Applications

A compressor is used to compress gas from a lower pressure at the intake to a higher pressure at the exhaust by reducing the volume of the gas. Applications are wide ranging, with the greatest applications in the refrigeration, chemical and petrochemical, food processing, pulp and paper, power generation, natural gas, and government and military industries. For tool and instrument air systems, air is often compressed, while for chemical processing, hydrogen or oxygen are often compressed.

Types

There are two primary types of compressors: positive displacement compressors and centrifugal compressors. Positive displacement compressors increase the gas pressure by simultaneously reducing the amount of space that surrounds the gas. On the other hand, centrifugal compressors raise the pressure of a gas by using a rotating blade, called an impeller, to add energy to the flow of a liquid, thereby increasing the gas’s velocity and pressure.

Positive displacement compressors can be divided into rotary and reciprocating type compressors. This white paper focuses on one type of rotary compressor, the screw compressor. Screw compressors raise the pressure of gasses by forcing gasses through a space between two rotors inside the compressor.

It is also important to note that there are two types of screw compressors, a “wet” type and a “dry” type. The main difference between the two types of screw compressors is that the “wet” screw compressor uses oil to lubricate the rotors that compress the gas.

Causes of Failure

Common mechanical causes of failure in compressor components can be linked to insufficient
or improper lubrication, seal failures, and/or the build-up of foreign material on components, and bearing wear. Also, compressor motors can fail for a variety of reasons, most notably in the bearings.

Failures

The most common cause of failure in a screw compressor are its bearings. A screw compressor has two types of bearings.

The first type, the journal bearing, consists of two rings that when they working correctly never touch each other, rather the bearing relies on a thin covering of oil in order to turn the compressor’s rotor. This type of bearing can fail when the oil, separating the two rings, either becomes contaminated, breaks down, or if the bearing is overloaded.

The second type of bearing is a rolling element bearing. This type of bearing consists of two rings riding on ball-bearings. Rolling element bearings can fail for multiple reasons, including:

- “Lubrication failure” (low oil pressure, low viscosity, or condensing oil).
- Spalling in bearings
- Debris build-up in bearings and rotors
- Mechanical mounting and coupling problems
- piping strain
- throttled suction
- liquid carryover
- excessive oil injection
- discharge line/vessel resonance
- mechanical interference

What Should Be Measured

The most typical vibration monitoring locations are located at radial bearing positions for the motor and the compressor, and axial positions adjacent to the bearings on the motor and compressor. These sensor locations will indicate bearing problems most accurately on the motor and bearing, and compressor problems on the compressor.

Analysis

Wet and dry screw compressors vibrate at multiples the motor running speed and of the compressors pocket-passing frequency, (PPF) or gas pulsation frequency (GPF) which is dictated by the number of lobes on the male rotor multiplied by the compressor’s running speed in hertz. In general, the maximum vibration levels occur at 1x PPF. On average, “dry” screw compressors have running speeds between 1,500 revolutions per minute (RPM) and 25,000 RPM. On the other hand, “wet” screw compressors have a running speed that corresponds to the motor that drives them, either around 1,800 RPM (4-pole motor) or 3,600 RPM (2-pole motor).

Excessive vibration at these frequencies can signify impending failure. (See “Additional Things You May Want to Know” for more information.)

Savings

Since compressors are an integral part of many industries it is important that they be monitored regularly. If maintenance does not occur on a compressor when required, the resulting failure of the machine could be very costly in both downtime and expenses related to overtime, shipping, etc. Approximately half of the maintenance cost can be saved with a properly implemented vibration monitoring program over the life of a compressor. Smart Diagnostics provides an alternative to traditional monitoring methods that is uniquely easy to install and inexpensive. (See KCF’s case study “Wireless Vibration Monitoring of Screw Compressors Improves ROI at Commercial Refrigeration Warehouse” for more information.)
The bearing frequencies are calculated based on the running speed and the bearing geometry. For rolling element bearings, the following formulas are used:

- Ball Pass Frequency Outer Race (BPFO) = \( \frac{Nb}{2} \times S \times (1 – \left( \frac{Bd}{Pd} \times \cos (\theta) \right) \)
- Ball Pass Frequency Inner Race (BPFI) = \( \frac{Nb}{2} \times S \times (1 + \left( \frac{Bd}{Pd} \times \cos (\theta) \right) \)
- Fundamental Train Frequency (FTF) = \( \frac{S}{2} \times (1 – (\frac{Bd}{Pd} \times \cos (\theta)) \)
- Ball Spin Frequency (BSF) = \( \frac{Pd}{2Bd} \times S \times (1 – (\frac{Bd}{Pd} \times \cos (\theta)) \)

Where:
- \( Nb \) = number of rolling elements
- \( S \) = speed (revolutions per second, in Hz)
- \( Bd \) = ball diameter
- \( Pd \) = pitch diameter
- \( \theta \) = contact angle (degrees)

The following guidelines can be used as a quick reference:

- Ball Pass Frequency Outer Race (BPFO) = \( Nb \times S \times 0.4 \)
- Ball Pass Frequency Inner Race (BPFI) = \( Nb \times S \times 0.6 \)
- Fundamental Train Frequency (FTF) = \( S \times 0.4 \)
- Ball Spin Frequency (BSF) = \( S \times 1.6 \)

Figure 1: Example sensor locations (marked in yellow) at the inboard motor radial (LEFT) and inboard compressor radial (RIGHT).
For example, a 6-lobe screw compressor operating at 3,600 RPM with 19 rolling elements in each bearing will have the following frequencies:

<table>
<thead>
<tr>
<th>Frequency Type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Train Frequency (FTF)</td>
<td>24Hz</td>
</tr>
<tr>
<td>1X Motor Speed</td>
<td>60Hz</td>
</tr>
<tr>
<td>Ball Spin Frequency (BSF)</td>
<td>96Hz</td>
</tr>
<tr>
<td>2X Motor Speed</td>
<td>20Hz</td>
</tr>
<tr>
<td>1X Gas Pulsation Frequency (GPF)</td>
<td>360Hz</td>
</tr>
<tr>
<td>Ball Pass Frequency Outer Race (BPFO)</td>
<td>456Hz</td>
</tr>
<tr>
<td>Ball Pass Frequency Outer Race (BPFI)</td>
<td>684Hz</td>
</tr>
<tr>
<td>2X Gas Pulsation Frequency (GPF)</td>
<td>720Hz</td>
</tr>
</tbody>
</table>

The vibration spectrum will display a peak at each frequency noted above. The actual frequency will be slightly lower as the speed slows under load with motor slip of a few percent. The analysis should be performed over a frequency band accommodated this range of speed variation.

Each peak is analyzed for a trend in amplitude against pre-set warning and alarm levels. Specific information may be available from individual manufacturers or through operational specifications. The following guidelines provide a useful start for analyzing the FFT max amplitudes in each band for a commercial screw compressor:

**General (rotation and bearing locations including motor speed, FTF, BSF, BPFO, BPFI)**

<table>
<thead>
<tr>
<th>Level</th>
<th>Amplitude (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>0.10 in/s</td>
</tr>
<tr>
<td>Alarm</td>
<td>0.25 in/s</td>
</tr>
<tr>
<td>Shutdown</td>
<td>0.62 in/s</td>
</tr>
</tbody>
</table>

**Gas Pulsation Frequencies (GPF and multiples)**

<table>
<thead>
<tr>
<th>Level</th>
<th>Amplitude (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>0.16 in/s</td>
</tr>
<tr>
<td>Alarm</td>
<td>0.40 in/s</td>
</tr>
<tr>
<td>Shutdown</td>
<td>1.00 in/s</td>
</tr>
</tbody>
</table>
