Case Study

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Is Frame Vibration Enough Protection?
Early Detection of a Wrist Pin Failure Using Crosshead Vibration

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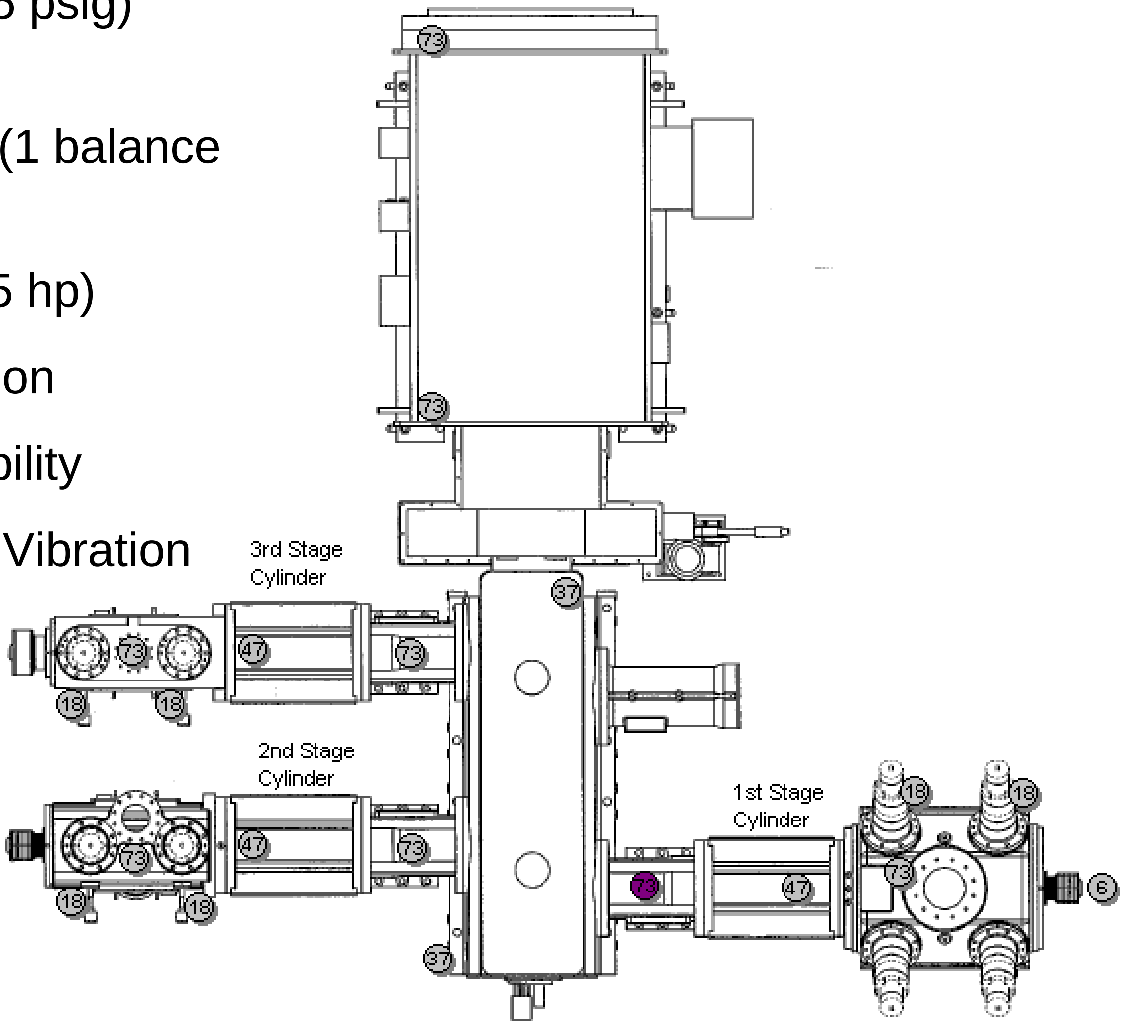
Site Particulars

- **BP Refinery Rotterdam, Facts and Figures (2007)**

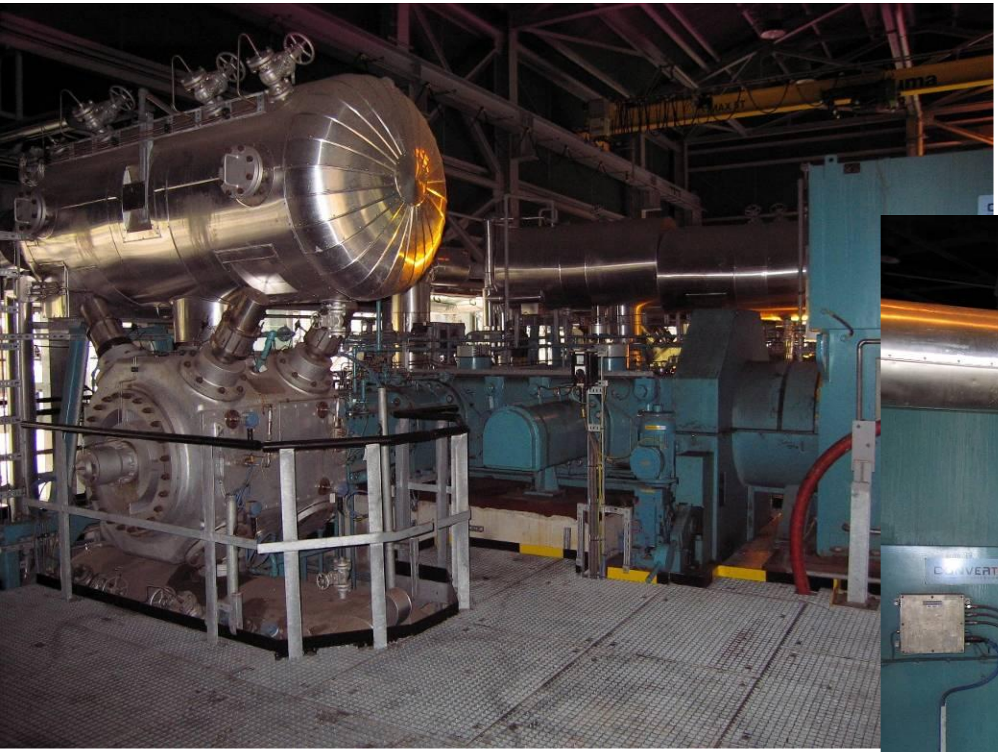
- Capacity
  - 400,000 barrels/day
- Primary units
  - 3 (2 x CDU - 1 x FCCU)
- Employees
  - 730
- Contractors
  - 500
- Vessels
  - 7,000 per year
- Tankers trucks at TTLR
  - 25,000 per year
- Storage tanks
  - 125

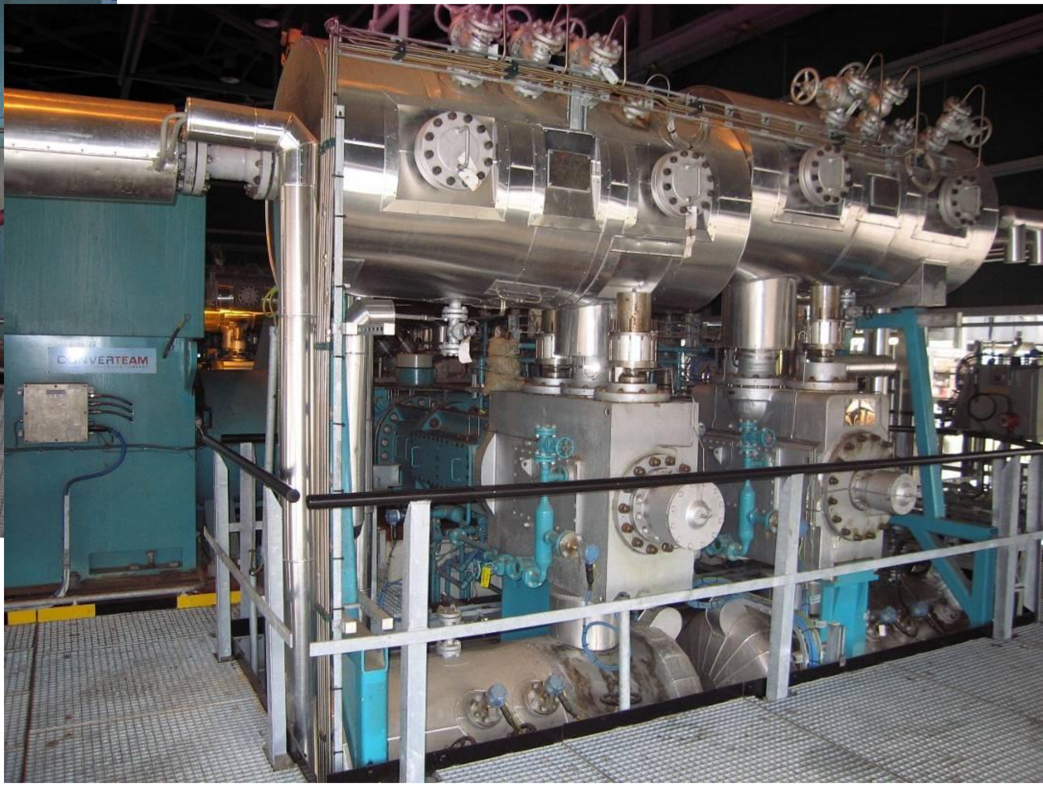
Compressor Application

- **Machine & Monitoring Info :**
- Hydrogen, Suction 3.3 barg (47.5 psig) Discharge 34 barg (495 psig)
- 4 throw – 3 cylinders – 3 stages (1 balance dummy throw)
- 2 bearing motor - 1400 kW (1875 hp)
- 2 compressors in parallel operation
- 100%, 85% and 50% load possibility
- Crosshead, Frame and Cylinder Vibration
- Piston Rod Position (Y-axis)
- Internal Cylinder Pressure (PV)
- Motor Vibration



Compressor Photos at Commissioning





General Sequence of Events

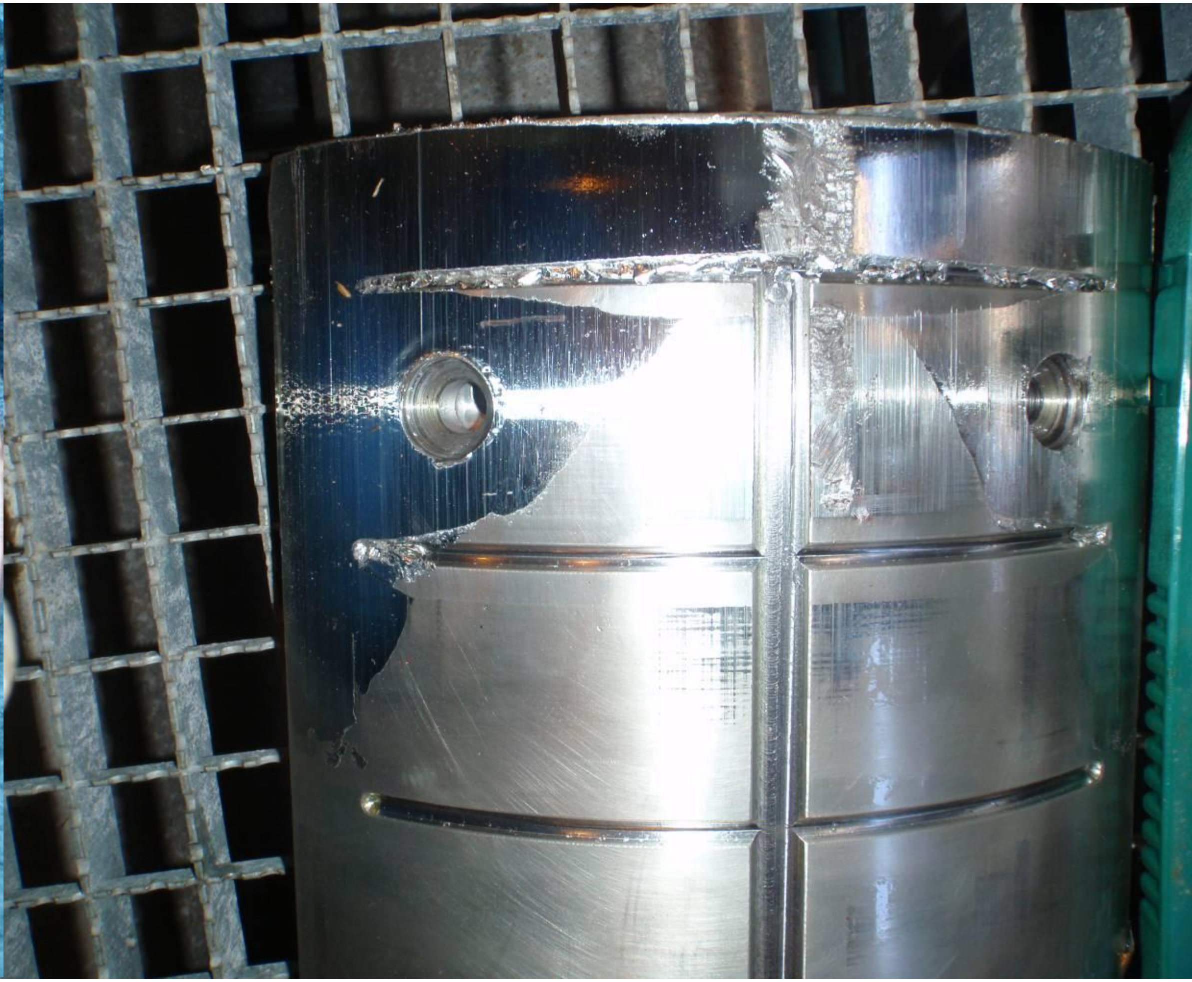
What happened ?

- During initial 24 hour full load test of this newly commissioned compressor, several load steps were executed
- Machine ran at 100% load for 20 hrs, with no indications of problems
- Load was changed to 50% load (using head end plug un-loaders)
- After 8 minutes at 50% load, the machinery protection system automatically stopped the compressor on high vibration of 1st stage crosshead (factory default safety limit was 6.5 g)
- High vibration and shut down was the result of a seized wrist pin caused by insufficient lubrication
- At the time of submission, root cause of loss of lube condition was still under investigation by compressor OEM and the final RCFA results have yet to be published

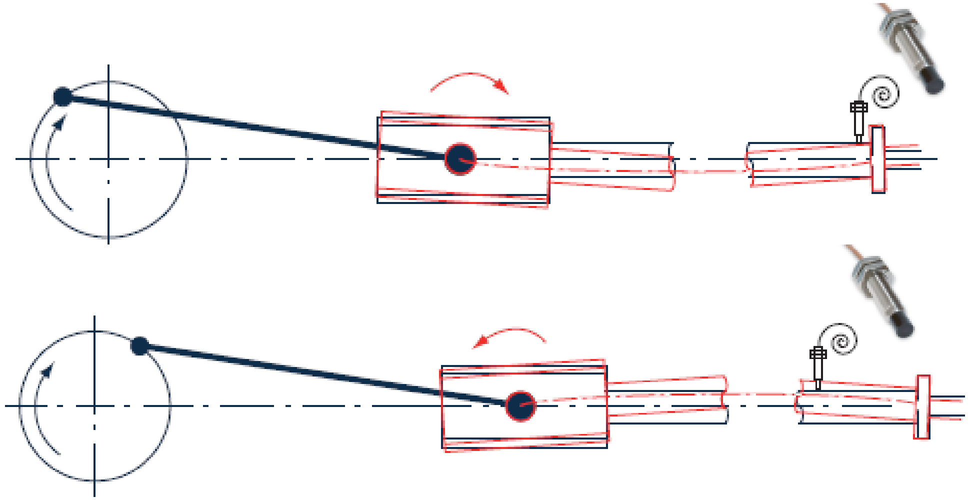
Failure Photos

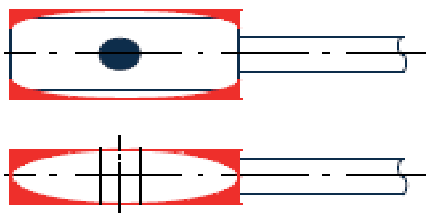
Small end of connecting rod

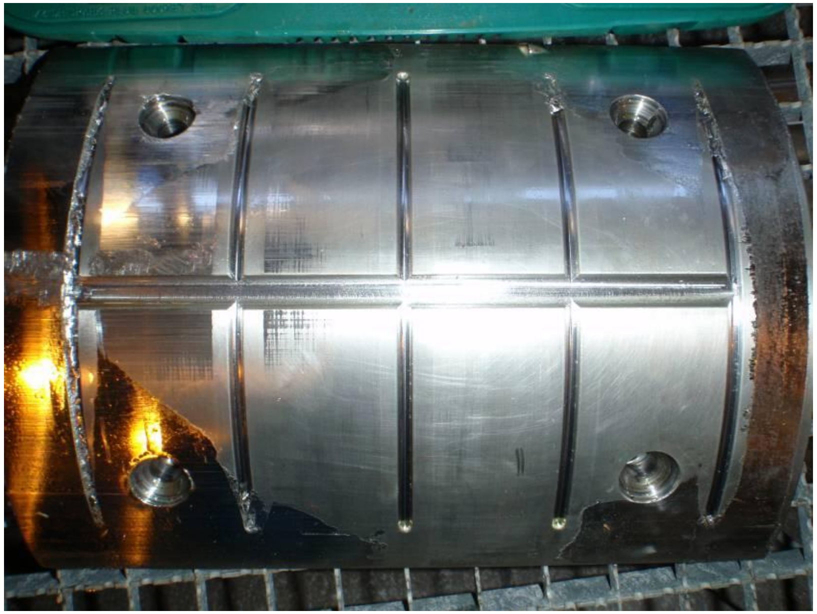
Crosshead slipper



Failure Mechanism

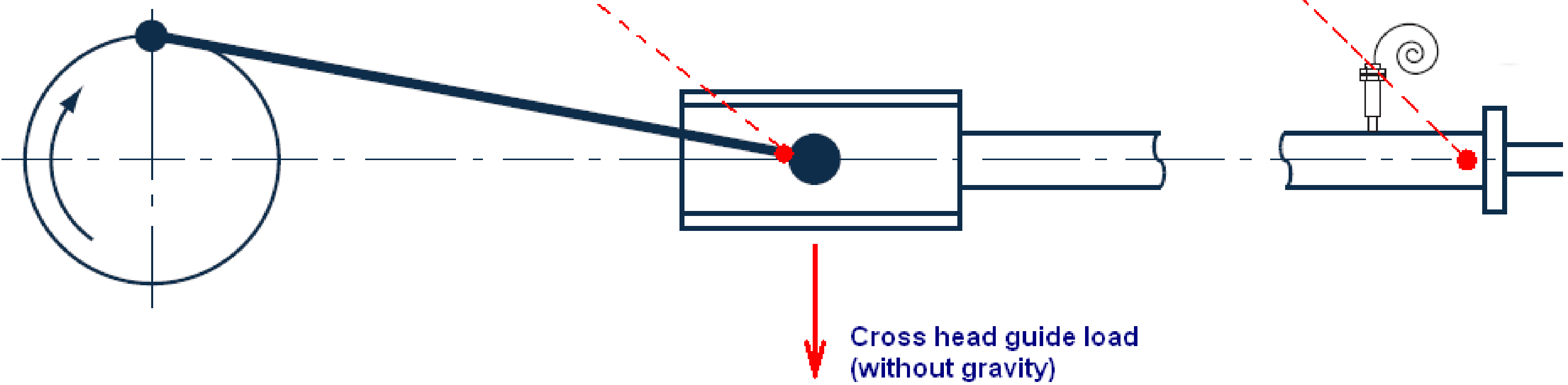


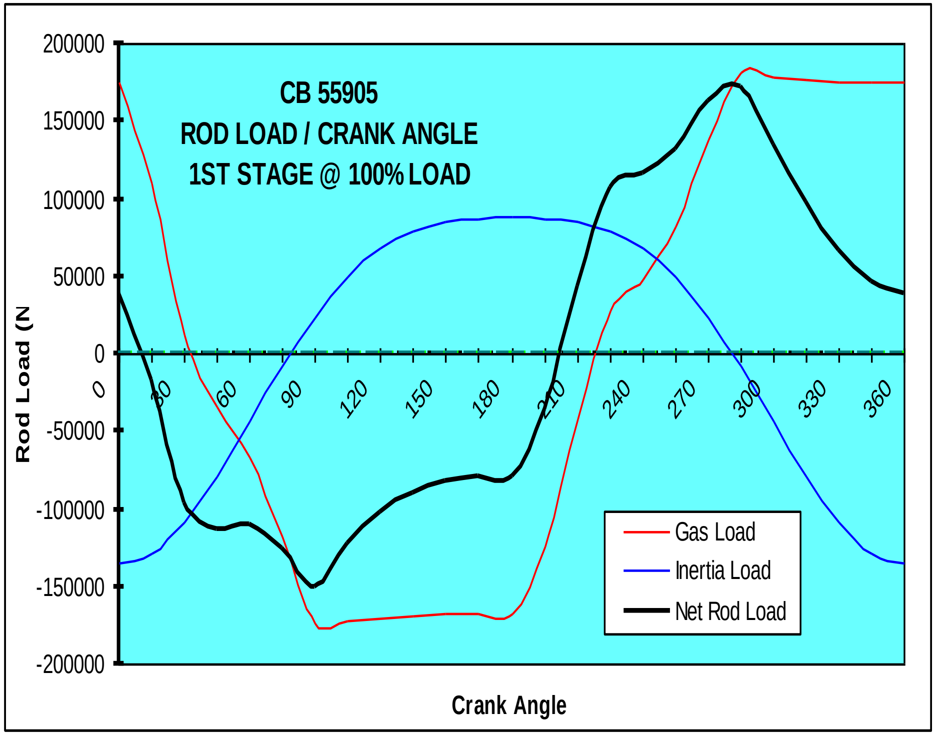


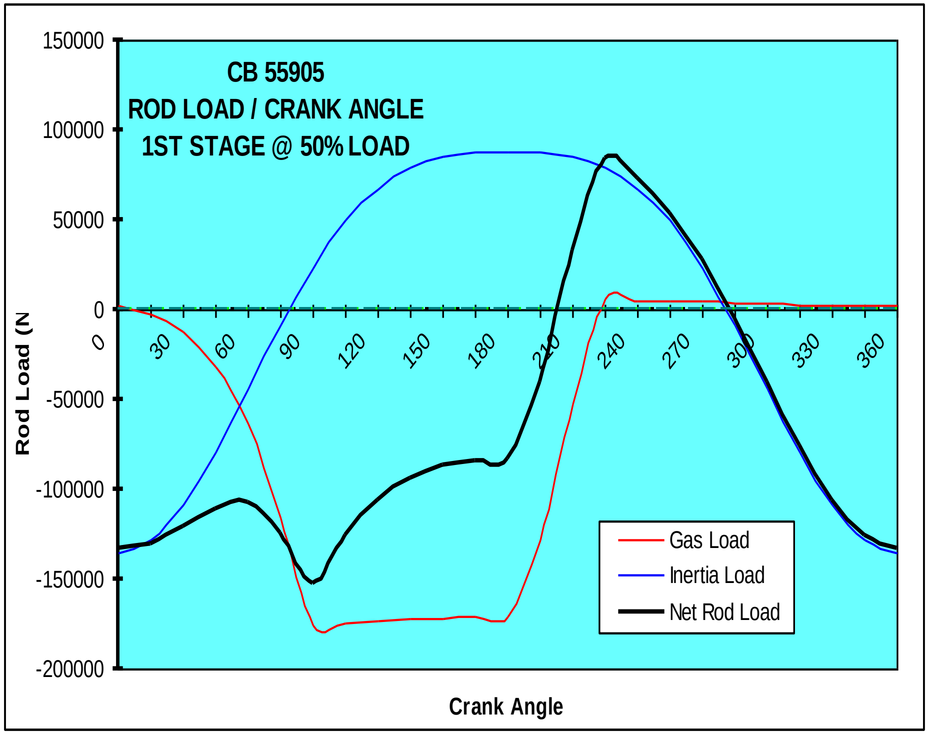


- Due to the resistance at the wrist pin, the crosshead is forced to tilt in the guide. Loss of babbitt at both ends of the slippers confirms the mechanism.
- Piston rod position data clearly shows the movement which occurs due to bending of piston rod and vertical displacement of crosshead

Crosshead Load (100% & 50%)

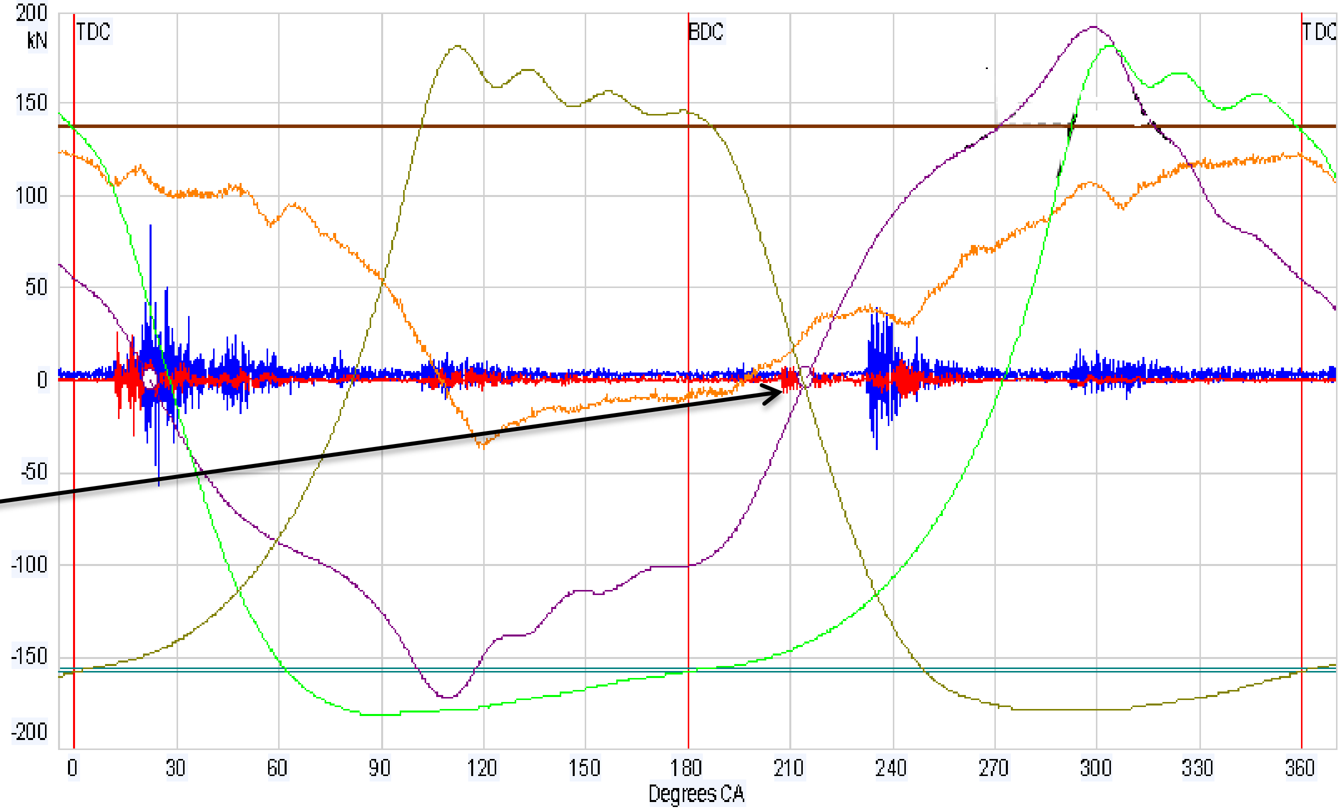






Online Data Plot at 100% Load (normal)

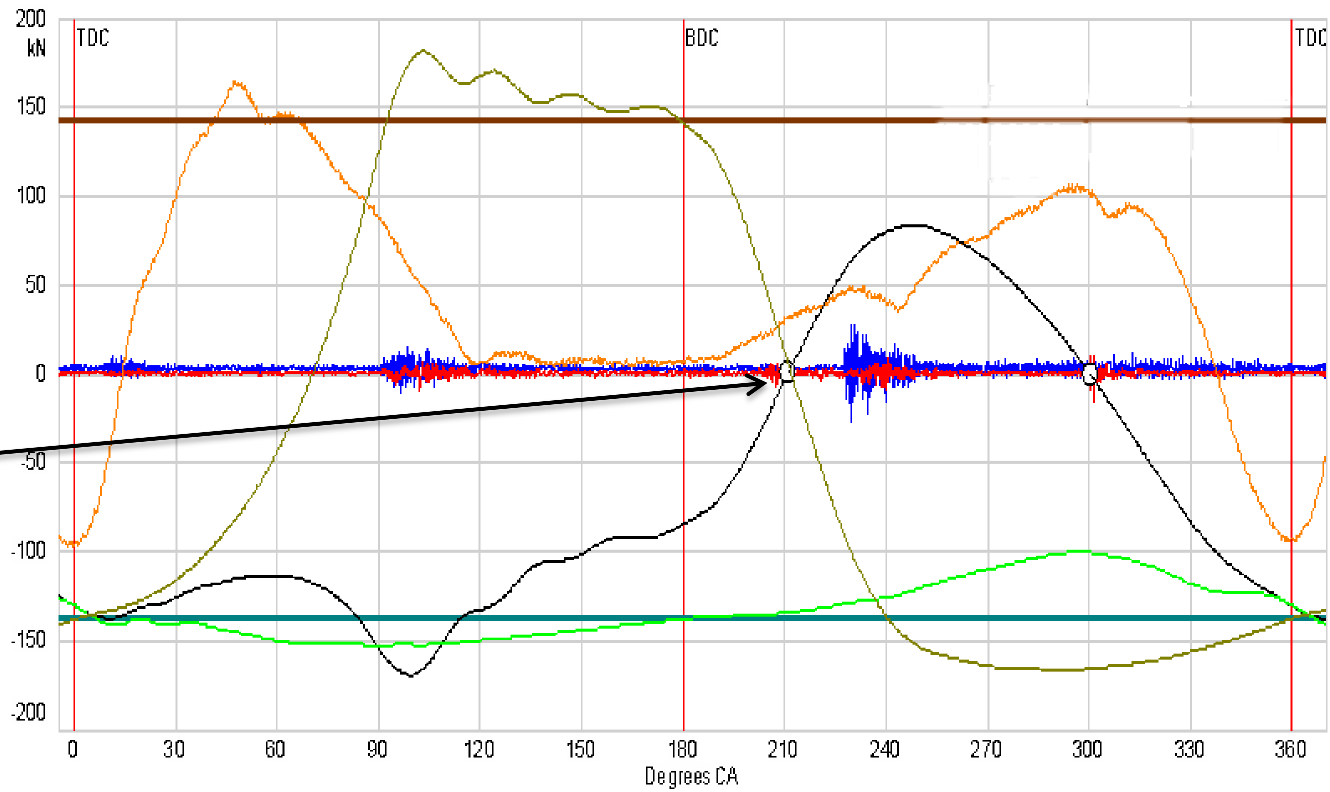
Rod load curve 100%



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	C504 B	V CYL 1st ST	Vibration signal	VE-5509	-2000 - 2000	m/s²
	C504 B	V CHS 1st ST	Vibration signal	XE-5511	-250.0 - 250.0	m/s²
	C504 B	P CYL 1st ST HE	Pressure signal	PT-55157	0 - 10.000	bar a
	C504 B	P CYL 1st ST CE	Pressure signal	PT-55155	0 - 10.000	bar a
	C504 B	RD 1st ST	Rod drop signal	ZE-5502	0 - 4793	µm
		P Suc. 1st St		PI-55072	0 - 4.000	bar a
		P Dis. 1st St		PI-55073	0 - 10.00	bar a
	C504 B	Cyl. 1st Stage	12-03-2009 09:08:27	Connecting rod lo	-201.6 - 201.6	kN

Online Data Plot at 50% Load (normal)

Rod load curve 50%



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	C504 B	V CYL 1st ST	Vibration signal	VE-5509	-2000 - 2000	m/s²
	C504 B	V CHS 1st ST	Vibration signal	XE-5511	-250.0 - 250.0	m/s²
	C504 B	P CYL 1st ST HE	Pressure signal	PT-55157	0 - 10.000	bar a
	C504 B	P CYL 1st ST CE	Pressure signal	PT-55155	0 - 10.000	bar a
	C504 B	RD 1st ST	Rod drop signal	ZE-5502	0 - 4793	µm
		P Suc. 1st St		PI-55072	0 - 4.000	bar a
		P Dis. 1st St		PI-55073	0 - 10.00	bar a
	C504 B	Cyl. 1st Stage	12-03-2009 09:09:30	Connecting rod lo	-178.2 - 178.2	kN

Compressor Loading / Trip Timeline

Sequence :
8:09:10 – load changed from 100 to 85%
9:10:34 – load changed from 85 to 50%
9:18:36 - trip activated on high crosshead vibration (RMS Acceleration)

Showing a lot of graphs would take too long… so let's switch to the actual data recorded by the monitoring system

The following movie starts 2 minutes before compressor trip (6 minutes after switching to 50% load)

Ringbuffer Movie

Signal legend:

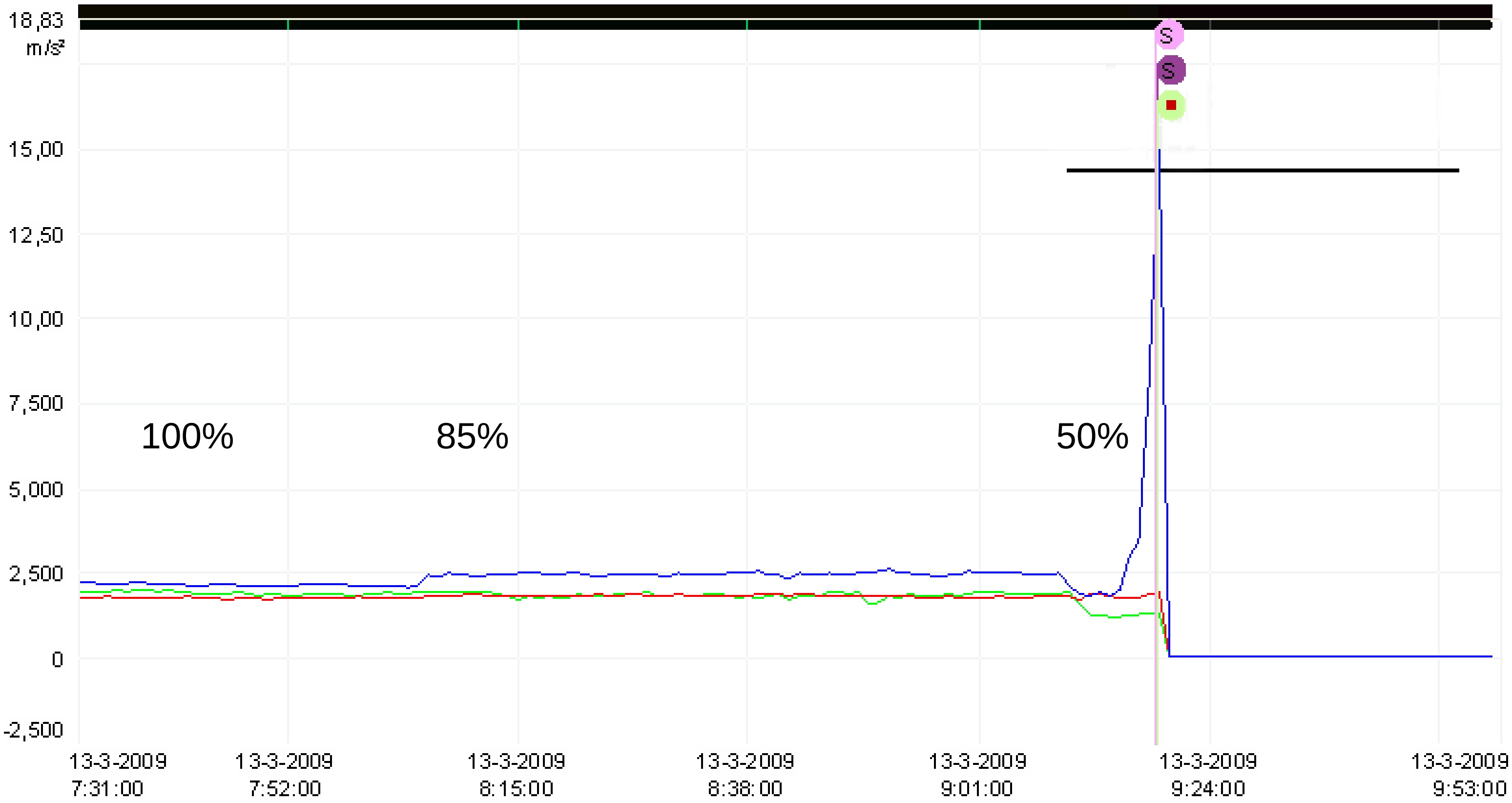
- **Red signal is the *crosshead* vibration sensor**
- **Black signal is the *frame* vibration sensor (NDE)**
- **Orange signal is the *rod position* sensor**

Notice crosshead and rod position signals compared to frame

Ringbuffer

2D Vibration Trend – All Crosshead Sensors

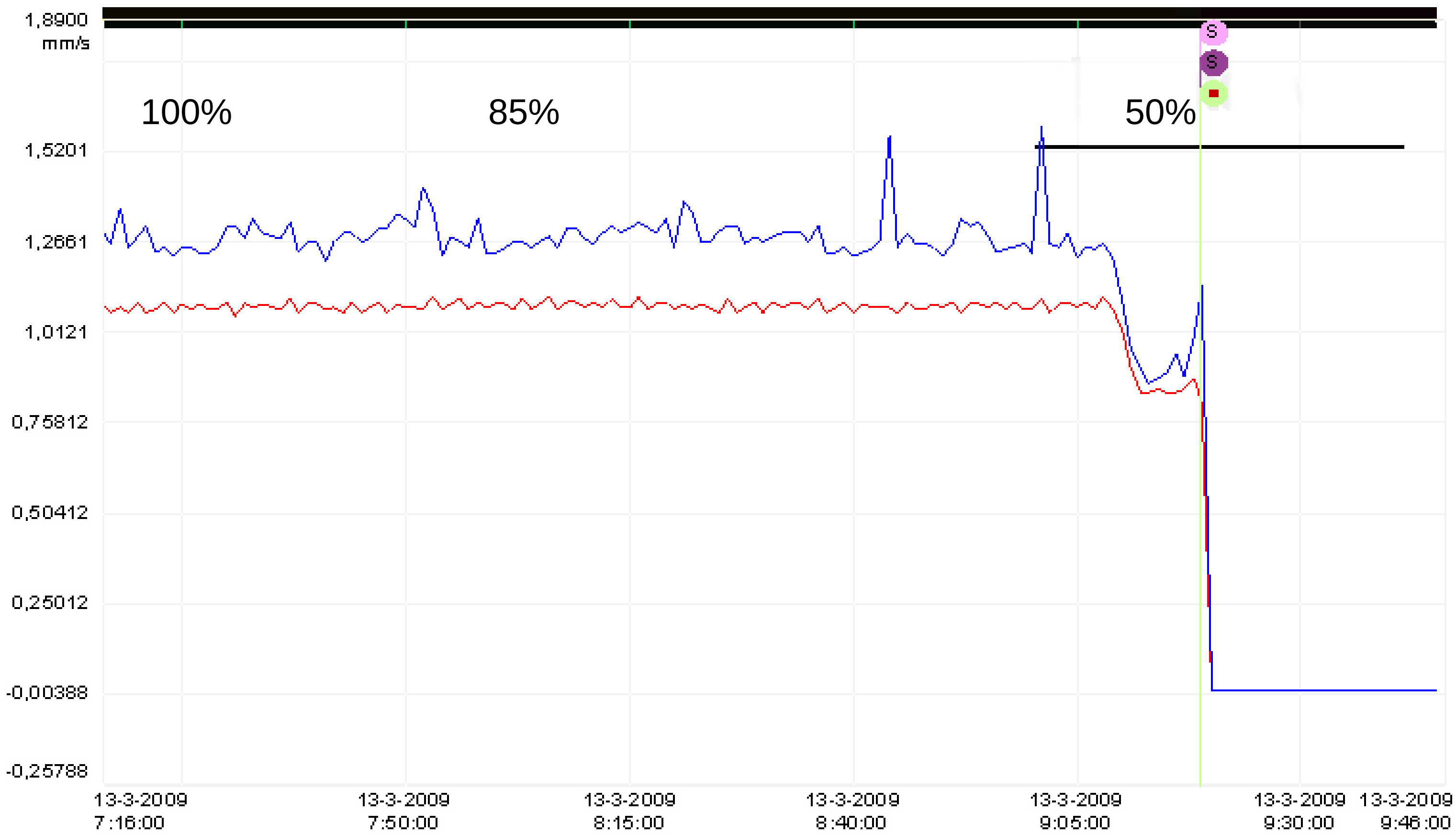
2 Hour Trend of Single Averaged RMS Acceleration – Blue curve is 1st stage



	Machine	Measurin	Data name	TAG-Name	S	Value	Unit	Status
(blue)	C504 A	VCHS 1s	Single RMS value	XE-5510	1	0 - 250,0	m/s²	
(red)	C504 A	VCHS 2r	Single RMS value	XE-5514	1	0 - 250,0	m/s²	
(green)	C504 A	VCHS 3r	Single RMS value	XE-5518	1	0 - 250,0	m/s²	

2D Vibration Trend – Both Frame Sensors

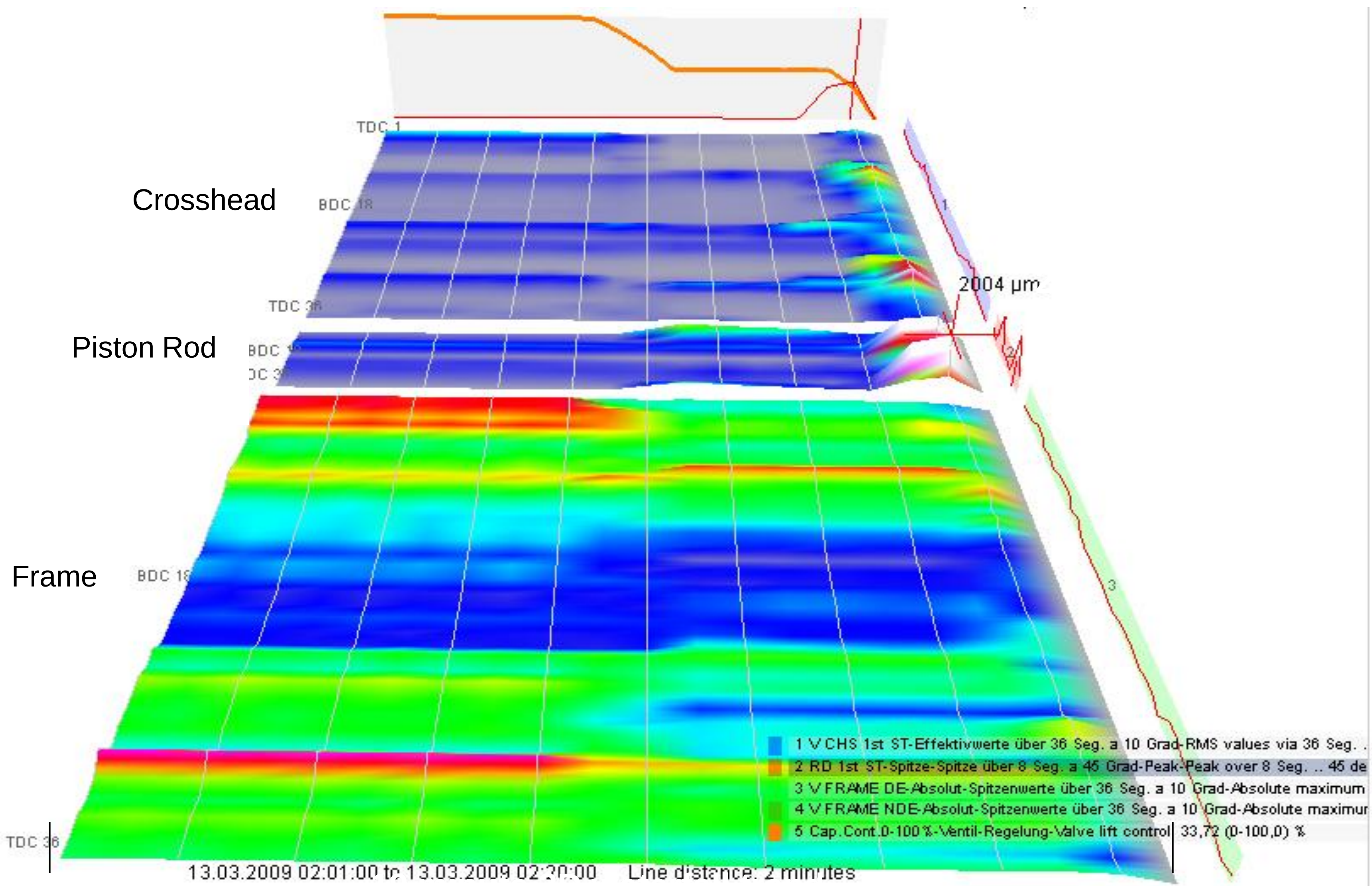
2 Hour Trend of Single Averaged RMS Velocity – Blue curve is NDE



	Machine	Measurin	Data name	TAG-Name	S	Value	Unit	Status
(blue)	C504 A	V FRAME	Single RMS value	VE-5520	1	4,0 - 254,0	mm/s	
(red)	C504 A	V FRAME	Single RMS value	VE-5528	1	4,0 - 254,0	mm/s	

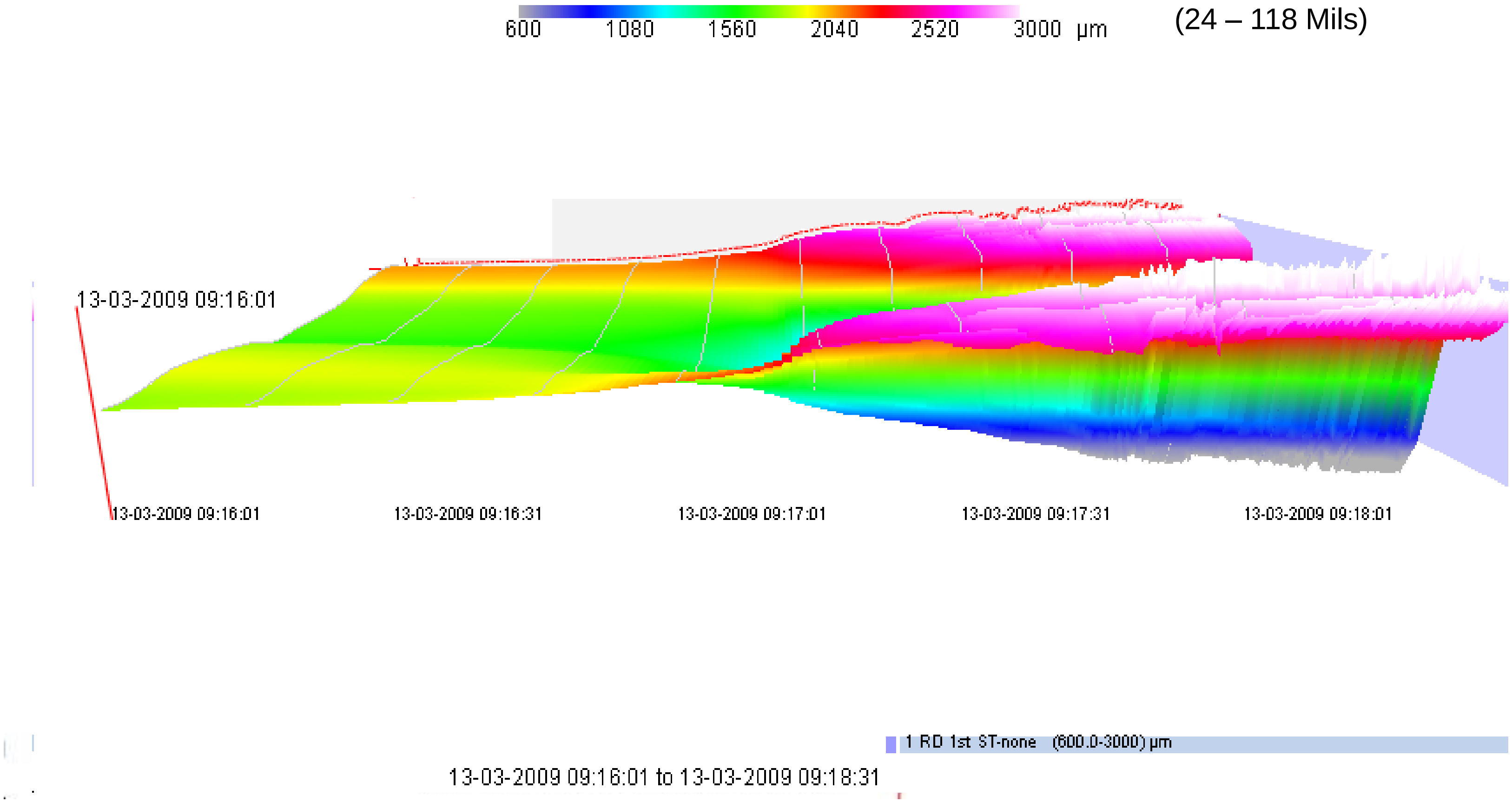
3D Trend of Last 20 min. (Crosshead – Rod Position – Frame)

100% Load **85% Load** **50% Load**



3D Trend of Last 2.5 min. (Rod Position)

Default Trip Limit of 1000 µm (not active) reached approx. 1 min. earlier



(24 – 118 Mils)

Conclusion

- Crank case vibration monitoring provides only limited protection for reciprocating compressors
- Crosshead vibration monitoring reduces risk of loss of mechanical integrity (recommended as mandatory in new 5th Edition of API 670)
- Rod position can detect development of certain recip failure modes earlier than crosshead vibration and can greatly reduce consequential damages
- By gaining a good understanding of a machine’s mechanical behavior and possible failure modes, and pre-determining acceptable damage levels, operators can implement a more sound shutdown philosophy

THANK YOU FOR YOUR ATTENTION !

QUESTIONS ?