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ANSI/ASA S2.75-2017/Part 1 Shaft Alignment Methodology, Part 1: General Principles, Methods, Practices, and Tolerances

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BACKGROUND

In the time period about 2010, the Vibration Institute sought to establish training for shaft alignment technicians, similar to their training for vibration technicians and analysts. However, there existed at that time no national or international standard for shaft alignment. Various alignment tool vendors and industry consultants had published tolerances for acceptable alignment of flexible couplings, but these varied among sources. Machinery manufacturers published various shaft alignment guides for their specific machines, but these varied widely in methodology and acceptable tolerances. Some industry specific standards did exist such as the API standard for machine installation, but these were not easily applied outside of those specific industries. The Vibration Institute then launched an effort in conjunction with the Acoustic Society of America, (ASA), to produce a shaft alignment standard that could be applied broadly across industries, and that would form a basis for the development of training for shaft alignment technicians. The standard presented here is the culmination of that effort.

SCOPE

It was apparent at the beginning of the effort that it would be necessary to limit the scope of the initial standard to machine configurations that are common across industries. There are literally dozens of potential machine configurations, each with certain shaft alignment constraints. The decision was made to limit the scope of this initial document to machines described as “4 bearing sets”, which are comprised of two independent shafts, each supported on a pair of bearing and coupled by means of a flexible coupling. The most common examples of this configuration is a horizontal motor-pump or motor-fan combination.
The intention is to expand on this initial document with additional standards that addressed the specific needs of other machine configurations, such as vertical machines, 3 bearing sets, etc. The format for beginning with an initial document and expanding with subsequent standards is established with the well-known ISO vibration standard, 10816. This initial vibration standard now has over 20 subsequent parts addressing vibration concerns for various types of machinery.
In addition to providing guidance on shaft alignment tolerances, the standard describes methodology applicable to manual and laser measurements. It establishes “Alignment Quality Grades”, describes best practice for corrective moves and addresses basic mounting and base issues.
The document includes a series of informative Annexes including the following:

- Alignment Principles
- Machine move calculation formulas
- Identifying and correcting pipe strain
- Off-line-to-running (OLTR) methods
- Laser detector systems
- Graphic alignment modeling
- Repeatability
- Alignment and machinery installation checklist

TOLERANCES

Tolerances for acceptable relative shaft position, (shaft alignment tolerances), are a fundamental concern and of course are provided in the standard. In addition, tolerances for other critical factors such as Base flatness and level, shaft runout, coupling runout, pipe and conduit strain, soft foot and Offline To Running (OLTR) machinery movement are also provided.

Table 1 — Guidelines for levelness, flatness, coplanarity of general process machinery.

Machinery type	Recommended levelness	Recommended foot flatness	Coplanar surface deviation (shimmed)
General process machinery up to 400 kW or 500 HP	≤0.8 μm/mm (≤10 mils/ft)	≤0.4 μm/mm (≤5 mils/ft)	≤50 μm (≤2 mils)
General process machinery 400 kW or 500 HP or above	≤0.4 μm/mm (≤5 mils/ft)	≤0.2 μm/mm (≤2 mils/ft)	≤50 μm (≤2 mils)

Figure 1: Guidlines for level, flatness and coplanarity, ANSI/ASA S2.75-2017/Part 1

Table 2 — Shaft runout tolerances

Shaft runout tolerance	Shaft diameters up to and including 160 mm (6.25 inches)	Shaft diameters over 160 mm (6.25 inches)
Standard	50 μm (2 mils) TIR	75 μm (3 mils) TIR
Precision	25 μm (1 mil) TIR	25 μm (1 mil) TIR

Figure 2: Shaft ruout tolerances, ANSI/ASA S2.75-2017/Part 1

The shaft runout tolerances in Table 2 above are provided as a guidance. It should be recognized that shaft runout and coupling surface runout do not affect shaft centerline alignment when both shafts are turned when making alignment measurements. The strong recommendation is to always turn both shafts when making alignment measurements.

A tolerance for pipe and conduit strain is provided. The standards states that pipe or conduit strain, "… shall not be sufficient to cause changes in the shaft alignment of magnitude greater than 50 micrometers (2 mils) vertical or horizontal measured at the coupling." In addition, the informative Annex C provides methodology for identifying and correcting pipe strain when performing shaft alignment on pumps.

Most technicians involved in shaft alignment understand the negative consequences of a soft foot condition and procedures for identifying it. The standard provides some direction in this regard: "An indication of 50 μm (2 mils) movement at any part of any foot, indicates a soft foot condition that would require correction by adjusting shims at the feet." Many soft foot conditions result from poor base levelness, flatness or coplanarity. The standard provides a table of guidelines, (Figure 1).

A machine may be in good alignment when setting idle and at ambient temperature, but the heat and torque strain of operation will cause machine cases across a flexible coupling to move in relation to each other, thus changing the shaft alignment in the operating condition. The standard defines "OLTR" (offline to running machinery movement). Appendix D provides a tutorial on evaluating OLTR and setting Target alignment values.

Tolerances for shaft-to-shaft alignment are included in the Alignment Principals section below.

METHODOLOGY

The standard provides a holistic approach to the shaft alignment process. A flow chart documenting key steps and decision points is provided.

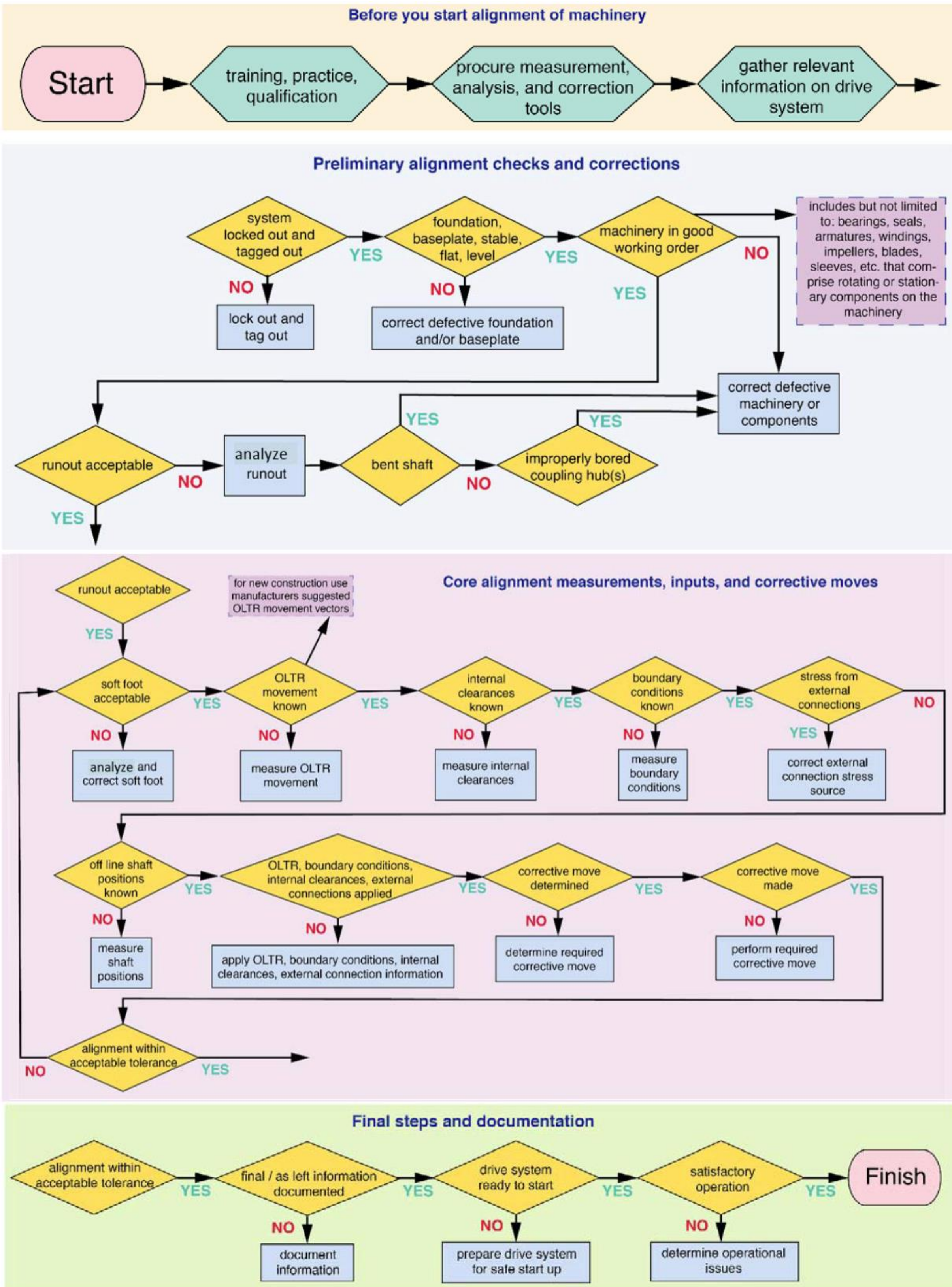


Figure 3: Alignment process flowchart

In addition to the Annexes described previously, the standard includes Annex B which provides details of the mathematical formulas for calculating correction moves for various dial indicator sets. The included summary of dial indicator mounting methods is instructive; Rim & Face, Reverse Dial, Double Radial, Shaft to Coupling Spool, and the Face-Face setups are all illustrated. Annex E explains the operation of common laser systems. An understanding of how the laser systems actually measure shaft to shaft misalignment is helpful when using these tools to analyze alignment condition. Annex F provides a tutorial on graphic alignment modeling. Graphic modeling is particularly useful when boundary conditions such as base bound or bolt bound constraints must be dealt with. Annex G provides guidance on methodology to insure measurements are repeatable. A distinction is drawn between accuracy and repeatability. A measurement may be accurate to a hundredth of a millimeter, but if subsequent measurements produce readings that vary by one or two millimeters, the results will not be very useful. Annex H provides a useful checklist that will ensure important steps do not get skipped and results are properly documented. A further description of some of these Annexes is included below.

ALIGNMENT PRINCIPLES

There are two common methods of evaluating shaft to shaft alignment. The offset and angularity between shaft centerlines can be used as an indicator of shaft alignment. An alternate method focusses on the actual work done by the flexible coupling to accommodate shaft to shaft misalignment. Flexible couplings are constructed of two shaft mounted hubs and a flexible member between the hubs. The standard refers to the flexible member of the coupling as a “Coupling Mechanical Link”, (CML). The shaft to shaft misalignment is accommodated by angularity between each of the hubs and the CML. The point where this angularity occurs is called the Flex Plane.

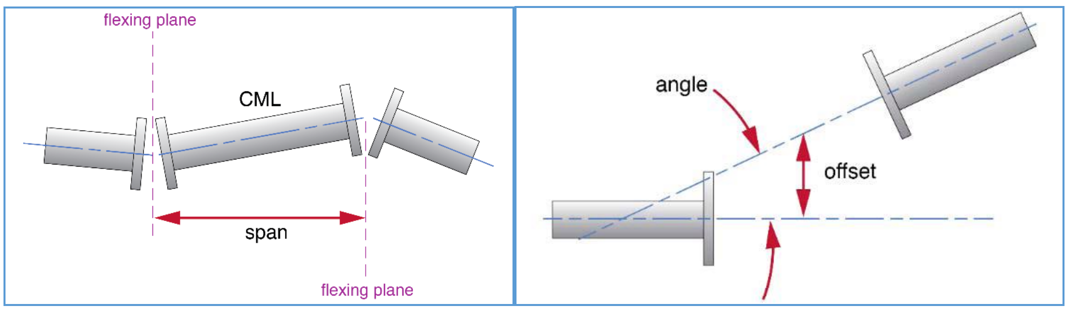


Figure 4: Flexplane angles vs. Offset & Angularity, ANSI/ASA S2.75-2017/Part 1

When shaft to shaft alignment is viewed at the flex planes, there are two flex plane angle values rather than an offset and an angularity value. Since the flex plane angles more accurately represent the work being done by the coupling than do the offset and angularity values, the flex plane angles are used in the standard to establish alignment tolerances for flexible couplings. This method of determining tolerances also has the advantage of being reduced to a single tolerance value – an angle, rather than two values – an offset and an angle. The single angle value tolerance is applied at each of the two flex planes and both must be within tolerance.

ALIGNMENT QUALITY GRADES

The standard provides Alignment Quality Grades (Alignment Grades) based on the flex plane angles and machine operating speed. The Alignment Grades are stated in units of mils/inch or µm/mm, directly related to the ratio of the offset at the flexplane to the flexplane separation. The Tolerance are provided graphically on a chart, in tables, or can be calculated by the formula:

$$T = \frac{ALG}{\sqrt{\frac{RPM}{1000} + 1}}$$

The standard has labeled three Alignment Grades: AL4.5 = Minimal, AL2.2 = Acceptable, AL1.2 = Excellent. A machine manufacturer or service provider can choose any Alignment Grade based on the machine construction and operating condition, independent of operating speed. So a fan manufacturer that builds a sturdy machine intended for rough service may specify AL2.0 for their machines. A machine tool manufacturer desiring exceptionally smooth operation may specify AL1.0 for their machines. A manufacturing plant could specify AL1.2 for any newly installed machines, but allow AL2.2 when boundary conditions limit machine moves.

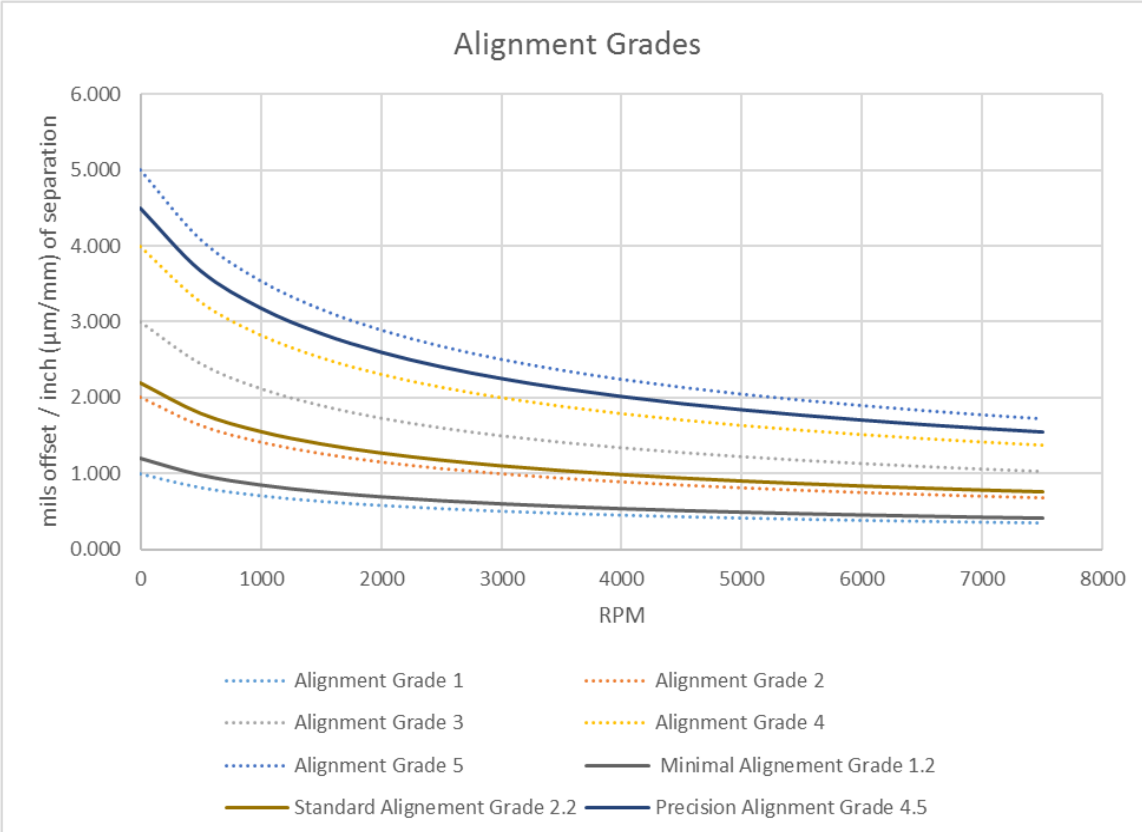


Figure 5: Alignment Grade Chart

To determine the actual alignment condition, determine both flexplane angles as the ratio of the offset at the flexplane to the flexplane separation. For most couplings the face of the coupling hub can be considered the flexplane. For reverse dial indicator setups with the indicator mounted at the flexplane, the flexplane angle is simply the offset indicated by the dial divided by the distance between the coupling faces.

So a coupling alignment offset measurement (reverse dial indicator or laser system) of 0.004" at one flexplane, and a flexplane separation of 2" would be a ratio of 4 mils/2" = 2 mils/in. The Alignment Quality Grade chart in the standard shows that at 1800 RPM, a flexplane angle of 2 mils/in is above AL2.2 and below AL4.5. To improve this alignment to AL1.2, both flexplane angles would have to be less than 0.72 mils/in; the actual measured offset would have to be less than 1.44 mils at each flexplane. These values can be calculated from the formula provided in the standard. Also, note that since both flexplane angles must be within tolerance, it is only necessary to evaluate the greater of the two flexplane angles.

The most common method for applying tolerances is to determine the tolerance value for the particular application, and then insure the actual measured value is below that tolerance. Since the Alignment Grade tolerance values are in mils/in, (or µm/mm), and the coupling separation is easily measured, it is easy to convert the Alignment grade to an actual offset value for any specific RPM. The results of those calculation for AL1.2, 2" coupling separation and 1800 RPM are described in the paragraph above. The formal calculations are shown here with a coupling separation of 4" and 1800 RPM:

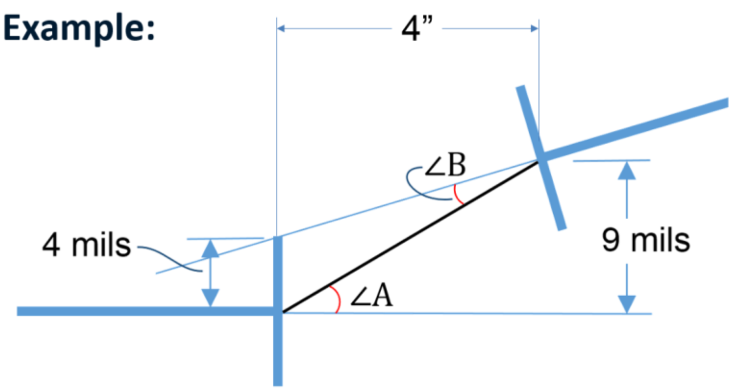
$$AL4.5:\ T = \frac{4.5}{\sqrt{\frac{1800}{1000}+1}} = 2.7 \text{ mils/in}, \quad 2.7 \times 4'' = 10.6 \text{ mils offset}$$

$$AL2.2:\ T = \frac{2.2}{\sqrt{2.8}} = 1.31 \text{ mils/in}, \quad 1.31 \times 4'' = 5.3 \text{ mils offset}$$

$$AL1.2:\ T = \frac{1.2}{1.673} = 0.72 \text{ mils/in}, \quad 0.72 \times 4'' = 2.9 \text{ mils offset}$$

Figure 6: Calculations for offset at the flexplanes for 4" separation and 1800 RPM

It should be apparent that the Alignment Grades are directly proportional to the actual measured offset at the flex plane. Reverse dial indicator setups and laser measurement systems can provide those offset values directly. Rim & Face and other measurement techniques require some simple geometry to determine the offset at the flexplane. That geometry and procedure is the same as for determining correction moves for the machine cases, so it should be familiar to alignment technicians.



$$\angle A = \frac{9\ mils}{4\ inches} = 2.25 \text{ mils/in} \qquad \angle B = \frac{4\ mils}{4\ inches} = 1.0 \text{ mils/in}$$

Figure 7: Example of calculating flexplane angles.

Figure 7 illustrates an example alignment condition, with the calculations for each of the two flexplane angles. Since angle A is greater, the tolerance would be applied to this angle. Tolerances for operation at 1800 RPM are shown in Figure 6, or can be read from the chart in Figure 5. The alignment condition in the example would meet the Minimal standard but would not meet the Standard tolerance.

Many alignment technicians are familiar with tolerance tables provided by various alignment tool vendors. The most common format for those tables is to provide shaft centerline offset and angularity values for common machine RPM when the coupling hub separation is less than 4”, and offset values at the coupling hub when separation is greater than 4”. This method represents a compromise between the concern for the forces actually imposed on the coupling by misalignment, and the desire to have tolerances in the format that was popular when coupling alignment was done only with straight edges and feeler gages. For convenience, the standard provides tables in that format with values that correspond to the AL4.5 Minimal, AL2.2 Acceptable and AL1.2 Excellent tolerances. Meeting the values in Offset & Angularity format will ensure that the corresponding tolerance is met, but because of the geometric differences between the tolerance formats, the shafts may actually be aligned closer than they need to be. That’s not bad for the machine, but it may require more time and effort than is necessary.

BACKGROUND

It may be helpful to understand where the Alignment Quality Grades originated; their validity is well grounded. Most of the prior published shaft alignment tolerances allow greater residual misalignment at lower rotating speeds, and require tighter alignment at greater speeds. Whatever format in which a tolerance may be stated, it can be converted to an equivalent flexplane angle value for reasonable machinery configurations. Thus, a tolerance can be represented graphically as curve of flexplane angles (vertical axis) vs. machine rotating speed (horizontal axis). An array of common alignment tolerance values are graphed in this way in the illustration below.

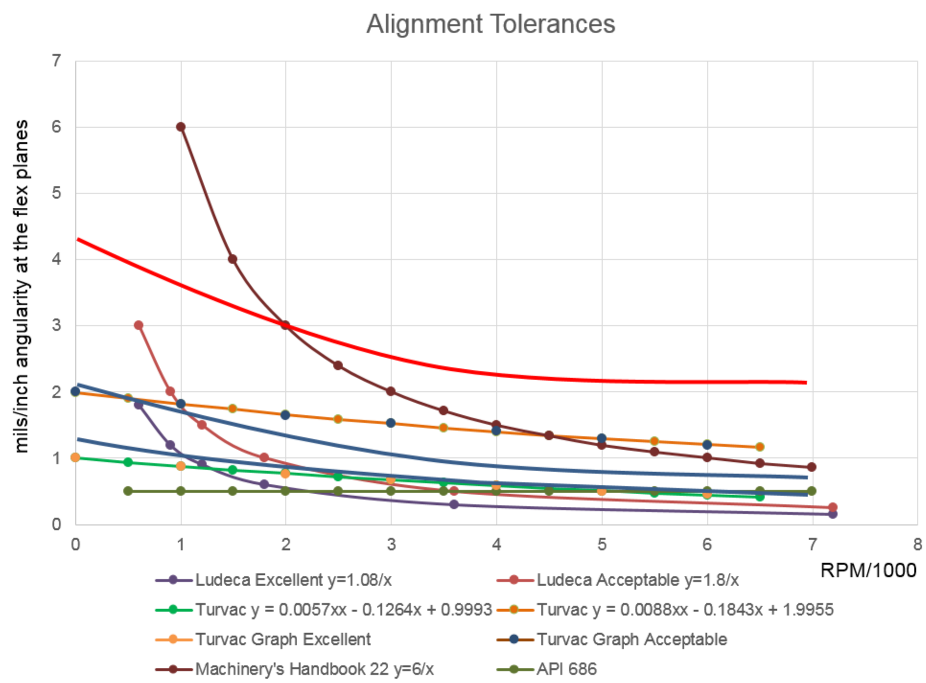


Figure 8: The graphic method used to establish Alignment Quality Grades; source ASC-S2-WG15 Committee documents

The committee that developed the standard used this graphic representation of existing tolerances, and drew in the Red and Blue Minimal, Acceptable and Excellent tolerance lines. Using mathematical curve-fitting techniques, these drawn lines were converted to the simple Alignment Grade formula. So whatever tolerance might have been in use prior to this standard, the corresponding Alignment Grade values won't be far off. Since the Alignment Grade values are in units of mils offset per inch or separation, (or µm offset per mm separation), and the formula is based on machine rotating speed, these Alignment Grade values can be specified without regard for either coupling hub separation or machine operating speed.

MAKING MACHINE MOVES

The standard provides useful information and guidelines for concerns related to moving the machine cases. The process of aligning machinery can be frustrated by issues such as Soft Foot, Base-Bound and Bolt-Bound conditions. The standard mentions the need for jacking screws and related techniques for adjusting machine position in a controlled manner. The importance of positioning axial spacing (coupling gap) is addressed. The scope of the standard is limited in these areas, clearly it is not a training manual, but alignment technicians who have encountered these issues will find the information provided in the standard helpful.

USEFUL ANNEXES
While the standard is not a training manual on shaft alignment, several of the Annexes do provide instruction on important related topics:

ANNEX B – CORRECTION MOVE FORMULAS
Laser alignment systems provide automatic calculations for corrective machine moves. But for those who may not have those systems available, the techniques for calculating how much a machine case must be moved to achieve proper alignment requires only proportioning the alignment measurement to the machine dimensions. Annex B provides details on those calculations. By inputting the setup and machine dimensions, and the dial reading, the amount of move at each foot is calculated. Calculations are included for five dial setups: Reverse dial, rim & face, double radial, shaft to coupling spool and face-face methods.

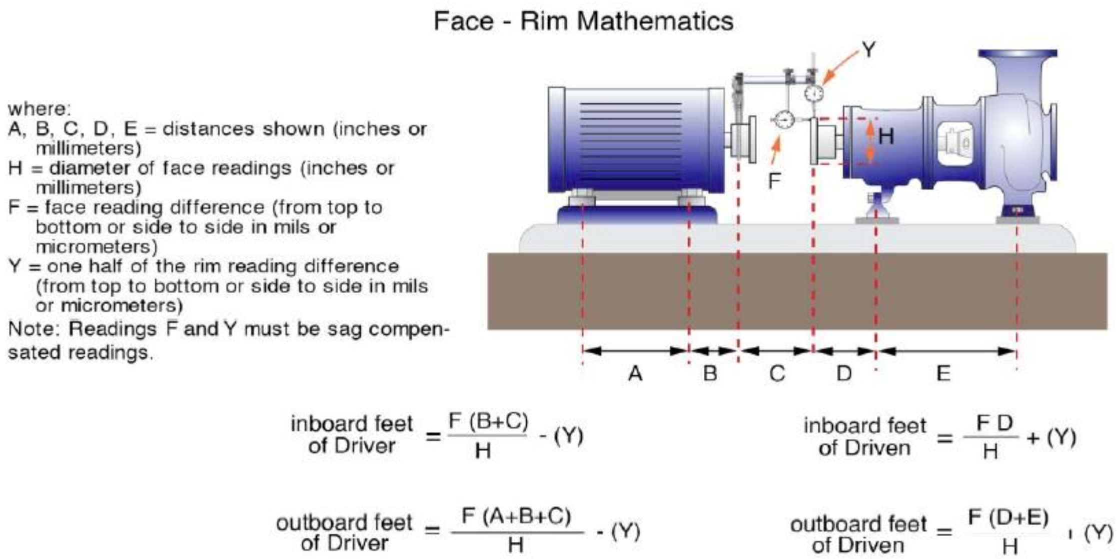


Figure 9: Example of correction move calculations

ANNEX D – OLTR MOVEMENT
Shaft alignment is normally done with a machine off line and cold (ambient temperature). But in normal operation, most machines experience some temperature change, usually a temperature increase. Machine movement results from the change in temperature. In addition, during operation torque strain and piping strain will cause a machine case to move from the cold aligned position. To allow for these off line to running (OLTR) movements, the cold alignment must be offset so that as the machine comes to normal operating condition it moves into proper alignment. A study of the machine OLTR movement is needed to determine the amount of off set, known as the "target" settings. Annex D details the process of establishing target values and applying them to the alignment process, with graphics and illustrations.

ANNEX F - ALIGNMENT MODELING

An alignment model is an exaggerated picture of a misalignment condition of a drive system. Alignment models can be as complex as the drive system. Multiple element drive systems, right angle drives and vertically oriented machinery can all be plotted onto alignment models. Modeling shows the relative amount and direction of machine case moves needed to achieve proper alignment. When models are properly scaled, the amount of move required can be accurately determined. This visual-graphic method is preferred by some technicians over the manual calculation described in Annex B.

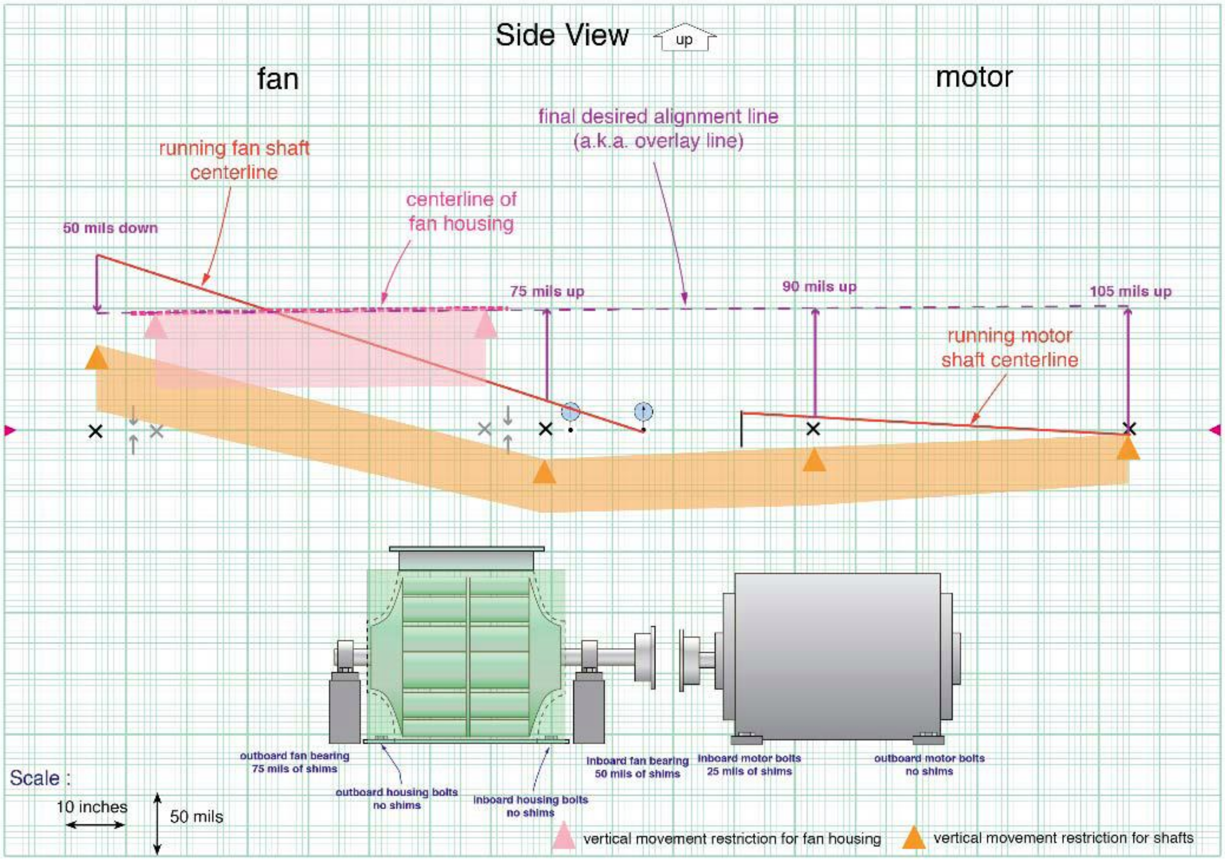


Figure 10: Example of a graphic alignment model.

ANNEX H – MACHINERY INSTALLATION CHECKLIST

Planning is important for success. The flowchart, (Figure: 3), illustrates a logical set up steps that will ensure an effective and efficient shaft alignment process. The checklist in Appendix H is a more streamlined approach to ensuring important steps are not missed. The checklist, like the flow chart, are intended as a template that can be modified as needed to meet specific plant, company or contractor situations.

CONCLUSION

The absence of a comprehensive shaft alignment standard has been a stumbling block to creating effective training and work procedures. This standard marks a new day for end users, instrument vendors and consultants involved with machinery shaft alignment. With a comprehensive standard, produced with input from broad array of machinery technical experts, work procedures and technical specifications can be in agreement and technicians actually doing the shaft alignment work don't have to rely on a patchwork of best practices and sometimes erroneous rules of thumb.

REFERENCES

DIN ISO 10816-1
Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts - Part 1: General guidelines

DIN ISO 7919-1▹
Mechanical vibration of non-reciprocating machines - Measurements on rotating shafts and evaluation - Part 1: General guidelines