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Practical experience with computer-aided online systems shows how useful they can be

Condition monitoring for reciprocating compressors

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Extending machine operating times and avoiding damage are key concerns in operating reciprocating machines in industrial plants, particularly when working with process gas. Large portions of a plant often depend on the operational capacity of a single compressor, so early planning of outages for maintenance purposes and avoiding consequential damage are essential.

Use of automatic, computer-aided condition monitoring systems for industrial machinery is increasing. This facilitates both conventional and innovative methods of maintenance and monitoring with the aid of modern instrumentation and computer technology. Moreover, specialized online monitoring systems provide the necessary basis for introducing condition-based maintenance.

Some condition monitoring systems have been in commercial use for more than 12 years. Dedicated systems have been specially designed to meet the requirements of reciprocating compressor monitoring, evaluation and diagnosis. Numerous systems have been installed in reciprocating machines with power outputs ranging from about 200 kW to 10 MW. The following practical examples present experience with online condition monitoring accumulated during routine maintenance work.

Faults in suction and discharge valves. The most frequent reasons for unplanned outage of reciprocating compressors are faults in suction and discharge valves. As a result, these valve types are regarded as the main wearing parts, so particular importance is attached to early recognition and precise diagnosis of a defective valve. The situation inside the compression chambers can be continuously evaluated directly by permanent measurement of cylinder pressure. The measured time characteristic of this pressure is also presented in the form of a *p–V* diagram, from which characteristic values are calculated and monitored.

Additional condition information on these valves is provided by measuring vibration acceleration at the cylinders, which is analyzed in 36 segments for each 10° of crank angle and monitored in relation to threshold values.

The following example, from a refinery operating a 700 kW two-stage, double-acting hydrogen compressor, demonstrates the

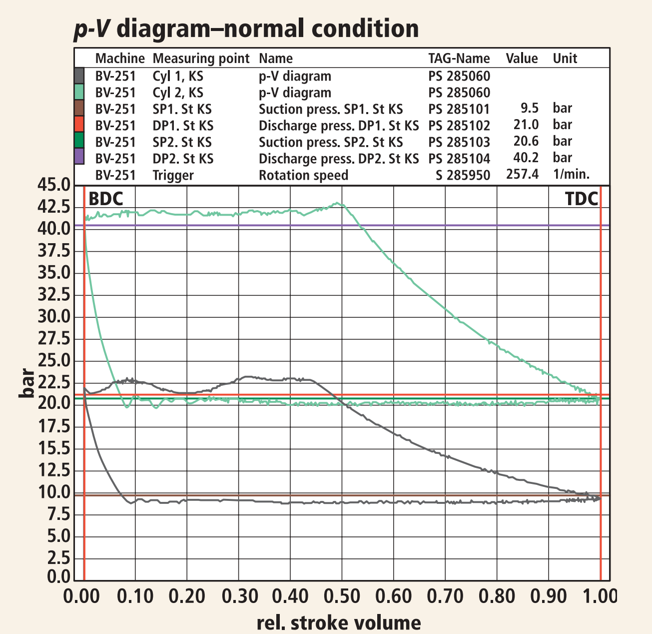

FIG. 1 *P–V* diagram of first- and-second stage cylinder with properly operating discharge valves.

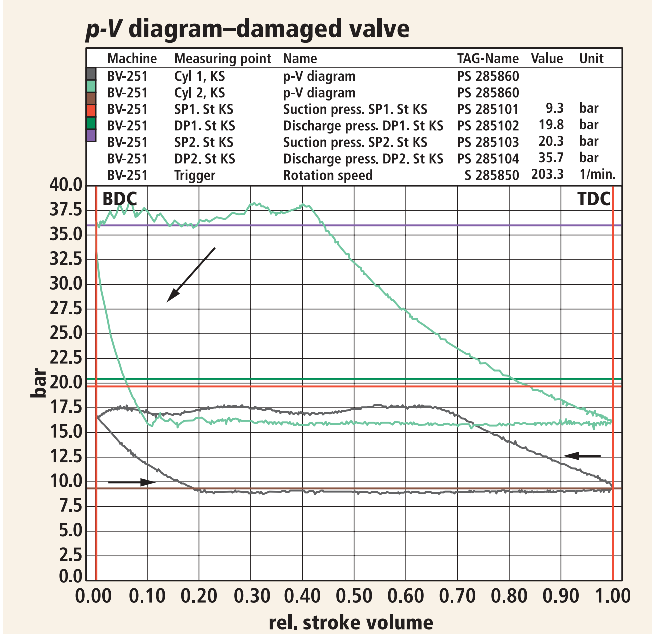

FIG. 2 *P–V* diagram of first- and-second-stage crank-end cylinder with faulty first-stage crank-end discharge valve.

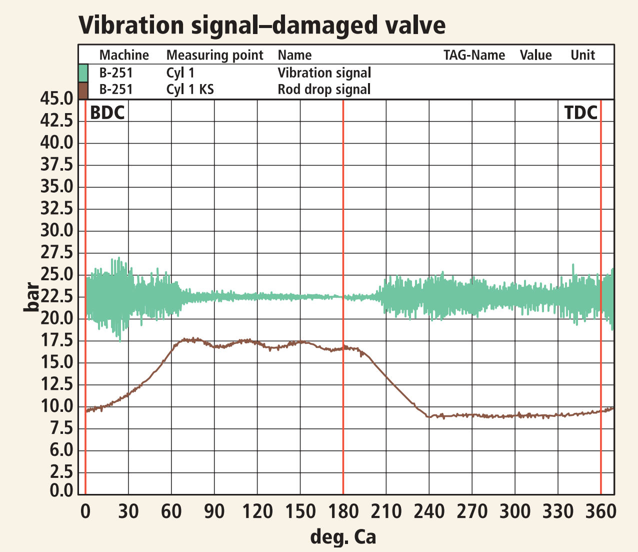

FIG. 3 Crank-end first-stage cylinder pressure and vibration characteristics with a faulty crank-end discharge valve.

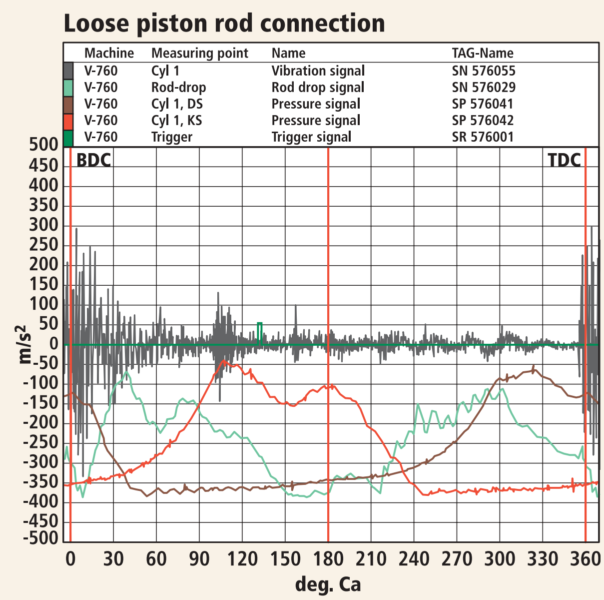

FIG. 4 Time characteristics of measured signals with a screwed connection between piston rod and crosshead detached.

characteristic changes in signals associated with damage to a pressure valve. Fig. 1 shows the *p–V* diagrams of the crank-end in the first and second stages. In our example, the monitoring system signalled a violation of the vibration thresholds in the first-stage cylinder and disturbance of the *p–V* characteristic values of the crank-end compression. Fig. 2 demonstrates the vibration and pressure characteristics recorded at the time of the alarm for one crank revolution. There is increased cylinder vibration during almost the entire crank stroke, less vibration being evident only within the discharge region (70° to 180° crank angle) of the crank-end compression space. The changes are even more obvious on comparison with the first- and second-stage *p–V* diagrams (Fig. 3).

The first-stage *p–V* diagram is visibly distorted and no longer reaches the target intermediate pressure of 20.3 bar. The compression ratio in the second stage rises because of the decrease in ultimate pressure in the first stage.

The analysis shows that the compression curve is steeper, while the re-expansion curve is flatter, so in these regions, gas is overflowing from the discharge side into the cylinder space. This is normally prevented by proper sealing of the discharge valves. It was, therefore, diagnosed that the problem could be due to a damaged discharge valve. Indeed, this was the case. Other possible causes, such as leakage along the piston rings, for instance, could be ruled out, because in that case, direction of gas overflow alternates between the cylinder crank-end and head-end during one crank revolution. Compression and back-expansion would then both be steeper as a result. The conspicuously increased vibration (which has also produced an alarm signal) is caused by flow-induced noise and chattering of the faulty valve plate.

Piston rider ring wear. One method of determining rider ring wear is rod-drop analysis, in which a proximity sensor continuously measures piston rod dropping during operation. Over time, rider ring wear and tear produce a measurable drop in the rider rod position.

In the following example, a twin-crank, double-acting compressor operating with hydrogen mixed gas was producing alarm messages due to violation of the limit values. Development of the rod-drop measured values over the previous eight weeks showed an exponential change in the measured clearance over a period of about six or seven weeks. After exceeding the first alarm threshold, the machine initially remained in operation for production-related reasons. Piston drop was approximately 0.16 mm at that time. About 10 days later, the second alarm threshold was also passed, and the machine was shut down for a maintenance outage. Examination showed that the rider rings had become severely worn over a short time due to insufficient cylinder lubrication.

Damage to crankgear and piston. Condition monitoring is very important in connection with damage in and around the crankgear. Loose connections between components in the power train from crankshaft to piston can cause severe consequential damage.

Alarm messages were triggered at a mixed gas compressor due to passing of the vibration limit for cylinder 1 and the compressor was shut down. Plant personnel also heard loud knocking noises. Thanks to the ring buffer memory feature within the monitoring system containing the original time characteristics of all directly connected sensors, the cause of the fault could be determined even with the machine shut down. Fig. 4 shows the original time characteristics the ring buffer memory had recorded for cylinder pressure, piston rod position and cylinder vibration. Severe vibration is noticeable within the range of 0° to about 40° crank angle, probably caused by an impact at top dead center (TDC). This impact was observed to cause a clearly audible noise.

Given the high amplitude of the vibration, the problem was unlikely to be caused by a sticking valve, or any other fault in and around the valves. However, overcoming mechanical clearance in or around the oscillating components in the flow of forces (piston, piston rod or crosshead) can produce much the same type of signal. Subsequent examination of the machine revealed that the fault was caused by a loose connection between the piston rod and the crosshead.

Early failure detection. Use of specialized systems for online condition monitoring of reciprocating machines allows rapid, reliable detection and accurate fault diagnosis. Possible damage can, therefore, be recognized at an early stage, allowing prompt action to be taken before any consequential damage arises. The maintenance engineer gets information on the location and operational significance of the cause of a fault and can schedule deployment of personnel and parts in advance—an important point in terms of economic justification.

Many plant operators have come to recognize the economic significance of condition monitoring, especially in regard to machines whose central importance could stop production of a whole plant on failure. Often, investment in such a system will pay for itself simply by preventing a production stoppage lasting just one day. The increasing popularity of online systems has been accelerated too, by the possibility of unmanned compressor operation through remote monitoring, for example, via the Internet.

Online condition monitoring systems have proven their value and are clearly key to modern, cost-effective operations. HP

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