EFRC Training Workshop

Basic Training of Reciprocating Compressor Systems

Condition Monitoring

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PROGNOST
Intelligence on Duty

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Topics

- Why condition monitoring?
- Sensor locations and data management
- Signal analyses:
  - -Acceleration (crosshead, 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?

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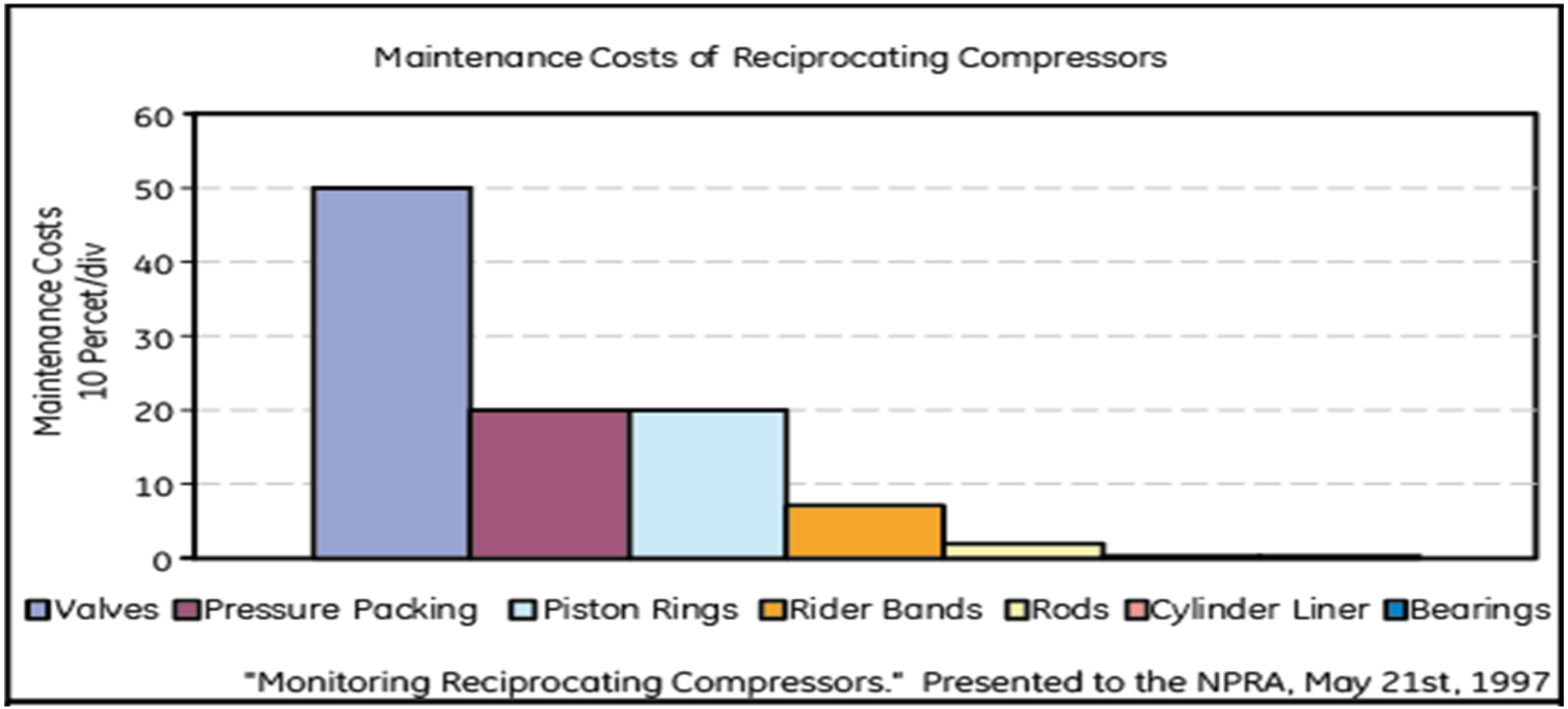
- ***Challenge:*** Increase machinery uptime with constant maintenance budget
- ***Solution:*** Max. component lifetime for extended meantime between maintenance (MTBM)
- ***Statement:*** Maximum MTBM depends on the "weakest link in the chain", i.e. valves
- ***Task:*** Determine and monitor the "weakest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

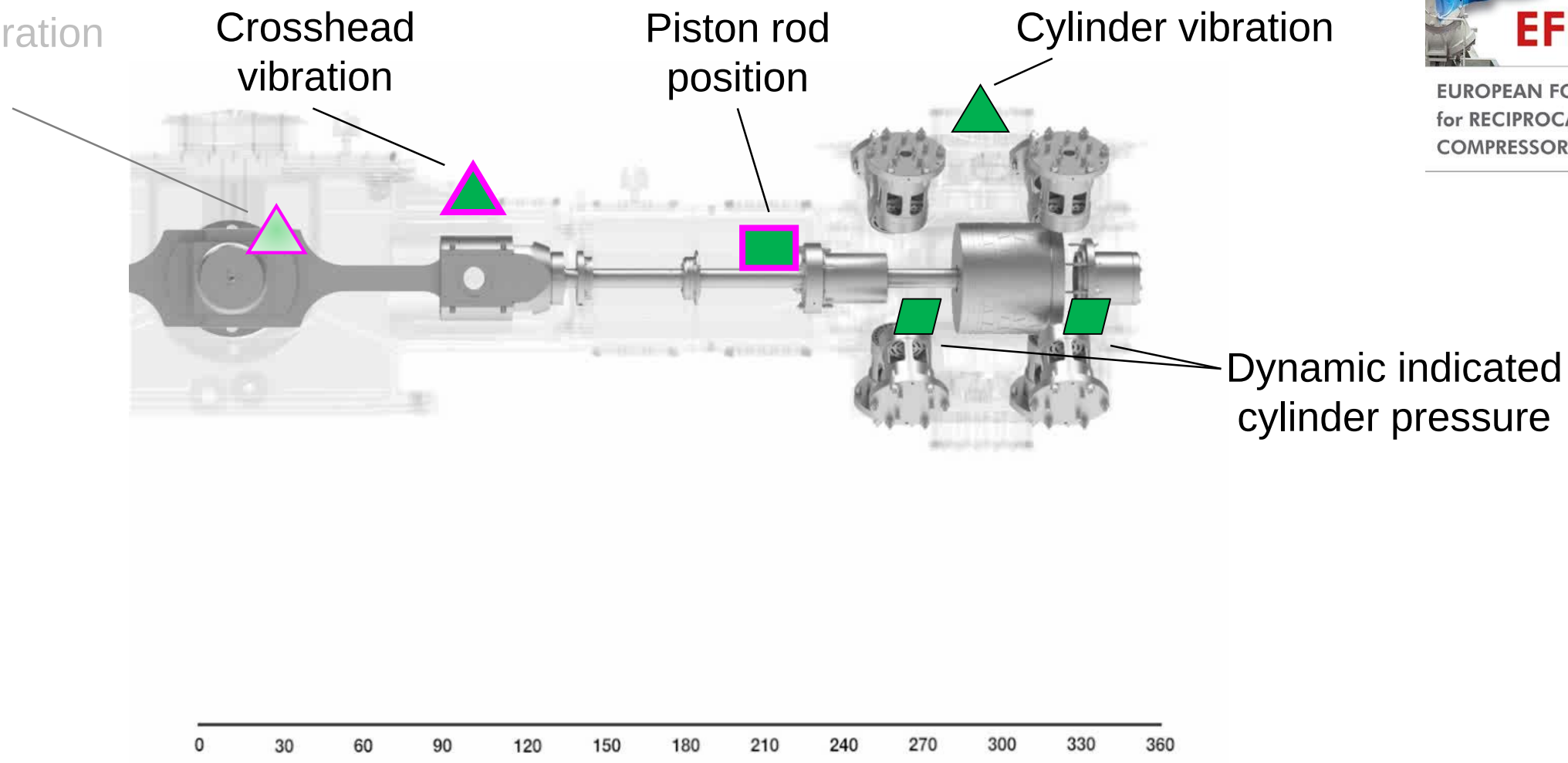
Maintenance Costs and Failure Modes



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

Sensor types and locations

Frame vibration



- Process data
- Speed / phase reference

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Data management

Data acquisition

Trend values

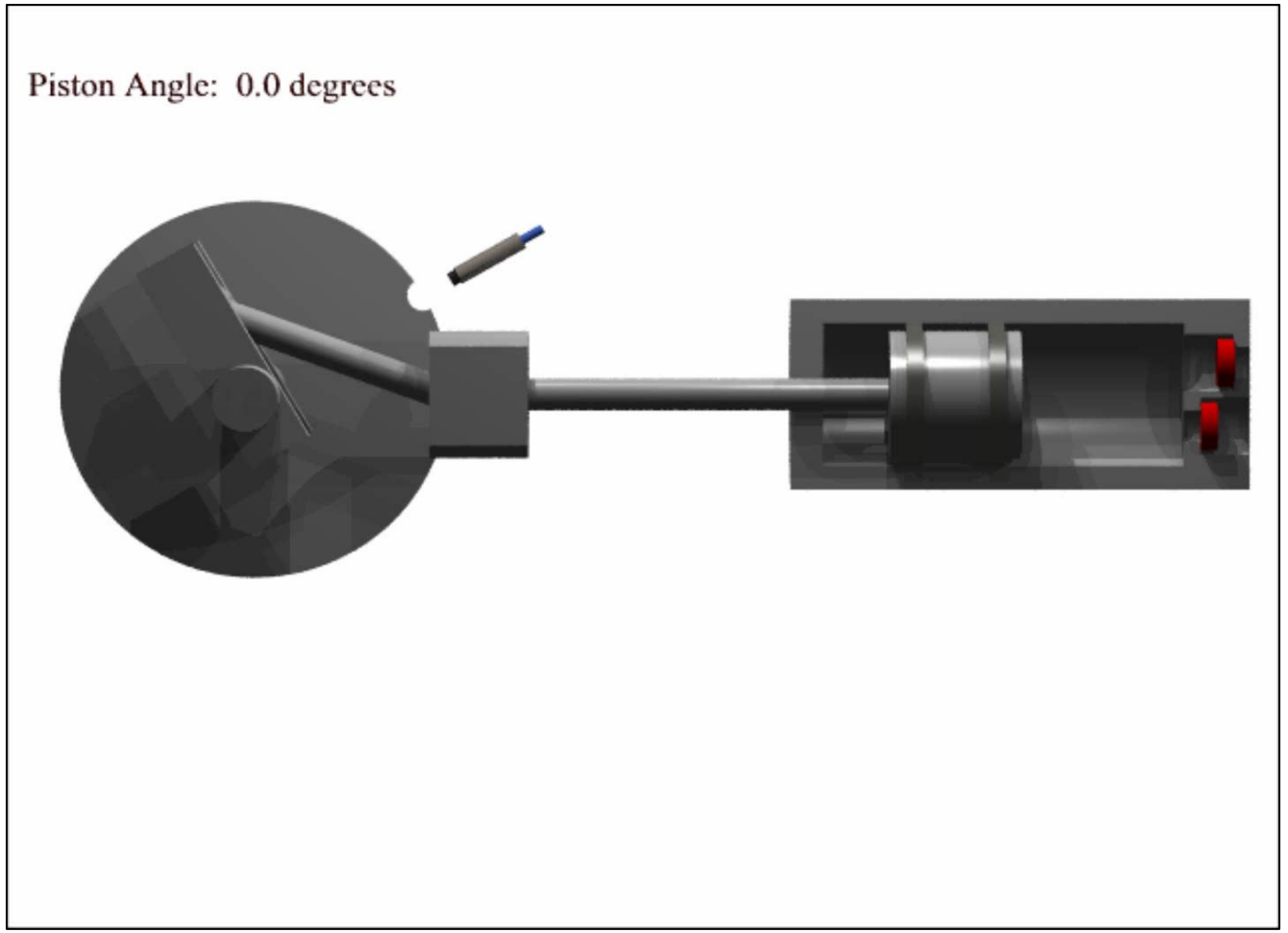
- Vibration amplitudes
- Temperatures
- Rotating speed
- Suction / Discharge pressure
- Etc …

Dynamic values

- 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 !**

Piston Angle / Phase reference



PistonAngle.wmv

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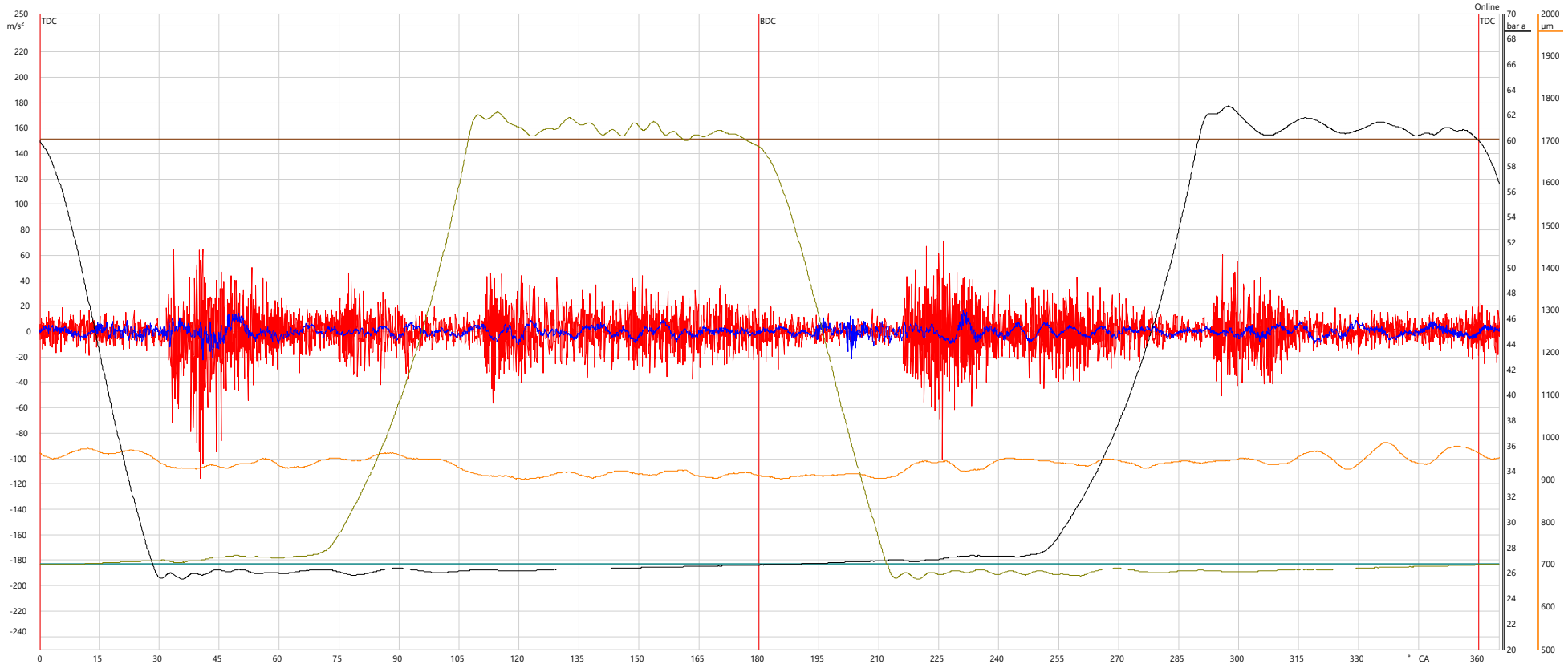
Crank Angle (P-θ) Plots



	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

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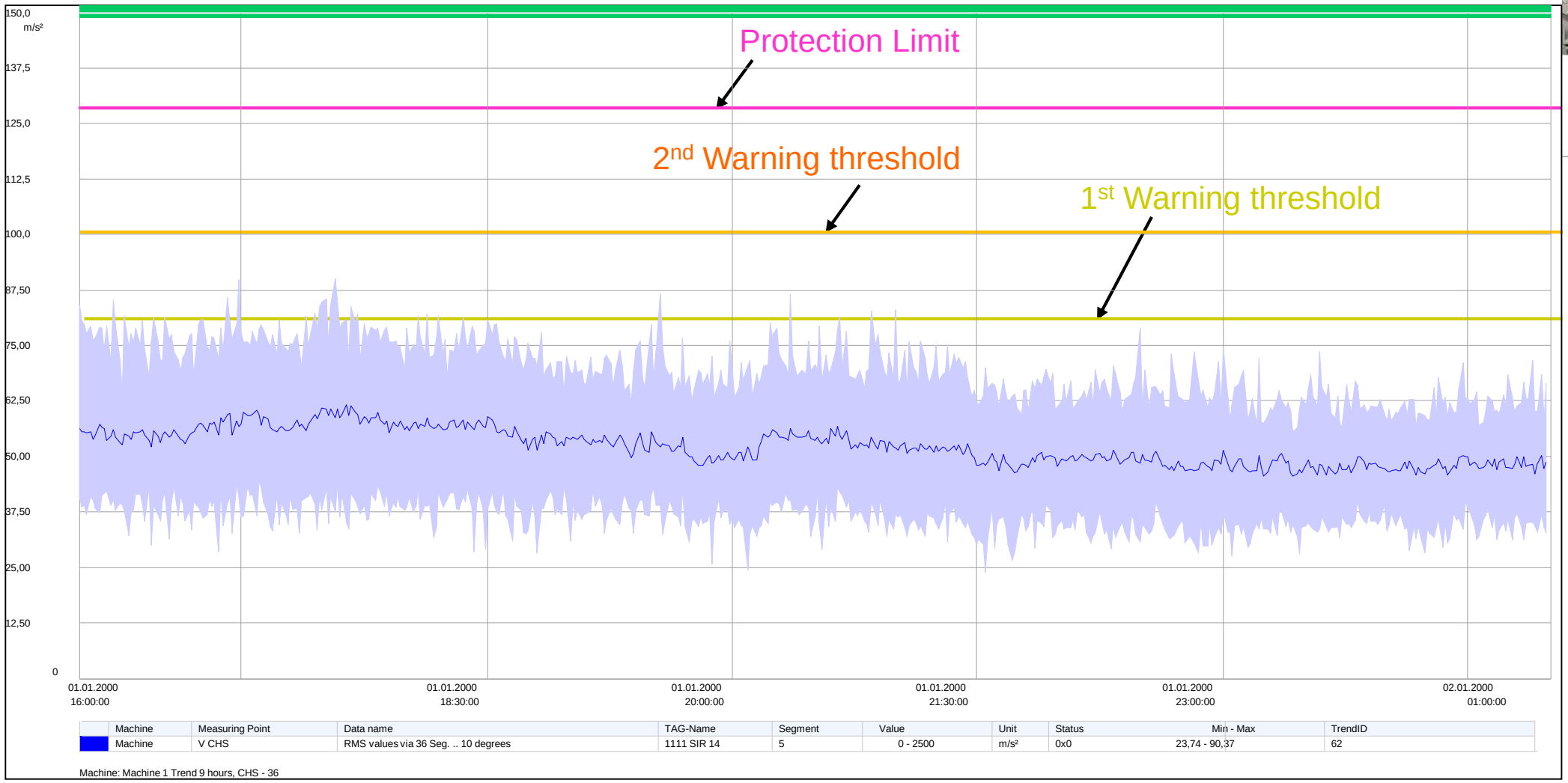
Trend plot



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

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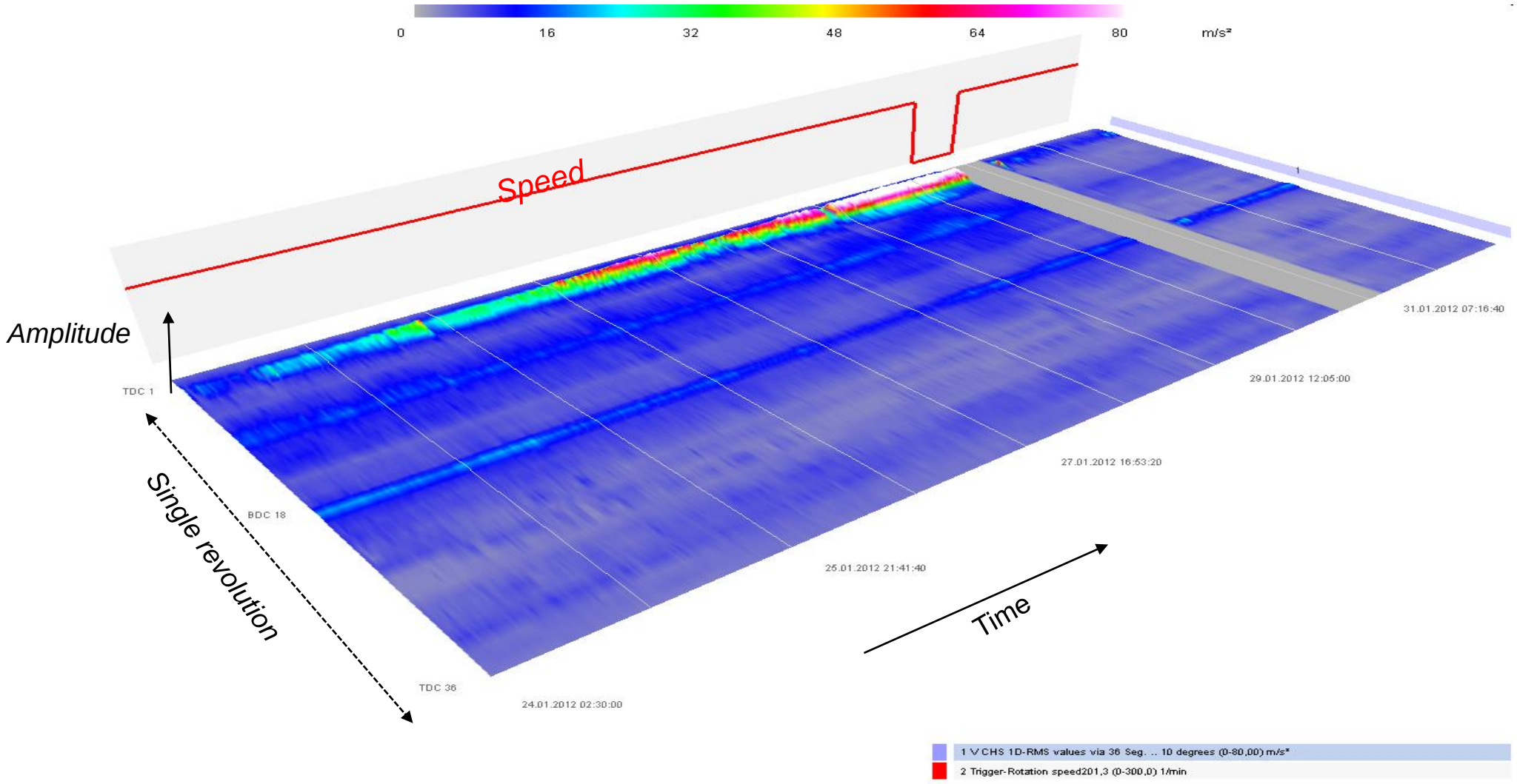
3-D trend / Waterfall plot



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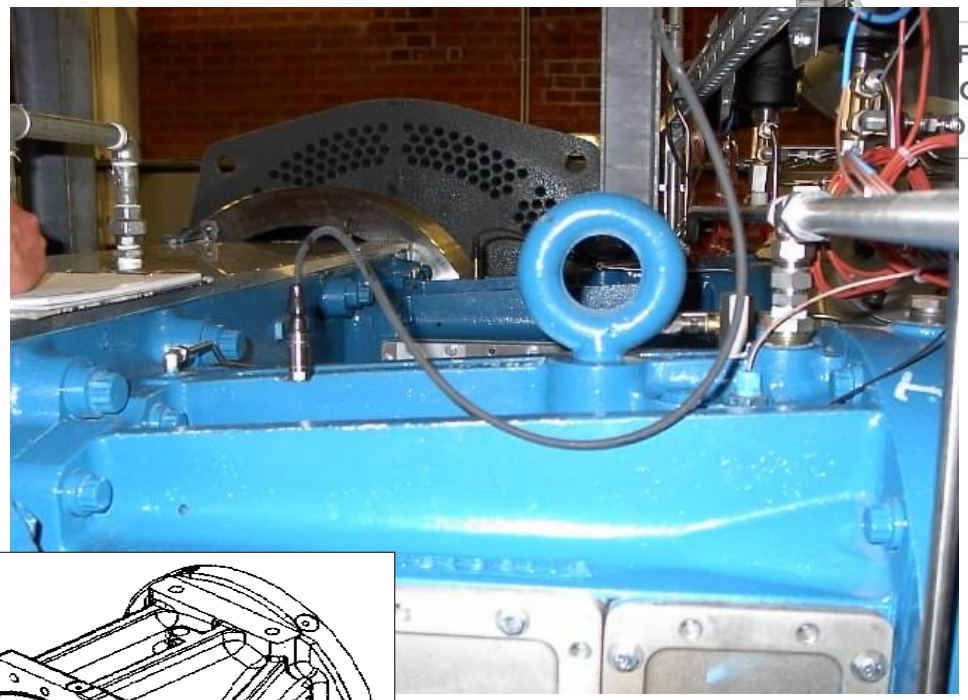
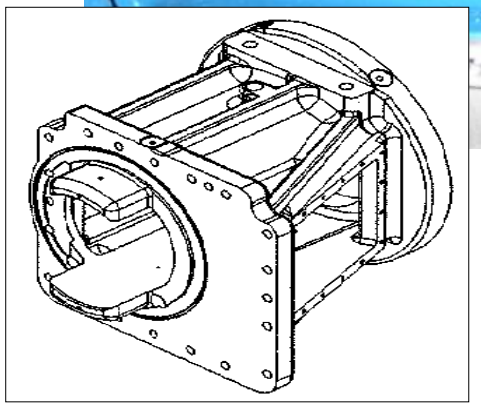
Crosshead vibration

With **acceleration sensors…**

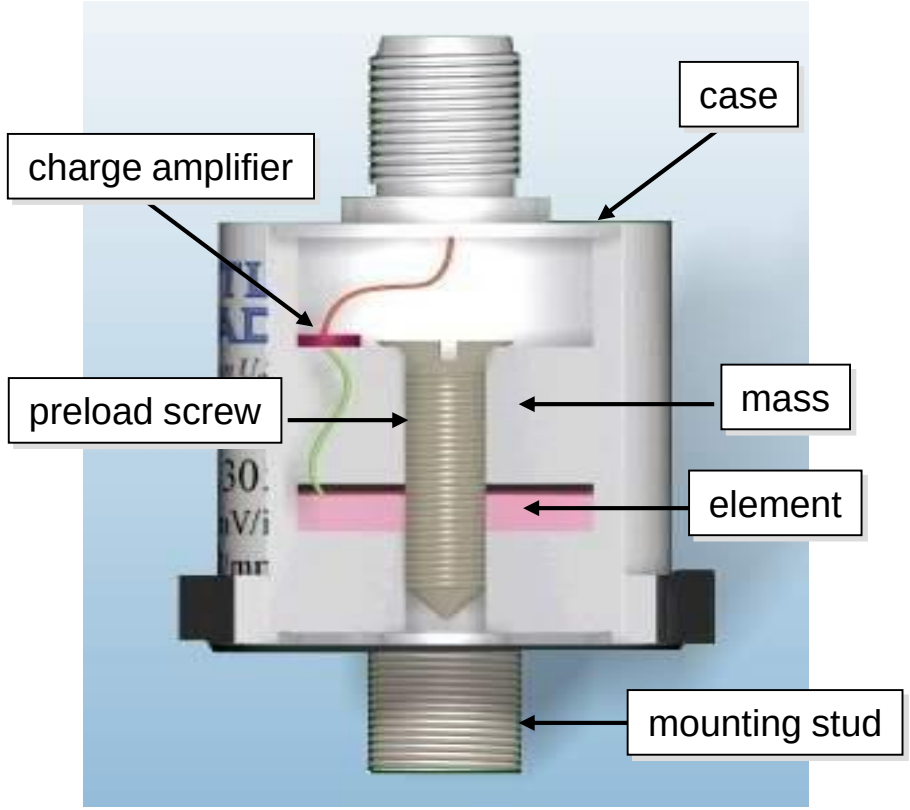
- mechanical damages
- clearance in the reciprocating drive train
- loose crosshead-piston rod connection

…can be detected in early stages

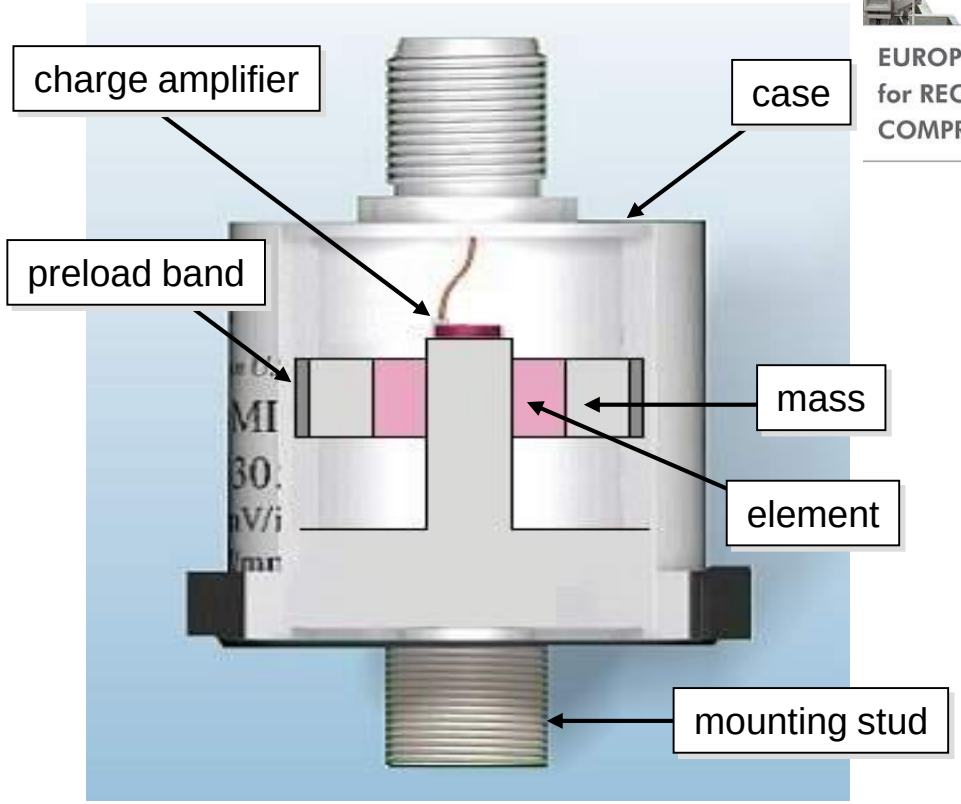




Accelerometer Specifics



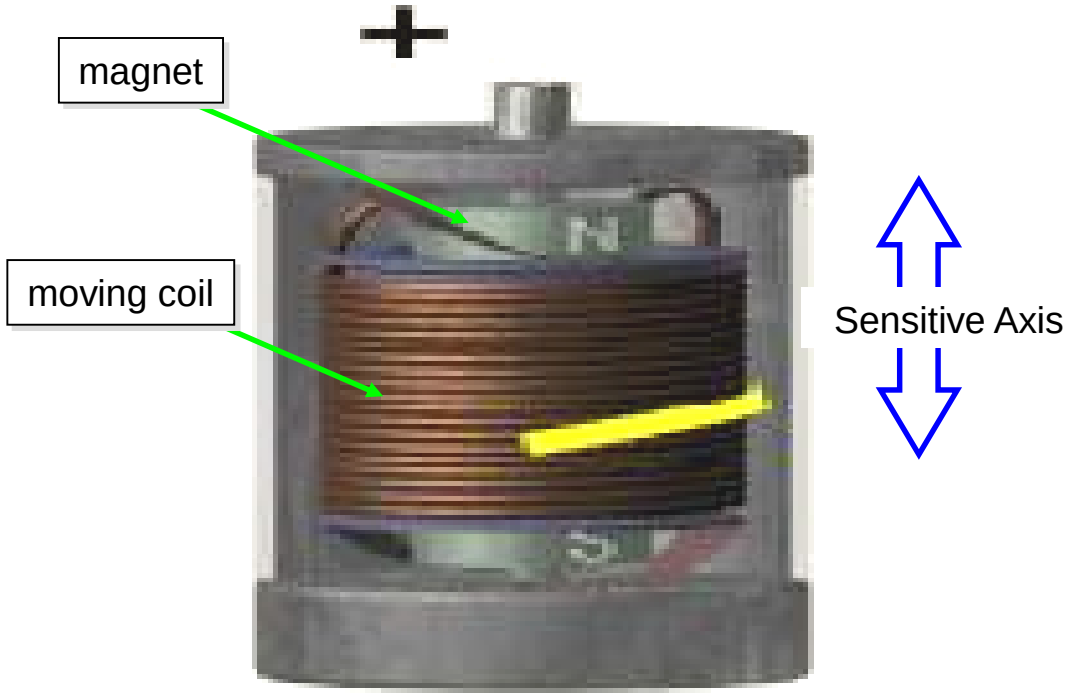
compression type sensor



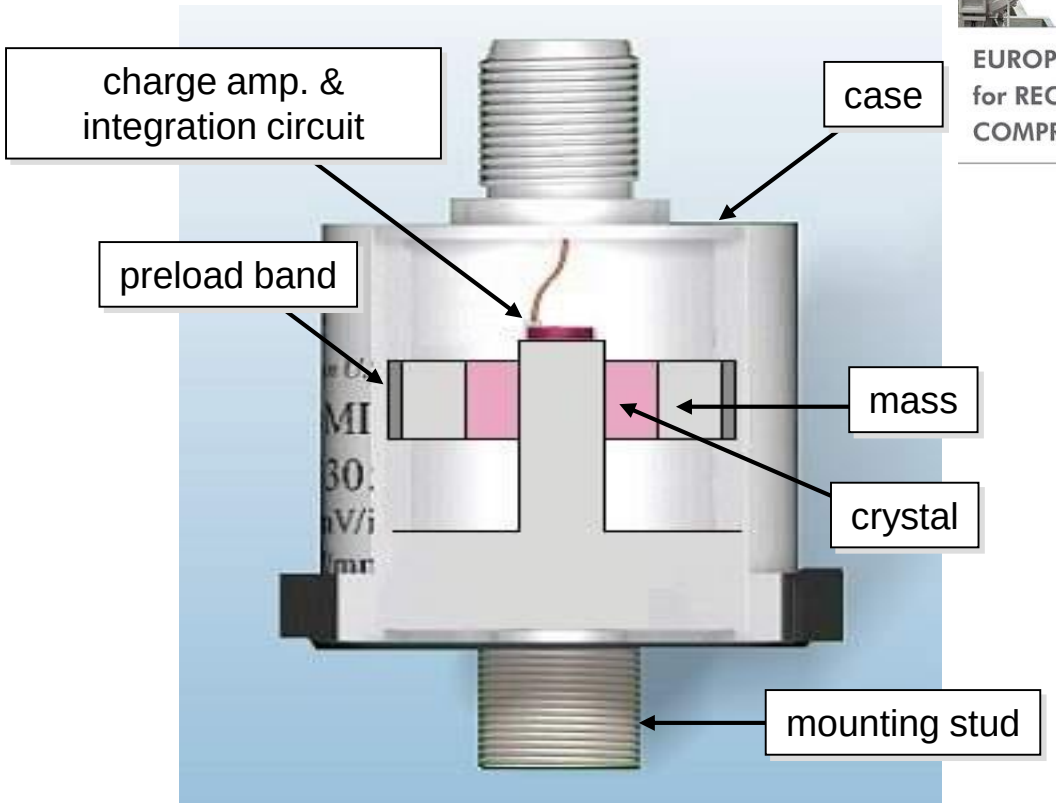
shear type sensor

Piezoelectric Accelerometer

Velocity Sensor Specifics



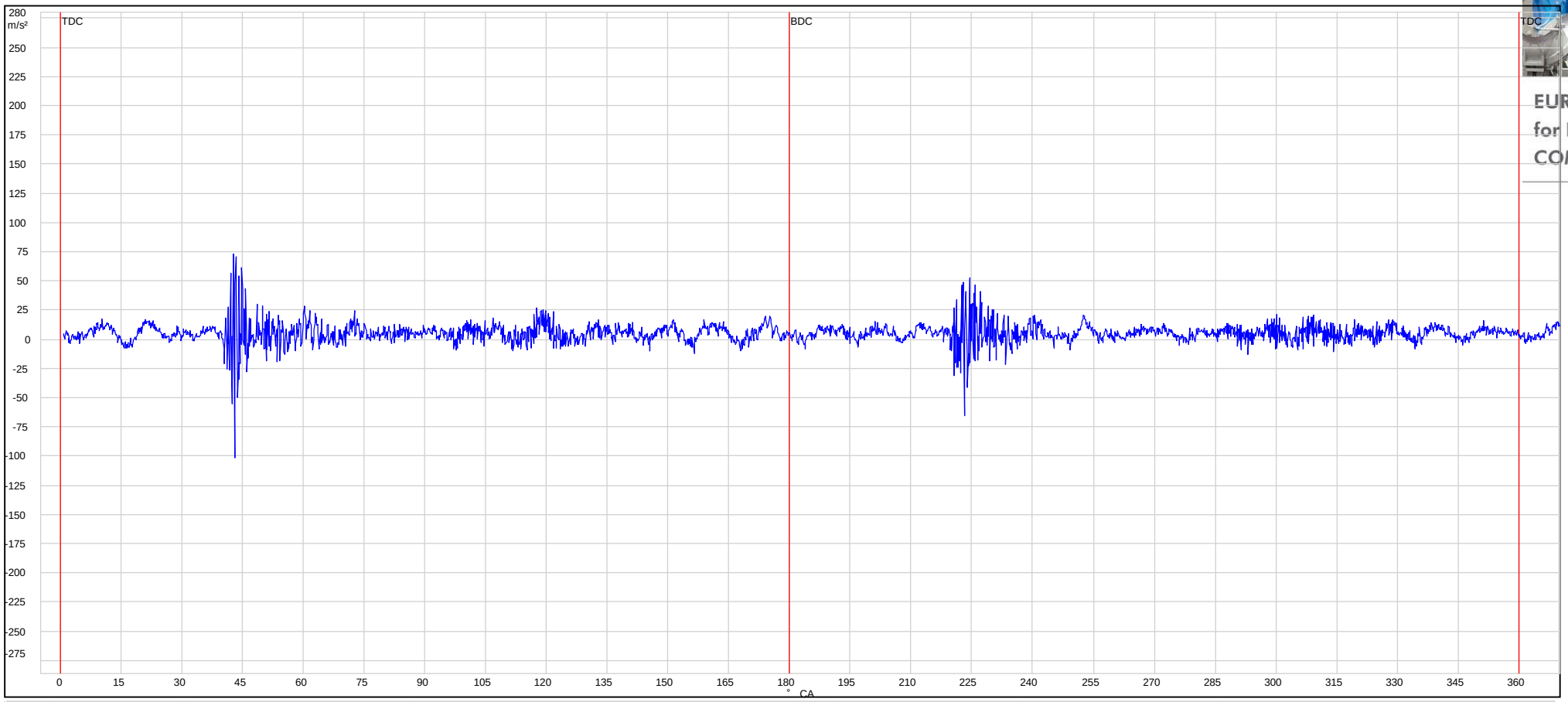
Traditional Moving-Coil Sensor
(self-powered)



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

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Case 1: Lubrication issue

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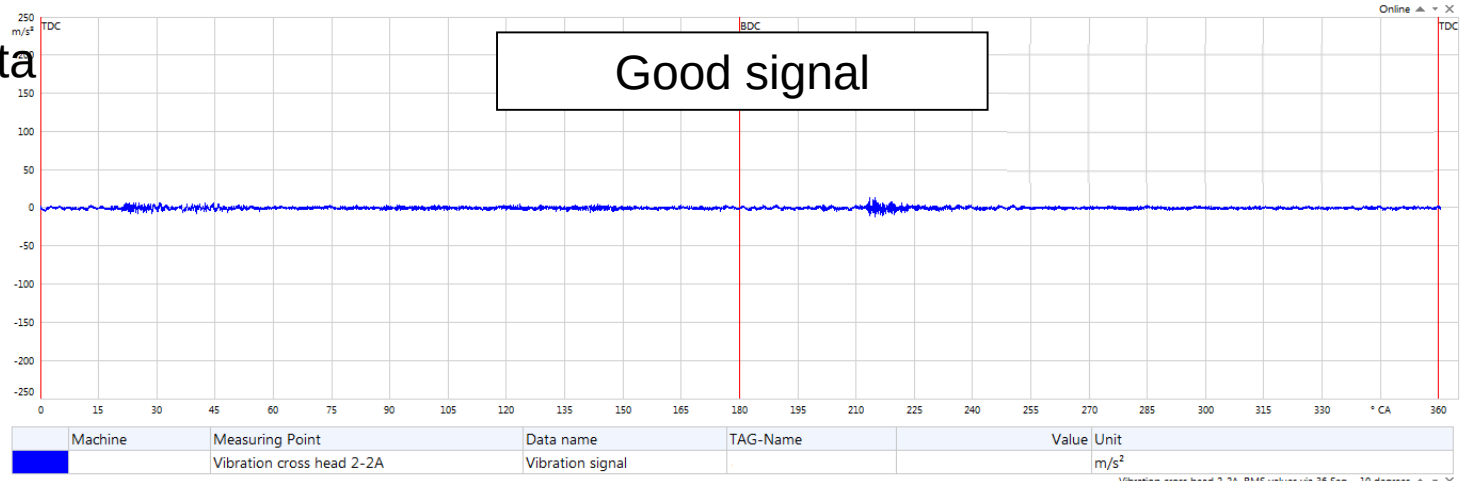
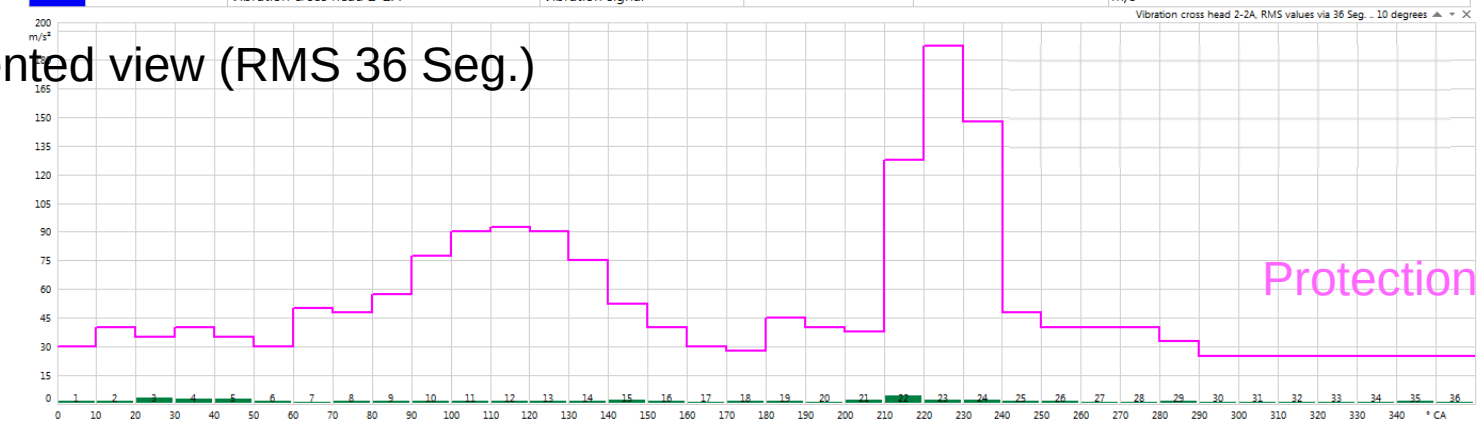
Raw data



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
		Vibration cross head 2-2A	Vibration signal			m/s²

Segmented view (RMS 36 Seg.)



Protection limits

	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
		Vibration cross head 2-2A	RMS values via 36 Seg. .. 10 degrees		0 - 250,0	m/s²

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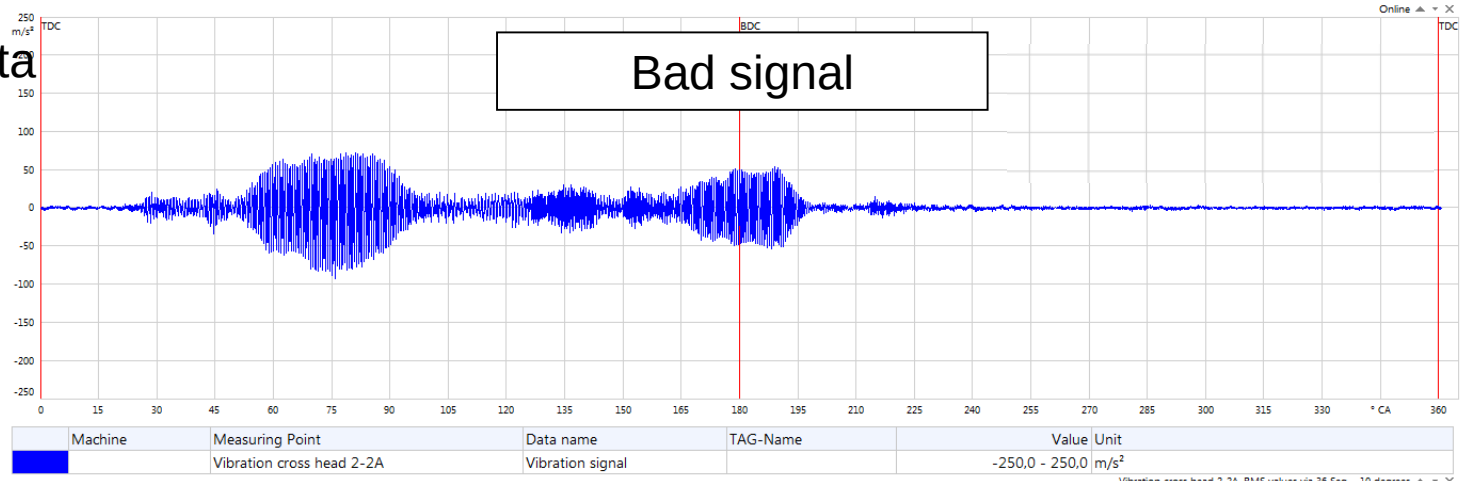
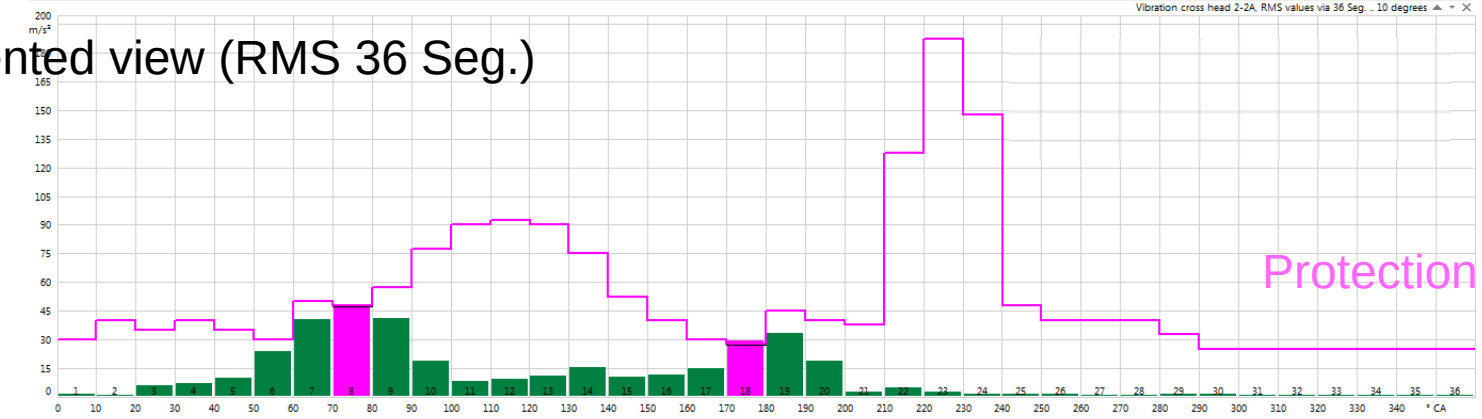
Case with lubrication issue

Raw data



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
		Vibration cross head 2-2A	Vibration signal		-250,0 - 250,0	m/s²

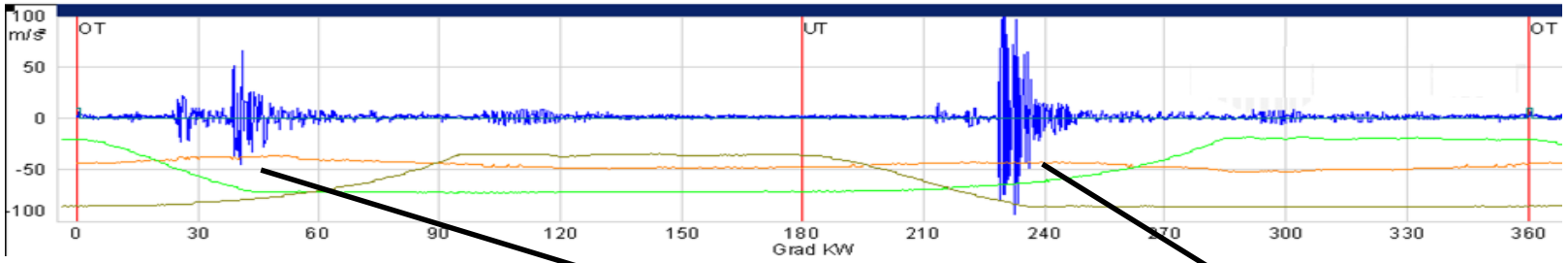
Segmented view (RMS 36 Seg.)



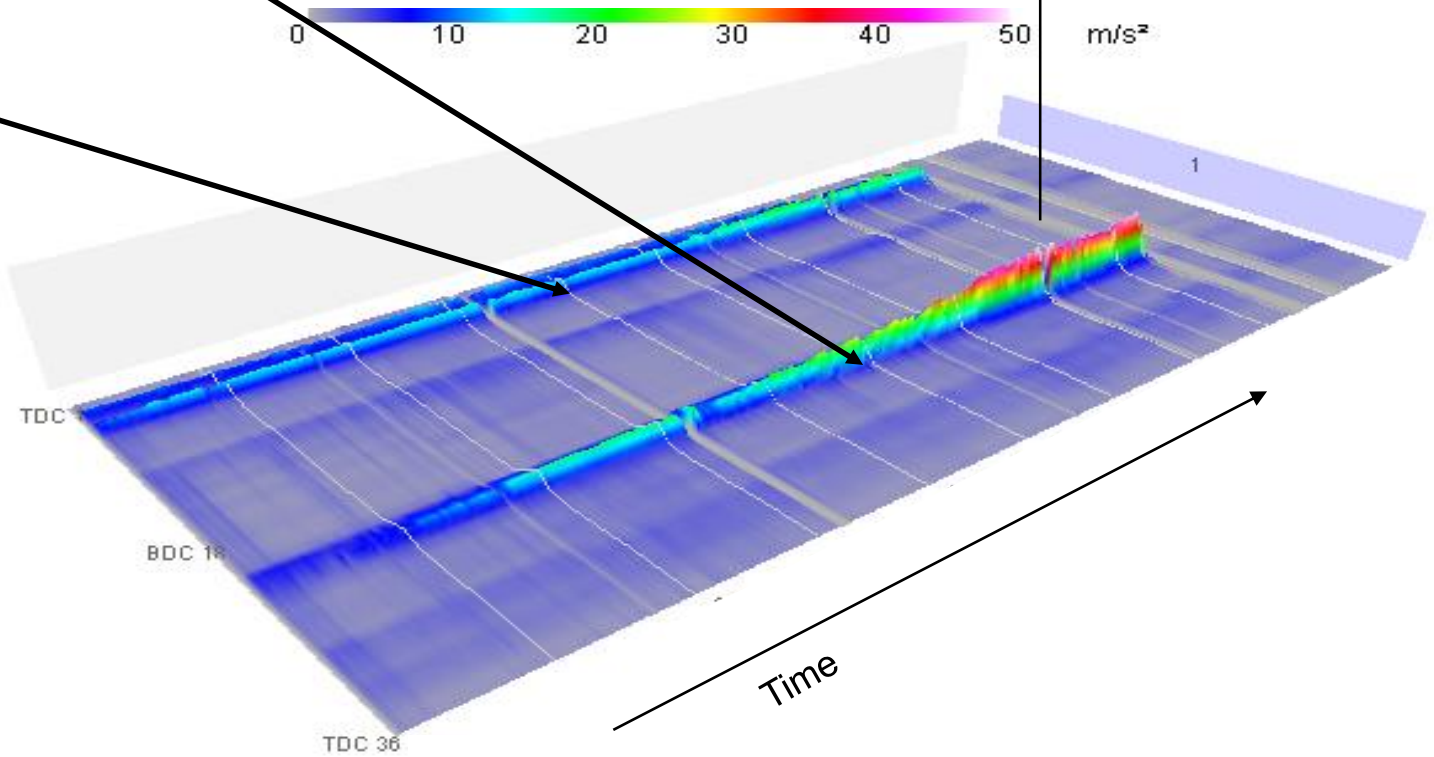
Protection limits

	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
		Vibration cross head 2-2A	RMS values via 36 Seg. .. 10 degrees		0 - 250,0	m/s²

Case 2: Loose piston nut



Large inspection found loose nut



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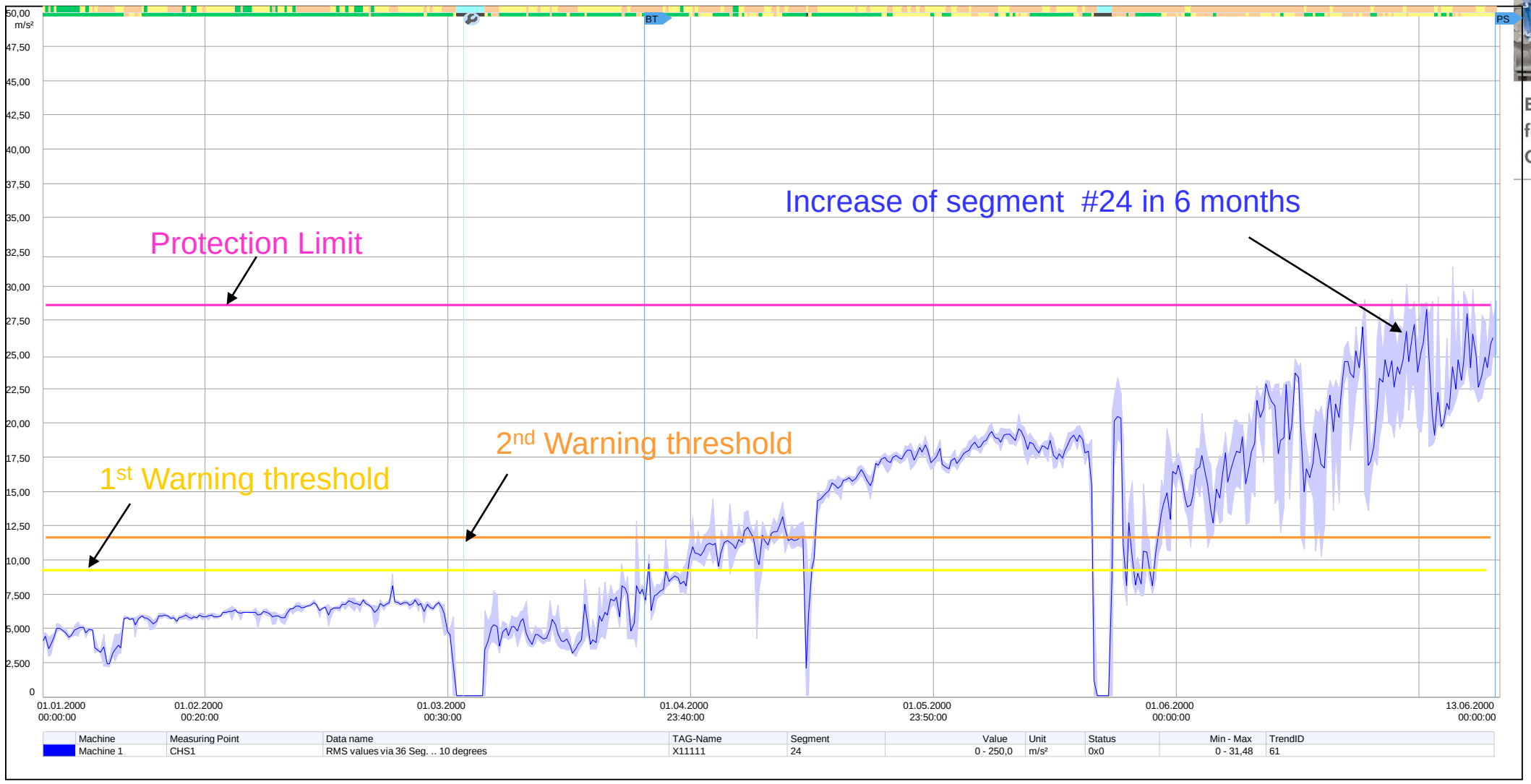
Case 2: Loose piston nut



Machine	Measuring Point	Data name	TAG-Name	Segment	Value	Unit	Status	Min - Max	TrendID
Machine 1	CHS1	RMS values via 36 Seg. .. 10 degrees	X11111	24	0 - 250,0	m/s²	0x0	0 - 31,48	61

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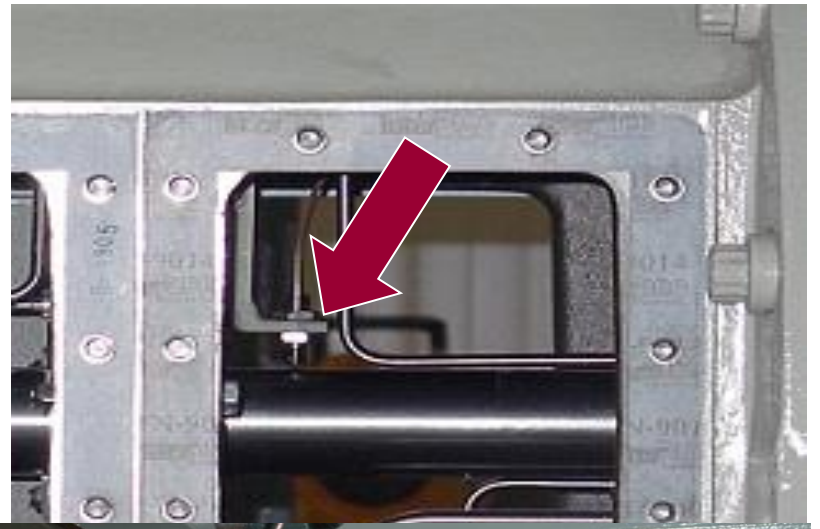
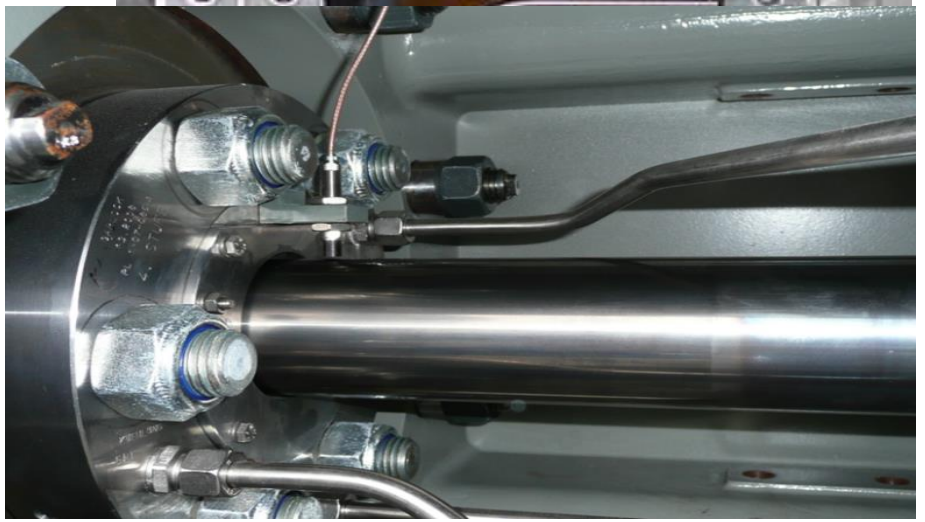
Piston rod displacement

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





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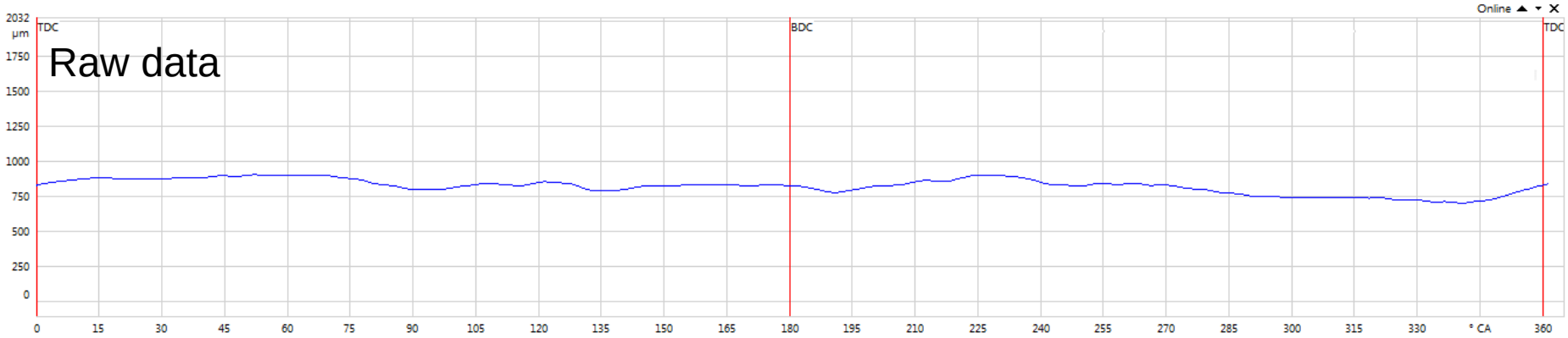
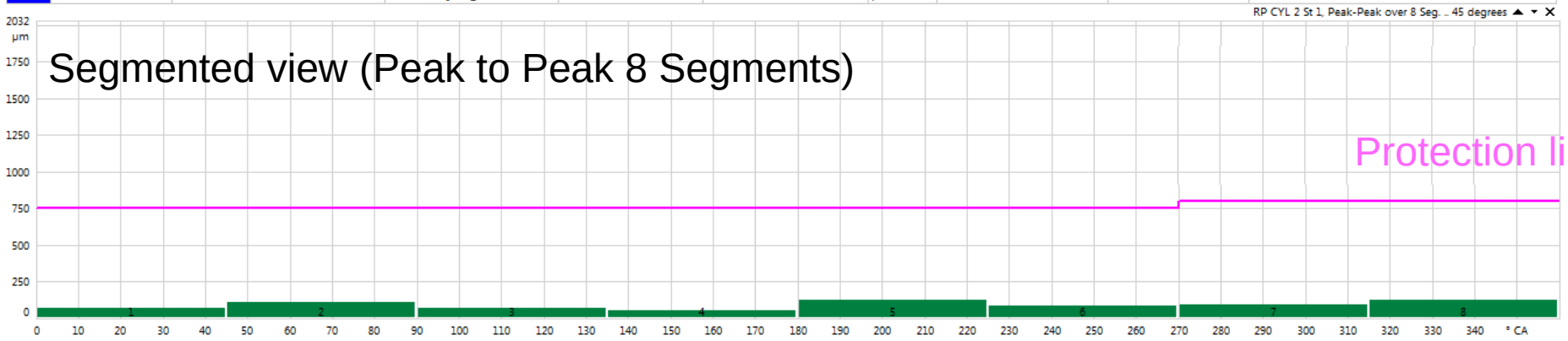
Case 3: Broken Piston Rod

Normal signals- 8 minutes before failure



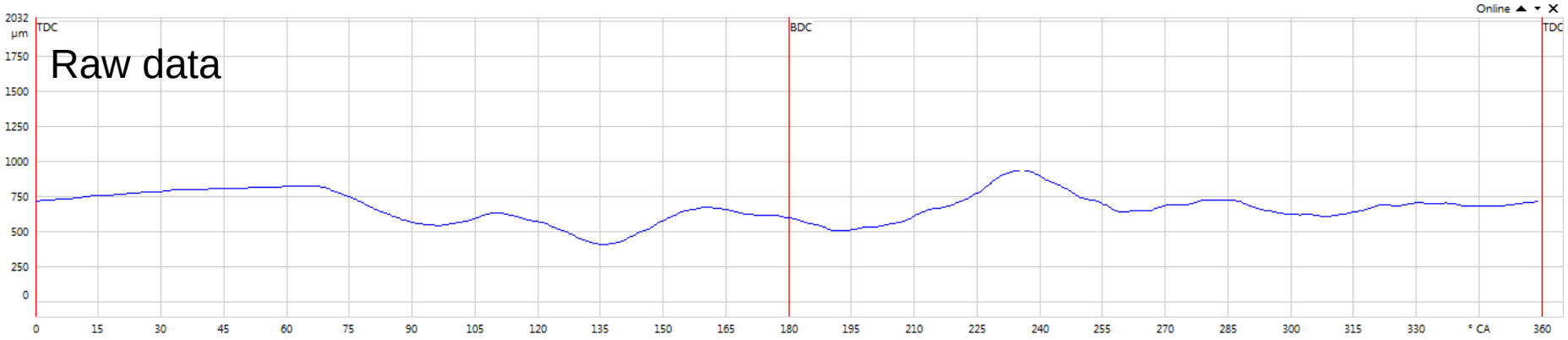
Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
	RP CYL 2 St 1	Proximity signal	XE-08132A	0 - 2032	µm	(A:0, S:0, U:0, F:0x0000	(D: 0x00) (M: 0x40;	(H: 0x80000000) No Error



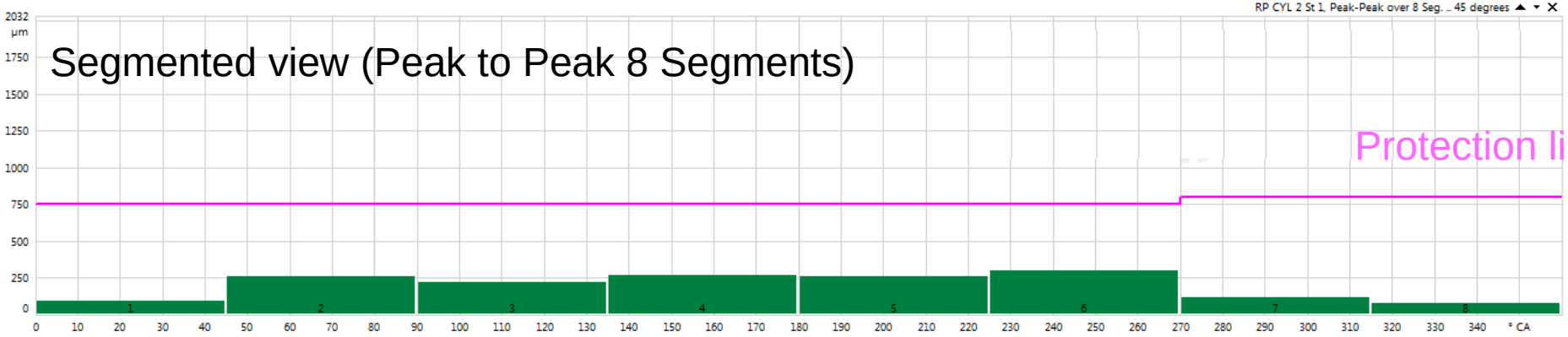
Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
	RP CYL 2 St 1	Peak-Peak over 8	XE-08132A		µm			

Case 3: Broken Piston Rod

First indications – 90 sec to failure



Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
..	RP CYL 2 St 1	Proximity signal	XE-08132A	0 - 2032	µm	(A:0, S:0, U:0, F:0x0000	(D: 0x00) (M: 0x40)	(H: 0x80000000) No Error



Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
	RP CYL 2 St 1	Peak-Peak over 8	XE-08132A		µm			

Case 3: Broken Piston Rod

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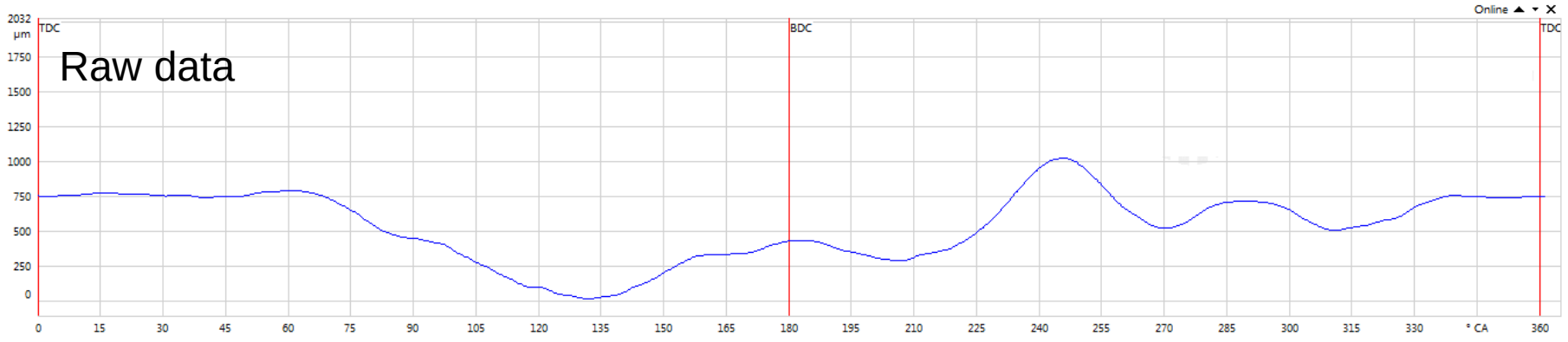
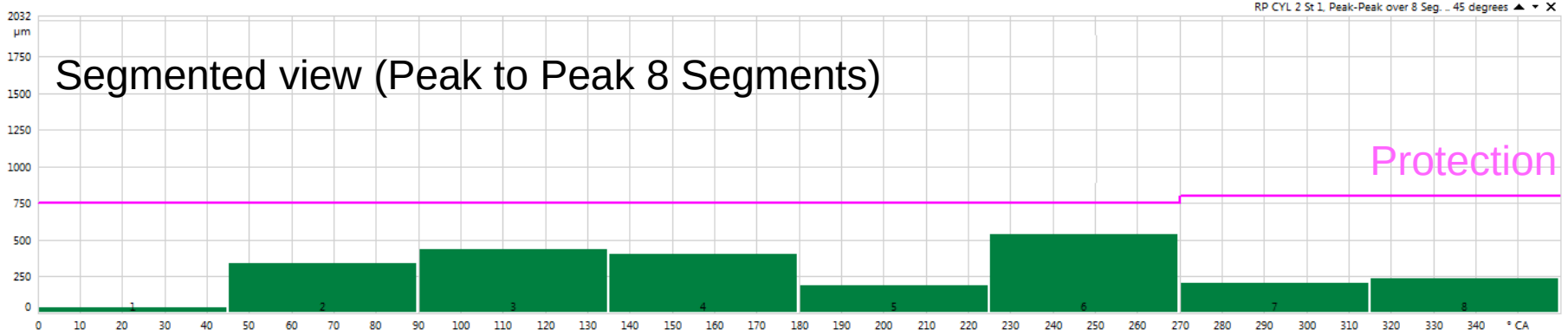
Bigger increase – 41 sec. to failure



Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
V01A	RP CYL 2 St 1	Proximity signal	XE-08132A	0 - 2032	µm	(A:0, S:0, U:0, F:0x0000	(D: 0x00) (M: 0x40)	(H: 0x80000000) No Error

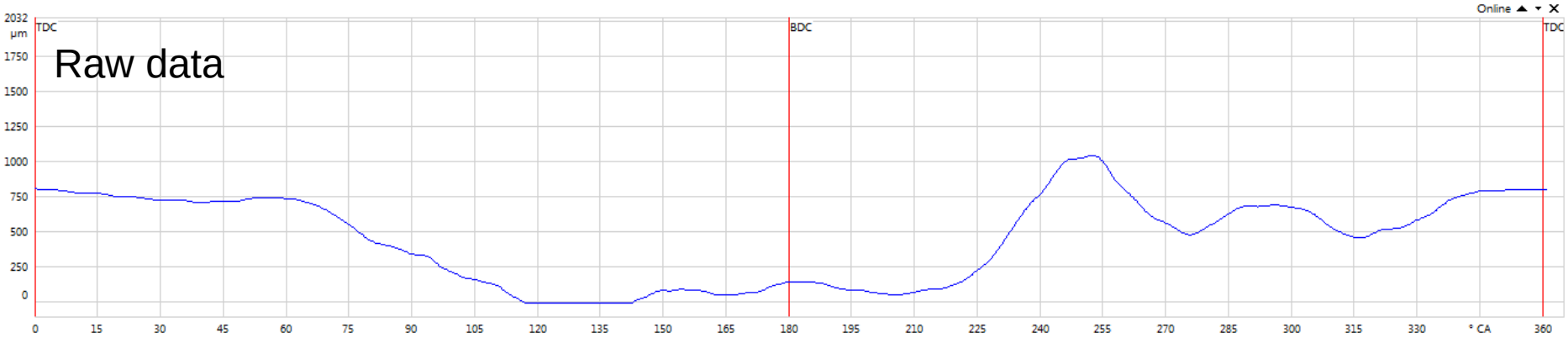


Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
V01A	RP CYL 2 St 1	Peak-Peak over 8	XE-08132A		µm			

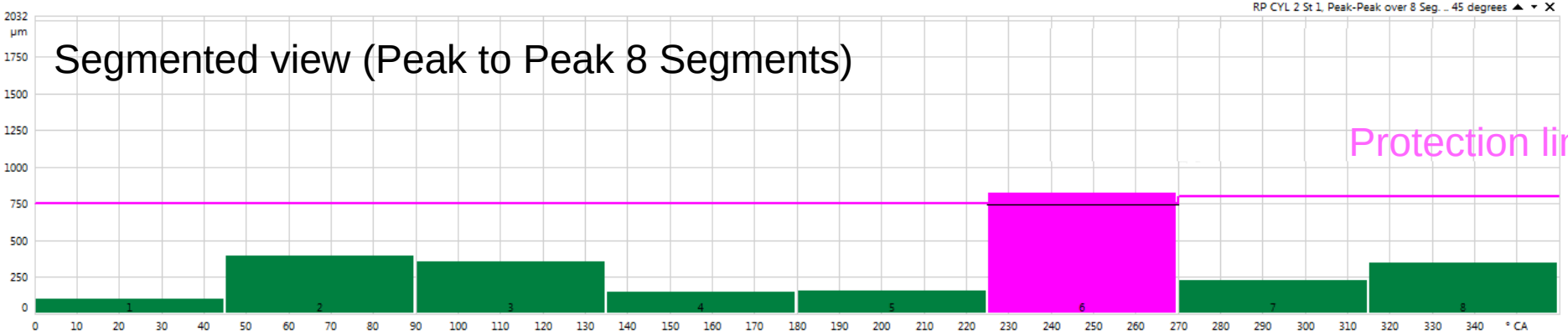
Ring Buffer 08.02.2016 23:08:24,417 (08.02.2016 23:08:24,417 BLOCK#5081451-5084817(3366)) , 892,3 1/min

Case 3: Broken Piston Rod

Shutdown released – 32 sec. to failure



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
		RP CYL 2 St 1	Proximity signal	XE-08132A	0 - 2032	µm	(A:0, S:0, U:0, F:0x0000	(D: 0x00) (M: 0x40)	(H: 0x80000000) No Error



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
		RP CYL 2 St 1	Peak-Peak over 8	XE-08132A		µm			

Case 3: Broken Piston Rod

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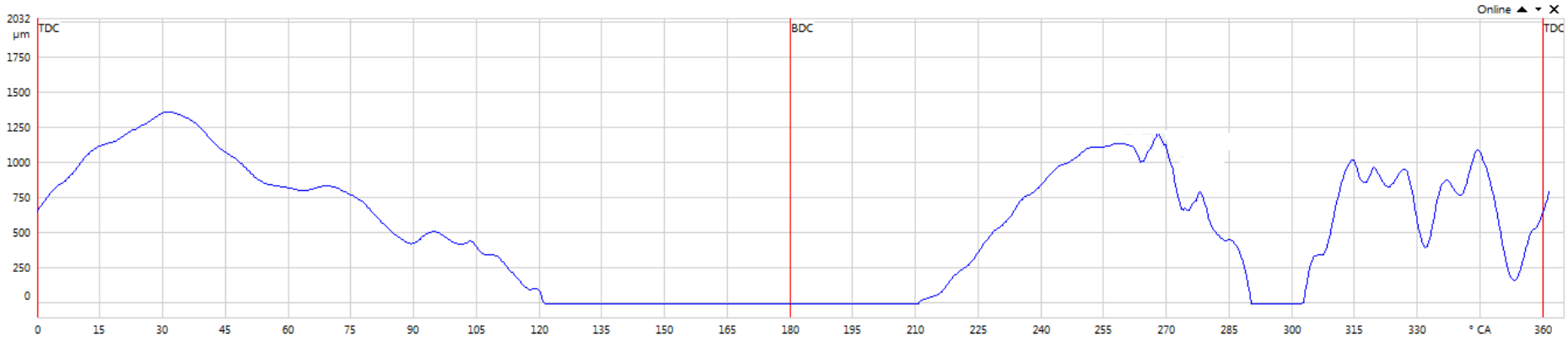
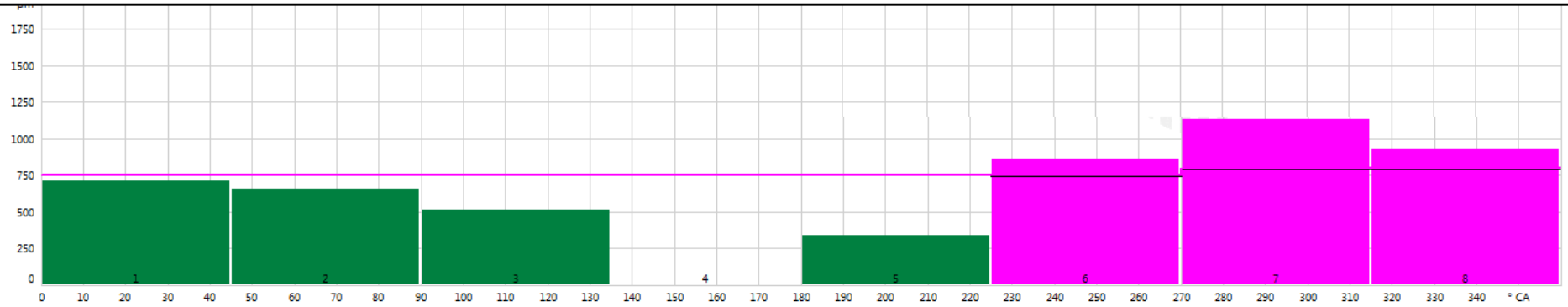
Piston rod broke

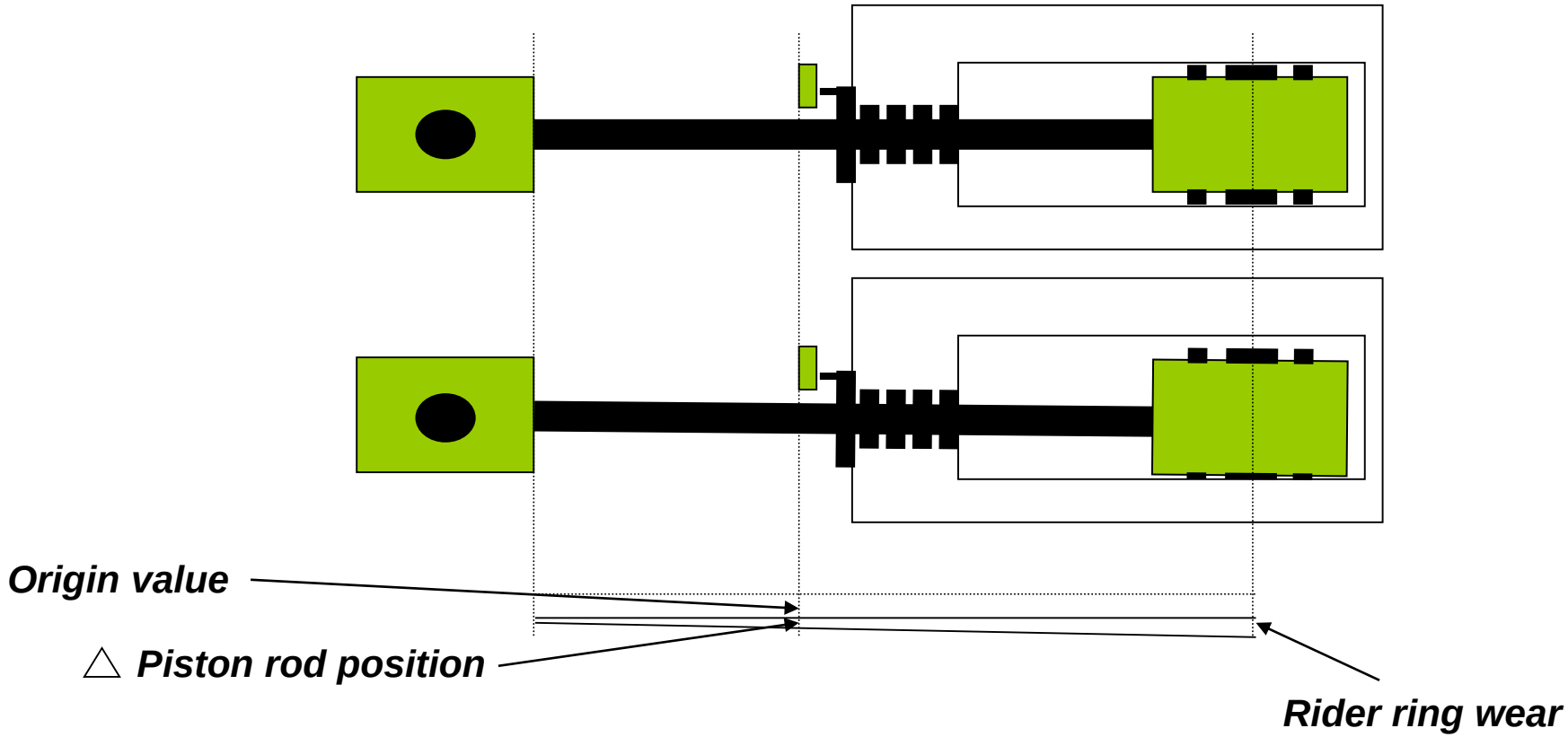


Automatic trip was no active!



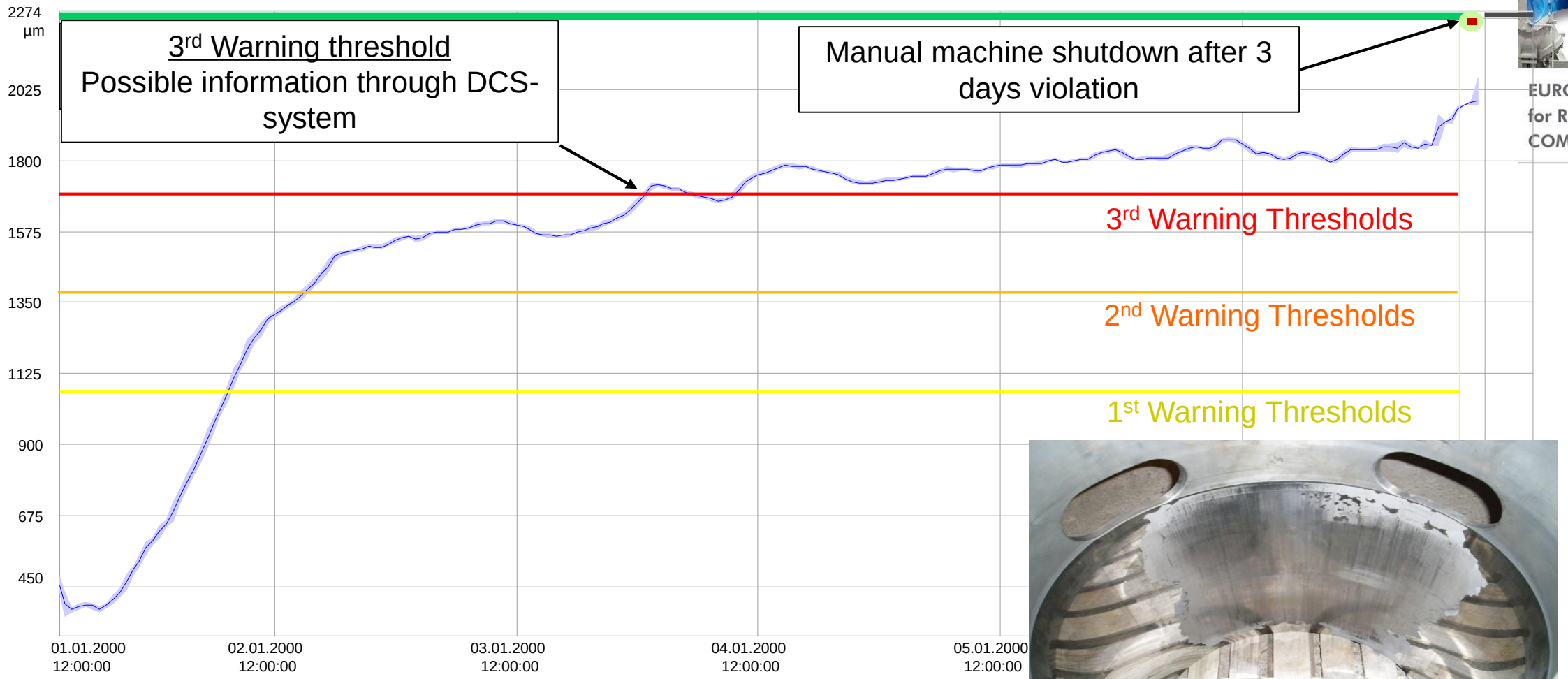
Machine	Measuring Point	Data name	TAG-Name	Value	Unit	Safety (Beta)	MP Status	Channel Status
.	RP CYL 2 St 1	Peak-Peak over ε	XE-08132A		µm			

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

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Cylinder vibration

With **acceleration sensors**…

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

…can be detected

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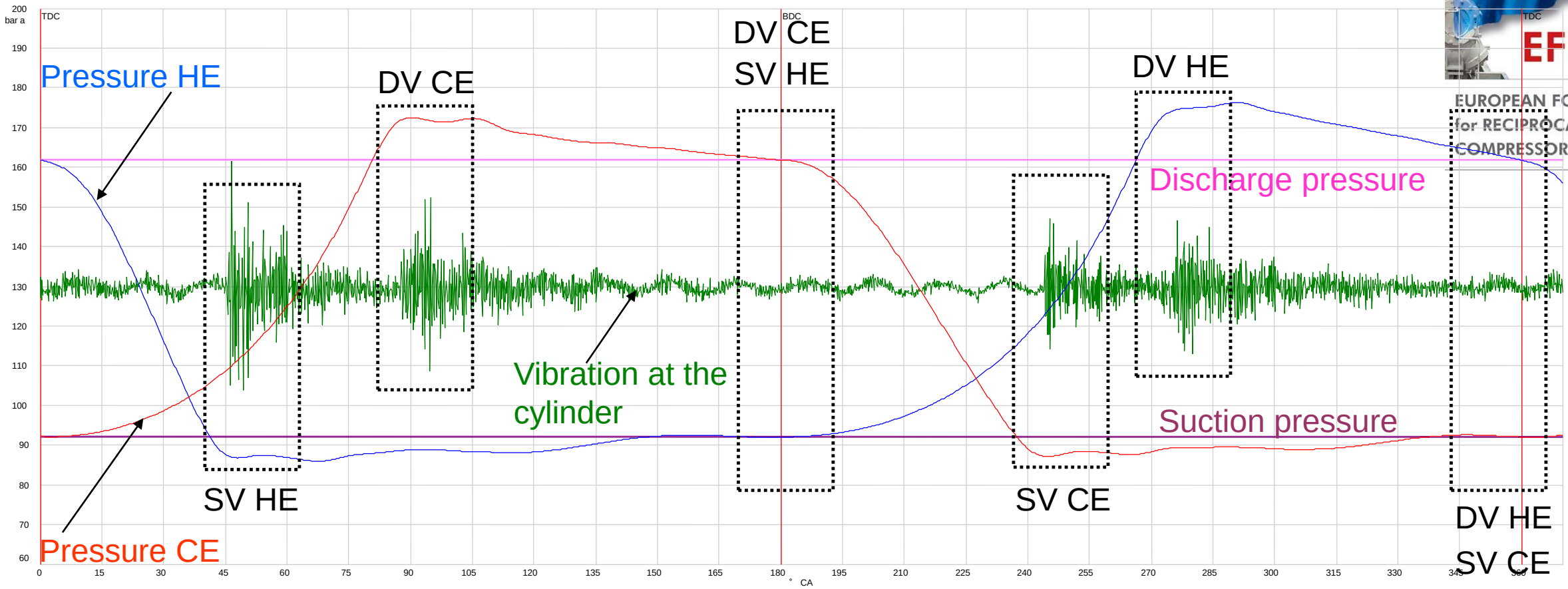
Cylinder vibration measurement



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

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

Online 01.01.2000 12:00:00, Machine 1 - Cyl.1 Stage 1 , 500,0 1/min

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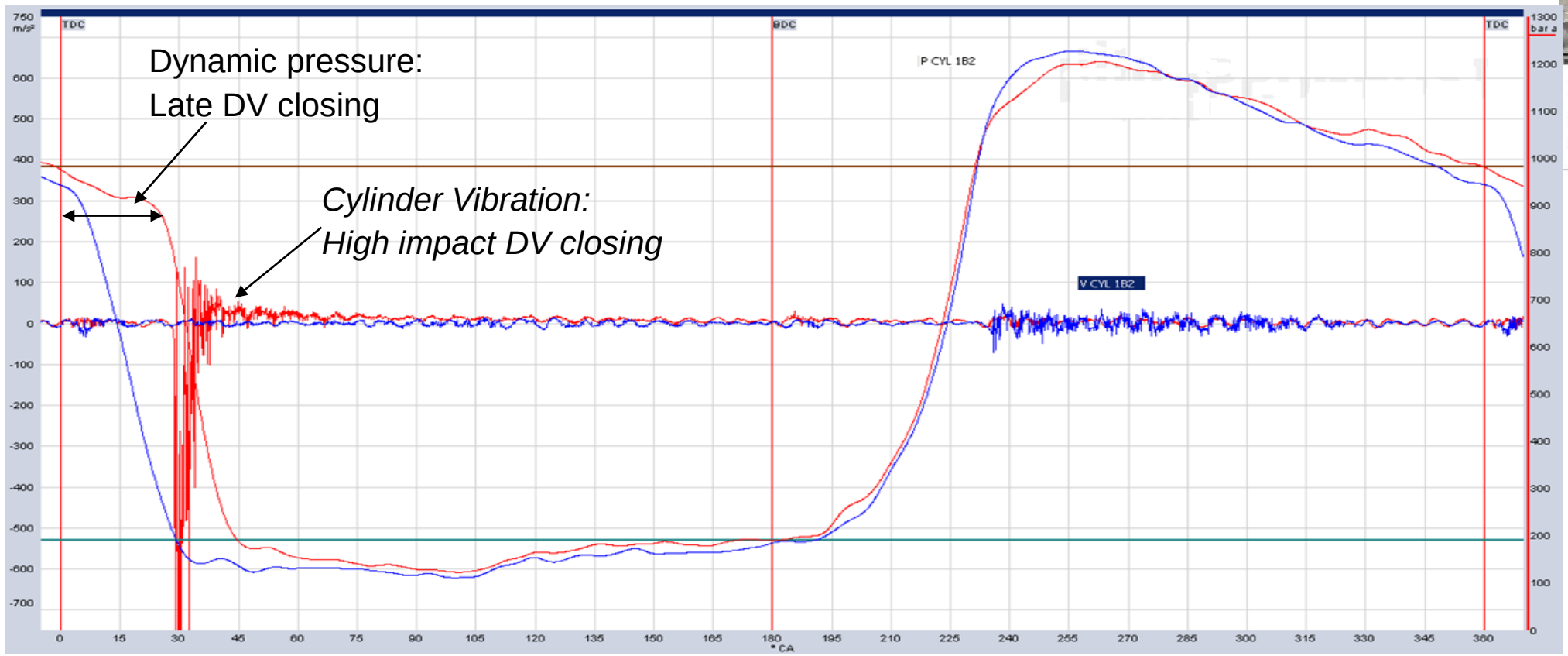
Case 5: Sticking poppet



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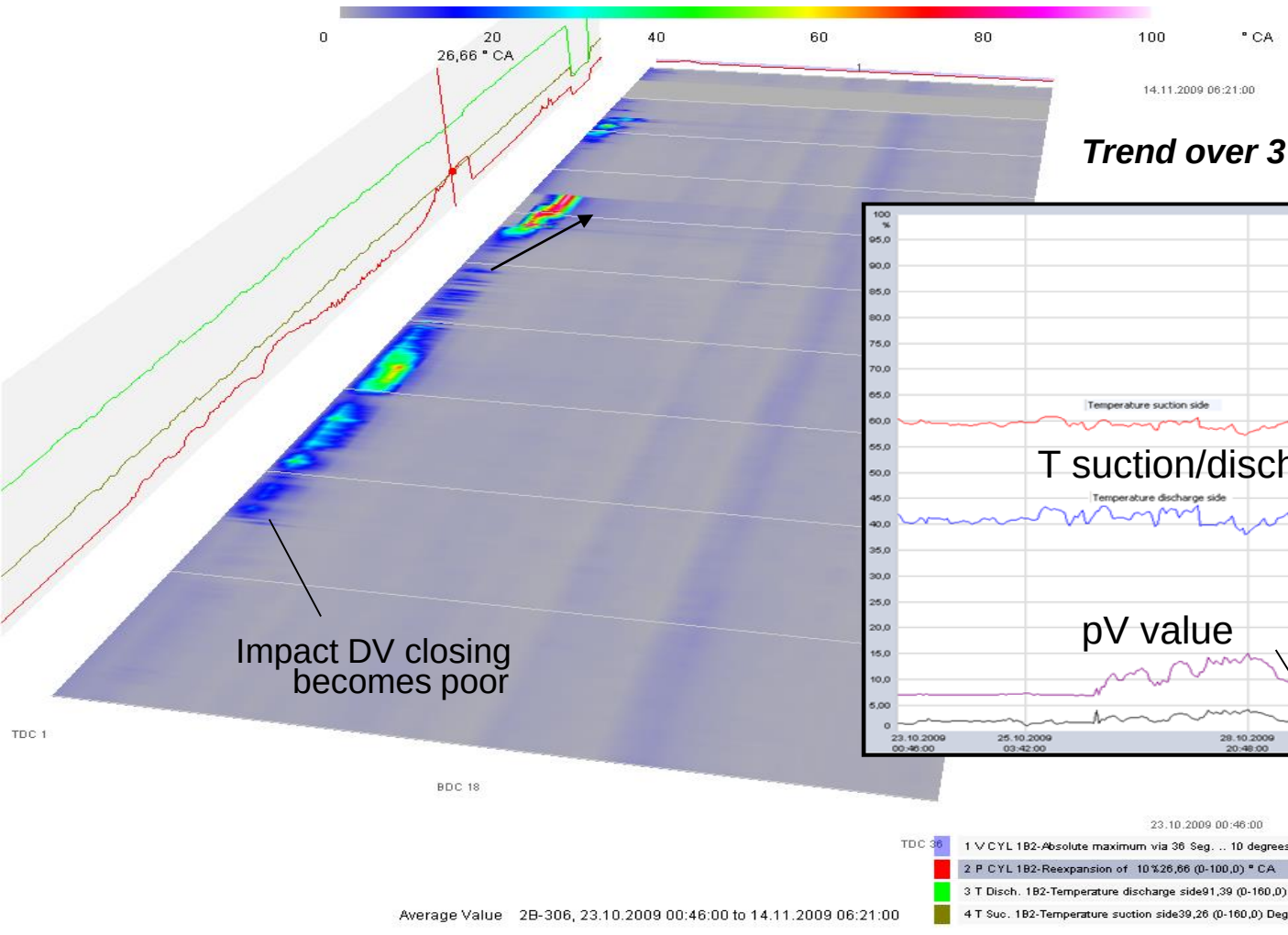
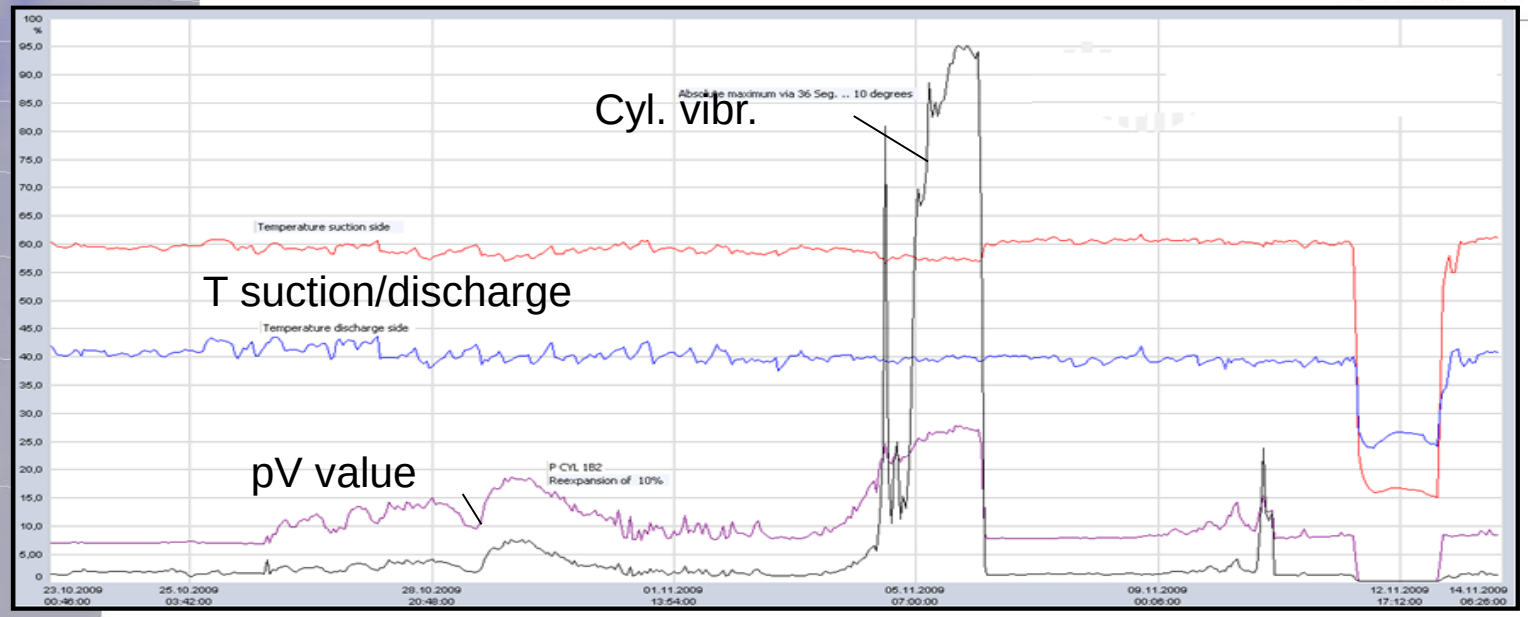
Case 5: Sticking poppet

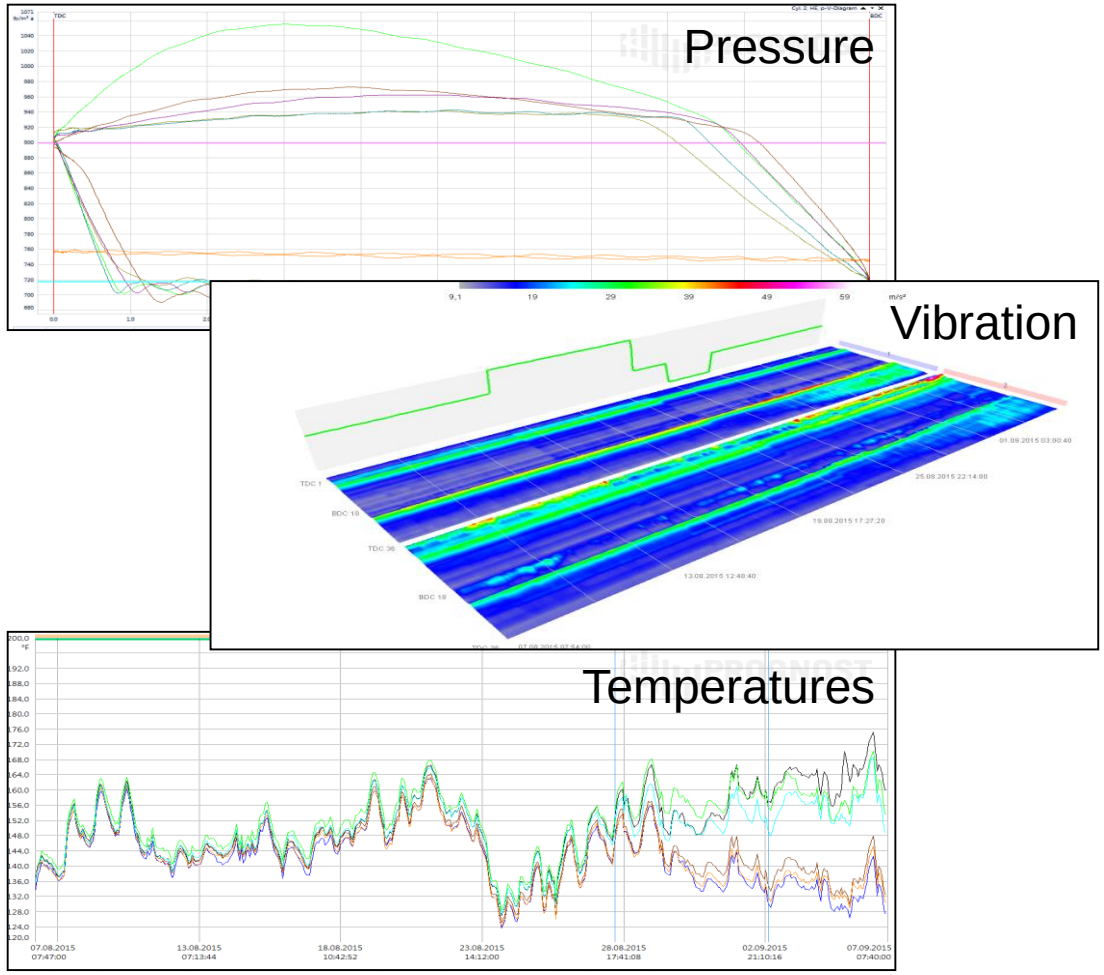


Trend over 3 weeks



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

Big Data – Example of usage in Condition Diagnostics



Pattern recognition compares signals based on known cases and results in automatic message:

„*Blocked discharge Valve issue Cyl. XY*"

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

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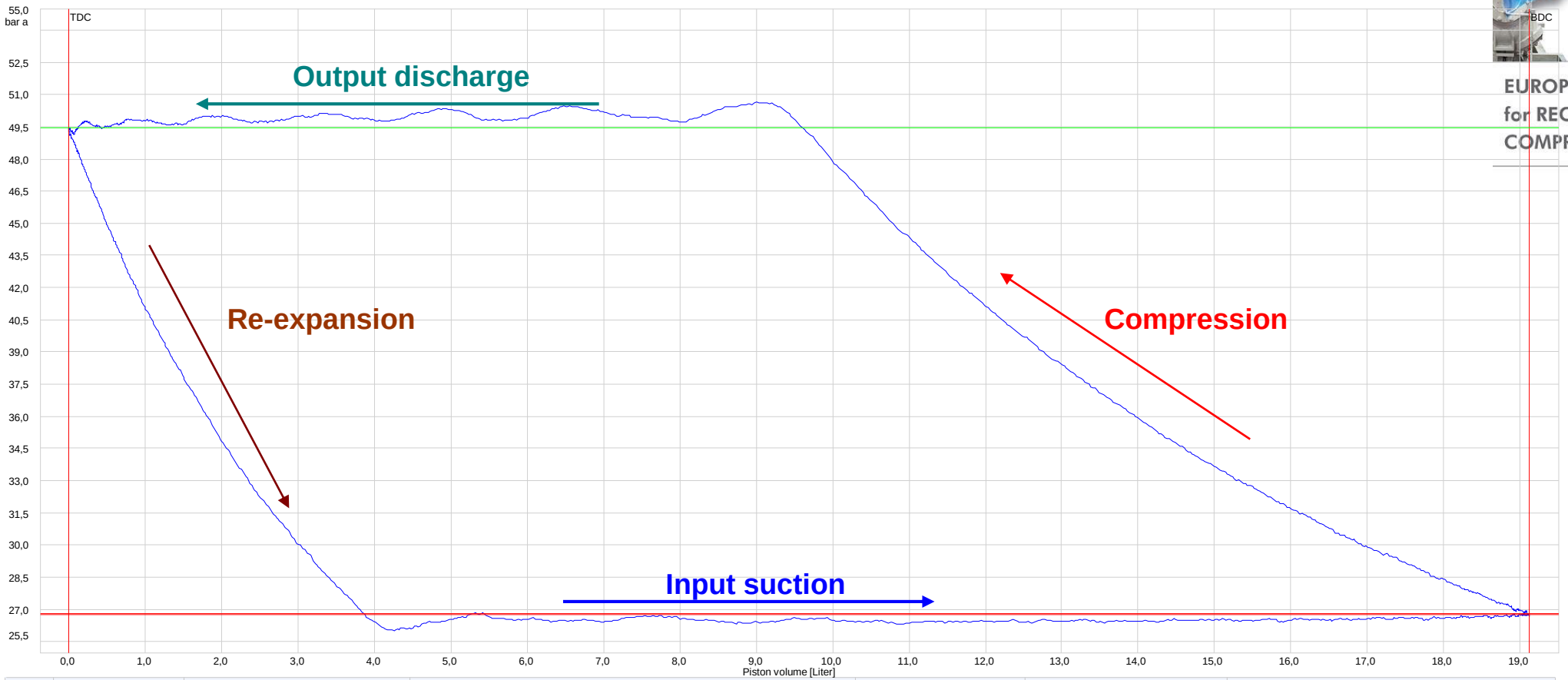
Dynamic pressure - pV diagram



	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	Machine 1	Cyl. 1, CE	p-V-Diagram	PR-1111	-87,77 - 109,0	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 - 350,0	° CA

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

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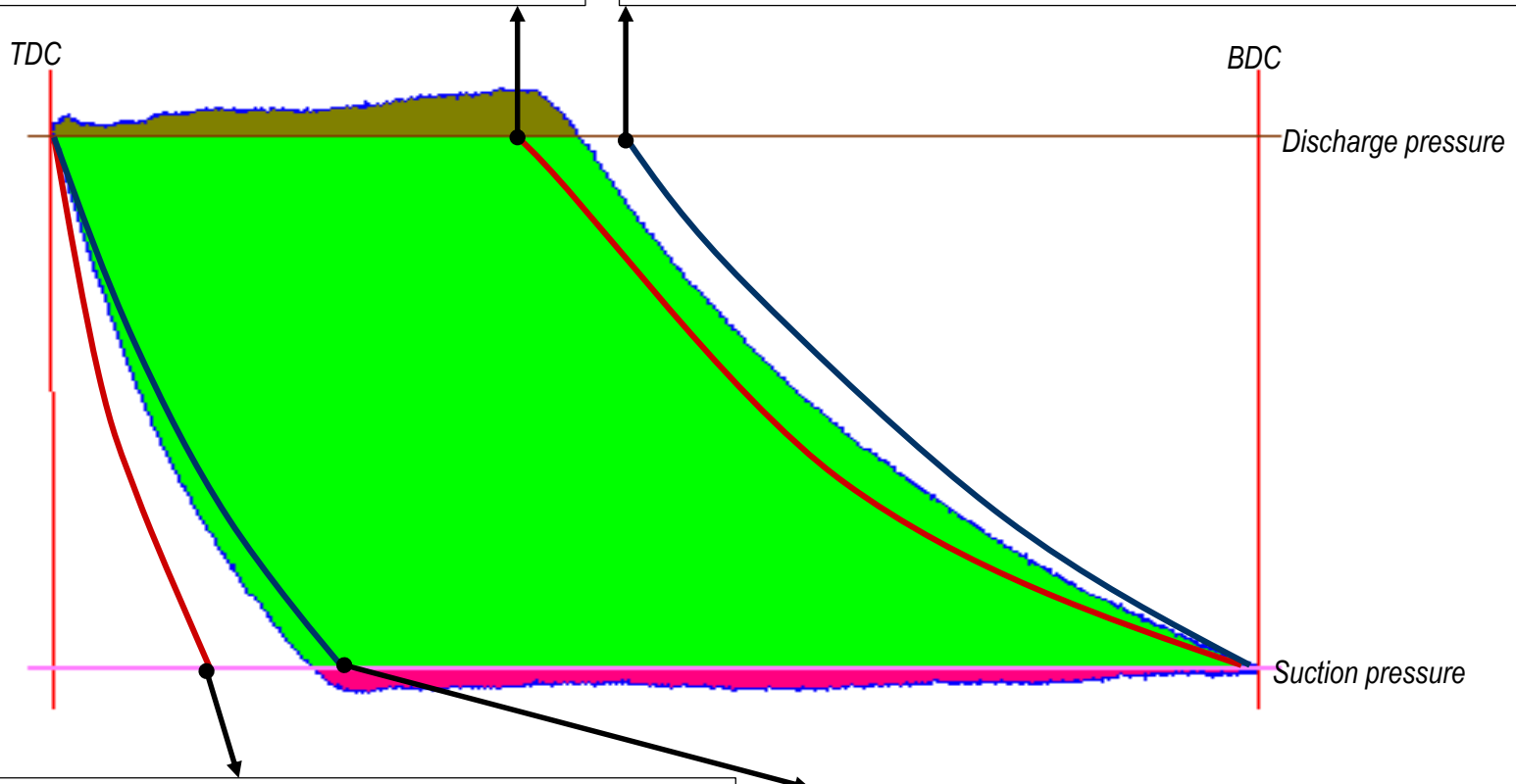
Exercise: Detection of leakages

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

„Shorter“ to discharge pressure
→ Discharge valves

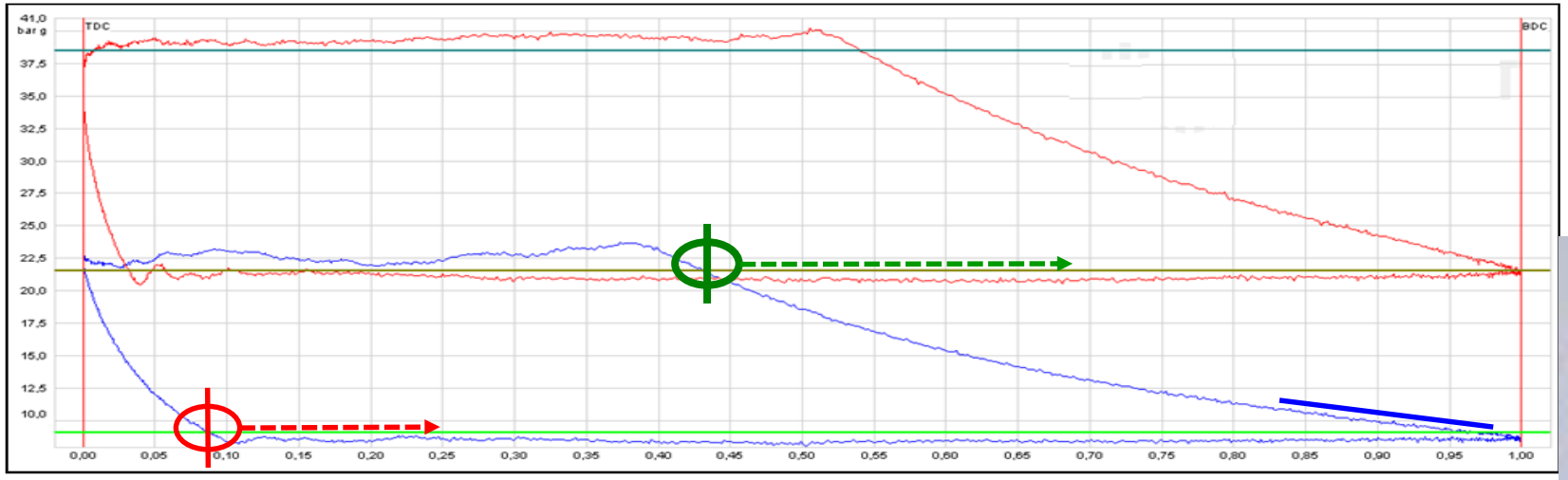


„Shorter“ to suction pressure
→ Suction valve or packing (crank end)

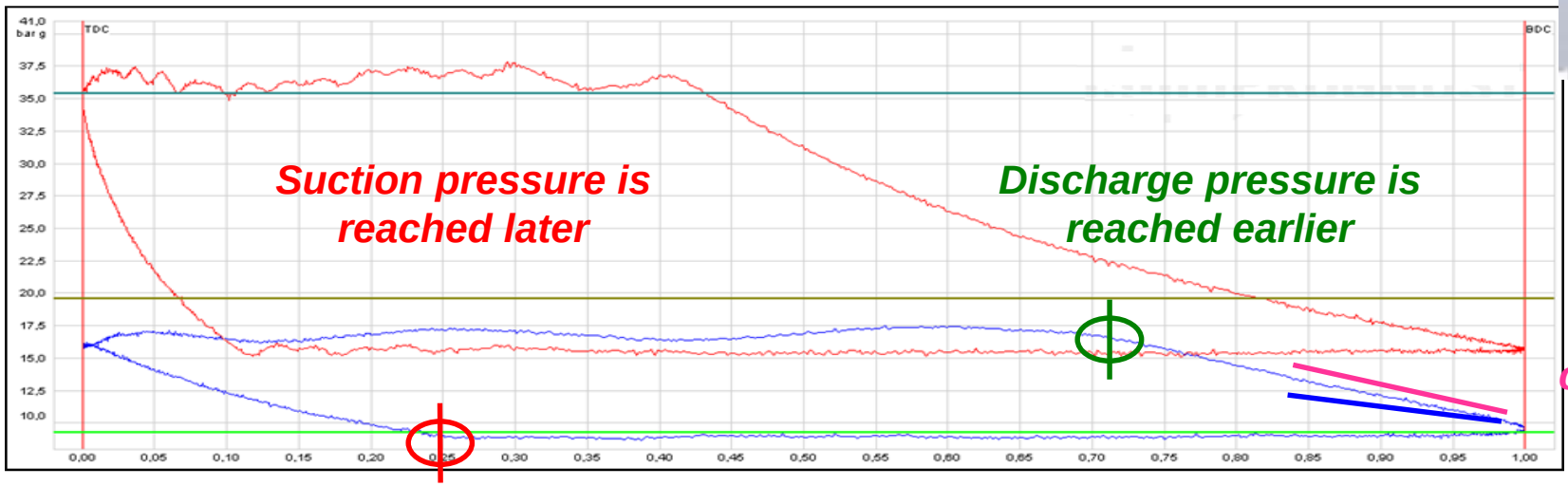
„Longer“ to suction pressure
→Discharge valve

Case 6: Valve failure

Good condition



Bad condition



Valve ?

Line of compression steeper

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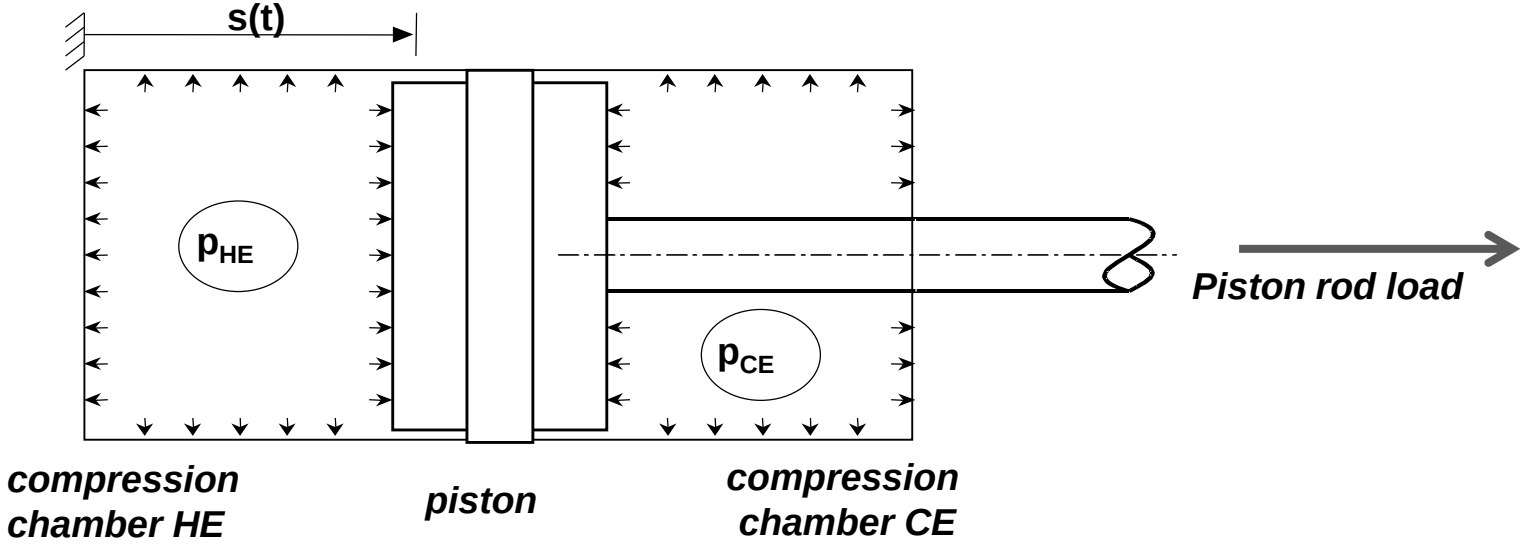
Piston rod load

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

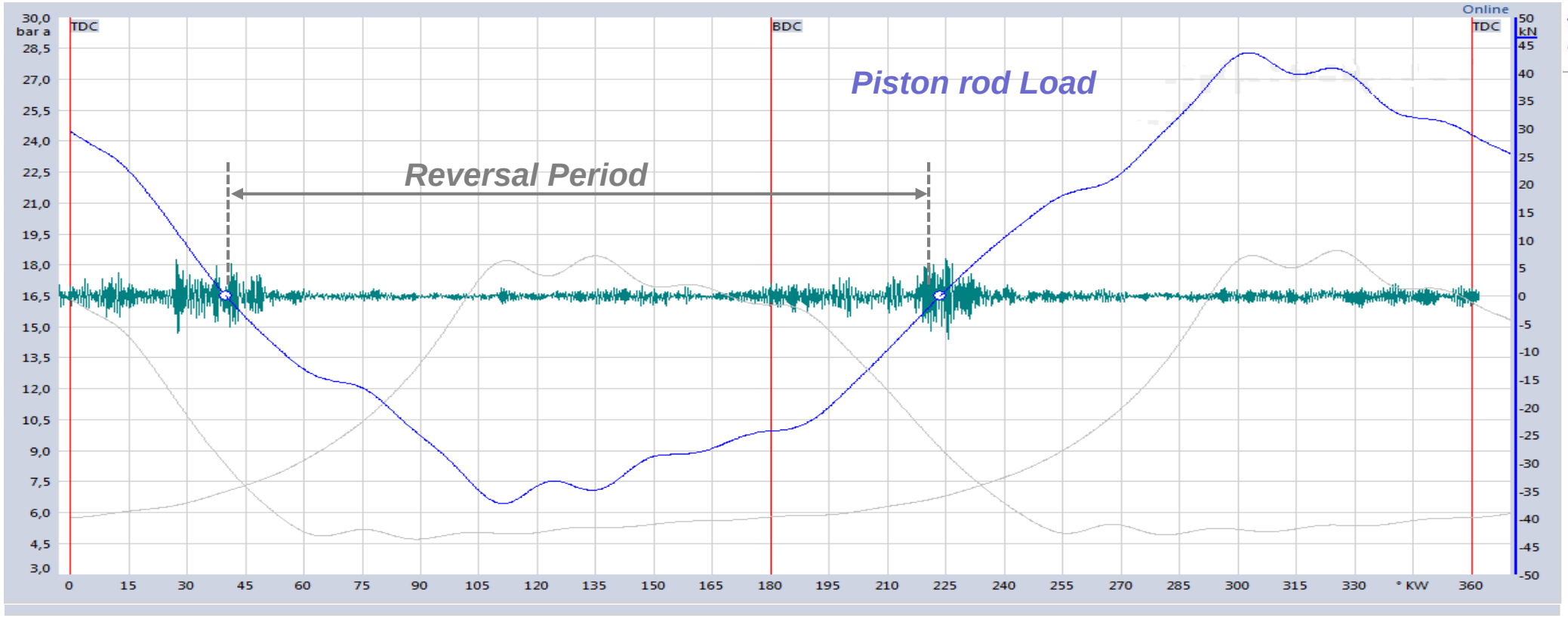


Inertia force
- piston, rod and crosshead mass
- speed
- connecting rod ratio

Gas force
- dynamic pressure
- piston area

HE = head end
CE = crank end

Piston rod load



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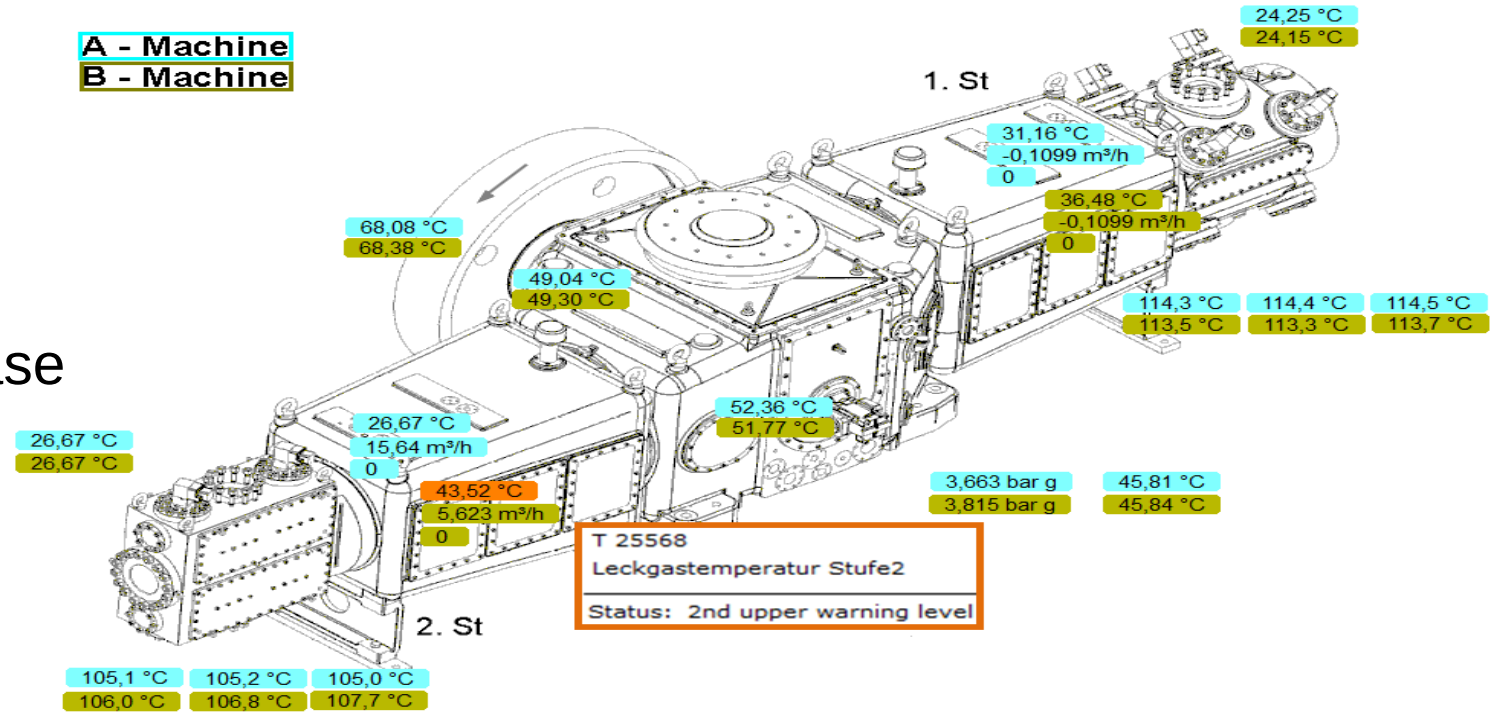
Temperature measurements



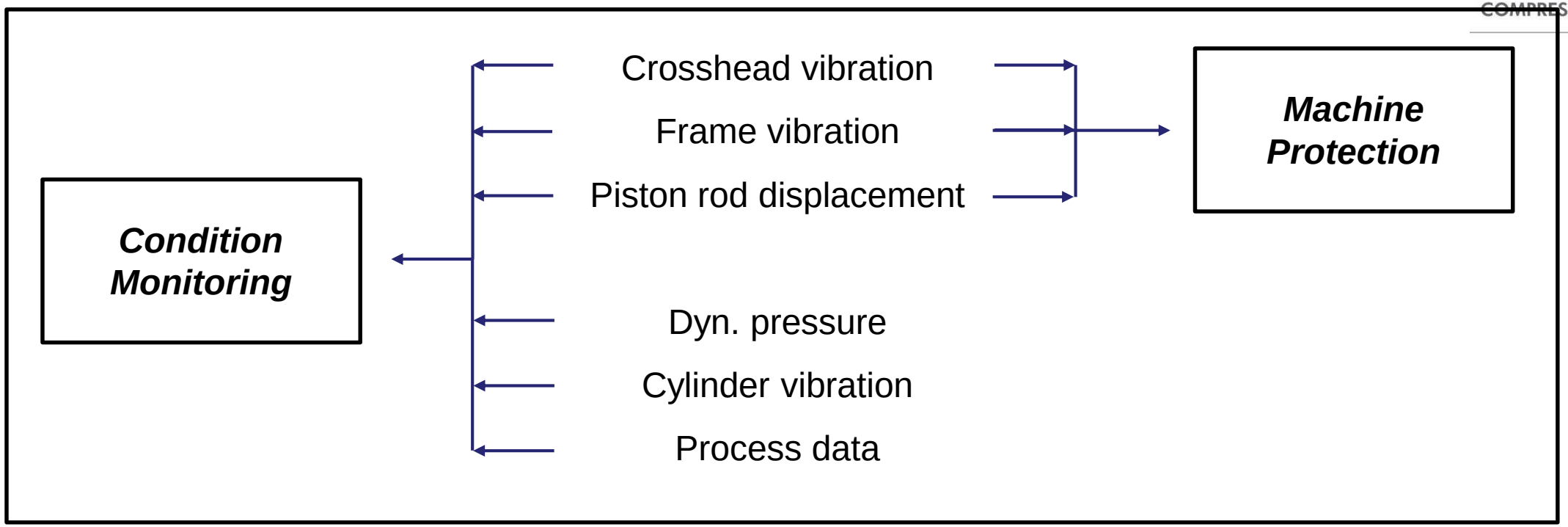
Common

- Valve
- Gas
- Packing vent or case
- Bearings

Uncommon

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

Standards: Experience



Technology developments and practical experience over recent years lead to additional recommended measurements for monitoring and diagnostics.

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