Machine alignment: an expense or an investment?

Poor machine alignment can result in costly increases in power consumption. JOHN COLEMAN outlines some of most common causes of misalignment and explains how to resolve them.

There is wide recognition of the damage that poor alignment can cause to rotating machine mechanical parts such as seals and bearings, with resultant losses in reliability and downtime. However, much less attention is paid to the role of poor alignment in reducing energy efficiency. Studies at ICI in the UK have indicated that good machine alignment standards and practice will produce significant financial savings.

A pump rig on a chemical plant at ICI was used to investigate how power consumption could be affected by different degrees of machine misalignment. Horizontal offsets and angular misalignment were introduced using a laser alignment system supplied by Pruftechnik Ltd. The pump was set to operate through a closed loop of piping, with a 7.5kW motor running at 3000rpm (± one per cent). To establish if different couplings would reduce power losses, two types of couplings were used: a tyre coupling and a pin and bush coupling. By reducing misalignment in terms of offset only, from a median figure of 0.4mm to 0.12mm or better, power savings of one per cent or greater could be achieved. Using laser alignment techniques such as Optalign or Rotalign, figures of less than 0.lmm are easily achieved.

Based on conservative estimates of power cost (at, say, 7c per kWhr.) and power saving (at just 0.75 per cent) it is easy to compute what are very surprising figures:

Power consumption in kW Hr	% saving	Power Cost	Save per hr
5000	0.75	€0.07	€2.63
Yearly savings for a 24/7 operation:		**€22,995.00**	

The current drawn by the motor was measured for different amounts of pre-set misalignment. The results show the progressive effect of misalignment on power consumption and the significant power savings that can be made through accurate shaft alignment.

Angular displacement has a more critical influence on power consumption with pin and bush couplings than with tyre couplings. The combination of offset and angular misalignment was found to be cumulative. The recommendations of the study were that engineers align machines within 0.12mm offset and 0.0005mm per mm of coupling diameter to limit power losses to less than one per cent. Offset displacement of 0.75mm and beyond gives rise to substantial increases in power consumption, whether a tyre or pin and bush coupling is used. Even operators with small power consumption budgets can very quickly reduce annual power costs.

Pump alignment

What is machine alignment?

In theory, machine alignment is a very straightforward process. With some type of measuring device extended across the coupling, the shafts are rotated to several positions to determine the relative position between them. Since alignment is an iterative process, it is theoretically only a matter of sufficiently repeating alignment corrections until an acceptable solution is achieved. However, in real world applications, alignment is often made difficult by structural faults such as 'soft foot', piping strain, induced frame distortion, excessive bearing clearance and thermal growth. These pitfalls can turn a simple job into an impossible task - frequently with unsatisfactory results despite a conscientious effort and a considerable investment in labour and downtime.

In very broad terms, shaft misalignment occurs when the centrelines of rotation of two (or more) machinery shafts are not in line with each other. As simple as that may sound, there is still a considerable amount of confusion when trying to define precisely the amount of misalignment that may exist between two shafts coupled together. How accurate does the alignment have to be? How do you measure misalignment when there are so many different coupling designs? Where should the misalignment be measured? How is the deviation measured?

What is the objective of accurate alignment?

Simply stated, the objective of shaft alignment is to align the driver and driven shafts of a machine to maximise the reliable operating lifespan of rotating machinery. To achieve this goal, machinery components must operate within their design limits. Since the components that are most likely to fail are the bearings, seals, coupling and shafts, accurately aligned machinery will achieve the following results:

- Reduce excessive axial and radial forces on the bearings to ensure longer bearing life under dynamic operating conditions,
- Minimise the amount of shaft bending in both the driver and driven machine,
- Minimise the amount of wear in the coupling components, and
- Extend the mechanical seal life.

Over the past number of years, the level of awareness concerning the importance of accurate and precise shaft alignment has increased dramatically. It would, therefore, appear that shaft alignment seems to have taken a more important role when installing and maintaining machinery, but this perception may be somewhat difficult to prove since it is quite rare to find any historical records on the alignment of rotating machinery in industry. There are several good reasons why historical alignment records should be kept and why shaft alignment should be checked periodically. Most people assume that once you align a drive system, it stays aligned forever. This cannot be further from the truth. Random checks of machinery during periods of shutdown will reveal the extent of the problem if alignment records are kept and compared. When deviations are found, it is important to analyse the reasons behind the system shifting its position. If it is a pump, compressor, or turbine, could there be an excessive amount of static or dynamic piping strain? Is there poor contact between the machine case and base plate due to a 'soft foot' condition causing shim packs to work loose, shifting the machine? Is the foundation shifting its position over long periods? I have observed the situation where the concrete foundation base of a large electrical motor kept sinking into the ground due to poor packing of the filling many years before, causing the machine to go out of alignment after approximately 500 hours running.

It is important to keep not only shaft position measurements, but also information on the preliminary checks such as shaft or coupling hub run out conditions, 'soft foot' and shim shapes and thickness.

Causes of misalignment

Space does not allow a discussion of all possible causes of misalignment here, but I will briefly look at a couple of the more common causes such as the 'flexible' coupling, 'soft foot' and thermal growth.

Flexible couplings

Several people in industry have the perception that 'flexible' couplings take care of misalignment and, in general, use them for that purpose. The word flexible along with the word coupling gives users a false sense of security that everything will be all right, regardless of the degree of misalignment. The word flexible, in turn, makes the installer believe that once the alignment is close enough it is good enough. This is not so.

If flexible couplings took care of misalignment, then there should be no related vibration problems. Why do the bearings and seals fail when these couplings are taking such good care of the misalignment? Because the couplings do not take care of the misalignment - they are not designed to handle excessive misalignment. Straight edge 'alignment' is not close enough. Good (precision) alignment, by whatever method, is required regardless of coupling type.

Some couplings perform better than others on particular applications, because most coupling manufacturers are using better materials and, increasingly, better designs. However, no matter how well the coupling is designed and manufactured, it will still not compensate for the absence of proper alignment. Often when couplings wear or fail, many

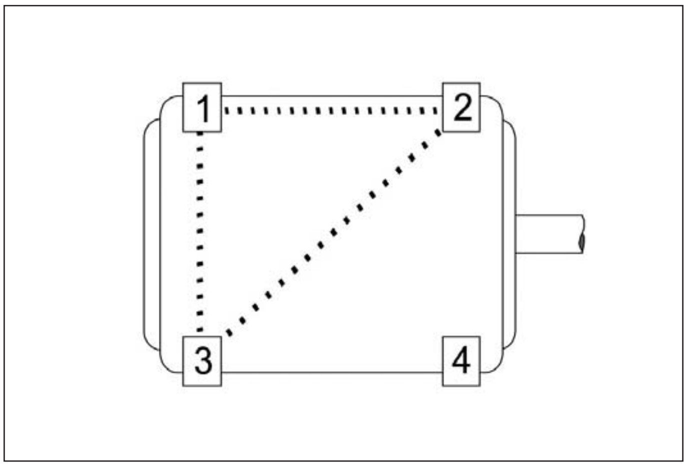

Figure 1: Soft foot arises when the machine sits on three points.

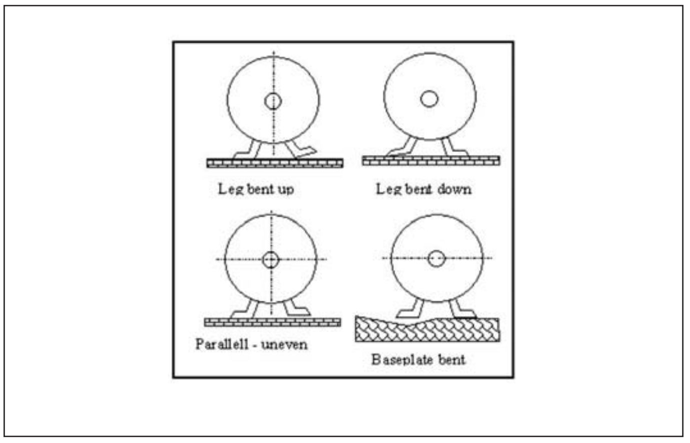

Figure 2: Different types of soft foot.

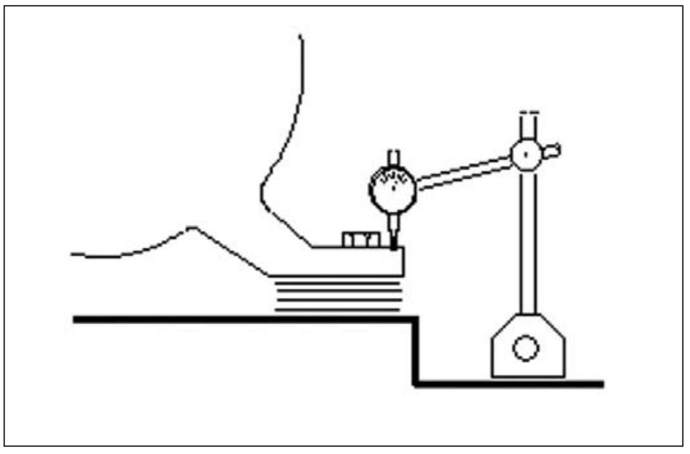

Figure 3: Locating a soft foot.

engineers look for a different style or different manufacturers' coupling. This is treating only the symptom and not the root cause - which is generally misalignment or in some cases lack of lubrication.

The primary purpose of the coupling is to transmit the power of the driver to the driven machine - period. Couplings, even 'flexible' types, stiffen under torque and do not flex the same way as they do in your hands or during assembly. This stiffness causes shaft deflection that, in turn, causes more bearing load and shortens the bearing life. If a mechanical seal is fitted, the constant flexing will cause premature failure.

A flexible coupling is not designed to compensate for poor alignment practice. Its purpose is to permit slight movement of shafts, while transmitting power. Excess misalignment will reduce coupling, bearing and seal life. Modern machinery operates at ever increasing speeds; even minor alignment errors lead to high vibration on bearing loads resulting in machinery damage and production downtime.

Soft foot

Soft foot arises when the machine sits on three points, a bit like the bar table balancing on three legs. See Figure 1. When the hold-down bolts are torqued up, the piece of equipment will actually distort, creating misalignment within the machine. A soft foot check is a vital part of the pre-alignment process. Unfortunately, due to misconceptions and pressure from production to get back on line, it is still viewed as an expendable step in many situations.

It must also be understood that there are different types of soft foot. In its simplest form, a foot can be either parallel or bent, or the base plate can be distorted. Figure 2 shows some possibilities. It is relatively easy to locate and correct a parallel foot. Shims will easily correct the height difference once it is identified. It is substantially more difficult to determine the profile of and correct a bent foot.

The traditional way to locate a soft foot is by installing a dial indicator on the foot and watching the movement as you loosen the hold down bolt. See Figure 3. This approach works fairly well in the case of a parallel foot but may give an incorrect indication of bent foot.

Thermal growth

Machine conditions change from the time the machine is off line to when it is running under normal operating conditions. The most significant of these changes is in the temperature of the machine. This is referred to as the machine's thermal growth and is calculated using the formula - α*L*T, where α represents the material's coefficient of linear expansion, T represents the change in the material's temperature in degrees Centigrade, and L represents the length of the component.

Different materials have different a values. Using the formula, we can anticipate the change in a machine's shaft alignment based on the expected changes in machine temperature.

Consider the following example: A motor with a starting temperature of 25^{o}C is perfectly aligned to the pump shaft it will be driving. For this exercise, the temperature of the pump will not change; however, the temperature of the motor will increase to 120^{o}C under normal operating conditions. The motor housing material is cast iron with an α value of 1.49*10-5. The distance from the bottom of the motor feet to the centre of the shaft is 381mm. We now can calculate the change in position of the motor shaft using the formula.

1.49*10-5 * 381* (120-25) = 0.5393mm

Based on this information, the motor will grow by over 0.5mm. If the growth of the motor is the same for both ends, this motor shaft should be aligned 0.5393 lower than the pump shaft that will allow the machine to grow into an aligned condition.

That was a simple example and does not accurately reflect what will happen in an actual situation. In reality, the temperatures of all the machine supports will almost never change equally, resulting in a far more complex situation. The important point is that changes in the temperature of machines from off line to running can have a significant impact on the shaft alignment. It is only by checking on line temperatures and referring to manufacturers' thermal growth data that accurate alignment parameters can be defined for each machine.

Multi-machine trains, involving three or more machines, coupled using two or more couplings, require great care in defining the alignment specification. This is particularly true if a gearbox is included in the train. Thermal changes in gearboxes can be especially difficult to calculate. Often the input shaft temperatures will be different from the output shaft temperatures. This causes the gearbox shaft alignments to change in the horizontal plane as well as the vertical plane.

Force-lubricated systems with an oil cooler also can have an effect on the final alignment condition of a machine. Higher oil temperatures, out of the cooler, will result in hotter operating condition of the machine, therefore creating a more drastic change in the running alignment condition.

Tests have proven that good alignment is an investment in the reliability and efficiency of rotating equipment. This provides an excellent opportunity for the maintenance engineer to directly influence a reduction in overall production cost, thus making a positive contribution to the balance sheet. Correct alignment will pay for itself many times over by making a valuable contribution to cost savings overall ■

Further reading

www.pruftechnikdirect.com/ici.html
ICI Report Misalignment
- The Effect on Power Consumption by J.C. Lambley
Pruftechnik Alignment Handbook – Pruftechnik AG.

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