Improving a compressor protection regime

Analysis of the build-up to the fracture of a compressor crosshead led a refiner to revise its approach to performance monitoring

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Compressor crosshead fractures are costly, leading to unplanned outage of the system and loss of production. Prognost Systems claims that the development of fractures in the motion work, especially on the crosshead, can be detected by using segmented peak-to-peak piston rod position analysis. The company also recommends this as a mandatory parameter and for safety interlock. This claim was proven to be true by a complete fracture of a crosshead which could have been avoided if the automatic interlock had been activated by the operator. The experience of this case also motivated the operator to improve their site shutdown philosophy.

The installation

At a refinery in the US, a Nuovo Pignone reciprocating compressor was put into operation in 2004. Since the initial start-up, a Prognost system had been used to detect common faults such as valves, riders, rings and others. The compressor's overall reliability had been very good. No failures in the motion works components occurred; no Prognost safety alert or alarm limit of CHS vibration (active) or rod position (inactive) had been reached.

Failure history

In 2011, the compressor had its first major overhaul in seven years due to a knock. Several parts such as a first stage connecting rod, bearings, crosshead pin and the main bearing liners were replaced. The crosshead failure described here occurred 11 months after these service works

2/29/2012 17:55		Status Main Alarm (2MP) for 'C200-A' activated !!!
2/29/2012 17:55 ST 2	V CHS ST2	Status Main Alarm dead center activated !
2/29/2012 17:55 ST 2	V CHS ST2	Status Pre-Alarm Safety limits violated in the following segments: 32 34 35 36
2/29/2012 17:55 ST 1	V CHS ST1	Status Main Alarm dead center activated !
2/29/2012 17:55 ST 1	V CHS ST1	Status Pre-Alarm Safety limits violated in the following segments: 32 34 35 36
2/29/2012 17:55 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:55 ST 1	V CHS ST1	Status Pre-Alarm Safety limits violated in the following segments: 5
2/29/2012 17:55 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:54 ST 1	V CHS ST1	Status Pre-Alarm Safety limits violated in the following segments: 6
2/29/2012 17:54 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:53 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:52 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:51 ST 1	RD ST1	5:51:00 PM Rod drop cylinder ST1 Peak-Peak over 8 Seg. ..45 degrees Segment: 4 |
2/29/2012 17:51 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:51 ST 1	RD ST1	5:46:00 PM Rod drop cylinder ST1 Peak-Peak over 8 Seg. ..45 degrees Segment: 7 | 5:45:00 P
2/29/2012 17:46 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:45 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:41 ST 1	RD ST1	5:38:00 PM Rod drop cylinder ST1 Peak-Peak over 8 Seg. ..45 degrees Segment: 8 | 5:38:00 P
2/29/2012 17:38 ST 1		Damage class: 'Crosshead / Piston Rod/ Piston' ST 1 correlation: 100.0 %
2/29/2012 17:31 ST 1	RD ST1	5:28:00 PM Rod drop cylinder ST1 Peak-Peak over 8 Seg. ..45 degrees Segment:
2/29/2012 17:28 ST 1	RD ST1	Safety Unsafe RD ST1 - Peak-Peak over 8 Seg. ..45 degrees: safety plausability violation

Figure 1 The logbook of the last 30 minutes before the fracture illustrates the sequence from the first diagnostic messages (green) to pre-alarm (orange) to the main alarm (red)

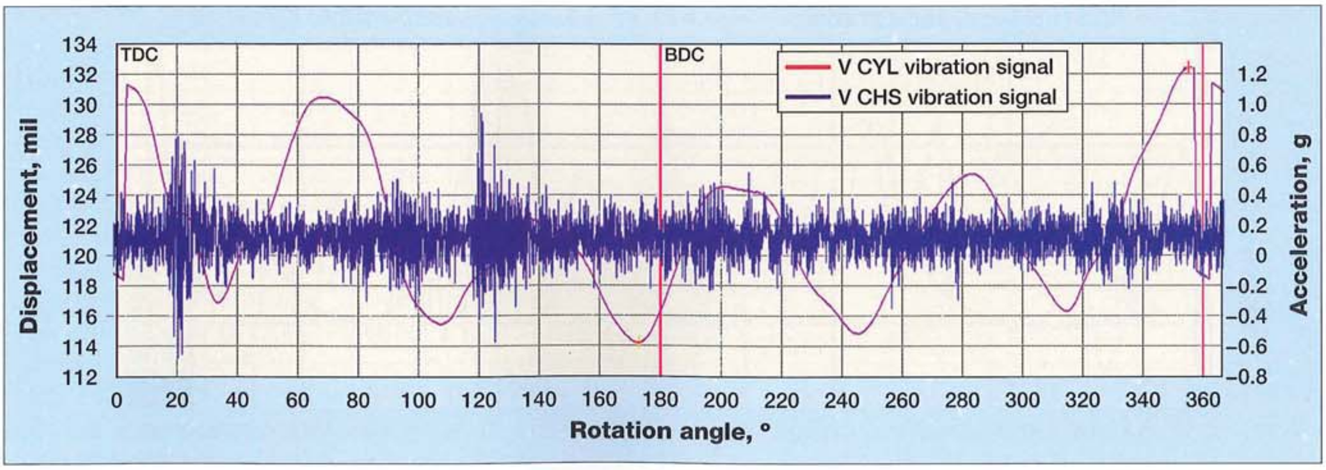

Figure 2 The normal online signature of the compressor seven days prior to the event (CHS RMS vibration = blue; piston rod position = red curve)

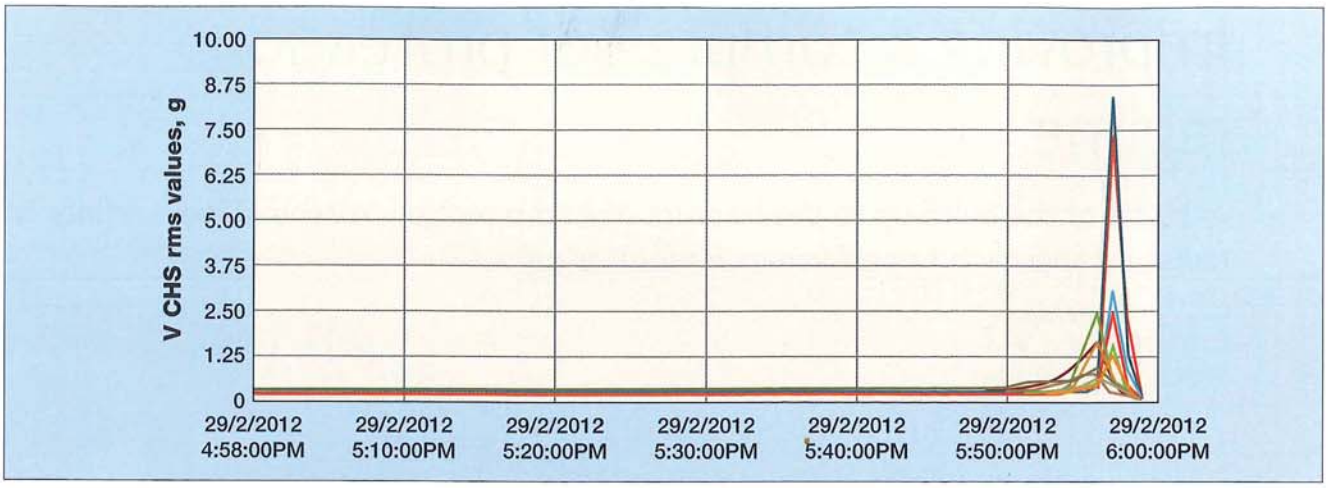

Figure 3 The crack development is visible in the RMS short term trend two minutes prior to the fracture, but only in four segments (33, 34, 35, 36). Six were needed for the trip

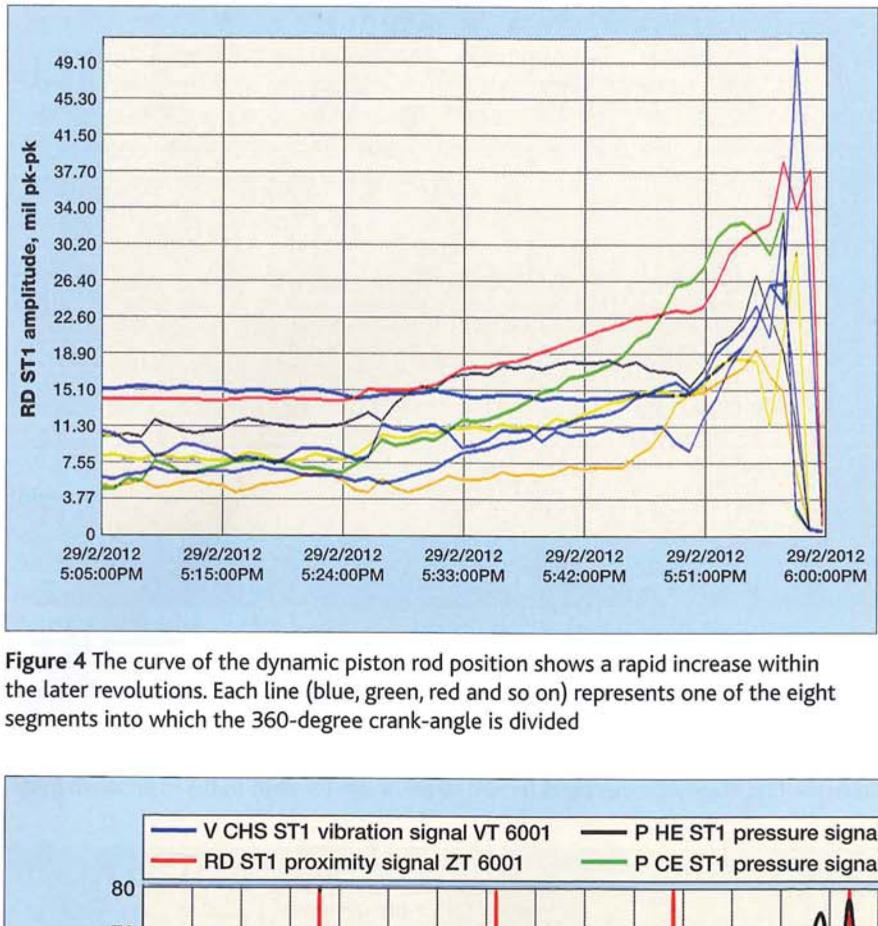

Figure 4 The curve of the dynamic piston rod position shows a rapid increase within the later revolutions. Each line (blue, green, red and so on) represents one of the eight segments into which the 360-degree crank-angle is divided

had been carried out by a non-OEM contractor.

Development of the crosshead fracture

At the time the event started, the compressor was running steadily at a normal load of 75%:

- Twenty-nine hours prior to the break, the Prognost-NT system issued the first diagnostic message. It reported the following damage class: 'Crosshead/Piston Rod/Piston Stage 1 with a correlation of 100%'
- During the following minutes, there was a steady increase from the first diagnostic message (pre-alarms) to alarm (shutdown). In addition, the vibration safety limits of the crosshead slide were violated in several segments
- Sixty seconds before the crosshead failed, the first stage piston

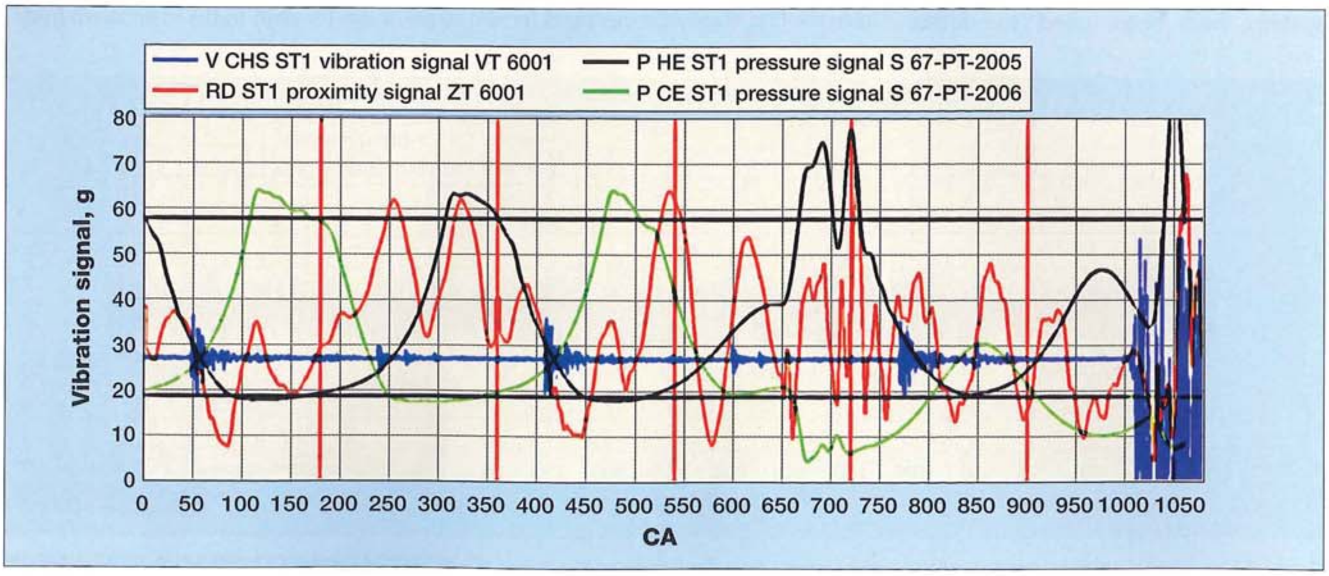

Figure 5 The green curve indicates the loss of pressure within the compressor caused by separation of the crosshead

rod position reached trip levels

- After the crosshead parted and the vibration alert conditions on both crossheads were reached, automatic shutdown was initiated on the crosshead slide vibration
- On previous trips, the operators had seen the low oil pressure annunciator on and assumed that was the cause of the shutdown, when in reality this is one of the alarms that comes in when the machine is tripped offline and is coasting down. They checked the oil system, found it to be good, and restarted the compressor 32 minutes after the safety shutdown.

A log of the 30 minutes leading up to the fracture is shown in **Figure 1**.

Data analyses showed that the crosshead slide vibration and the rod position were both giving a normal online signature seven days prior to the failure (see **Figure 2**). The crosshead vibration safety limits were set between 2.0g and 2.3g.

Sixty minutes before the event, the crosshead vibration and the rod position were well below the safety limits. Two minutes prior to the fracture, development of the crack was visible in the CHS vibration RMS analysis in four segments (see **Figure 3**). For the safety shutdown, violations in six segments were needed.

Compared to the crosshead, the rod position increased 10 minutes earlier, averaging 51.23 mils 60 seconds prior to the trip. Some 15 seconds before the trip, the rod position reached 71.2 mils, exceeding 90 mils during the last three revolutions (see **Figures 4-6**). The sequence of events is shown in **Table 1**.

Taken together, all of the gathered data fully illustrated the reaction of the system shortly before the separation of the crosshead as well as what happened when the operator team overruled the shutdown initiated by the Prognost system. The shutdown settings from the site acceptance test (SAT) protocol showed the detailed safety limits and criteria for the activation of pre-alarm and main alarm. It also proved the disabling of analyses by resetting the safety alarm if the machine stops.

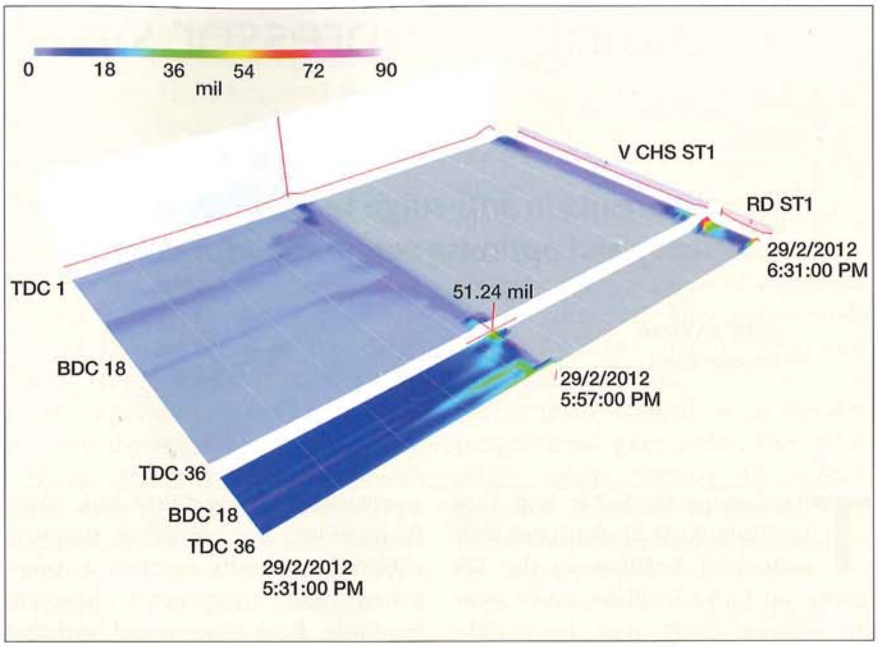

Figure 6 3D Waterfall trend of one hour. The blue surface represents the RMS of crosshead vibration over a 360-degree crank-angle: reaction after the operator overruled the trip released by the Prognost system

A new safety shutdown philosophy

After the complete fracture of the crosshead, the data analyses led to several conclusions on the operator's side. First of all, Prognost monitoring showed that the developments of this type of crosshead fracture cannot be detected at an early enough stage by using the crosshead vibration alone. The use of piston rod position measurements has proven to be a reliable factor for safety protection.

As a result, the monitoring of piston rod measurements is now part of the site shutdown philosophy on machines equipped with Prognost at the refinery. In addition, operators are no longer permitted to restart a compressor tripped by a Prognost system. Thus, the Prognost-NT system now helps to avoid costly damages to rotating equipment, lowering outage and securing productivity at the refinery.

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Sequence of events leading to shutdown

Time	Event	Cause
SAT	Crosshead RMS safety limits settings between 2.0g and 2.3g	
-7 days	Crosshead RMS ~0.4g, rod position ~18 mils	
-29 hrs	Diagnostic message	'Crosshead, Stage 1, 100%'
-10 min	Rod position ~22 mils	
-120 sec	Crack development visible	CHS RMS vibration (4 of 6 segments)
-60 sec	Prognost main alarm (automatic trip deactivated by customer)	1st stage piston rod position (51.24 mils)
	Pre-alarm	1st stage CHS RMS vibration
-15 sec	Rod position 71.2 mils	
Last 3 revs	Rod position exceeded 90 mils	
	Crosshead parted	
	Pressure curves show crosshead separation	
17:55 hrs (5:55pm)	**Compressor tripped**	**RMS crosshead vibration Stage 1 and 2**
+32 min	Restart by operators on deck Immediate shutdown by Prognost-NT	

Table 1