Recips?
Yes We Can.

Comprehensive hardware, software, and service offerings are now available to address reciprocating compressors

In the mid-1970s, our office in the Netherlands was approached with a special request: Could a proximity probe be used to observe a piston rod as it dropped due to rider band wear? "Yes," was our answer, and a modified thrust position monitor became our first rod drop monitor. Thus was born our lengthy association with condition monitoring solutions for reciprocating compressors.

From those humble beginnings nearly 30 years ago, we're today pleased to offer a considerably expanded offering of hardware, software, and services specifically designed to address the special monitoring requirements of reciprocating compressors using our state-of-the-art 3500 Series Machinery Protection System and System 1™ software platform. Today's monitoring capabilities address far more than just rider band wear with measurements that indicate valve condition, pressure ring condition, pressure packing case condition, crosshead pin condition, and many others.
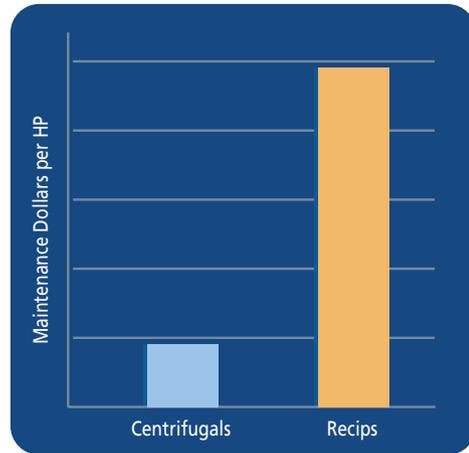
But before we look at that offering in more detail, a more fundamental question is in order: why should you monitor reciprocating compressors?
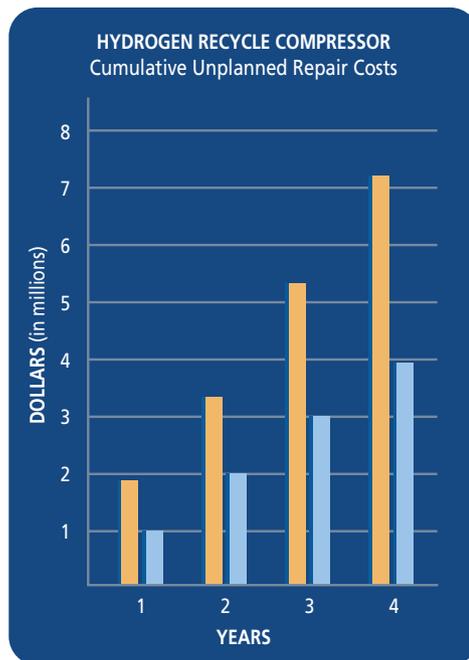
WHY MONITORING

As one of the oldest compressor designs, recips enjoy unique capabilities such as broad capacity control ranges, interstage cooling, the flexibility to efficiently compress gas regardless of mole weight or k value, and extremely high compression ratios. Consequently, they're an ideal fit for selected applications such as hydrogen compression in the de-sulfurization process of many refineries and as part of low-density polyethylene production processes – to name just a few.

However, reciprocating compressors suffer from one very serious drawback: higher maintenance costs. In fact, compared to similarly sized centrifugals, recips can consume as much as five times the amount of maintenance dollars. A condition monitoring system designed to cover the most frequent causes of failure and routine wear in reciprocating compressors can help close that gap, bringing maintenance costs down to the levels associated with centrifugal compressors.

For many facilities employing reciprocating compressors, the machines occupy a critical role in the overall process flow – loss of a compressor often means a significant reduction in or loss of plant output. That lost production translates to very expensive downtime. Thus, maintenance costs are not the only driving factor that can help justify a monitoring system – lost production costs also factor heavily into the economic benefits a monitoring system can deliver.

WHAT MONITORING

A monitoring system for reciprocating compressors – as with any other type of machine – must first consider the types of failures and malfunctions that can occur, and then provide the specific measurements that can detect these problems. Table 1 summarizes both the malfunctions typical of reciprocating compressors and the corresponding measurements Bently Nevada can provide through our monitoring systems.

Recips can consume five times as many maintenance dollars as an equivalently sized centrifugal compressor!

HYDROGEN RECYCLE COMPRESSOR
Cumulative Unplanned Repair Costs

A monitoring system from Bently Nevada will often more than pay for itself in the first year, and can save millions of dollars over the life of the compressor.

Malfunction / Measurement In Detail.

MALFUNCTION [1]

MEASUREMENT	System	Excessive Crankcase and Cylinder Vibration	Excessive Main Bearing Temperature	Excessive Combined Rod Load	Faulty Cylinder Suction Valves	Faulty Cylinder Discharge Valves	Leaky Pressure Rings	Worn Rider Bands	Excessive Piston Rod Flex	Leaky Pressure Packing Case	Excessive Crosshead Bushing/Pin Clearance	Excessive Crosshead Clearance
Frame Vibration [2]	🔴🟡🟢	■										
Main Bearing Temperature [2]	🔴🟡🟢		■									
Crosshead Acceleration [2]	🟡🟢			■							■	■
Multi-Event-Per-Revolution Keyphasor® Signal	🟡🟢			■	■	■	■	■	■		■	■
Cylinder Pressure [3]	🟡🟢			■	■	■	■			■	■	■
Trending and Analysis Software	🟢		■	■	■	■	■	■	■	■	■	■
Piston Rod/Plunger Position [4]	🟢							■	■			■
Suction Valve Temperature	🟢				■							
Discharge Valve Temperature	🟢					■						
Pressure Packing Case Temperature	🟢									■		
Crosshead Shoe Temperature	🟢											■
Suction Gas Temperature [2]	🟢				■							
Discharge Gas Temperature [2]	🟢					■	■					

[1] Detection of a particular malfunction requires all of the measurements checked in that column.

[2] Bently recommends the use of these parameters for auto-shutdown machinery protection.

[3] Rod reversal is recommended as an auto-shutdown machinery protection parameter. This measurement is available from the 3500/77M Recip Cylinder Pressure Monitor.

[4] When applied on hyper-compressors, Bently Nevada recommends that plunger position and vibration be used as auto-shutdown machinery protection parameters.

🔴 Minimal System – Measurements required for basic safety shutdown when catastrophic failure occurs, no condition monitoring or proactive capabilities.

🟡 Basic System – Measurements required for basic compressor protection with selected condition monitoring, some proactive capabilities.

🟢 Recommended System – Measurements required for optimal compressor protection and condition monitoring, full proactive capabilities.

HOW MONITORING

For each of the measurements in Table 1, Bently Nevada can now provide a monitoring solution in our 3500 Series platform. This is done with the appropriate combination of transducers and monitoring modules as summarized in Table 2.

3500/70M Recip Impulse/Velocity Monitor

Casing measurements, such as frame vibration and crosshead acceleration, provide important information on the condition of reciprocating machinery. However, the particular types of recip compressor malfunctions for which casing transducers are recommended often manifest themselves as impact-type events. Such impact events generate high-amplitude, short-duration impulses in the velocity or acceleration signal – almost as if the machine case were being struck by a hammer. These impact events are not generally typical of other machine types where our 3500/42M monitor is the recommended offering.

To address the unique requirements of reciprocating compressors, Bently Nevada has introduced the 3500/70M Recip Impulse/Velocity Monitor. As the name implies, the 3500/70M provides casing vibration monitoring specifically for recips and the impulsive vibration signals they can generate. It provides functionality similar to our 3500/42M, but eliminates configuration features that are not suitable for reciprocating compressors. The monitor also features a unique, enhanced sampling algorithm to ensure that the complete waveform for impulsive events can be captured and displayed properly when the monitor is coupled to our System 1™ condition monitoring software. Additional information on the 3500/70M is available on www.bently.com or from your nearest Bently Nevada sales professional.

Note: The enhanced functionality provided by the 3500/70M monitor will be supported in System 1 software beginning with release 5.0, scheduled for release in mid-2004.

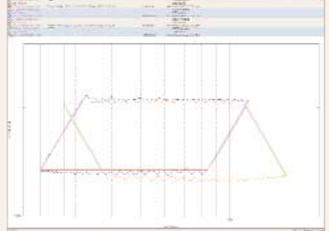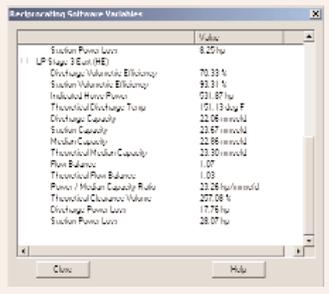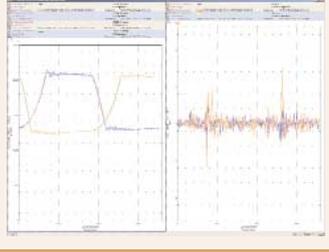| MEASUREMENT	MONITOR	TRANSDUCER
Main Bearing Temperature This measurement indicates problems related to fluid-film bearings including overload, bearing fatigue, or insufficient lubrication.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple
Multi-Event Keyphasor® Signal A proximity probe observing a special multi-toothed wheel on the crankshaft provides a precise reference timing signal every 30 degrees of rotation in addition to a once-per-turn reference point. This allows measurements such as rod position and cylinder pressure to be correlated with a highly accurate crank angle measurement. Rod position can be captured at the same point in the piston rod stroke, and cylinder volume can be computed precisely at each point in the stroke for highly accurate PV curves.	3500/25 Keyphasor® Module	3300 XL Series Proximity Transducer 146973-01 Multi-Event Wheel Kit
Cylinder Pressure Profile The single most effective way of determining the overall health of a reciprocating gas compressor is by examining the cylinder pressure profile. Online access to the internal pressure for each compressor cylinder enables continuous monitoring of cylinder pressures, compression ratios, peak rod loads, and rod reversal. This provides valuable information on the condition of suction valves, discharge valves, piston rings, packing glands, and crosshead pin. And, interfacing the 3500 System with System 1™ software provides valuable diagnostic plots such as Pressure versus Volume (PV), Log P versus Log V, and pressure versus crank angle.	3500/77M 4-channel Recip Cylinder Pressure Monitor	165855 Cylinder Pressure Transducer (see article on next page)
Piston Rod/Plunger Position X-Y proximity probes observing the piston rod provide information on rod bow and rider band wear. Continuous monitoring gives maximum magnitude and direction of rod movement along with the crank angle at which the maximum occurs. The source of movement can be identified enabling the proactive scheduling of maintenance for rider band replacement or crosshead repair.	3500/72M 4-channel Recip Rod Position Monitor	3300 XL Series Proximity Transducer
Suction/Discharge Valve Temperature Suction and discharge valves are typically the highest maintenance items on recips. Faulty valves can significantly reduce the compressor's efficiency as well as increase combined rod load. By recompressing the same gas, a leaky valve becomes hotter than normal, causing the valve cover plate temperature to increase. By monitoring both absolute valve temperature, and differential temperature between a group of valves, valve problems can be spotted early and repaired before efficiency losses mount.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple
Pressure Packing Case Temperature Continuous monitoring of pressure packing temperature provides useful information on developing problems related to the packing including excessive wear, insufficient cooling, and inadequate lubrication.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple
Crosshead Shoe Temperature Continuous monitoring of crosshead shoe (slipper) temperature provides useful information on developing slipper problems such as overload, fatigue, and insufficient lubrication.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple
Frame Vibration Increases in frame vibration can indicate problems such as imbalance due to unusual pressure differential or inertial unbalance, looseness in the foundation attachment (such as deteriorating grout or shims), and high moments caused by excessive rod load.	3500/70M 4-channel Recip Impulse/Velocity Monitor	330500 Velomitor® or 190501 Velomitor® CT Piezo-Velocity Transducer
Crosshead Acceleration Crosshead-mounted accelerometers can detect machinery problems due to impact-type events such as crosshead looseness, liquid ingestion into the cylinder, or excessive clearance in the wrist pin bushing.	3500/70M 4-channel Recip Impulse/Velocity Monitor	330400 or 330425 Accelerometer
Suction Gas Temperature Continuous monitoring of suction gas temperature provides a useful baseline against which to compare suction valve temperature. Relative changes in the temperature between suction valves and suction gas can give an indication of worn suction valves. In addition, suction gas temperature, combined with the integrated equation of state engine in System 1™ software, provides the information necessary to calculate capacity at suction conditions and cylinder flow balance numbers.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple
Discharge Gas Temperature Continuous monitoring of discharge gas temperature can give an indication of worn valves, unloaders, piston rings, inadequate lubrication, excessive compression ratio, or insufficient cooling water.	3500/61 6-channel Temperature Monitor	RTD or Thermocouple
Continuous Rod Load Combined (inertia and gas) rod loads calculated at the crosshead provide information about lubrication condition of the crosshead pin. Insufficient reversal or excessive rod load can be identified and corrected before costly running gear damage occurs.	3500/77M 4-channel Recip Cylinder Pressure Monitor	165855 Cylinder Pressure Transducer (see article on next page)

Recips?

Yes We Can.

In addition to the underlying recip-specific 3500 Series monitoring modules and associated transducers, Bently Nevada is also pleased to introduce a series of recip-specific capabilities in our System 1™ software. By adding condition monitoring software to the underlying monitoring hardware, customers can take an important step forward in their ability to proactively manage these machines. System 1 is able to take the data from the monitoring hardware and process it into additional derived measurements that provide a more comprehensive picture of machinery condition as summarized below.

DATA COMPUTED IN 3500 MONITORING HARDWARE	ADDITIONAL VALUES COMPUTED IN SYSTEM 1 SOFTWARE
⊗ Discharge pressure	⊗ Indicated horsepower
⊗ Suction pressure	⊗ Capacity at suction conditions
⊗ Minimum/Maximum pressure for each crankshaft revolution	⊗ Capacity at discharge conditions
⊗ Compression ratio	⊗ Suction horsepower losses
⊗ Peak rod load for both compression and tension	⊗ Discharge horsepower losses
⊗ Number of degrees of rod reversal	⊗ Theoretical clearance
	⊗ Flow balance of suction to discharge
	⊗ Median capacity between suction and discharge capacity
	⊗ Adiabatic flow balance between theoretical discharge and suction flow
	⊗ Power to median capacity
	⊗ Displaced volume
	⊗ Adiabatic discharge temperature

In addition, System 1 provides several new plot types, specifically for recips. Table 3 summarizes the new plot types.

TABLE 3 >>

NEW RECIP-SPECIFIC PLOT TYPES IN SYSTEM 1		
PRESSURE VERSUS DISPLACED VOLUME	Displays cylinder pressure with respect to the percent of displaced volume. This plot, combined with theoretical overlays, provides information that can be used to diagnose suction valve condition, discharge valve condition, pressure packing condition, and pressure ring condition.	
ROD POSITION PLOTS	Rod Position plots display the total movement of the piston rod at the pressure packing case. Changes in this motion can be caused by changes in mechanical clearance between the crosshead and crosshead guide or changes in mechanical clearance between the rider bands and cylinder bore.	
LOG PRESSURE VERSUS LOG VOLUME	Plotting the PV data on log-log scale axes provides instant information on the expansion/compression process of the compression cycle. Changes in the expansion/compression process can be leading indicators of valve or ring failures.	
PERFORMANCE VARIABLES AT-A-GLANCE	For each cylinder pressure curve collected, right click on the curve to bring up this handy software variable reference box displaying the performance variables for each end of the cylinder. Changes in these performance variables, such as cylinder flow balance, can confirm diagnosis of valve, piston ring, or pressure packing failure.	
X VERSUS CRANK ANGLE	Plotting any X (such as cylinder pressure data) versus crank angle (or any other Y), provides powerful diagnostic tools. For example, acceleration versus crank angle lets the user correlate valve opening and closing with events in the acceleration signal. Cause-and-effect relationships and correlation can be easily visualized and understood.	
ROD LOAD PLOTS	Multiple parameters can be displayed on the same plot. For example, plotting gas and combined rod load with crosshead acceleration provides the ability to immediately identify events associated with reversal in the acceleration signal. Changes in the duration and amplitude of these events can be an indication of excessive wear or clearance at the connecting rod or mechanical looseness between the piston and rod.	
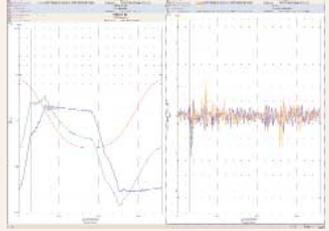
Decision Support℠ – Confidence and Speed

We refer to System 1 software's ability to automatically analyze its collected data and identify developing machinery problems as its Decision Support capabilities. Our first generation "expert" systems appeared in the early 1990s. We quickly learned that while these early systems added value, customers wanted and needed the ability to customize their systems to reflect their specific operating and maintenance practices, "chain of command" personnel notification processes, and machine idiosyncrasies. In other words, for an automated Decision Support tool to be truly useful, the user must be able to personalize it.

We're pleased to deliver such capabilities in today's Decision Support offering within System 1. You can now easily augment the built-in rules and knowledge base with your own. In addition to customizable rules for analyzing data, the system is also totally configurable in its messaging and notification capabilities. For example, you might want to customize the system with special rules that reflect a known set of conditions that, through experience, you've found always indicate crosshead shoe (slipper) problems and are unique to a particular machine and plant – even unique to a particular set of process conditions that are only intermittently present in the plant. However, your ability to customize doesn't stop with just writing rules to identify the problem. You can also generate "intelligent alarm notifications." For example, when your criteria for a crosshead shoe problem have been met, you might have three people in the plant that you want to notify – the plant's on-shift operator, the region's machinery engineer, and the maintenance planner. A different event notification message (with content completely customized to the recipient…even their name and phone number!) can be sent to each individual, with any severity you determine, using any of System 1's notification mediums (process control system alarm, e-mail, cell phone, pager, desktop software notifier, etc.).

We have also introduced a series of pre-configured rule collections – RulePaks – for specific machine types, including reciprocating compressors. RulePaks can be loaded directly into the Decision Support module of System 1, giving you ready-made capabilities to automatically isolate and identify numerous common problems for specific machine types or machine components. Recip-specific RulePaks address many of the most common (and highest-maintenance-cost) problems in cylinders and running gear, covering components such as suction and discharge valves, pressure packing, piston rods, wrist pins, crosshead slippers, and others.

Armed with these Decision Support capabilities, your company's ability to make faster, more confident operating and maintenance decisions is easier than ever.

Services – From Turnkey to Do-It-Yourself

Every customer is different. Some prefer to monitor their machines themselves and install the systems themselves. Others want help with installation, but not with the actual use of the system to perform machinery diagnostics. Still others may require occasional help with balancing or alignment, but little else.

Whatever your needs, Bently Nevada is pleased to offer a comprehensive portfolio of services for reciprocating compressors, including:

- Monitoring system design, site installation, site project management, and full system documentation (both new machines and retrofits)

- System integration to ensure your condition monitoring system can interchange data and information with process control, maintenance management, reliability management, and other pertinent systems

- Balancing and alignment

- Training – for both machinery diagnostic fundamentals and operation/maintenance of monitoring system instrumentation

- Reliability Services including Opportunity/Risk Assessment (see companion article on page 32)

- Lubrication consulting/management

- Foundation/footing problems

- Remote or onsite machinery diagnostics

- Condition monitoring program management

- Support for all Bently Nevada and selected other instrumentation and software solutions from GE's Optimization Services offerings

Summary

Many of today's petrochemical processes are relying on reciprocating compressors more heavily than ever with the machines occupying a critical role that can significantly impact, or even curtail altogether, plant output. Historically, the condition monitoring instrumentation on these machines has been minimal or completely absent. The combination of maintenance expenses that can be as much as five times higher than their centrifugal counterparts, coupled with the significant effect that machine downtime can have on plant production has led customers to seek more

sophisticated condition monitoring capabilities for these machines. Bently Nevada's latest offering provides comprehensive monitoring for virtually every major portion of a reciprocating compressor train, from the prime mover, to the gearbox, to the compressor and its individual components – valves, rings, pistons, rods, rider bands, and much more.
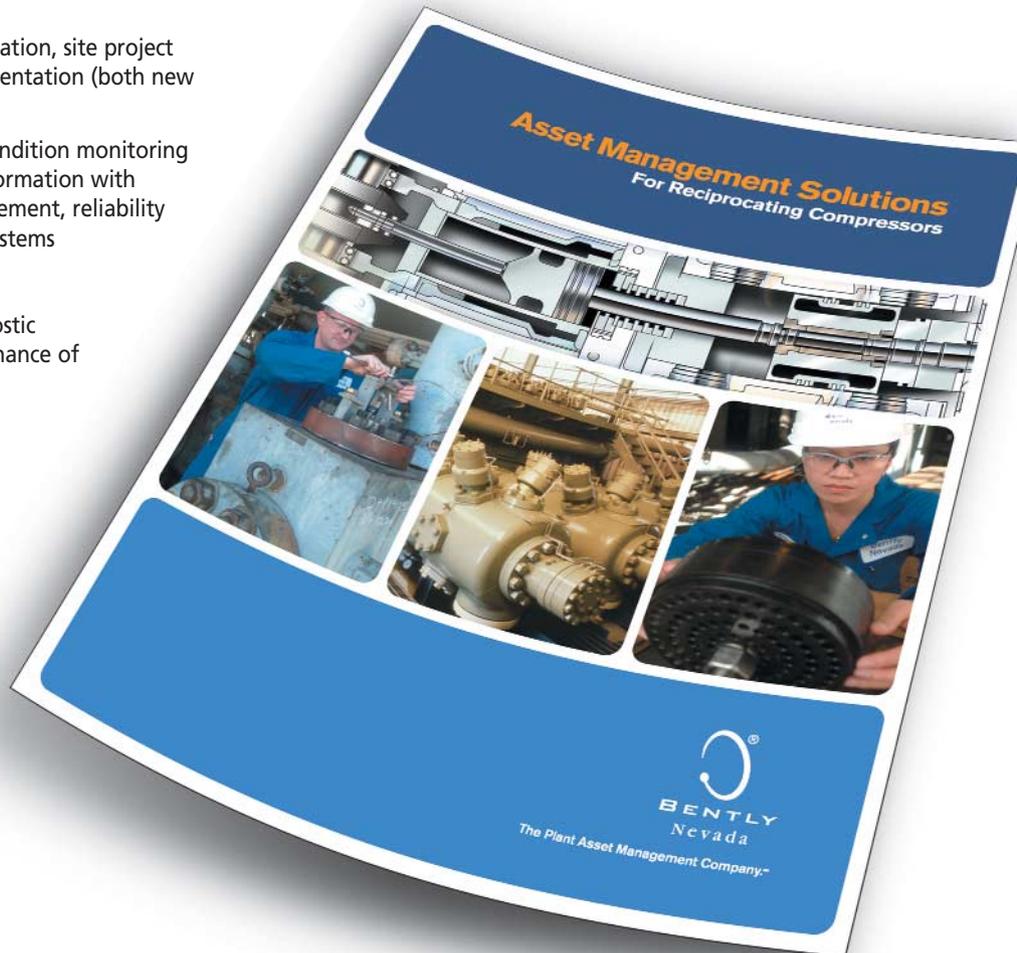
For more information, contact your nearest Bently Nevada sales professional or visit us online at www.bently.com. We've also prepared an informative 16-page brochure outlining our offering in more detail. You can download it from our website, request a copy from your local salesperson, or use the reader service card included with this issue of ORBIT, and we'll be happy to mail it to you.