Successful monitoring strategy for LNG reciprocating compressors

Mike Hastings, Briel & Kjær Vibro, Denmark and Jos Schrijver, Thomassen Compression Systems, The Netherlands

The authors’ companies have cooperated with the aim of helping to reduce maintenance costs and downtime of LNG reciprocating compressors. The article describes the development and refinement of automatic monitoring techniques that require minimal diagnosis expertise from the end-user, with examples of applications.

Reciprocating compressors are widely used in the LNG industry, and will continue to be used because of the many processes that require their high pressure and variable loading characteristics. These machines, however, are much more maintenance demanding than their centrifugal and axial compressor counterparts, and yet are some of the least monitored machines in the plant. This issue becomes even more important as LNG process technology improves and consequently the time between plant shutdowns is increased. This makes the reciprocating compressor increasingly the bottleneck when optimising plant maintenance and operation strategies.

Monitoring techniques available

Experience shows that the cylinder components such as the valves, piston rings, rider rings (also called wear bands), packing case, piston, piston rods, and crosshead pin, have been identified as the major cause of both planned and unplanned shutdowns. There are a number of performance, vibration, acoustic emission and other measurement techniques that can be used for both the online and off-line monitoring of these components. A few of the techniques are used for safety monitoring, others are just for diagnosis and some for automatic condition monitoring (also called predictive monitoring, which includes early fault detection, fault trending and performance monitoring).

Some of the measurement techniques used specifically for the cylinder portion of the reciprocating compressor are listed below. These particular measurement techniques have proven to be accurate, repeatable and reliable for detecting and diagnosing reciprocating compressor faults when properly set up and used. Figure 1 shows the typical sensor configuration for these measurements.

- Rod drop - A fixed proximity probe automatically measures the distance from the probe tip to the rod, which gives an indication of the wear of the rider rings.
- Impact vibrations - An accelerometer can be used for safety monitoring of machine components that are loose (e.g. worn pins), damaged (valves, bearings, rings, rods, crossheads, crankshaft, etc.), or unbalanced, or for detecting the presence of liquids in the gas stream.
- Valve gas temperatures - This is one of the most effective safety and condition monitoring methods for detecting incorrect valve condition or operation.
- Stuffing box seal temperature - Automatic condition monitoring for seal leaks.

There are also a number of automatically monitored calculated performance monitoring parameters for monitoring reciprocating compressors that require minimal diagnosis, such as flow, rod load, discharge temperature, volumetric efficiency and power.

More monitoring has to be done

Although much maintenance is needed for reciprocating compressors, there is a wide range of measurement techniques available for monitoring these machines, condition monitoring is not done as widely as is done for other critical machines. In fact, reciprocating compressors are some of the least monitored critical machines in many plants. What is most disturbing is that most of the previously mentioned measurement techniques, contrary to popular belief, can give effective results if properly set up and used.

Industrial cooperation to find a solution

An instrument supplier, Briel & Kjær Vibro (BKV) and a compressor manufacturer, Thomassen Compression Systems (TCS), formed a long-term cooperation in order to come up with a solution for overcoming the lack of confidence in, and limitations of, the various measurement techniques so that end-users can reduce maintenance costs and downtime. A major part of the focus was on reciprocating compressors used in the stabilizing process of an LNG plant (in addition to compressors used on the compressor island):
used in other applications, such as natural gas compressor stations). The solution that came out of this cooperation was based on evaluating the customer’s needs, evaluating and modifying the existing monitoring techniques, integrating these into the monitoring system, and providing low-cost yet effective services that ensure proper installation, set-up, fine-tuning and long-term operation. The monitoring system selected for this purpose was Brüel & Kjær Vibro’s COMPASS system, a plant-wide automatic monitoring and safety system with integrated vibration, process and performance monitoring capability.

After evaluating the customer requirements, the emphasis was to concentrate on those measurement techniques that are automatically monitored and do not require extensive resources for diagnosis from the end-user’s side, yet still can give accurate reliable results (Figure 2 shows some of these recommended measurement techniques).

Other measurement diagnosis techniques such as PV-diagram analysis, which can still be offered as a solution to customers that require it, were not part of the initial focus since these still require a lot of diagnostic resources that many end-users cannot provide, and it is difficult to automatically monitor these to alarm limits. The instrument supplier / machine manufacturer reciprocating compressor monitoring solution provides the following benefits to the end-user:

- Instrumentation on the machine is matched to the monitoring system and fine-tuned as a fast and efficient service
- The machine manufacturer has compressor test facilities for researching new monitoring techniques and analysing or refining existing ones
- Sales and support network for the monitoring solution for both organizations is essentially ‘doubled’
- The machine manufacturer can provide machine dependent variables for calculated performance monitoring parameters such as power, volumetric efficiency, rod load, flow and discharge temperature
- The cooperation is not a merger, so both companies are unaligned - the solutions can be used with all makes of compressors
- It is possible for both the machine manufacturer and the instrument supplier to have remote access to the monitoring database, so site visits can be minimized.

**Improved monitoring solution**

The rod drop measurement was one of the measurement techniques that were ideal to focus on. This is because the end-user’s...
confident in the rod-drop measurement was low, although there was considerable downtime associated with changing the rider rings too early or too late. Some instrument suppliers even recommend to the operator to set and tune remotely without a site visit.

Smart alarming techniques - The COMPASS System (Figure 3) has an alarm system that allows groups of similar sensors to be compared, and alarms are generated on deviations, not on the absolute levels. As seen in Figure 4, the suction valve temperatures for two cylinders vary over time by more than 20 °C due to changing process conditions (from 44 to 65 °C). The temperature deviation from one suction valve to another, however, varies only 1.5 °C, which means the temperature deviation or spread measurement is much more sensitive in identifying a valve problem.

The reliability and accuracy of other reciprocating compressor measurement techniques were also addressed by the TCS/BKV cooperation. Most of these case studies are focused on rod drop measurements for reciprocating compressors in an LNG and natural gas processing application, but other monitoring techniques are also described.

Improved rod drop measurements: Rod drop monitoring can give effective results if properly set up and used. In Table 1, statistical deviations for the rod drop wear and actual dimensions are given for six different machines for different applications at different locations (mostly

![Figure 4](image-url) Upper plot: Actual temperature monitoring technique at all, or suggest instrument suppliers even recommend to the rider rings too early or too late. Some downtime associated with changing the rod-drop measurement which means it could drift over time giving a false trend.

![Figure 5](image-url) The 4-day average can establish a good long-term trend.
**PLANT MAINTENANCE**

<table>
<thead>
<tr>
<th>Wear Band Measurement Deviations</th>
<th>Difference</th>
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<tr>
<td>Average deviation</td>
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<td>Minimum deviation</td>
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<td>Maximum deviation</td>
<td>0.4</td>
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<tr>
<td>Standard deviation</td>
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Table 1: Statistical comparison of wear band wear for a number of different machines as determined by monitoring rod drop just before replacement, and the physical dimensions as measured during replacement.

In the LNG industry, the monitored rod drop measurement (just prior to wear band replacement) is compared to the actual physical dimensions of the bands measured during disassembly. In all situations, an optimized rod drop measurement technique was implemented within the TCS/BKV cooperation. As seen in Table 1, the average difference between the rod drop measurement and the physical measured bands is less than 0.15 mm.

Another method of using rod drop measurements to the maximum effectiveness is the use of both averaged and non-averaged rod drop measurements. The averaged measurement makes it a little easier to identify a trend so maintenance can be planned ahead of time (Figure 5), as the non-averaged measurement is important for catching short-term faults such as lubrication system failure and sand in the cylinder caused by a faulty filter (both occurred in the stabilizing unit of an LNG plant).

**Broken piston ring detected by impact monitoring**: Impact safety monitoring protects the compressor from rapid destructive faults such as broken components or liquid ingestion. The measurement can also be treated as a trend monitoring measurement to keep track of increasing clearances such as for worn sliders, rod bearings, etc. Figure 6 shows a compressor with a broken piston ring.

The constant percentage bandwidth (CPB) spectrum measurement in the right-hand plot of Figure 6 indicates a 1 kHz signal amplitude increase. In this case the 1 kHz increase is not necessarily due to the impact signals themselves, but is most likely the result of structural resonances being excited by the impacting pieces of the broken piston ring.

The CPB measurement is a composite spectrum consisting of a series of individually filtered measurement components, each of which has a bandwidth that is a constant proportion of the centre frequency (6% in this example). It is much more sensitive to non-sinusoidal impacts than a FFT (fast fourier transform) spectrum analysis and has much higher resolution at lower frequencies.

**Leaking suction valve**: The overlay plot in Figure 7 shows the suction valve temperature for two different cylinders of the same machine in an unmanned gas compression station. As seen in the plot, on Oct 20, one of the cylinders suddenly increases 3°C warmer than the other. This temperature spread is observed for 10 days up until repair, which was done Oct 30. The suction temperature spread returns to normal after the valve repair.

**Conclusion**

The TCS/BKV cooperation was aimed at helping LNG reciprocating compressor end-users to reduce maintenance costs and downtime. There are several accurate measurement techniques that can be used for monitoring most of the reciprocating compressor potential failure modes, but these are not always being used. This is partially due to the difficulty in setting up these measurements and a lack of knowledge and confidence in the diagnosis.

After evaluating customer needs, it was determined that using reliable automatic monitoring techniques that require minimal diagnosis expertise from the end-user, will give faster, more effective results. Educating end-users in using diagnostic and analysis tools such as PV-diagram analysis will not give immediate results, and thus is not the immediate goal of this co-operation. Automatic monitoring techniques were evaluated and refined from both a technical and service point of view to improve their effectiveness. As all the compressors are remotely monitored, diagnoses can be done without site visits. This approach is proving itself successful as demonstrated by the case studies. There is, however, a “learning curve” in promoting and refining this solution, so the TCS/BKV cooperation is intended as a long-term project.

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