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Effective Vibration Monitoring For Reciprocating Compressors

Modern standards require frame sensors and more

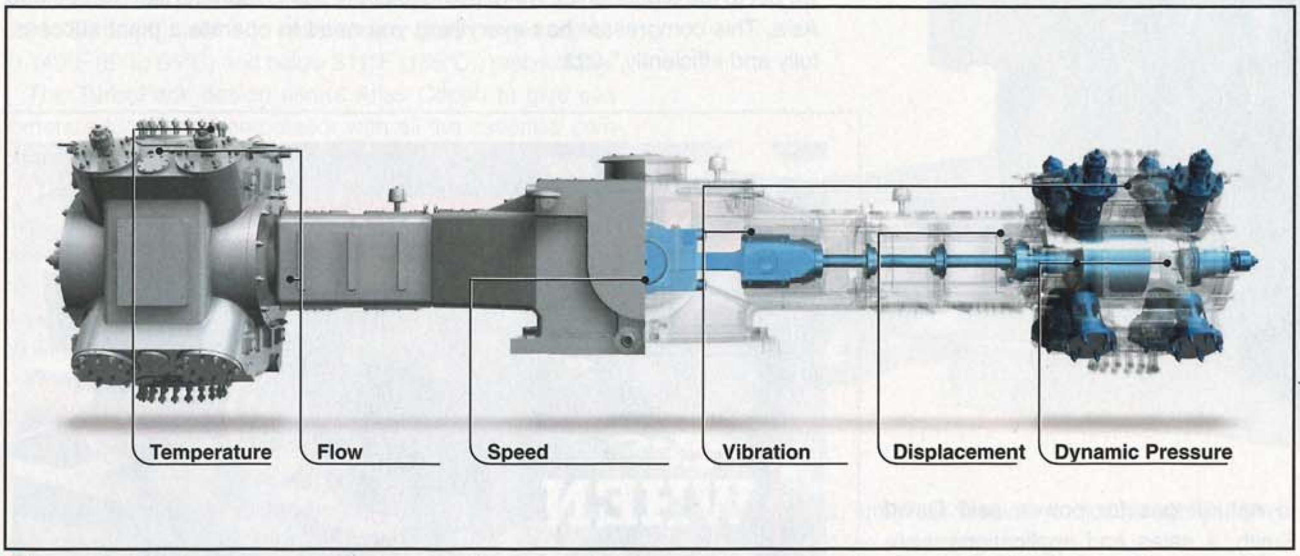

Figure 1. Schematic of the components in a reciprocating compressor and measurement points for the different operating parameters.

BY OLIVER FRANZ AND ALEXANDER HARENKAMP

This paper reviews and discusses the machinery protection philosophy for reciprocating compressors that once was state of the art, and examines how technology, as well as applicable standards, have evolved since the 1970s, a time when many refineries have been built with a large fleet of reciprocating compressors installed.

For decades, reciprocating compressors did not enjoy the high-priority monitoring given to centrifugal machines. The reasons why are partially based on the higher number of centrifugal machines in comparison to reciprocating compressors, and operators just did not fear severe damages due to the lower kinetic energy of these comparably slow-running machines.

However, they show the highest number of damages while being process-critical at the same time. Although this is a crucial combination, insufficient protection and condition monitoring principles are still being applied on some reciprocating machinery.

At all times, operators, engineering procurement and construction companies (EPCs) and original equipment manufacturers (OEMs) have followed the existing, applicable guidelines and standards during the final engineering stage. Those standards were valid at the time of construction, and to a large extent are still valid today. However, upon reviewing the age of the reciprocating compressor population, one will recognize that, in many cases, these large, critical machines have never been replaced and they have been in operation since their initial startup date many decades ago.

To understand why, even after numerous catastrophic failures, we still find inadequate machinery protection on many of these machines, a view into the history of applicable standards can help to lift the fog.

The American Petroleum Institute (API) has always been one of the leading organizations in compiling information about available and proven monitoring technologies for critical machinery and transforming them into standards that have become widely used as guiding standards. It is remarkable that the first revision of the widely known API Standard 670 was released in 1976. It was named "Noncontacting Vibration and Axial Position Monitoring System," a standard focused on the application of proximity sensor-based machinery monitoring. The second revision of the same standard was released in 1986.

As a consequence of evolving vibration-monitoring technology, API has followed up with a parallel standard covering vibration technology within the 1981-released API 678 "Accelerometer-Based Vibration Monitoring System — 1st Edition."

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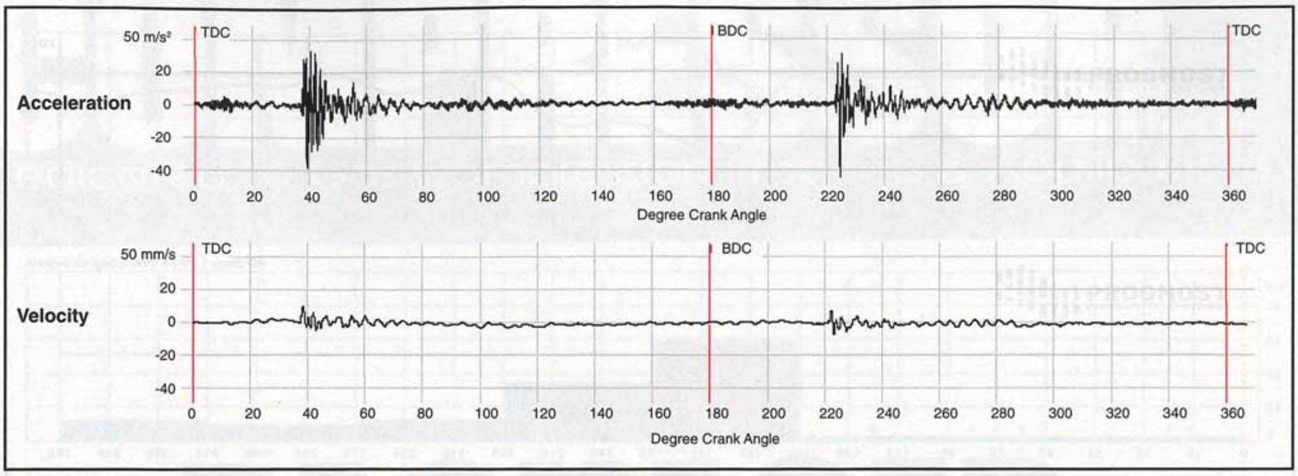

Figure 2. Acceleration and velocity signals in a reciprocating compressor. Usually these machines show very smooth crosshead acceleration characteristics with two distinct impacts around the two rod-load-reversal points. Changes in the acceleration signature and amplitude are a sure indicator of a different mechanical behavior.

The third revision of API 670, released in 1993, was not only an extension and update of the previous API 670, but also incorporated and thereby replaced the API 678 standard focused on accelerometer-based monitoring. To better reflect its safety-relevant character, API 670 was renamed "Machinery Protection Systems" in its fourth edition released in 2000 and still valid today.

From its very beginning in 1976 until the current fourth edition, the API standards covering monitoring of critical machinery focused very much on the technical requirements of centrifugal equipment (e.g., gas and steam turbines, centrifugal compressors). These require monitoring axial and radial shaft positions, speed and surge along with bearing and frame vibration.

Until 2007/2008, when the API 670 fifth edition task force was formed, reciprocating compressors had never been in

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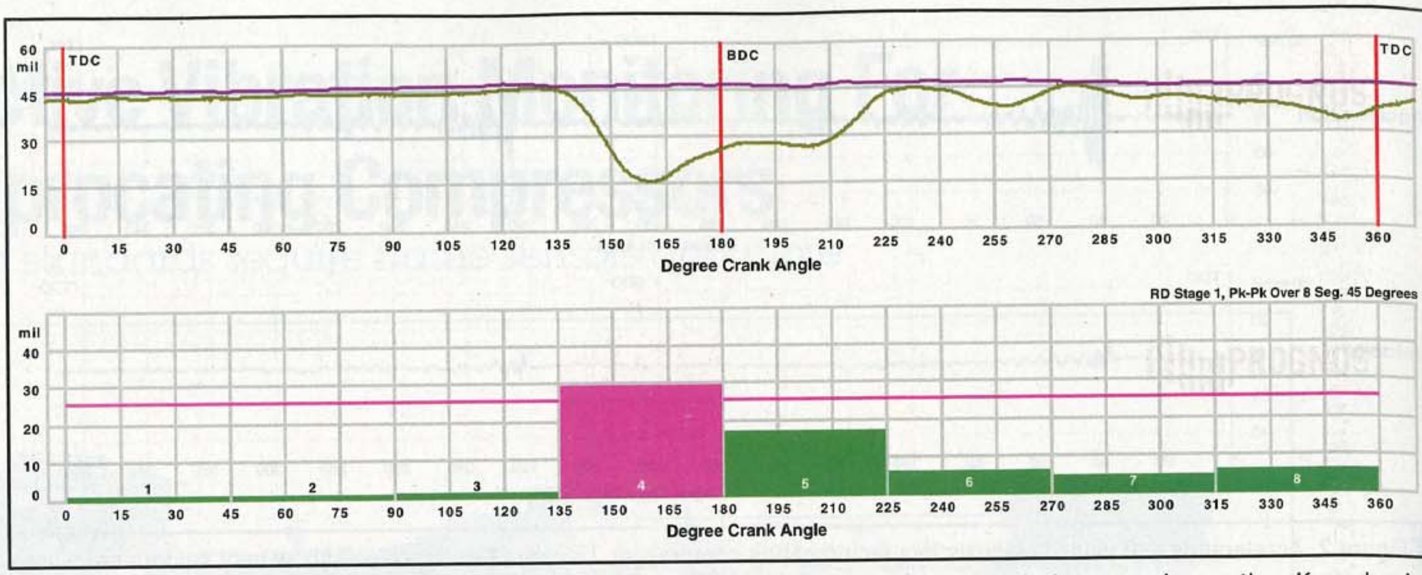

Figure 3. In reciprocating compressors, it is typical for the piston rod to move and bend during normal operation. If mechanical damages and cracks develop, these movements change and can be detected and evaluated using an eight-segmented analysis based on the dynamic rod position signal (shown here: 36 segments, each at a 10° crank angle).

focus within API 670. The API 670 fifth edition, released in November 2014, offers valuable information and guidance on how to effectively protect reciprocating compressors.

Users and machinery protection system vendors have agreed upon the inclusion of applying crosshead acceleration as a safety shutdown parameter, which is a pivotal decision.

While the machine-specific standards (such as API 610, API 611, API 612, API 613, API 616, API 617 and API 618) mainly deal with the aspects of machinery design, installation, performance and support systems, limited guidance for monitoring and safeguarding is offered. API 670 increasingly developed to become the central document of all aspects for machinery protection in one concise standard along with useful appendices, covering machinery with special needs like reciprocating compressors.

This short excurse into the historical background explains to a large extent why we find numerous reciprocating compressors equipped with machinery protection systems originally designed for centrifugal machinery. Two of the most widely adopted approaches that can often be found on aged reciprocating machinery are frame vibrations, measured as velocity, and piston rod position measurement.

Many compressor operators confirm the inadequacy of these outdated systems to protect against the most-feared compressor damages, such as breaking piston rods, seizing wrist pins and other failure modes involving loss of containment in some cases. While old-school systems often miss detecting the development of catastrophic damages in time or at all, users regularly report about a history of nuisance trips due to transient process peaks or single-time, uncritical impacts. Consequentially, operators often consider disarming their outdated protection system and putting their trust in proven maintenance practices and relying on the sturdy machine design.

To understand the limitations of the standard approach of monitoring reciprocating machinery, it is important to understand the difference between a uniform rotating movement of a turbine shaft in comparison to a reciprocating movement. Machines with a uniform rotation typically show almost zero shaft deflection per cycle along with a solid, stiff connection to the ground and virtually no frame vibration detectable.

In contrast, a reciprocating compressor shows a very different behavior, requiring a different monitoring approach. Pistons are driven back and forth by crosshead-type drive trains, involving reversal of piston rod forces from tension into compression, making the entire frame with all its components shake and bend to a good degree. Suction and discharge valves create opening and closing impacts, leaving vibration amplitudes on the entire machine — and we call this a normal operating condition.

When comparing the working principles of a reciprocating compressor with a centrifugal machine, it becomes apparent that a reciprocating unit requires a more dedicated monitoring approach designed to handle all the special challenges reciprocating machinery bears.

Looking at the working principal of reciprocating machines, the crosshead is clearly the focal point. Here, the rotating movement of the crankshaft is transformed into a reciprocating (linear) movement of the piston rod. It is the central component where all the major forces are transferred via the rather sophisticated crosshead pin/wrist pin to the piston rod. In order to facilitate these forces into the right direction, a solid crosshead guide is an integral part of each reciprocating compressor. The crosshead guide is the most direct connection of the moving drive train to the frame and is the best position to install vibration sensors.

As illustrated in Figure 2, reciprocating machinery typically shows very smooth crosshead acceleration characteristics with two distinct impacts around the two rod-load-reversal points. Changes of the acceleration signature and amplitude immediately indicate a different mechanical behavior.

This allows modern machinery protection systems to detect typical failures involving crosshead wrist pin failure, increased crosshead bearing clearance, loose connections between crosshead, piston rod and piston, increased con-rod bearing clearance, piston nut failure and liquid slugs, and eliminate consequential damage.

When installing the sensor on the crosshead guide, it is well worth considering the rotating direction (clockwise/counter-clockwise) of the crankshaft. For best results, it is recommended that the sensor be installed on the top side for up-running crosshead shoes and on the bottom side for down-running crosshead shoes in order to be in-line with the effective direction of forces transmitted to the crosshead.

A brief view into basic physics supports the philosophy of why today many operators rely on crosshead slide acceleration as the primary machinery protection parameter.

To explain why acceleration should always be the first parameter detectable, let's follow this example as an illustration: A car drives from location A to B. At your starting point A, you begin accelerating your vehicle mass long enough (acceleration, [m/s^2]) until you reach the desired speed (velocity, [m/s]) to finally make enough way (displacement [m]) to location B. Note that before any velocity can be recorded, acceleration must be applied to the masses.

Nevertheless, we want to emphasize that frame vibration (velocity) and especially rod position measurement (displacement) provide some good value when applied and evaluated correctly.

Frame velocity can reveal slowly developing foundation issues as well as failure modes involving a high number of impacts with high energy agitating the equipment in its natural frequency range, which can develop a dangerous rate of mechanical movement. The installation of frame vibration transducers often involves voting schemes (i.e., two out of three) to reduce nuisance trips, with two groups of three velocity transducers mounted on the drive end and nondrive end of the frame. Solid reciprocating compressor construction, including the heavy foundation, requires a tremendous amount of kinetic energy provided over multiple strong impacts to reach critical velocity limits. Velocity transducers are typically installed far away from likely failing components where frame velocity is an inaccurate parameter. That should be considered as a second layer of protection only. Please note that modern monitoring systems have the capability to mathematically integrate the acceleration signal over time, delivering a velocity analysis per acceleration sensor location. This finally reduces the value of adding frame velocity transducers to a monitoring sensor scope.

During its early days of implementation, piston rod position measurement can be considered as meaningful as shaft position measurements on a centrifugal machine, applying the same hardware and the same signal analysis logic. The major difference and monitoring challenge that has led to a long-lasting bad reputation of "rod drop" is the simple fact that a piston rod's purpose is not to rotate, but

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to push and pull the piston, which may lead to significant bending of the rod and varying due to different load steps. These effects are not known from monitoring centrifugal machinery to this degree. For its intended purpose — the detection of rider band wear — the signal must be phased and correctly analyzed to keep the rod from bending under different load conditions. Even greater value can be found when analyzing the dynamic component of the rod position signal for machinery protection.

Segmented signal analysis (segmenting the 360° crank angle into portions of smaller degrees) — such as, for example, an eight-segmented analysis determining safety-critical piston rod bending effects — has proven to be highly reliable at detecting loose connections in the drive train, such as piston rod-crosshead and piston rod-cylinder connections, as well as impending piston rod cracks before the rod completely fails.

As described earlier, the piston rod typically moves and bends even during normal operation, but in case of developing mechanical damages and cracks, the behavior of the piston rod changes significantly. These changes can be detected using an eight segmented analysis based on the dynamic rod position signal as shown in Figure 3.

In many cases, old reciprocating compressors may be satisfactorily upgraded with a modern monitoring system instead of being replaced, whether considering safety, machine rerates or increased load conditions.

In conclusion, looking back at the development of the API standards starting in the '70s, it is understandable from where some of the today's standards derived. The once state-of-the-art monitoring approach used on centrifugal machines was adopted and applied on reciprocating machinery. That was the time when frame vibration monitoring and rod position monitoring made their way into the monitoring standards of reciprocating compressors. However, experience has shown that the former standards did not deliver the desired effect in monitoring reciprocating machinery and eventually led to the development of today's modern monitoring approach.

One of the main aspects is to make use of the working principle of a reciprocating compressor and to focus on the crosshead guide in order to detect developing failures early and reliably. Frame vibration measurement simply is too far away from the main functional components, and the velocity-type measurement leads to missed detection. Nevertheless, frame velocity offers some — but very limited — machinery protection value when looking at common failures experienced on reciprocating compressors.

Based on the experience of more than 1000 critical machines equipped, it is recommended to employ crosshead slide acceleration as the prime protection parameter. In addition, applying dynamic piston rod position measurement as a reliable second layer of protection is also recommended. CT2

Prime Movers

CAT Oil & Gas

Caterpillar Oil & Gas has acquired Kemper Valve & Fittings Corp.

Kemper is a manufacturer of high- and low-pressure pipe unions and related oil field fluid control products in the U.S. Their product line includes hammer unions, plug valves, swivel joints, pup joints, hose loops, check valves, pressure relief valves and other high-pressure fittings. The company is headquartered in Chicago and has nine facilities across the U.S. and Canada.

According to Cat, the acquisition of Kemper is meant to expand their well service portfolio to include high- and low-pressure flow iron.

Bacharach

Bacharach Inc., a manufacturer of refrigerant gas detection and combustion analyzers, offers a 24-hour priority calibration and repair service option from its New Kensington, Pennsylvania, location. This option builds on the company's current service support offerings, the company said.

"The main driver for this … service is to keep our instruments in the hands of the technicians who rely on them for their work." said Doug Keeports, president of Bacharach.

When 24-hour service is needed, customers complete a service request form on the Bacharach website, which also includes a pricing guide for all standard service offerings and associated costs.

Bacharach also offers the BSmart pre-calibrated sensor program, where the company sends pre-calibrated sensors directly to the customer on a planned schedule basis. This program allows customers to install pre-calibrated sensors in the field, without the need for returning the instrument for sensor replacement and calibration at the end of its life, the company said.

Chart Industries

Chart Industries' subsidiary, Chart Lifecycle, has acquired Hetsco from Global Power Equipment Group for US$22 million. The combined business venture will look to extend equipment lifespans by offering across-the-board services, including installation, operations, maintenance, monitoring, repair, training and extended warranty.

The move aids Chart's capabilities by adding a full range of welding services for industrial gas and gas processing facilities, including repair, specialty maintenance, construction, fabrication and safety services, with a focus on brazed aluminum heat exchangers.

Hetsco, formed in 1982, provides specialty welding and construction services to the natural gas processing, petrochemical and air gas separation industries.