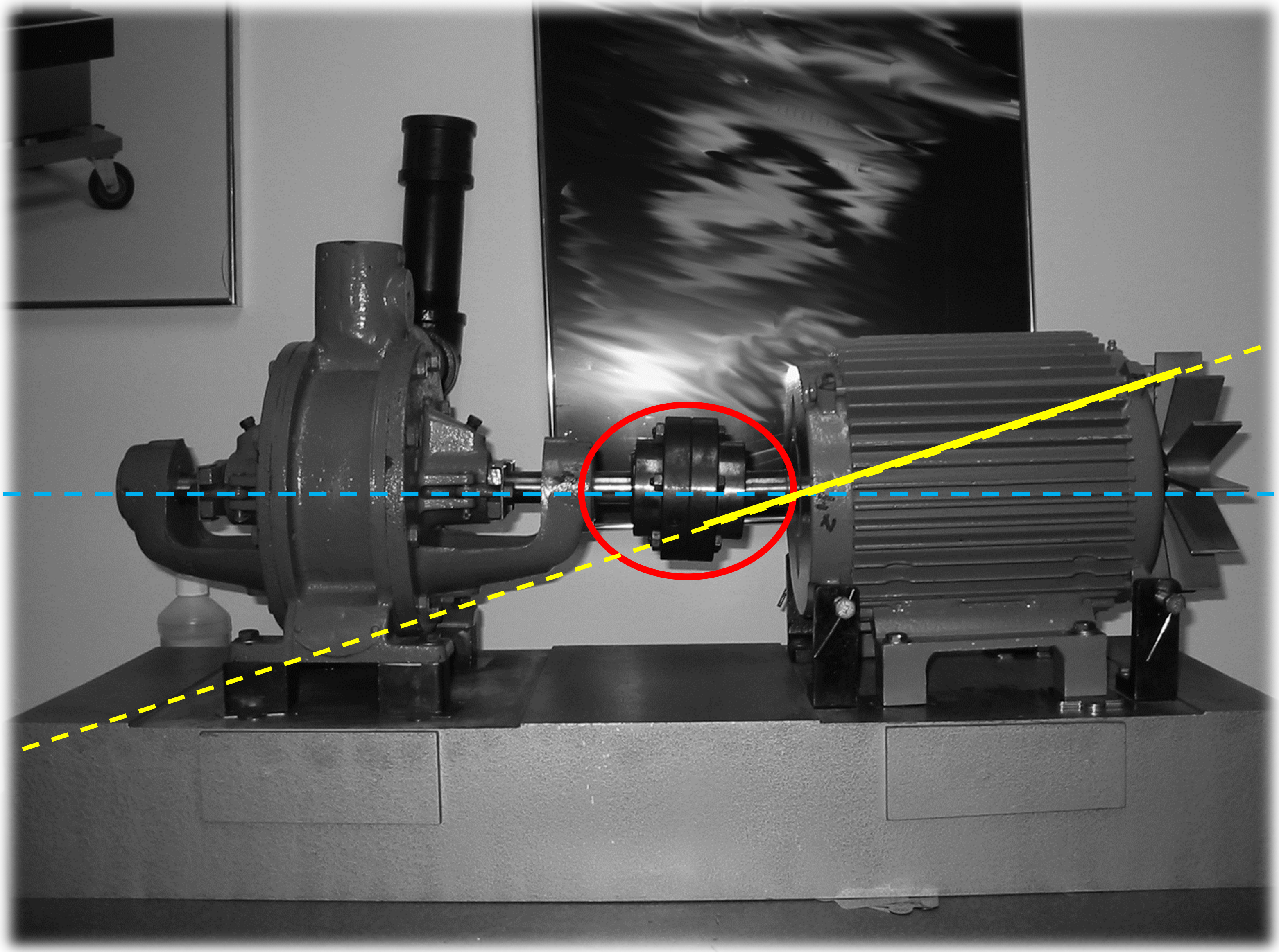
PIPE STRESS

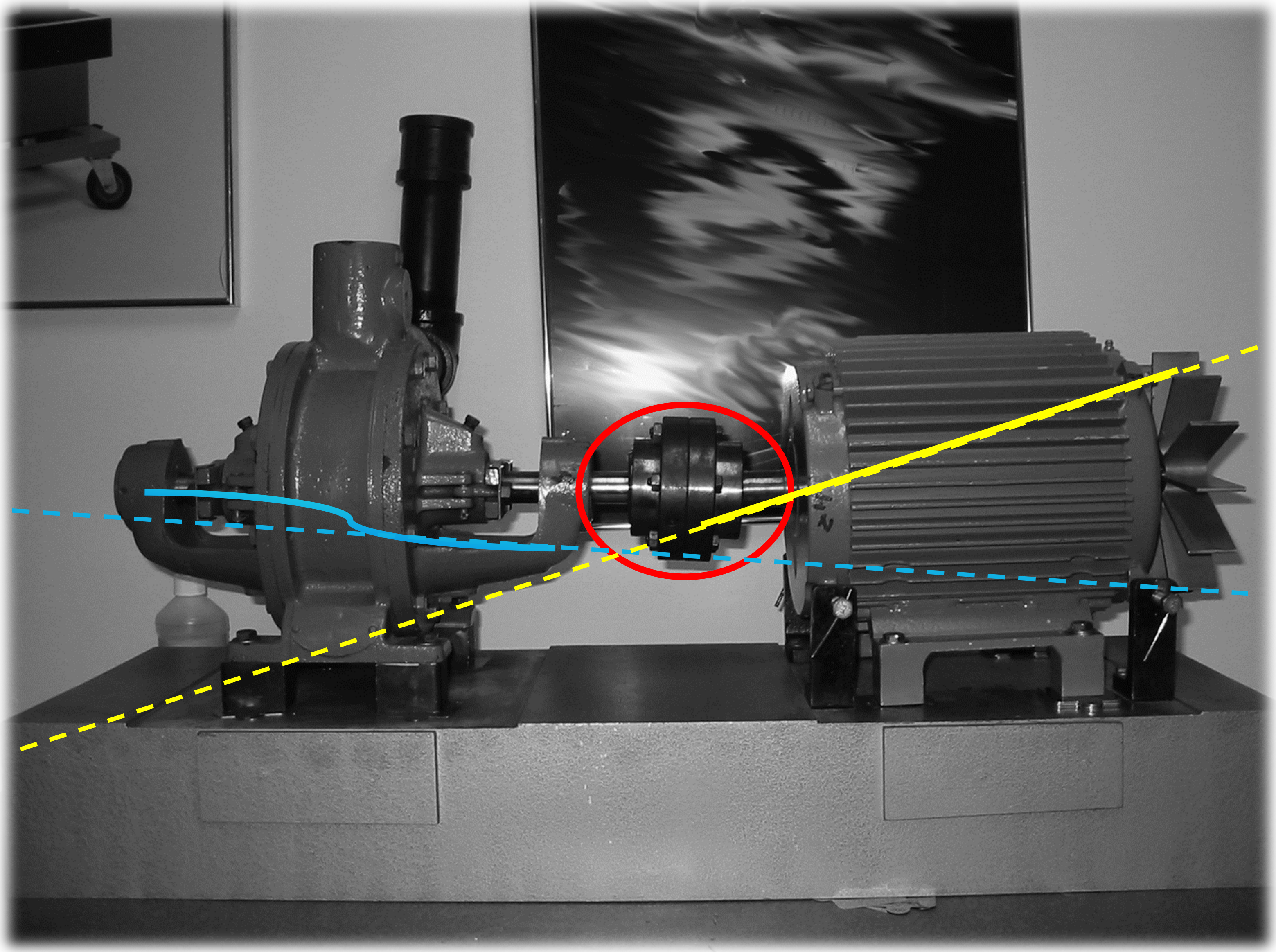
PIPE STRESS

- Pipes should be well fitted and supported, and flexible when possible.

- Monitor or measure the change in misalignment as flange is being bolted.

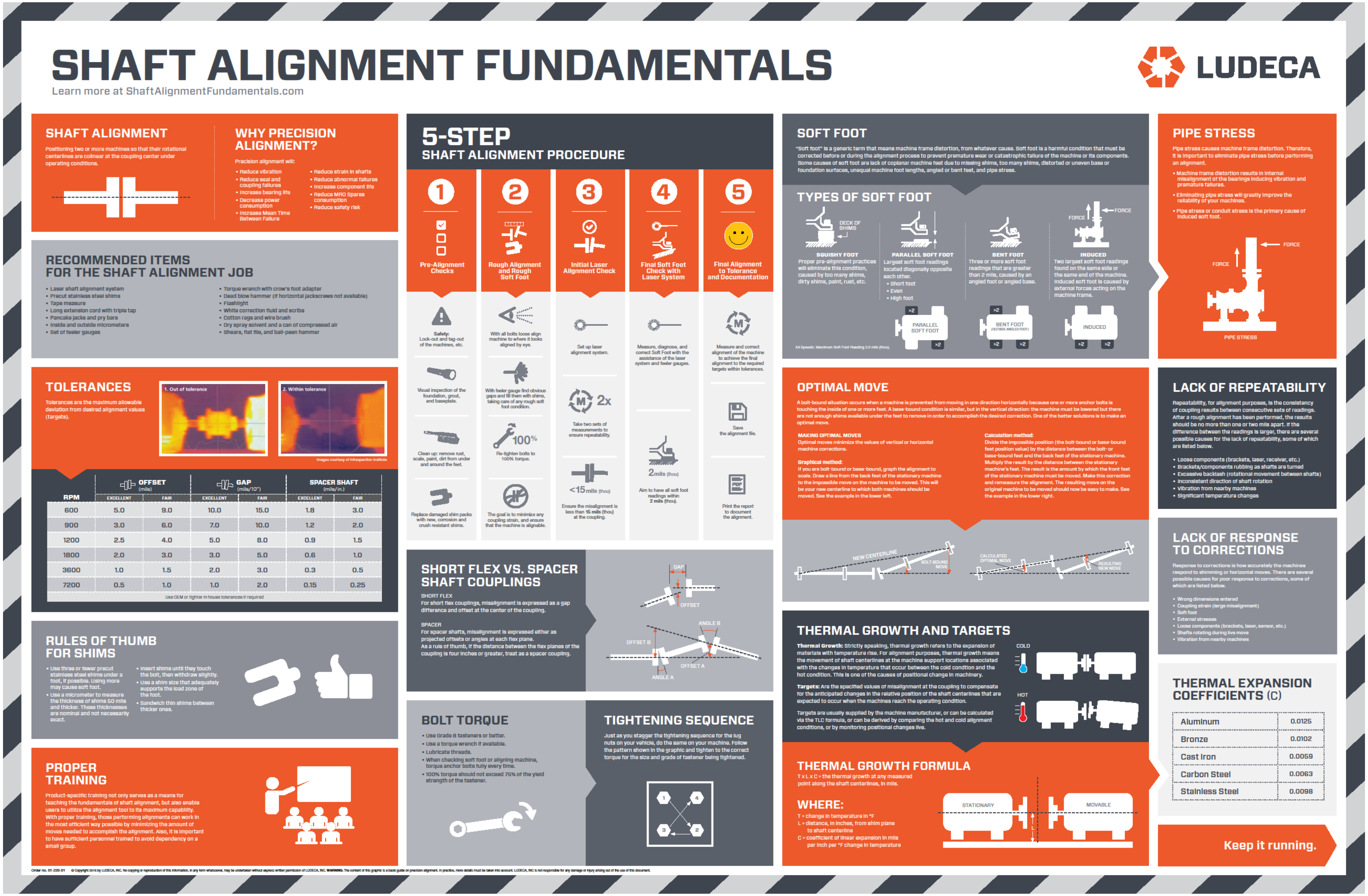






TAKEAWAYS

- Be proactive!
- Picture the lines
- Do proper installation
- Minimize soft foot condition



SHAFT ALIGNMENT FUNDAMENTALS

Learn more at ShaftAlignmentFundamentals.com

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SHAFT ALIGNMENT

Positioning two or more machines so that their rotational centerlines are colinear at the coupling center under operating conditions.

WHY PRECISION ALIGNMENT?

Precision alignment will:

- Reduce vibration
- Reduce seal and coupling failures
- Increase bearing life
- Decrease power consumption
- Increase Mean Time Between Failure
- Reduce strain in shafts
- Reduce abnormal failures
- Increase component life
- Reduce MRO Spares consumption
- Reduce safety risk

RECOMMENDED ITEMS FOR THE SHAFT ALIGNMENT JOB

- Laser shaft alignment system
- Precut stainless steel shims
- Tape measure
- Long extension cord with triple tap
- Pancake jacks and pry bars
- Inside and outside micrometers
- Set of feeler gauges
- Torque wrench with crow's foot adapter
- Dead blow hammer (if horizontal jackscrews not available)
- Flashlight
- White correction fluid and scribe
- Cotton rags and wire brush
- Dry spray solvent and a can of compressed air
- Shears, flat file, and ball-peen hammer

TOLERANCES

Tolerances are the maximum allowable deviation from desired alignment values (targets).

1. Out of tolerance
2. Within tolerance

Images courtesy of Infraspection Institute

RPM	OFFSET (mils)		GAP (mils/10")		SPACER SHAFT (mils/in.)	
	EXCELLENT	FAIR	EXCELLENT	FAIR	EXCELLENT	FAIR
600	5.0	9.0	10.0	15.0	1.8	3.0
900	3.0	6.0	7.0	10.0	1.2	2.0
1200	2.5	4.0	5.0	8.0	0.9	1.5
1800	2.0	3.0	3.0	5.0	0.6	1.0
3600	1.0	1.5	2.0	3.0	0.3	0.5
7200	0.5	1.0	1.0	2.0	0.15	0.25

Use OEM or tighter in house tolerances if required

RULES OF THUMB FOR SHIMS

- Use three or fewer precut stainless steel shims under a foot, if possible. Using more may cause soft foot.
- Use a micrometer to measure the thickness of shims 50 mils and thicker. These thicknesses are nominal and not necessarily exact.
- Insert shims until they touch the bolt, then withdraw slightly.
- Use a shim size that adequately supports the load zone of the foot.
- Sandwich thin shims between thicker ones.

PROPER TRAINING

Product-specific training not only serves as a means for teaching the fundamentals of shaft alignment, but also enable users to utilize the alignment tool to its maximum capability. With proper training, those performing alignments can work in the most efficient way possible by minimizing the amount of moves needed to accomplish the alignment. Also, it is important to have sufficient personnel trained to avoid dependency on a small group.

5-STEP SHAFT ALIGNMENT PROCEDURE

1 Pre-Alignment Checks

- Safety: Lock-out and tag-out of the machines, etc.
- Visual inspection of the foundation, grout, and baseplate.
- Clean up: remove rust, scale, paint, dirt from under and around the feet.
- Replace damaged shim packs with new, corrosion and crush resistant shims.

2 Rough Alignment and Rough Soft Foot

- With all bolts loose align machine to where it looks aligned by eye.
- With feeler gauge find obvious gaps and fill them with shims, taking care of any rough soft foot condition.
- 100% Re-tighten bolts to 100% torque.
- The goal is to minimize any coupling strain, and ensure that the machine is alignable.

3 Initial Laser Alignment Check

- Set up laser alignment system.
- 2x Take two sets of measurements to ensure repeatability.
- <15 mils (thou) Ensure the misalignment is less than **15 mils** (thou) at the coupling.

4 Final Soft Foot Check with Laser System

- Measure, diagnose, and correct Soft Foot with the assistance of the laser system and feeler gauges.
- 2 mils (thou) Aim to have all soft foot readings within **2 mils** (thou).

5 Final Alignment to Tolerance and Documentation

- Measure and correct alignment of the machine to achieve the final alignment to the required targets within tolerances.
- Save the alignment file.
- Print the report to document the alignment.

SHORT FLEX VS. SPACER SHAFT COUPLINGS

SHORT FLEX

For short flex couplings, misalignment is expressed as a gap difference and offset at the center of the coupling.

SPACER

For spacer shafts, misalignment is expressed either as projected offsets or angles at each flex plane.

As a rule of thumb, if the distance between the flex planes of the coupling is four inches or greater, treat as a spacer coupling.

GAP
OFFSET
ANGLE B
OFFSET B
OFFSET A
ANGLE A

BOLT TORQUE

- Use Grade 8 fasteners or better.
- Use a torque wrench if available.
- Lubricate threads.
- When checking soft foot or aligning machine, torque anchor bolts fully every time.
- 100% torque should not exceed 75% of the yield strength of the fastener.

TIGHTENING SEQUENCE

Just as you stagger the tightening sequence for the lug nuts on your vehicle, do the same on your machine. Follow the pattern shown in the graphic and tighten to the correct torque for the size and grade of fastener being tightened.

1 4 3 2

SOFT FOOT

"Soft foot" is a generic term that means machine frame distortion, from whatever cause. Soft foot is a harmful condition that must be corrected before or during the alignment process to prevent premature wear or catastrophic failure of the machine or its components. Some causes of soft foot are lack of coplanar machine feet due to missing shims, too many shims, distorted or uneven base or foundation surfaces, unequal machine foot lengths, angled or bent feet, and pipe stress.

TYPES OF SOFT FOOT

DECK OF SHIMS

SQUISHY FOOT
Proper pre-alignment practices will eliminate this condition, caused by too many shims, dirty shims, paint, rust, etc.

PARALLEL SOFT FOOT
Largest soft foot readings located diagonally opposite each other.

- Short foot
- Even
- High foot

BENT FOOT
Three or more soft foot readings that are greater than 2 mils, caused by an angled foot or angled base.

FORCE
FORCE

INDUCED
Two largest soft foot readings found on the same side or the same end of the machine. Induced soft foot is caused by external forces acting on the machine frame.

>2 PARALLEL SOFT FOOT >2
>2 BENT FOOT (OUTSIDE ANGLED FOOT) >2 >2
INDUCED >2 >2

All Speeds: Maximum Soft Foot Reading 2.0 mils (thou).

PIPE STRESS

Pipe stress causes machine frame distortion. Therefore, it is important to eliminate pipe stress before performing an alignment.

- Machine frame distortion results in internal misalignment of the bearings inducing vibration and premature failures.
- Eliminating pipe stress will greatly improve the reliability of your machines.
- Pipe stress or conduit stress is the primary cause of induced soft foot.

FORCE
FORCE
PIPE STRESS

OPTIMAL MOVE

A bolt-bound situation occurs when a machine is prevented from moving in one direction horizontally because one or more anchor bolts is touching the inside of one or more feet. A base-bound condition is similar, but in the vertical direction: the machine must be lowered but there are not enough shims available under the feet to remove in order to accomplish the desired correction. One of the better solutions is to make an optimal move.

MAKING OPTIMAL MOVES
Optimal moves minimize the values of vertical or horizontal machine corrections.

Graphical method:
If you are bolt-bound or base-bound, graph the alignment to scale. Draw a line from the back feet of the stationary machine to the impossible move on the machine to be moved. This will be your new centerline to which both machines should be moved. See the example in the lower left.

Calculation method:
Divide the impossible position (the bolt-bound or base-bound feet position value) by the distance between the bolt- or base-bound feet and the back feet of the stationary machine. Multiply the result by the distance between the stationary machine's feet. The result is the amount by which the front feet of the stationary machine must be moved. Make this correction and remeasure the alignment. The resulting move on the original machine to be moved should now be easy to make. See the example in the lower right.

NEW CENTERLINE
BOLT-BOUND MOVE
CALCULATED OPTIMAL MOVE
RESULTING NEW MOVE

LACK OF REPEATABILITY

Repeatability, for alignment purposes, is the consistency of coupling results between consecutive sets of readings. After a rough alignment has been performed, the results should be no more than one or two mils apart. If the difference between the readings is larger, there are several possible causes for the lack of repeatability, some of which are listed below.

- Loose components (brackets, laser, receiver, etc.)
- Brackets/components rubbing as shafts are turned
- Excessive backlash (rotational movement between shafts)
- Inconsistent direction of shaft rotation
- Vibration from nearby machines
- Significant temperature changes

LACK OF RESPONSE TO CORRECTIONS

Response to corrections is how accurately the machines respond to shimming or horizontal moves. There are several possible causes for poor response to corrections, some of which are listed below.

- Wrong dimensions entered
- Coupling strain (large misalignment)
- Soft foot
- External stresses
- Loose components (brackets, laser, sensor, etc.)
- Shafts rotating during live move
- Vibration from nearby machines

THERMAL GROWTH AND TARGETS

Thermal Growth: Strictly speaking, thermal growth refers to the expansion of materials with temperature rise. For alignment purposes, thermal growth means the movement of shaft centerlines at the machine support locations associated with the changes in temperature that occur between the cold condtion and the hot condition. This is one of the causes of positional change in machinery.

Targets: Are the specified values of misalignment at the coupling to compensate for the anticipated changes in the relative position of the shaft centerlines that are expected to occur when the machines reach the operating condition.

Targets are usually supplied by the machine manufacturer, or can be calculated via the TLC formula, or can be derived by comparing the hot and cold alignment conditions, or by monitoring positional changes live.

COLD
HOT

THERMAL GROWTH FORMULA

T x L x C = the thermal growth at any measured point along the shaft centerlines, in mils.

WHERE:

T = change in temperature in °F
L = distance, in inches, from shim plane to shaft centerline
C = coefficient of linear expansion in mils per inch per °F change in temperature

STATIONARY
MOVABLE
L

THERMAL EXPANSION COEFFICIENTS (C)

Aluminum	0.0125
Bronze	0.0102
Cast Iron	0.0059
Carbon Steel	0.0063
Stainless Steel	0.0098

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THANK YOU!

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