

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

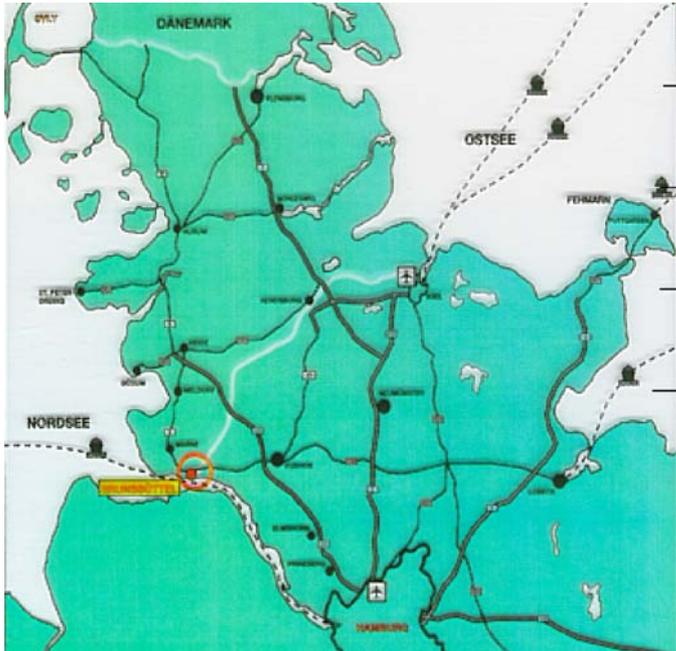
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Brunsbüttel, Germany

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President & General Manager  
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Houston, Texas

# 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

<b>Machine type:</b>	4-throw, horizontal, double-acting, 4-stage
<b>Stroke:</b>	300 mm (11.7 in.)
<b>Piston diameter:</b>	920, 500, 280, 160 mm (36, 20, 11, 6 in.)
<b>Speed:</b>	424 RPM
<b>Power:</b>	2,700 KW (3,600 HP)
<b>Year of manufacture:</b>	1977

<b>Medium:</b>	CO2 (~98.5%)
<b>Suction pressure:</b>	1.8 bar (26 psig)
<b>Discharge pressure:</b>	165 bar (2,400 psig)
<b>Flow rate:</b>	13,000 Nm <sup>3</sup> /h
<b>Capacity control:</b>	fine tuning by suction pressure



GB-101B

# Background

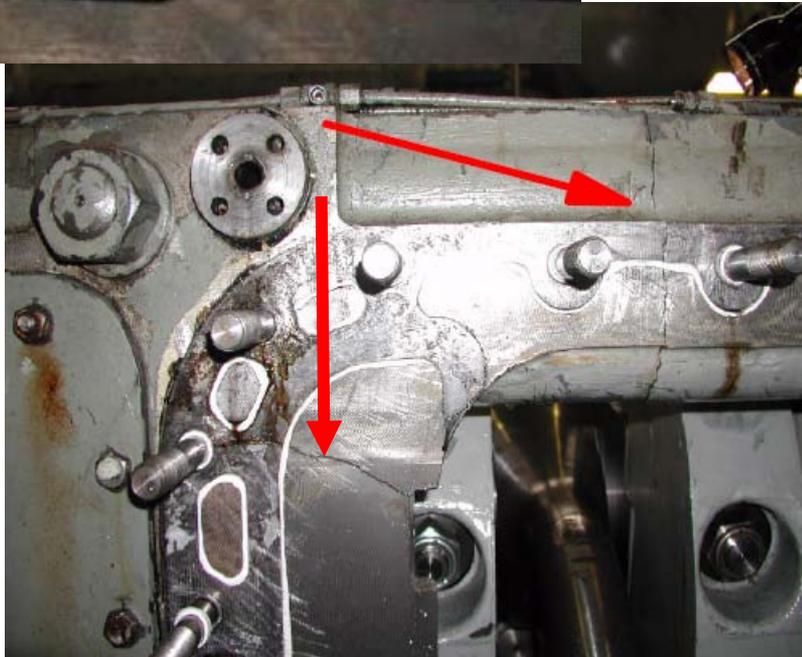
- Site has operated two identical 4-throw reciprocating compressors in carbon dioxide service since 1978.
- Since 2001, when an on-line condition monitoring system was installed on both compressors, numerous component failures have been detected by the system including: rider band wear, valve problems 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

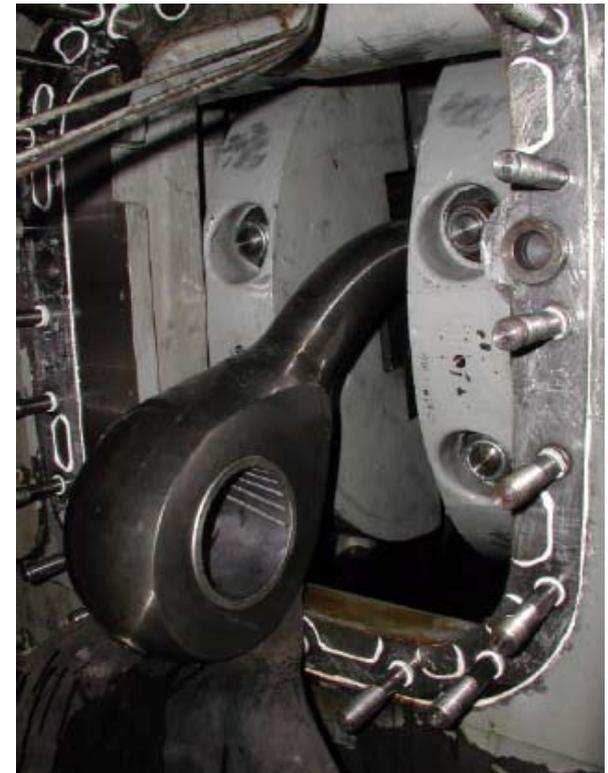


Damaged piston rod

## Photos of damaged components



Ripped casing

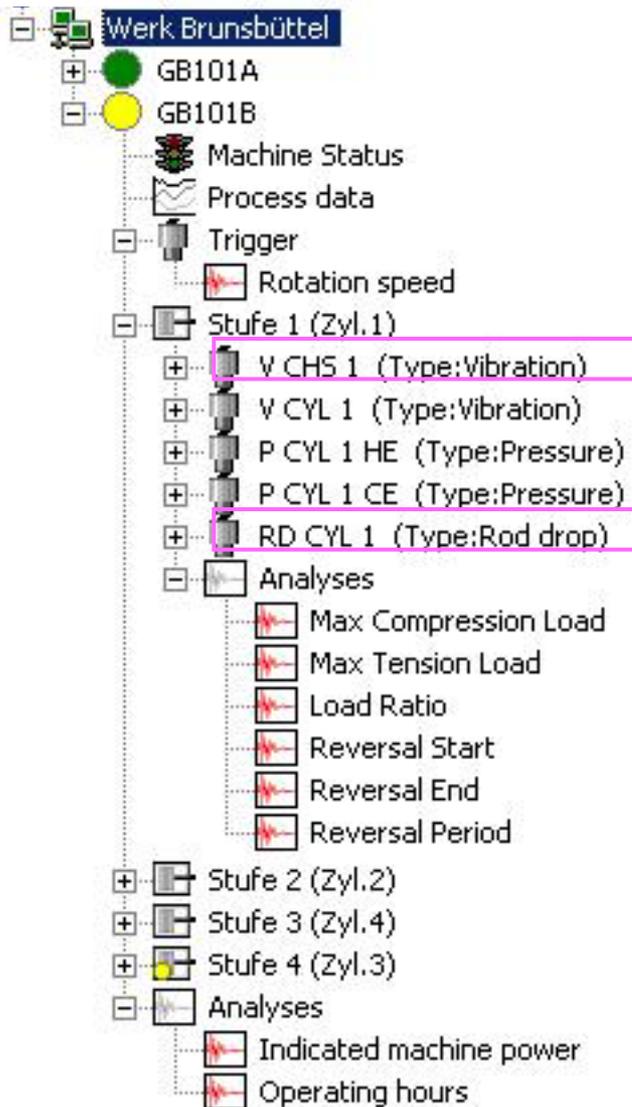


Bent con-rod

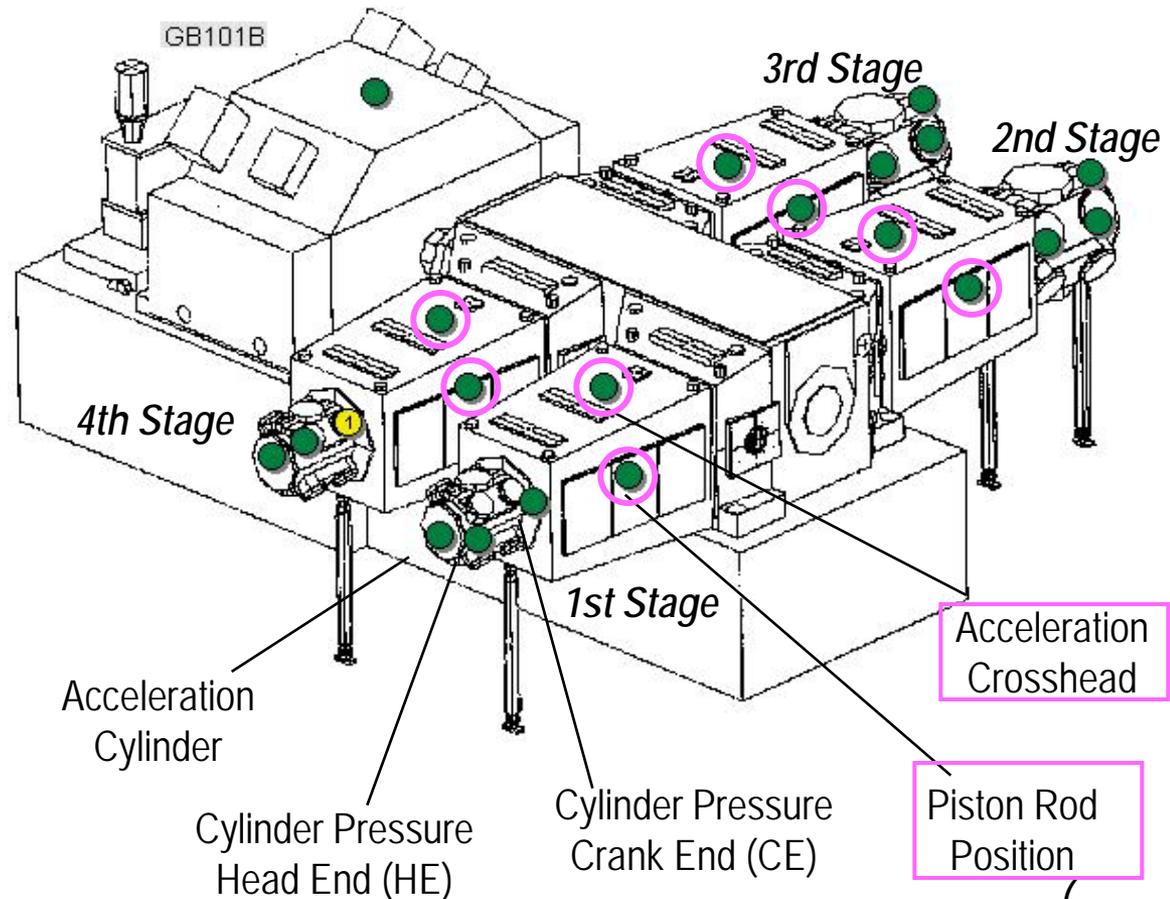
## Background (cont'd)

- 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 1<sup>st</sup> stage piston rod and automatically tripping the machine prior to complete failure, using peak-to-peak rod run out analyses.

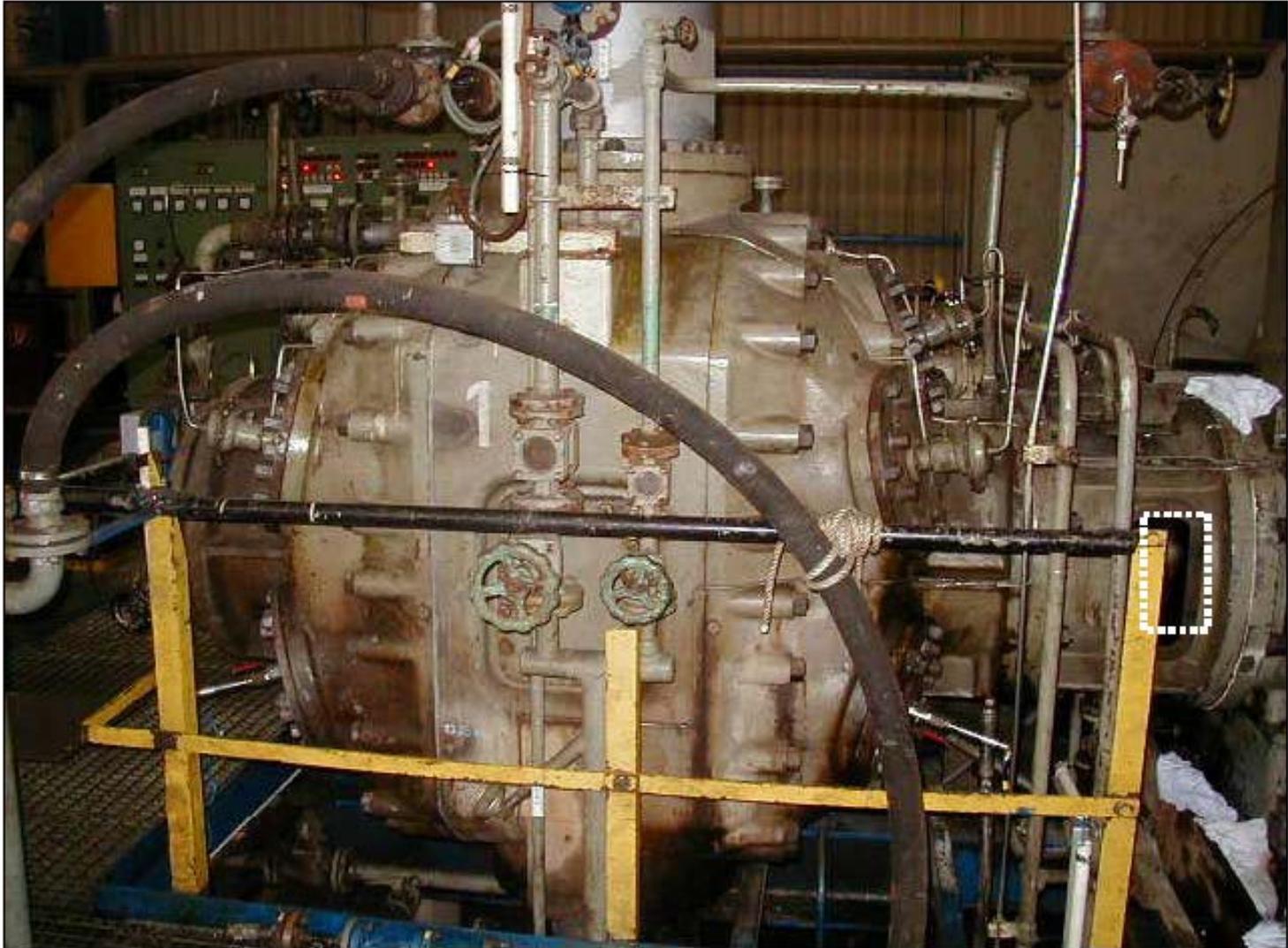
# Sensor Positions



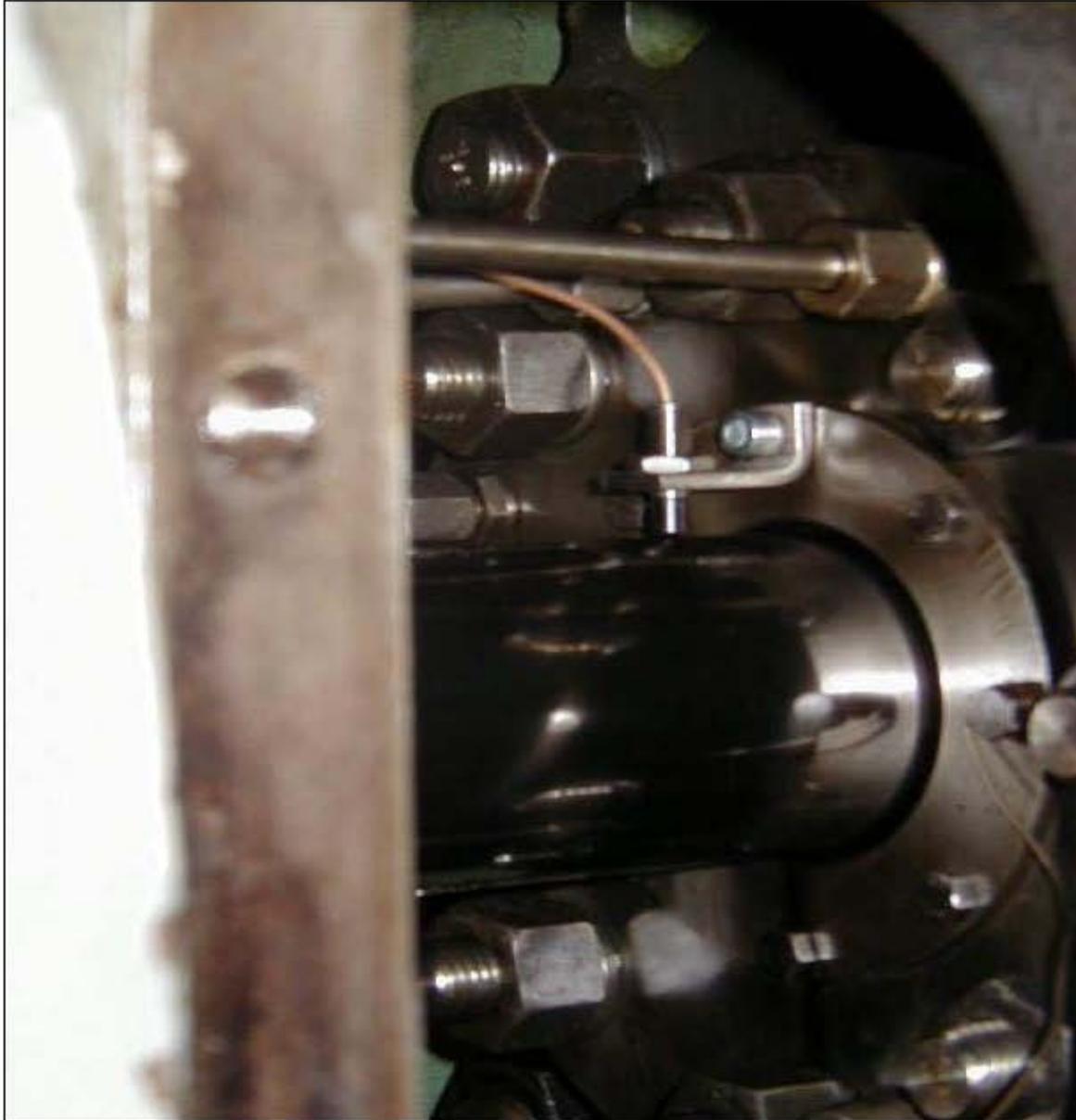
Safety shutdown relevant sensors (2007)



## Photograph of Affected Cylinder (1<sup>st</sup> stage)



## Photograph of Proximity Probe (1<sup>st</sup> 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

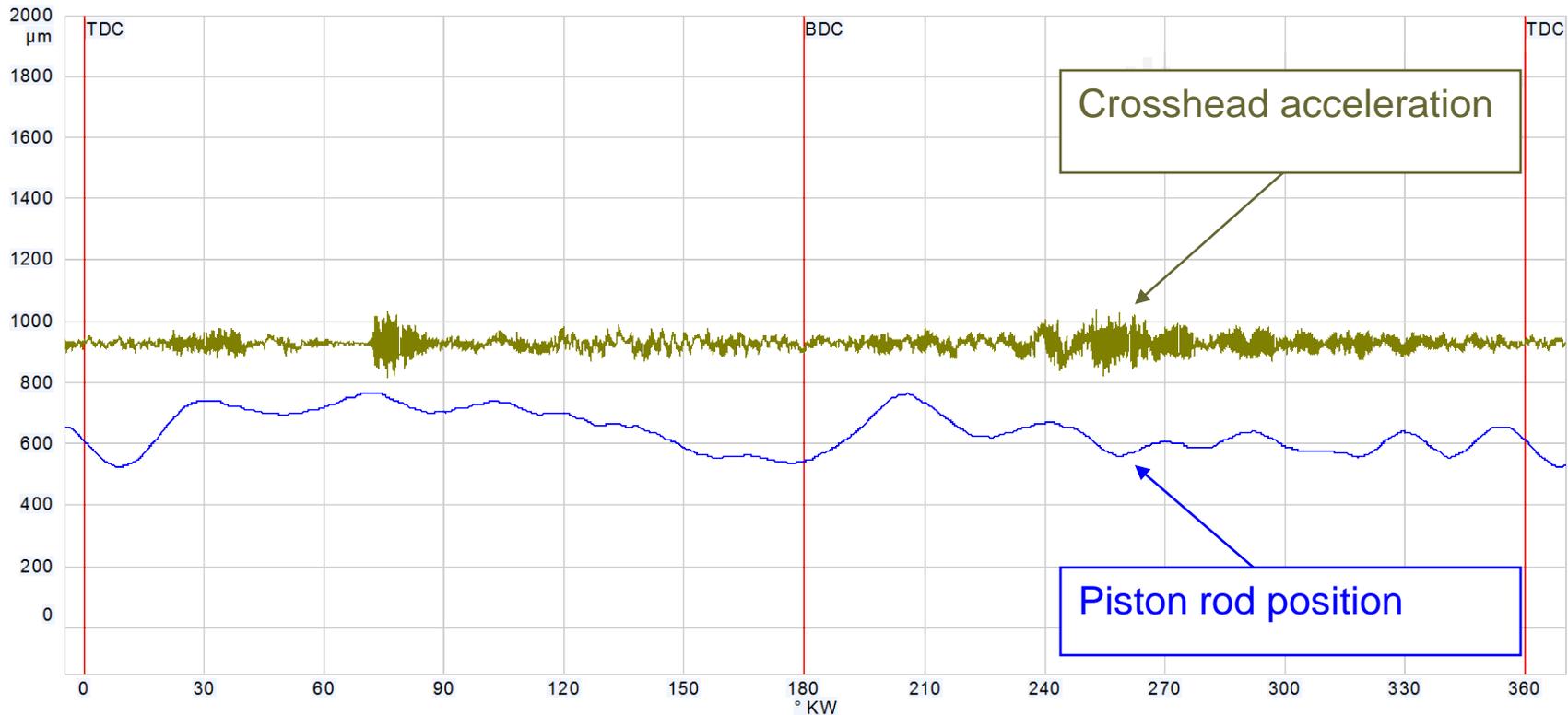
*Note: After 6 years of experience with this machine monitoring system site was confident that the compressor would be safely tripped in time if the overloading caused mechanical problems.*

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

# Data Analysis

## Crosshead Vibration & Rod Position

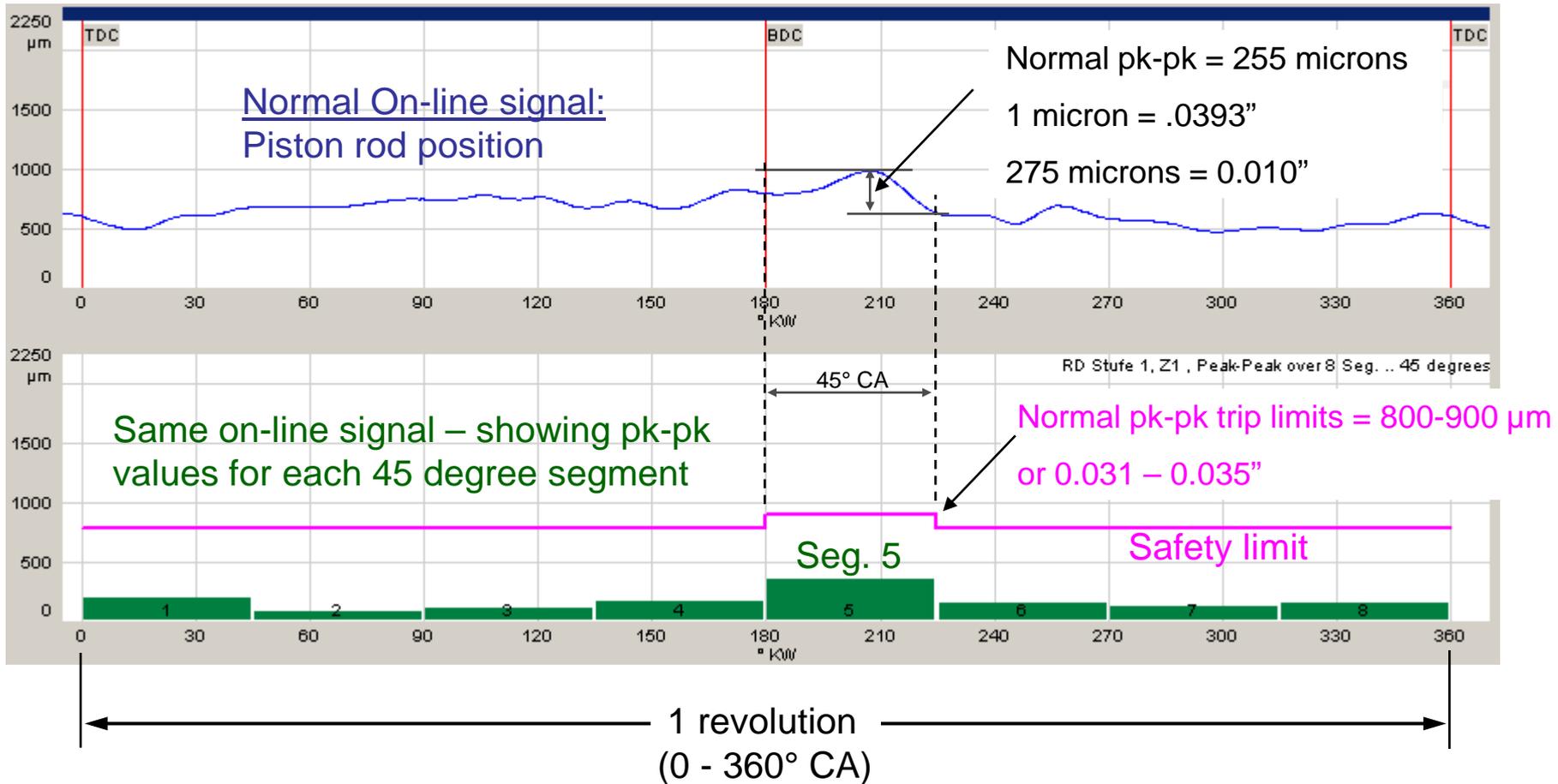
### Normal signatures 1<sup>st</sup> Stage - 10:00 am Sept. 6 (before change)



Machine	Measuring Point	Data name	TAG-Name	Value	Unit
GB101B	KKB Stufe 1, Z1	Schwingungssignal		-250,0 - 250,0	m/s <sup>2</sup>
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

# 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.)

Type	Date	Module	Measuring Point	S.	Message
Information	06.09.2007 23:53:49	Analysis			Maschine steht
IMPORTANT	06.09.2007 23:53:44	Safety	RD Stufe 1, Z1		HzA: Roddrop-Schwingung oberhalb der Safety-Grenze
IMPORTANT	06.09.2007 23:53:43	Safety	RD Stufe 1, Z1		VzA: Roddrop-Schwingung oberhalb der Safety-Grenze
IMPORTANT	06.09.2007 23:53:42	Safety	RD Stufe 1, Z1		VzA: Roddrop-Schwingung oberhalb der Safety-Grenze
IMPORTANT	06.09.2007 23:53:41	Safety	RD Stufe 1, Z1		Safety-Grenze in den folgenden Segmenten überschritten: 6
Information	06.09.2007 23:52:06	Pattern			Neues Zustands-Muster Nr. 25468 eingetragen
Event	06.09.2007 23:52:00	Alarm	KKB Stufe 1, Z1		9 24 Ab25 Ab30 RM9 Abs17 Ab36 RM17 Ab18 Ab9 Abs18 Ab18 RM24 RMFFT R19 Ab20 Ab24 Ab20 RMFFT R17 Ab24 Ab
Event	06.09.2007 23:51:00	Alarm	KKB Stufe 2, Z2		FFT RMS value
Information	06.09.2007 23:49:02	Pattern			Neues Zustands-Muster Nr. 25467 eingetragen
Event	06.09.2007 23:46:57	Alarm	RD Stufe 1, Z1		137 Pistc6 Pistc10 Pist3 PistcPeak t21 Pist24 Pist4 Pistc6 Pistc17 Pist11 Pist15 Pist16 Pist26 Pist4 Pistc7 PistcPeak t22 Pist4
Event	06.09.2007 23:43:57	Alarm	KKB Stufe 3, Z4		FFT RMS value FFT RMS value 10 RMS values FFT RMS
Information	06.09.2007 23:42:04	Pattern			Neues Zustands-Muster Nr. 25466 eingetragen
Event	06.09.2007 23:41:59	Alarm	KKB Stufe 4, Z3		4 Absolute maximum
Event	06.09.2007 23:41:59	Alarm	KKB Stufe 1, Z1		25 Absolute30 RMS values 30 RMS values 25 Absolute ma29 Absolute ma25 Absolute ma29 Absolute ma24 Absolute ma2
Event	06.09.2007 23:39:59	Alarm	Zyl. St. 2, Z2		11 RMS values 11 RMS values
Event	06.09.2007 23:35:02	Alarm	RD Stufe 2, Z2		5 Piston-rod position analysis 28 Piston-rod position analysis
Event	06.09.2007 23:32:56	Alarm	RD Stufe 1, Z1		21 Piston-rod position analysis 12 Piston-rod position analysis
Event	06.09.2007 23:31:57	Alarm	RD Stufe 2, Z2		7 Piston-rod position analy28 Piston-rod position analysis 28 Piston-rod position analysis 7 Piston-rod position analysis 7
Event	06.09.2007 23:31:56	Alarm	KKB Stufe 1, Z1		30 Absc33 Absolute30 Absolute9 Absolute r9 Absolute r30 AbsoluteFFT RMS vaFFT RMS va25 Absolute35 Absolute25 Ab
Event	06.09.2007 23:30:57	Alarm	KKB Stufe 3, Z4		FFT RMS value FFT RMS value FFT RMS value FFT RMS
Event	06.09.2007 23:26:57	Alarm	RD Stufe 1, Z1		17 Piston-rod position analysis 11 Piston-rod position analysis 3 Piston-rod Peak-Peak 17 Pistor
Event	06.09.2007 23:22:00	Alarm	RD Stufe 3, Z4		2 Piston-rod Peak-Peak
Event	06.09.2007 23:22:00	Alarm	KKB Stufe 1, Z1		35 Absolute maximum30 Absolute maximum 30 RMS values 30 Absolute maximum 30 RMS values

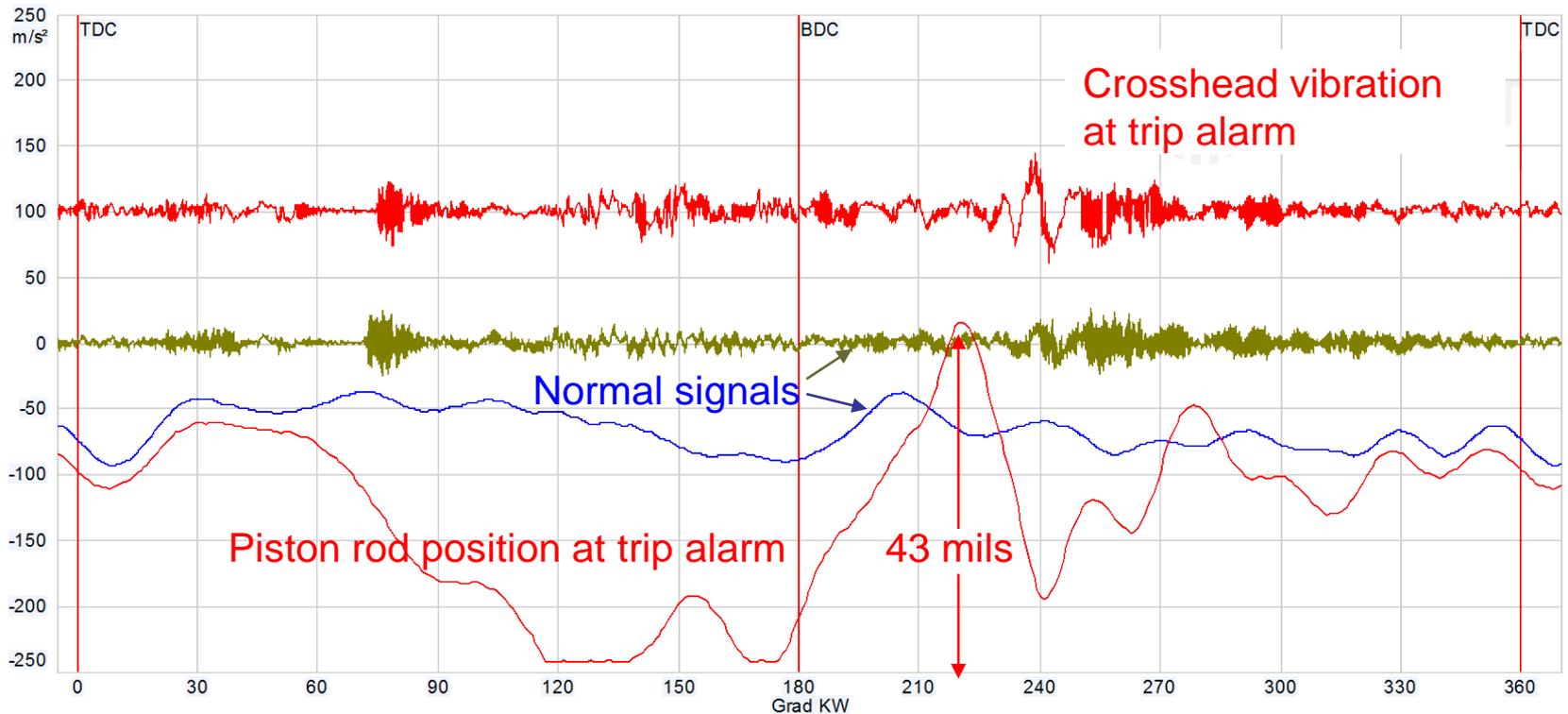
5 Sec.  
2 Sec.

Stop!  
Trip!  
Alert!

Early failure warnings

# Data Analysis

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

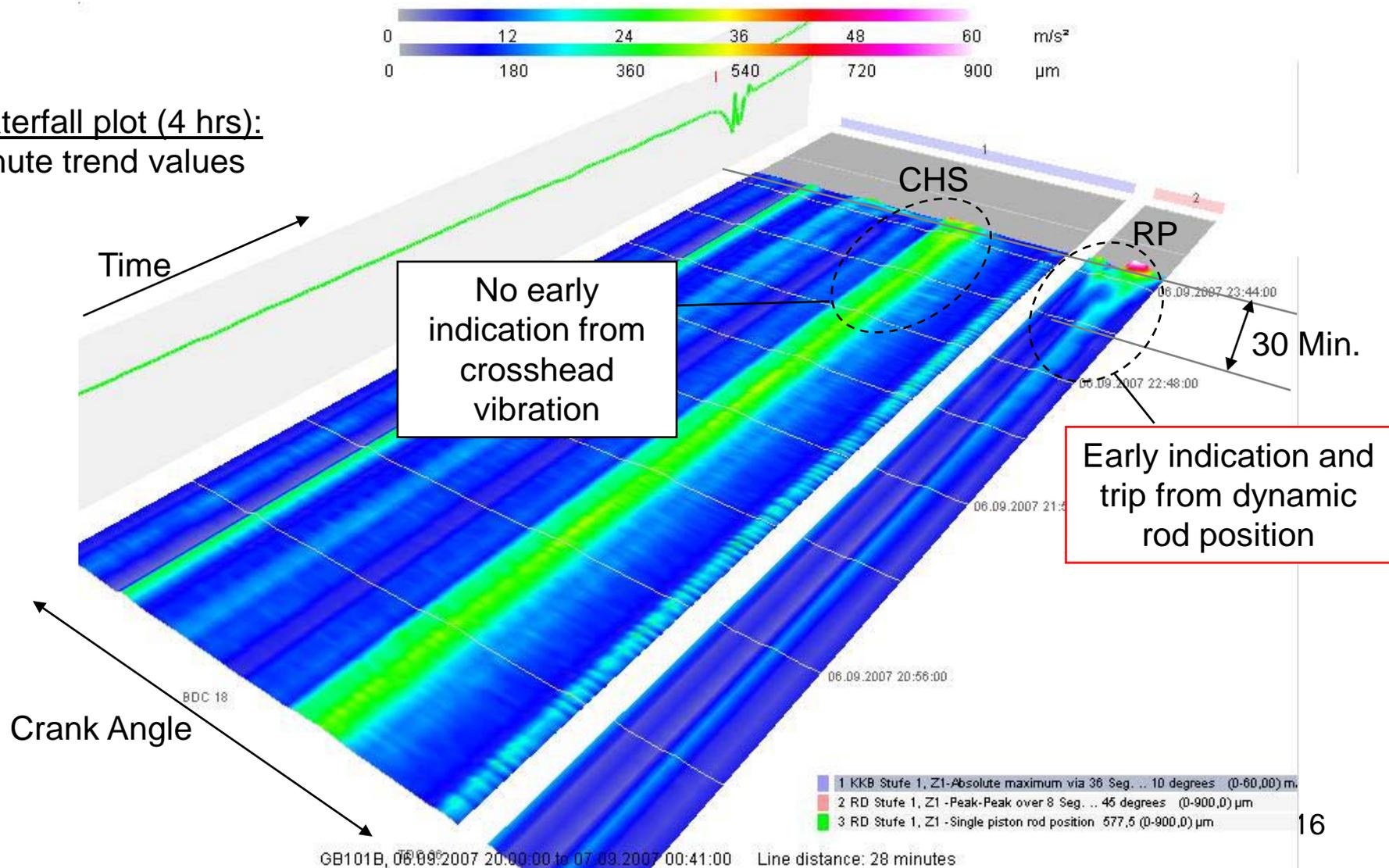


	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
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	GB101B	RD Stufe 1, Z1	Kolbenstangenlage-Signal		0 - 2250	µm
	GB101B	RD Stufe 1, Z1	06.09.2007 23:51:50		0 - 2250	µm
	GB101B	KKB Stufe 1, Z1	06.09.2007 23:51:50		-250,0 - 250,0	m/s <sup>2</sup>
	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

# 3D Trend Data Analysis

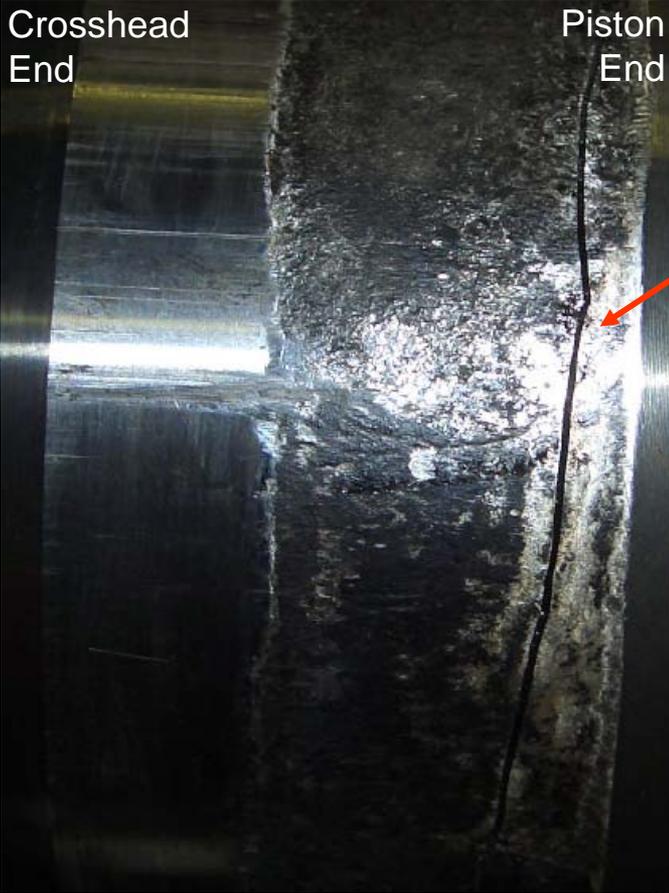
## Comparison: RMS Crosshead Vibration and Pk-Pk Rod Run Out

Waterfall plot (4 hrs):  
Minute trend values



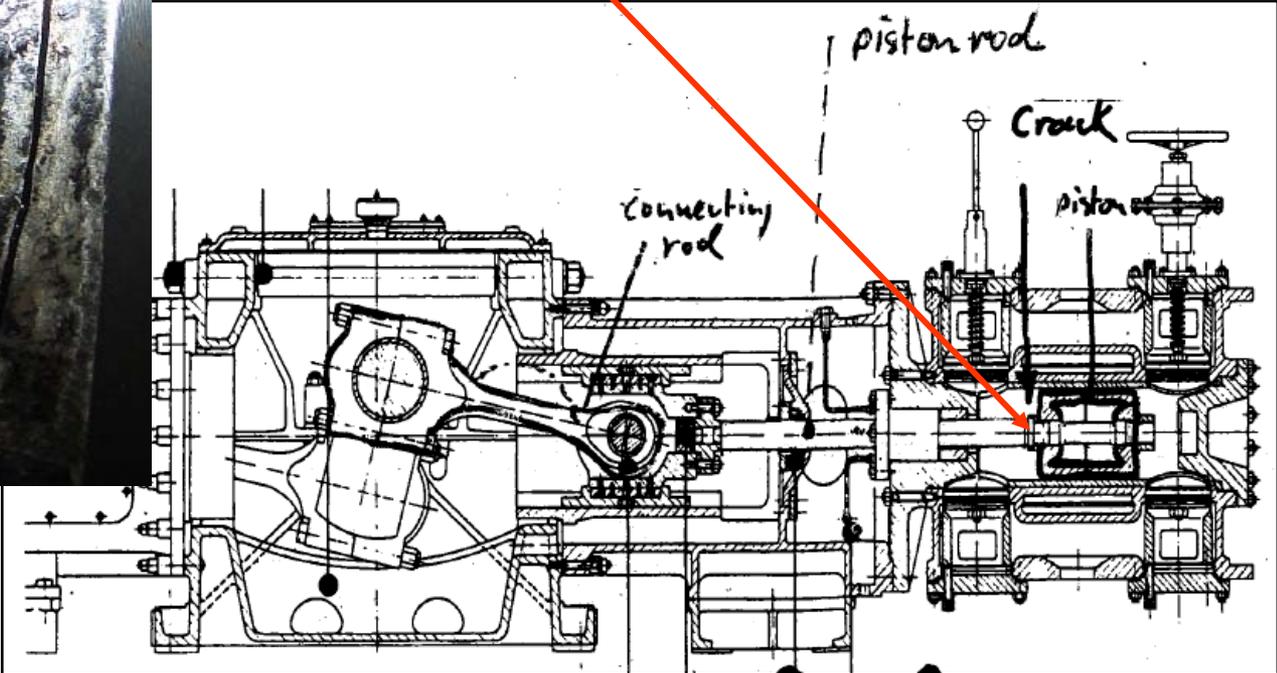
# Findings

## Failed Component 2007



75% circumferential crack

Cross section 1st stage



Piston rod / piston flange connection 1st stage

# Findings

## Comparison with 2002 Rod Failure

	<b>2002</b>	<b>2007</b>
<u>Shutdown Parameter</u>	Vibration at CHS	Vibration at CHS & Piston rod position
<u>Shutdown Limits (% measure range)</u>		
Vibration at Crosshead	+30 %, 36 segments	+8 %, 36 segments
Piston rod position	NA	+35 %, 8 segments
<u>Damages</u>	<ul style="list-style-type: none"> <li>• Complete rod break</li> <li>• Bent con-rod</li> <li>• Ripped casing</li> </ul>	<ul style="list-style-type: none"> <li>• Only a partially cracked piston rod</li> </ul>
<u>Avoided damages</u>	<ul style="list-style-type: none"> <li>• Total loss of machine frame</li> </ul>	<ul style="list-style-type: none"> <li>• Complete piston rod break</li> <li>• Bent con-rod</li> <li>• Ripped casing</li> <li>• Total loss of machine frame</li> </ul>
<u>Duration of repairs</u>	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 ?**