Successful Avoidance of Major Secondary Damages Using Proximity Measurements to Detect a Partially Fractured Piston Rod

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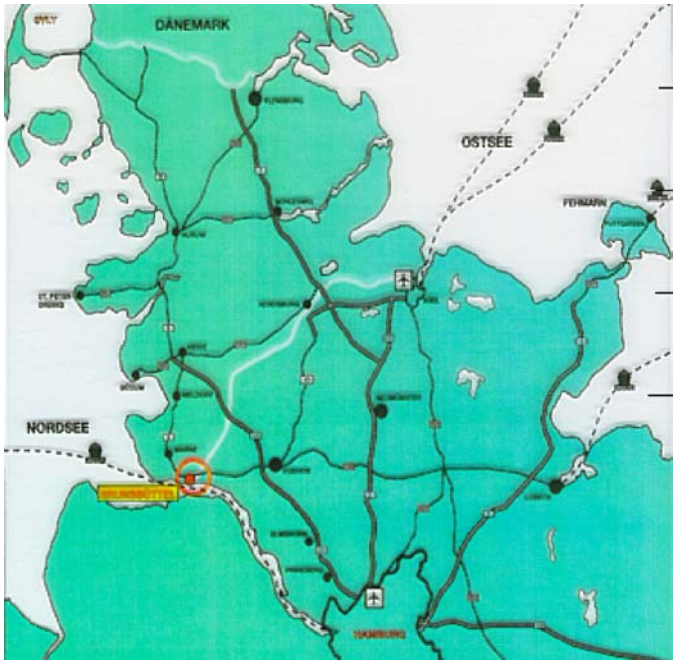
Plant Location - Brunsbüttel, Germany



Production	t / day	t / year
Ammonia	1,950	690,000
Urea	1,450	500,000
Argon	60	21,000
Sulphur	50	17,000

Compressor Data

Machine type:	4-throw, horizontal, double-acting, 4-stage
Stroke:	300 mm (11.7 in.)
Piston diameter:	920, 500, 280, 160 mm (36, 20, 11, 6 in.)
Speed:	424 RPM
Power:	2,700 KW (3,600 HP)
Year of manufacture:	1977
Medium:	CO2 (~98.5%)
Suction pressure:	1.8 bar (26 psig)
Discharge pressure:	165 bar (2,400 psig)
Flow rate:	13,000 Nm3/h
Capacity control:	fine tuning by suction pressure

GB-101B

Background

• Site has operated two identical 4-throw reciprocating compressors in carbon dioxide service since 1978.

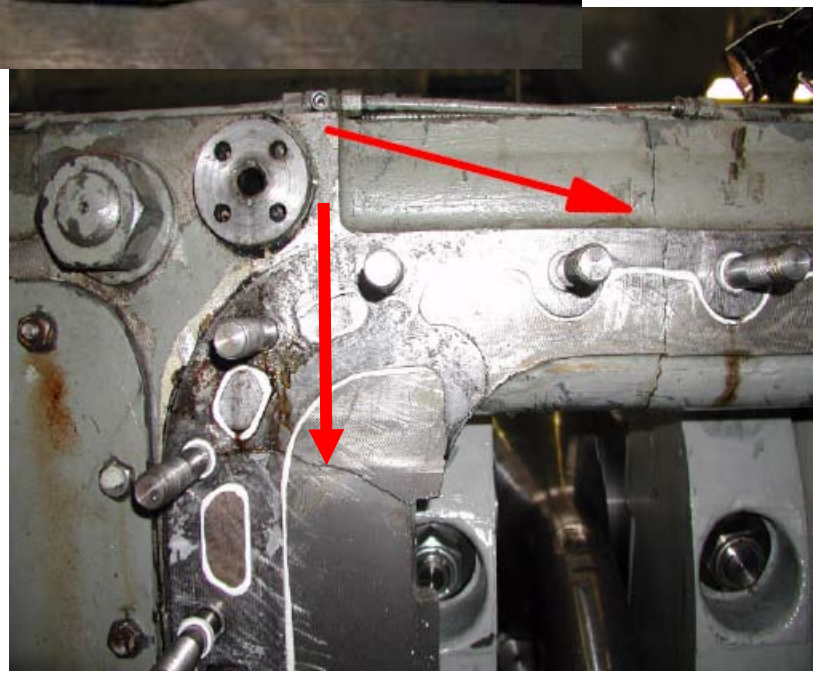
• Since 2001, when an on-line condition monitoring system was installed on both compressors, numerous component failures have been detected by the system including: rider band wear, valve problems and loose components (valve cages, etc.)

• In 2002 the automatic machinery protection function of the system limited additional consequential damages caused by a piston rod failure, utilizing crosshead acceleration as the only shut down parameter.

Failed Components - 2002 Rod Failure

Photos of damaged components

Damaged piston rod



Ripped casing

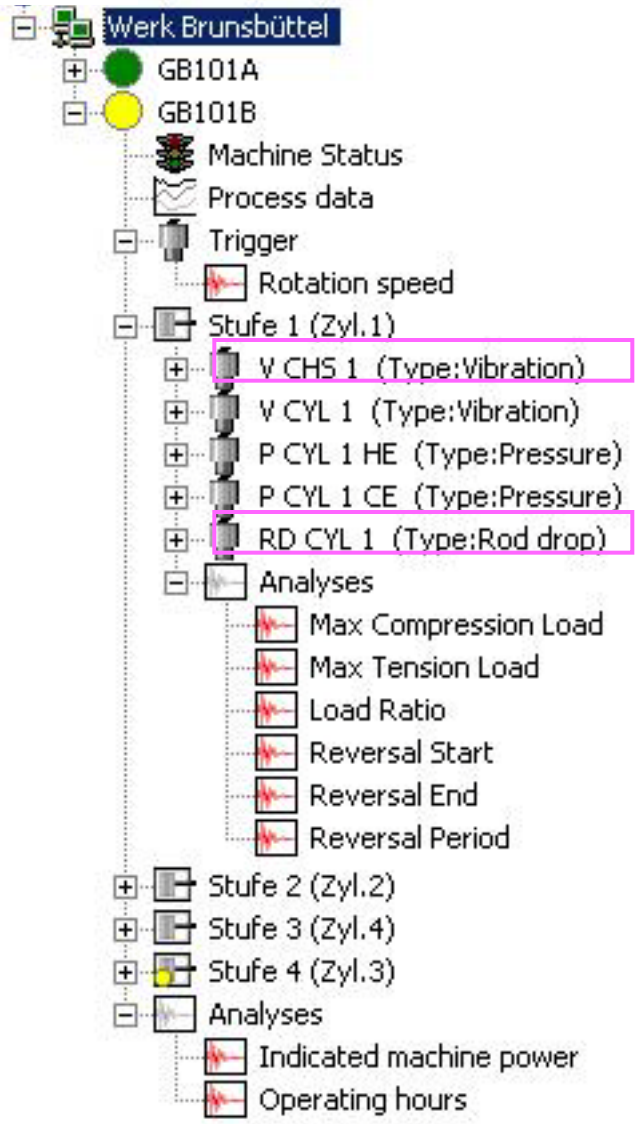
Bent con-rod

Background (cont'd)

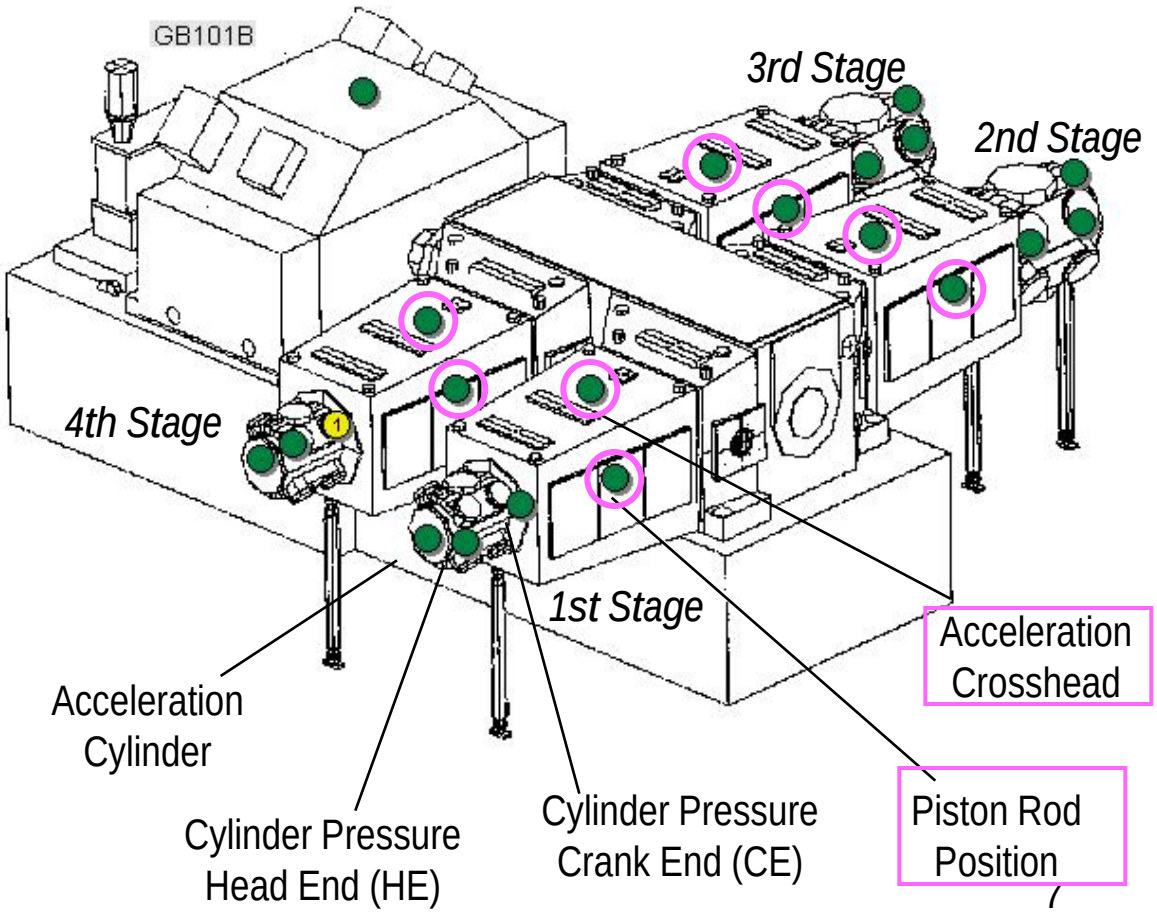
• In 2006 piston rod position signals from the existing rod drop probes were added to the machinery protection function, initiated by YARA from the experience in 2002, that piston rod movement increases rapidly a short time prior to complete failure

- In Sept. 2007 the system successfully avoided potentially major cost-intensive damages to one compressor by detecting the development of a cracked 1st stage piston rod and automatically tripping the machine prior to complete failure, using peak-to-peak rod run out analyses.

Sensor Positions



Safety shutdown relevant sensors (2007)



Photograph of Affected Cylinder (1st stage)

Photograph of Proximity Probe (1st stage)

Sequence of Events Sept. 6, 2007

- Site planned to operate above rod load design limits to:

  - simulate a capacity increase of the urea process and
  - identify potential bottlenecks of the urea plant caused by an increased flow rate in advance of installation of an additional new compressor and HP equipment

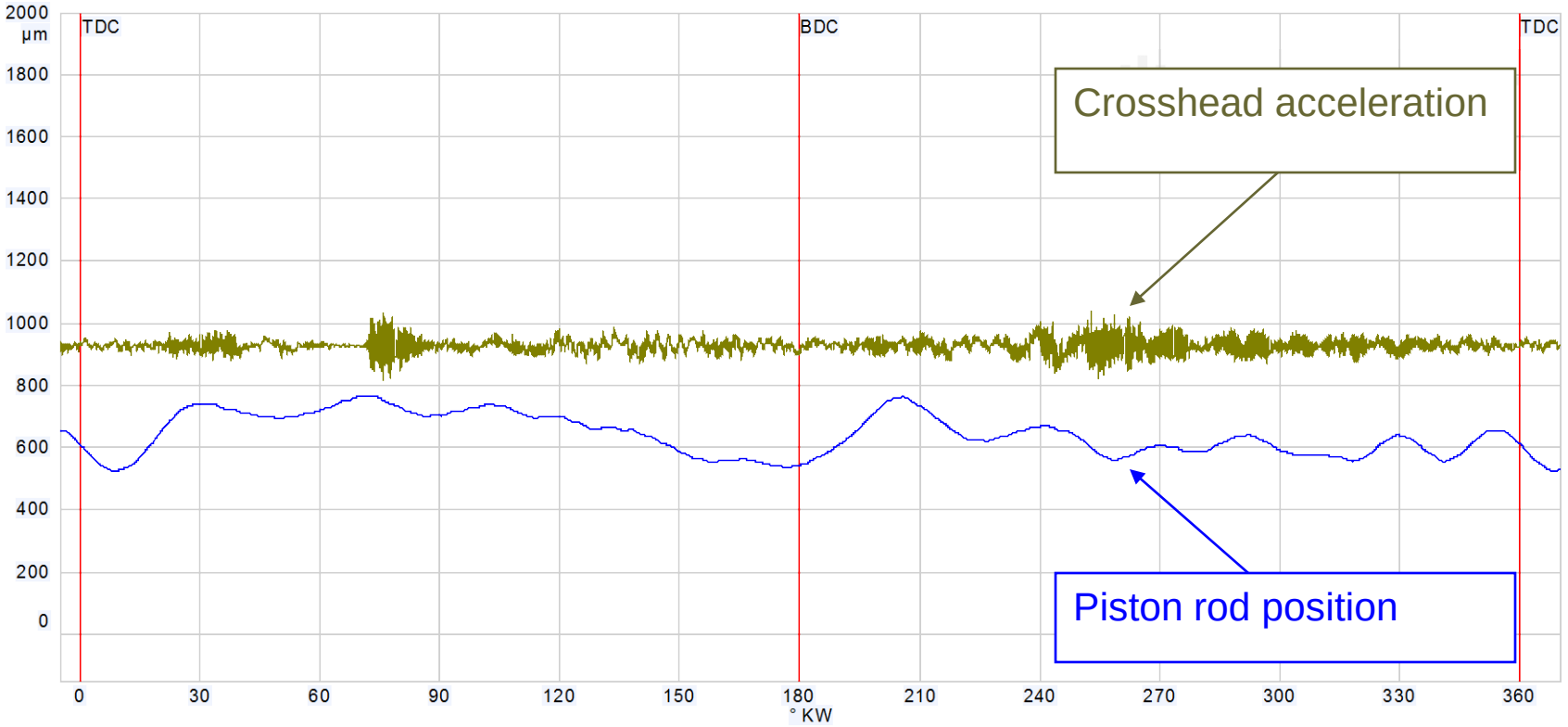
<u>Note:</u> After 6 years of experience with this machine monitoring system site was confident that the compressor would be safely tripped in time if the overloading caused mechanical problems.

- Trip limits for rod run out analysis were set corresponding to operating conditions

Data Analysis

Crosshead Vibration & Rod Position

Normal signatures 1st Stage - 10:00 am Sept. 6 (before change)



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	GB101B	KKB Stufe 1, Z1	Schwingungssignal		-250,0 - 250,0	m/s²
	GB101B	RD Stufe 1, Z1	Kolbenstangenlage-Signal		0 - 2250	µm
	GB101B	Stufe 1, DS, Z1	Durchstichpunkt Expansions-Linie durch Saugdruck		0 - 150,0	° CA
	GB101B	Stufe 1, KS, Z1	Durchstichpunkt Expansions-Linie durch Saugdruck		0 - 150,0	° CA
	GB101B	Stufe 1, DS, Z1	Durchstichpunkt Kompressions-Linie durch Enddruck		0 - 150,0	° CA
	GB101B	Stufe 1, KS, Z1	Durchstichpunkt Kompressions-Linie durch Enddruck		0 - 150,0	° CA

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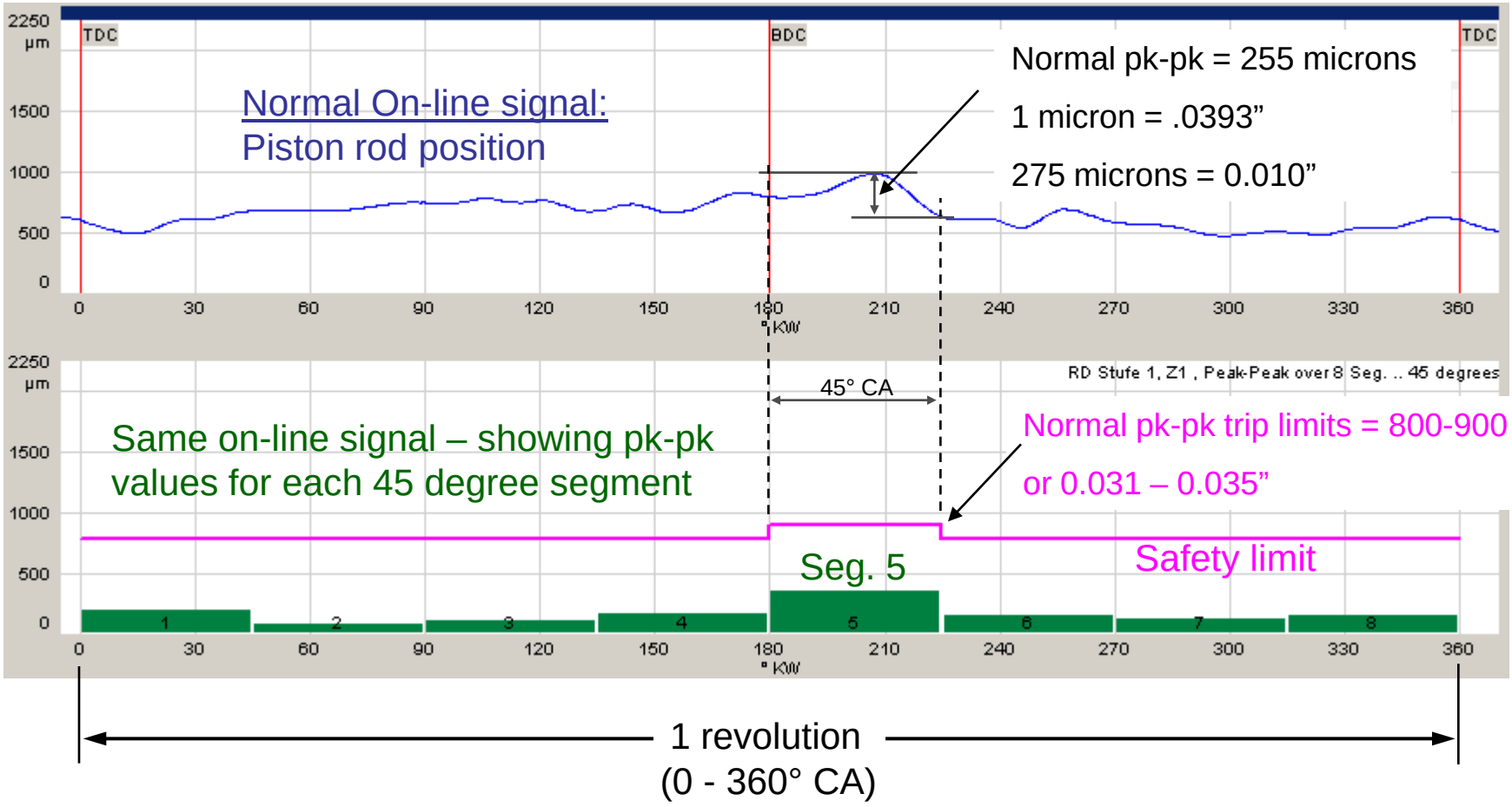
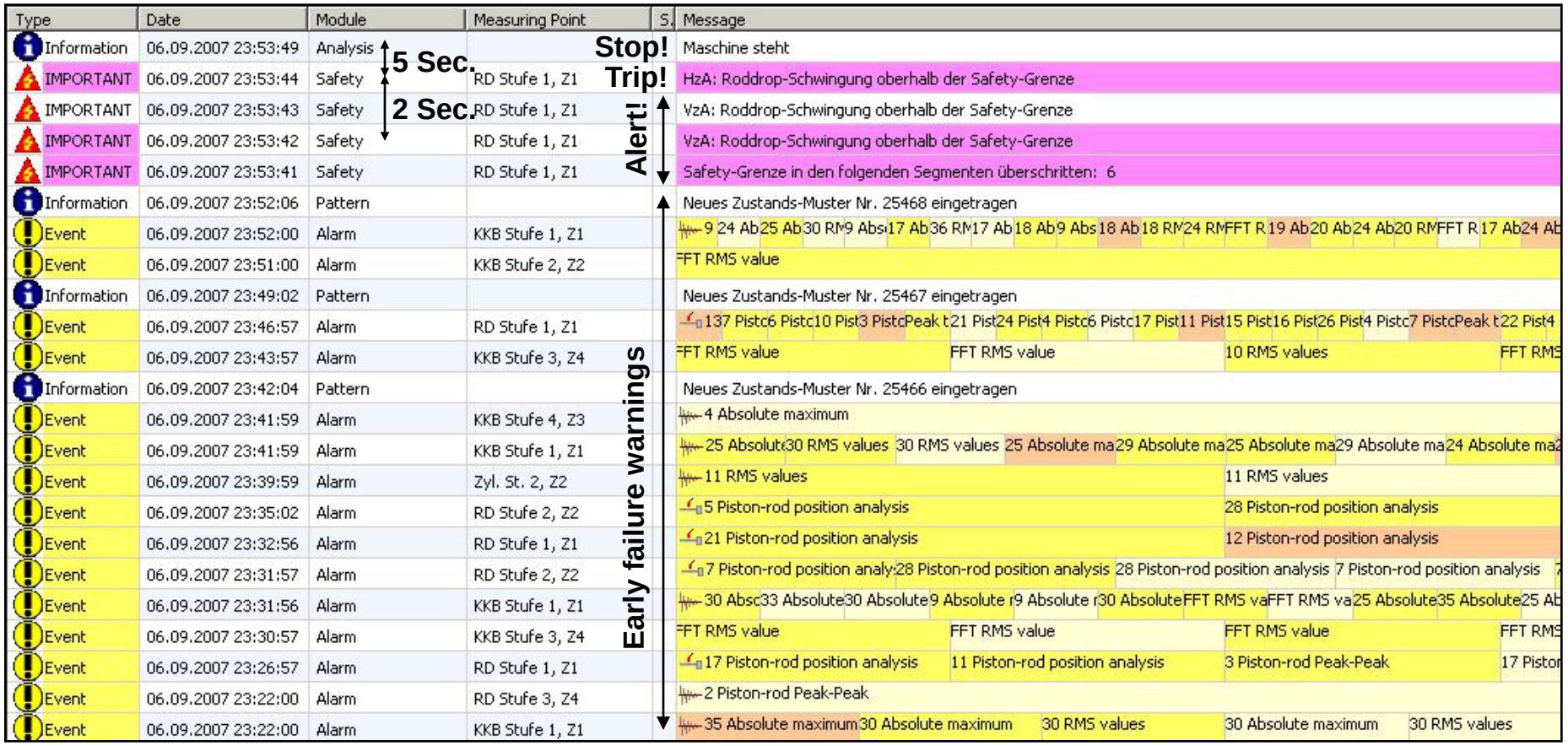
Definition of Analysis

Piston rod position, peak-to-peak, 8 segments



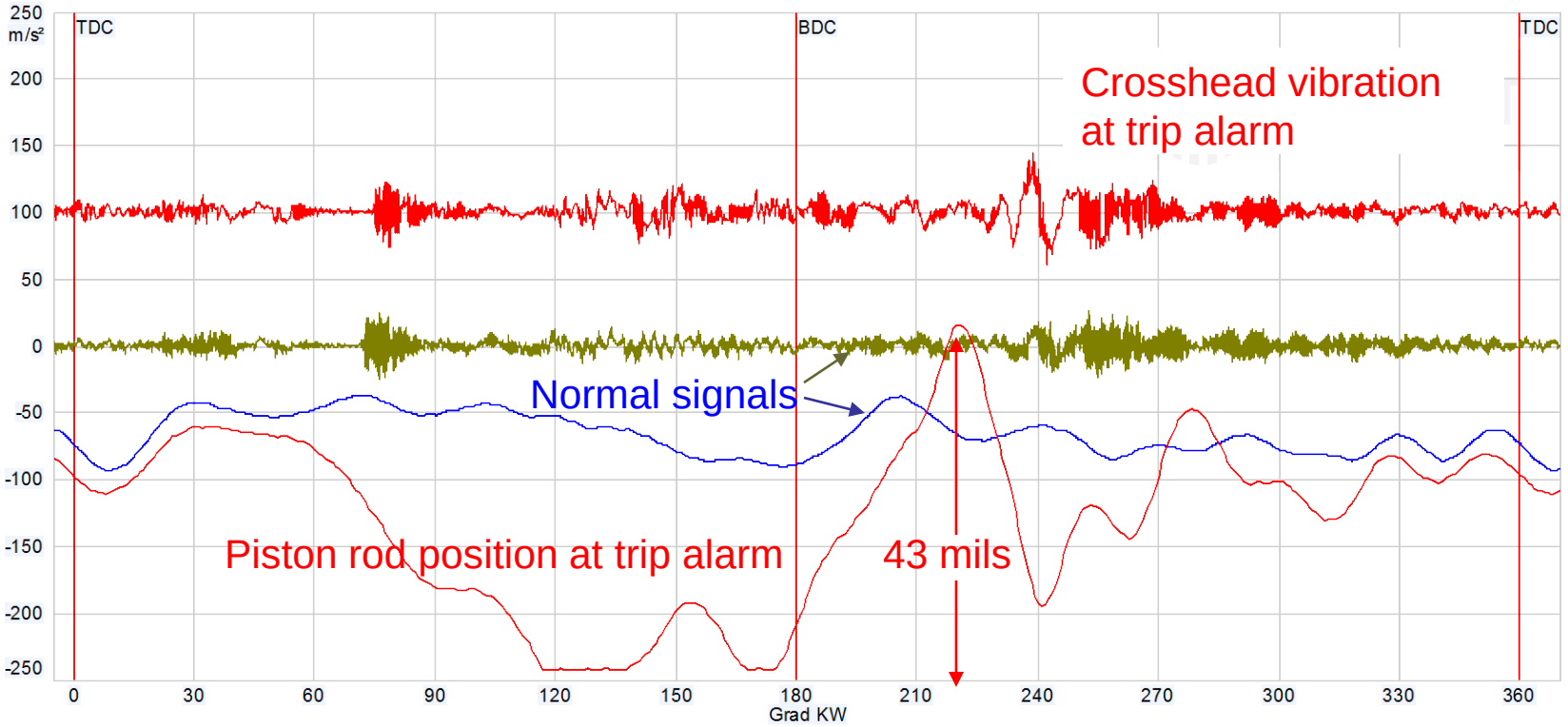
Data Analysis - 4 hr. Trend (following process change)
Rod Position - Segment 6 (60-70 deg Crank Angle)

System Log Book
Warning and Alarm Outputs (20 min.)



Data Analysis

Crosshead Vibration & Rod Position - Normal Signatures and at Trip Alarm



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	GB101B	RD Stufe 1, Z1	06.09.2007 23:51:50		0 - 2250	µm
	GB101B	KKB Stufe 1, Z1	06.09.2007 23:51:50		-250,0 - 250,0	m/s²
	GB101B	Stufe 1, DS, Z1	Durchstichpunkt Expansions-Linie durch Saugdruck		0 - 150,0	° CA
	GB101B	Stufe 1, KS, Z1	Durchstichpunkt Expansions-Linie durch Saugdruck		0 - 150,0	° CA
	GB101B	Stufe 1, DS, Z1	Durchstichpunkt Kompressions-Linie durch Enddruck		0 - 150,0	° CA
	GB101B	Stufe 1, KS, Z1	Durchstichpunkt Kompressions-Linie durch Enddruck		0 - 150,0	° CA

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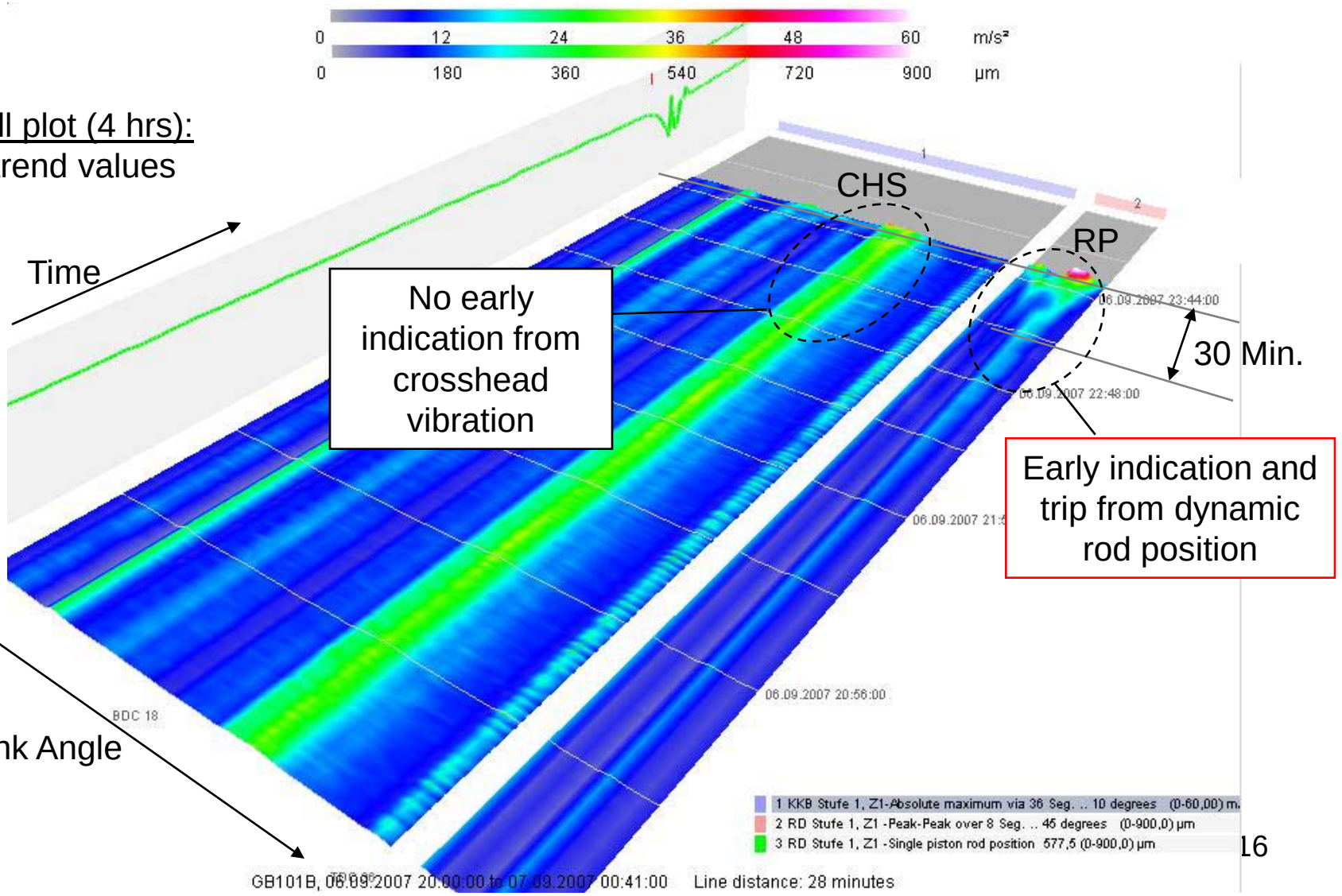
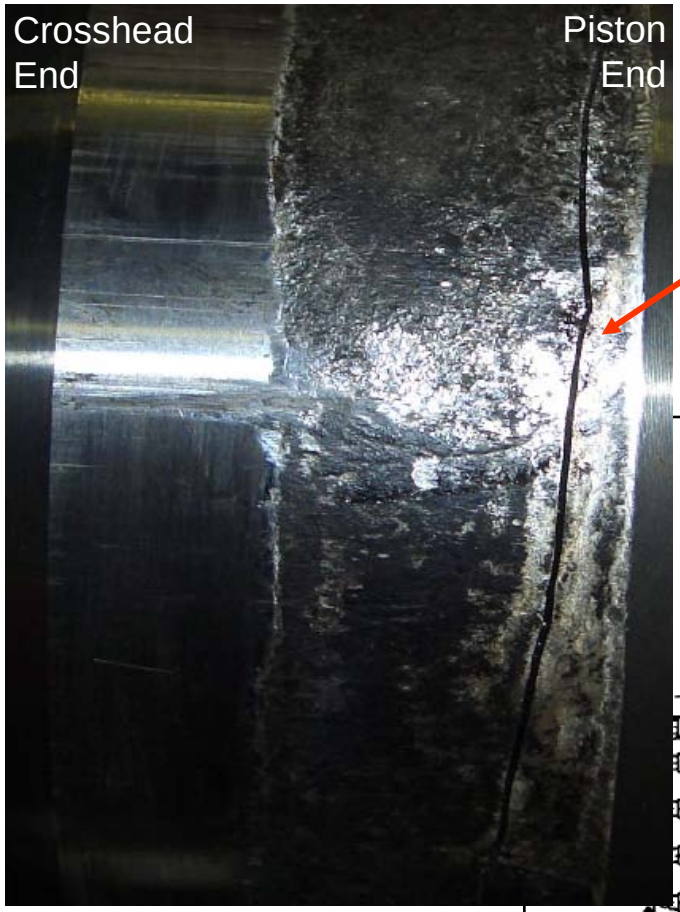
3D Trend Data Analysis

Comparison: RMS Crosshead Vibration and Pk-Pk Rod Run Out



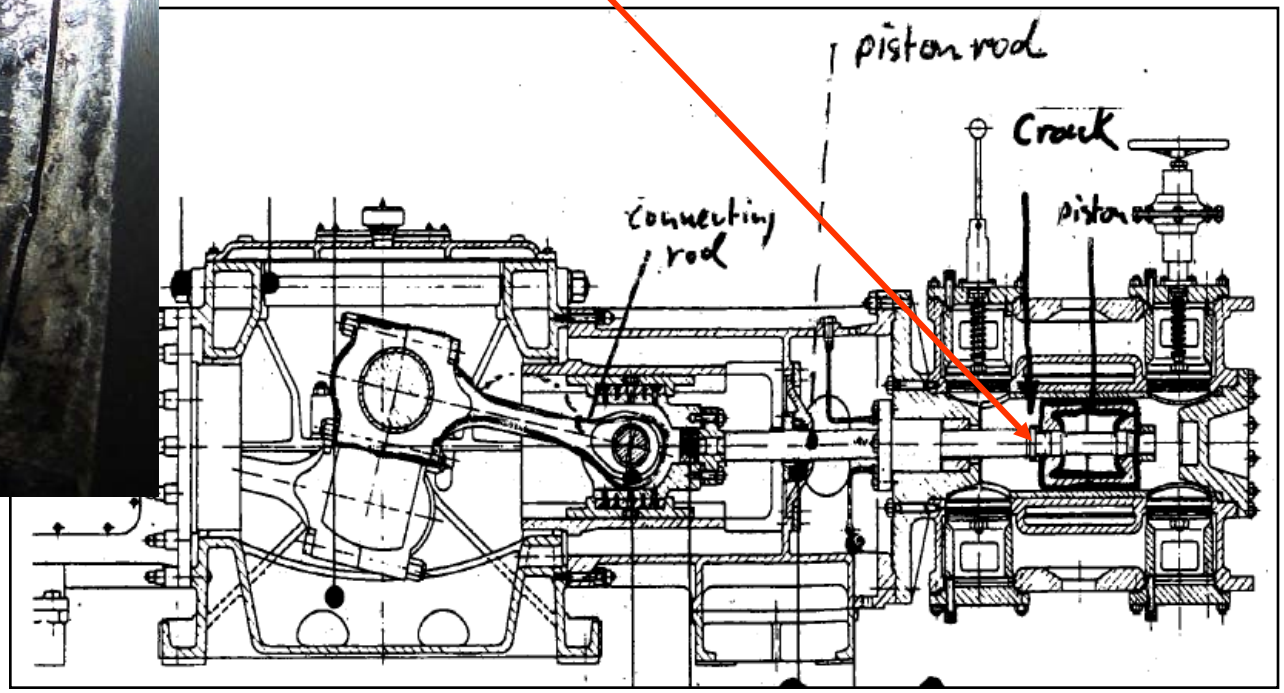
Findings
Failed Component 2007



Piston rod / piston flange
connection 1st stage

75% circumferential crack

Cross section 1st stage



Findings
Comparison with 2002 Rod Failure

	2002	***2007***
Shutdown Parameter	Vibration at CHS	Vibration at CHS & Piston rod position
Shutdown Limits (% measure range)		
Vibration at Crosshead	+30 %, 36 segments	+8 %, 36 segments
Piston rod position	NA	+35 %, 8 segments
Damages	• Complete rod break • Bent con-rod • Ripped casing	• Only a partially cracked piston rod
Avoided damages	• Total loss of machine frame	• Complete piston rod break • Bent con-rod • Ripped casing • Total loss of machine frame
Duration of repairs	6 weeks	24 hours

Findings
Comparison of Economic Impact

- Since 2002, following the adoption of the online monitoring system, maintenance expenses for this compressor have decreased by: **$123,000 USD p.a.**
- Production down time of **6 weeks** resulting from the 2002 event could have exceeded 3 to 6 months without online monitoring.
- By increasing functionality of the MMS to include piston rod position production outage time was decreased to only **24 hours**
- Production losses due to the shutdown in 2007 compared with the unplanned shutdown 2002 were decreased by **43,400 mt urea**

Summary / Lessons Learned

- Using crosshead vibration as a shut down parameter, modern reciprocating machinery protection systems can significantly reduce consequential damages resulting from piston rod failures.

- Using rod run out as a shut down parameter, it is possible to detect the development of a piston rod crack (possibly not detectable with vibration) and successfully trip, before it fails completely.

- Automated machine monitoring systems with rod position shutdown functions lead to lower cost of production and higher plant efficiency.

THANK YOU

FOR YOUR ATTENTION !

QUESTIONS ?