Machinery MESsages

Determining shaft centerline position in four easy steps

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To accurately assess the overall mechanical integrity of a rotating machine, the obvious and the less obvious indicators must be evaluated.

The obvious indicators are shaft and housing vibration amplitude, frequency, and phase information. Yet, we cannot assume that low vibration amplitudes indicate the acceptable mechanical performance of a machine.

As we described in the last issue, the vibration levels of a barrel compressor after startup were under 0.7 mil, and from this data alone, the machine appeared healthy. Calculation of the shaft centerline position, however, indicated that there was a problem. The shaft position indicated that the clearance had been exceeded on the compressor outboard bearing (see October 1983 Orbit).

The moral of this story is that a less obvious indicator -- radial shaft centerline position information -- should not be overlooked when determining overall machine condition. Changes in shaft centerline position can reveal hidden, and potentially catastrophic, problems that may not have yet manifested themselves in high vibration amplitudes. Such problems include bearing wear, bearing degradation caused by electrostatic discharge, external and internal preloads, and loose bearing fits.

Following is the step-by-step procedure for determining shaft centerline position. Caculating shaft centerline position changes is a relatively simple procedure that involves evaluation of the dc gap voltage information from radially-mounted XY proximity probes. The only tools required are a voltmeter, polar graph paper, a set of triangles, and a pencil.

The machine

With some exceptions, the machine used in the following example can be considered 'typical.' It has sleeve bearings with the shaft supported between them. One atypical machine is a gearbox, which may not behave as depicted in this article because of the radial forces that are transmitted through the gear train.

Gearboxes, as well as overhung and vertical equipment, have other 'normal' shaft position changes associated with their operation, but space limitations will not allow us to discuss all possible machinery configurations and their typical shaft positions within the bearing.

Step 1

The first step is to set up a polar plot (Plot 1). This plot shows the actual location of the proxmity probes relative to the machine geometry. The plot is used as a reference to compare shaft centerline position changes to the true machine vertical orientation.

In this example, we show a very prevalent arrangement with the probes at 45 degrees on either side of the true vertical plane. Other probe orientations can be defined by simply showing their angular relationship to true vertical.

For the measurement of shaft position change, zero degrees is at top dead center (true vertical on the machine) and angles are measured against the direction of rotation.

Step 2

Next, calculate the shaft position change for each probe. Subtract the initial probe gap voltage acquired when the machine is at rest from the final probe gap voltage acquired when the machine is at full speed. The difference is then divided by the transducer scale factor.

Let's work through the following example:

Transducer Scale Factor =
.200 Vdc/mil (200 mVdc/mil)

Initial Gap Voltages at Zero Speed	X = -7.50 Vdc Y = -8.00 Vdc
Final Gap Voltages at 5600 Rpm	X = -7.00 Vdc Y = -8.10 Vdc

To calculate the shaft position change relative to the X and Y probes, perform the following calculation:

$$\frac{\text{Final Gap Vdc - Initial Gap Vdc}}{\text{Scale Factor Vdc/Mil}} = \text{Mils Change}$$

$$\text{X Position Change} = \frac{-7.00 - (-7.50) =}{.200}$$

$$\frac{+.50}{.200} = +2.5 \text{ mils change}$$

$$\text{Y Position Change} = \frac{-8.10 - (-8.00) =}{.200}$$

$$\frac{-.10}{.200} = -0.5 \text{ mils change}$$

Step 3

The next step is to plot the X and Y position changes on the polar graph (Plot 2). Remember that a positive sign represents a position change toward the probe and a negative sign represents a position change away from the probe.

Step 4

The final step is to calculate the shaft centerline position change by the addition of the two vectors (Plot 3). This is accomplished by drawing two lines which are perpendicular to the X and Y probe axes. The origin for each line is the position change plotted in Step 3, and the lines should be extended until they intersect. Then draw a line from the plot origin to the intersection of the two perpendicular lines. This line represents the shaft position change vector.

In this example, the shaft centerline position change is 2.55 mils at 56 degrees from true vertical. This vector addition can also be performed on engineering/scientific calculators (2.5 mils at 45° + 0.5 mils at 135°). At this point, we can immediately compare the shaft position change to the bearing clearance to see if the design clearance has been exceeded.

The basic assumption for any shaft position change vector is at zero rpm the shaft is located at the bottom center of the bearing (due to the force of gravity).

With this assumption, Plot 4 can now be generated. The center of this plot represents the bearing centerline. Notice that for this example, the plot also indicates a 4 mil radial bearing clearance.

The calculated shaft position change vector has been transposed so that it is referenced to the bottom center of the bearing. This enables you to get a full appreciation of the shaft position change relative to the bearing geometry.

Attitude Angle

Plot 5 takes us one step further in our evaluation. By drawing a line from the bearing centerline through the shaft centerline, we can measure the shaft "attitude angle."

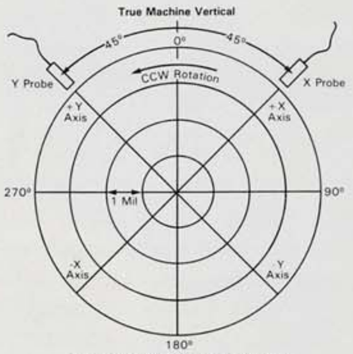
In this example, the attitude angle is 40 degrees. Notice that for this measurement, 0 degrees is located at *bottom* dead center. Positive angles are measured *in* the direction of rotation and negative angles are measured *against* rotation, 0 to 180 degrees.

An attitude angle of 40 degrees is quite normal for a sleeve bearing. The usual range is from 20 to 50 degrees (less for tilting pad bearings). Plot 6 depicts a normal shaft centerline position change and associated attitude angle for a shaft which rotates in the clockwise direction.

Eccentricity ratio

Once the attitude angle has been measured, we can glean another important piece of information from our plot -- the shaft "eccentricity ratio." The measurement of eccentricity ratio provides significant insight into the stability characteristics of a rotating system.

To calculate eccentricity ratio, divide the distance from the bearing centerline to the shaft centerline by the radial bearing clearance. The result of this calculation is a dimensionless number from 0 to 1.



Plot 1. Transducer Orientation and Measurement Polarity.

An eccentricity ratio of zero indicates that the bearing centerline and shaft centerline are coincident. An eccentricity ratio of 1 indicates the shaft centerline coincides with the radial bearing clearance (shaft is in contact with the bearing).

For Plot 5, we can calculate the eccentricity ratio as follows:

$$\frac{\text{Distance from bearing to shaft centerline}}{\text{Radial bearing clearance}} =$$

$$\frac{3.3 \text{ mils}}{4.0 \text{ mils}} = .83$$

In general, eccentricity ratios greater than .7 indicate a stable system that should not be prone to instability mechanisms, such as oil whirl and oil whip. An eccentricity ratio less than .7 indicates a higher probability that instability mechanisms will occur. Actually, stability is also a function of rotational speed and bearing clearance.

For additional information on shaft centerline position measurements, please check the following numbers on the return card:

Shaft Position Changes Reveal Machinery Behavior/Malfunctions, L0246.

Mechanical Degradation Due to Electrostatic Shaft Voltage Discharge, L0247.

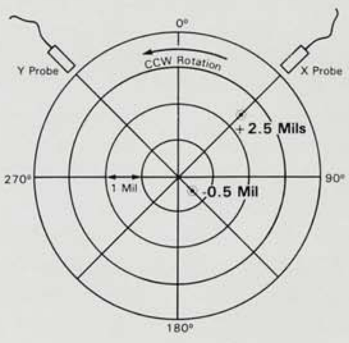
Data Presentation Techniques for Trend Analysis and Malfunction, L0237.

Plotting Average Shaft Centerline Position, L0248.

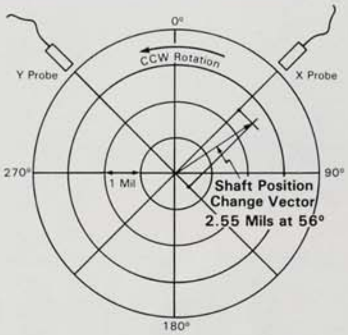
Preloads on Rotating Shafts, L0243.

Vibration Measurement: Parameters for Predictive Maintenance, L0234.

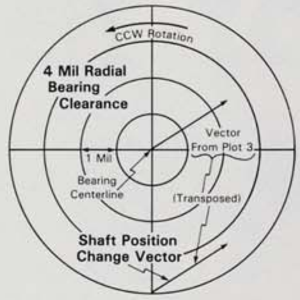
Diagnosis in Operation of Bearing Misalignment in Turbogenerators, by A. Clapis, G. Lapini, and T. Rossini, L0363.



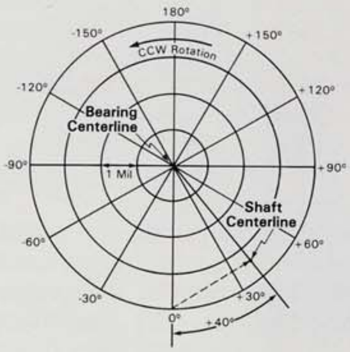
Plot 2. Gap Change for Each Probe.



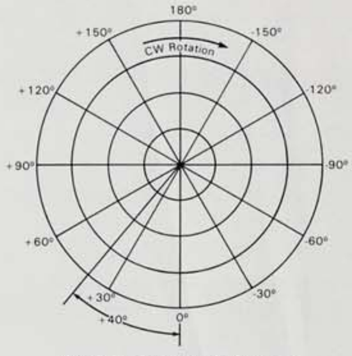
Plot 3. Construction of Shaft Position Change Vector.



Plot 4. Shaft Position Change Referenced to Bearing Geometry.



Plot 5. Attitude Angle.



Plot 6. Typical Attitude Angle for Shaft Rotating Clockwise.