In many industrial sectors, different types of gases used for transportation or processing need to be reliably compressed to high pressures. Turbo or reciprocating compressors are normally used for these tasks. Today, diagnostic systems help with the monitoring and planning of maintenance cycles, thus increasing the availability of the units. However, many of the available systems are based on technology designed purely for rotating machines, and can only meet the special requirements of reciprocating compressors to a limited extent. Only a monitoring and protection system that is specifically tailored to the special features of these compressors can ensure the prompt and accurate detection of malfunctions and damage. A practical example highlights this and relates to two compressors at the TOTAL Normandie refinery in Gonfreville, France.

In many cases, large compressors are the heart and soul of a complex industrial plant. This means that compressor failures are often associated with major production losses and thus can lead to significant costs for the operator. Preventative, scheduled maintenance and fast reactions to damage events prevent consequential damage and long or unscheduled downtime. There is therefore a high demand among operators of reciprocating compressors for monitoring solutions that are tailored to these machines. HOERBIGER has developed a special monitoring and protection system for this type of machine. This system promptly detects upcoming problems, thus preventing more significant consequential damage.

KLAUS STACHEL AND MARKUS WENISCH, HOERBIGER COMPRESSION TECHNOLOGY, AUSTRIA, OUTLINE A NEW PROTECTION AND DIAGNOSTIC SYSTEM FOR RECIPROCATING COMPRESSORS.
The big difference

In the past, many monitoring solutions used for reciprocating compressors were originally designed purely for rotating machines such as turbo compressors. However, this can have a serious effect on the performance of such systems. In the case of turbo compressors, when the machine is working normally and in good condition, the mechanical vibration levels only fluctuate during start up and shut down, and otherwise only change to a negligible extent over a complete revolution. By contrast, a reciprocating compressor behaves completely differently due to the crank drive. The mechanical vibrations of purely rotating machines are practically the same for long periods of time, and only occasional changes require more detailed analysis (Figure 1). On the other hand, even under normal operation, reciprocating machines produce a wide range of oscillations and vibrations which must be analysed at a high resolution and require phased vibration monitoring. In addition, a true monitoring system (Figure 2) must monitor a range of signals from each separate cylinder and must process and analyse these signals in real time.

Previously, it has not been possible to reliably implement this in practice with systems designed for turbomachines. The modular RecipCOM monitoring and protection system, which has been developed especially for reciprocating compressors, can be precisely adapted in line with the requirements of the operator and thus offers advantages when compared with current systems. RecipCOM enables the evaluation of highly dynamic signals such as piston rod position, vibration and cylinder pressure. The data is evaluated by powerful hardware and specially developed software during each individual revolution (i.e. over 360° of crank angle). The signals are sampled with a high sampling rate and are immediately analysed and evaluated. To enable the prompt and reliable detection of malfunctions on reciprocating compressors, alarms can be configured with a resolution of just 1° of crank angle. On the basis of this, the data on condition diagnostics can be analysed in associated software and the analysis can be used to enable condition based maintenance of the machine.

Effective monitoring and maintenance

The most effective monitoring of the performance relevant components of a compressor (suction valves, discharge valves, piston rings and packings) is achieved through the analysis of the corresponding cylinder pressure curve and the associated vibration signature. The resulting data set obtained for one crankshaft revolution, which appears extremely complex at first, is very informative and allows conclusions to be drawn as to the performance of the machine. For example, it is possible to detect a defective suction valve or a leaking packing on the basis of the longer compression visualised in the pressure volume (pV) diagram. Conversely, a steeper rise in the compression line can indicate a defective discharge valve. In both cases, the result is a reduced compressor output.

The optimum operation of the piston rings is also important for the performance of the compressor. Again, the high resolution pressure curve over the entire revolution returns all the data required for a targeted analysis (Figure 3). If the piston rings are worn or ruptured, gas flows from the high pressure cylinder side to the lower pressure cylinder side. The diagram shows that such internal leakages initially result in a steeper compression line because of ‘topping up’ caused by the leaking gas, until the pressure equalises on the two sides. The internal gas leakage is then no longer evident during further compression, resulting in the typical error pattern. Both variations in the pressure curve reliably indicate a ring defect.

Optionally, static measurement data such as valve temperatures, bearing temperatures and line pressures can be integrated into the system for even more detailed analysis. Further important elements for the safe operation of a reciprocating compressor are the maximum permitted piston rod load and the minimum required rod load reversal on the crosshead pins. For example, a loss of load reversal during operation results in major damage to the crosshead and long, unscheduled machine downtimes. The cylinder pressure measurement allows these
forces to be determined in real time. They can then be depicted for monitoring purposes over the course of each revolution. This ensures the safe operation of the machine.

In addition to the aforementioned types of damage, the system detects loose connections on oscillating components on the basis of piston rod run out. This is measured in a contact free manner by a sensor installed on the packing. This measurement can also be used to determine the rider ring stand out. With RecipCOM, the machine no longer needs to be switched off in order to find out how long it can still be safely used for with the existing rider ring. The monitoring system displays the current rider ring stand out to the operator during operation. This allows the remaining wear potential of the component to be fully utilised.

Thanks to the possibility of a connection to the process control system, further process data that is already available in this system can be transferred between RecipCOM and the programmable logic controller (PLC). This data can also be used for evaluations and analyses in the RecipCOM system, which can include temperature and pressure measurements.

The range of intelligent evaluation routines must be adapted in line with the compressor in question. A training phase that runs through various operating conditions enables the normal state of the machine to be recorded so that alarm limits can be set as precisely as possible. This is the only way to ensure that upcoming problems are detected quickly and promptly. Thanks to the implementation of the training phase, during which the individual properties of the compressor are identified and taken into account for the setting of limits, false alarms are reduced to practically zero.

Further functions to prevent false alarms are integrated into the system. In addition to the usual hardware 'fault' output signal, there is a ‘trust’ function. The trust output tells the operator that the safety relevant parts of the system are fully functional. If this output signal is missing, this indicates that the safety relevant functions of the machine are impaired and the operator should rectify the problem. In addition, the trust function ensures that false alarms are not generated due to a system malfunction. This function thus increases the availability of the compressor since it is possible to clearly distinguish between non-critical system problems and problems with safety relevant functions.

An additional smart alarm counter enhances the safety system by counting the number of consecutive revolutions with limit violations. A safety alarm is issued only if the number of limit violations exceeds the configurable number of revolutions. Consequently, false alarms are effectively prevented.

Figure 4. Two compressors working in parallel were fitted with the new monitoring system.

Figure 5. Increase in piston rod clearance.

Figure 6. Piston rod run out as a function of the crankshaft angle 12/30 mins after the first alarm.

Figure 7. The cause of the damage/fragments of the defective component would have caused considerable follow on damage if the old monitoring system had been used alone, since the problem would not have been detected in time.
Changing operating conditions generate different vibration signals and pressure curves in the compressor. The compressor may be operated with a control system such as the stepless HydroCOM system. This must be taken into account for limits and alarms because otherwise false alarms may be issued. RecipCOM has an automatic limit selector, which allows the definition of up to 16 different alarm limits that are adapted automatically in accordance with operating conditions.

Internal and external experts can access the information and data of the monitoring system via a secure LAN or internet connection, if required. This means that engineers from a company’s head office can monitor machines at several locations, or Hoerbiger can be consulted for analysis support purposes, for example.

**Theory in practice**

The practical example of a two stage compressor with approximately 5800 kW (Figure 4) demonstrates the theory behind the system. Two of these compressors are used in parallel at a TOTAL refinery to compress hydrogen for downstream plant sections. A conventional analysis system was already installed. The new RecipCOM system (tailored to these reciprocating compressors) was retrofitted and both systems worked simultaneously. The cylinder pressure, piston rod position and vibrations on the crosshead were measured. This enabled conclusions to be drawn about valve function, piston rod load and the state/wear of the piston rings. The temperatures of the suction valves were also integrated into the evaluation.

The first error message from the new monitoring system occurred at approximately 09:15 am, indicating an abnormal rise in vibrations on the crosshead of the third cylinder of compressor no. 1. The vibrations were being registered with increasing strength. A simultaneous rise in the dynamic piston rod run out from 100 μm to 170 μm confirmed the suspicion of a loose connection on the crosshead (Figure 5). A more detailed analysis and comparison of the current data with earlier reference data stored in the system showed a major deviation in the movement of the piston rod (Figure 6). The vertical movement of the rod corresponded to crank angles of 90° and 120°.

At 11:00 am, the compressor was safely shut down without interrupting production. The maintenance team dismantled the affected parts on the third cylinder. The inspection found an imminent defect on the connection between the crosshead and piston rod resulting from component failure. If the compressor had been allowed to operate any longer, this would have caused significant damage to the machine. Small fragments of the damaged component were found in the intermediate piece of the compressor (Figure 7). The prompt alarm issued by the RecipCOM system helped to prevent major damage and production losses. The conventional monitoring system did not detect the damage and therefore failed.

Monitoring systems that have been optimally tailored to the special needs of reciprocating compressors can detect damage quickly and reliably. This means that early wear can be detected and preventative maintenance can be scheduled in advance. Unscheduled downtimes and major (consequential) damage can be avoided, and the availability and productivity of the compressor are also improved. Both of these results can save the user time and money.