Reciprocating Compressor Condition Monitoring

Piston Rod Peak to Peak Displacement – Using Dynamic Waveform Analysis for Detecting Piston Rod Failure in Reciprocating Compressors

Background

Bently Nevada engineers have observed piston rod failures across the globe on different OEMs’ reciprocating compressors monitored by our products (Bently Nevada 3500 and System 1*). Currently, there are no industry standards for piston rod vibration to be used for protection. In addition to API recommended shutdown parameters, there is an emergent need to look towards peak-to-peak piston rod vibration as another protection mechanism that can give early indication of an impending failure (such as sudden breakage due to fatigue or cracks) on a piston rod. Current measurements of crankcase vibration and crosshead vibration will only detect these failures after they have occurred (piston rod is broken) and do not provide an early warning capability.

What is Piston Rod Peak-Peak Displacement?

In the Bently Nevada 3500/72M monitor, the rod position channel type provides an important peak-to-peak (pp) displacement measurement, which quantifies the maximum change in distance or position of the rod with respect to the probe face during one stroke (one revolution of the crankshaft). If two orthogonal probes (horizontal and vertical) are mounted across the pressure packing flange (Figure 1), the system provides the measurement of this piston rod movement in both axes.
This photo shows the installation of a proximity probe pair (horizontal and vertical) on the face of the packing flange. These “orthogonal” (perpendicular) probes allow us to measure the movement of the piston rod within the plane of measurement.

Figure 1: Rod Position Pair Setup

The data plot in Figure 2 shows piston rod displacement on the y-axis and crank angle on the x-axis. The dark blue curve indicates pp displacement measured by the vertical probe, and the orange curve shows pp displacement measured by the horizontal probe.

Figure 2: Piston rod displacement curves showing pp measurements for one revolution of the crankshaft.

Peak-to-peak displacement gives an indication of the rod flexing which can happen due to excessive rod loading or cracks caused by constant/cyclic fatigue over time.

Protection Philosophy

Several case studies (mentioned in references) have shown that pp rod displacement starts increasing several minutes before actual failure. Because of this effect, setting proper trip setpoints can save machines from secondary failures.

The Bently Nevada 3500/72M offers the option to configure alert (high / alarm) and danger (high high / trip) for rod position pp displacement and it is highly recommended to configure setpoints on this parameter to ensure machine protection. Note: The setpoints criterion is based on mechanical component’s dimensions and operating parameters and should be established after an observed period of all operating load conditions.

Case studies have also demonstrated that sudden piston rod failures did not show any significant rise in crankcase nor crosshead vibration from failure initiation and only increased above trip setpoints when piston rod breakage had occurred. However, pp rod displacement trends showed a gradual increase over time from initial failure point to final piston rod breakage. Moreover, it is recommended to have both...
vertical and horizontal probes installed as the piston rod movement axis is directly related to crack propagation.

**Case 1 Example**

![Figure 3: (Case 1): High vertical pp displacement](image)

Figure 3 shows a trend plot for a period of about 45 minutes. Peak-to-peak piston rod displacement values for the monitored throw (crank 1) are shown for the vertical probe (blue line) and the horizontal probe (orange line). Approximately 40 minutes before piston rod breakage the vertical pp vibration begins a slow increase and then the rate of change of this increase also begins to increase, indicating the piston rod is already in a failed state, but is not yet completely broken.

The horizontal pp vibration does not indicate a perceptible change until about 15 minutes before the piston rod breakage occurs, indicating the failure mechanism is most probably a crack in the vertical axis. At 2 minutes before the piston rod breakage (time stamp 04:01:27) the vertical piston rod vibration has its first peak before a small decrease. This is most likely an indication that the metallurgical properties of the piston rod had reached its yield strength and has exceeded its plastic deformation state. Piston rod breakage occurs quickly and at 04:04:05 the piston rod fails completely.

Note: Piston rod vibration (pp displacement value) was normally less than 250 µm pk-pk (~ 10 mil pp) but the levels increased to more than twice that amount before continuing further to the breakage point. Since normal vibration levels were near 250 µm (10 mil) pp displacement, an alarm set at just 2.0 times (500 µm) would have provided an early warning almost 8 minutes before the piston rod broke. And a danger setting at 2.5 times (625 µm or 25 mil) pp displacement could have shut the machine down safely more than 4 minutes before the piston rod breakage occurred.

In Figures 4 through 6 below, the crank angle-based plots for the dynamic measurement points; cylinder pressure (upper and lower left), piston rod vibration (lower right) and crosshead acceleration (upper right) are shown.
Figure 4: Crank Angle Plots at 03:10:45 (55 minutes before piston rod failure)

Figure 4 shows normal behavior of the compressor.

Figure 5: Crank Angle Plots at 04:00:45 (3 minutes before piston rod failure)

Figure 5 shows the increased pp displacement value for the vertical piston rod probe (lower right pane) while the filtered crosshead acceleration (orange curve in the upper right pane) has no perceptible vibration change from that seen in Figure 4, above.
Figure 6: Crank Angle Plots @ 04:04:03 (Rod is disconnected)

Figure 6 reflects conditions just after the piston rod failed and became disconnected. This is indicated by no compression pressure being developed at the normal section of the stroke in the lower left pane. The sharp knock demonstrated in the crosshead acceleration (unfiltered and filtered waveforms) plot (upper right pane) occurs at the point where the reciprocating components hit the disconnected piston. At this point (300 degrees after top dead center) in the stroke there can be seen in the lower left pane the pressure buildup indicating the disconnected piston has been hit and moved so the head end chamber has an indication of compression process.

Case 2 Example

Figure 7 (Case2): High horizontal pp displacement
Figure 7 shows a trend plot for a period of about 11 minutes. Peak-to-peak piston rod displacement values for the monitored throw (crank 2) are shown for the vertical probe (blue line) and the horizontal probe (orange line). Typical normal levels appear to be less than 200 µm pp (8 mil pp) for both probes. In this example, both probes’ pp displacement values generally start their increase at the same time but then the rate of change for the horizontal probe’s pp displacement increases more than the signal from the vertical probe. This example reveals the importance for having proximity probes in both the horizontal and vertical axes for piston rod vibration measurement. The maximum excursion occurs first on the horizontal probe with the vertical probe measurement peaking.

Since normal vibration levels were near 200 µm pp displacement, an alarm set at just 2.5 times (500 µm) would have provided an early warning almost 3 minutes before the piston rod broke and a danger setting of 3 times normal (600 µm) could have shut the machine down more than a minute before the piston rod breakage.

**Case Study References**

- Broken Piston Rod on Crank 1 of Makeup Hydrogen Compressor B in a Saudi Refinery
- Broken Piston Rod on Crank 2 of Makeup Hydrogen Compressor C in a Saudi Refinery
- Broken Piston Rod at a Compressor, operating on an European Offshore Platform
- Broken Piston at Compressor A, operating in an European Refinery
- Broken Piston at Compressor B, operating in an European Refinery

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