

Monitoring mechanical behaviour of reciprocating compressors

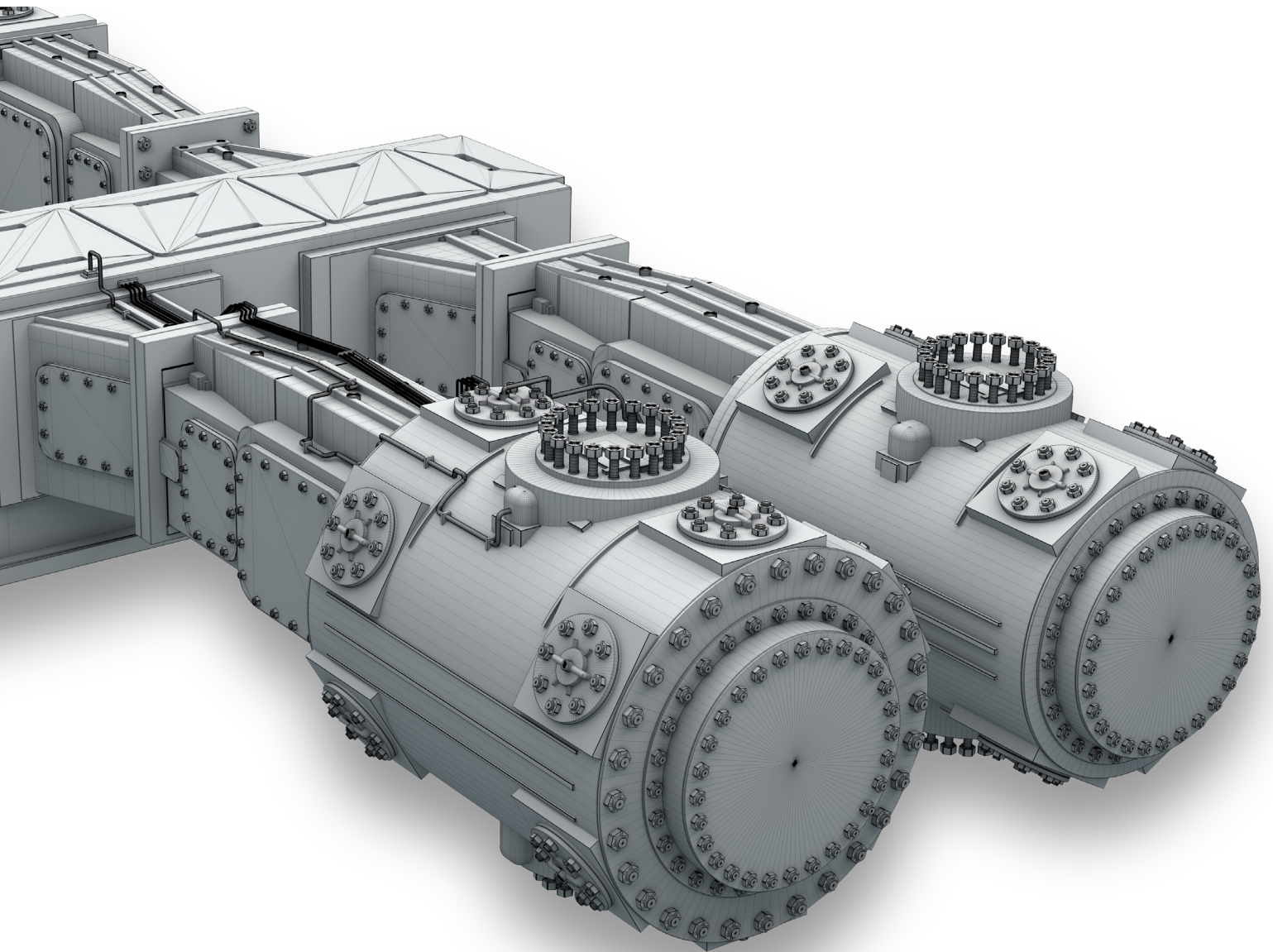


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1 Why monitor reciprocating compressors?

Reciprocating compressors are often called the workhorses of the industry. These compressors fulfil critical parts of industrial processes and add an important value to production. But there is a significant downside to these heavy and powerful machines: high maintenance costs.

Reciprocating compressors are among the most critical machinery in industrial processes. Their unique capabilities make reciprocating compressors indispensable to the industry. Due to their mechanical behaviour, these machines require advanced monitoring systems to ensure proper operation and timely fault detection.

The increasing demands of machine directives and standards (like API 670) on sufficient monitoring and protection confirm the importance of the subject. But in reality, only few compressors are equipped with sufficient monitoring systems and

as a result, the maintenance costs of reciprocating compressors are often (unnecessarily) high; up to five times higher than the maintenance costs of similar-sized centrifugal compressors.

To address this issue, advanced monitoring systems must be implemented to continuously monitor various parameters of reciprocating compressors (table 1). Periodic and reactive maintenance should make place for predictive and condition-based maintenance, to improve the reliability, availability and safety of reciprocating machinery. ■



Which parameters should be monitored?

In this whitepaper we focus on the mechanical health and behaviour of reciprocating compressors with three important indicators; temperature (valves and bearings), vibration and rod drop. Table 1 shows the typical measurements for reciprocating compressors. It covers each of these measurement types and provides an in-depth description of rod drop / displacement monitoring.

APPLICATION	MEASUREMENT TYPE
TEMPERATURE	VALVES BEARINGS
VIBRATION	CASING (FRAME) VIBRATION CROSSHEAD VIBRATION
ROD DROP	PISTON ROD DISPLACEMENT (INDIRECTLY: RIDER BAND WEAR)

Table 1

Temperature

Suction and discharge valves are the most maintenance-demanding components of reciprocating compressors. Monitoring valve and bearing temperatures allows for the early detection and repair or replace components before the machines' efficiency decreases.

[Read more on page 8 →](#)

Vibration

Vibration monitoring on reciprocating compressors

should be done for both casing (frame) vibration and crosshead vibration as these are crucial mechanical indicators for this type of machinery.

[Read more on page 10 →](#)

Rod drop

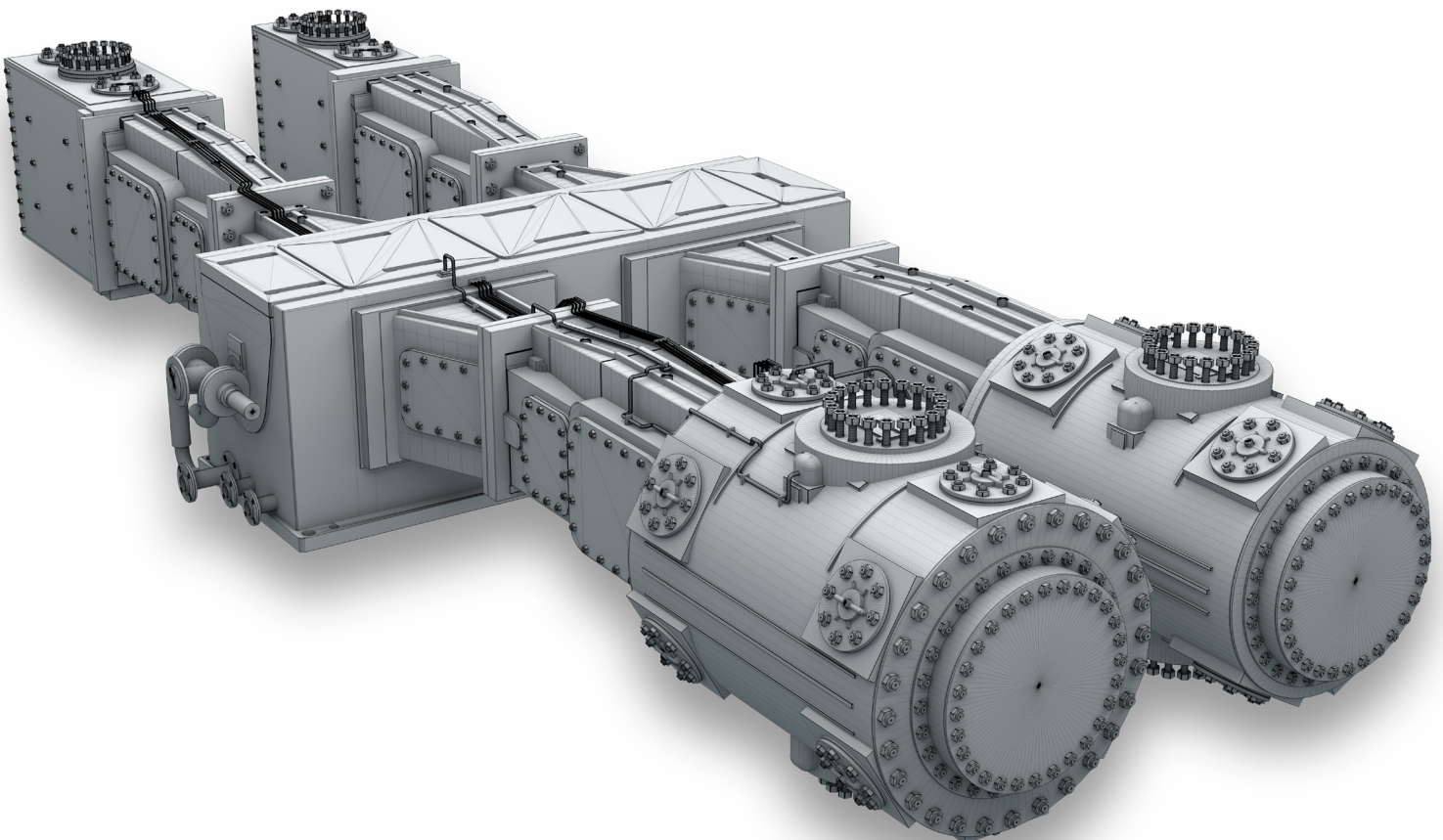
Rod drop measurements for reciprocating compressors provide accurate information on rider band wear, allowing the predictive scheduling of rider band replacements.

[Read more on page 12 →](#)

3 The API 670 about reciprocating compressors

The API 670 machine directive demands certain protective and condition monitoring measures. The tables on the next pages show the recommended combination of parameters, measurement types, sensor types and sensor specifications that are required to operate conform the API 670. Table 2 provides information about the parameters that require protection. Table 3 provides information about the parameters that require condition monitoring.

Note that only the mechanical health indicators within the scope of Istec are in the tables, including vibration, speed and temperature. For a full overview of protection and condition monitoring guidelines for reciprocating compressors, please refer to the newest version of the API 670.



API 670 - Protective measures

APPLICATION	MEASUREMENT TYPE	SENSOR TYPE	ALARM / SHUTDOWN FUNCTIONS
GAS DISCHARGE (FOR EACH CYLINDER)	TEMPERATURE	RTD / THERMOCOUPLE	ALARM RECOMMENDED
JACKET COOLING SYSTEM	TEMPERATURE	RTD / THERMOCOUPLE	ALARM RECOMMENDED
MAIN BEARING	TEMPERATURE	RTD / THERMOCOUPLE	OPTIONAL
CRANK PIN BEARING	TEMPERATURE	RTD / THERMOCOUPLE	OPTIONAL
CROSSHEAD PIN BEARING	TEMPERATURE	RTD / THERMOCOUPLE	OPTIONAL
FRAME / CASING	VIBRATION	ACCELEROMETER / VELOCITY SENSOR	ALARM AND SHUTDOWN RECOMMENDED
CROSSHEAD GUIDE	VIBRATION	ACCELEROMETER	ALARM AND SHUTDOWN RECOMMENDED
CYLINDER	VIBRATION	ACCELEROMETER	ALARM RECOMMENDED
CYLINDER VALVES	VIBRATION	ACCELEROMETER	OPTIONAL
MAIN DRIVER	VIBRATION	ACCELEROMETER / VELOCITY SENSOR / DISPLACEMENT PROBE	ALARM AND SHUTDOWN RECOMMENDED
PISTON ROD DROP	DISTANCE	DISPLACEMENT (PROXIMITY) PROBE	ALARM AND SHUTDOWN RECOMMENDED

Table 2. Typical protective measures for reciprocating compressors according to the API 670

API 670 - Condition measures

APPLICATION	MEASUREMENT TYPE	SENSOR TYPE	RECOMMENDED / OPTIONAL
PROCESS PARAMETERS			
SUCTION AND DISCHARGE NOZZLE	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
FRAME AND RUNNING GEAR			
OIL HEADER SUPPLY	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
VALVES AND PRESSURE PACKING			
SUCTION AND DISCHARGE VALVE	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
PRESSURE PACKING (VENT)	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
MAIN DRIVE MOTOR			
MOTOR STATOR	TEMPERATURE	RTD	RECOMMENDED
MOTOR BEARING(S)	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
FRAME LUBE OIL SYSTEM			
OIL PUMP SUPPLY	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
HEAT EXCHANGER – WATER INLET/OUTLET	TEMPERATURE	RTD OR THERMOCOUPLE	OPTIONAL
JACKET WATER SYSTEM (IF APPLICABLE)			
MAIN SUPPLY HEADER	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
RETURN LINE TEMPERATURE AT EACH CYLINDER	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
NON-TEMPERED WATER TEMPERATURE TO PRESSURE PACKING	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
RETURN LINE TEMPERATURE FROM EACH PACKING	TEMPERATURE	RTD OR THERMOCOUPLE	OPTIONAL
RESERVOIR	TEMPERATURE	RTD OR THERMOCOUPLE	OPTIONAL
HYDRAULIC VALVE CONTROL SYSTEM (IF APPLICABLE)			
HYDRAULIC OIL SUPPLY HEADER	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED
RESERVOIR	TEMPERATURE	RTD OR THERMOCOUPLE	RECOMMENDED

Table 3. Typical condition monitoring applications for reciprocating compressors according to the API 670

4 Three important parameters for reciprocating compressors

Temperature

Valve temperature

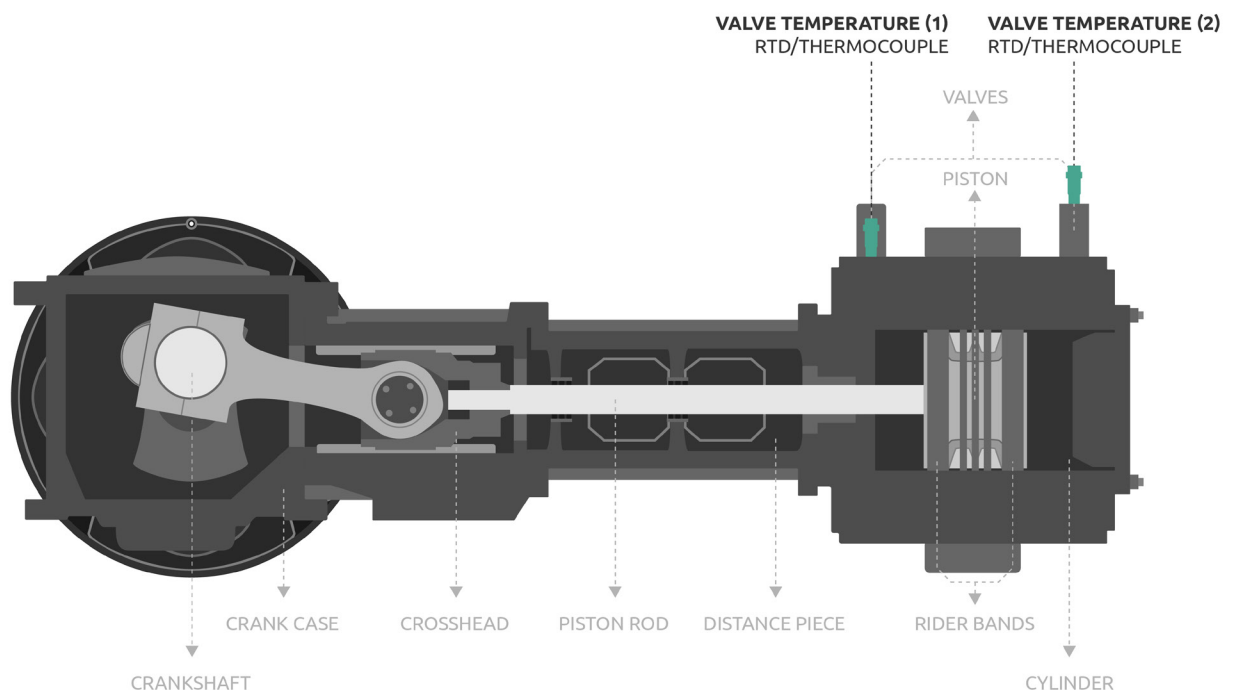
The suction and discharge valves are typically the most maintenance-demanding parts of reciprocating compressors. Faulty valves are considered the main cause for unplanned shutdowns. The monitoring of valve temperature offers insight into the condition of the valves. If a leak occurs at one of the valves the valve temperature changes. By monitoring valve temperature, a defect at the valves can be detected quickly. Monitoring valve temperatures is a must, as defective valves can significantly decrease the

efficiency of reciprocating compressors.

RTD or thermocouple sensors are used to measure valve temperatures. There are two common methods of positioning these sensors:

1. Sensor positioning in the valve through a thermowell

When the temperature sensor is mounted in a sleeve that is installed in the valve pocket, the quality of the measurement is higher than measurements on the valve cover. There are no environmental conditions that influence the measurement using



this type of sensor positioning. The sensors that are installed in the valve pocket also provide a faster detection of changing temperatures and valve leaks. However, the valve design is not always suitable for the installation of thermowells.

2. Sensor positioning on the valve cover

Mounting the temperature sensor directly to the valve cover makes the sensor vulnerable to be influenced by environmental conditions. It also has a slight delay on detecting valve leaks compared to the aforementioned method.

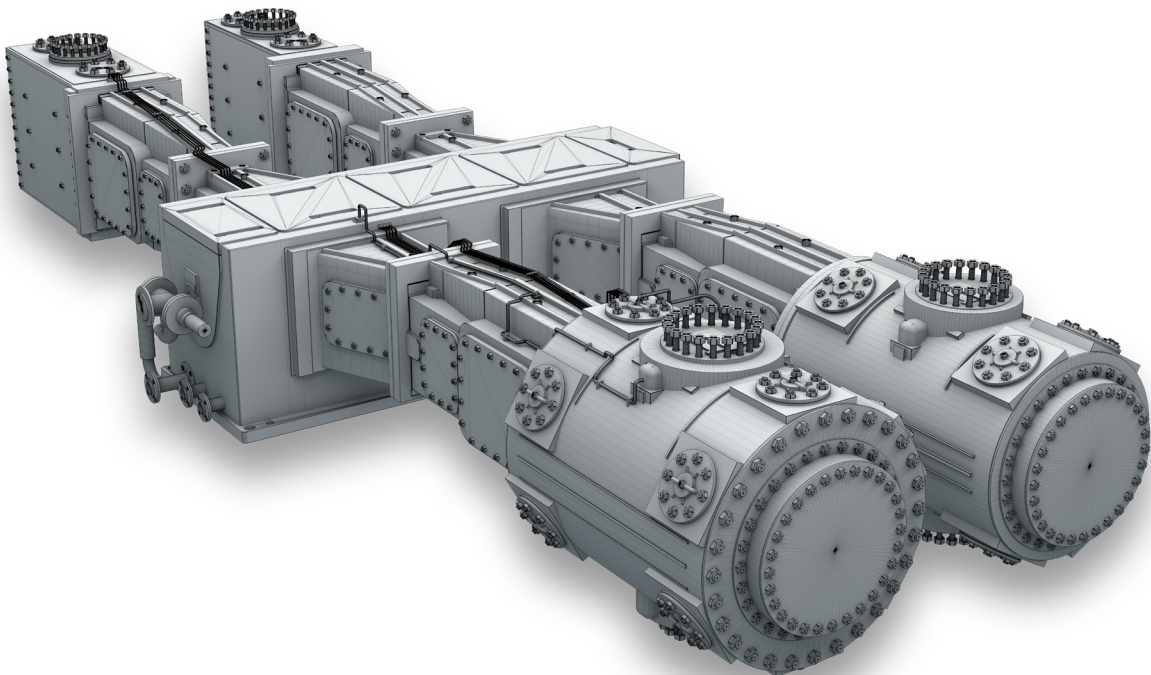
Bearing temperature

The bearings of reciprocating compressors assure the proper running of the compressor. It is important to monitor the temperatures on the bearings as overheating could lead to bearing

failure, which may in turn lead to damage or downtime. Various types of bearings are fitted on different locations of the reciprocating compressor.

1. Main bearings are located in the frame to position the crankshaft properly
2. Crank pin bearings are located between the crankshaft and the connecting rod
3. Wrist pin bearings are located between the connecting rod and crosshead pin
4. Crosshead bearings are located at the top and bottom of the crosshead

Pressurized oil is supplied to the bearings through grooves on the bearing surface in order to prevent overheating. If the oil supply is failing or friction increases the bearing temperatures will increase to a point where damage is likely



to occur.

RTD or thermocouple sensors are used to monitor the temperature of main bearings, crank/wrist pin bearings and crosshead bearings. They are externally mounted and include a conduit head to be able to access the sensor and cabling.

Vibration

Vibration measurements on reciprocating compressors can be difficult due to the natural mechanical movement of reciprocating machinery. However, there are some important parts that should be monitored for changes in vibration behaviour.

Casing vibration (frame vibration)

Casing vibration results from various forces and movements inside the machine and are part of

normal running conditions. Due to the pistons being driven back and forth the entire frame with all its components continuously vibrate, move and deform. Moreover, suction and discharge valves create impacts due to opening and closing during every revolution of the crankshaft. Every force during a revolution has its impact and affects the vibration behaviour of the machine. Such forces include gas load forces, inertial load forces, reciprocating and rotating unbalance forces and gas unbalance forces. It's important to note that even when in good condition, reciprocating compressors vibrate much more than their rotating equivalents.

To measure casing vibration on reciprocating compressors, velocity measurements are used. Typically, these are integrating piezoelectric accelerometers or moving coil velocity sensors, as the vibration frequencies for this application



usually include components below 10 Hz. The sensors are used to detect defects like unbalance, mechanical looseness and structural or foundation issues. One sensor should be positioned at the drive end side and one at the non-drive end side.

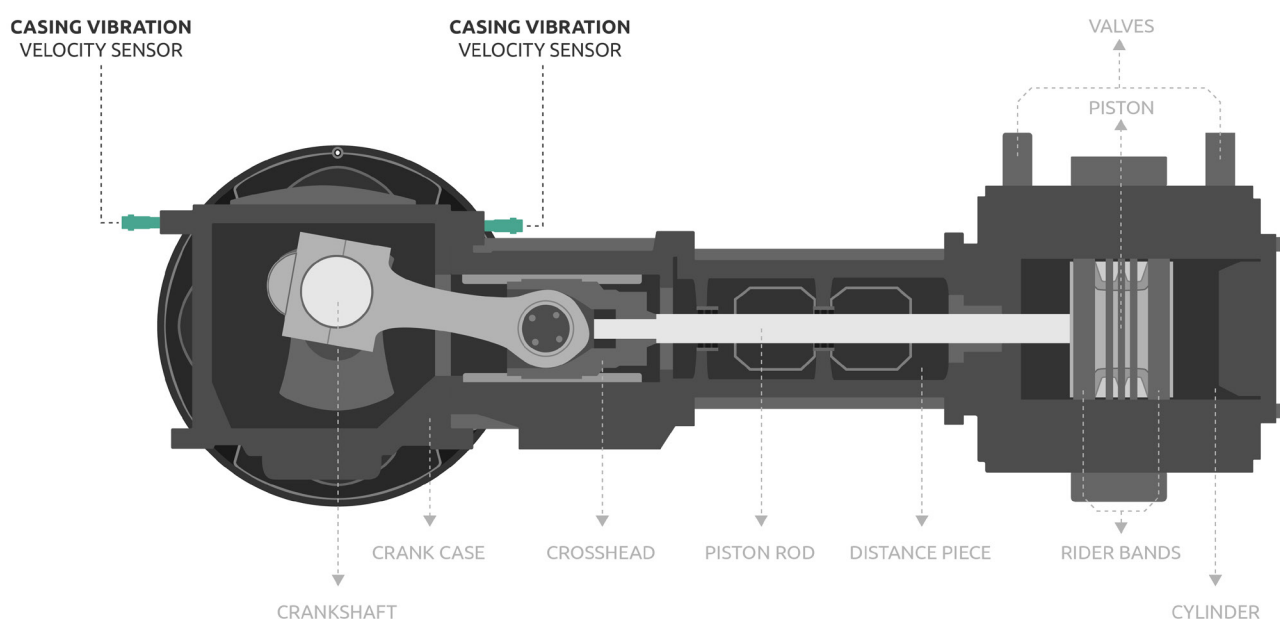
Crosshead vibration

The crosshead slides on a lubricated surface and moves back and forth (reciprocating). When the clearance between the crosshead and the surface increases, the crosshead vibration level will also increase. Monitoring crosshead vibration allows the operator to schedule maintenance in time and make sure the clearance between the surface and the crosshead stays within acceptable limits.

Accelerometers are typically used to measure crosshead vibration due to their ability to monitor high frequency components. These sensors can detect problems related to excessive crosshead

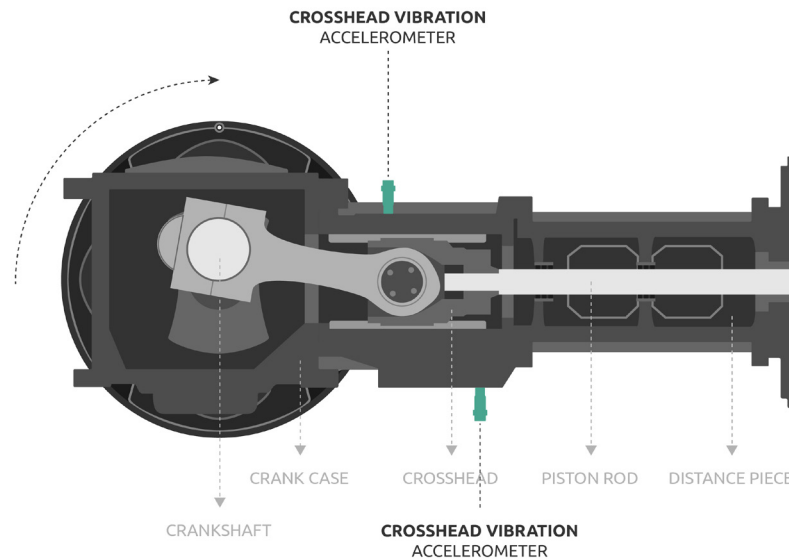
clearance, excessive clearance in the crosshead pin bushing and loose or cracked nuts, bolts or pistons.

Two sensors should be placed on the crosshead of which the positioning depends on the direction of rotation. ▶



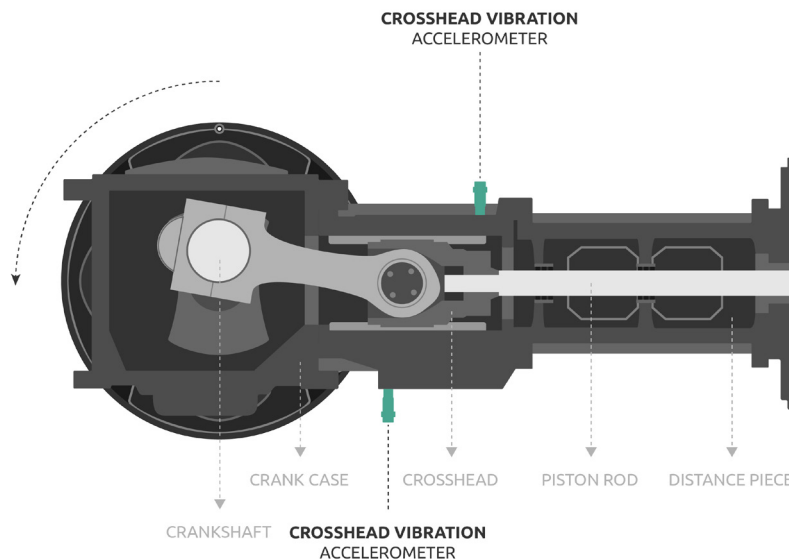
Clockwise shaft rotation

One accelerometer should be mounted vertically above the crosshead guide on the left and one vertically below the crosshead guide on the right.



Counter clockwise shaft rotation

One accelerometer should be mounted vertically below the crosshead guide on the left and one vertically above the crosshead guide on the right.



Rod drop measurement

Rider bands are critical components that support the piston while moving through the cylinder of the reciprocating compressor. They are used to secure the piston positioning inside the cylinder, to protect the piston from scraping and damaging the cylinder wall. These rider bands wear down over time, which manifests itself in a vertical displacement of piston and piston rod. To prevent damage to the piston and cylinder wall, the wear of these rider bands should be monitored.

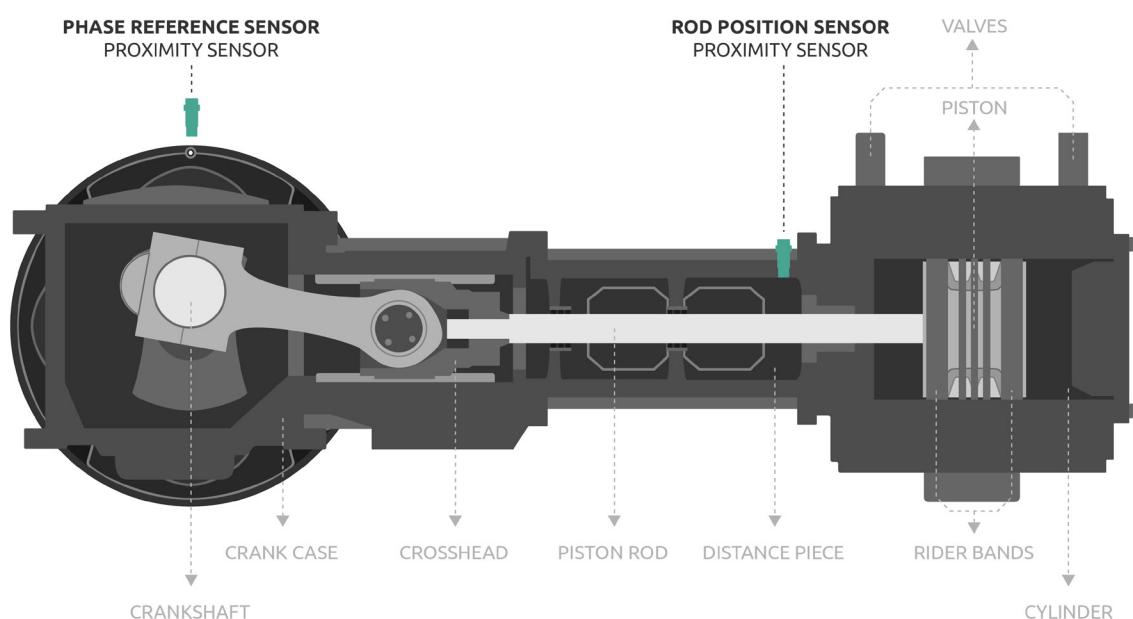
Proximity sensors are used to monitor rider band wear. It is difficult to monitor the piston in the cylinder due to high pressure in the cylinder chamber, so the vertical displacement of the piston rod is monitored instead. The piston rod drops proportional to the piston as a result of rider band wear and is therefore a reliable monitoring method.

The proximity sensor must be vertically mounted (90 degree angle) above or below the piston rod, as close to the cylinder as possible. Optionally, a second proximity sensor can be mounted horizontally to the piston rod. This enables the measurement of horizontal piston rod movement, which may indicate piston float or rod flexing.

Phase reference sensors are used to provide a reference point to measure the position of the piston and piston rod. The sensor is a crucial addition for reliable rider band wear monitoring as rod displacement should be measured at a specific point during the cycle. ■

Learn more about rod drop

See page 16 for deeper insights into rod drop monitoring!



EDITORS REVIEW;

Transmitter-based systems versus centralised systems

Reciprocating compressors are often critical to industrial processes. However, the prevailing idea that this type of machinery needs complex centralised monitoring and protection systems, appears to be without technical foundation.

There are a lot of components and parameters that can be monitored and protected, but that doesn't necessarily mean you have to measure each of them. Smaller and/or less critical reciprocating compressors require monitoring and protection too, but the costs of these complex centralised systems can be out of balance with the criticality or value of the machine. Therefore, the investment that is required to implement such systems cannot always be financially justified.

Rack-based approach

Rack-based systems offer great solutions for large machinery or machine trains that require advanced monitoring and protection on multiple parameters. These complex systems feature a higher channel density and offer a more complete solution to

monitor and integrate several parameters. These solutions require large investments that should be proportional to the criticality and size of the machine. This is why rack-based solutions are rarely suitable for smaller and less critical reciprocating compressors, which need a low-entry solution rather than a complete system.

Market needs

A growing demand for better and more data of the condition of reciprocating machinery is emerging alongside the general increasing industrial demands. The imbalance between the criticality of the machine and the costs of the required monitoring solution has created a need for less complex and more affordable solutions to provide monitoring and protection on various parameters for reciprocating compressors.

Transmitter approach

Recent transmitter developments allow for more financially accessible solutions for advanced monitoring and protection of parameters ►

"Rack-based solutions are rarely suitable for smaller and less critical reciprocating compressors, which need a low-entry solution rather than a complete system."

such as impact, temperature, vibration and rod drop. A transmitter-based approach enables users to monitor only the parameters the application requires, with a small technical footprint. Transmitter solutions feature less measurement channels, often focus on just one parameter (i.e. vibration), and are the ideal solution for smaller

“Transmitter-based systems are often scalable to expand the amount of measurement channels, making them suitable for larger applications.”

and less critical reciprocating compressors. A strong advantage of a transmitter approach is the scalability and modularity that comes inherently with their architecture. Transmitter-based systems are often scalable to expand the amount of measurement channels, making them suitable for larger applications. As for modularity, these systems are often integrable with other systems that monitor different parameters. For example, vibration and temperature may affect each other, which can be only seen in the parallel data output of both a vibration transmitter and the temperature transmitter. ■



A deeper insight into rod drop monitoring

Rod displacement is a key mechanical indicator for reciprocating machinery, to detect and trend rider band wear. Monitoring rider band wear contributes to the maintenance efficiency and process efficiency of reciprocating compressors.

Rider band wear

A rider band is the component that supports the piston while it is moving through the cylinder chamber and prevents it from damaging the cylinder wall. Over time these rider bands wear out. By monitoring the piston rod displacement (rod drop), it can be determined when the rider bands need to be replaced before damage occurs. Rod drop monitoring contributes to a condition based maintenance (CBM) or predictive maintenance strategy.

As traditional monitoring methods such as vibration measurements proved to be insufficient to accurately monitor rider band wear, different methods were developed. Rod drop monitoring is the most reliable way to accurately monitor rider band wear.

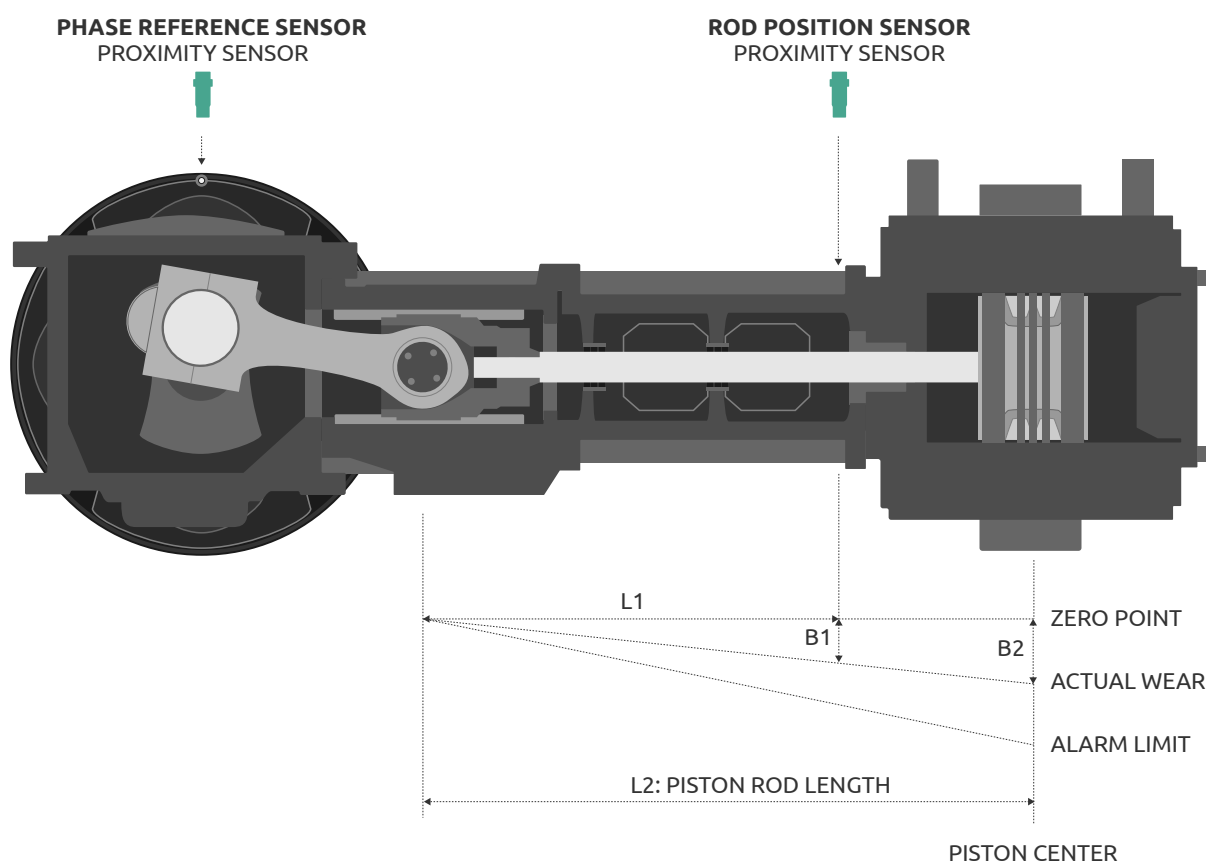
Rod drop measurements

Monitoring rider band wear is crucial to avoid major damage and improve maintenance planning. It allows operators to efficiently schedule the

“Instead of measuring the actual drop of the piston, the drop of the piston rod is measured, which is way more accessible”

replacement of these rider bands during a turnaround/standstill that was already scheduled, instead of having to shut down the machine just to inspect or replace the rider bands. Moreover, early detection of rider band wear provides the opportunity to shut down the machine before excessive damage and machine failures occur.

To detect wear on the rider bands the position (relative to the reference point) of the piston needs to be monitored. However, measuring the actual drop of the piston is very difficult because of the high pressure in the cylinder chamber. Instead of measuring the actual drop of the piston, the drop of the piston rod is measured, which is way more accessible (see image on the next page). Rod drop monitoring provides information about the condition of the rider bands by monitoring changes in the position of the piston rod. ▶



Rod drop measurement methods

Generally, two primary methods are used for rod drop monitoring:

Method 1; Digital measurements with proximity probes

With proximity measurements the sensor is mounted vertically above or below the piston rod, as close as possible to the cylinder. A proximity probe works by using eddy current technology, and measures the distance between the sensor tip and a metal object. In the case of a rod drop measurement it measures the distance to the piston rod. When the piston rod moves vertically, relative to the sensor, the change in distance is detected. These measurements make it possible to determine the vertical displacement of the piston rod. This signal indicates the rider band wear and

effectively schedule maintenance.

A *phase trigger* can be used to determine the phase of the compression cycle. By using a phase trigger, the rod displacement signal can be filtered to a specific position in the cycle to eliminate phase related signal distortions from the measurement and allows for accurate and reliable determination of vertical rod displacement.

Method 2; Mechanical measurements

Generally, two mechanical methods are used for rod drop monitoring. The first method uses a block of abrasive material with a space inside that contains nitrogen. This block is placed directly under the piston rod. When the piston rod drops as a result of wear on the rider band, the block will wear ►

down until a point where nitrogen escapes. This nitrogen leak will cause a decrease in the pressure supply, leading to an alarm or machine shutdown.

The second mechanical method for rod drop monitoring involves a type of roller that is mounted under the piston rod. When the rider band wears down, the piston rod drops gradually till a point where it touches the roller. Upon contact between the piston rod and the roller, the roller will start to rotate which allows nitrogen to escape from a reservoir below. This nitrogen leak will cause a decrease in the pressure supply, leading to an alarm or machine shutdown.

Mechanical versus proximity

The main disadvantage of mechanical rod drop systems is the inability to do measurements, and use these measurements for trending. The only thing these mechanical systems provide is an alarm that is triggered when the rider bands are worn out. There is no indication of the extent to which the rider band is worn out. A digital measurement can trend the actual displacement of the piston rod, and therefore the extent of the rider band wear. Using the proximity sensor measurements a trend can be monitored over time, allowing for better maintenance planning (CBM).

Rod drop monitoring solutions

There are several solutions for rod drop monitoring, both mechanical and digital. With data and insights becoming more important in the current industrial era, mechanical systems are becoming less suitable as they do not comply to this demand for data. Periodic and reactive maintenance is making place for predictive maintenance, which requires online systems to provide accurate data and insights.

As for digital solutions, rod drop monitoring is often part of larger systems that were developed to monitor various parameters. Such systems are too expensive for smaller and less critical reciprocating compressors. A more accessible solution is required for these applications. Istec has developed the **RecipSys 200**; a scalable and modular transmitter-based rod drop monitoring system. ■

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Istec RecipSys 200

RecipSys 200 is a transmitter-based monitoring- and protection system for reciprocating machinery, that offers advanced rod displacement measurements for rod drop and rod flex applications.

The 2-channel system provides essential monitoring on key mechanical indicators of rider band wear and can be used as a stand-alone system or as an add-on to advanced vibration monitoring systems.

Triggered rod drop measurements

RecipSys 200 indicates the vertical movement of a piston inside a cylinder by measuring the vertical rod displacement, which provides crucial information on rider band wear. By using a phase trigger the position of the rod is measured at a specific point in the cycle, for an accurate and reliable measurement.

Scalable and modular

The RecipSys 200 is designed with a DIN-rail transmitter layout and offers excellent scalability and integrability. Multiple modules can be used for 3 or more cylinder applications. Its modularity allows the integration with other transmitter systems, like crosshead / casing vibration, impact



or temperature, creating cost-effective, suitable monitoring systems.

Cost-effective solution

The module offers simple and effective monitoring rod displacement monitoring system for key mechanical behaviour of reciprocating machinery. The cost-effectiveness and scalability of a transmitter layout makes the system suitable for every monitoring need.

Simplicity over complexity

The RecipSys 200 is the answer to the market need for a financially accessible, simple solution to monitor a single mechanical indicator: rod displacement. No need for an expensive and complex system, but simple stand-alone rod drop monitoring with extensive scalability and modularity options. ■

Learn more: www.istec.com/recipsys-200