Specifying Shaft Alignment

By Victor Wowk, P.E., Machine Dynamics, Inc.

Draft standard specifies alignment results, allowing aligner to choose the most appropriate method and instrumentation.

Shaft alignment is a technical skill that is not common in the construction and maintenance professions, but categorized more like a specialty. It requires unique and expensive measurement instruments, some calculation capability, and relies heavily on experience for successful results on heavy, high-speed, or high-temperature machines. At present there are no universally accepted standards that define good results. The U.S. Navy has some alignment specifications, as do some industrial companies. Unfortunately, the various specifications do not appear similar, nor even cover the same subject matter.

There is also no testing or certification of alignment craft people. With no common training, no certification, and no common standards, it should come as no surprise that there is large variability in the results.

The guidelines for when to require alignment checks are:
1. All new shaft coupled equipment.
2. After repair work is done that disturbs shafts or bearings, and before energizing.
3. Whenever vibration indicates the need.
4. Periodically on critical equipment.

An Alignment Standard was composed for Sandia National Laboratories in 1997 at the request of the facilities organization. That Alignment Standard is presently under review and is reprinted here beginning on the next page. Permission has been granted by Sandia National Laboratories to make this document available to the public.

Instruments and methods

There are many good commercially available instruments for measuring shaft misalignment and for calculating the moves. There are also two good alignment methods, the reverse-indicator and the face-and-rim methods, with some variations for unique machines.

However, a good standard should not define the instruments or methods. It should only define the results at the machine. This was the approach taken in composing the alignment standard for Sandia. A standard that describes the instruments to use would unfairly exclude those contractors who do not have access to those instruments. A standard that describes specific methods, limits the aligner and stifles creativity. There may be a better way, but the aligner becomes non-accountable for the results and can always have the fall-back excuse that "I followed the procedure."

Some requirements for the measurement system are specified. The most important requirement for any shaft alignment system is repeatability of the readings. This is evaluated with a 360 deg repeatability test. It is also a good way to evaluate a fixture system when considering a purchase. Basically, measuring systems that do not return to zero (within 0.002 inch) after a 360 deg rotation should be rejected. Be suspicious of plastic straps or other flexible fixture components.

The choice of measuring systems and methods is up to the aligner. The two fundamental choices are dial indicators or lasers. Dial-indicator systems are the most useful because they can be used to measure shaft runout, bearing alignment, and soft foot directly. All of the above measurements are required by the standard, and needed to assure a good-running machine, but not attainable with lasers. Lasers require batteries, are not intrinsically safe for use in explosive environments, and cannot do face-and-rim measurements.

Overview of the standard

The standard does not restrict the aligner to any instrument or method. It only describes the acceptable tolerances of shaft offset and angularity from perfect coaxial alignment. The aligner is free to choose how he or she arrives at that condition.

The aligner is required to consider other factors that affect the running condition, besides just shaft alignment. These are coupling axial position, casing distortion, bearing alignment (if the bearings are disturbed), uneven bases,

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ALIGNMENT STANDARD FOR NEW AND REBUILT EQUIPMENT

Prepared for Sandia National Laboratories by Victor Wowk, Machine Dynamics

1.0 Purpose

The purpose of this standard is to guarantee reliability of mechanical equipment when first placed into service and after major repair. It specifies the alignment condition of components to reduce vibration and minimize wear.

Reducing dynamics forces at mechanical joints is the objective of alignment, but vibration shall not be used as a judgment criterion for acceptable alignment. Other defects can cause vibration, including the foundation and other building parts. The craftsperson who performs the alignment uses static measurements when the machine is stopped, and the same static methods shall be used to judge acceptability.

This standard does not limit the contractor, or owner's technician, with required instruments or methods. Rather, it defines the final orientation. It does, however, require that some preliminary factors be considered and that some additional measurements be taken to insure that the mechanical system is not strained or distorted. These are considered part of the general process of setting up machinery, of which precision alignment is a part. The purpose of this standard is to make sure that these general factors are not overlooked.

The aligner will be required to document the alignment task. As a minimum, the before and after orientation shall be reported, along with any changes made. The vibration after start-up is not directly relevant to acceptable alignment. If the final orientation is within acceptable limits as determined with static measurements, and the mechanical system is demonstrated to be not distorted or strained, then the alignment is acceptable. The purpose of this standard is to guarantee that mechanical equipment is set up in a manner that minimizes dynamic forces and wear. The equipment is adjusted to an orientation that makes it so. A second purpose is to detect grossly defective components, like bent shafts or non-flat bases, that are not easily detectable with only a shaft-to-shaft static measurement. Some of these conditions can also be adjusted. It will be the aligner's responsibility to detect such defects and correct them, if reliability would be affected.

2.0 Scope

This standard defines acceptable limits for shaft-to-shaft alignment of coupled machines. The limits are defined in terms of maximum offset and angularity. It also defines axial spacing for thrust conditions. Acceptable shim materials are defined. Safety procedures and how to move machines without introducing additional damage are covered.

The following complicating factors are discussed in terms of acceptable fixes: Uneven bases, resonances, thermal growth, bent shafts, bolt-bound conditions, piping strain, casing distortion, and bar sag.

In addition to coaxial shafts, other geometric features are relevant for smooth-running machines. These are perpendicularity, parallelism, straightness, roundness, flatness, eccentricity, and runout. It is the aligner's responsibility to report any of these conditions that could affect reliability, and correct them as part of the alignment task.

The final alignment is done when the machine is in a ready-to-run condition. Additional hot alignment checks can also be done after some running in time. However, under no circumstances should the driver machine be energized before an alignment check is made. In other words, all coupled machine systems shall have the alignment checked and verified to be acceptable, prior to start-up.

Bearing alignment and pulley alignment are covered in Appendices.

3.0 Referenced documents

V.R. Dodd, *Total Alignment*, Petroleum Publishing Company, Tulsa, Oklahoma, 1975.

Malcolm G. Murray, Jr., *Alignment Manual for Horizontal, Flexibly-Coupled Rotating Machines, Third Edition*, Murray & Garig Tool Works, Baytown, Texas, 1983.

Michael Neale, Paul Needham, and Roger Horrell, *Couplings and Shaft Alignment*, Mechanical Engineering Publications Limited, London, 1991.

John Piotrowski, *Shaft Alignment Handbook*, Second Edition, Marcel Dekker, 1995.

Erik Oberg, Franklin D. Jones, Holbrook L. Horton, *Machinery's Handbook, Twenty-first Edition*, Industrial Press, New York, 1979 (first printing 1914).

Joseph E. Shigley, Charles R. Mischke, *Standard Handbook of Machine Design*, McGraw-Hill, New York, 1986.

Alignment of Rotating Machinery, Vibration Institute Proceedings, Houston, Texas, 1991.

Falk Alignment Correction System, Operating Manual, The Falk Corporation.

Machinery Alignment Handbook, Vibralign, 1994.

Optical Alignment Manual, Cubic Precision, 1986.

Piranha Shaft Alignment System, *Instruction Manual*, Mechanical Maintenance Products, Inc., 1995.

4.0 Instrumentation requirements and measurement methods

This standard places no requirements on the types of instruments or the methods to achieve alignment. Rather, the final orientation is defined as an objective. The aligner is free to use whatever equipment is most suitable for the task at hand.

The measurement system needs to be repeatable to within 0.002 inch when exercised through one complete cycle.

Repeatability is the significant characteristic that guarantees adherence to the specifications. The measurement system shall be checked for repeatability at the start of each alignment task after the system is fixtured in place on the machine. The machine shafts shall be rotated (a full 360 deg if possible) and the shaft orientation returned to the starting point. The measuring system shall read to within 0.002 inch of the initial reading. If it does not, the fixture is too flexible and must be rigidized. If 0.002-inch repeatability is not achievable, then the measurement system is not useable for alignment purposes.

There is no requirement for accuracy or calibration to absolute standards. However, the acceptable tolerances are specified in thousandths of an inch (0.001 inch, or 1 mil) so it is expected that the measurement system should have a resolution of 1 mil or less. The calculation capability shall also maintain this level of resolution by producing machine movement numbers to 1-mil resolution.

If gravity sag of the fixture creates an error greater than 0.002 inch, then it shall be compensated for. The aligner will be required to demonstrate to an owner's representative that bar sag has been measured and corrected for.

Mechanical dial indicators, properly fixtured, are acceptable as measuring devices.

5.0 Safety

All sources of energy to the machine system, that pose a hazard to the aligner, shall be de-energized. The controls shall be physically locked to prevent operation during the alignment process. Typical energy sources to be locked out are electrical controls, but could also be steam valves, or gas controls.

After physically locking the energy source, an attempt to start the machine shall be made to verify that the correct controls are locked out.

6.0 Prealignment considerations

Shaft-to-shaft alignment is part of the total task of setting up machinery. The aligner is in a position to affect long-term reliability by detecting and correcting other factors. He/she is in position with measuring instruments, tools, and a window of opportunity to make some changes prior to start-up. It will be the responsibility of the aligner to recognize when these factors are active players and to properly respond. The proper response may be to correct it immediately or to advise the owner when correction is more than a routine alignment task.

A. Timing

Final alignment is normally done just prior to start up after all utility connections have been made, especially piping. Preliminary alignments can be done to roughly position machines, but a final alignment check should also be done after all movement or strain causing activity is done.

B. Piping strain

Newly-assembled piping shall have flanges that mate well without excessive force. Prior to bolting the flanges, an alignment inspector shall verify that the two flanges can be brought together into intimate contact and assembled with no more than 200-pounds force (an average adult male can arm push 200 pounds).

Fluid-handling machines shall be checked for residual pipe strain. Two dial indicators, or other measuring devices, shall be fixtured near each end of the machine in orthogonal directions, and "zeroed." All of the holddown bolts shall be completely loosened. Movements greater than 0.005 inch indicate external strain on the machine. The strain shall be corrected prior to proceeding.

C. Couplings

The coupling shall be assembled according to the manufacturer's instructions. The instructions typically specify the axial spacing and lubrication requirements, if any. For machines with plain bearings, the axial spacing shall be set with the machines pushed against their thrust bearings similar to the operating conditions. For electric motors with plain bearings, the axial spacing shall be set with the armature positioned at the motor magnetic center.

If the coupling was previously assembled by someone else, the aligner shall verify the proper setup in accordance with the previous paragraph. The coupling bolts, or screws, shall be tightened to the specified torque.

The coupling type can be changed to a different style or manufacturer as long as it is rated for the speed and power. Coupling types for reciprocating machines shall not be changed unless a torsional analysis is done. The torsional analysis shall verify that the torsional natural frequency of the system is at least 20 percent separated from the fundamental rotating speed, or any harmonic.

D. Bases and foundations

The base and foundation shall be visually inspected for cracks and uneven mating surfaces. Cracks in the concrete and cracks in steel bases between the driver and driven machines shall be reported to the owner.

Grossly uneven mating surfaces that are visible shall be corrected by grinding or machining. The bottoms of the machine feet shall rest on the base or foundation with 90 percent contact of the footprint. A 0.003-inch thick shim shall not penetrate under any foot with all holddown bolts loose. This is an unforeseen condition and will require more time to correct. Small gaps are correctable with shim changes as described in Section E, "Casing Distortion."

Resonant foundations or bases are dynamic structural defects. This will cause high vibration at specific speeds. Resonances are not detectable during static alignment measurements. They are only apparent during operation of the machine. The aligner is not responsible for detecting or correcting resonances.

E. Casing distortion, also known as soft foot

A dial indicator, or other measuring device, shall be fixtured to measure the vertical rise at each foot as the holddown bolt is loosened. All other bolts shall remain tight. A rise of less than 0.002 inch is acceptable. A rise of more than 0.002 inch shall be corrected by adding shims.

After shim changes are made, the above test shall be repeated at all feet until less than 0.002 inch rise is measured at each foot. If shim changes cannot adjust the rise, then the base will need to be ground or machined. See Section D, "Bases and Foundations."

F. Shims
Only stainless-steel pre-stamped shims shall be added. Brass, plastic, aluminum, or unplated low-carbon steel shims are unacceptable in thicknesses less than 0.200 in. Thick spacer blocks, or risers, of these materials are acceptable when thicker than 0.200 in.

G. Shaft runout
The exposed shaft of each machine shall be measured for runout. The total indicator reading (TIR) shall be no more than 0.001 inch. Runouts greater than this shall be reported to the owner.

H. Thermal growth
Any change, thermal or mechanical, from cold-alignment conditions to hot-running conditions are the responsibility of the aligner to estimate and correct for. Thermal growth calculations shall be made for any temperature changes greater than 100 F.

I. Bearings
The bearings shall be examined for looseness, wear, or binding. This is typically done by slow-turning while listening and feeling. Obviously worn or damaged bearings will be reported to the owner.

Misaligned bearings have vibration symptoms identical to misaligned shafts. The damage also follows a similar pattern. If installing or moving bearings is part of the alignment task, then bearing alignment shall be checked and adjusted according to Appendix A.

If the temperature difference between the shaft, or rotor, and the support structure is expected to exceed 50 F, or the distance between bearings is more than 24 in., then one bearing shall be verified to be "floating" in accordance with Appendix A.

J. Tools
Prior to de-energizing the machine and beginning the alignment task, the aligner shall verify that the proper tools are on hand to safely and efficiently move the machines. This includes lifting devices, wrenches, shims, and measuring instruments.

7.0 Machinery movement

Every machine is considered moveable, even those with rigid piping attached. Some machines are more easily moved than others. The aligner has the option to move one or the other, or both machines.

Machines shall be adjusted with small, precise movements. Excessive force, that could cause internal or external damage, is to be avoided. Steel-hammer blows on bare steel or iron machine housings are unacceptable. Hammering on wooden blocks is OK. Jackscrews are the preferred movement method.

Horizontal movements shall be monitored with dial indicators, or other measuring instruments, to know when to stop.

"Bolt bound" conditions can be handled in various ways, depending on the situation at the job site. The following methods are allowable:

1. Moving both machines
2. Undercutting the bolt diameter to remove threads
3. Reducing bolt size one nominal fractional size (i.e., 3/4 bolts to 5/8 bolts is OK)
4. Enlarging the hole is OK if structural integrity is not compromised
5. Tilting the machine with differential shimming

After all movement is done, the machines will be secured by tightening the holddown bolts to the recommended torque in accordance with the manufacturer's instructions. If no instructions are available, the torque values in Appendix D shall be used.

After torquing the holddown bolts, a final set of shaft-to-shaft readings will be taken and reported as the final orientation.

Doweling of machines in place will not be done unless the installation instructions specifically require it.

8.0 Alignment limits

The shaft-to-shaft residual misalignment is acceptable when the intersection point of the two shafts is within the coupling area and the included angle between the shaft centerlines is small. These two criteria must be applied in two orthogonal directions, typically horizontal and vertical for convenience, and normalized to speed. That is, slow-speed machines are allowed a larger tolerance. High-speed machines are required to be better aligned.

The intersection point of the two shafts is considered to be within the coupling area when the separation of the shaft

TABLE 1. MAXIMUM ALLOWABLE OFFSET

At center, mils	Speed, rpm
5.0	600
4.0	900
3.0	1200
2.0	1800
1.0	3600
0.5	>4000

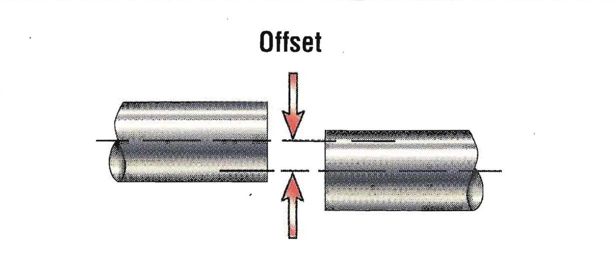

Fig. 1. Offset misalignment

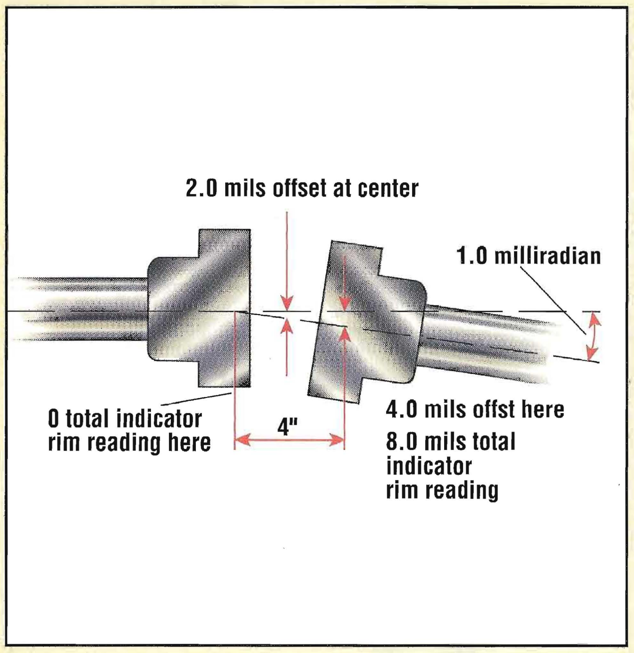

Fig. 2. Example of an acceptable misalignment for an 1800 rpm machine.

TABLE 2. MAXIMUM ALLOWABLE ANGULARITY

Mils/in. or milliradians	Speed, rpm
2.5	600
2.0	900
1.5	1200
1.0	1800
0.0	3600
0.25	>4000

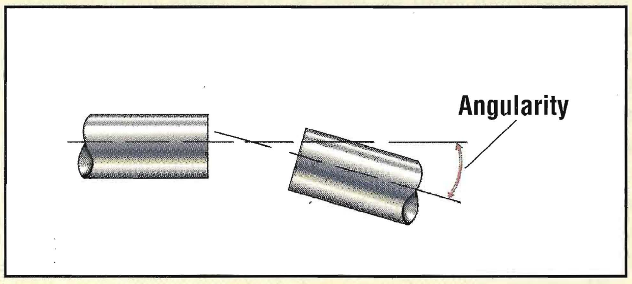

Fig. 3. Angular misalignment

centerlines at the center of the coupling is less than the tolerance values in Table 1.

This offset tolerance zone is similar to parallel misalignment, and can be interpreted in a similar manner. That is, a rim reading on each coupling half less than 0.004-inch TIR (assuming zero bar sag) is proof that the offset tolerance Table 1, is achieved for an 1800-rpm machine. Readings greater than 0.004 inch can also be acceptable if the plotted shaft centerlines remain with the zone (Fig. 2).

The allowable angularity is shown in Table 2.

The values in the Table 2 are angles and can be measured from the plotted intersection point to any other convenient axial position. These are angular orientations of the shaft centerlines. Face readings on a coupling half are unacceptable unless the aligner can prove that the coupling face is perpendicular to the shaft centerline, with a runout reading, or the method obviates this defect, like rotating both shafts together such that the reading target remains constant.

The values from the Tables 1 and 2 can be interpolated for different speeds.

The alignment is acceptable when the offset from Table 1 and the angularity from Table 2 are both satisfied.

For machines with more than one coupling (long drive shafts), the tolerances apply separately at each coupling. That is, the allowable misalignment between driver and driven machine shafts is effectively doubled if there are two couplings.

The tolerance values from the Tables 1 and 2 are suggested standards based on commercial, industrial, and Department of Defense practice. The objective with these standards is to minimize wear and achieve normal mean time between failures of about 10 years. The owner's representative has the authority to depart from these recommended guidelines if operational considerations dictate that long reliable life is an unnecessary requirement.

The tolerance values in the Tables 1 and 2 must be achieved in two orthogonal planes, typically horizontal and vertical views. The values apply to the final hot running conditions. Machines can be left in a cold orientation outside of these bands if the expected growth, or other movement, will put them in tolerance at normal running conditions.

9.0 Documentation

A report shall be issued to the owner that documents, as a minimum, the initial and final shaft orientations, and the changes made. Appendix C contains a sample report.

The report shall also describe the conditions for alignment, i.e:

- Prior to installation on the final foundation
- After installation and prior to piping connections
- After piping connections and prior to operation
- After running-in for __ hours
- Repair after rebuild
- The report shall describe the instruments and method used to measure and calculate machine moves. It shall describe any other measurements or abnormalities detected, e.g.:
- Shaft runouts
- Uneven bases
- Soft foot corrections

If the shaft positions were left outside of the tolerance bands to accommodate thermal growth, that shall be so stated, and the growth calculations, or estimate, shall be included in the report.

10.0 Prestartup verification

The coupling bolts (or screws) and the holddown bolts shall be verified to be all tight, even on those machines that were not adjusted. The screws or bolts shall be torqued in accordance with the manufacturer's instructions, or Appendix D.

The shafts shall be rotated by hand to verify no binding. The coupling covers shall be installed. All tools shall be picked up and removed from the immediate area. The locks shall be removed from the energy source controls. The machine shall be left in a ready-to-run condition.

11.0 Alignment versus vibration

Vibration shall not be used as a criteria to judge alignment, even though the purpose of alignment is to reduce vibration. The alignment shall be judged with static measurement instruments fixtured to the shafts and judged in accordance with the tables in Section 8.0, "Alignment Limits." Other factors can cause excessive vibration, such as structural resonances or unbalance. See the separate vibration standard for analysis guidelines.

In a similar manner, noise and excessive bearing temperature could indicate shaft misalignment but these symptoms could also indicate other problems. Noise and excessive bearing temperatures shall not be used alone to judge alignment.

These discussions do not preclude the aligner from remaining on site during start-up and observe the running condition for his/her own satisfaction. Nor does this preclude running alignment being done with a vibration instrument as a feedback device to achieve a smoother running condition.

Appendix A—Bearing Alignment

Bearing alignment is the centerline angular orientation of the inner race to the outer race. Ideally, they should be coaxial. Other interpretations of bearing alignment are that the faces of both races be parallel, or that the face of the outer race be perpendicular to the shaft rotating center (normally the same as the shaft axis if the shaft is straight). This last criteria can be measured on installed bearings if the outer race is accessible, Fig. 4.

This standard is directed primarily to shaft-to-shaft alignment, but misaligned bearings generate the same vibration symptoms and wear patterns as do misaligned shafts. In addition, bearing-to-bearing misalignment on a common shaft generates the same symptoms as a bent shaft. An aligner who installs or repositions bearings has the responsibility to leave them in an aligned condition. It is also the aligner's responsibility to detect and correct bearing misalignment when vibration indicates that it is a possibility. The preferred method of aligning bearings is statically with a measuring fixture as shown in Fig. 4. The outer race is lightly tapped with a punch and hammer to reposition it in the housing. The race is adjusted until the total indicator reading around the diameter is acceptable. The allowable tolerances are in the Table 3.

Alternately, the bearings can be adjusted dynamically using a vibration instrument. The bearing is partially loosened and lightly tapped while rotating under power to seat the bearing for minimum vibration. This method should only be attempted by those knowledgeable and experienced in the art of dynamically seating bearings.

Self-aligning bearings shall be set within the manufacturer's angular limits and verified to be free swiveling so that they will adjust themselves under dynamic rotating forces. If they do not freely swivel, then they shall be statically adjusted in accordance with Table 3.

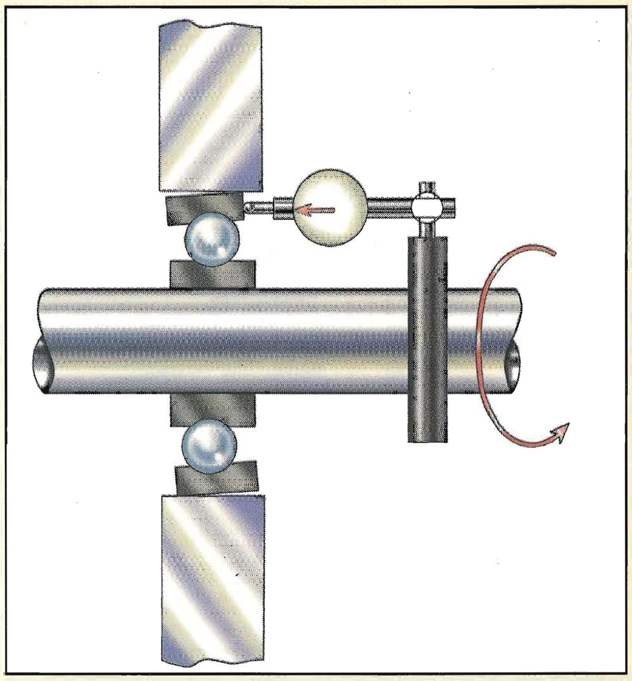

Fig. 4. Measuring bearing misalignment with a dial indicator

TABLE 3. ACCEPTABLE RACE RUNOUT, MILS/IN. (REFERENCED TO ROTATING CENTER)

Bearings	mils/in.
Ball bearings	2.0
Cylindrical roller bearings	1.0
Plain bearings	1.0
Plain thrust bearings	0.5

Bearing alignment also refers to the fit in the housing and on the shaft. These sizes shall be measured with micrometers and verified to be the proper sizes in accordance with the bearing manufacturer's instructions.

Bearing alignment also refers to the need for a floating bearing on high-temperature applications where the axial thermal expansion of the shaft will consume the internal bearing clearances. If the temperature difference between the rotor and the bearing supports is greater than 50 F, or the distance between bearings is greater than 24 inches, then a floating bearing should be considered. It is the aligner's responsibility to verify the existence of a floating (or expansion) bearing, and to verify that the expansion clearance is set in the proper direction, and of the correct amount.

Appendix B—Pulley Alignment

Machines with belt drive shall be positioned so that the belt is not distorted. Generally, a string or straight-edge alignment of the pulley grooves is satisfactory. More important, the belt tension shall be set as loose as possible without slipping.

If vibration remains after these adjustments are made, then the roundness of the pulley shall be measured with a dial indicator. The pulley shall be adjusted (or replaced) to have a maximum total indicator runout of 0.005 inch.

Appendix C—Sample Alignment Report

Name
Company
Address
City, State, Zip

Dear __________:

This is a report of precision alignment of Process Chilled Water Pump No. 6 at Building 858. This alignment was done as part of the repair of the motor, after it came back from a rewind and new bearings were installed.

The base and foundation were visually inspected and were normal. The total indicator runouts of the motor shaft and pump shaft were both less than 0.001 inch. There was a minor soft foot under the motor feet, which was corrected with shims. There was no indication of piping strain during the alignment process. The coupling was assembled and set to an axial spacing of 2.57 inches. The manufacturer's tolerance is 2.50 ± 0.125 inches.

The motor became bolt bound horizontally and was corrected by undercutting the threads of the two outboard feet of the motor.

Dial indicators were used to measure the shaft positions using the reverse-indicator method. The move calculations were done graphically. The table below documents the before and after conditions.

PCW pump No. 6 1800 rpm	Vertical		Horizontal	
	Offset, mils	Angularity, mils/in.	Offset, mils	Angularity, mils/in.
Initial misalign.	2.0	1.5	7.5	4.5
Final misalign.	2.8 motor low	0.7	2.5	0.5

The motor was left slightly low to accommodate thermal growth of 0.002 inch. The final alignment condition is within specification.

The coupling bolts were tightened securely, and the hold-down bolts torqued to the proper values. he pump was operated and observed for 30 minutes. The vibration and bearing temperatures were normal.

Respectfully submitted,

Signature

Appendix D

MAXIMUM RECOMMENDED TORQUE FOR LOW CARBON STEEL BOLTS AND SCREWS

Fastener size	Torque, in.-lb
1/4–20	65
1/4–28	90
5/16–18	129
5/16–24	139
3/8–16	212
3/8–24	232
7/16–14	338
7/16–20	361
1/2–13	465
1/2–20	487
9/16–12	613
9/16–18	668
5/8–11	1000
5/8–18	1140
3/4–10	1259
3/4–16	1230
7/8–9	1919
7/8–14	1911
1–8	2832
1–14	2562

Notes:

1. Stainless steel fasteners can be safely torqued 10 percent above the values in the table.
2. These torques will result in bolt tensions somewhat less than the yield point.
3. The threaded assemblies are assumed to be dry and clean with a resulting torque coefficient of 0.2.

thermal growth, bent shafts, pipe strain, and bar sag. It is the responsibility of the aligner to determine if any of these are factors and to make the appropriate corrections.

Vibration should not be used as rejection criteria, but it could be used as an acceptance criteria. That is, many other mechanical defects can cause excessive vibration even with an excellent alignment (such as unbalance or resonance). So vibration should not be used as a symptom to fault the alignment. However, a smooth-running machine is evidence that the alignment is satisfactory, and it should be accepted.

Finally, a report is required. The owner is entitled to know what was measured and what changes were made. Every honest aligner must generate some data to discover the initial shaft orientation. The aligner must also measure the final orientation to judge acceptability. The inability to produce the data in written form means that no data was generated or the aligner can't write.

> **Vibration should not be used as rejection criteria, but it could be used as an acceptance criteria.**

Cost control

Standards are a means of scoping the work expected of either employees or contractors. By precisely defining the results, standards are a means of controlling the cost to the level where the results are achieved and no more. Whether alignment is done in-house, or as a contracted service, the results should be consistently the same when the same standards are enforced.

All alignment jobs should be on a time-and-materials basis. Since the existing condition is unknown until the first readings are taken, the aligner does not know the extent of correction required. For this reason, it is inappropriate to require a fixed-price bid before the aligner has an opportunity to examine the machine. The range of contract service rates for alignment are $45 to $145/hour per person. Most alignment jobs are one-person tasks, or one alignment specialist with some helpers.

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