A closer look at turbomachinery alignment

Successful shaft alignment requires consideration of all factors that influence movement of the machinery. Here's what to look for before and during the actual alignment

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Good turbomachinery alignment consists of three interrelated parts. Each part is an equally important step in realizing the goal of an equipment train capable of operating safely for long periods without the many problems resulting from severe misalignment.

1. The system survey. Many steps vital to good turbomachinery alignment are taken well ahead of the actual "cold alignment." Unless the person responsible for alignment has first-hand knowledge that pre-alignment preparations have been properly carried out and completed, verification is essential. Some of the items which warrant specific attention are:

1. Piping. A visual piping inspection by those responsible for alignment is vital. This inspection will assure that the piping is installed in apparent agreement with design criteria, is complete and in its functional state. Obvious items to look for are proper placement and adjustment of guides, anchors and supports; proper adjustment of tie-bolts on expansion joints; correct positioning of spring hangers; complete make-up of flanges with gaskets in place and bolts tightened; absence of slip-blinds which may have been installed for hydrotesting of pipe lines, and proper orientation of check valves. In short, it must be verified that the system is in order so post-alignment piping modifications will not nullify the alignment effort.

2. Grouting should be checked to be sure it is complete and apparently well done.

3. Foundation bolts should be checked for tightness.

4. Check all shimpacks. Shims are the vital link between the machine and the foundation and are essential to maintaining alignment over long periods. It is my experience that the only reasonable assurance of proper shimpacks is to physically remove and inspect the shims at every machine support just prior to final alignment. Obvious problems with shims include rust, improperly cut shims, folds and wrinkles, burrs, hammer marks and dirt. I once found a turbine installed on shimpacks wrapped in masking tape. It is good practice to use as few shims as possible and replace many thin shims with fewer shims of greater thickness. Stainless steel shims will pay for themselves many times over by minimizing alignment problems associated with shim deterioration. It is equally important to see that surfaces of equipment supports and soleplate/baseplate are clean and in good condition.

5. Check for misalignment of machine supports relative to the soleplate. A relatively simple test for problems in this area can be made when shimpacks are checked. Mount a dial indicator on the machine support with the indicator stem resting on the soleplate. Watch the indicator as the hold-down bolts are loosened. If movement of the indicator is more than 0.001 to 0.002 inches, it is an indication of a problem that must be defined and eliminated. Remove the shimpack and check with feeler gages to be certain the machine support is parallel with the soleplate. If not, re-grout, re-machine the support or prepare tapered shims.

Be suspicious if one support moves less than others. If three of the supports move 0.001 to 0.002 inches, and the fourth shows no movement, it may indicate that the support is carrying more than its share of the load.

6. Check the casing for distortion. Despite the massive appearance of turbomachinery casings, they are flexible and easily distorted. This relatively simple test for gross distortion can be made when shimpacks are checked:

a. With three supports tightened down, remove the shimpack from the fourth support.

b. Determine the total thickness of the shimpack and record the dimension.

c. Let this corner of the machine down (the machine is now supported only at three points). Using feeler gages, determine the distance from the soleplate to the machine support. Record the dimension.

d. Subtract the feeler gage dimension from the shimpack thickness. This is the total deflection of the machine casing with no support at the corner being checked.

e. Repeat the procedure at each of the four supports and compare the deflection of each. Gross differences in deflections at any of the four supports is an indication of probable casing distortion.

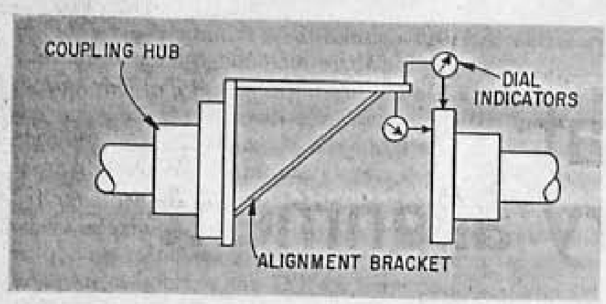

Fig. 1—Typical arrangement for "Face-OD" readings to determine cold alignment of shafts.

7. Check for piping strain. Piping strain is seldom detectable by visual observation. However, gross problems can be detected by a rather simple test. Following the check for casing distortion, place dial indicators on the machine to monitor both vertical and horizontal movement of the casing or shaft. Now loosen all the hold-down bolts. If the machine moves more than the average observed when checking individual supports, it is obviously the result of an external force—probably the piping.

8. See that bearings are properly installed in the machines, that they are lubricated and that the bearing covers are properly tightened. These are rudimentary precautions made on the basis of experience through attempted alignment of machines with the bearings removed.

9. For turbomachinery trains with high-speed gearing, extraordinary precautions should be taken to set and align the gear itself. High-speed gearing is normally the most precisely made equipment in the train; it is also the most sensitive and most vulnerable to catastrophic failure as a result of poor installation. Unfortunately, installation instructions for most gears are grossly inadequate. One fundamental precaution is offered: if a gear is involved, be very, very careful.

Planning. Since turbomachinery alignment normally involves the participation of many people in various functions, it is imperative that an over-all plan be developed to assure that the goals of the program are known and understood and that the method of attack is consistent with the desired results. Moreover, such planning is valuable from the standpoint of minimizing the time involved (hence, the cost) to achieve satisfactory alignment. Plans should include:

1. Determine the desired placement of the shafts (cold settings) considering anticipated thermal growth of the various components. Define movement of shafts within bearing clearances (rising-pinion gears, for example), hydraulic loading and any other factors expected to produce relative movement of shaft centerlines when the machines are operated.

2. The sequence of alignment must be determined for multi-unit trains. For two-component trains, determine which of the two machines is to be moved.

3. Select a specific method for determining relative shaft positions.

4. Decide on tolerances for theoretical cold alignment settings. Allowable deviations which are unrealistically strict cost time and money, and may not be attainable. Tolerances which are too loose are an invitation to trouble.

5. Make a list of tools and instruments required for the alignment and make certain they are available and in good working condition. These include such items as alignment brackets, dial indicators, tools required for hot alignment checks, pre-cut shims of various thicknesses, tools for lifting the machines during shim changes, wrenches of the proper size for hold-down bolts, coupling tools and a device for rotating the shafts.

6. Provisions should be made for permanent recording of alignment data. Many good sets of alignment readings, written upon the side of a compressor, have been covered by the painter's gun.

2. Cold alignment. The term "cold alignment" refers to the position of a turbomachine's shaft centerline relative to the shaft centerline of a connected machine, with both machines in a non-operating or "cold" condition. Offset and angularity are both implied by the term. Cold alignment is important because it is normally the only check made to directly determine the relative position of the two shafts. Results of the check form the basis for determining shaft alignment during operation.

The only cold alignment techniques discussed here are those using dial indicators. Procedures are old and well established, but do have problems and pitfalls.

Fig. 1 illustrates the most widely used of the traditional alignment methods, commonly referred to as the "Face—OD" method. A bracket is attached to one shaft and extends near the coupling hub on the adjacent shaft. Dial indicators are attached to the bracket as shown, with the stem of one indicator resting on the face of the coupling hub. The stem of the other indicator is resting on the OD of the same hub. Offset of the shafts is determined by the OD readings. Angularity is determined by "face" readings.

The method has and continues to serve well in the vast majority of industrial alignment problems. Indeed, it is the specific method outlined in virtually every maintenance manual for industrial rotating equipment.

For high-speed, high-hp turbomachinery, where requirements for precise alignment are more stringent, shortcomings of the method become increasingly important. Consider the following points:

- The indicator readings from this method reflect not only misalignment of the shafts of the two machines, but inaccuracies in geometry of the coupling hub upon which readings are made. Typically, the measurements should have an accuracy approaching 0.001 inches. It is not uncommon to find runout of the face or the OD of a coupling hub in excess of this amount, even on good quality, high-speed couplings. This error can be eliminated, of course, by determining the geometry of the coupling hub and making appropriate allowances or by turning both shafts simultaneously such that indicator readings are always taken at the same place on the hub, but these precautions are difficult on large equipment and are seldom taken.

- When making face measurements it is absolutely necessary that the axial floats in both shafts be accounted for. This is of little concern with small equipment where shafts are fixed axially by ball bearings. It becomes a problem, however, on machines equipped with hydrodynamic thrust bearings (or no thrust bearings at all). The normal procedure is to separate the shafts axially each time a reading is taken. The axial position of the shafts as they come to rest depends on how hard the craftsman pushes. Thus, consistent readings are difficult to obtain. The practice also leads to the use of makeshift tools to pry the shafts apart, and a coupling seldom comes through the alignment procedure unscathed.

- The face diameter upon which readings are taken to determine angularity of the two machines is relatively small, especially in high-speed equipment—sometimes no larger than 3 inches. For example, a reading of 0.002 inches (normally termed "acceptable") on the face of a 4-inch diameter coupling hub represents an angularity of 0.006 inches per foot or an error of 0.030 inches at the opposite end of a machine 5 feet long. Add to this a 0.001 inch error in the face of the coupling and the outboard end of the machine is 0.045 inches from the desired position. In most instances such an error is not catastrophic, but it is an error that should not exist.

- The tool normally used to hold the dial indicators is either a "universal" bracket, or makeshift device contrived on the spur of the moment. Brackets specifically designed for the machines being aligned are not normally considered necessary and are, therefore, not used. The assumption is usually made that the bracket being used is stiff; i.e., it does not deflect under its own weight. Normally there is no attempt to verify the assumption, which is a very poor one, especially for couplings with relatively long spacers. I have found many brackets which deflect 0.005 to 0.010 inches over a 12-inch span. In an extreme case (a machine in trouble), it was found that the indicator bracket which had been used deflected about 0.040 inches.

- The method requires that the coupling spacer be removed to make readings. For routine alignment checks this means added effort and the ever-present risk of coupling damage during disassembly and re-assembly. For new installations, it normally means that the coupling is left open until after cold alignment is complete. The interval is usually several weeks from the time equipment is first set upon the foundation until the alignment is completed, during which time the coupling is subjected to corrosion, dirt and physical abuse. Some couplings do not survive this initial treatment.

Reverse indicator method. In contrast to the "Face—OD" method, indicator readings can be taken by the reverse indicator method on the OD of the coupling hubs (or the shaft) only. Two brackets are used simultaneously, which is normally preferred.

Equally acceptable but less convenient is a method that uses a single bracket switched back and fourth for each set of readings.[1] Analysis of information gathered by this method yields sufficient data for determination of relative shaft positions. Advantages of this method over "Face—OD" are:

1. By proper design of the alignment brackets, the required removal of the coupling spacer is eliminated in most cases (shafts must be sufficiently in alignment to prevent binding of the coupling, of course). This feature provides three distinct advantages:

   a. Wear and tear on the coupling is reduced.

   b. Since both shafts turn as a unit with the spacer in-

Alignment hints

- Assign a responsible, technically astute individual to follow details of the alignment. It is too important to receive second-class attention.

- Spend adequate time in preparation. It is money well spent.

- Make sure the craftsmen understand both the method and the intent of the alignment procedures.

- Check the tools. A sticky indicator has no place among the alignment tools.

- Assure yourself that the indicator brackets are sturdy. The best test is a healthy shake; if the indicator readings do not return to the original position, the bracket is inadequate. The use of magnetic indicator brackets is never permitted for shaft alignment.

- Find a good way to turn the shafts. If you are lucky, the person who specified the machine had the manufacturer put wrench flats on the shaft extension at the outboard end of the machine. If not, find another means, such as a strap wrench or a clamp-on fixture made specifically for the purpose.

- When placing the indicator, be sure it starts out at mid-range, and be sure it rests squarely on the shaft. An indicator which sets askew gives bad readings. Likewise, be sure that the range of the indicator is not exceeded when readings are taken.

- Before making any moves (and before final acceptance), get at least two sets of identical readings. If the readings cannot be repeated, they are not acceptable.

- Check the data before making a shim change or horizontal move of the machine. It takes very little time to check the data—it takes a long time to move a large machine.

- Make one move at a time, then check the work. Don't worry about horizontal movements until the elevation is proper.

- Be alert to peculiarities of the specific machines being aligned. Tilting-pad bearings, for example, sometimes give trouble by permitting the shaft to rock back and forth on the lower pad, making repeatable measurements difficult. It is sometimes necessary to put temporary shims in such bearings to assure that the shaft is stabilized for alignment purposes.

- Stop the shaft at precise 90-degree increments for measurements. Turn the shafts in one direction only. If you pass the 90-degree mark, go around another complete turn. Extremely handy for the purpose of determining the quarter turn is a tool with four spirit levels mounted at 90-degree increments.

- Be wary of planned changes that do not turn out right. Alignment changes are calculable and predictable; if they consistently go wrong, look for something amiss in the system.

stalled, errors caused by coupling hub runout are entirely eliminated.

c. By spanning the entire coupling, angular misalignment is greatly magnified and more precisely diagnosed. For example, a span of 16 inches gives angular misalignment readings eight times as great as if measured on the face of a 4-inch-diameter hub.

2. Since face readings have been eliminated, there is no concern about axial float of shafts.

3. This method is not successful if makeshift tools are used—special tools must be constructed. Alignment results are simply better when proper tools are used. I wonder why alignment tools for high-speed couplings are not available in standard designs from the coupling manufacturer?

The single problem with the "Face—OD" method that is not solved by the "reverse indicator" method is deflection in the alignment bracket. This is a matter of real concern, and one which must not be ignored if proper cold alignment is to be achieved. The problem is readily handled, however, by determining the deflection in the alignment fixture and making appropriate corrections in alignment data. Fig. 2 indicates one method for determining the error. As shown, barstock of appropriate size is chucked in a lathe, and the end is turned to the proper diameter to accept the alignment bracket.

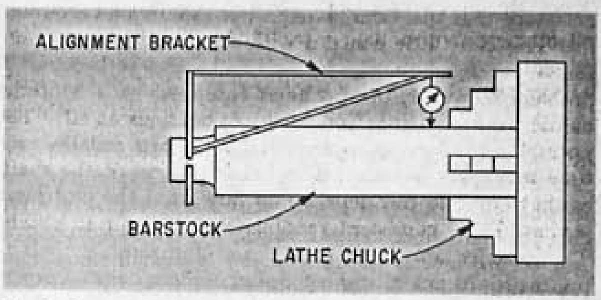

Fig. 2—Setup for determining deflection in alignment brackets.

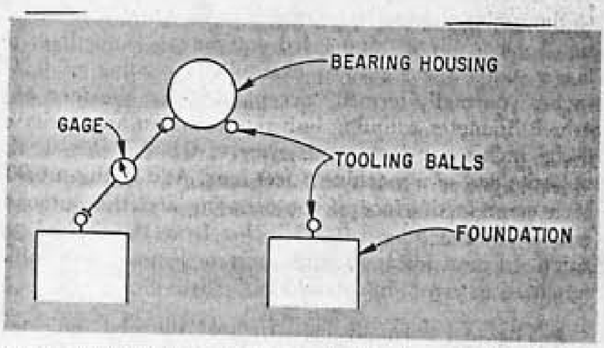

Fig. 3—Basic elements of mechanical device for checking hot alignment.

Without removing the barstock from the lathe, the alignment bracket is attached. With the bracket on top of the barstock, the indicator is set to zero. The entire assembly is then rotated 180 degrees, so the indicator now reads directly on the bottom of the barstock. The indicator reading thus obtained is reflective of the deflection in the alignment bracket.

Once determined, deflection should be stamped prominently upon the bracket, as should the designation of the equipment for which the bracket was specifically made. The alignment bracket becomes a special tool for that machine, and should be cared for as such.

3. The hot alignment check. It is now generally accepted that the traditional "hot check" for turbomachinery alignment is of little value. Not only is it costly and time consuming to bring a machine up to temperature, stop it, break couplings and attempt to determine alignment before it cools off, but results are highly questionable. In some instances a hot check is dangerous because it creates an unwarranted sense of security.

It is not possible to make the check quickly enough to accurately determine thermal growth of the equipment. For machines operating at temperatures well away from ambient, it is not uncommon to see a thermal change of 0.001 inch per minute when the machine is first shut down. At this rate, the effectiveness of the hot check is certainly lost before the alignment data can be obtained. Misalignment resulting from hydraulic forces and torque reactions, which can be significant, are never revealed by the traditional methods because the forces disappear when the machine is stopped.

About the author

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It is generally accepted today that a superior alternative is to use the cold position of the shafts as a benchmark and deduce the hot alignment by monitoring the movement of the machine casings, or shafts, from the cold position to the hot position. Several methods have been used for this monitoring, with a variety of techniques applied to the actual determination of casing or shaft movements. The most widely known methods use optical or electronic techniques.

Details of these techniques have been well publicized.[2] However, a purely mechanical method for measuring hot alignment is also being used successfully. This method uses permanently mounted tooling balls for measurement location references. A spring-loaded mechanical gaging device measures relative movement between the reference tooling balls in increments of 0.001 inches. Fig. 3 shows the basic elements of this method as applied to a typical turbomachine. Again, the cold position is used as a benchmark for alignment corrections.

ACKNOWLEDGMENT

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