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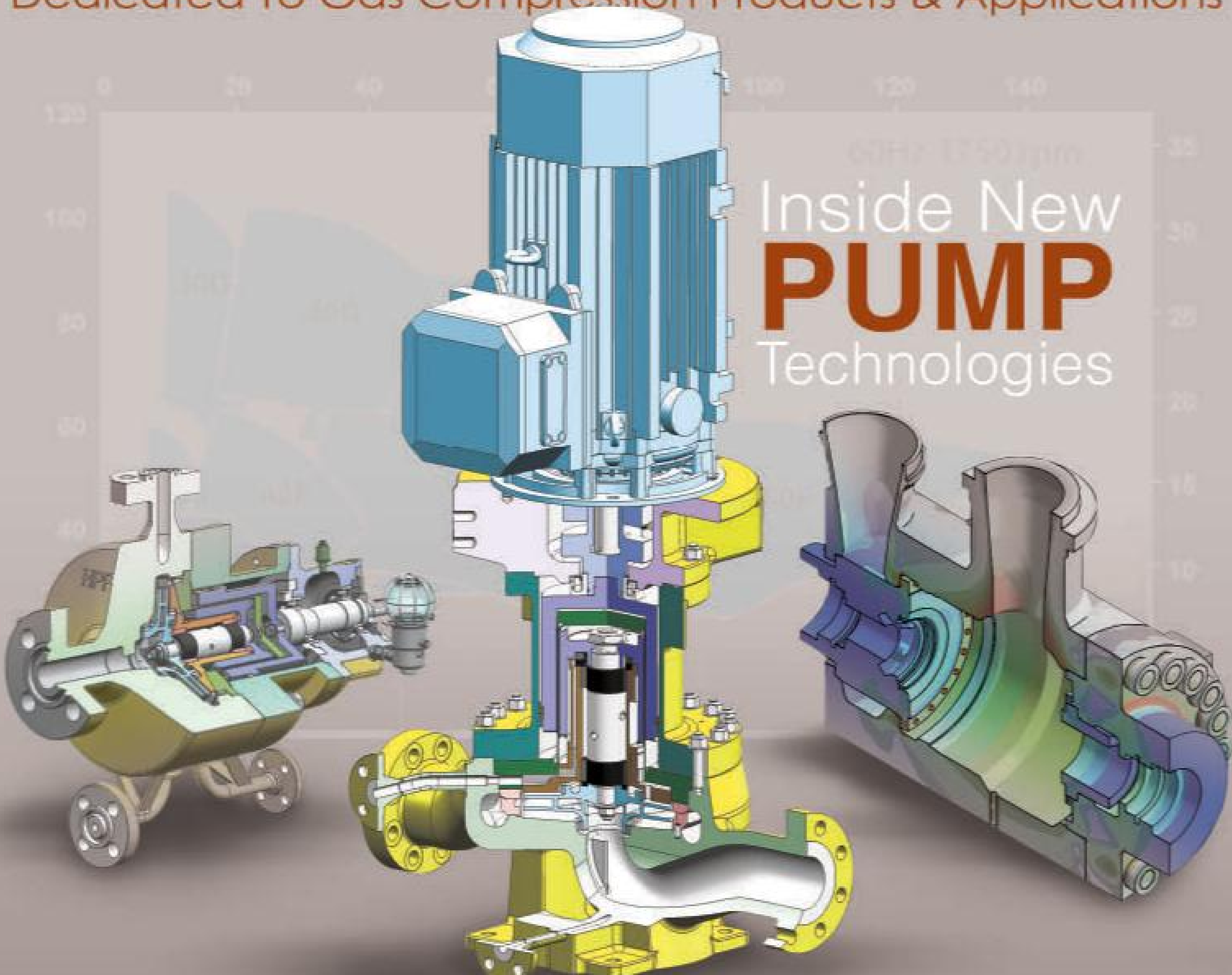

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Reciprocating Compressor Suction And Discharge-Valve Monitoring

> Evaluating the strengths and weaknesses of the most common online monitoring technologies

BY DANIEL GOEBEL

Prognost Systems' failure mode survey of most common reciprocating compressor failure modes shows valve failures among the most frequent root cause for unplanned compressor shutdowns. New valve designs and improved materials have been introduced in the past 10 years and have reduced the percentage significantly. However, for many compressor operators valve monitoring is a main concern when evaluating condition monitoring systems to reduce unplanned downtime.

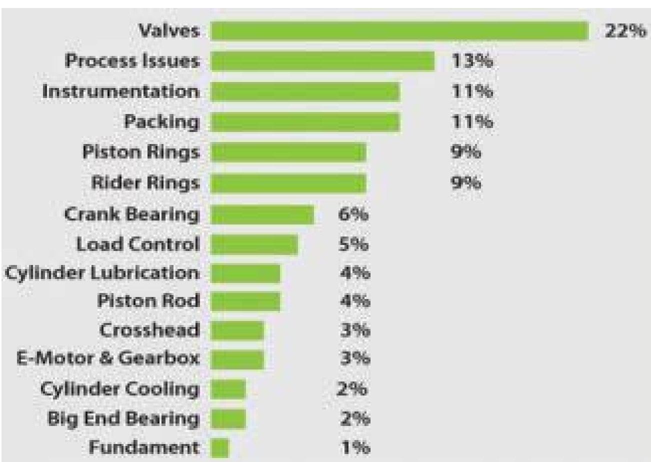

Figure 1. Prognost Systems' failure mode survey 2009; an evaluation of 524 compressor damage records detected at 192 machines, located in 72 different plants.

While the high percentage against other machine failures calls for further improvement, valve leakages in an early stage are usually not safety relevant. Undetected suction valve failures might lead into a complete loss of compression causing more dangerous failures, e.g., seizing crosshead wrist pins resulting from missing rod load reversal.

In the early days of reciprocating machine monitoring, maintenance strategies were mainly based on temperature measurement. Today, different methods of online condition monitoring can be applied to create precise diagnostic information of the valves and other components.

By comparing strengths and weaknesses of temperature monitoring with cylinder acceleration vibration measurement and PV diagram analyses, this article provides a decision making guideline to identify the best suitable permanent monitoring technology for a specific compressor.

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Description of the methods

Highlighting these completely different methods, it becomes obvious that valve monitoring can be improved regardless whether it is delivered with a new machine or retrofitted to an existing machine. In any case, it is the main objective to detect a leakage of a valve that is causing a loss in efficiency of the compressor. Other damages such as broken valve springs or cracks in the valve plate or rings are considered as early stages of a leaking valve.

Valve temperature monitoring

In compressor thermodynamics, it is considered that a gas leakage in either a suction or discharge valve is causing an increase of the gas temperature in the valve pocket. Two installation options are common to monitor the valve temperature:

a) Temperature sensor mounted into the valve cover.
b) Temperature sensor mounted in a sleeve installed in the valve pocket through a drilled valve cover.

In both cases, typically one temperature sensor is installed on each valve cover. The valve pocket temperature provides a higher quality of the measurement in terms of early detection of the leakage. Valve cover temperatures are subject to bigger influences from environmental conditions such as sunlight or wind. Temperature sensors installed through the valve cover into the valve pocket provide an earlier indication of changing temperatures. The signal coming from, e.g., RTD or thermocouple sensors can be transferred to the distributed control system (DCS), to a PLC or machine monitoring system (MMS). In the DCS or MMS, temperatures can be trended to generate long-term information about the valve condition. Condition-monitoring systems provide additional analyses for the signals such as the group deviation analysis to maximize the value of valve temperature monitoring, no matter at which position (cover or pocket) the sensor is mounted.

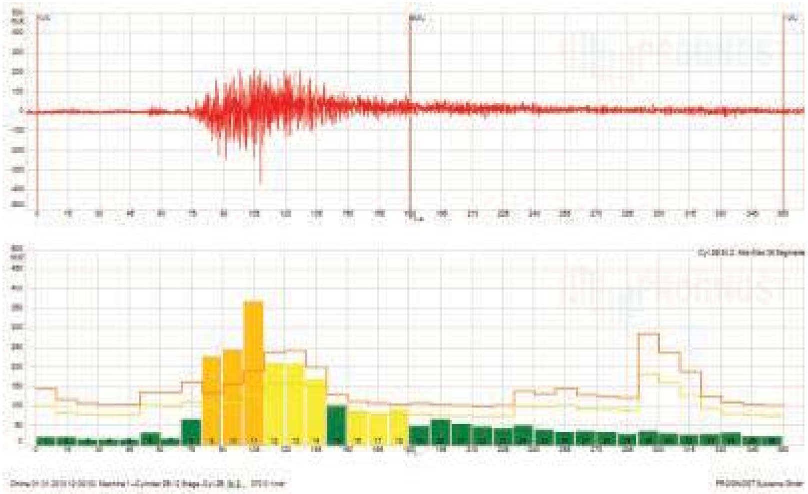

Figure 2. Online acceleration signal and segmented analysis with two thresholds.

PV diagram monitoring

PV diagram analyses require the installation of one pressure sensor for each compression chamber to monitor the condition of suction and discharge valves. The sensors can be installed on indicator taps prepared by the machine manufacturer and may not be mixed up with the suction and discharge cylinder pressure sensor installed in the pulsation dampers or piping. Such taps are required for API 618 machines and typically indicator valves are installed between the sensor and the cylinder to allow easy replacement of sensors without machine shutdown. If indicator taps are not available, e.g., old machines, suction or discharge valves can be modified with a special centre bolt.

PV diagram analyses are based on dynamic pressure measurement and require sensors that allow sampling rates in the kHz range to allow detect small leakages and high frequency pressure pulsations caused by valve dynamics or stepless unloaders. The PV diagram can be visualized with suitable software. Intelligent diagnostic systems automatically monitor the PV diagrams. In addition to the suction/discharge valves, the PV diagram analysis indicates leakage of various other sealing elements such as piston sealing rings, piston rod packing etc.

Furthermore, the dynamic cylinder pressures in conjunction with other parameters, e.g., speed of the compressor,

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Low Cost For Instrumentation	PV, Vibration		Temperature	High Cost For Instrumentation
Early Detection Of Component Condition Changes	PV, Vibration		Temperature	Slow Detection Of Component Condition Changes
Definite Assignment Of Failing Component	Temperature	PV, Vibration		Vague Assignment Of Failing Component
Versatile Usage Of Signal For Monitoring Additional Components	PV	Vibration	Temperature	No Usage Of Signal For Monitoring Additional Components
No CMS Required	Temperature		PV, Vibration	CMS Required

Figure 3. Strengths and weaknesses of valve monitoring methods.

connecting rod ratio and weight of the piston, allows the calculation and monitoring of the dynamic piston rod load and its reversal periods. Piston rod load is amongst the most critical when monitoring the condition and integrity of a compressor and help to identify critical overload conditions.

Cylinder acceleration monitoring

The third method of interest involves acceleration sensors typically mounted on the cylinder. For permanent installation, cylinder vibration sensors can either be installed by screwing them to a drilled thread hole in the cylinder or using a drilled mounting pad that is glued to the surface of the cylinder.

Combining this piezoelectric sensor with suitable software enables users to identify failures of suction and discharge valves based on segmented vibration monitoring, making use of individual threshold monitoring for each segment. The segmented monitoring requires only one vibration sensor per cylinder to monitor four groups of valves (suction and discharge valves on head end and crank end side) on a double-acting cylinder.

Strengths and weaknesses

What are the criteria to be evaluated when deciding about the best suitable method for valve monitoring? Starting point, typically, is a cost-benefit analysis. Examining solely the investment for sensors and the monitoring system is insufficient. Additional effects have to be taken into account such as MTTR optimization, increase in machine uptime or the system's ability to detect critical failures other than valve problems.

Figure 3 shows a simplified view to the different strengths and weaknesses of the methods that are affecting the initial investment, maintenance cost of the valves and associated efforts to operate the measurement loops during operation for the lifetime of the equipment.

Valve temperature measurements are only reasonable in case each valve is equipped with a temperature sensor. This results in a large temperature channel count of at least 16, in most cases 32 channels for a standard four-cylinder compressor. Temperature as a measurement parameter is considered an easy to understand information that reflects the condition of the dedicated valve it is monitoring. The cost for installation and maintenance of the loops stress the budget throughout the lifecycle of the system.

Valve cover temperature measurements with fixed temperature sensors require all valve covers to be drilled for the installation of probes. For this measurement, the valve covers have to be drilled through either by the OEM or retrofitted to the existing covers. This creates a potential source for gas leakage that needs to be maintained throughout the life cycle of the machine.

The advantage of having one dedicated sensor per monitored valve is often neglected in maintenance routines. In most cases if one discharge valve has been identified as damaged; typically all discharge valves on the affected cylinder are replaced and not only the one identified as leaking. Hence the benefit of having one temperature value for each valve is lost.

In the same way the cylinder acceleration vibration mea-

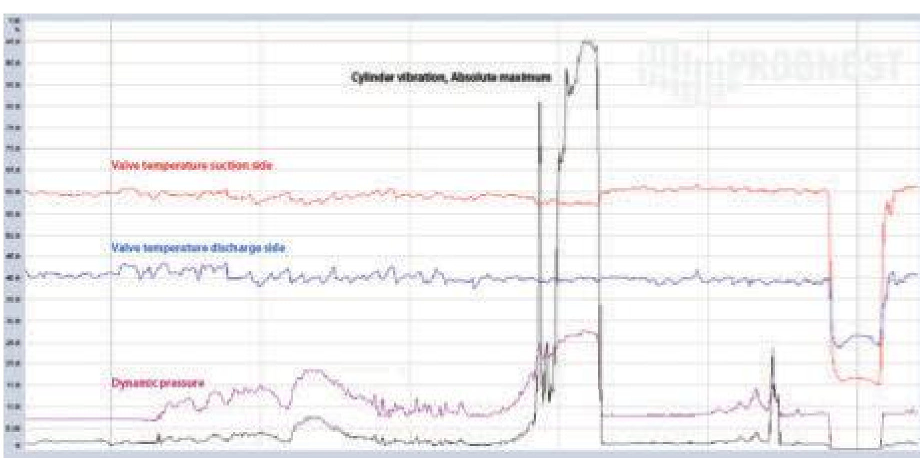

Figure 4. Comparison of trended suction/discharge valve temperature, cylinder vibration and two monitoring parameters derived from pressure measurement three weeks.

surement identifies functional groups of valves on the same cylinder side (head end or crank end). However, this is achieved by installing only one sensor on a double-acting cylinder and applying segmented vibration monitoring of the acceleration signal. This method allows to locally and functionally determine impending valve failures at a very early stage. Vibration impacts are measurable before, e.g., a broken valve plate causes a significant increase in gas or valve cover temperature. Unlike valve temperature sensors, the acceleration sensors mounted on the cylinder do not have to be removed during valve replacements and no gas sealing needs to be checked and maintained after servicing the valves.

Figure 4 shows the temperatures of a suction and a discharge valve (blue/red) along with two monitoring parameters derived from the PV diagram (purple) and one segment of the maximum cylinder acceleration vibration (black) for one cylinder. The change to bad condition became noticeable with the pressure and the cylinder vibration signals. The temperature did not change significantly before the machine was stopped by the operator.

Taking into account the downtime of the machine which is related to the MTTR, the cylinder vibration is most convenient, as the valves can be exchanged without disassembling the sensors. Using temperature measurement, all temperature sensors have to be carefully dismounted before valve maintenance can take place with further time spent to install them back and checking the installation for proper sealing.

While PV diagram analyses and cylinder vibration monitoring call for a suitable monitoring software, the temperature measurement is a simple parameter that can be trended even in less sophisticated systems such as PLC or DCS. However, a temperature increase can be caused by other reasons than leaking valves, e.g., an increase in differential pressure. Such changes in operating conditions can cause false warnings. Furthermore, temperature crosstalk between neighboring valves mounted in angles of 90 degrees or smaller can cause uncertainty on the leaking valve. Only with a more sophisticated monitoring method that compares valve temperatures of the same function, a reliable failure assignment can be produced.

While valve temperature monitoring focuses on the valve condition information, PV diagram and cylinder vibration monitoring provide condition information of additional components as well. Vibration monitoring provides information about the piston rings, the piston and the cylinder liner due to specific changes in the vibrational behaviour.

With PV diagram analyses, piston rings and packing leakages are monitored in addition to the valves. Furthermore, it is the only method that can quantify the amount of leakage of components and therefore provide critical information for maintenance decisions. Based on the dynamic pressure, the combined gas and inertia piston rod load can be calculated — the only way to detect the loss of piston rod reversal conditions

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which are a main cause for severe motion work damages and complete machine loss. A reliable dynamic piston rod load monitoring is a most effective method to reduce the risk of machine failure especially on capacity controlled machines.

If indicator taps are available on the cylinders, as required for new API 618 machines, the advantages of having only two indicated pressure transducers per cylinder along with minimum lifetime maintenance efforts for the indicator valves and the loops itself are inherent of the PV diagram monitoring. State of the art software informs the users of any change in the PV diagram.

The lowest install cost and effort are involved for the installation for the cylinder vibration sensors. The vibration sensors at the cylinder can be retrofitted by gluing special sensor mounting pads to the cylinder casing without violating the mechanical machine integrity.

Guideline for evaluating valve monitoring strategies

Three different options for valve monitoring have been discussed. Each method provides its own strengths and weaknesses. Decision makers have to consider, whether monitoring shall exclusively focus on suction/discharge valves or shall be part of a monitoring solution, covering various machine components. Valve temperature measurements traditionally seem to be the best choice, because they are expected to deliver reliable information — one-to-one sensor to valve. However, for larger cylinders with multiple valves and multicylinder compressors, one acceleration sensor per cylinder with a segmented vibration monitoring provides a better cost benefit ratio as it requires less mechanical work for installation and causes less efforts during valve replacement. This is especially true when suction and discharge valves of one cylinder side are always replaced at the same time.

If advanced monitoring information is required, e.g., on the piston sealing rings or in case a quantitative assessment of the leakage is requested to determine the best time of replacement the PV diagram provides the best results. This is especially true when the compressor is load controlled by (stepless) unloader systems or clearance pockets as those control functions result in changes of the valve temperatures.

General questions to be asked

Is the process or the machine critical?

Yes	No
More versatile and sophisticated monitoring, e.g., PV diagram as should be considered.	Simple monitoring such as cylinder vibration could be sufficient.

Have failures, other than valve failures, been experienced in the past at the machine?

Yes	No
Valve temperature monitoring might be too limited. Cylinder vibration and PV diagram provide more information.	Valve temperature or/and cylinder vibration could be sufficient.

Instrumentation

How many suction and discharge valves are installed on the head end and crank end side of the compressor?

If more than two suction and two discharge valves are installed per cylinder side, cylinder vibration or PV diagram might be commercially attractive. If fewer valves than mentioned above are installed valve temperature should be the choice.

Are free channel inputs available on the local compressor control PLC?

If a sufficient number of channels exists to integrate temperature signals, valve temperature installation could be an alternative to cylinder vibration. If inputs to existing PLC or DCS have to be installed, valve temperature investment cost have to be evaluated carefully.

Is the compressor controlled by a capacity control, e.g., (stepless) valve unloaders?

If so, PV diagram monitoring is the best option to monitor, because it allows monitoring the valves depending on the load condition of the capacity control. Valve temperature and cylinder vibration are more likely to create false warnings.

Installation and maintenance

Are the cylinders fitted with indicator taps?

Yes	No
PV diagram monitoring can be done cost effective and should be seriously considered.	Valve temperature and cylinder vibration provide the smallest installation cost. If required PV diagram monitoring can be installed by modifying the one valve center bolt per cylinder side.

Monitoring tasks

The earliest indication of a valve leakage/damage shall be provided?

Typically the earliest information is received by cylinder vibration followed by valve temperature measurements. Both methods do not allow a quantitative assessment of the leakage volume. This can only be achieved by PV diagram monitoring.

Shall the monitoring solution be scalable and extendable for future expansions?

Best options for upgrades are provided with dedicated monitoring platforms (CMS).

Should other sealing elements e.g. piston rings or stuffing box be monitored?

Other sealing elements especially piston rings can best be monitored with PV diagram monitoring.

Shall the monitoring provide more than valve monitoring?

Cylinder vibration and PV diagram analysis are the most versatile methods that provide further information on mechanical changes, e.g., loose valve cages etc.

Shall the quantity of the leakage be monitored?

PV diagram analysis is the only quantitative monitoring

	Temperature	PV diagram	Vibration
General			
Machine Criticality	-	++	-
Failure History Besides Valves Exists	--	++	-
Instrumentation			
Sensors Required*	32	8	4
Indicator Caps Exist	No Relevance	++	No Relevance
Integration In Existing PLC/DCS	+	--	--
Fault Tolerance With Changing Loads, e.g., Capacity Control	--	++	-
Maintenance			
Installation Efforts	--	+	++
Maintenance Friendliness	--	+	++
Monitoring Tasks			
Early Failure Detection	--	-	++
Diagnostic Information Of Other Components Than Valves	-	++	-
Monitoring Other Sealing Elements	--	++	++
Leakage Quantity	--	++	--
* 4-Throw Compressor			

■ Legend: The better a monitoring strategy meets the specified requirement (left), the better the mark; from low (--) to high (++).

methods that allows to determine the best time for a valve change by assessing the quantity of leakage. CT2

References

[1] 1995 API STD 618 (Fourth Edition 1995): Reciprocating Compressors for petroleum Chemical and Gas Industry Service

[2] www.prognost.com