1. Introduction

Orbits are Lissajous patterns of time domain signals that are simultaneously plotted in the X–Y coordinate plane of an oscilloscope or vibration analyzer. In this form of display, it is very difficult to trace the start of the orbit as it appears to be an endless loop. In order for us to determine the direction of rotation, a phase trigger is employed. The trigger will show the direction of rotation by looking at the dot on the orbit as the starting point of 1× RPM and the blank space as the end point.

Orbit analysis is the vibration measure of any rotor system in an X–Y plot (Figure 1). In most applications, the unit of measurement is displacement which is measured directly using proximity probes. These types of measurements are relative vibration readings. Relative readings are considered vibration measurements of the shaft with respect to the bearing housing. As the probes are clamped firmly to the housing, there is no relative motion between the probe and the housing. Thus, the orbit is achieved. With that in mind, orbit plots give a visual graph of the actual shaft centerline movement inside the bearing housing. Accelerometers and velocity pickups can also be used to create orbits. These are external transducers, which require mounting on the outside of the bearing housing. These types of measurements are called case orbits. Case orbits are useful to separate shaft and case vibrations. This can provide absolute shaft motion (relative to space). Orbit may be done for the overall signals as measured or it can be done for filtered signals where it is required to show orbit for specific frequency such as the frequency of rotation or its multiples.

2. Understanding Orbit Plot

To understand orbits, waveforms and their relationship to orbits must be explained. Let us begin with waveforms. The waveform plot shown in Figure 2 has two sine waves, Y and
X. The Y plot is on the top and the X plot is at the bottom. The waveform signature runs left to right and the amplitudes change from negative to positive, whatever the case may be. The changes in the waveform cause the orbit to form. An orbit is made up of an X- and Y-axis with zero in the center. Starting from the center, up is positive and down is negative. Right is positive and left is negative. Now that we know waveform and orbit conventions, let us trace the waveforms and create an orbit.

Figure (2) Waveforms and their Orbit

3. Effect of Probes Direction and Keyphasor

In many cases, you cannot mount probes easily in the desired 90 degrees out of phase horizontal and vertical orientation. Probes often have a 45-degree deviation instead. The following illustration shows the common mounting positions for X and Y probes.

Figure (3) Pickups Arrangement and Related Angle Deviation
When using keyphaser signal to specify the starting point of orbit plot, the resulting plot will be referenced to the keyphaser location. Therefore, if the keyphaser is positioned in the same angle as the X-sensor, the result is the actual orbit of shaft movement, otherwise, the plot will be shifted by angle between keyphaser and X-sensor.

4. Types of Orbit Plots

Orbits may be divided into two main categories, floating and absolute orbits. Floating orbit analyses do not use keyphasors, hence, the orbit direction is floating and starting point may differ from cycle to another. Referenced or absolute orbits have fixed starting point due to the use of keyphasors. Most modern vibration analysis and monitoring system possess keyphasors. Orbits may also be divided into filtered and overall. The filtered orbits normally track one order such as 1xRPM, 2xRPM… etc. and utilize the keyphaser signal for synchronous filtering as well as reference point. The filtered orbits are useful to track a certain order and neglecting other orders which may cause unclear orbit plot. The overall orbit do not use any filter and it is useful to obtain the actual shaft movement.

5. Applications of Orbit Analysis

Orbit plots can efficiently be used in vibration diagnosis where other techniques, such as FFT and time waveform, may not provide sufficient information. In the following, some vibration problems will be discussed.

5.1 Unbalance

Unbalance will generally produce 1xRPM vibration with 90° phase shift between the horizontal and vertical directions. This will result is ellipse-shaped orbit as that shown in Figures 1 and 2 above.

5.2 Misalignment

When radial preloads due to misalignment, gravity, fluid forces and other causes increase in magnitude, the orbit will become acutely ellipsoid. A bearing preload due to a cocked assembly can also cause the orbit to have lower amplitude in one axis that makes the ellipse look thinner. The average shaft centerline will move from the normal position to the upper left quadrant, for example, all points on the orbit are moving clockwise (which is the same as the direction of rotation) and therefore the orbit is still in forward precession. If the preloading increases further, it will result in the orbit’s shape to resemble a number 8 character as shown in Figure 4. In this case, it is also interesting to follow the average shaft centerline position, which has now moved further upwards into the left quadrant. If this orbit is carefully studied, it will be noticed that if a point on the orbit begins its journey from the dot, it is moving counter-clockwise initially, whereas the shaft is rotating in the clockwise direction. Thus, heavy preloading due to misalignment can cause the shaft to go into reverse precession. Forward precession is normal, reverse is not. If the trajectory of our imaginary point on the trace of the orbit is continued, one can visualize that precessions keep changing continuously.
5.3 Rotor Rub

Orbit analysis is a good tool to identify rubs. As mentioned earlier, partial or complete rubs can occur when a rotating shaft comes in contact with stationary parts like seals or in abnormal cases of bearing (and/or instrumentation) failures. The rub causes the orbit to take on different shapes. From a number 8 to a full circle to something like the orbit shown in Figure 5.

5.4 Oil Whirl

Oil whirl is basically a sub-synchronous fluid instability. When viewed in the orbit domain, it is shown with the characteristic two dots. When viewed with an oscilloscope, the two dots do not appear stationary, but seem to be rotating instead. This is because the frequency is marginally less than 0.5x. An oil whirl phenomenon generates a vibration precession, which is always forward as shown in Figure 6.
5.5 Oil Whip

The oil whip phenomenon occurs when the rotor is passing through its critical speed. Oil whip is a destructive bearing defect. The precession of vibration is in the forward direction in this case, but some reverse 1× and sub-synchronous components are present due to anisotropy (changes in response when operating conditions change) of the bearing pedestal stiffness. The period of this self-excited defect may, or might not, be harmonically related to the rotating speed of the shaft. When it is not harmonically related, the dots appear to be moving randomly as shown in Figure 7. When it is harmonically related they appear stationary.