EFRC Training Workshop
Condition Monitoring for reciprocating compressors

Block I – CM Basics

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Topics

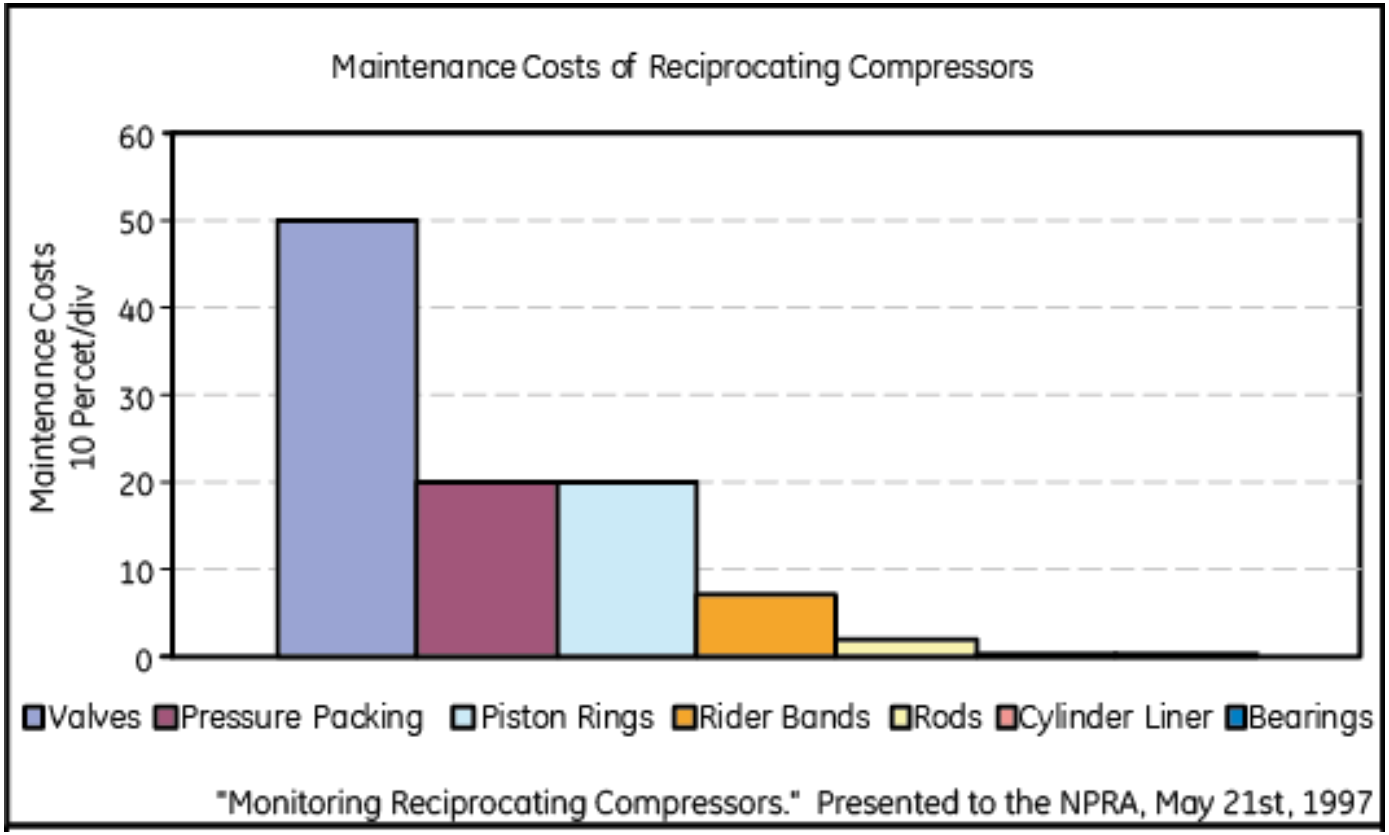
- Why condition monitoring?
- Sensor locations and data management
- Signal analyses:
  - -Acceleration (CHS, cylinder, bearings)
  - -Velocity (frame)
  - -Proximity (piston rod)
  - -Dynamic pressure (compression chamber)
  - -Piston rod load
  - -Temperatures (valve, gas and bearings)
- Early Failure Detection vs. Machine Protection

Why Condition Monitoring?

- ***Challenge:*** Increase machinery uptime with constant maintenance budget
- ***Solution:*** Max. component lifetime for extended meantime between maintenance (MTBM)
- ***Statement:*** Maximum MTBM depends on the "weakest link in the chain", i.e. valves
- ***Task:*** Determine and monitor the "weakest link" to predict necessary overhaul stops

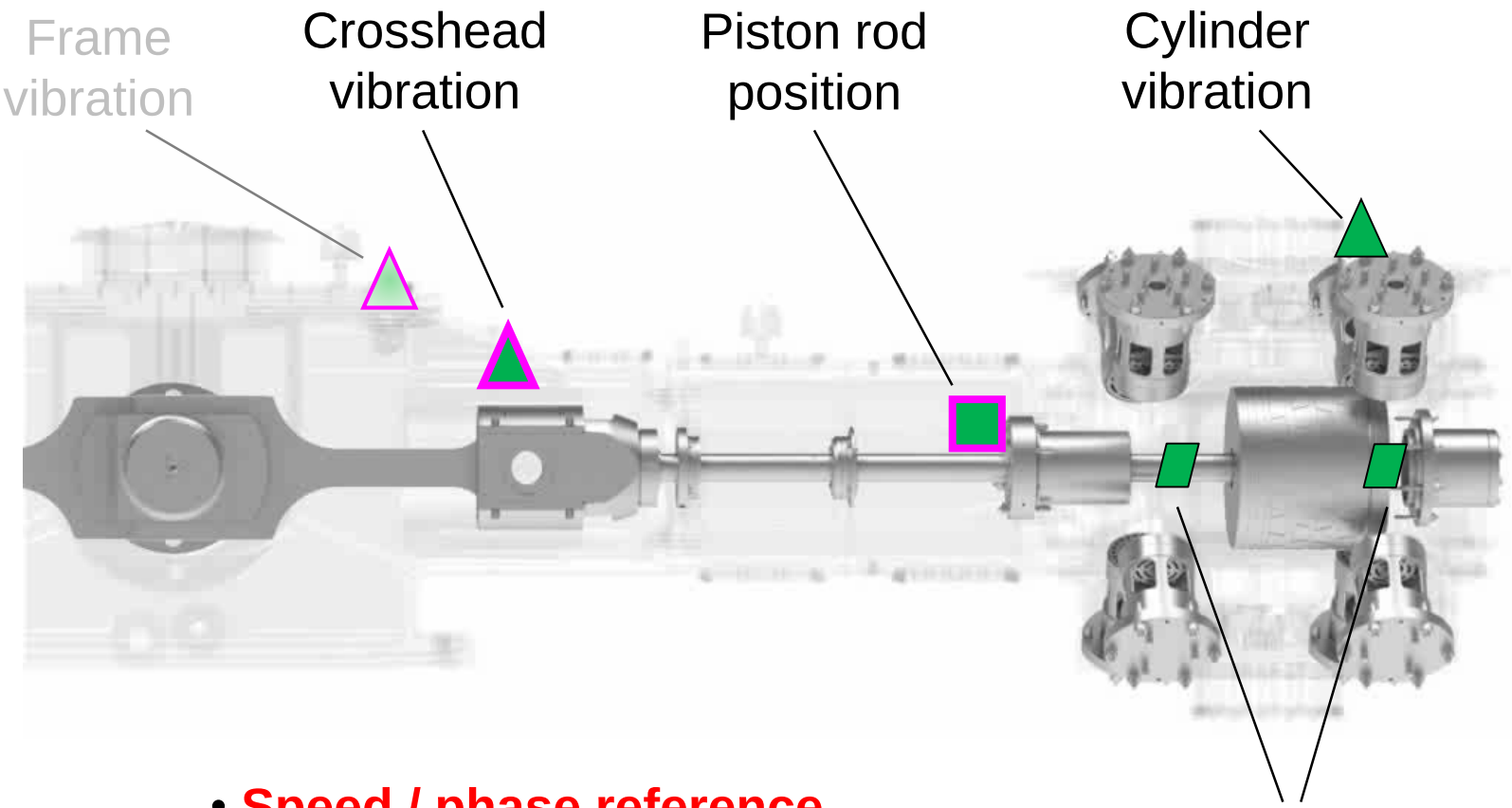
Maintenance Costs and Failure Modes

Reciprocating Compressor Condition Monitoring



Maintenance personnel must decide between taking a leaking compressor offline or running to a scheduled period.

Sensor types and locations



- **Speed / phase reference**
- Process data

Data management

Data acquisition

Trend values

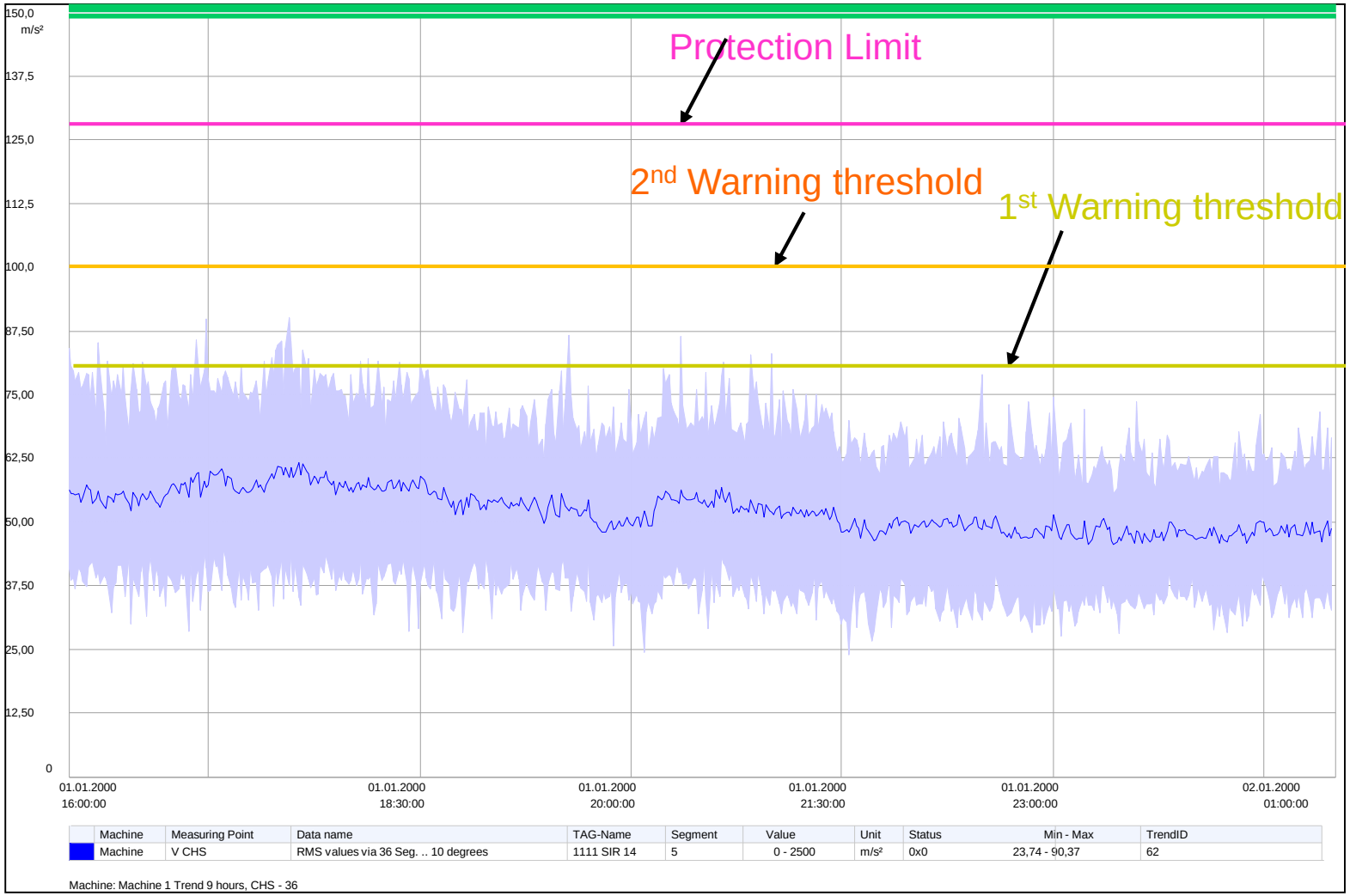
- Vibration amplitudes
- Temperatures
- Rotating speed
- Suction / Discharge pressure
- Etc …

Dynamic signals

- Crosshead acceleration vs Crank angle.
- Cylinder acceleration vs Crank angle
- Rod movement vs Crank angle
- Pressure vs Cranck angle
- PV diagram

- **Spectrum are useless ?? …**
- **Timing is the key !**

Trend plot

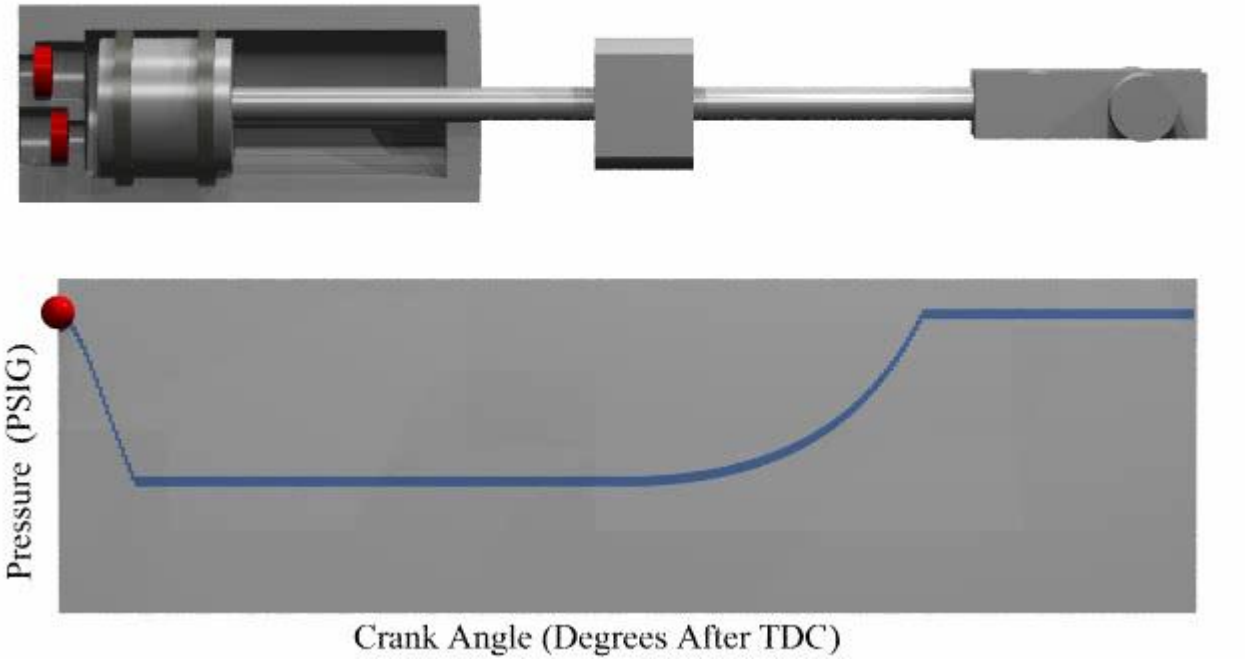


Machine	Measuring Point	Data name	TAG-Name	Segment	Value	Unit	Status	Min - Max	TrendID
Machine	V CHS	RMS values via 36 Seg. .. 10 degrees	1111 SIR 14	5	0 - 2500	m/s²	0x0	23,74 - 90,37	62

Crank Angle (P-θ) Plots

Animation: Pressure vs. crank angle for head-end chamber.

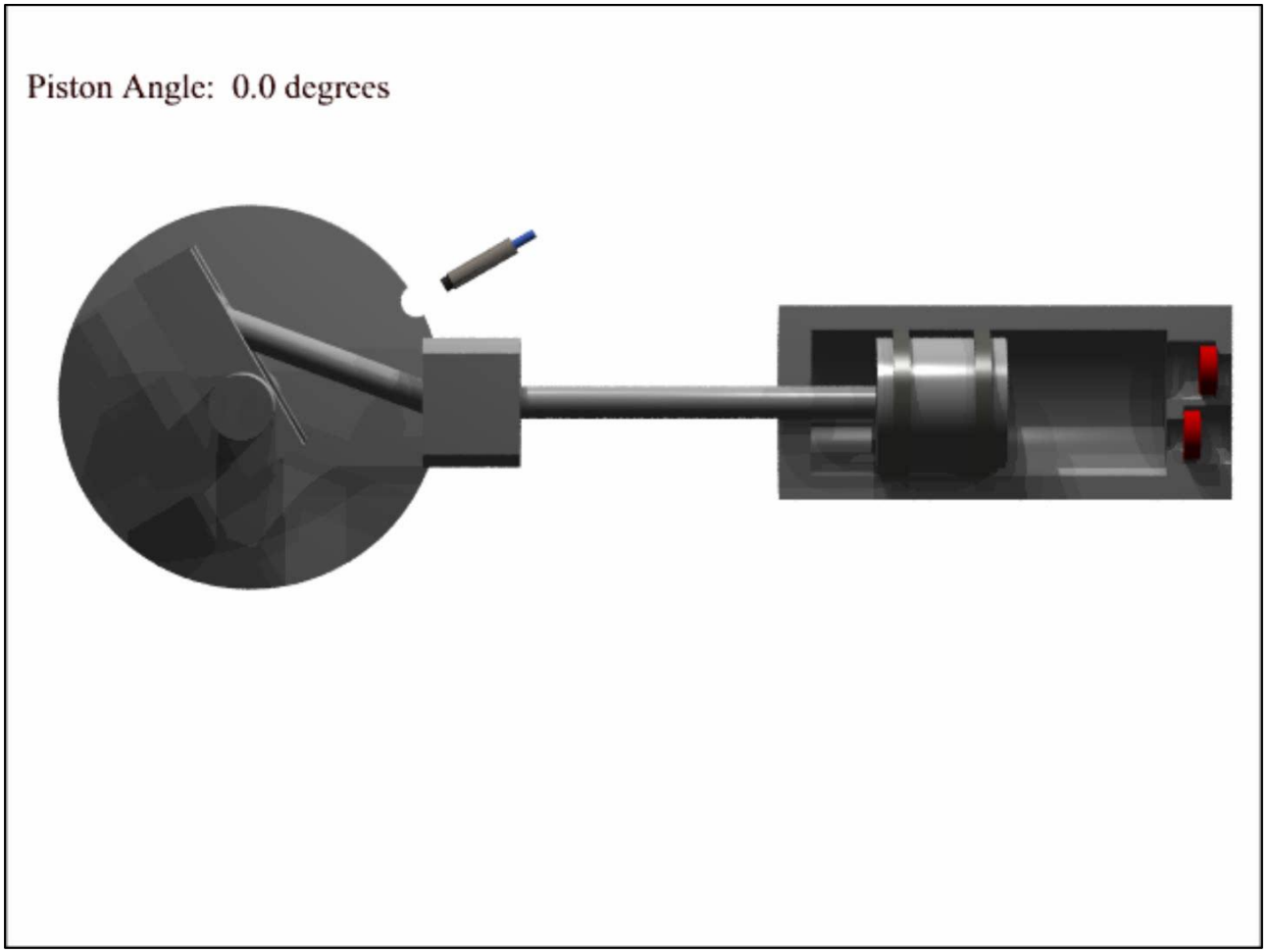
Crank Angle: 1 degrees
HE Pressure: 100 PSIG



Full Screen: PT_animation.wmv

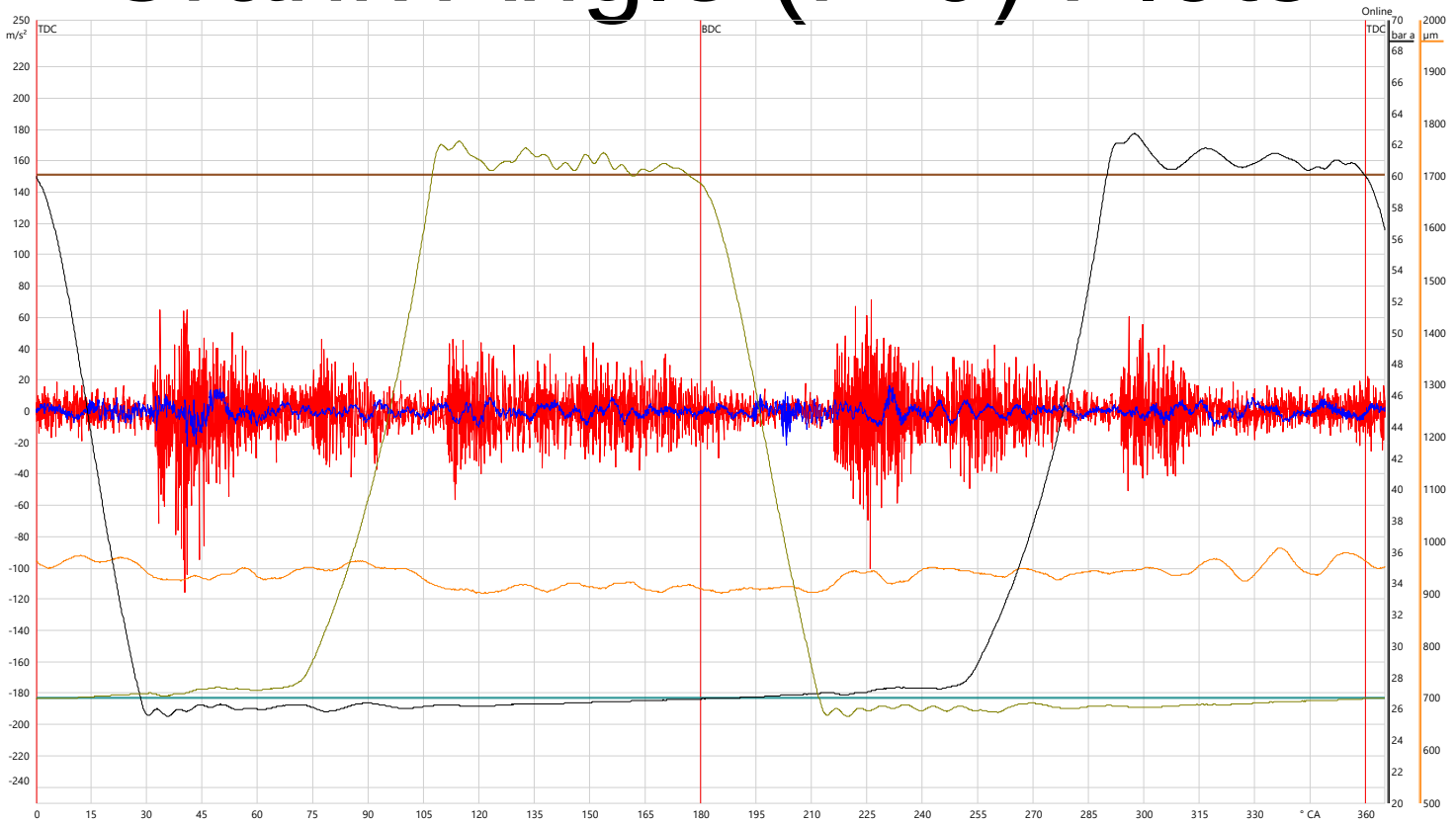
Piston Angle / Phase reference

Determining Piston Angle



PistonAngle.wmv

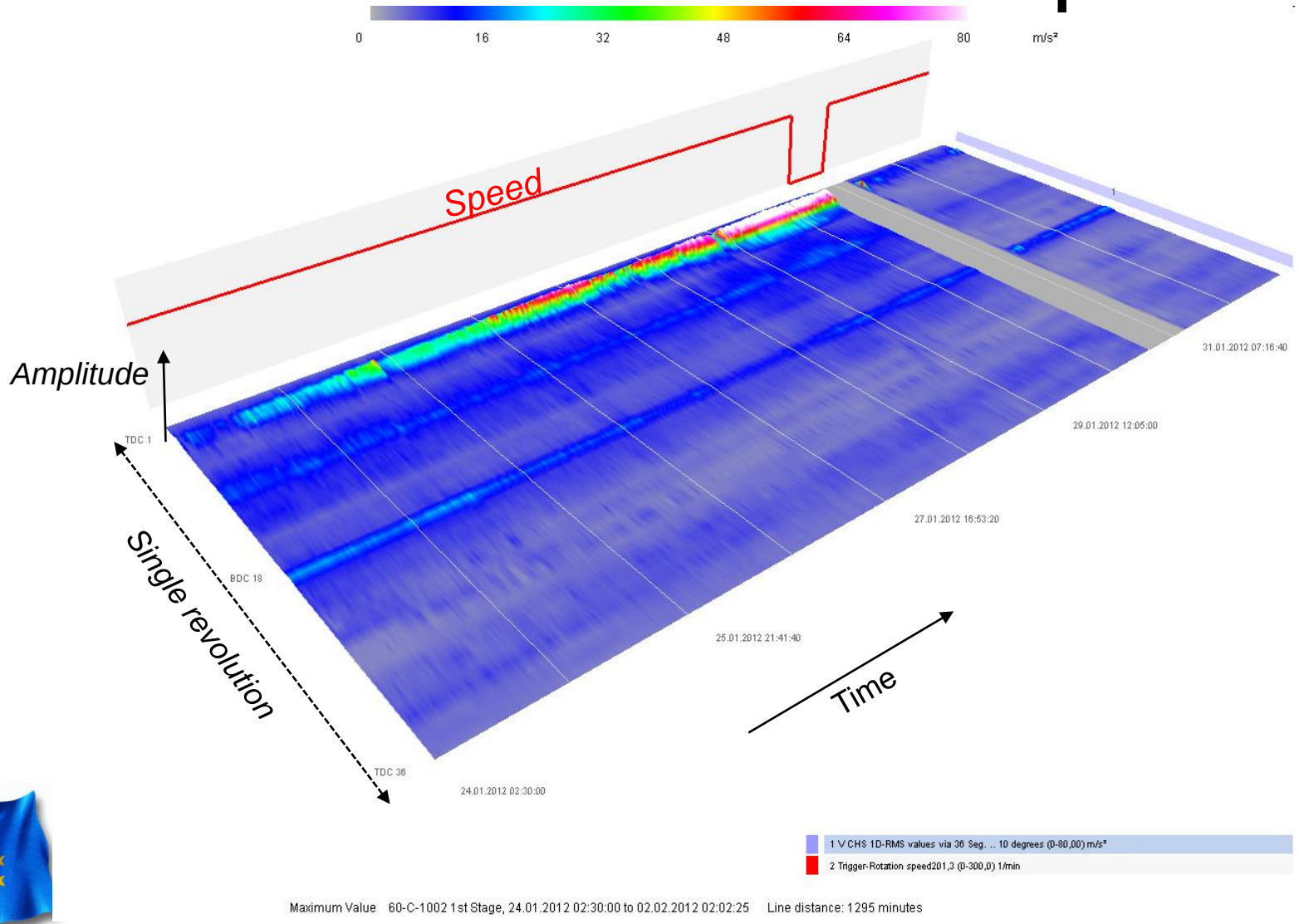
Crank Angle (P-θ) Plots



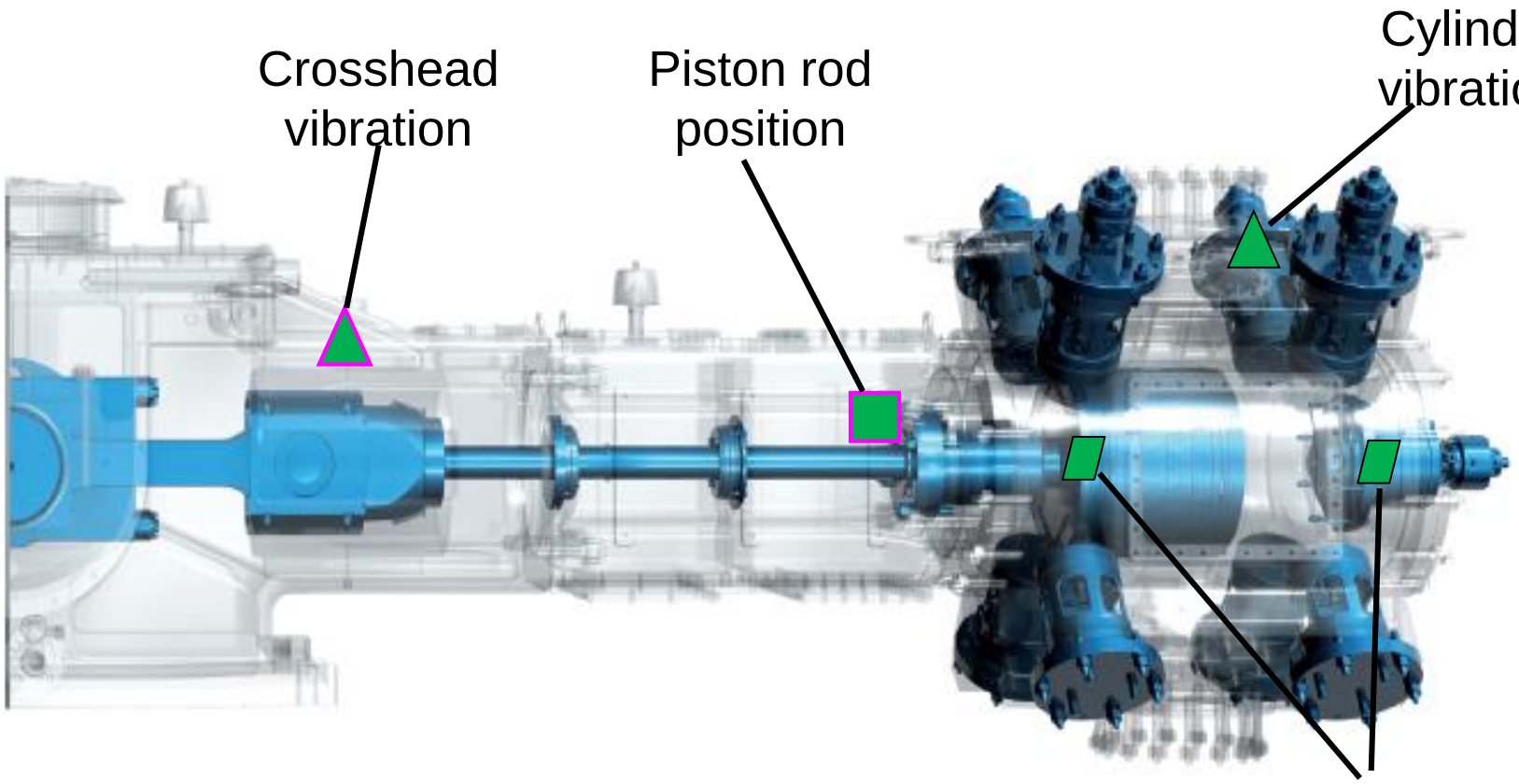
	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	M1000	Zylinder St.1	Vib. cylinder	S 10044	-2000 - 2000	m/s²
	M1000	KKB Stufe 1	Vib. cross head slide	S 10043	-250,0 - 250,0	m/s²
	M1000	Druck St.1 DS	Press. head end	P 10047	-2,207 - 97,79	bar a
	M1000	Druck St.1 KS	Press. crank end	P 10046	-1,438 - 98,56	bar a
	M1000	RD Stufe1	Rod position	X 10044	0 - 2250	µm
	M1000	Saugdruck St.1	Suction pressure	P 10049	0 - 40,00	bar a
	M1000	Enddruck St.1	Discharge pressure	P 10056	0 - 100,0	bar a
	M1000	HydroCOM St.1	HydroCOM regulation	PV 10049B	50	%

Online 14.09.2015 15:52:14, M1000 , 332,7 1/min

3-D trend / Waterfall plot



Sensor locations



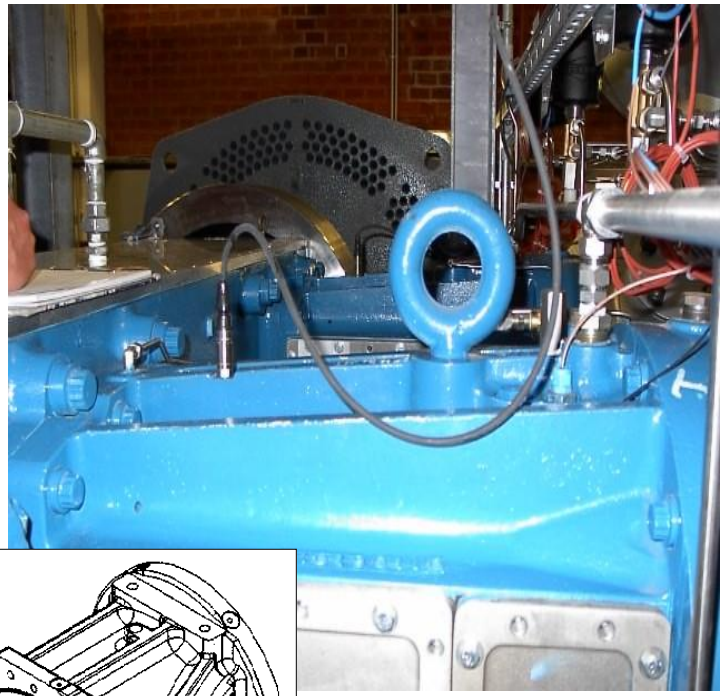
- **Speed / phase reference**
- Process data

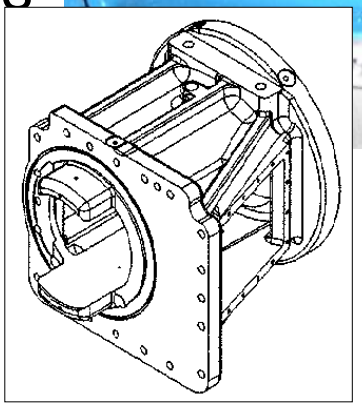
Crosshead vibration

With **acceleration sensors…**

- mechanical damages
- clearance in the reciprocating drive train
- loose crosshead-piston rod connection

…can be detected in early stages





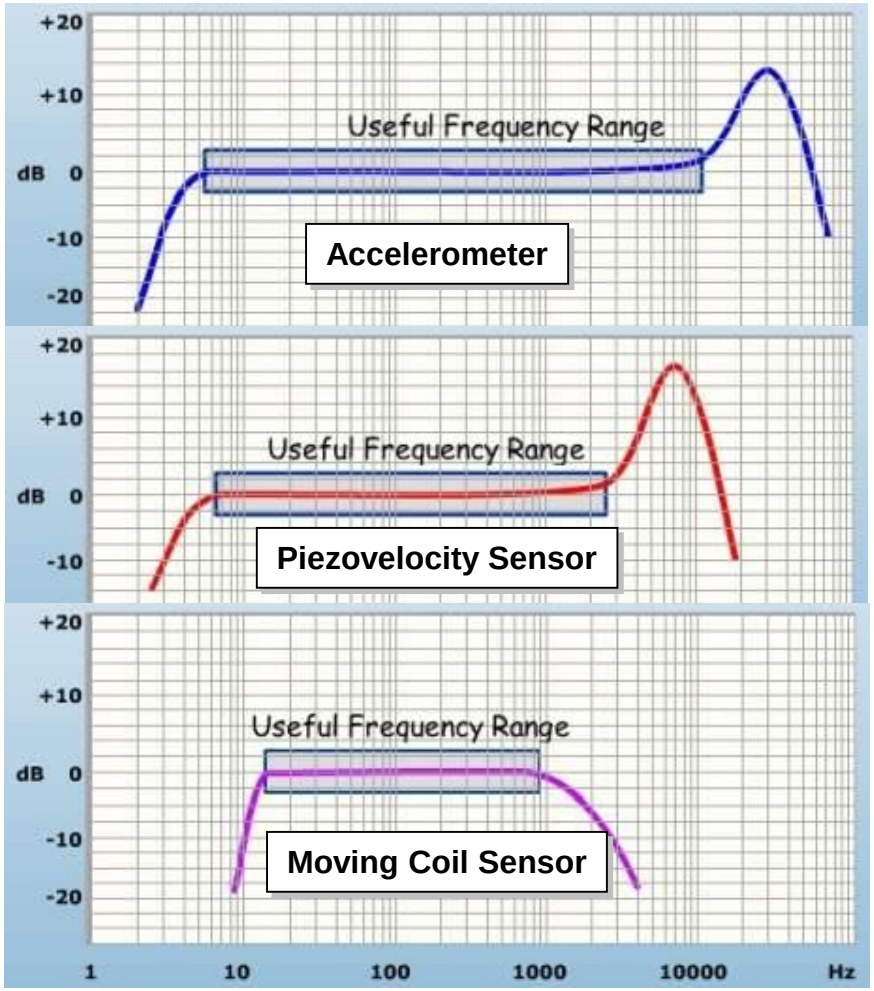
Typical Frequency Ranges

Seismic Transducers

Accelerometer: Highest frequency response. Used for crosshead and cylinder impulse/impact monitoring

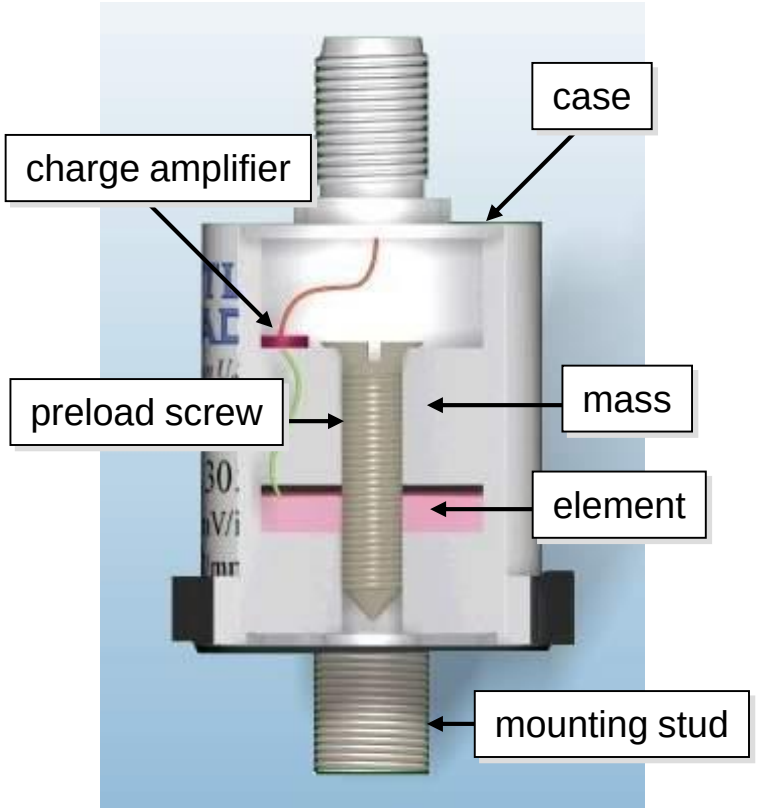
Piezovelocity Sensor: Lower high frequency response, but less noise than using an external integrating amplifier with an accelerometer, used for frame vibration

Moving Coil Sensor: Limited frequency response, no requirement for an external power supply. Widely used before piezo sensors perfected

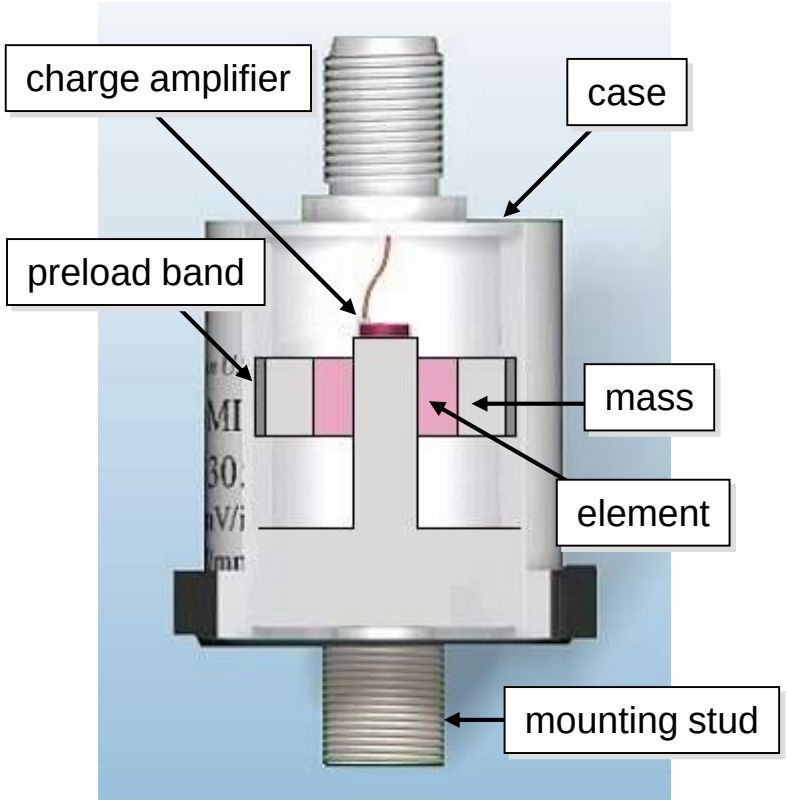


Typical Frequency Ranges

Accelerometer Specifics



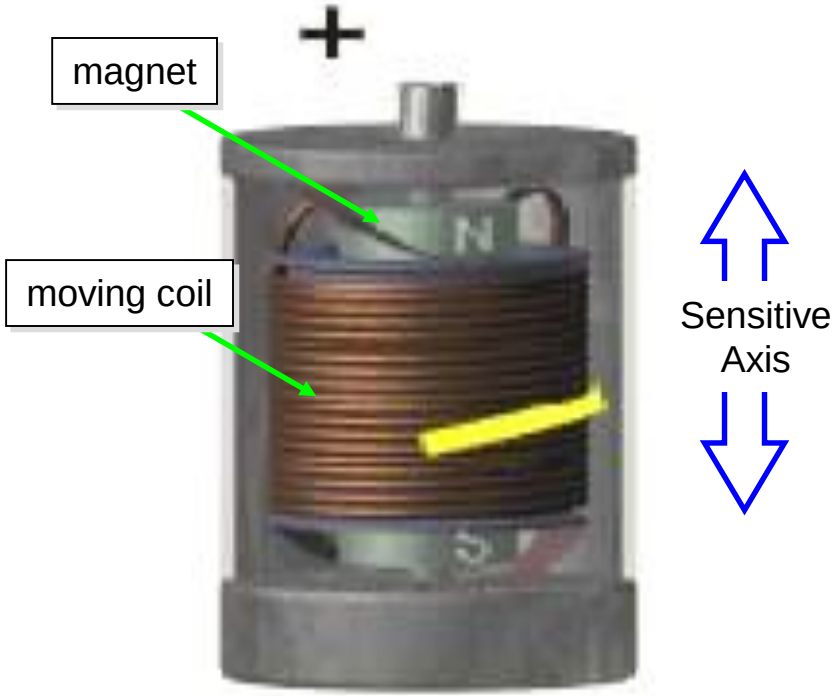
compression type sensor



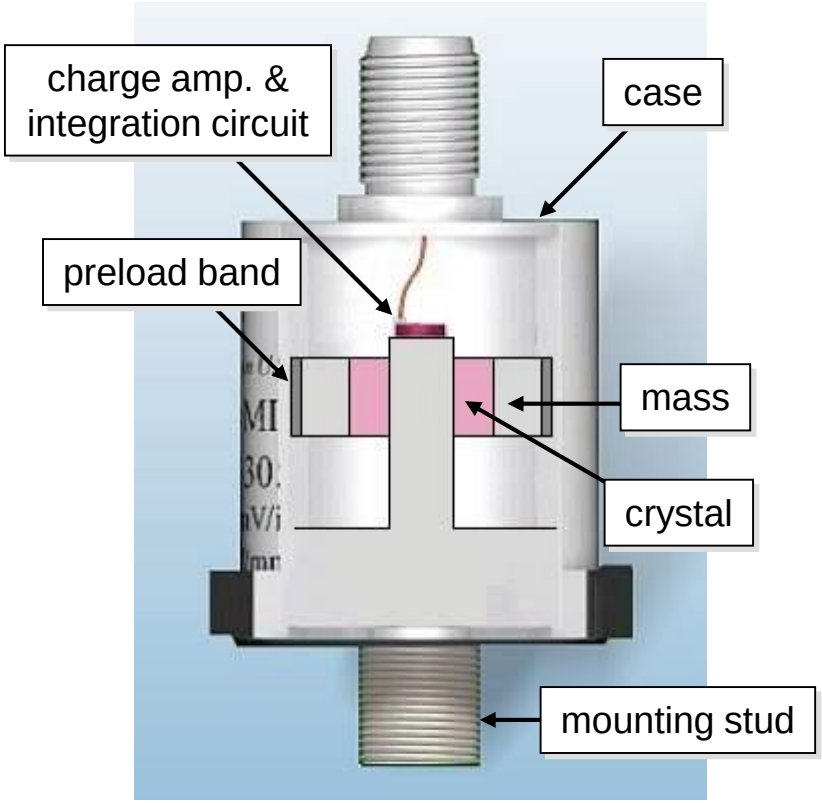
shear type sensor

Piezoelectric Accelerometer

Velocity Sensor Specifics



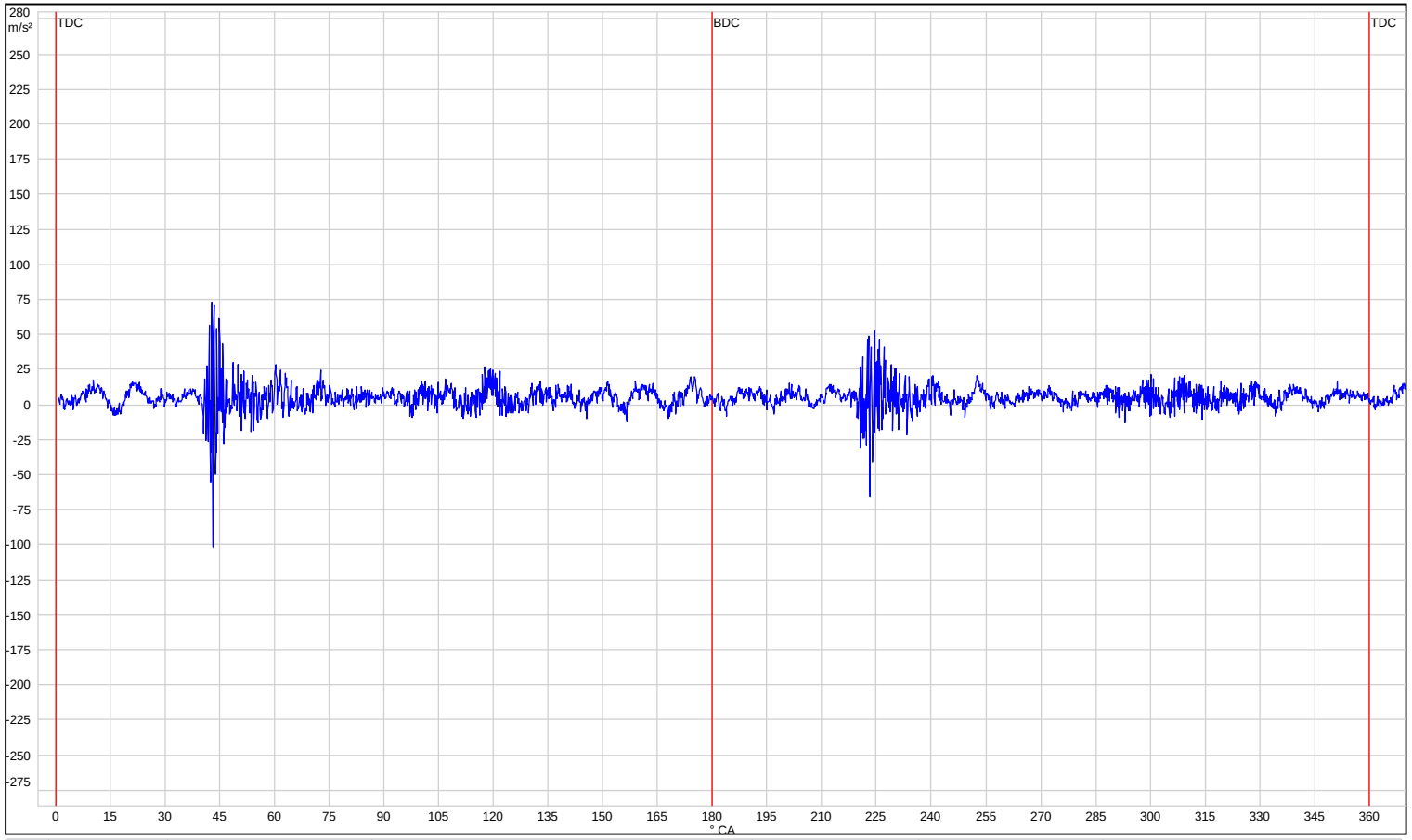
Traditional Moving-Coil Sensor
(self-powered)



Piezo-Velocity Sensor
(Accelerometer with onboard integrating circuit)

Integration within the sensor minimizes signal noise

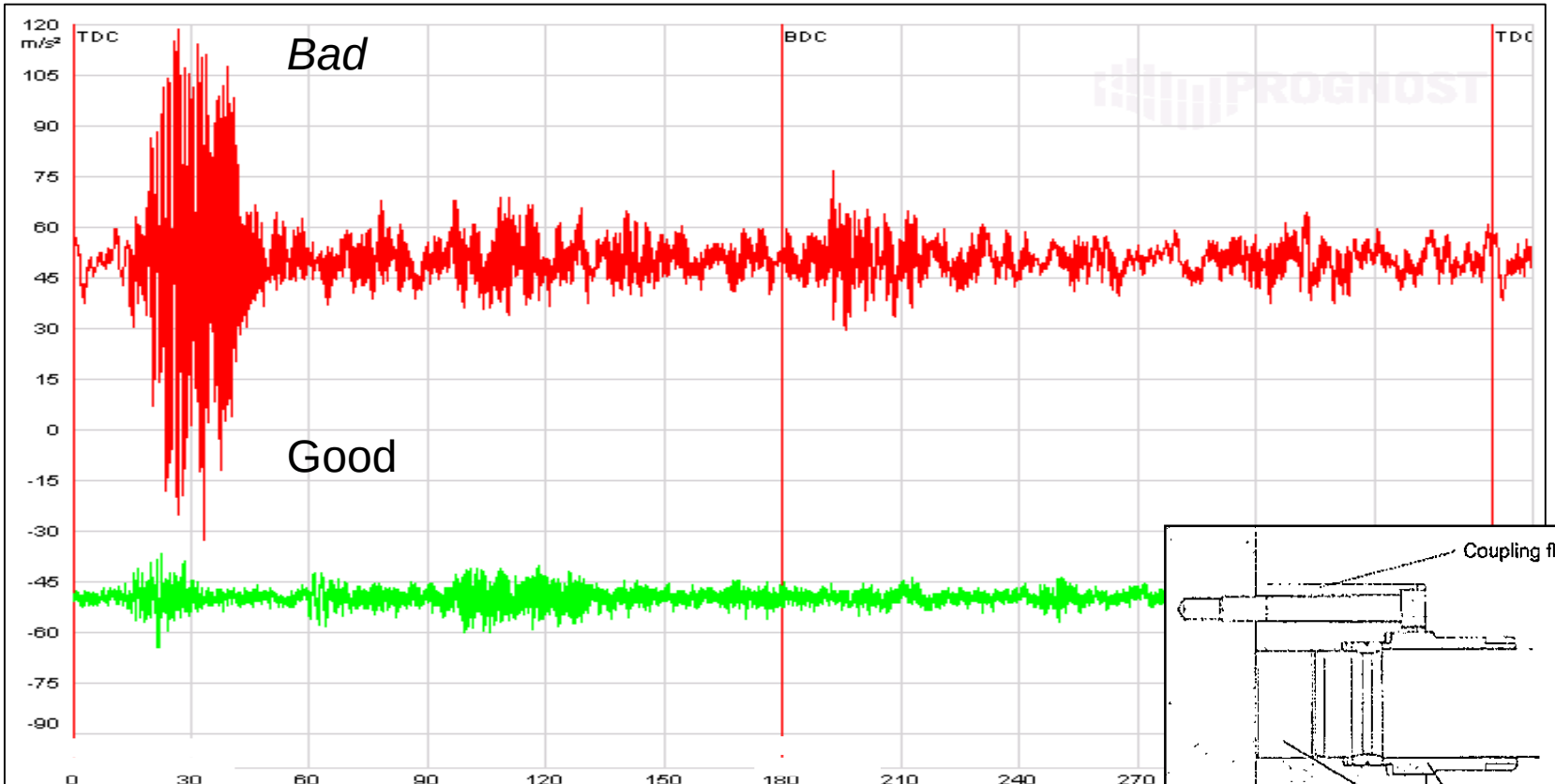
Crosshead vibration



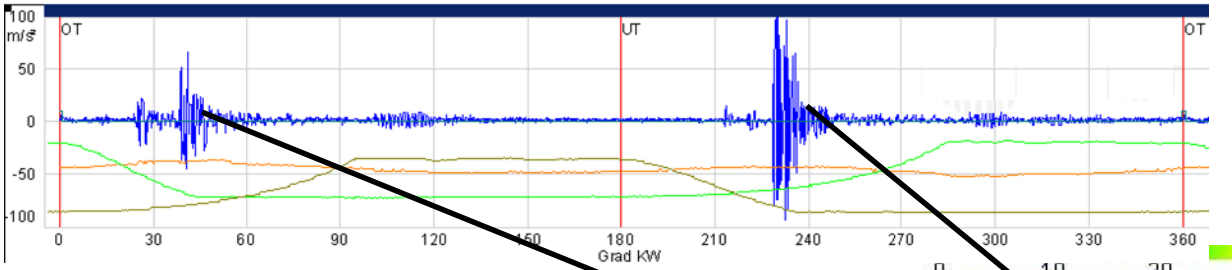
	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	V3	V Z1St.1 KKB	Vib. cross head slide	5328 SIR 14	-2500 - 2500	m/s²

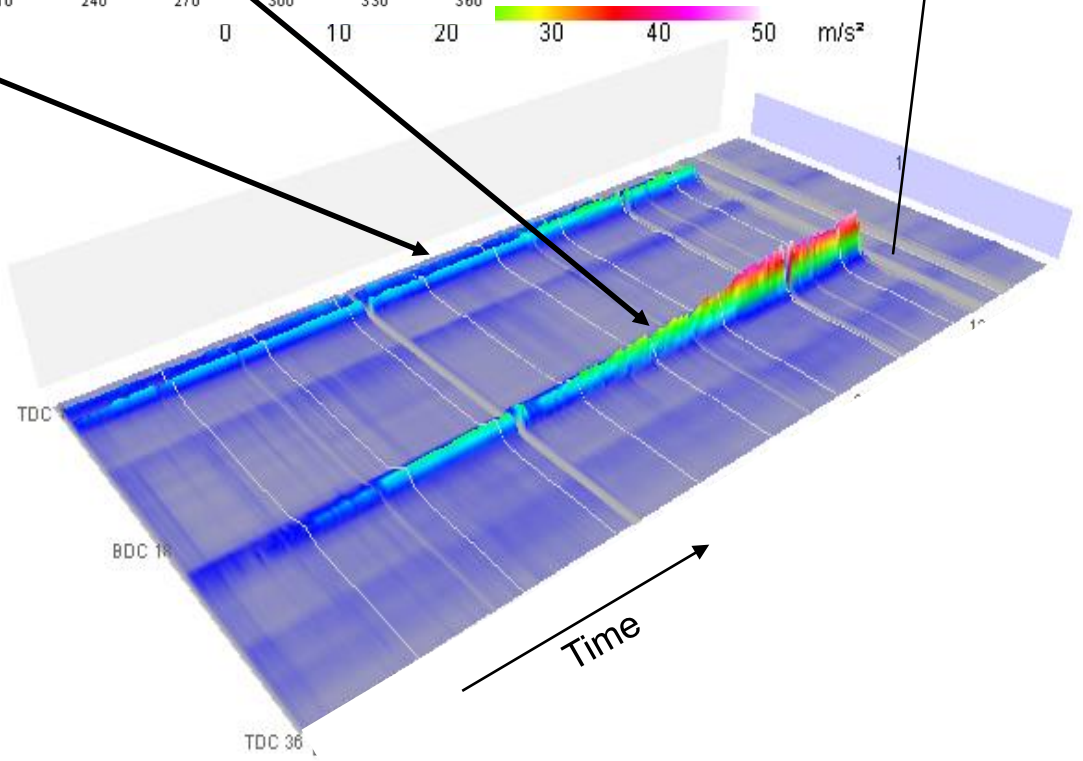
Online 20.10.2012 12:00:01, 5321 V 01 - Zyl.1 Stufe 1 , 570,1 rpm

Case 1: Loose Connection



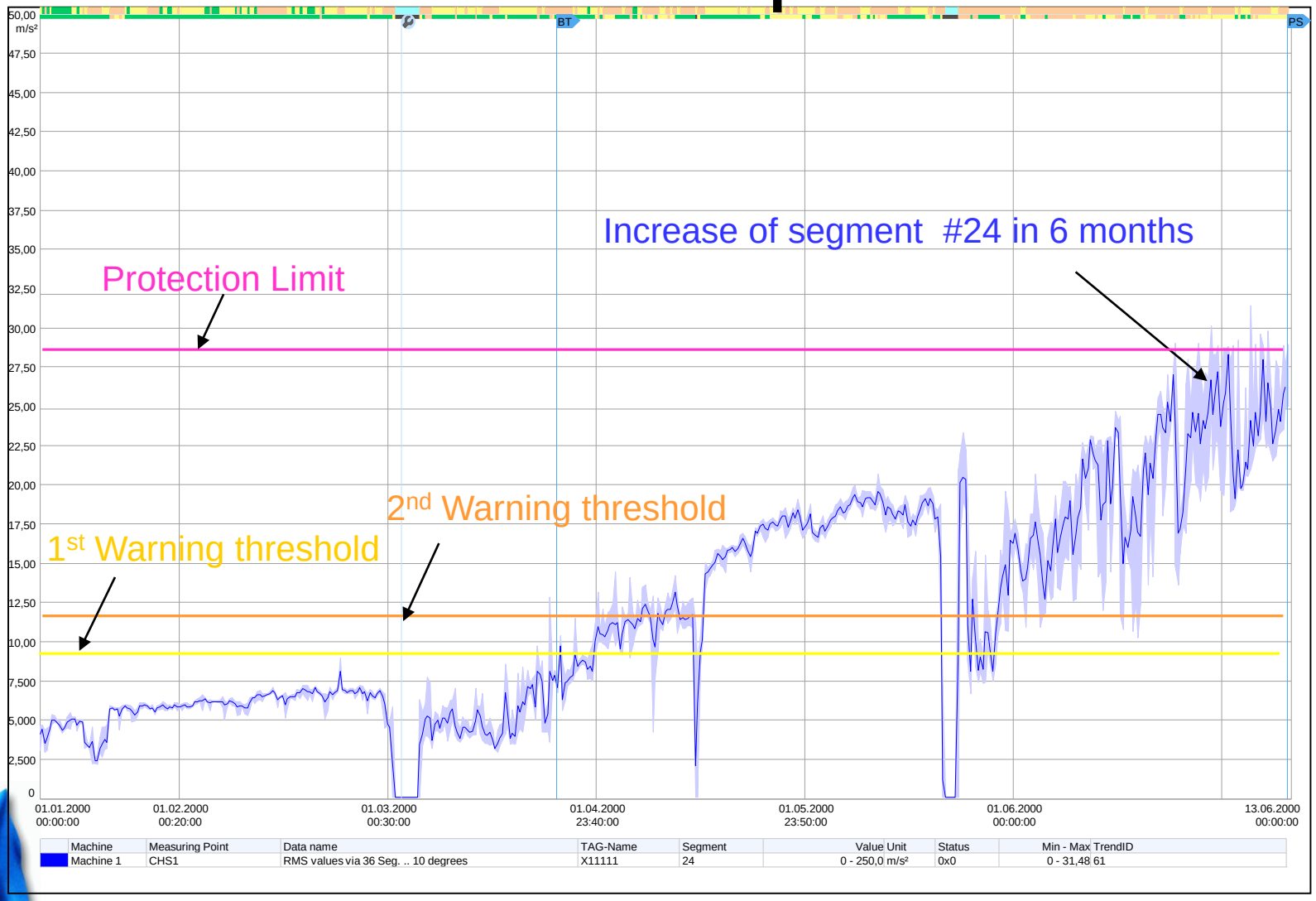
Case 2: Loose piston nut





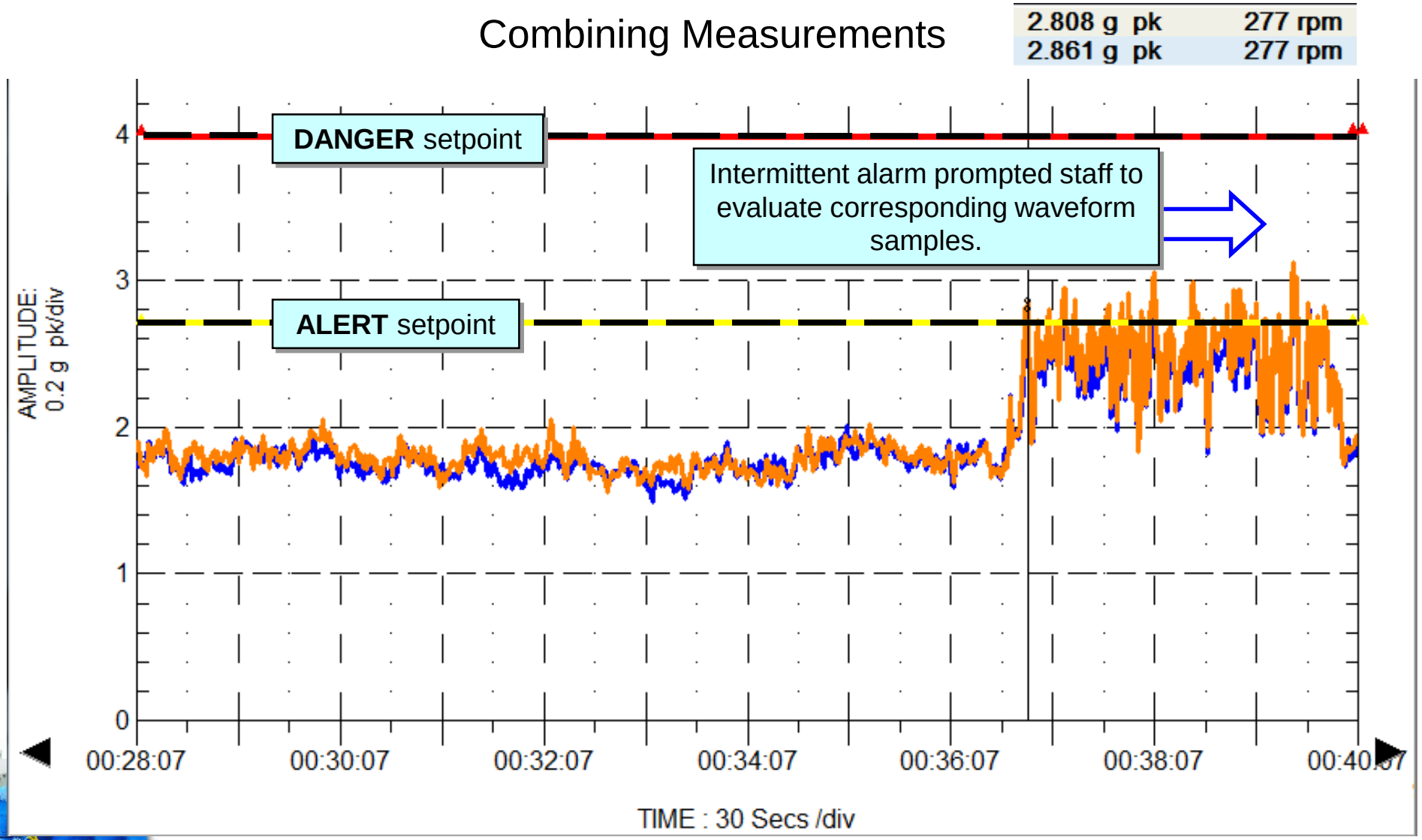
Large inspection found loose nut

Case 2: Loose piston nut

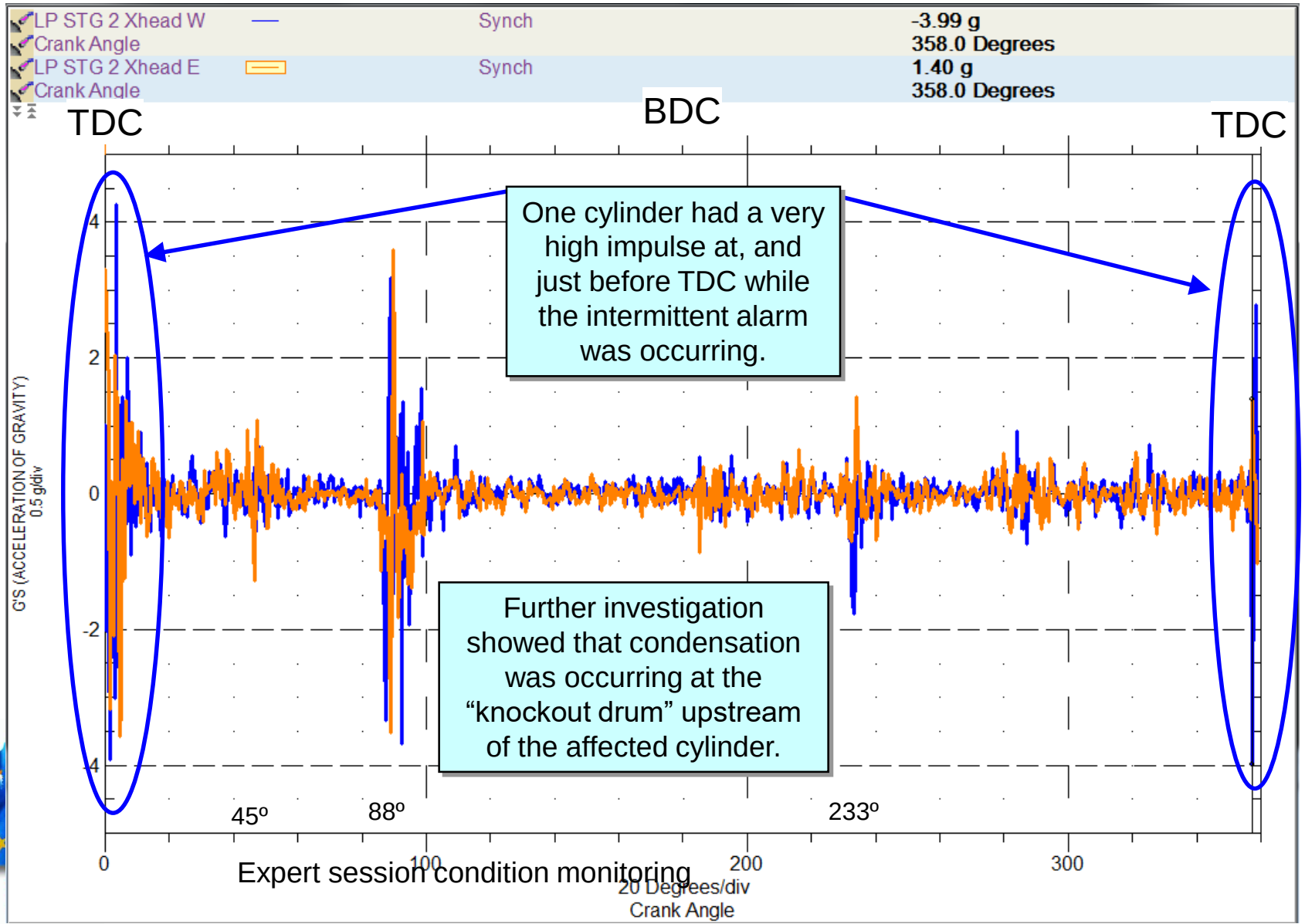


Case 3– Acceleration Trend

Combining Measurements



Case 3 – Acceleration Waveform



Case 3 – Liquid injection

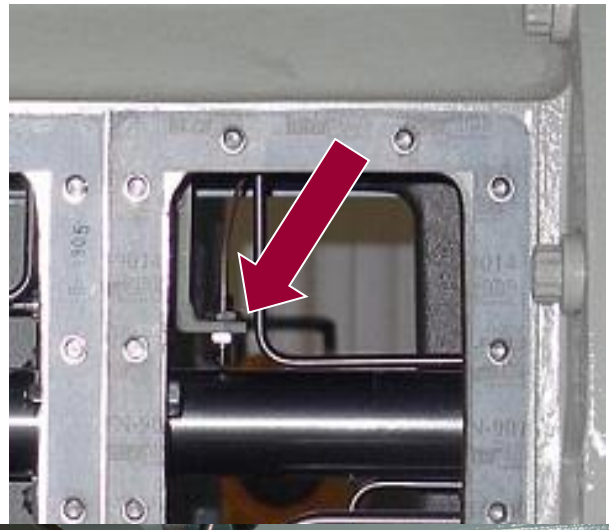
Combining Measurements – looped playback of event

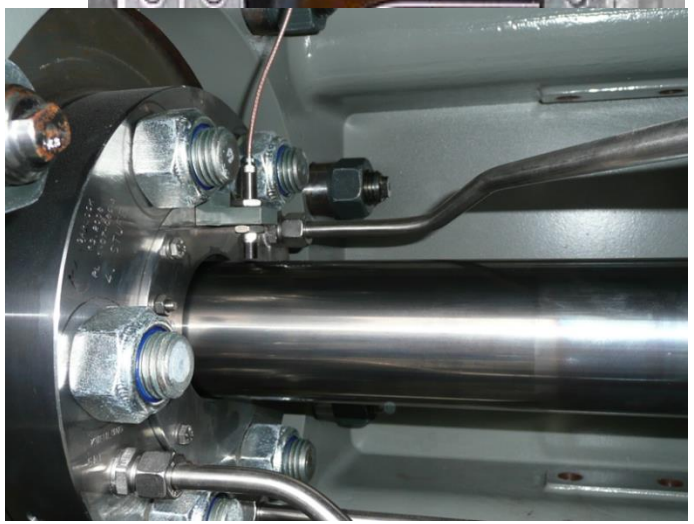
ADD the VIDEO / file to big to send by email

Piston rod displacement

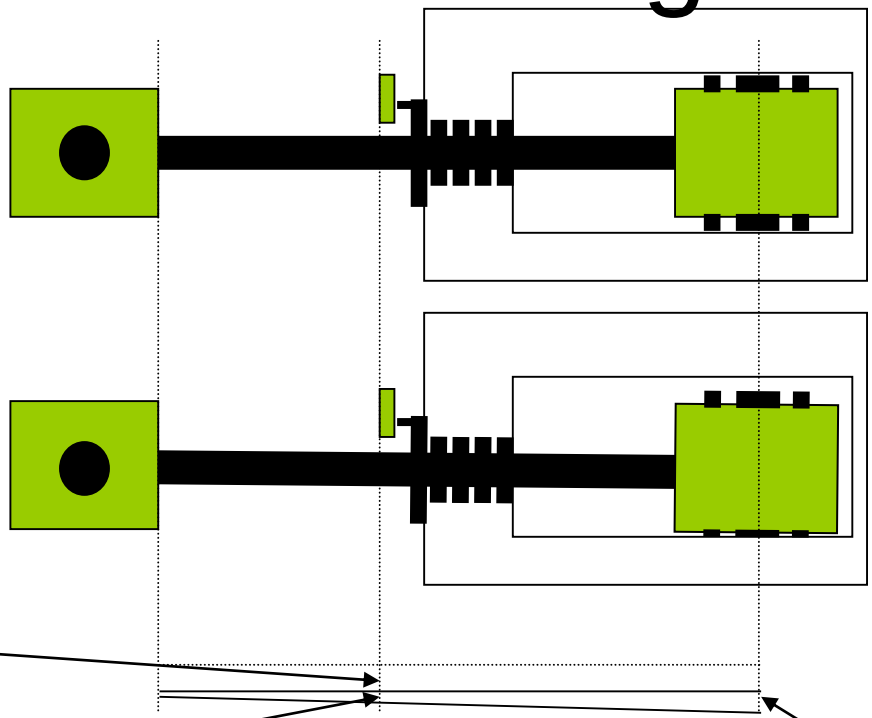
Movement / displacement of the rod measured with a proximity probe…

- **Debris and contaminants** (e.g. piston ring or valve fragments)
- **Oil or condensate** accumulation in the compression chamber
- Condition of the piston rod (incipient **fracture**)
- **Rider ring wear** monitoring



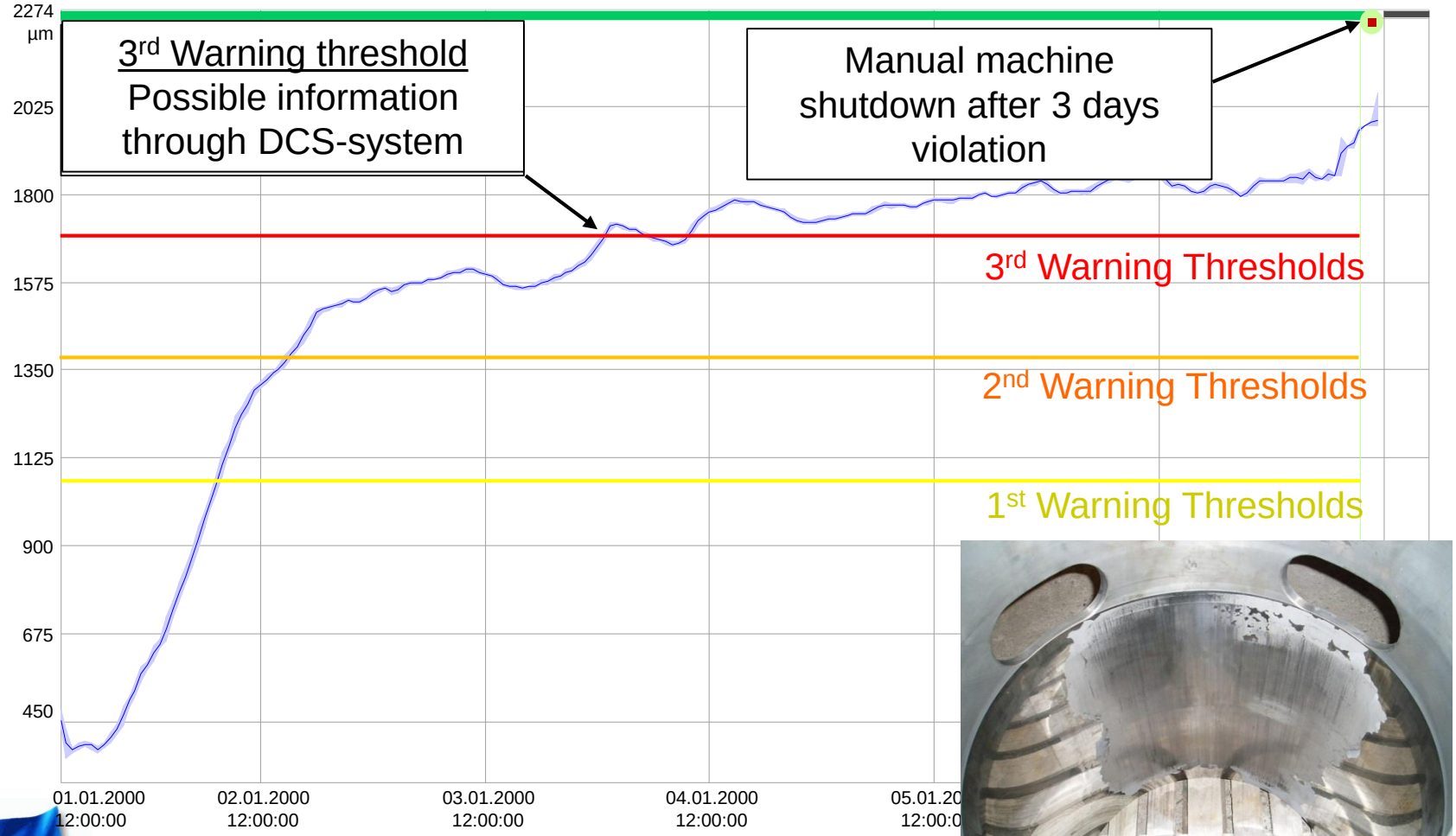


Rider ring wear



- The actual wear will be compared to a reference point of time
- Analysis is based on rod piston and dimensions (applied intercept theorem
- Adjustment of reference point necessary (zero adjustment)

Case 4: Rider ring wear

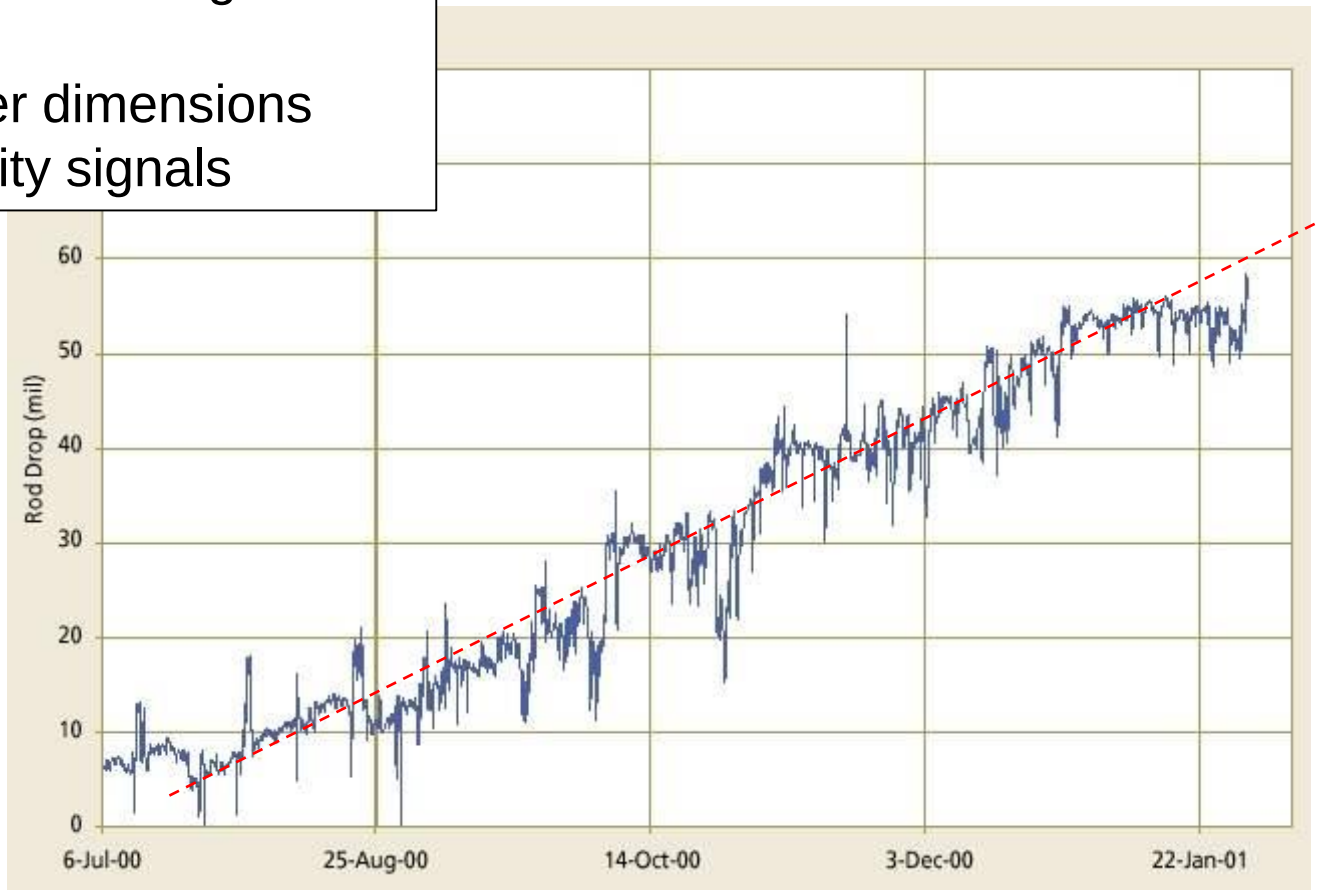


Machine	Measuring Point	Data name	TAG-Name	Segment	Value	Unit
Machine 1	RD Stufe 1	Rider ring wear	X1.111	1	0 - 2250	µm

Case 5 : Rod Drop Trend Example

Fundamentals

Calculated rider ring wear
Based on:
- Cylinder dimensions
- Proximity signals



Proactive maintenance

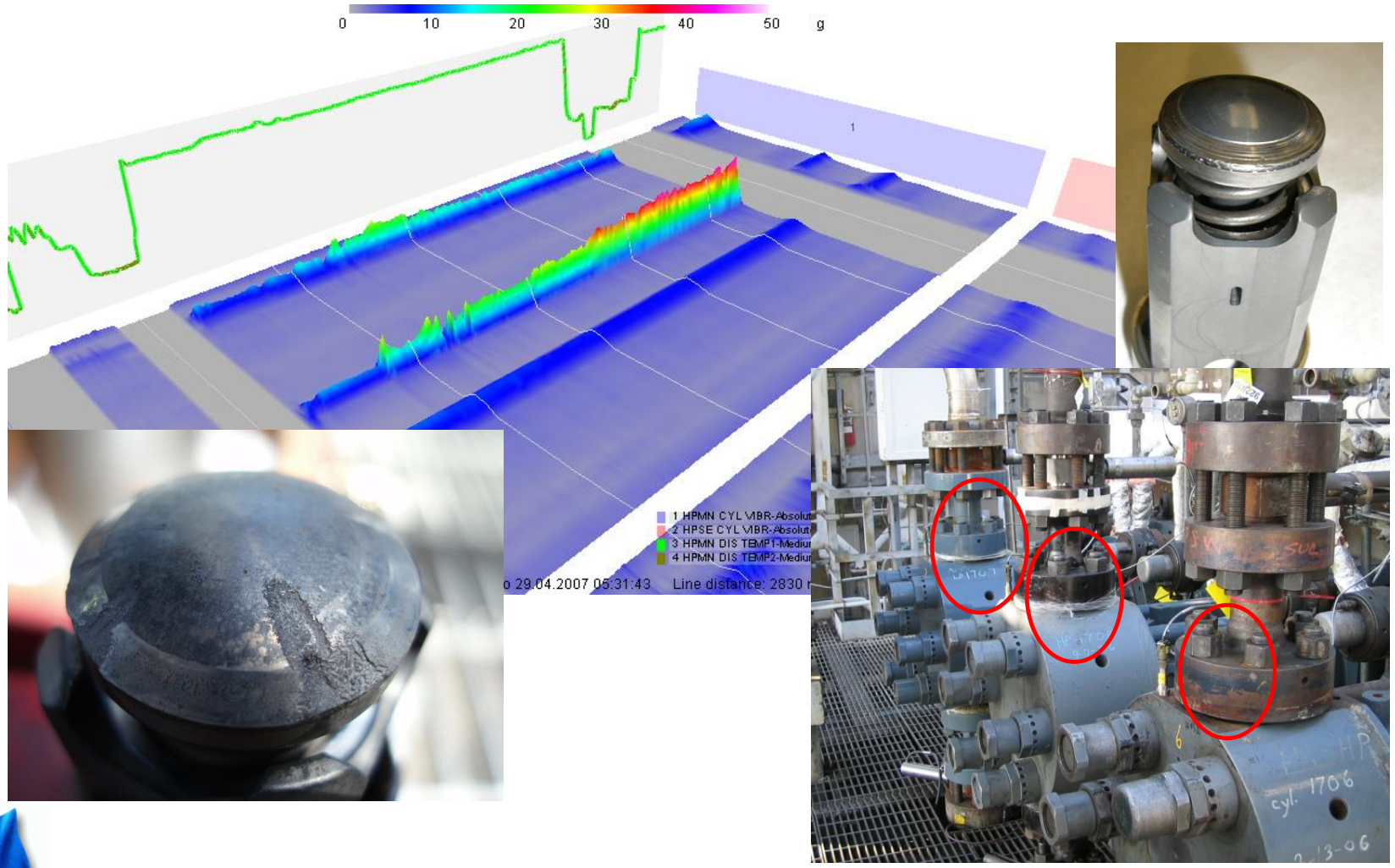
Cylinder vibration

With **acceleration sensors**…

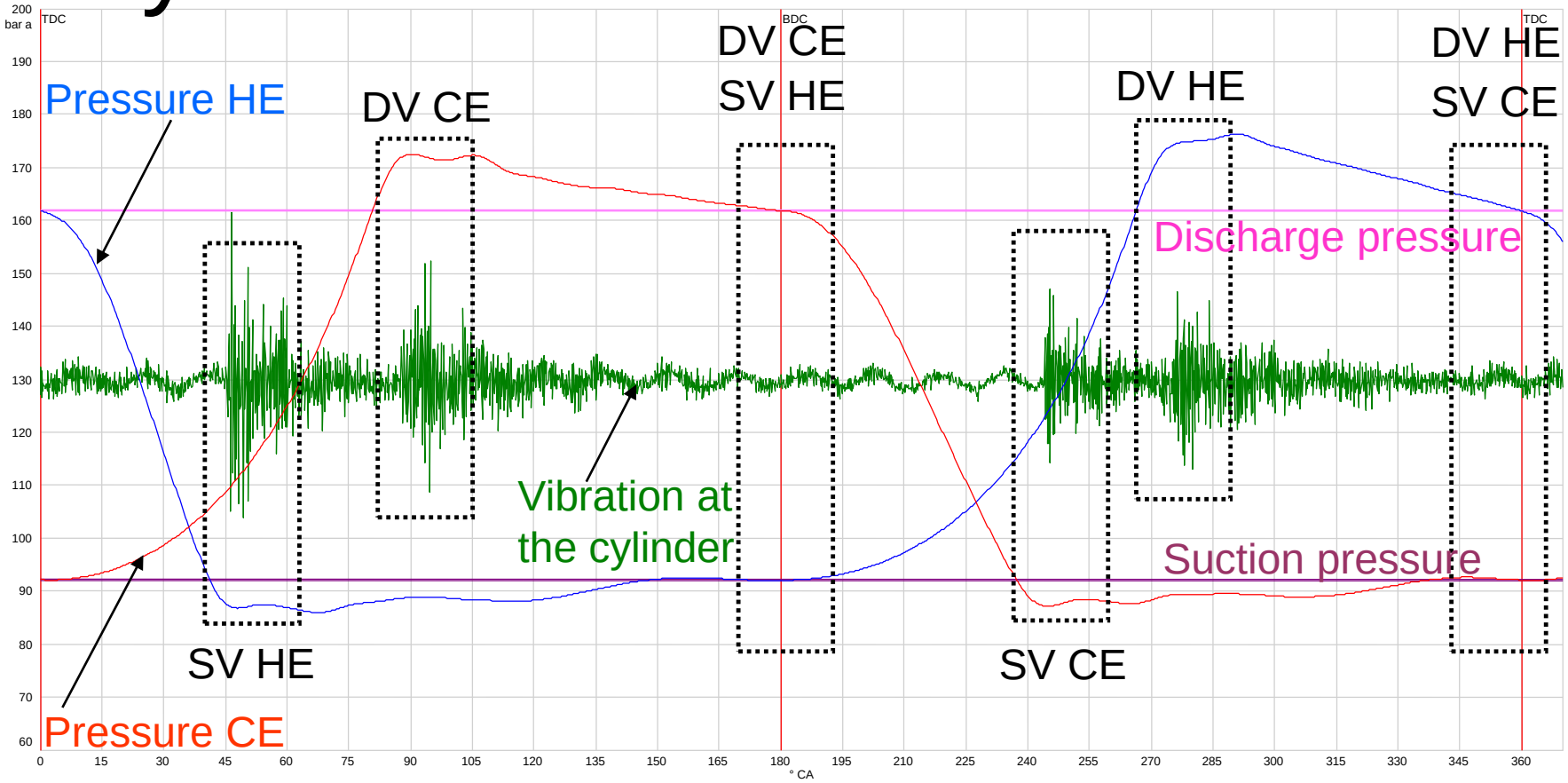
- Valve impacts
- Broken valve plate
- Loose valve cage
- Leakages
- Liquids

…can be detected

Case 6: Poppet valve failure



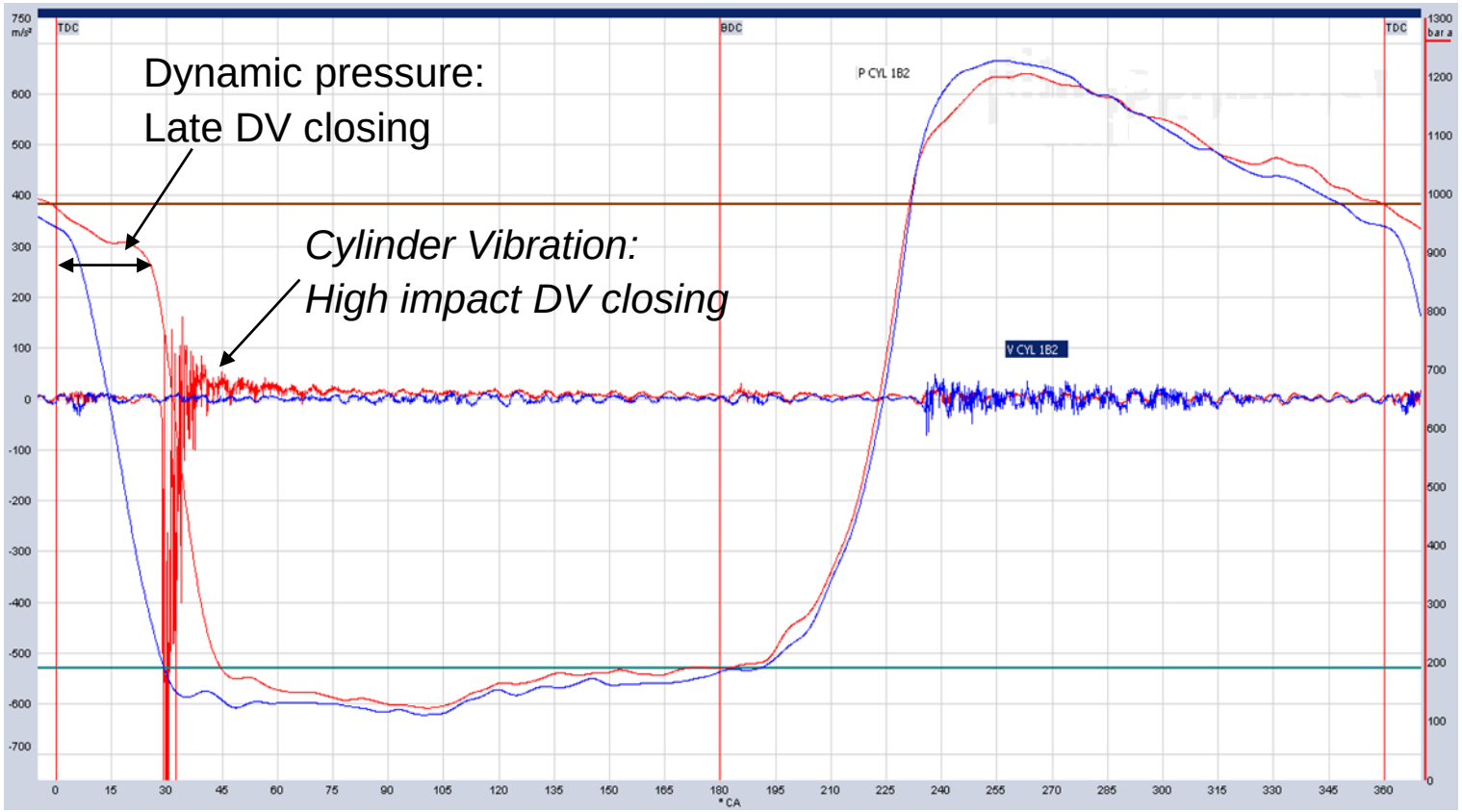
Cylinder vibration measurement



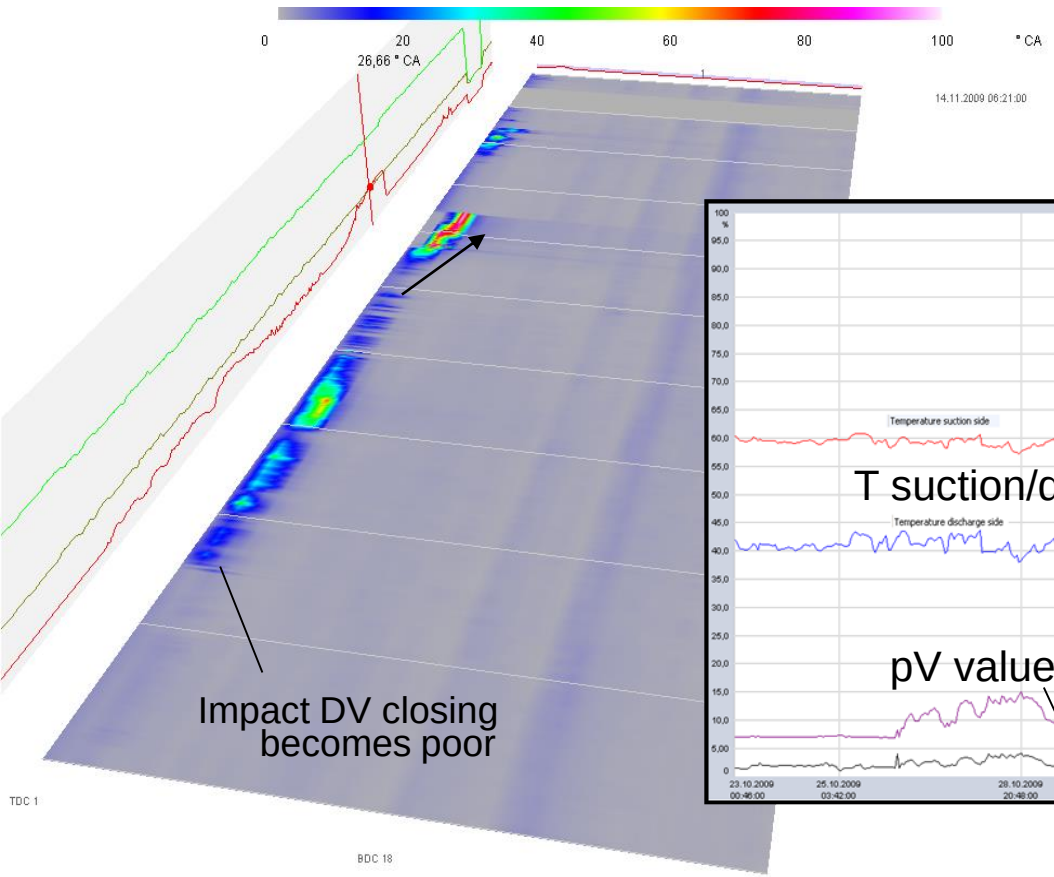
Those impacts always take place at the same time / °CA

HE = head end CE = crank end; DV= discharge valve; SV=suction valve

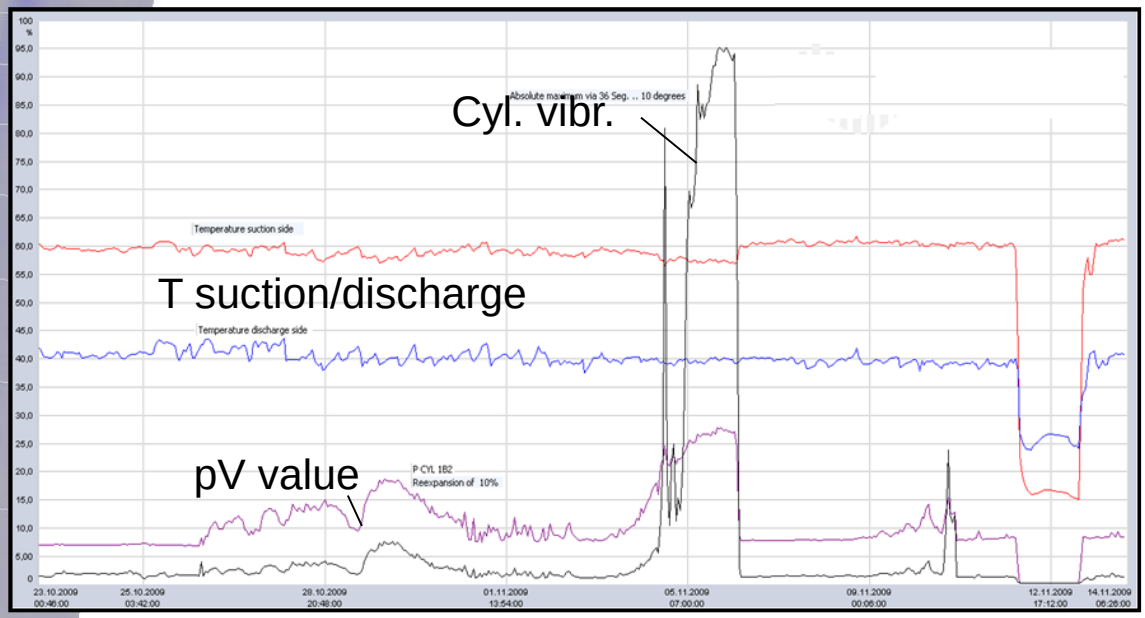
Case 7: Sticking poppet

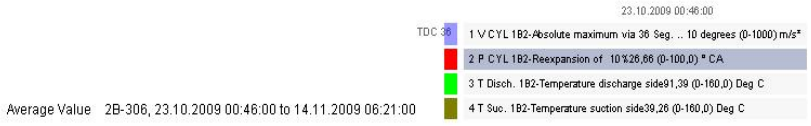


Case 7: Sticking poppet



Trend over 3 weeks



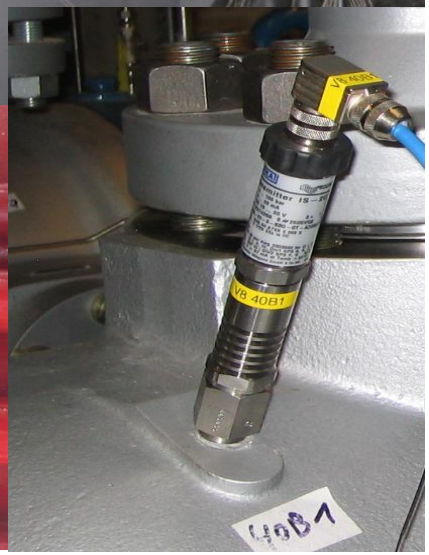


- ***Const. temperature values***
- ***Early indication on pV***
- ***Early indication on cyl. vibr***

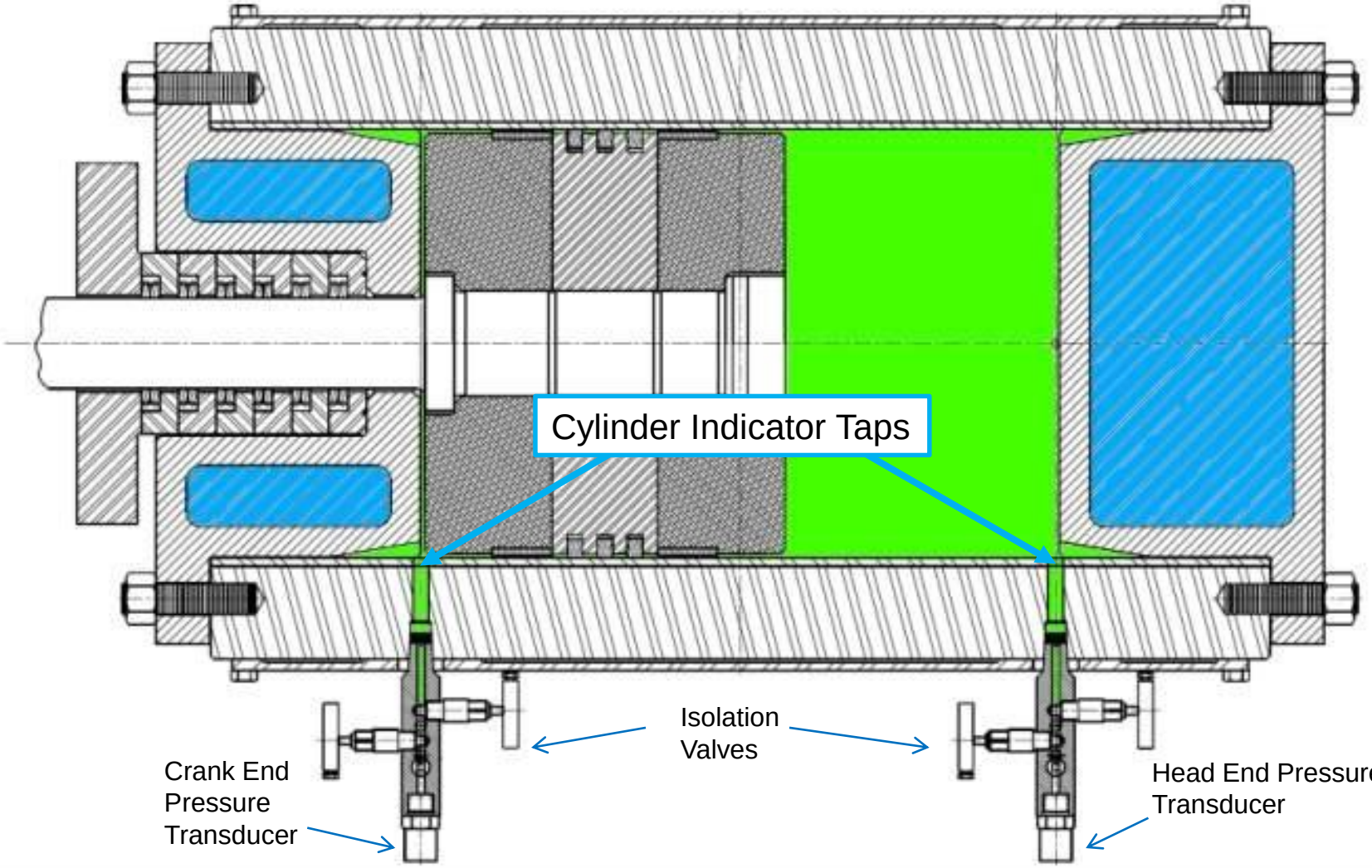
Dynamic pressure

With **pressure probes** or **strain rings**

- Condition of the valves
- Condition of the sealing elements such as piston rings and stuffing boxes
- Efficiency / losses
- Pulsations
- Monitoring of the control devices:
  - Suction valve unloaders
  - Clearance pocket unloaders

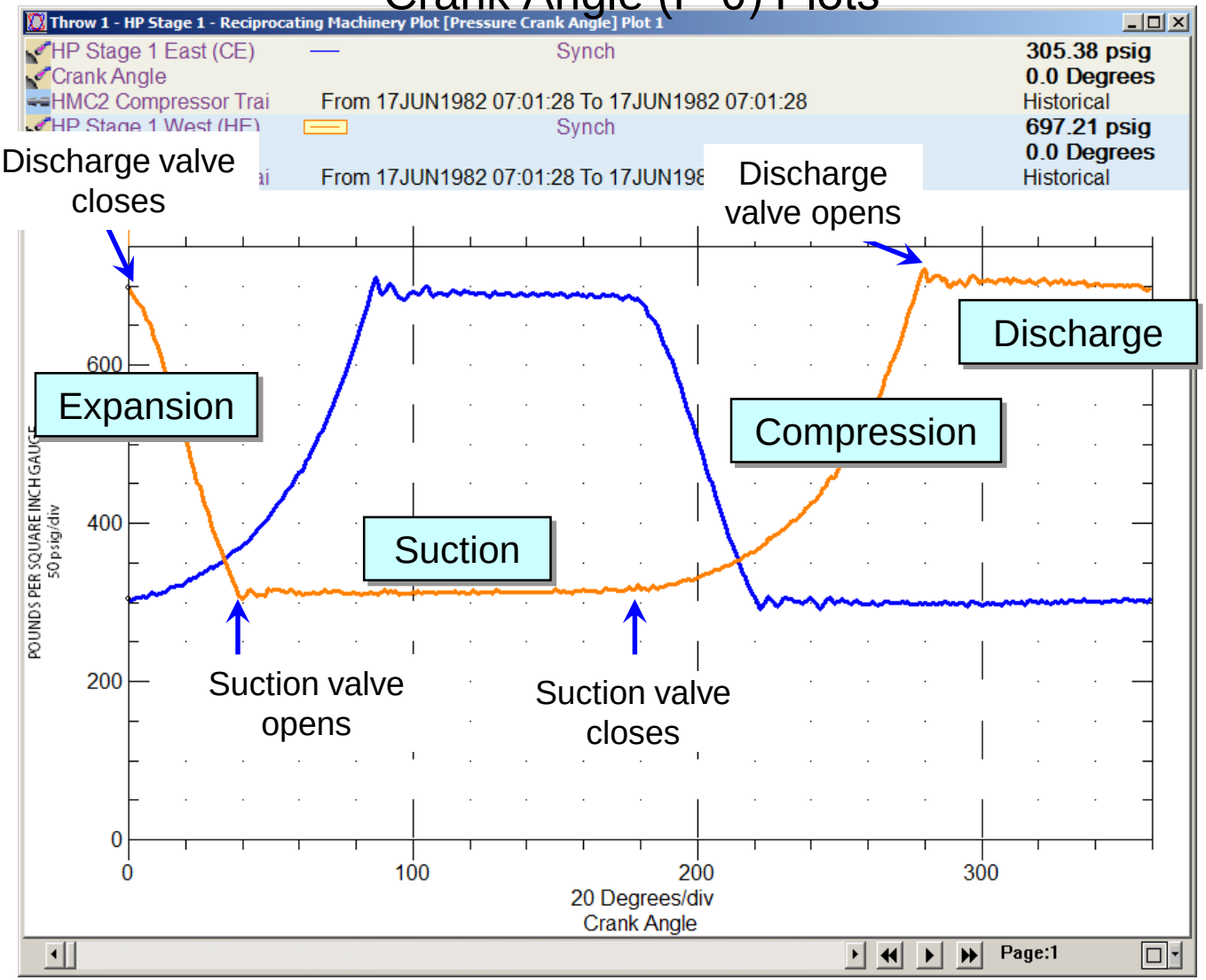


Pressure Sensor Installation

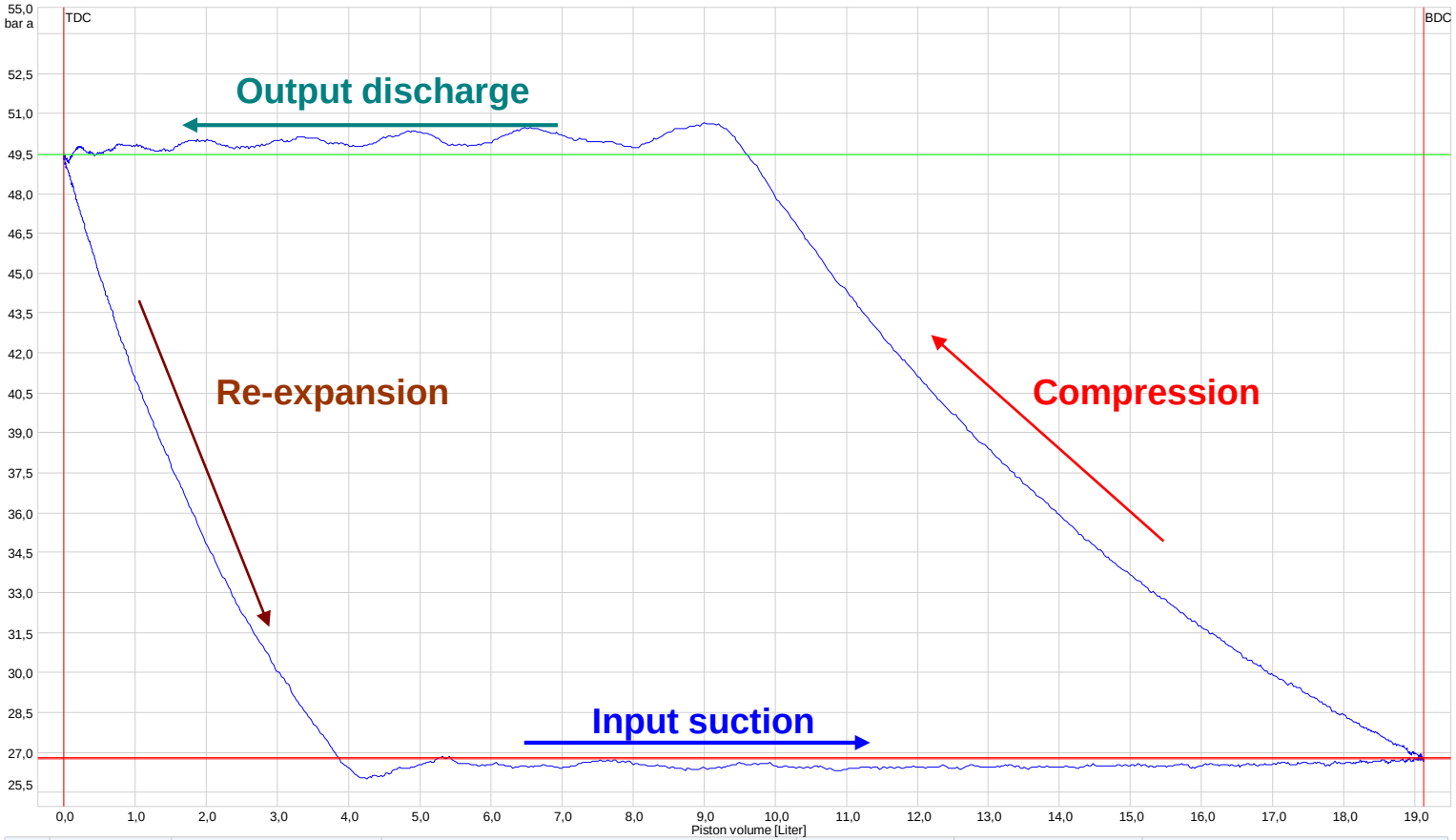


Valve Events & Processes

Crank Angle (P-θ) Plots



Dynamic pressure - pV diagram



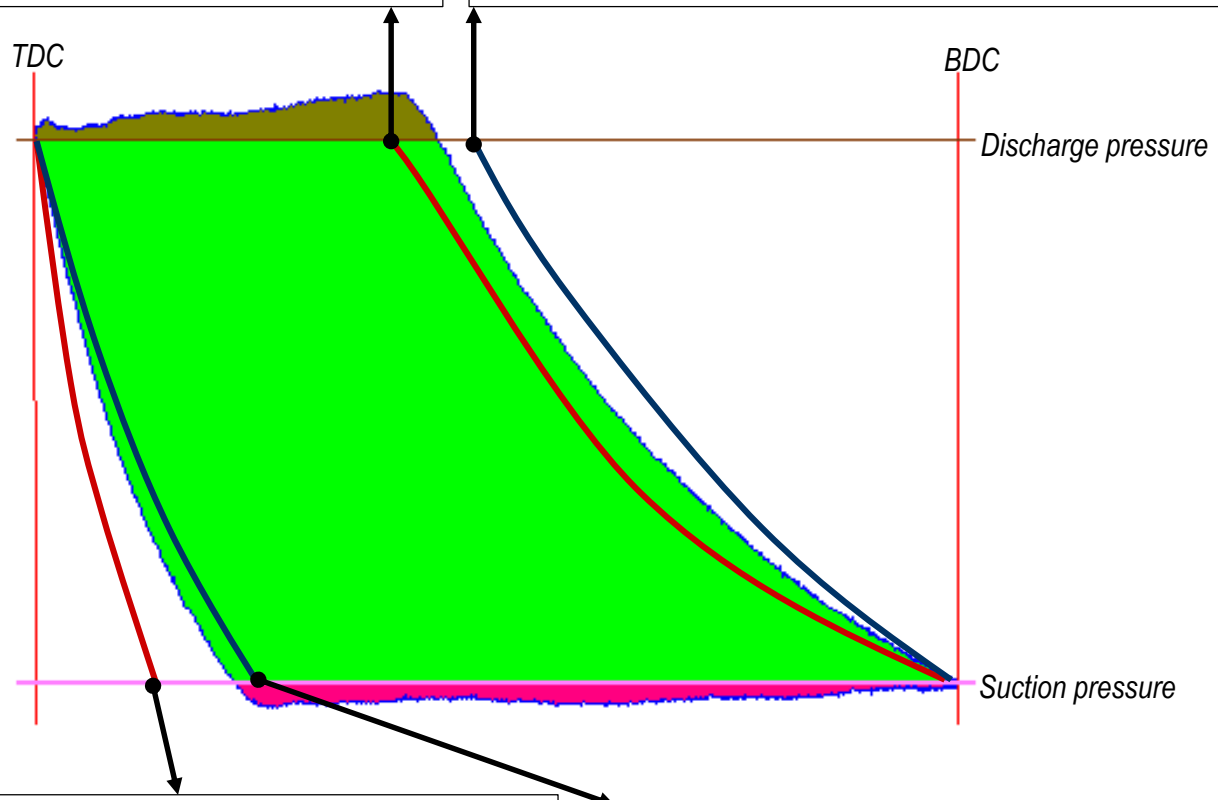
	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	Machine 1	Cyl. 1, CE	p-V-Diagram	PR-1111	-87,77 - 109,(	bar a
	Machine 1	SP Cyl.1	Process Data Standard Analysis	PR-1111T	0 - 110,3	bar a
	Machine 1	DP Cyl.1	Process Data Standard Analysis	PR-1111T	0 - 110,3	bar a
	Machine 1	Cyl. 1, CE	Break through suction pressure	PR-1111	0 - 150,0	° CA
	Machine 1	Cyl. 1, CE	Break through discharge pressure	PR-1111	200,0 - 350,(	° CA

Online 01.01.2000 12:00:00, Machine 1 - Cylinder 1 - Cyl. 1, CE (Type:Pressure) , 500,0 1/min

Exercise: Detection of leakages

„Longer“ to discharge pressure
→ Suction valves or packing (crank end)

„Shorter“ to discharge pressure
→ Discharge valves

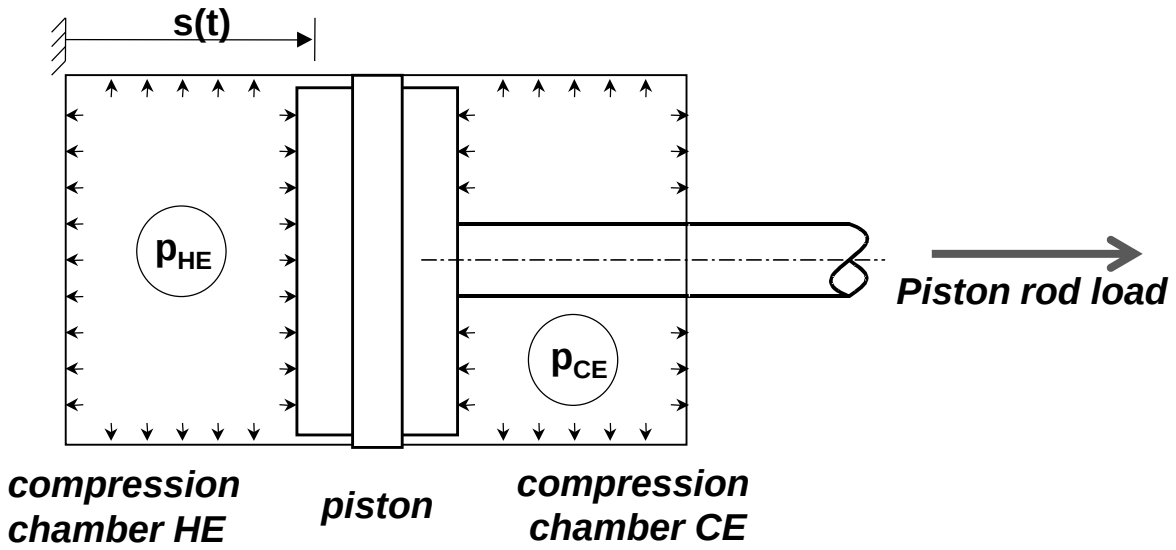


„Shorter“ to suction pressure
→ Suction valve or packing (crank end)

„Longer“ to suction pressure
→Discharge valve

Piston rod load

- Calculation = ***Inertia*** force + **Gas** forces

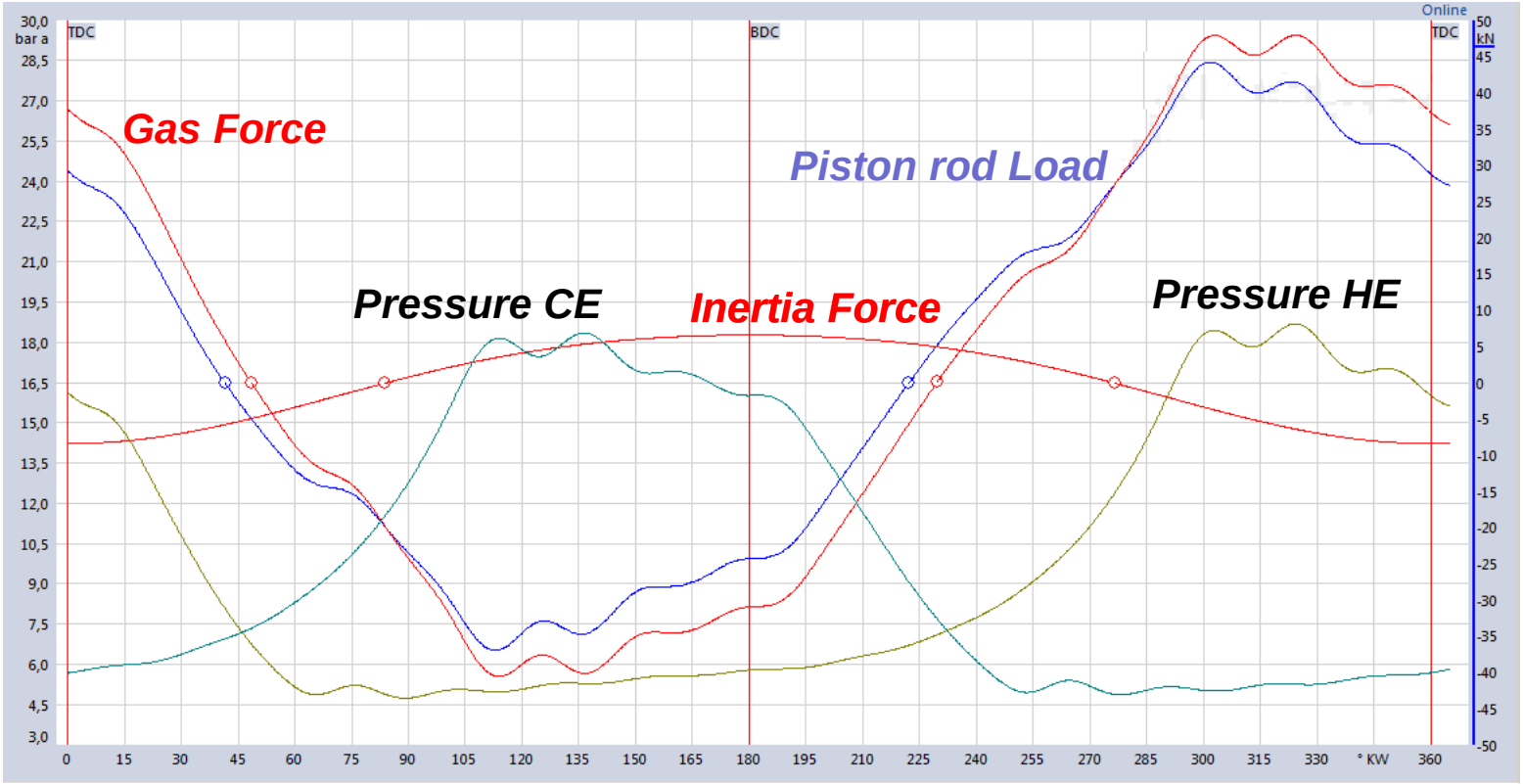


Inertia force
- piston, rod and crosshead mass
- speed
- connecting rod ratio

Gas force
- dynamic pressure
- piston area

HE = head end
CE = crank end

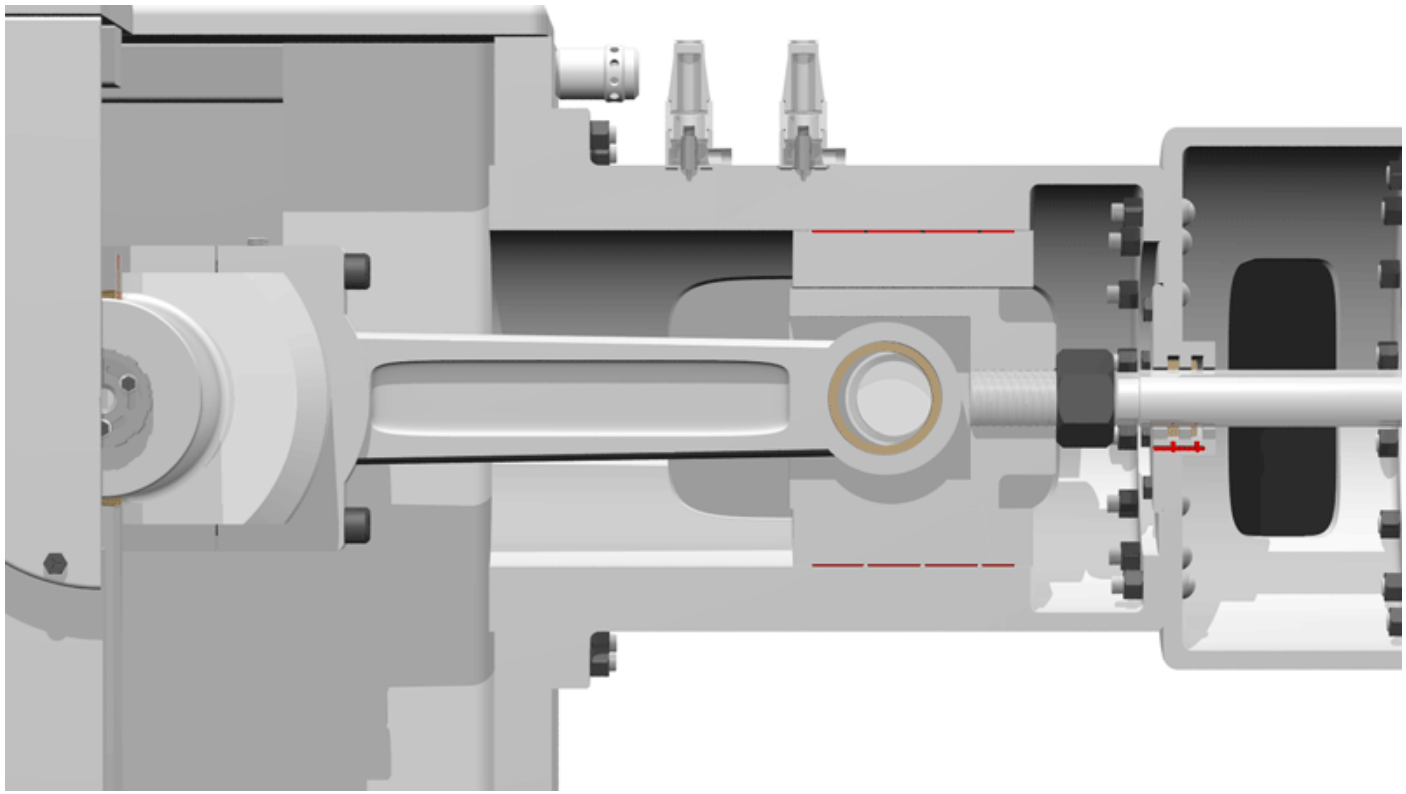
Piston rod load



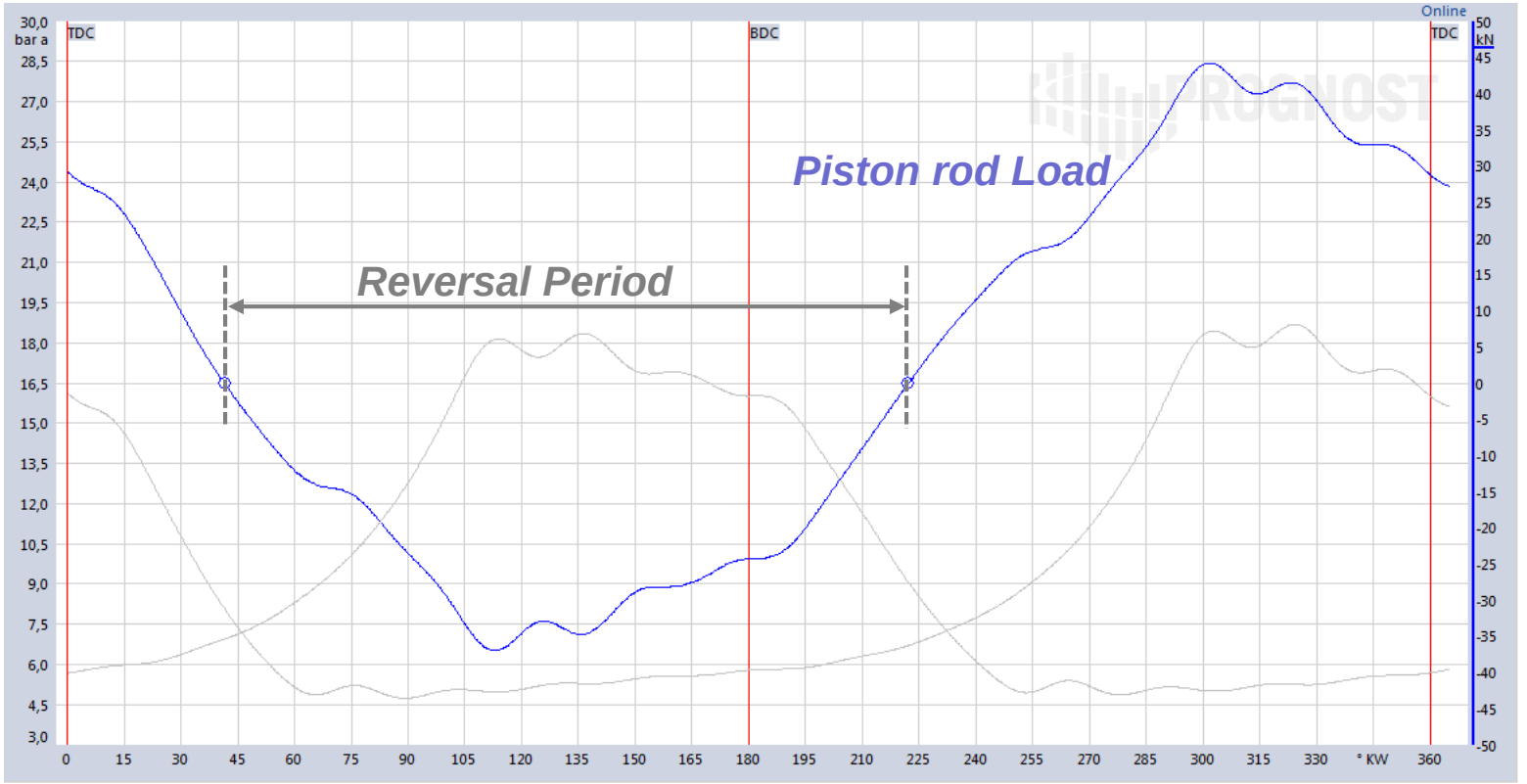
What are MACGL and MACRL ?

Degree of rod reversal

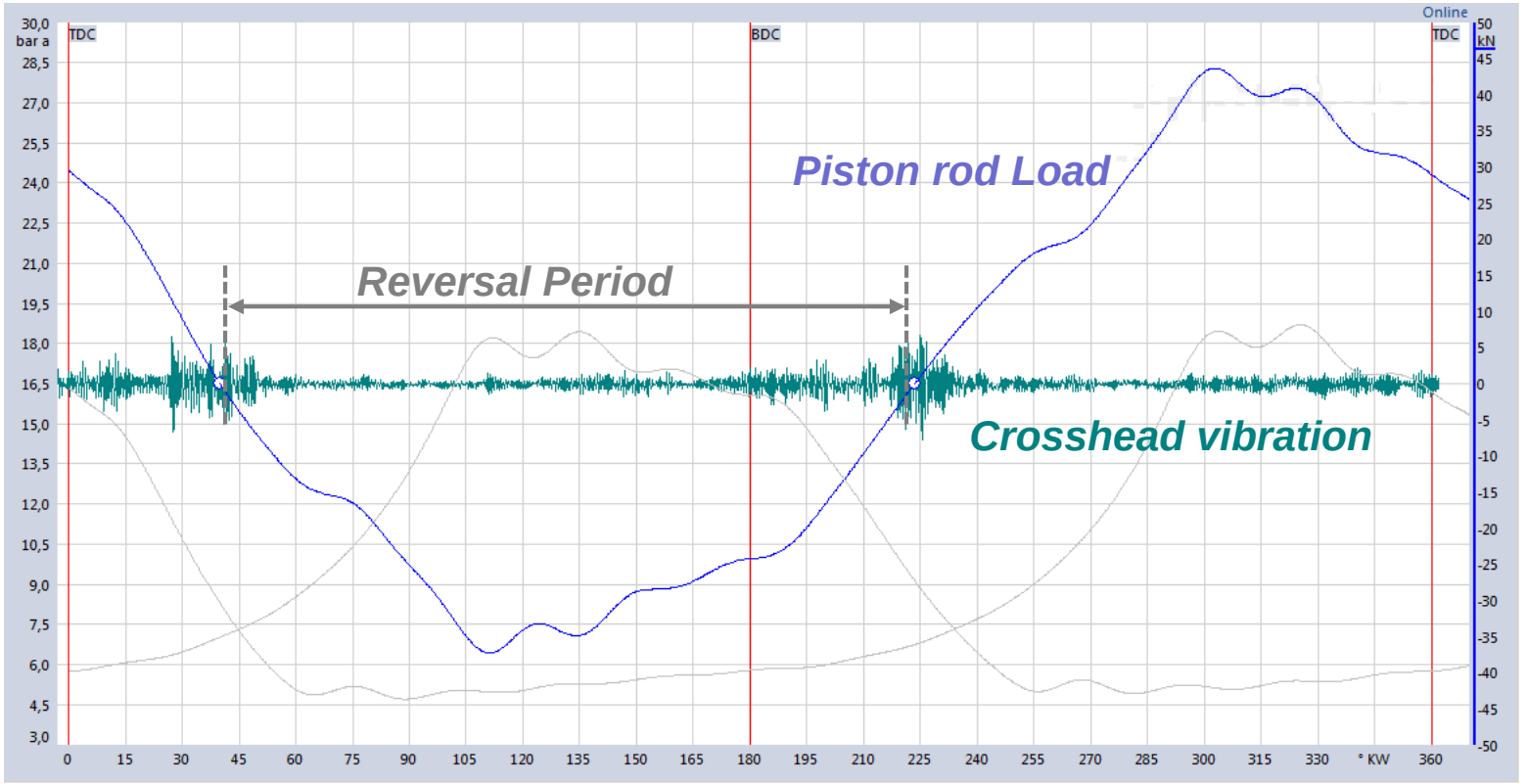
- Rod load reversal is the periodic shifting of piston rod load between tension and compression during a complete stroke.
  - Important for adequate crosshead pin and bushing lubrication.



Piston rod load

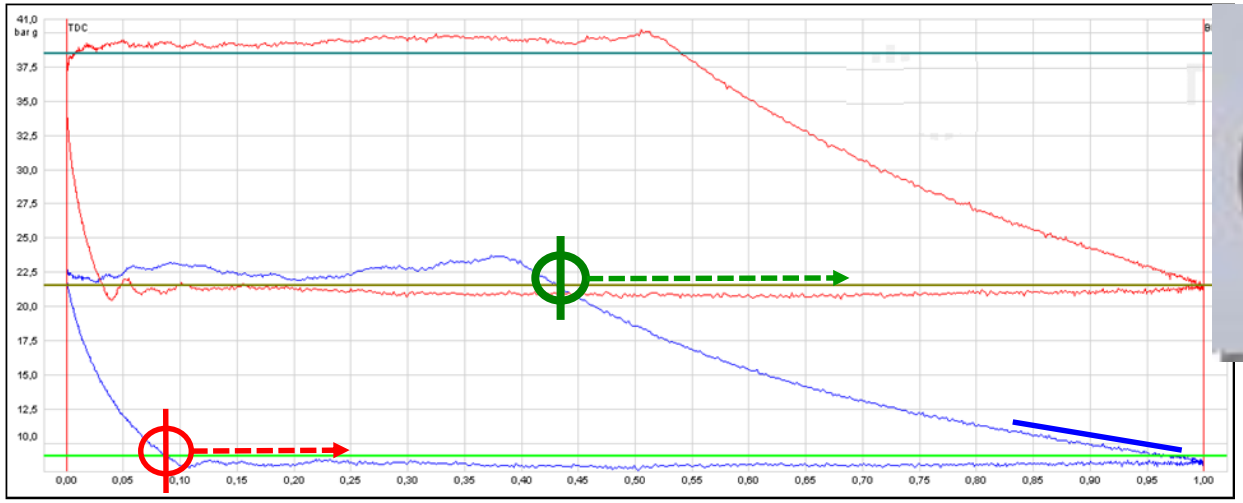


Piston rod load vs. Vibration

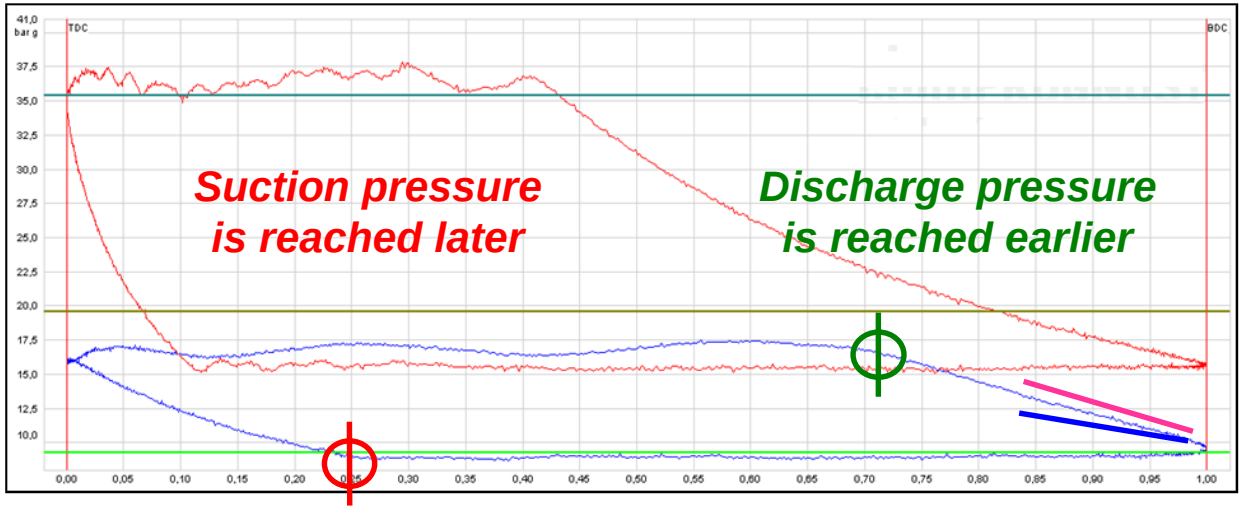


Case 8: Valve failure

Good condition



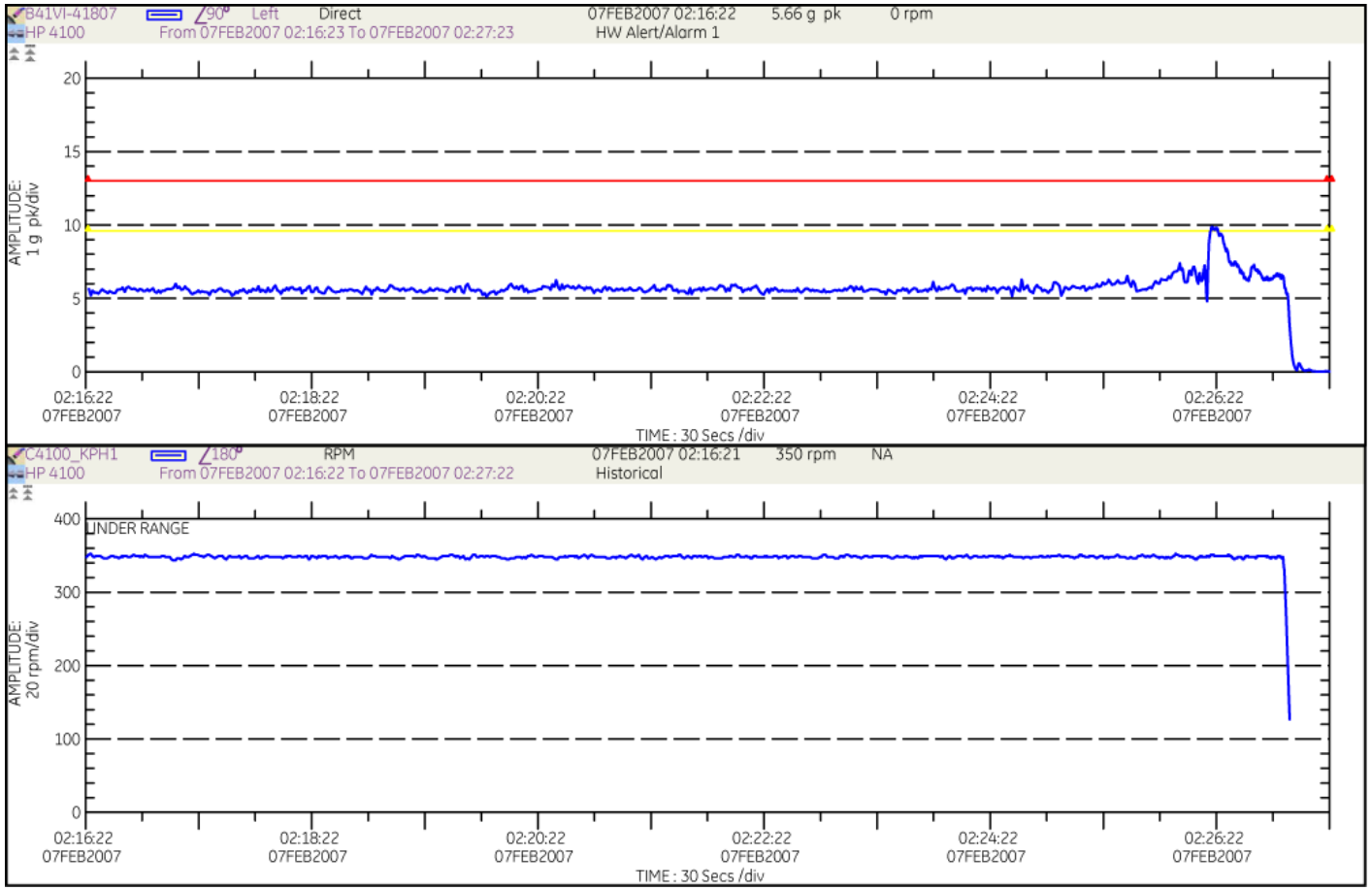
Bad condition



Valve ?

Line of compression steeper

Case 9: Valve failure 2



On February 7th, 2007 at 2:26 in morning, the 3500 rack issued a hardware alarm on the crosshead acceleration As it can be seen in Figure 2, the compressor shut down 2:27 am as a result of this high vibration .

Case 9: Valve failure 2

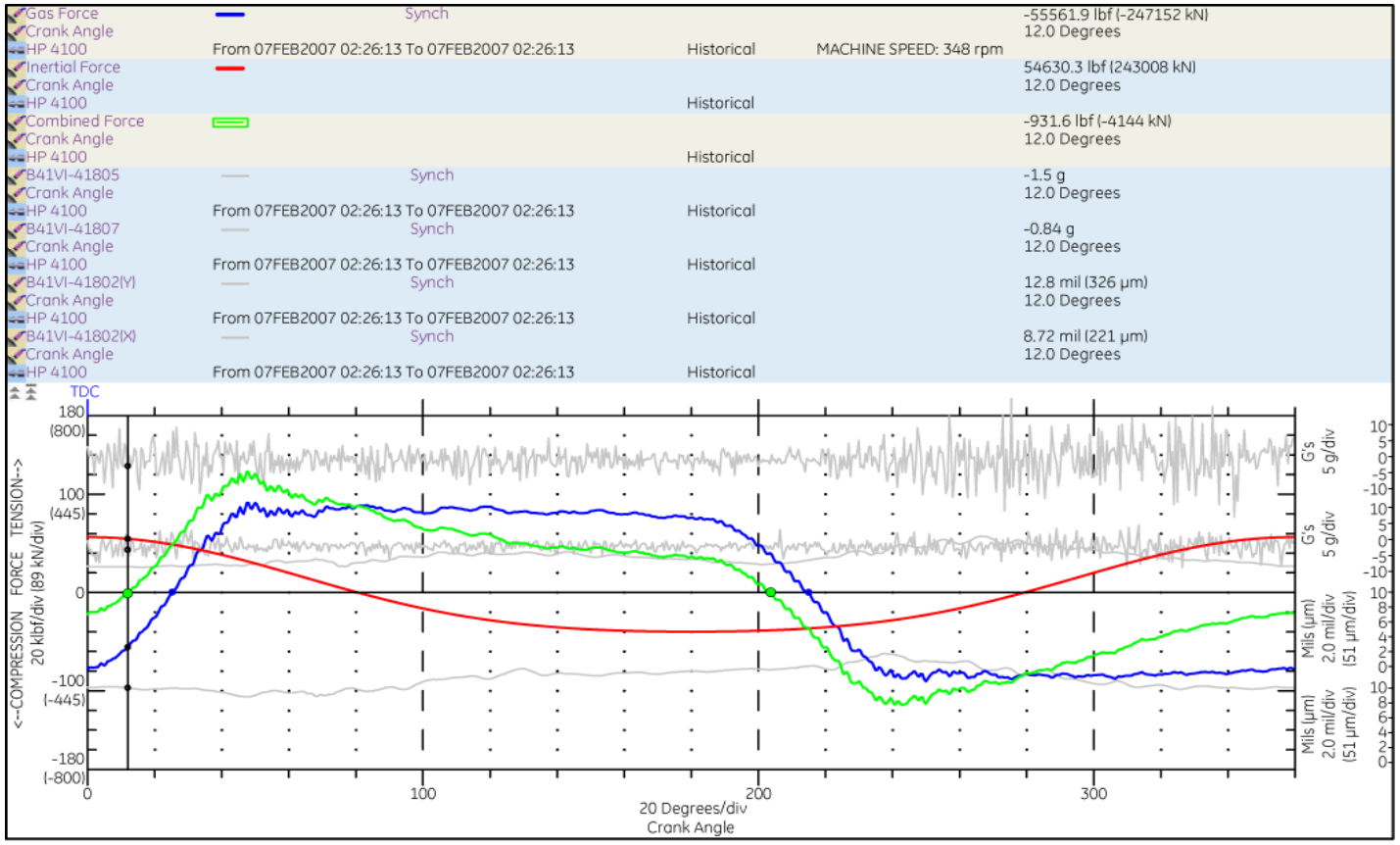
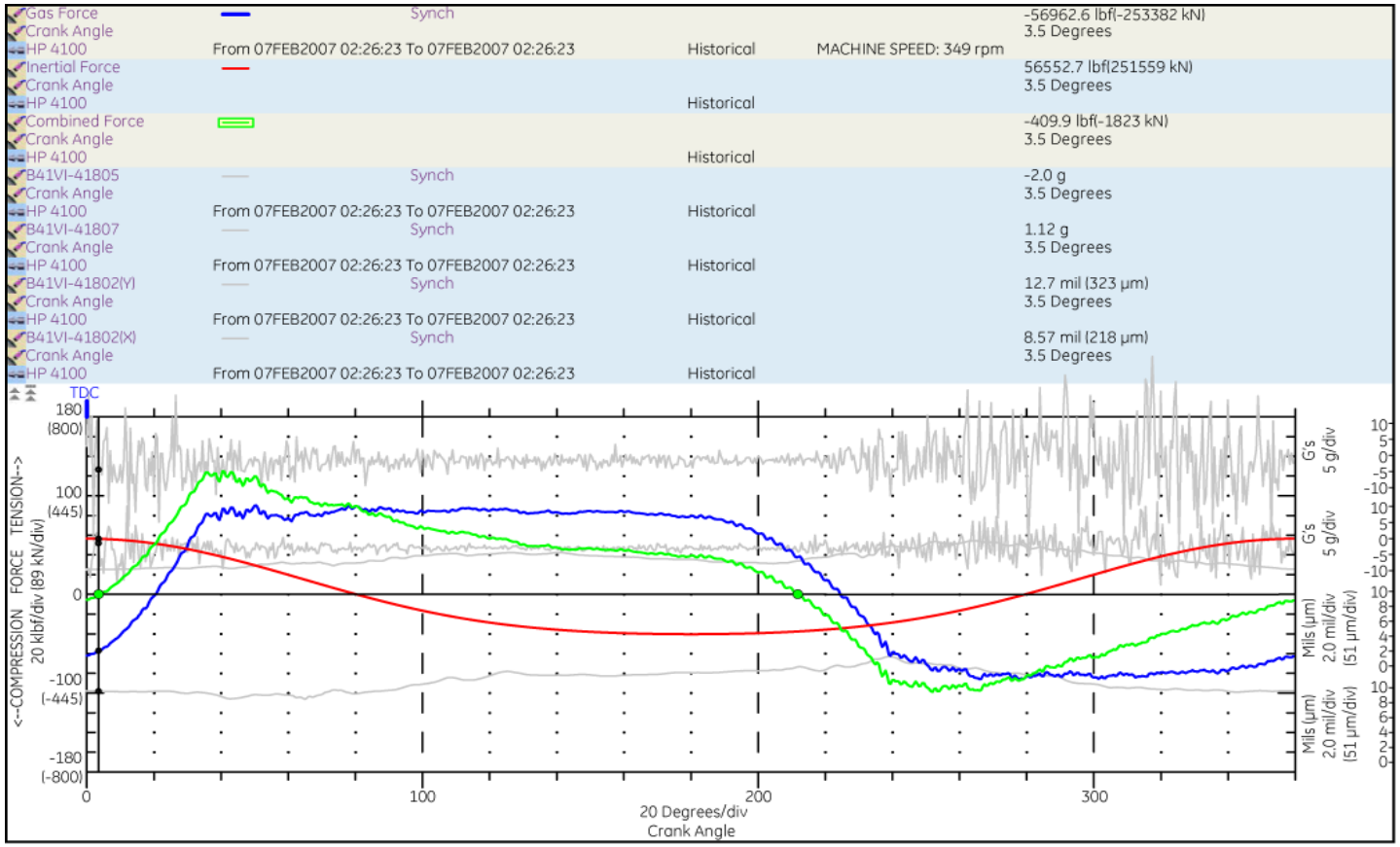


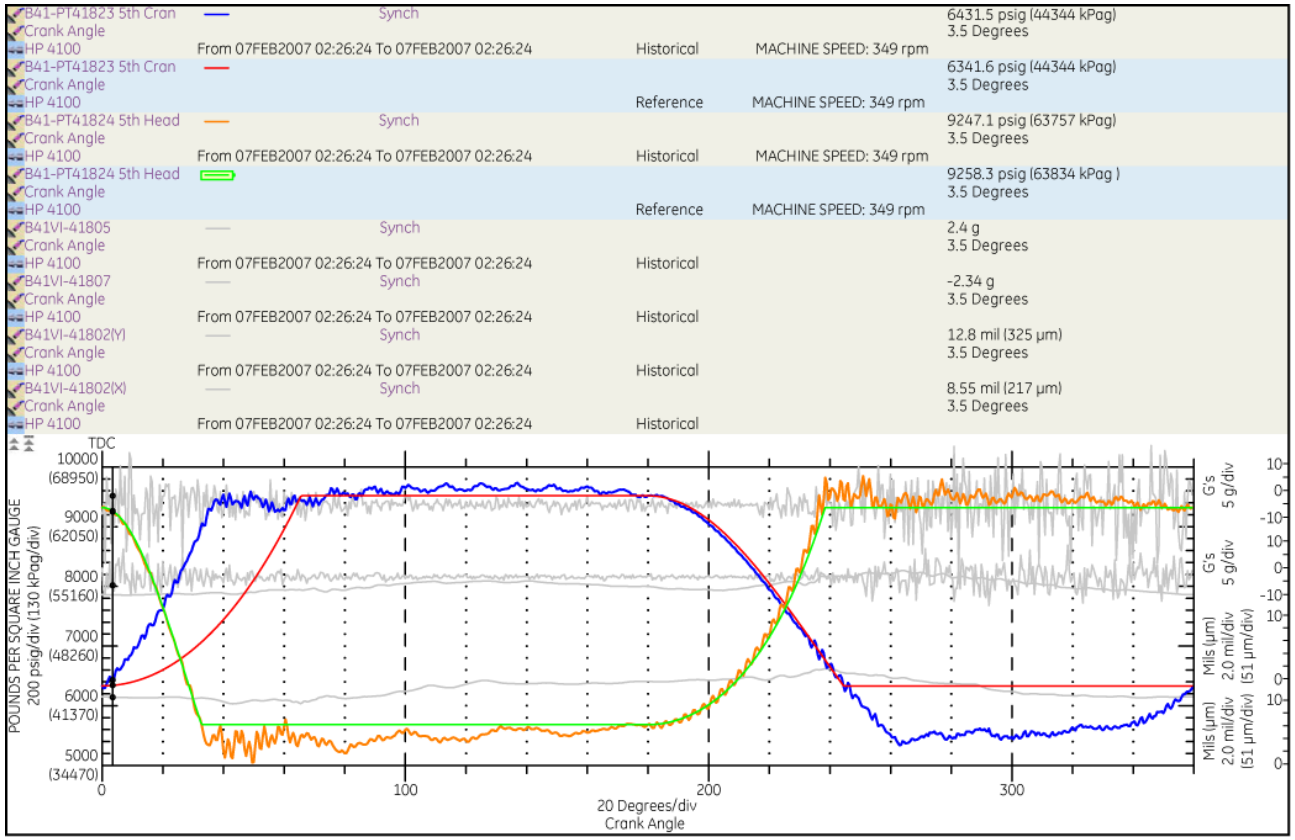
Figure 3 shows the combined rod load data 6 seconds prior to the alarm. The red line is the inertial load curve, the blue line is the gas load curve and the green line is the combination of the two. The top grey line shows the unfiltered cylinder accelerometer

Case 9: Valve failure 2



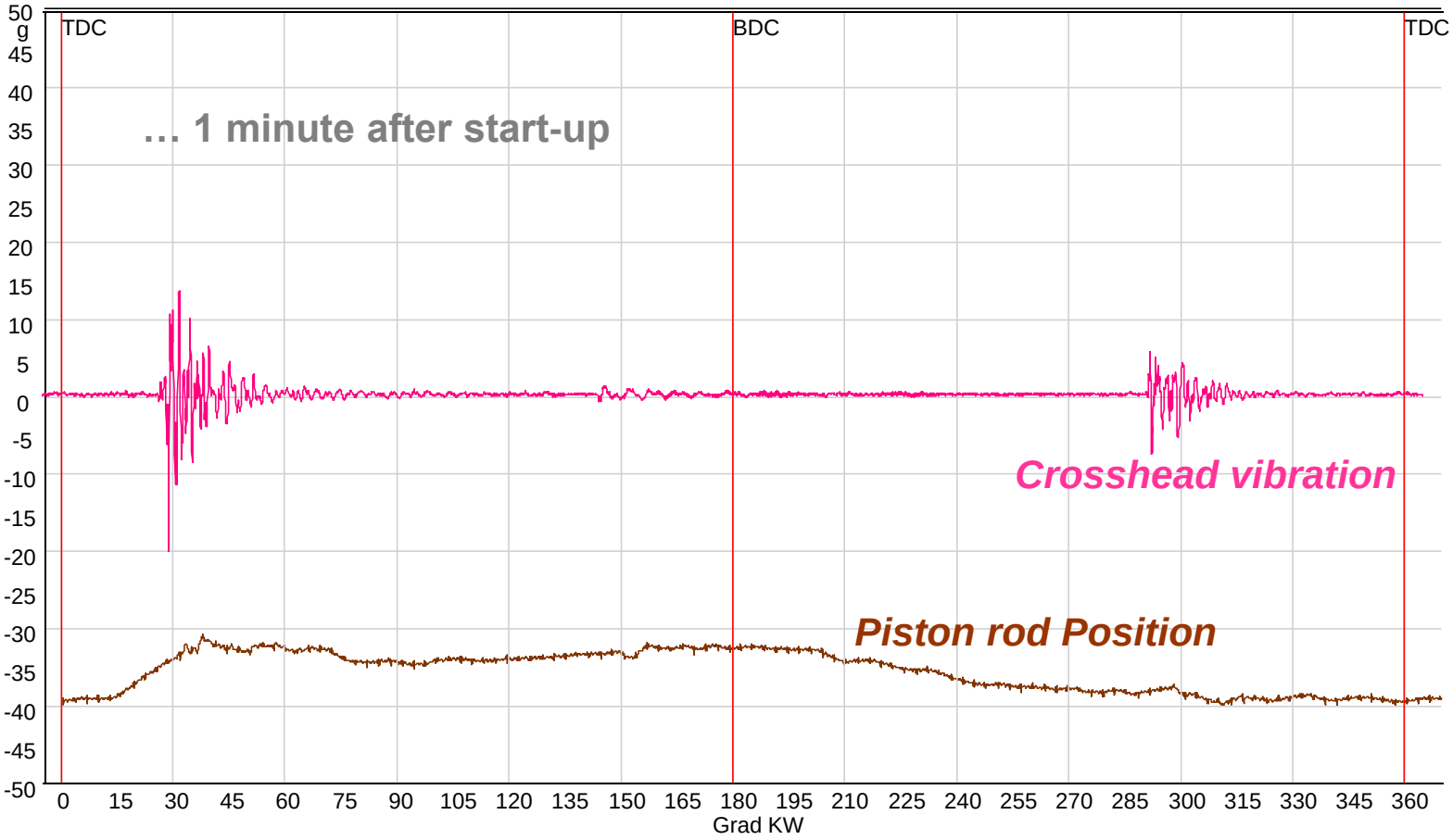
it can be seen that the crosshead vibration, from approximately 230º after TDC to 0° TDC, has increased. In addition, the crosshead vibration, from 0° TDC to approximately 100º after TDC, has also increased. A leaking crank end discharge valve or a leaking head end suction valve can cause this pattern of vibration.

Case 9: Valve failure 2

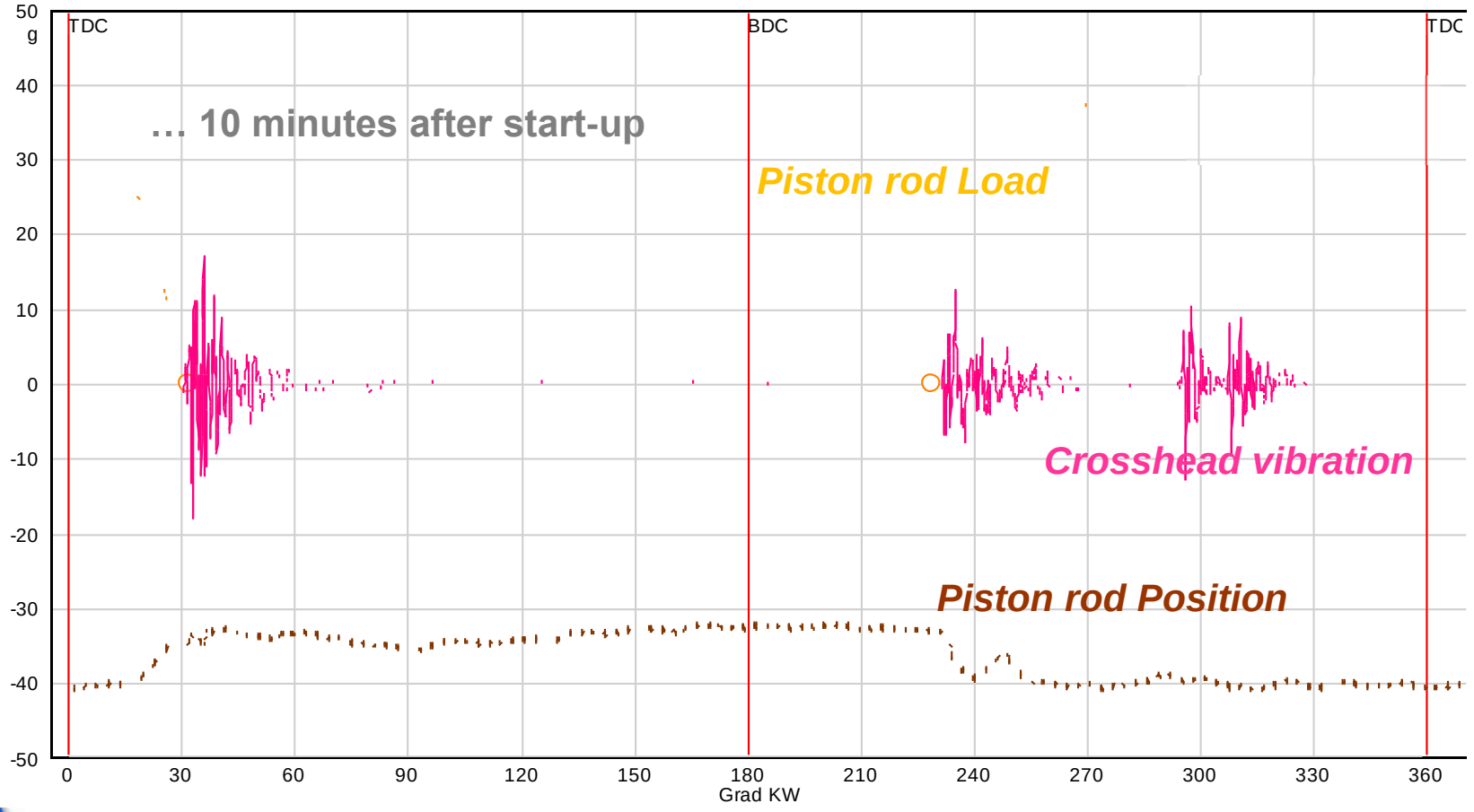


Pressure can only rise faster if gas enters the cylinder from another source. The cylinder discharge manifold is the only potential source for this leak and the crank end discharge valve seems the most likely candidate.

Case 10: Loose connection CHG

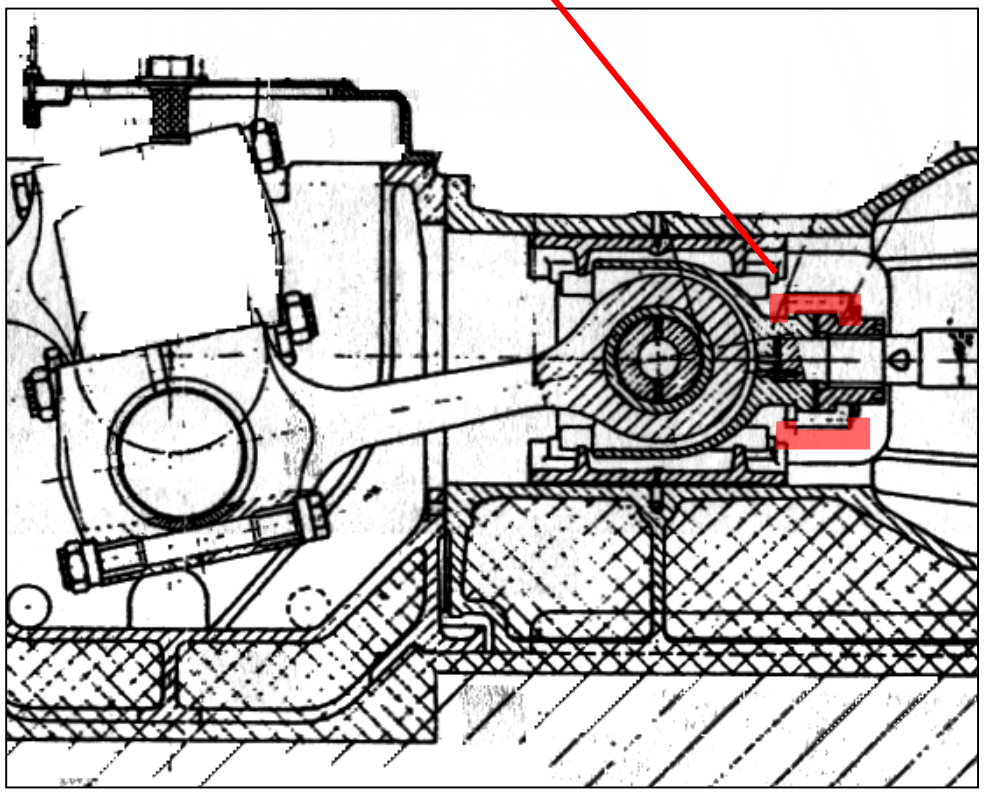


Case 10: Loose connection CHG

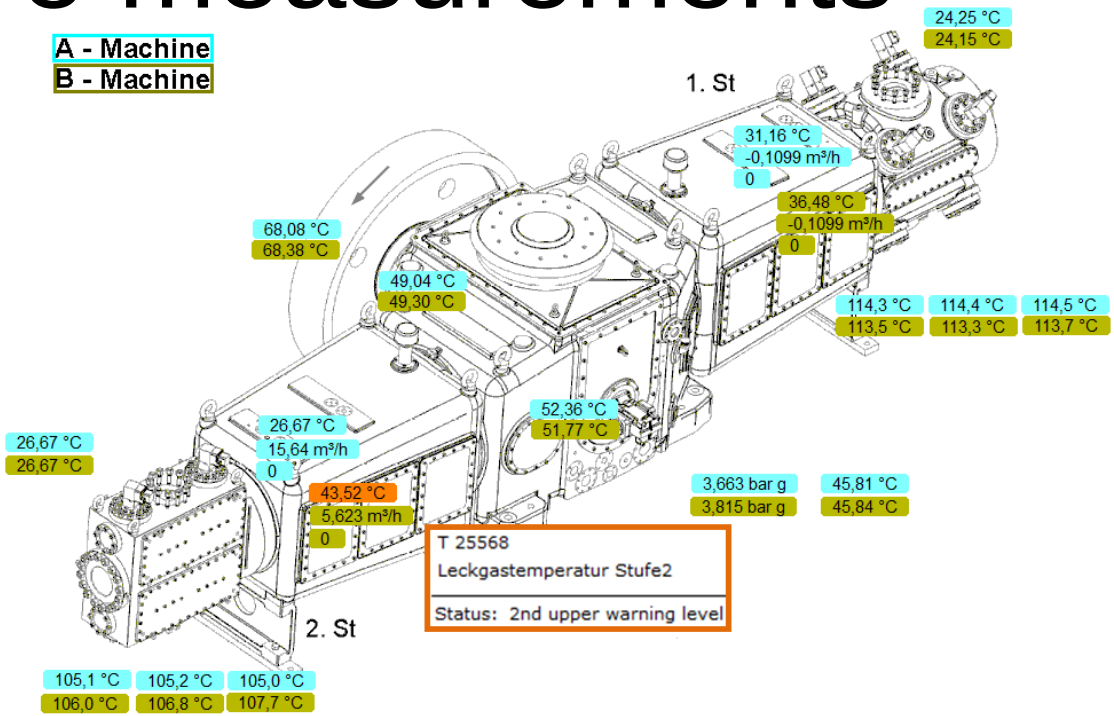


Case 10: Loose connection CHG

- Loose connection crosshead / piston rod after restart of a overhauled compressor



Temperature measurements



Common

- Valve
- Gas
- Packing vent or case
- Bearings

Uncommon

- Crosshead guide
- Connecting rod bearing and crosshead pin based on wireless very expensive and not reliable

Summary

Benefits & Challenges of Condition Monitoring are:

- Ability is there to avoid successfully secondary damage
- Technology is available to provide early failure recognition to increase machine running time
- The latest system generation is providing end user information instead of data display

- Different approach for recips, which is not comparable with those for centrifugal machines
- Threshold and limit setting demands experiences and dedication