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THE NEED FOR PRECISION ALIGNMENT

INTRODUCTION

Machinery vibration, regardless of source, has the effect of reducing the wear life of the operating system. In previous FACT SHEETS we have reviewed balance as well as other factors that produce vibration. We have also defined vibration as "Energy diverted from a useful purpose to a destructive end". In this fact sheet, we will discuss another major contributor to machinery vibration, misalignment.

Alignment, as reviewed here, will be the relative relationship of rotating shafts within a system and the degree that they are colinear at service conditions.

The intent of this FACT SHEET is to review:

1. The reason for precise alignment.
2. Alignment procedures and considerations.
3. Methods of alignment.
4. Alignment principles.
5. Alignment tolerances.
6. The results of applying proper alignment practices.

DISCUSSION

Alignment is one of the most misunderstood subjects in the field of maintenance. Major coupling manufacturers advertise the degree of permissable misalignment of their particular unit. From this information, the user makes the assumption that if his unit is within these misalignment limits, the equipment is in good form. This is not the case, however, for barely tolerable alignment yields barely tolerable operation. Misalignment, or the deviation from colinear shaft conditions, will show itself as wasted energy and vibration. This wasted energy in turn will cause several conditions:

1. A reduction in useful operating life of coupling, bearings, etc.
2. A reduction of system efficiency. More of the input energy will be diverted to harmful purposes than the desired operational objective.
3. A significant acceleration of fatigue factors, thereby increasing the potential of catastrophic failure.

Much, of course, depends on the degree of misalignment. Perfection is unattainable even under the most optimum conditions. The primary problem is that many people responsible for installation and maintenance believe that flexible couplings eliminate the need for accurate alignment. In actuality, the primary purpose of flexible couplings is to allow "float" or axial movement between the coupled equipment; not to absorb deviations from colinear positions of the connected shafts.

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Thus, maximum equipment life cannot be realized unless the coupled equipment is essentially colinear at operating conditions. This means when the system has reached equilibrium under operational temperatures, pressures, etc., the shafts are precisely aligned.

Purpose of "Float" or Axial Movement in Couplings

In a train of driving units (motors, turbines, engines, etc.) and driven units (gear sets, pumps, generators, etc.) there exists significant differences in design, operational and thermal characteristics. For example, AC motors have the inherent characteristic that during operation the armature seeks a magnetic center. The inherent design of a motor is to allow for the axial movement of the armature so that the natural operating position is reached without restriction. For larger motors, this axial float can be great (inches). A system not allowing for unrestricted axial movement would waste a considerable portion of the electrical energy attempting to force the armature to an unachievable end. The forcing or wasted energy of the armature also will be felt in the driven member, causing premature failure.

A feedwater pump, for example, has limited axial movement. (The same is true for many gear sets, compressors, fans, etc.) A feedwater pump must be designed with close axial clearances. The axial clearance between the moving section (the rings) is a few thousandths of an inch. Clearances in excess of this amount allow the pumped media to "blow back", thus creating wasted energy and making desired pressures unachievable.

Therefore, it is possible to incorporate a motor that inherently has a great deal of axial movement and a pump that has little. If the two units are directly coupled without provisions for end float, the motor will push or pull the impeller of the pump. The thrust of the pump will initially prevent the motor from realizing this movement. Significant axial force from the motor will be directed to finding the magnetic center. In actuality, a bumping action takes place on the pump thrust until failure. If the thrust on the pump fails, the impellers contact the rings, causing damage. A failure of this type can take place in seconds. Thus, a coupling is a necessity to allow two or more connected units with different axial float characteristics to be connected.

End Float Couplings

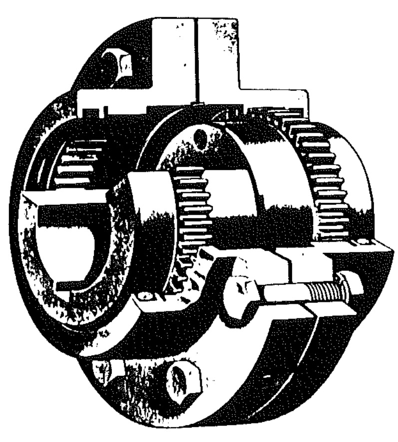

Figure 1

Figure 1 shows a cutaway section of a gear-type coupling. The gear teeth of the hub connected to the driving unit transmit the rotational force to the gear teeth of the sleeve and in turn to the gear teeth of the driven hub. This type of connection is efficient in that most of the input energy of the driver is transmitted to the driven unit when properly aligned.

Alignment Methods

There are many means of performing alignment between two or more units in a train. These range from "eyeball" methods to utilizing optical and laser systems. An understanding of the principles of alignment is necessary if proper performance is to be realized.

Prior to reviewing the principles of alignment, we will review some of the tools necessary to perform alignment. These include:

1. Outside micrometers (0 to 12")
2. Inside micrometers (0 to 12")
3. Snap gauges (0 to 12")
4. Parallel gauges
5. Precision tape
6. Dial indicators with appropriate holding bars, chains, etc.
7. Precision scale

A detailed working knowledge in the use of these tools is necessary to perform precision alignment.

Basically, there is little alignment work that cannot be performed with the above listed tools. As the machinery becomes restrictive, other devices become more accurate and practical.

Years ago, when aligning a train of equipment or large machinery, the primary tool utilized was piano wire. Because of inherent difficulties, as well as the time required for accurate application, other tooling has been developed that has proven superior.

Optical and laser systems are available today which take the place of piano wire. The inherent accuracy of this equipment is significantly greater than anything previously available. An optical system, for example, can establish a horizontal plane for base plate alignment and transfer this plane accurately over distances. This instrument can sight remote points to within .0006 inches.

In the past, it sometimes took weeks to align a major unit with piano wire. Today, the same can be accomplished in far less time and with greater accuracy.

Figure 2 shows a typical optical system. The scopes employed with accurate scales (designed for optical sighting) make it possible to do virtually any job.

Another important application of optical tooling is the charting of thermal growth of machinery. Other special purpose equipment has been developed to chart the thermal effects on units in a train using proximity probes and volt meters.

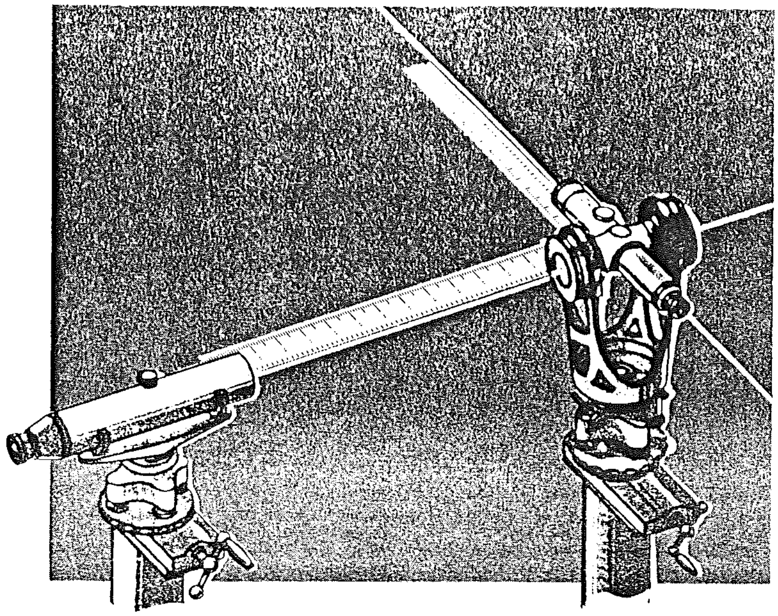

Figure 2

Effects of Thermal Growth

Previously we discussed how different types of equipment have different characteristics of axial movement. It is also a fact that different types of equipment are subject to different thermal conditions.

Our original example of a motor driving a feedwater pump is a good example. After sustained operation, the motor can be 50° C warmer than when thoroughly cooled. A feedwater pump transfers heated water of over 100°C. This water in turn transfers this heat to the metal of the pump and the metal expands according to the laws of physics.

Turbines are subject to considerable growth due to utilizing a hot medium to drive the turbine rotor. Turbines become complex because the medium entering the turbine is hotter than leaving. Thus a turbine is subject to different thermal growth from one end to the other.

Compressors are similar to turbines in that heat is transferred to the media being compressed. The intake of a compressor can be hundreds of degrees cooler than the discharge.

Thus, compensation must be made for thermal conditions within an operating unit. It does no good to have operating equipment only aligned in a cool state. Thermal growth can easily cause the most perfectly aligned unit to be outside good alignment tolerances.

Calculations can be made as to the thermal growth of some pieces of equipment. As stated previously, optical equipment can be used to measure growth of operating units. Hot alignment equipment is available that relates the relative growth of specific points on operating equipment.

The basis of each approach is to relate to the cold condition. If thermal growth is detected, then the units must be purposely misaligned in the cold state to compensate for the in-service temperatures.

Piping and Foundations

Thus far there has been no discussion as to compensation for the thermal effect on piping, etc. This is on purpose, as it should not be necessary to compensate for piping strain. Proper isolation should always be present to separate the operating equipment from these effects.

In the discussion of alignment, rarely is much said about the equipment foundations. However, it does not take much reflection to understand the importance of this factor. Too much emphasis cannot be placed on the original foundation preparation.

Some specific points to be noted in foundation preparation are:

1. The materials used must be appropriate for the operating conditions.
2. Operating speeds of the machinery must be taken into consideration to insure that components are not near points of resonance.
3. Accurate means must be employed when setting foundations so that contact points for the operating equipment do not require excessive shimming.
4. Good contact must be present at all key points with the operating equipment. Remember the operating equipment is to be in service for many years. Unless good contact is present throughout, wear and sag due to operating conditions can bring about major alignment problems.

Technology to Our Aid

There have been developments to simplify foundation problems. Exothermic materials are available that can be applied with excellent results on new equipment or when reestablishing old foundations.

The most important characteristics of these materials are:

1. Minimum thermal effect due to temperatures (maximum temperature exposure 90°C).
2. The machinery can be set perfectly and then the final foundation poured.
3. 100 percent contact is present on all key bearing points. Thus, no settling or equipment sag.
4. The materials afford excellent vibration isolation characteristics
5. Base bolts can be anchored with these materials, affording excellent strength properties with extreme accuracy and minimum cure times.

Basically, these materials offer far better properties than grout or the normal shimming techniques. Further, it may be possible to reuse existing foundations with minimum preparation expenditure.

Alignment Principles

Thus far we have discussed the importance of alignment as well as methods and tools applied. Next we will review the basic conditions to look for when checking alignment.

Alignment is basically a three-plane problem. Two planes (X and Y) intersect the horizontal and vertical axis of the centerline of the shafts. The third plane is the perpendicular intersection of X and Y (normally at the connection point between units).

The basic types of misalignment are classified in three categories:

1. Parallel misalignment
2. Angular misalignment
3. A combination of both parallel and angular misalignment.

Parallel misalignment occurs when the shafts are parallel to each other but displaced linearly. A simple one-plane representation of this can be seen in Figure 3.

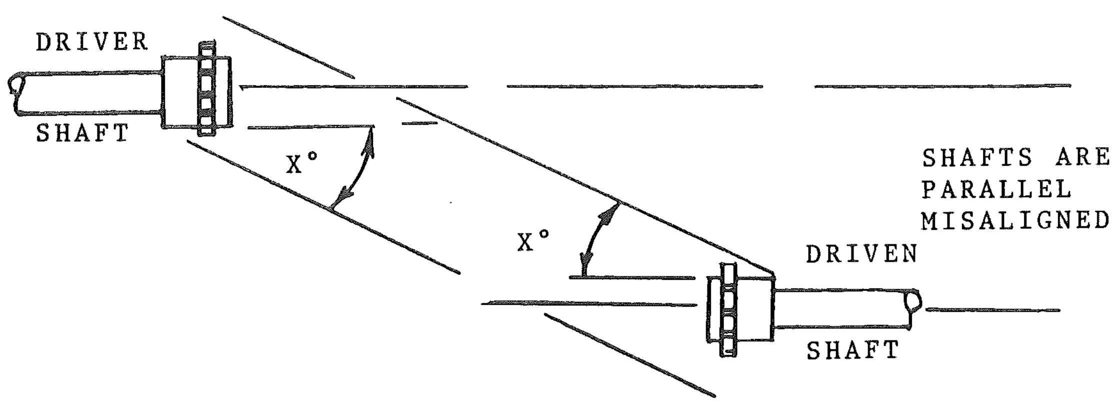

Figure 3

Angular misalignment as shown in Figure 4 is characterized by one shaft being in the proper centerline with the other but displaced at an angle.

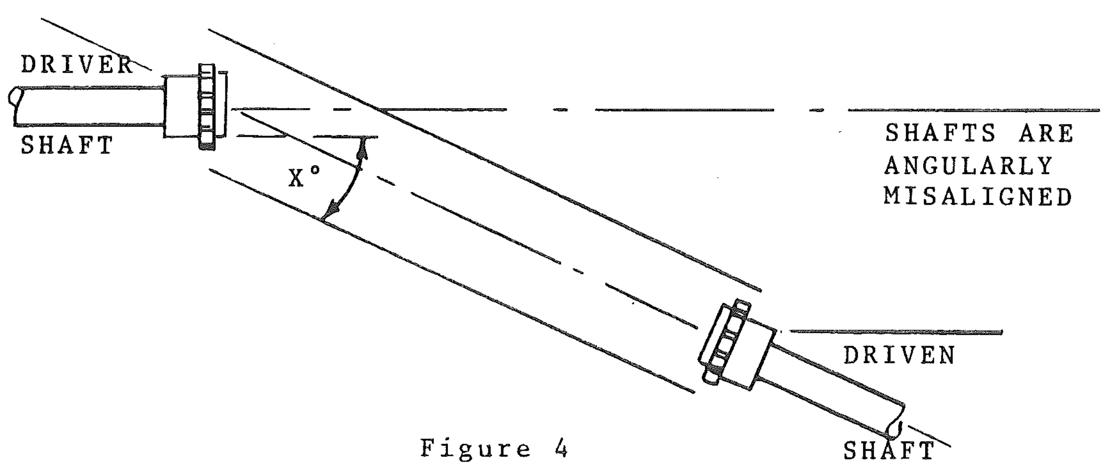

Figure 4

The final condition as shown in Figure 5 requires that both units be repositioned along a common centerline.

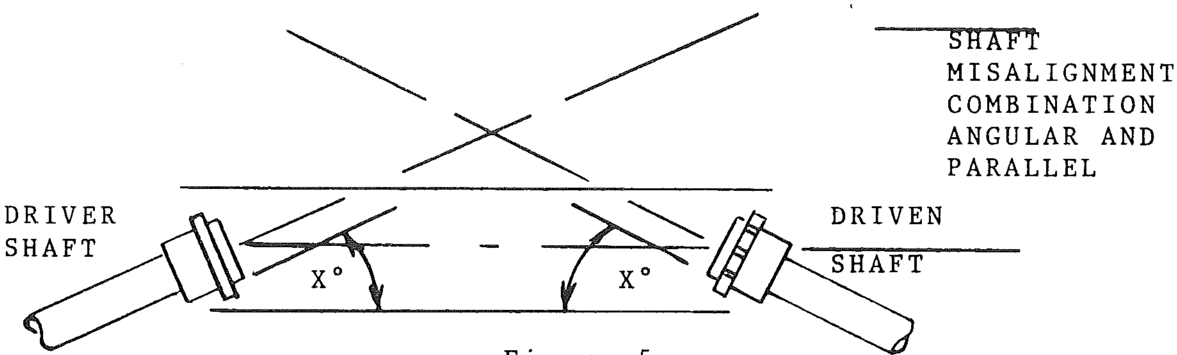

Figure 5

When setting alignment, it does not matter where the original datum or centerline is taken. Normally, the types of units and their respective anchoring systems dictate the starting point. However, when setting alignment, one unit must be set and a starting point established along with an imaginary centerline so that all other units can be set thereto. This is true whether there be two or more units in a train.

Allowable Alignment Tolerances

The ultimate objective, as continually stated herein, is a colinear alignment for the common axis of rotation for all shafts within the system. Since perfection is the objective sought but never realized, a tolerance must be established between mating equipment of the system.

Tolerance for rotating equipment is normally based on two factors:

1. Operating speed of equipment
2. The coupling span between operating units.

A good reference source for any driving or driven unit is the specification of the original equipment manufacturer.

The table shown in Figure 6 is a guideline for setting alignment between units. This guideline represents in-service conditions and thus reflects the results of growth or shrinkage due to temperature, pressure, etc.

Coupling Span	SPEED RPM									
(inches)	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
2	10.6	5.8	3.9	2.9	2.4	1.9	1.7	1.6	1.4	1.2
4	23.0	10.6	7.6	5.8	4.8	3.8	3.4	3.2	2.8	2.4
6	-	17.5	12.0	8.6	6.8	5.8	5.0	4.4	3.9	3.6
8	-	23.0	16.0	12.0	9.2	7.7	6.6	5.8	5.2	4.8
10	-	30.0	19.5	14.5	12.0	9.6	8.3	7.2	6.6	5.8
12	-	-	23.0	17.5	14.0	12.0	9.9	8.8	7.8	6.9
16	-	-	-	23.5	17.5	16.0	13.5	12.0	11.0	9.3
20	-	-	-	30.0	23.0	19.0	16.0	14.5	13.5	12.5

Figure 6 Tolerance Offset in Mils

This table is intended only as a guide. There are many conditions that could be present on specific units that could dictate greater accuracy.

End Results - Longer Equipment Life, Reduction in Maintenance Costs and Downtime

The procedure as outlined appears complex. The return, however, in reduced maintenance costs and maximum operating life for the equipment, is excellent. When coupled with good balance of rotating elements as well as good lubrication, the results are outstanding.

Vibration Specialty has been involved in alignment and foundations for many units, both new and old. The principles stated herein are not based on theory, but the practical application thereof. These include mammoth crushers and generating units, as well as minute optical and laser systems. In our history, as well as other equipment users', the practical application of these principles has brought about substantial benefits.

Summary

Good alignment means:

1. Proper foundations and machinery settings.
2. Compensation for service conditions.
3. Isolation of equipment from external factors, such as:
    (a) piping strains;
    (b) structural resonance;
    (c) electro-magnetic forces.
4. Colinear alignment of the common axis of rotation of the shafts within the system.

Today, more accurate alignment can be realized. Equipment and methods exist which insure the user of colinear alignment at service conditions. These simplify the setting and alignment of complex machinery, large or small.

Further materials are available that allow for 100 percent contact at load points. These same materials also afford excellent vibration characteristics.

Precision alignment takes a little more time. However, the savings in the form of reduced maintenance and increased equipment life and availability make the payback extraordinary.