EFRC Training Workshop
Design and operation of reciprocating compressors

Condition Monitoring

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PROGNOST

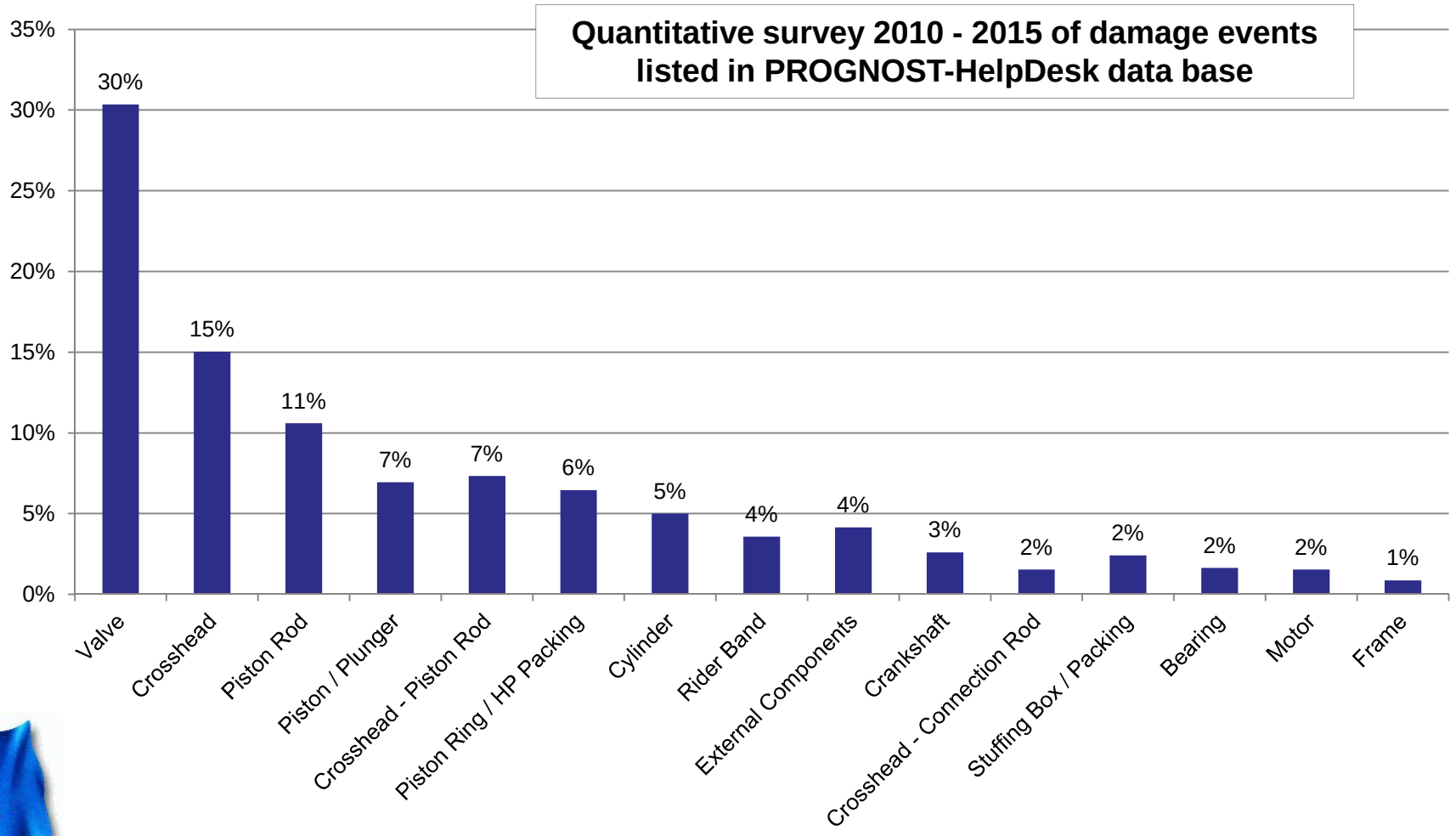
Topics

- Why condition monitoring
- Sensor locations and data management
- Signal analysis: -Acceleration (CHS, cylinder, bearings)
  -Velocity (frame)
  -Proximity (piston rod)
  -Dyn. pressure (compression chamber)
  -Piston rod load
  -Temperatures (valve, gas and bearings)
- API 618 recommendation
- Early failure vs. safety protection

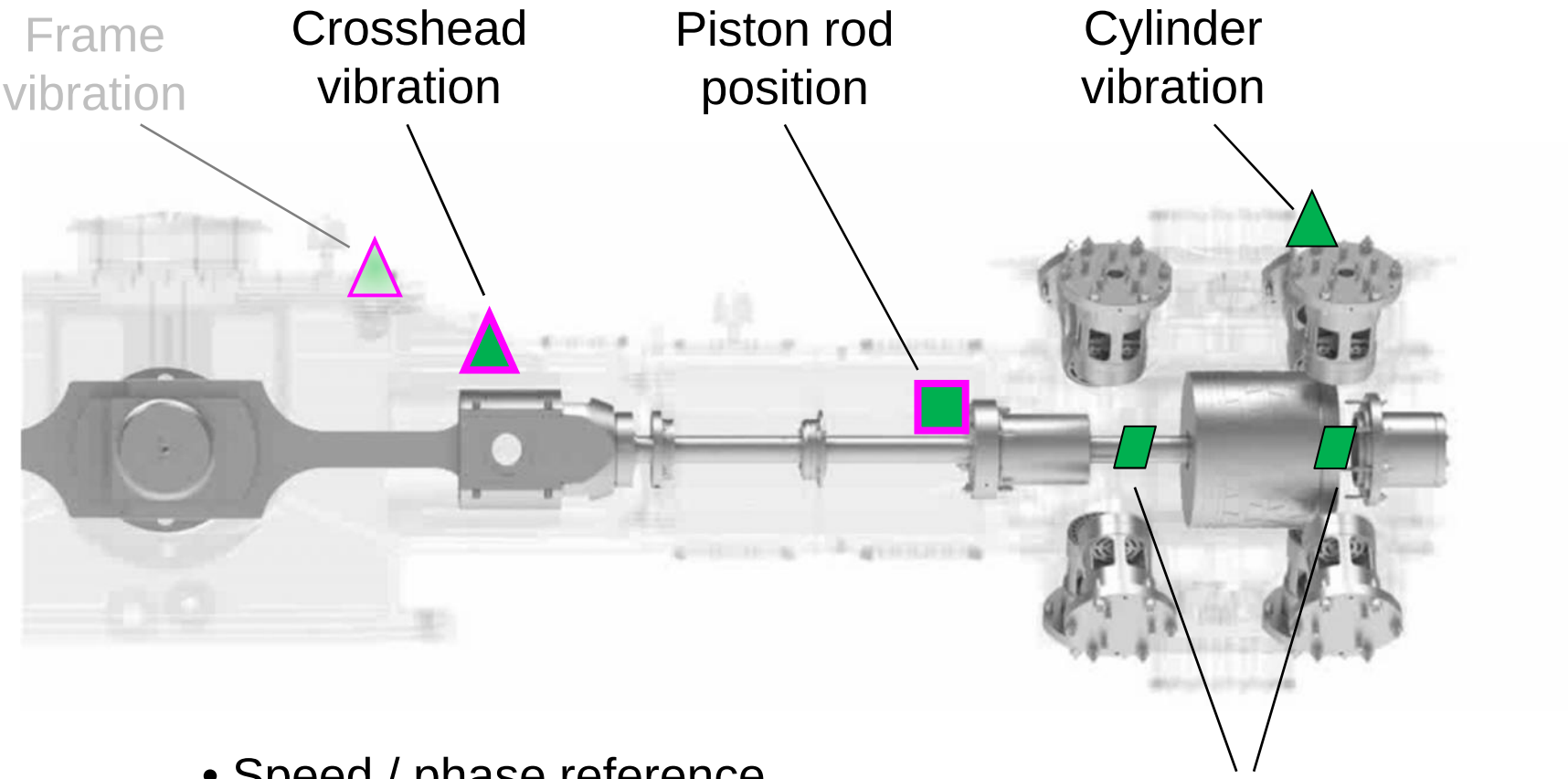
Why condition monitoring?

- ***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

Total failures by component

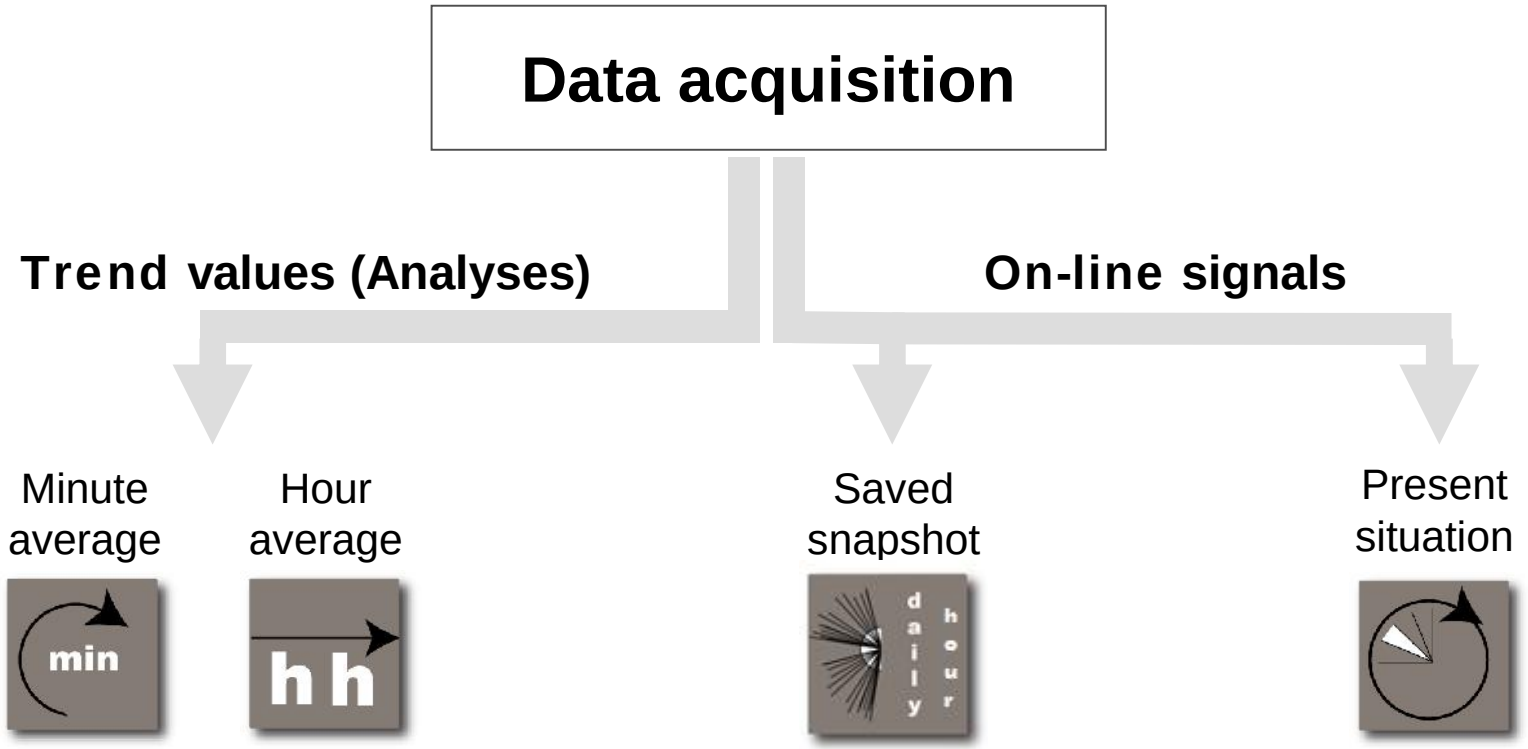


Sensor types and locations

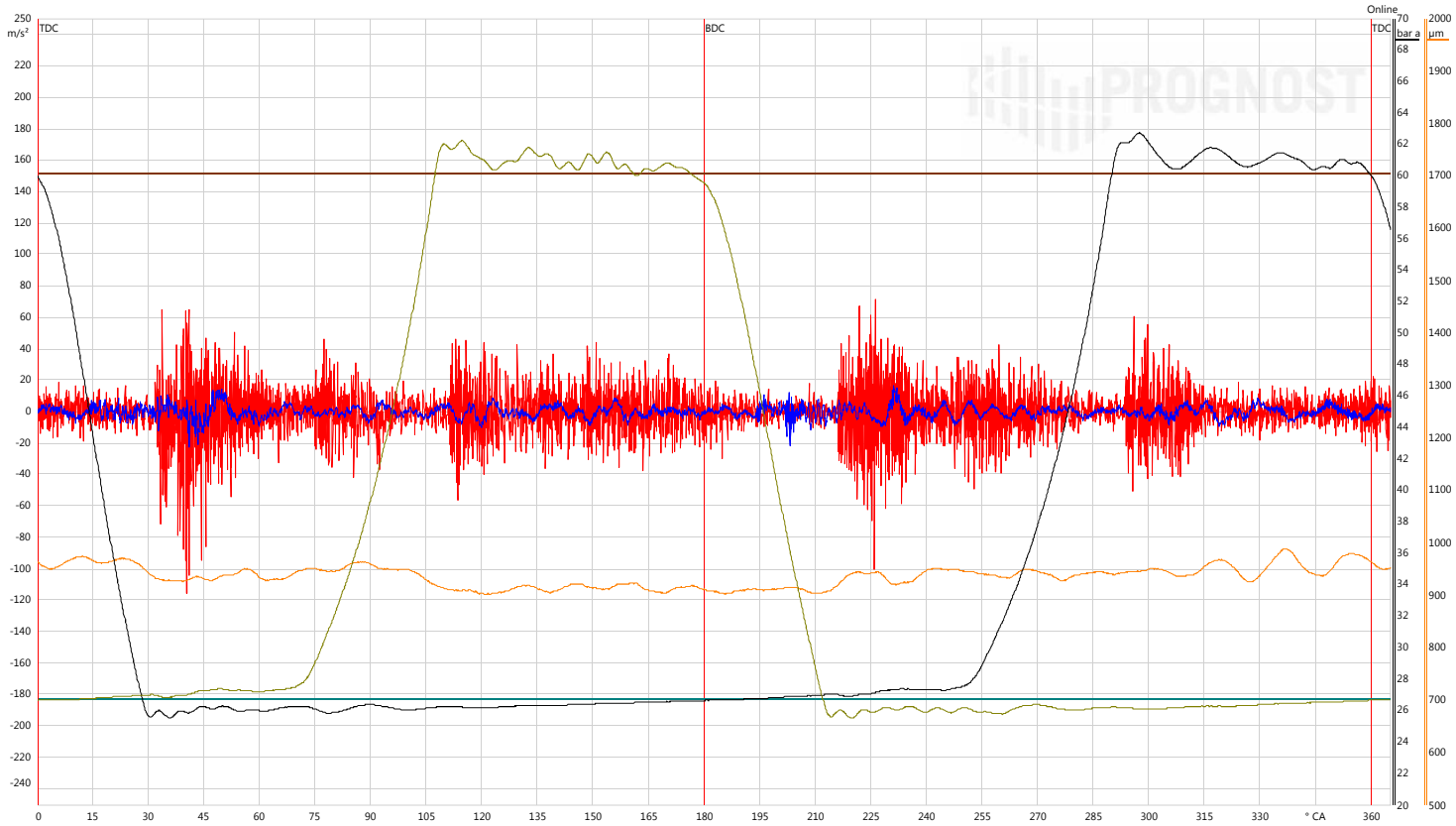


- Speed / phase reference
- Process data

Data management



On-line



	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

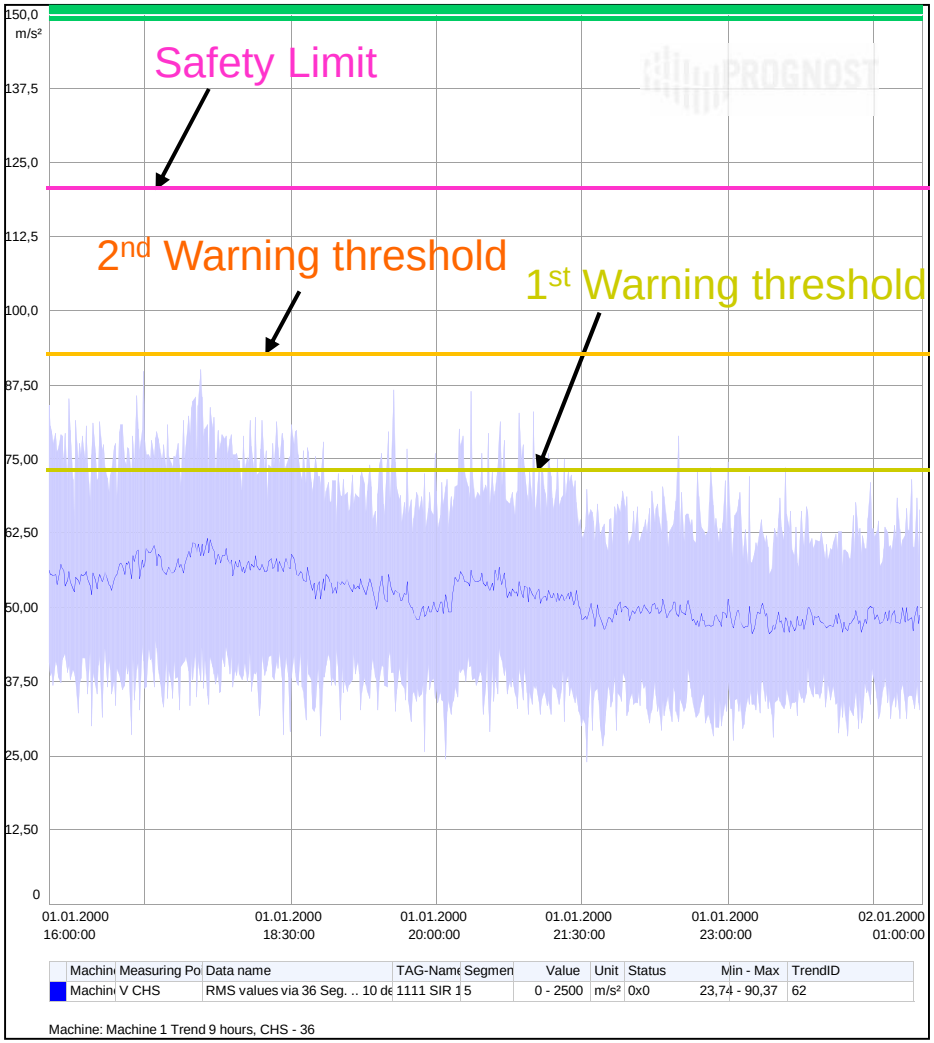
Trend

Short term

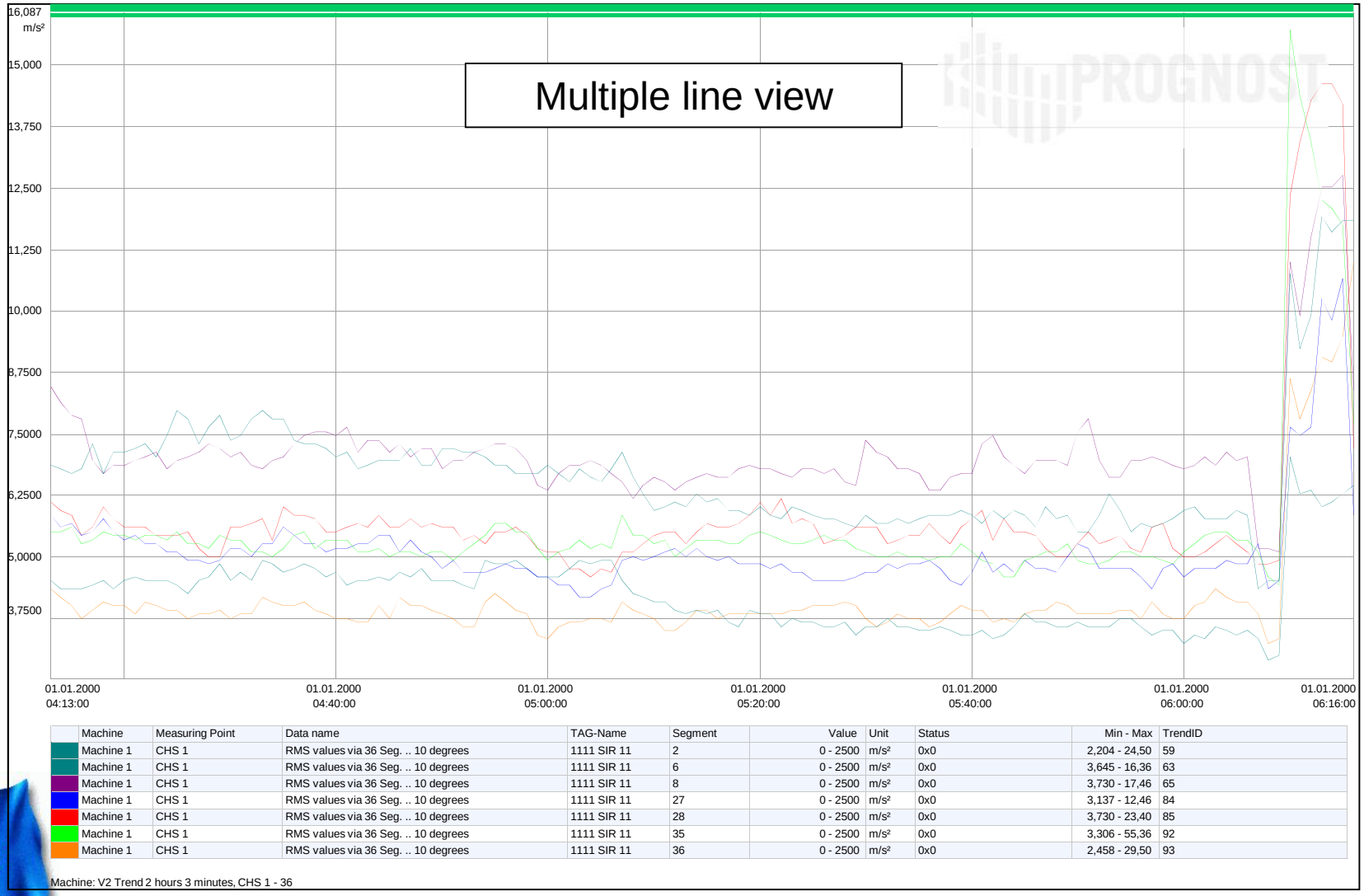
- Average & min/max over a minute
- Early Failure Detection

Long term

- Hourly average
- Archiving character
- Available up to lifetime of the system



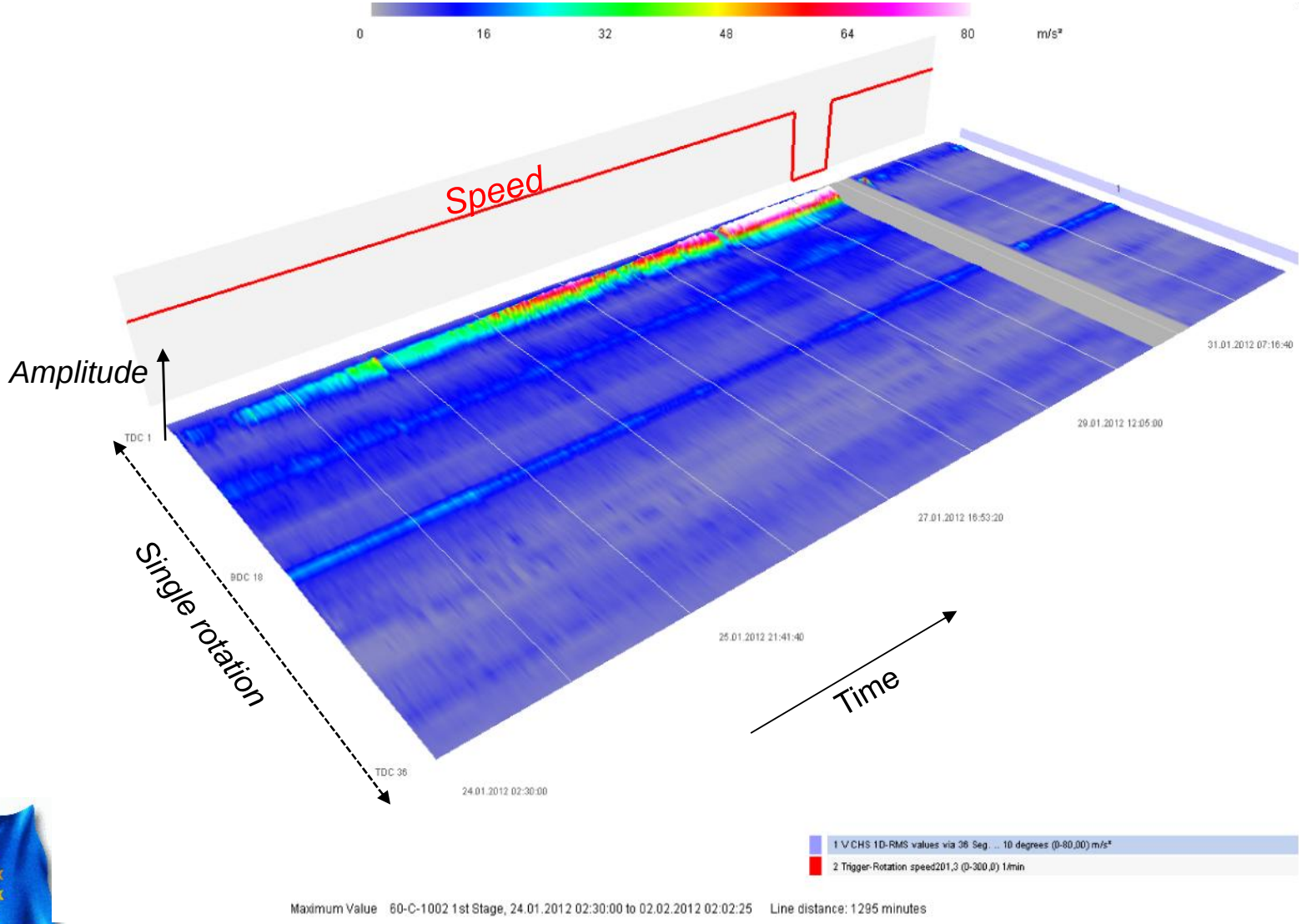
Trend



	Machine	Measuring Point	Data name	TAG-Name	Segment	Value	Unit	Status	Min - Max	TrendID
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	2	0 - 2500	m/s²	0x0	2,204 - 24,50	59
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	6	0 - 2500	m/s²	0x0	3,645 - 16,36	63
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	8	0 - 2500	m/s²	0x0	3,730 - 17,46	65
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	27	0 - 2500	m/s²	0x0	3,137 - 12,46	84
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	28	0 - 2500	m/s²	0x0	3,730 - 23,40	85
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	35	0 - 2500	m/s²	0x0	3,306 - 55,36	92
	Machine 1	CHS 1	RMS values via 36 Seg. .. 10 degrees	1111 SIR 11	36	0 - 2500	m/s²	0x0	2,458 - 29,50	93

Machine: V2 Trend 2 hours 3 minutes, CHS 1 - 36

3D-waterfall trend



Alarming

- Warning
  Early failure detection based on thresholds

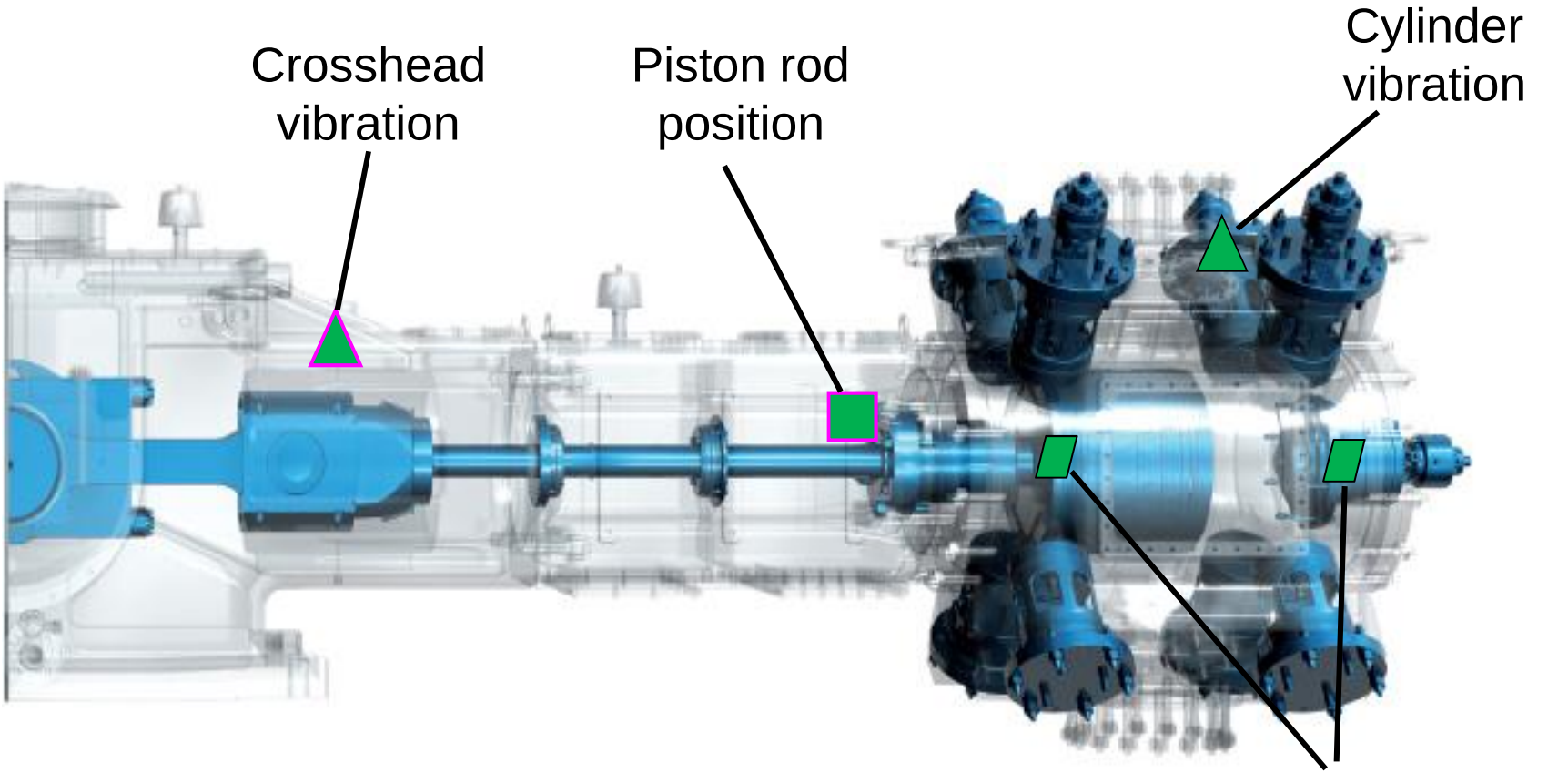
- Alarm & Automatic Shutdown
  Safety based on limits

- Unsafe Message
  System failure self detection / plausibility check

In addition HMI interface for …

- detailed diagnostic analysis
- data recall for archiving
- tool for measuring loop maintenance

Sensor locations



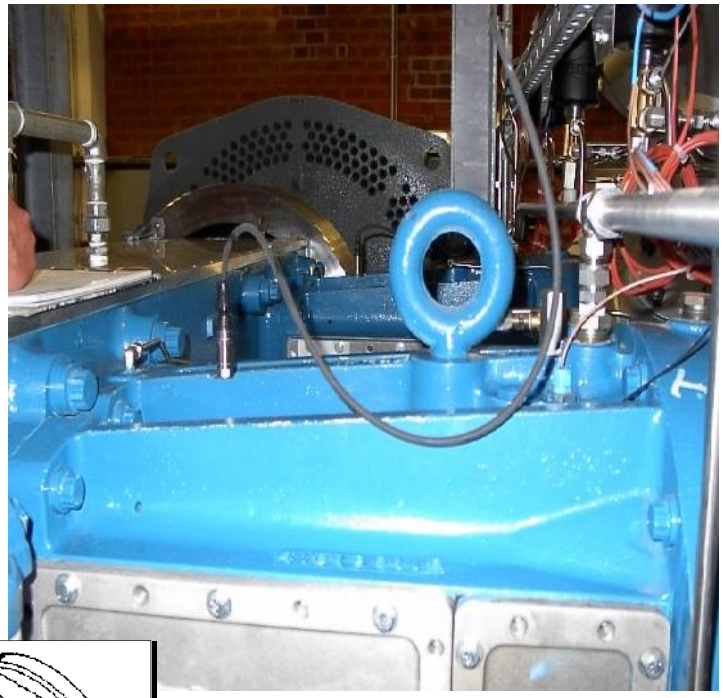
- Speed / phase reference
- Process data

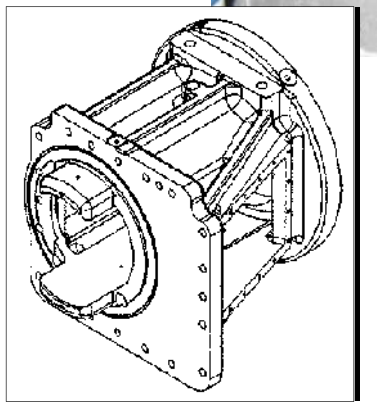
Crosshead vibration

With **acceleration sensors…**

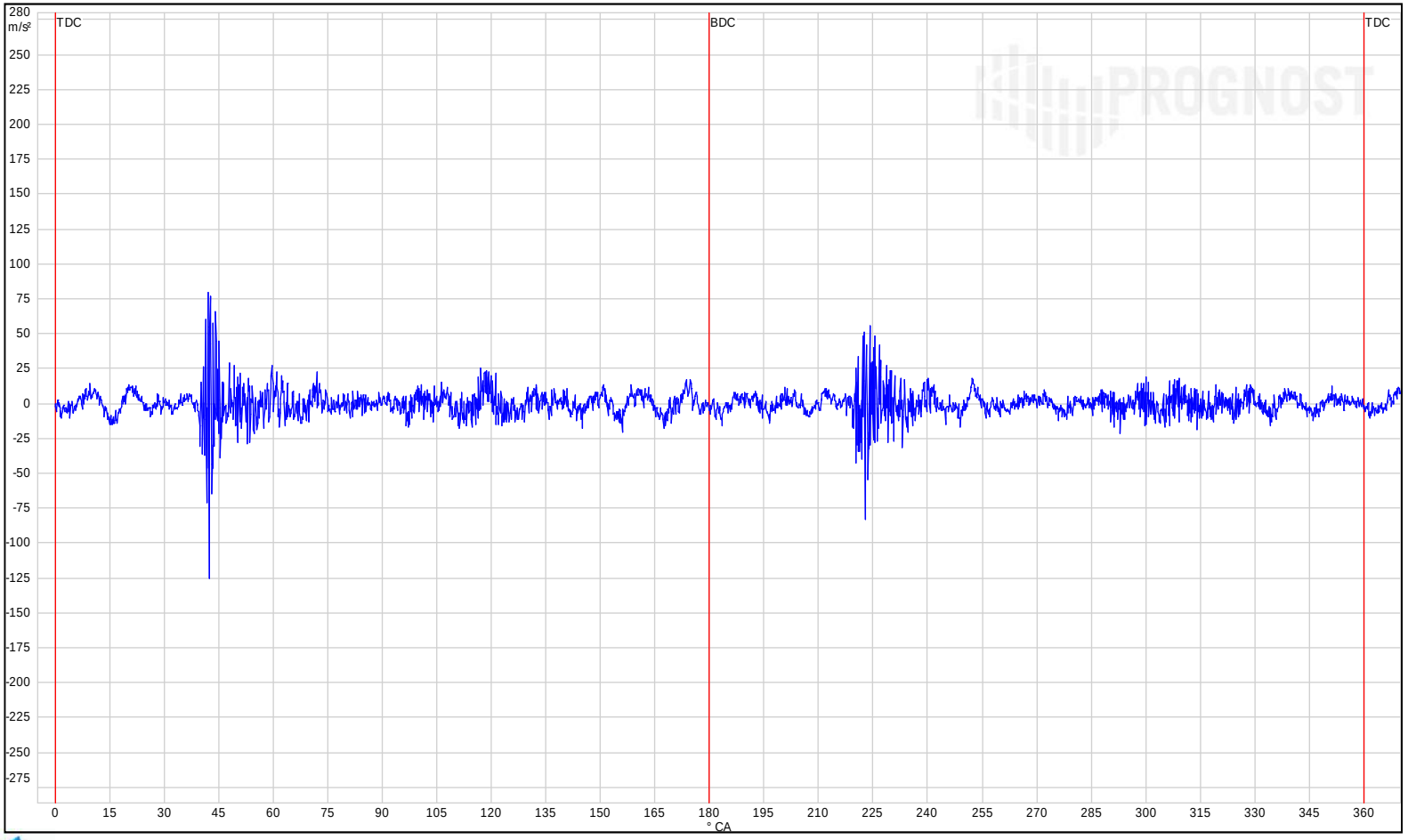
- mechanical damages
- clearance in the reciprocating drive train
- loose crosshead-piston rod connection

…can be detected in early stages

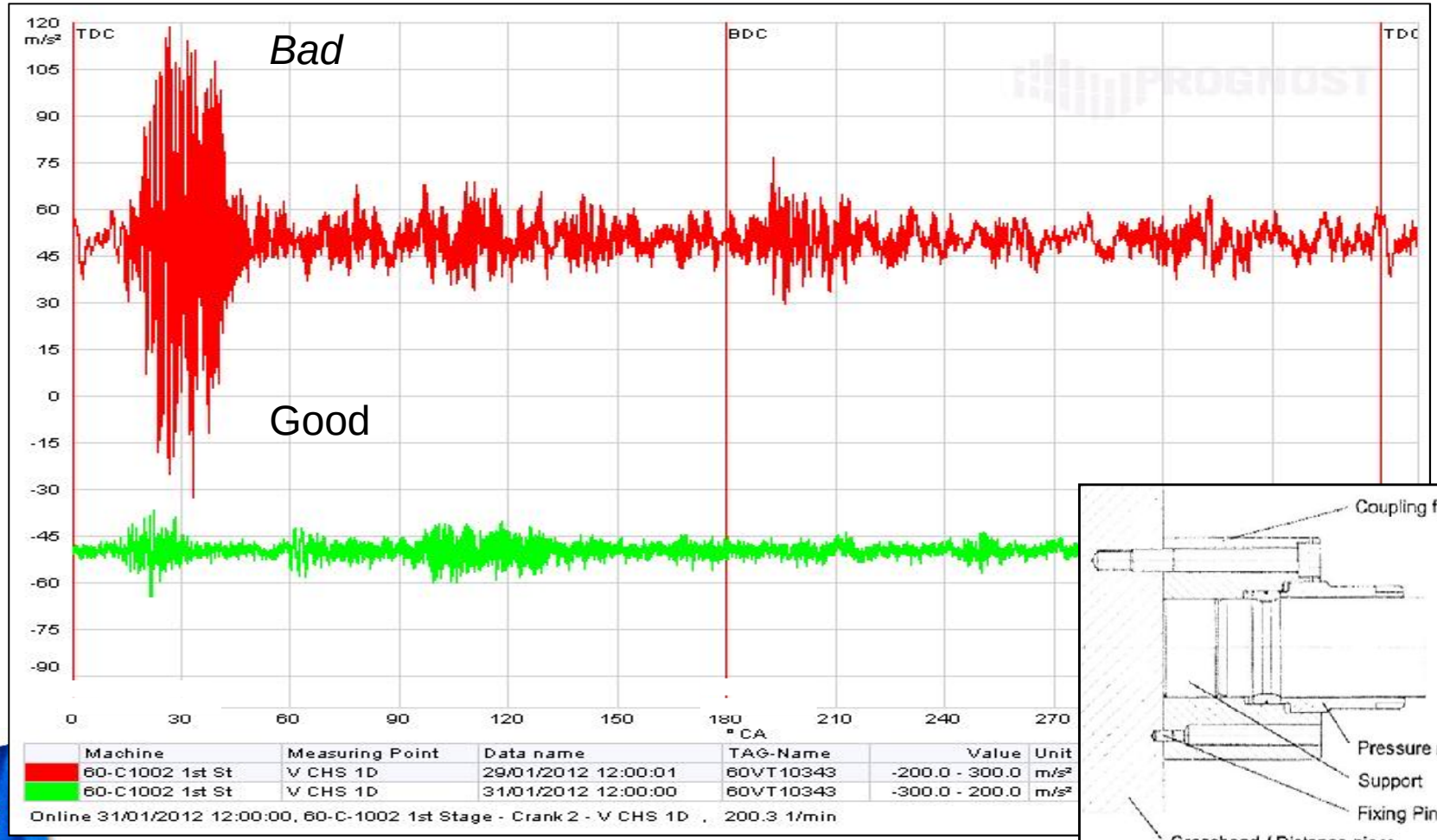




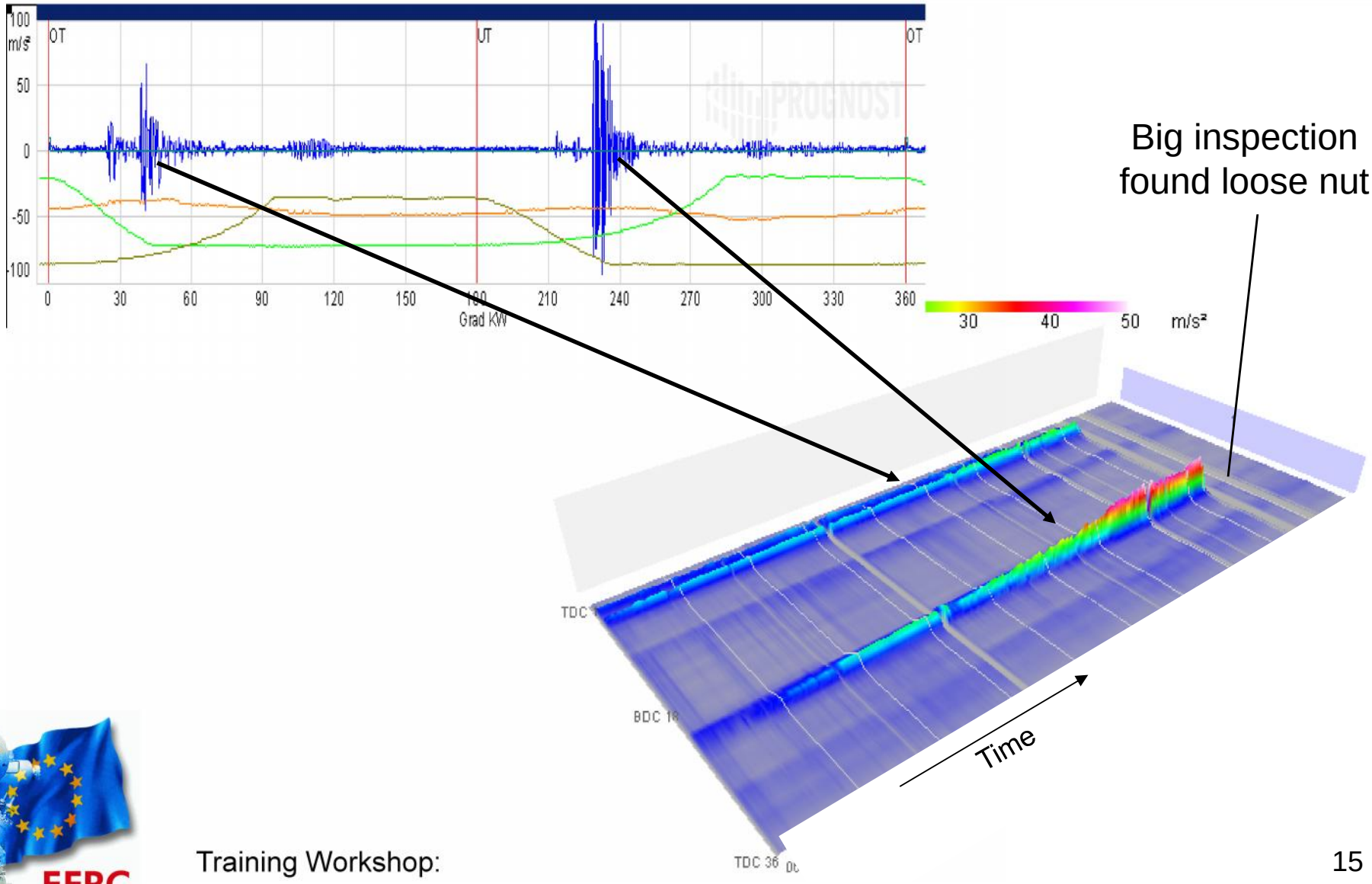
Crosshead vibration



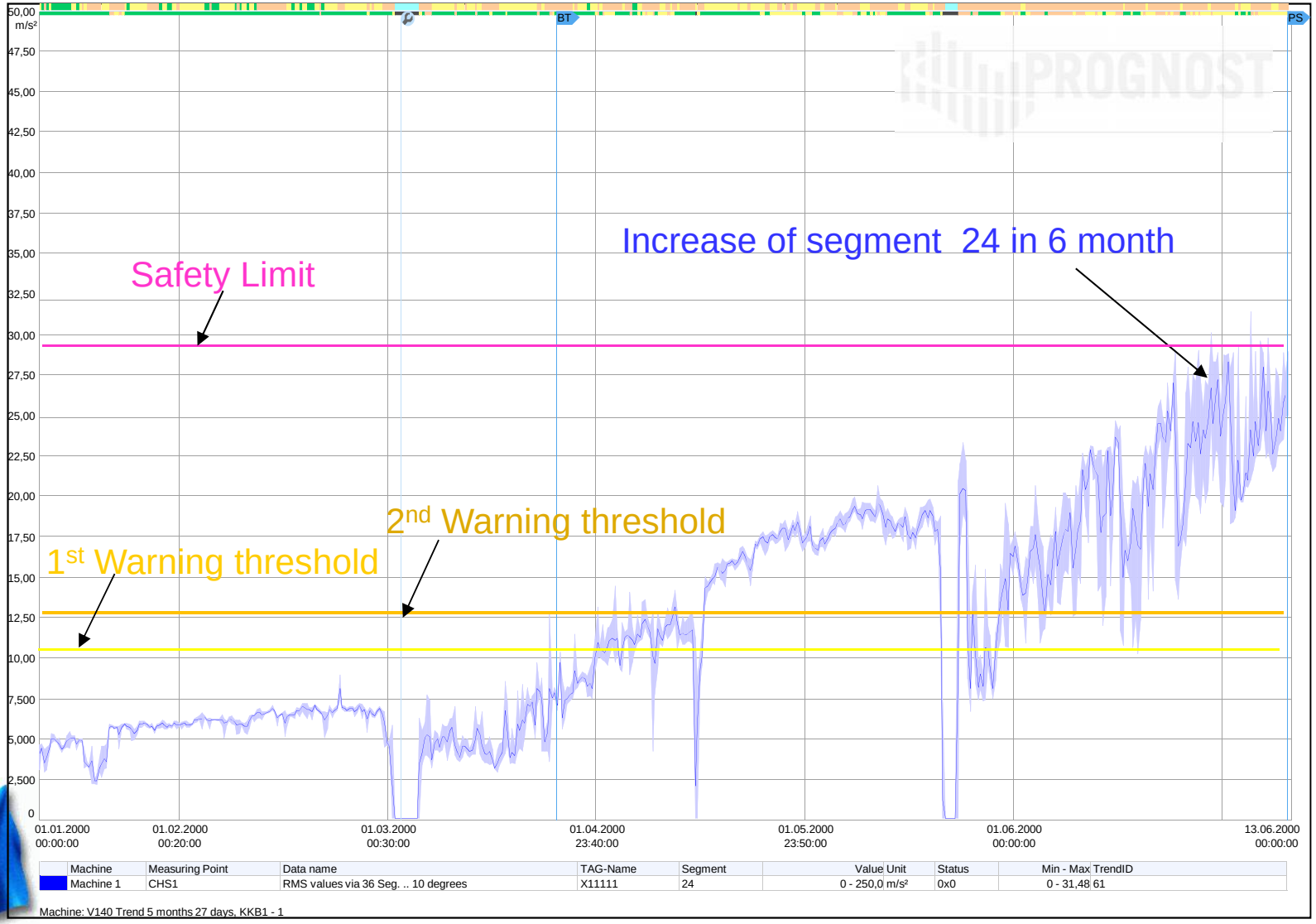
Case 1: Loose elastic rod coupling (Hyper)



Case 2: Loose piston nut



Case 2: Loose piston nut

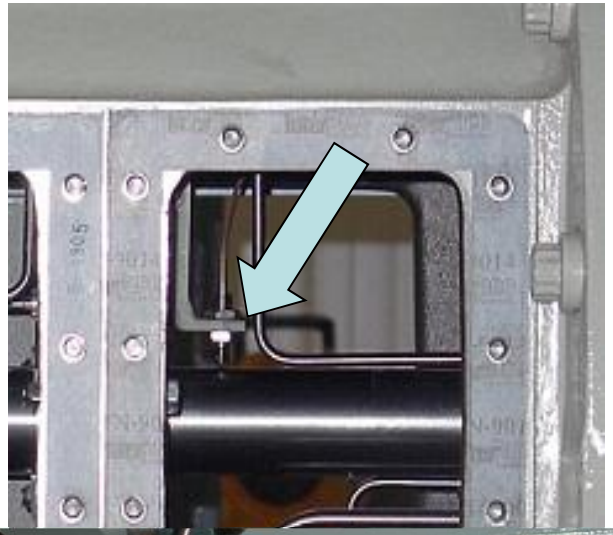


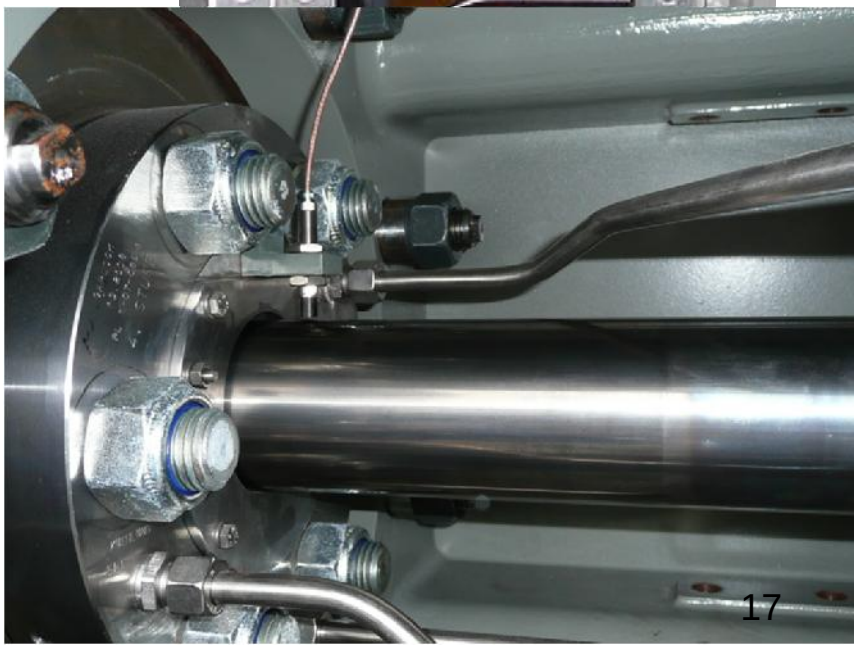
Machine	Measuring Point	Data name	TAG-Name	Segment	Value	Unit	Status	Min - Max	TrendID
Machine 1	CHS1	RMS values via 36 Seg. .. 10 degrees	X11111	24	0 - 250,0	m/s²	0x0	0 - 31,48	61

Piston rod position

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

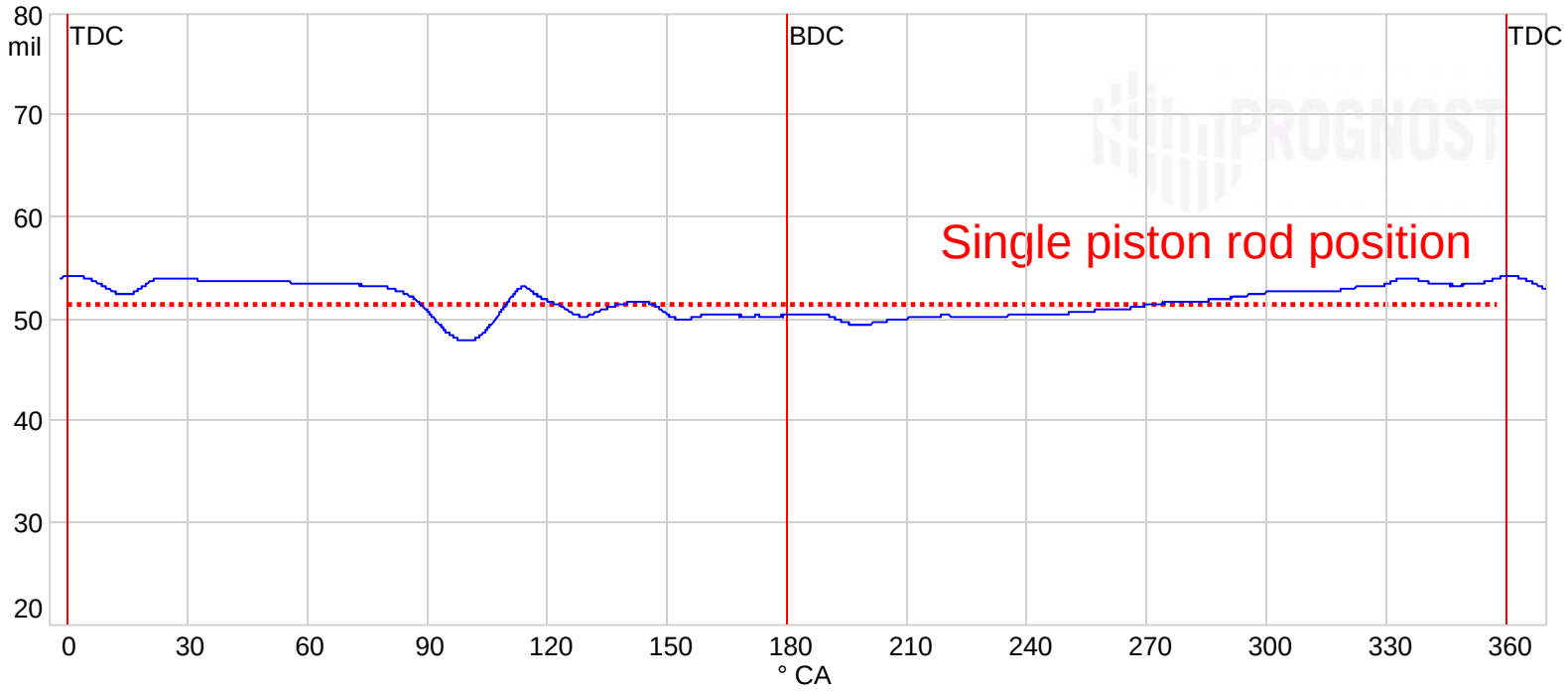
- **Debris and contaminants** (e.g. piston ring or valve fragments)
- **Oil or condensate** accumulation in the compression chamber
- Condition of the piston rod (incipient **fracture**)
- **Rider ring wear** monitoring



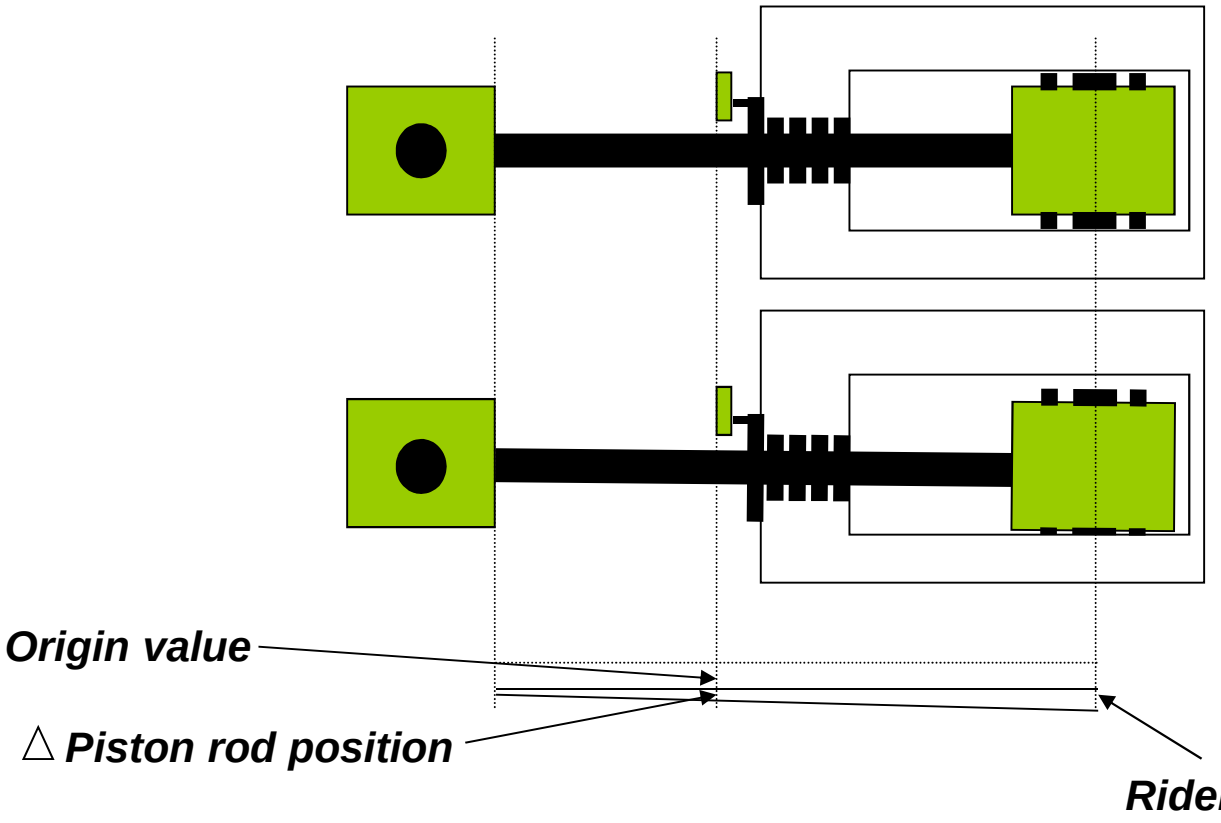


Piston rod position

- Single piston rod position = Average per revolution



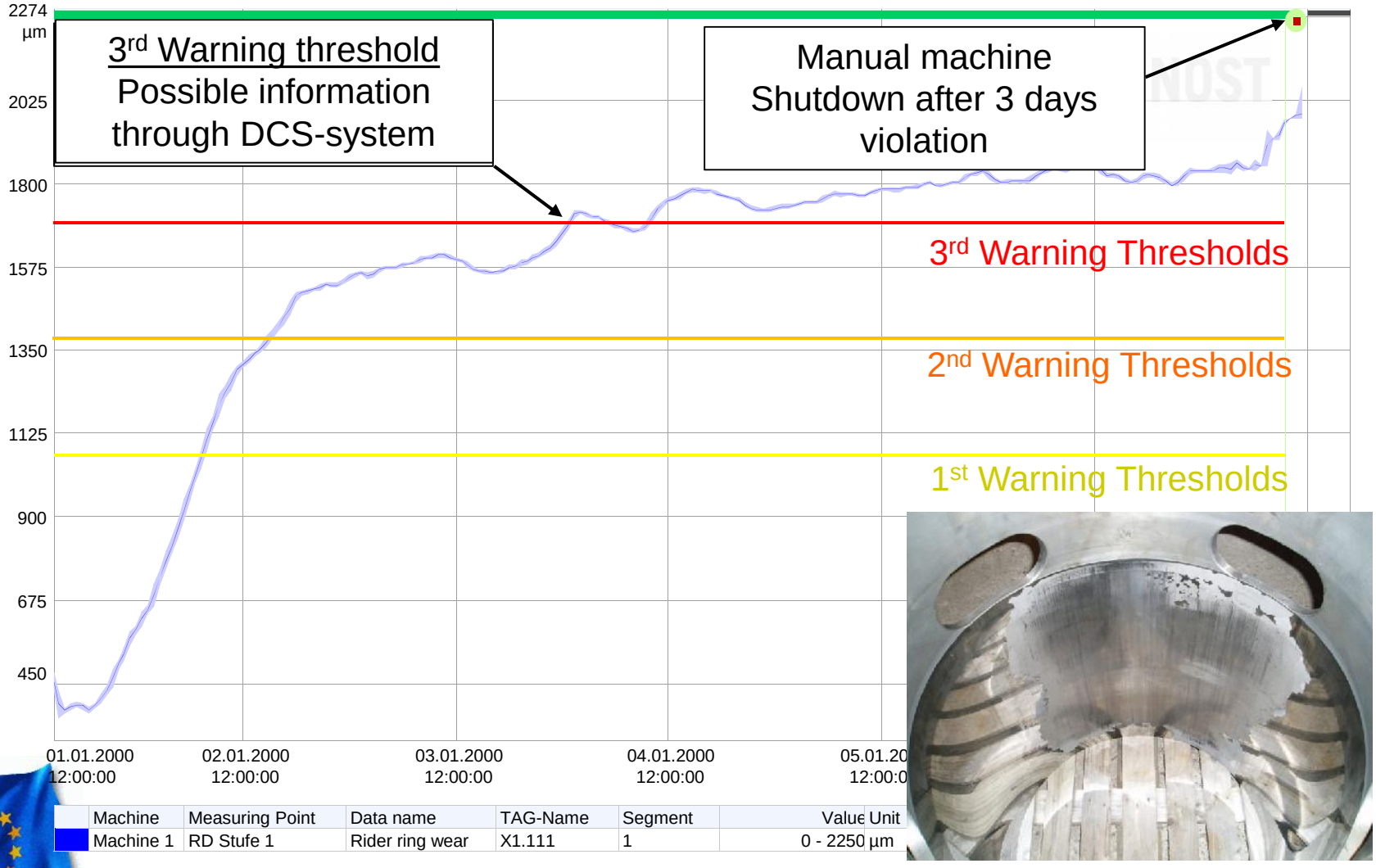
Rider ring wear



Animation

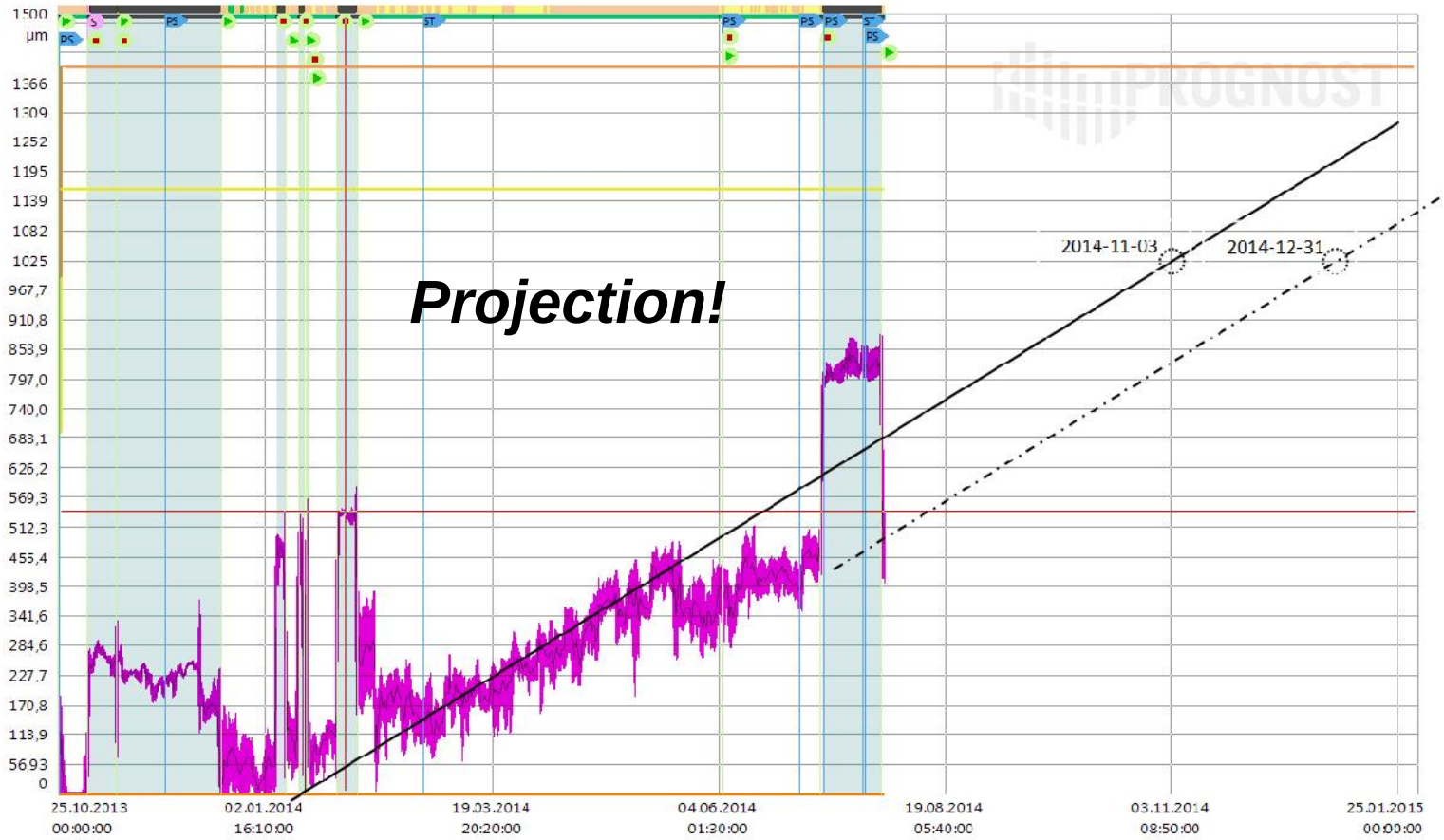
- The actual wear will be compared to a reference point of time
- The analysis is based on rod, piston and cylinder dimensions and the applied intercept theorem
- After each replacement of the piston rider rings a new reference point of time is necessary (zero adjustment)

Case 3: 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 4: Rider ring wear



	Machine	Measuring Point	Data name	TAG-Name	Segment	Value	Unit	Status
	GV-201B	Kolbe4/ 2Stf VS	Rider ring wear	XIA 3988	1	541,9	µm	Rotation speed under minimum value

Machine: GV-201B Trend 457 days 1 hour, K-Stange: Einzelwert & Tragringverschleiß Cursor: 29.01.2014 13:15:01

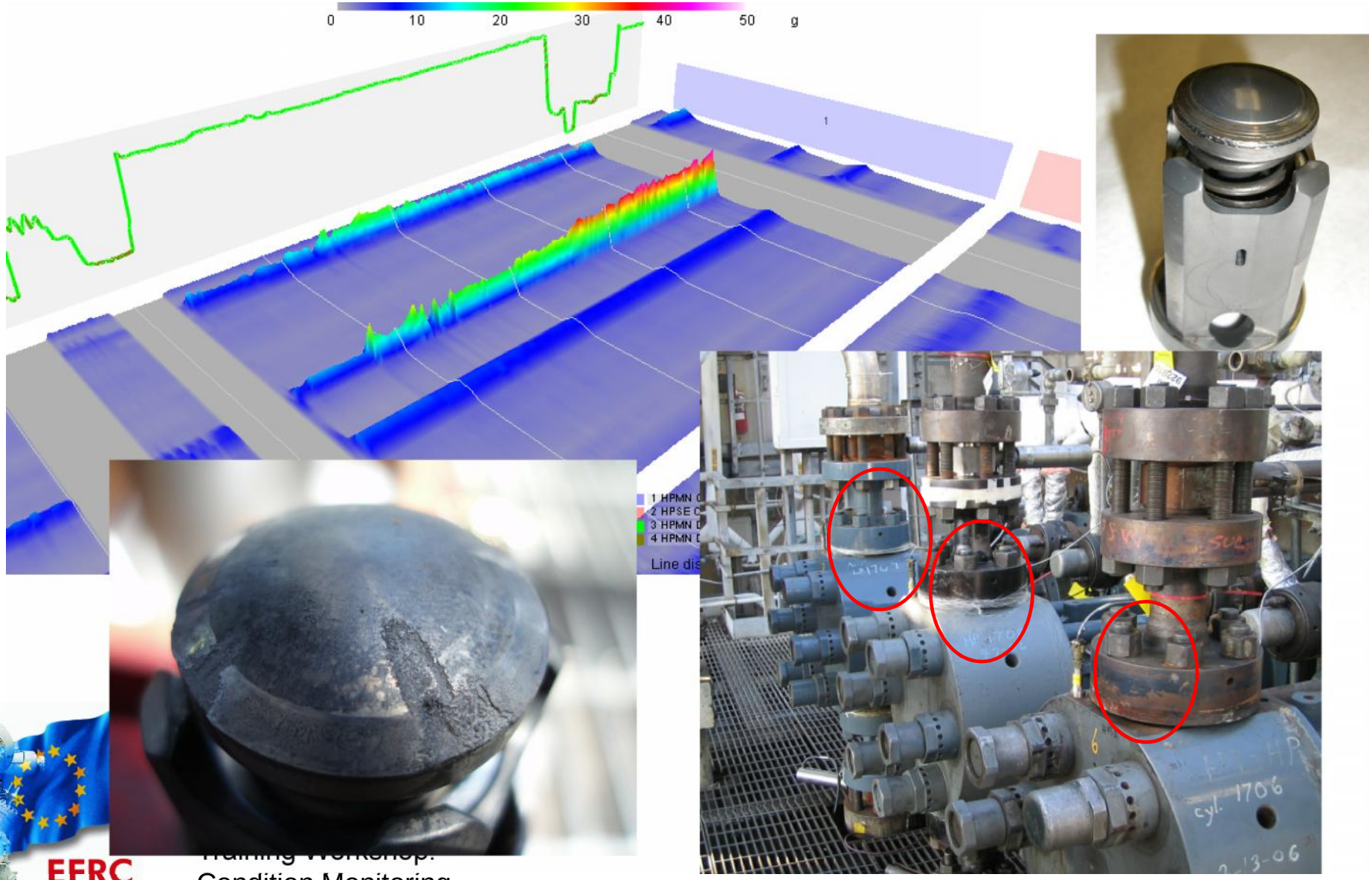
Cylinder vibration

With **acceleration sensors**…

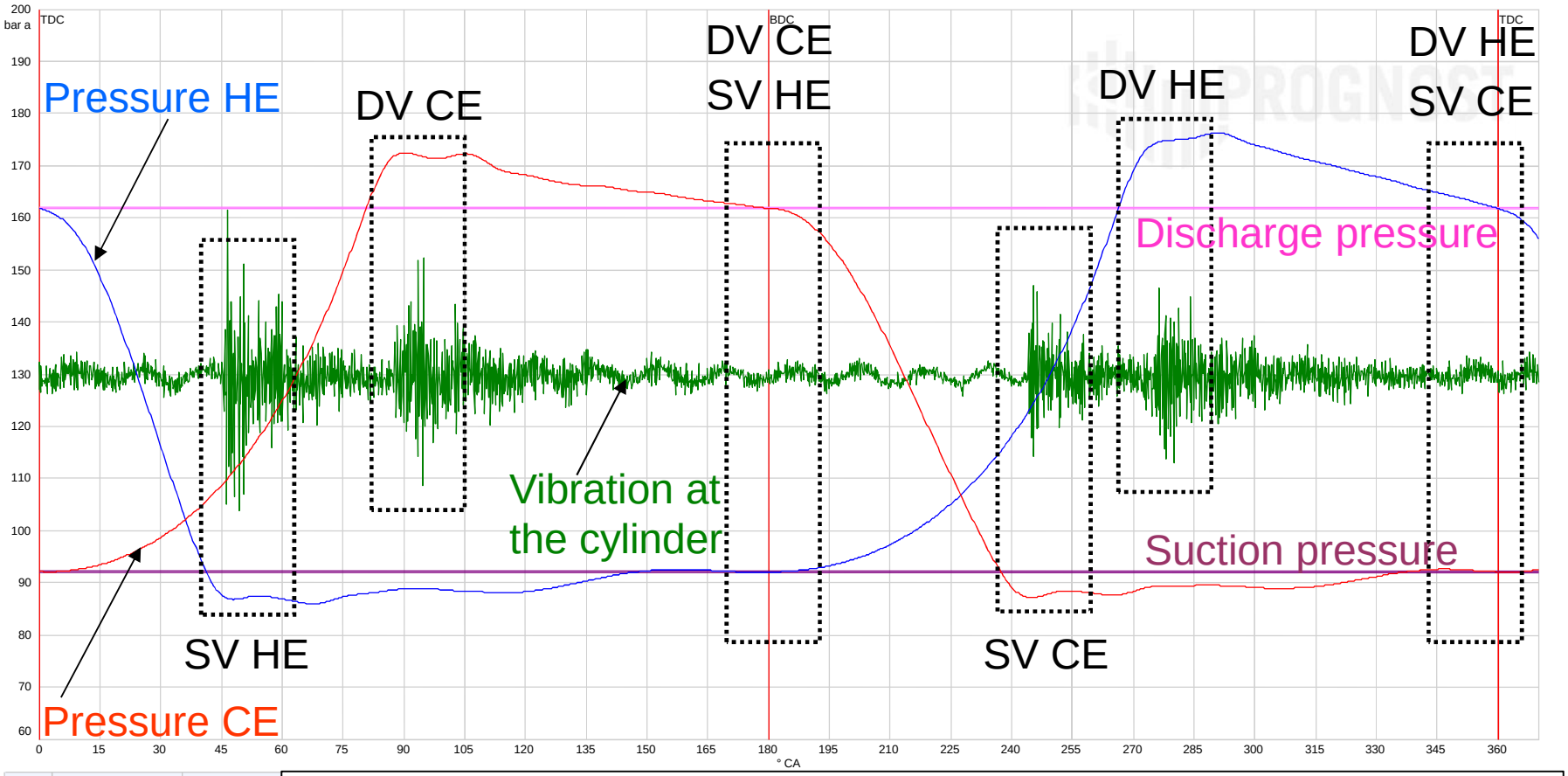
- valve impacts
- broken valve plate
- loose valve cage
- leakages

…can be detected

Case 5: Poppet valve failure (Hyper)



Cylinder vibration measurement



	Machine	Measuring Point
	Machine 1	V Cyl 1 St.1 ZYL
	Machine 1	P Cyl 1 St.1 HE
	Machine 1	P Cyl 1 St.1 CE
	Machine 1	P Cyl 1 St.1 CA
	Machine 1	P Cyl 1 St.1 CA

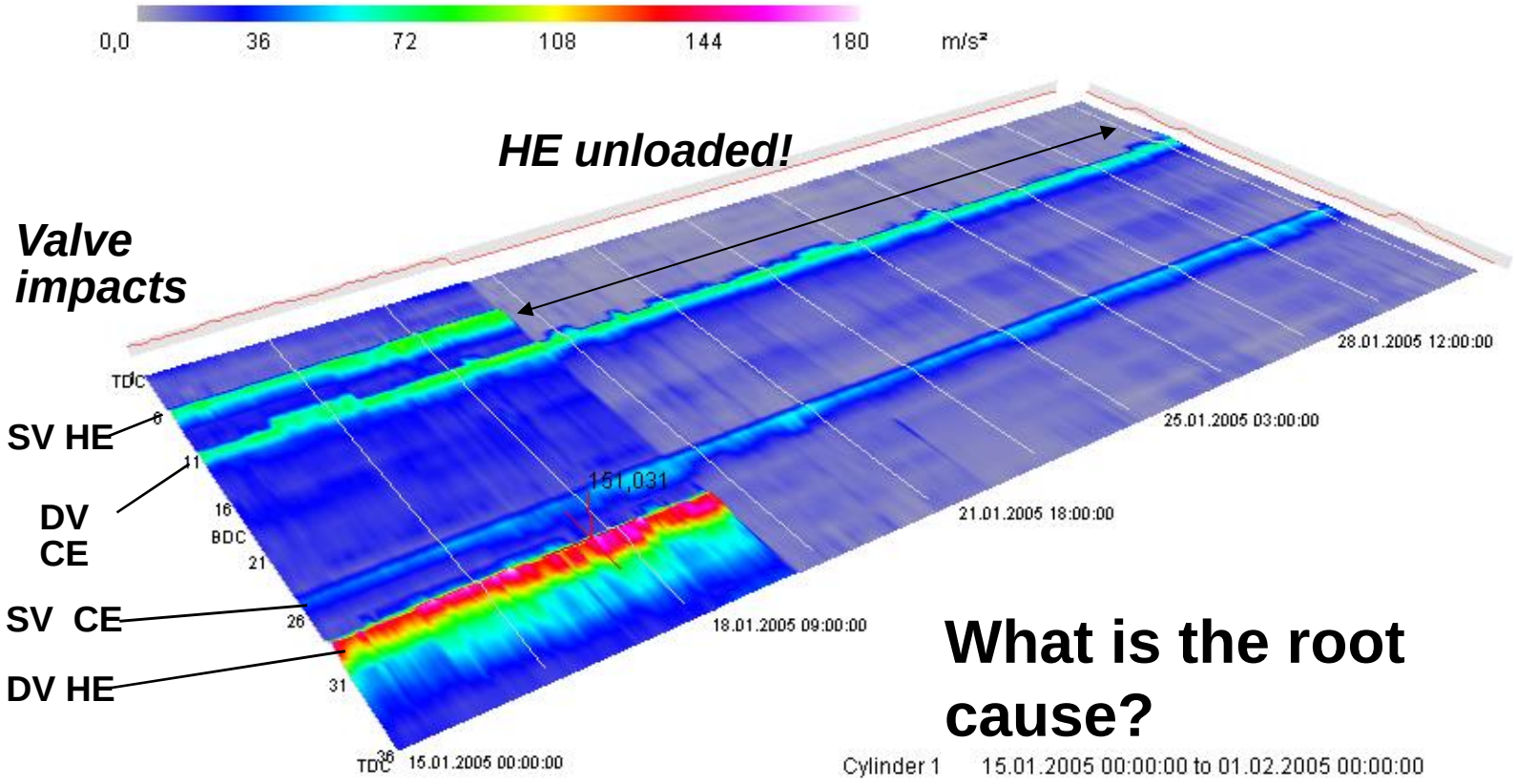
Online 01.01.2000 12:00:00, Machine 1 - Cyl.1 Stage

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

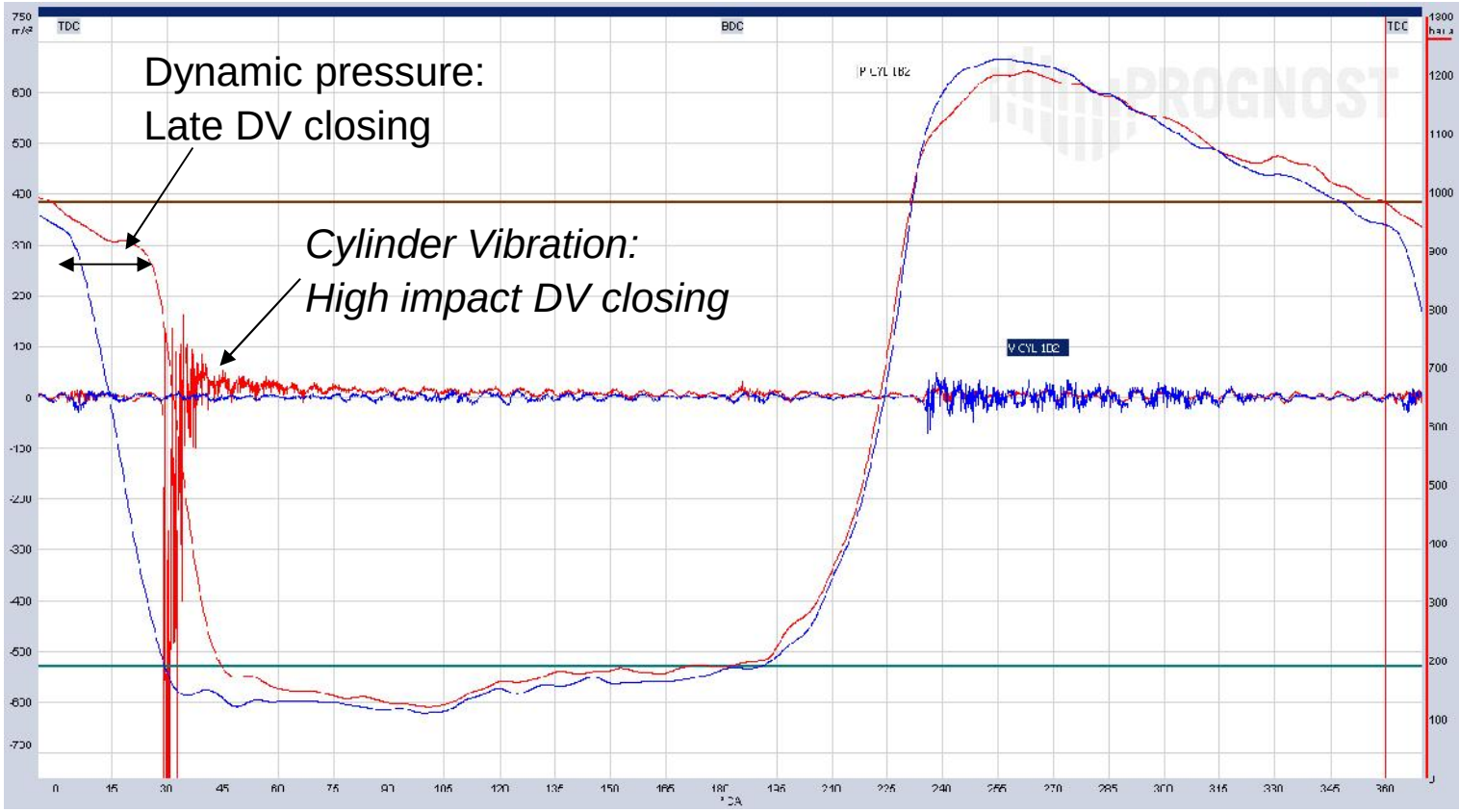
HE = head end CE = crank end

DV= discharge valve; SV=suction valve

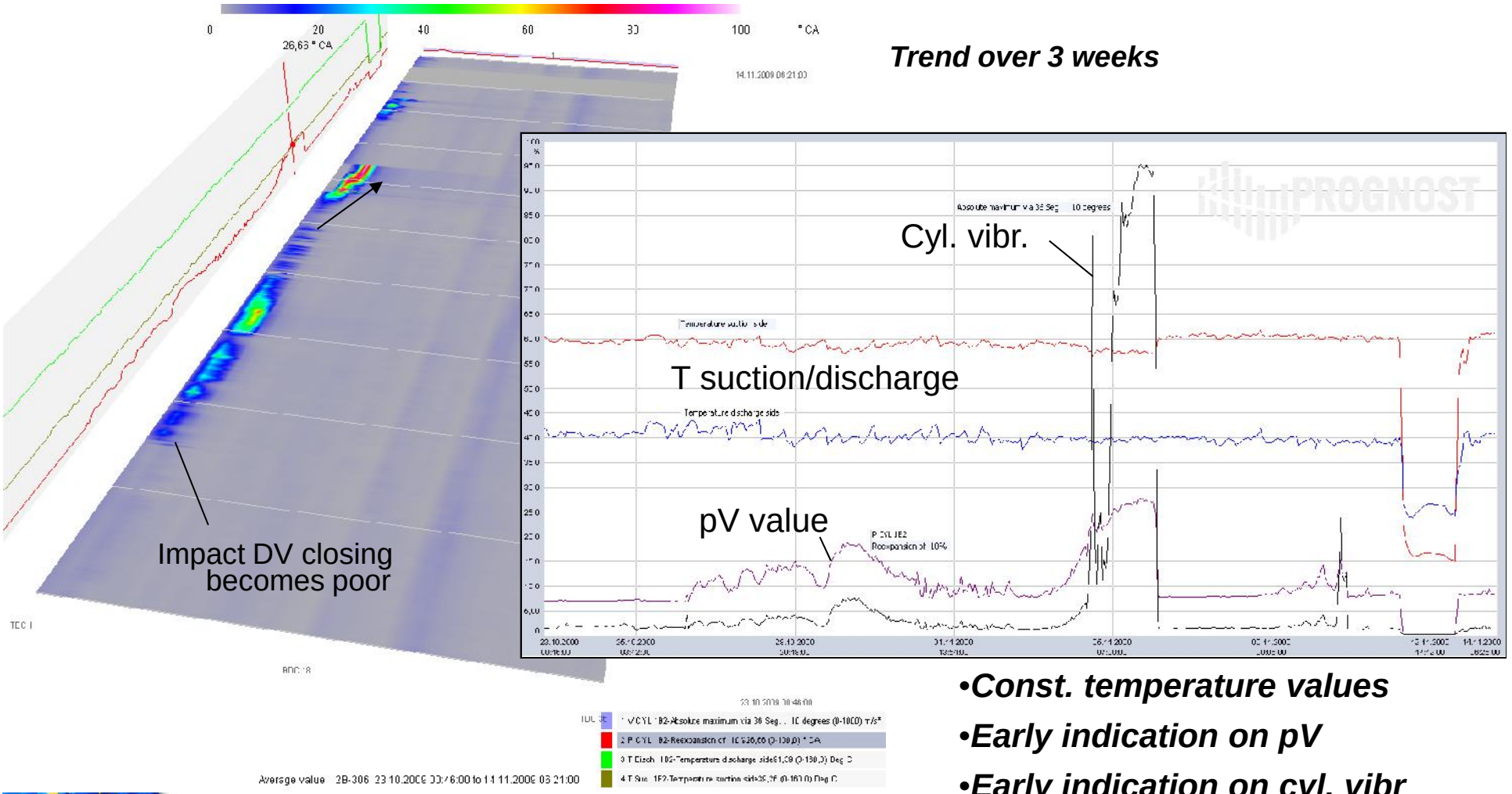
Case 6: Vibrations at a cylinder



Case 7: Sticking poppet



Case 7: Sticking poppet



Trend over 3 weeks

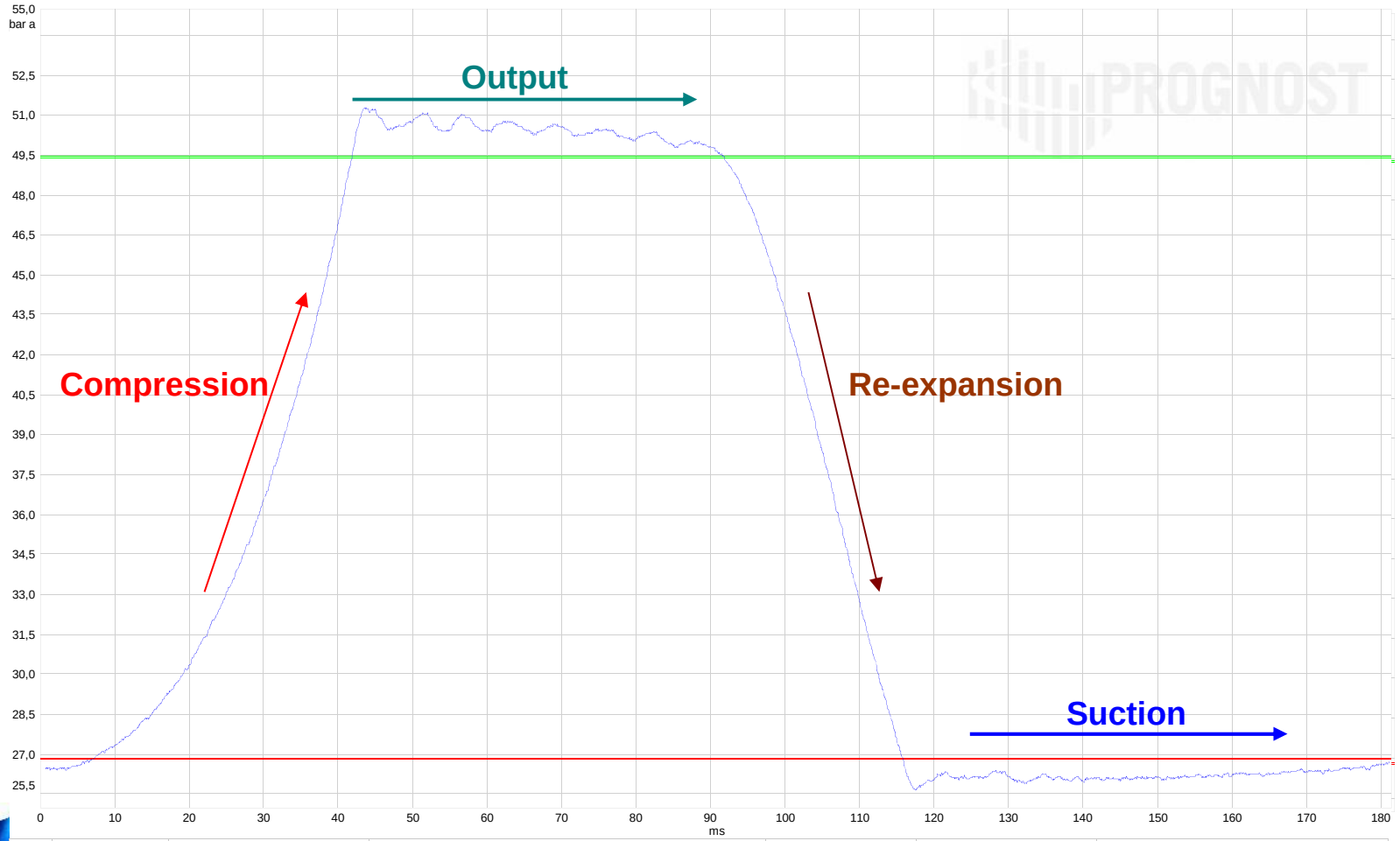
- ***Const. temperature values***
- ***Early indication on pV***
- ***Early indication on cyl. vibr***

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
- Monitoring of the control devices:
  - Suction valve unloaders
  - Clearance pocket unloaders

Pressure cycle - pt diagram

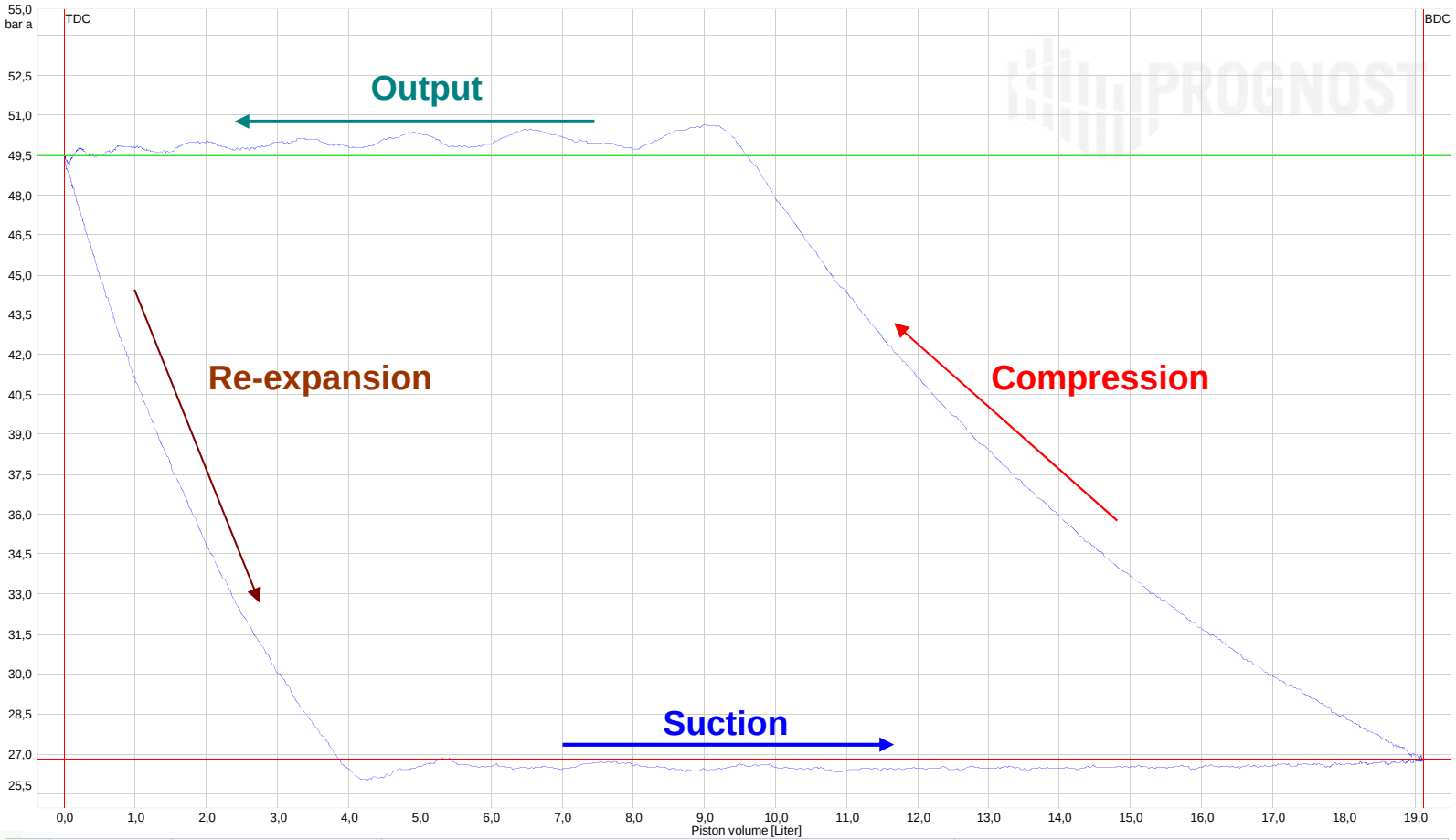


	Machine	Measuring Point	Data name	TAG-Name	Value	Unit
	Machine 1	Cyl. 1, CE	Press. crank end	PR-1111	-87,85 - 109,0	bar a
	Machine 1	SP Cyl.1	Process Data Standard Analysis	PR-1111T	0 - 110,3	bar a
	Machine 1	DP Cyl.1	Process Data Standard Analysis	PR-1111T	0 - 110,3	bar a
	Machine 1	Cyl. 1, CE	Break 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

bH

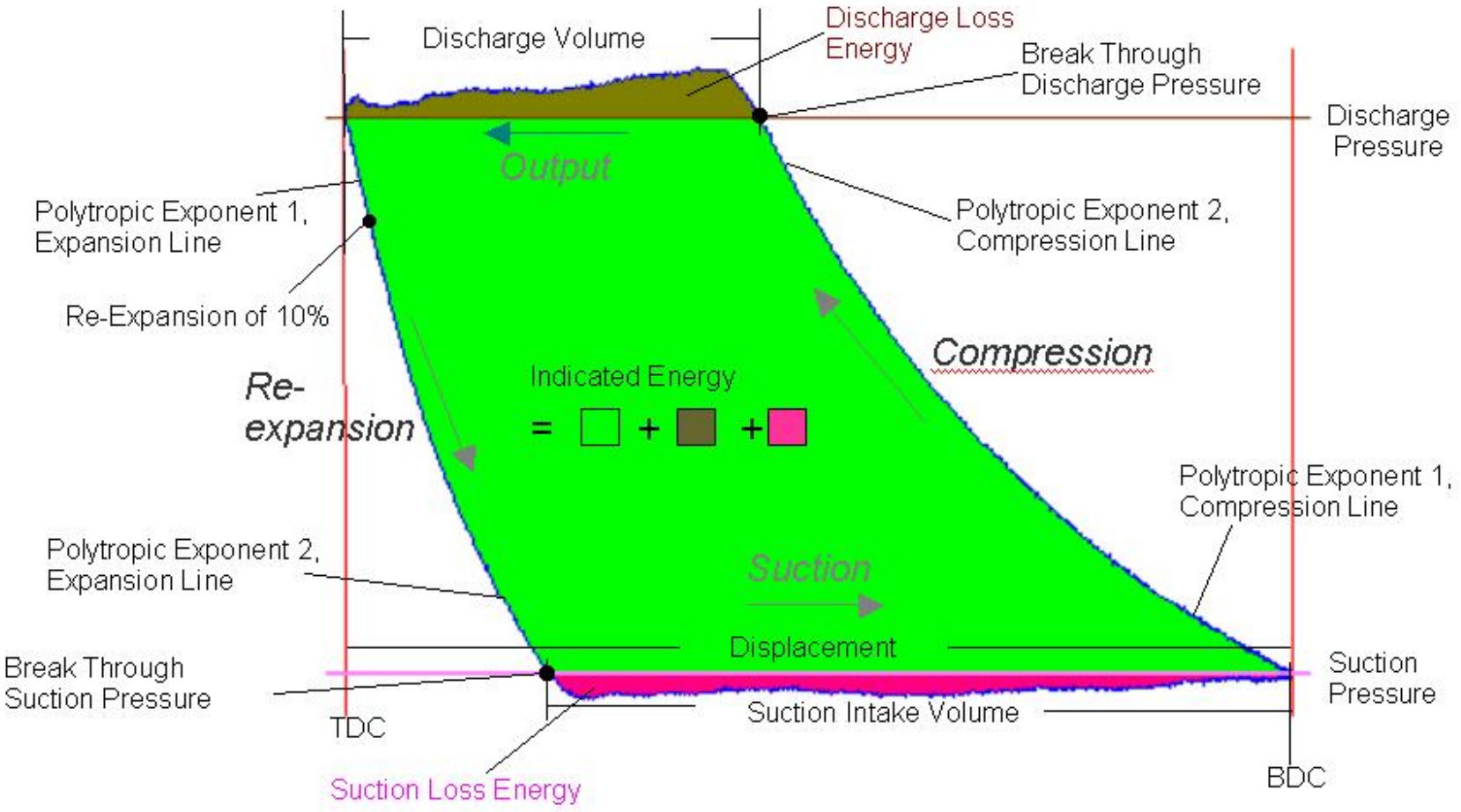
Pressure cycle - pV diagram



	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

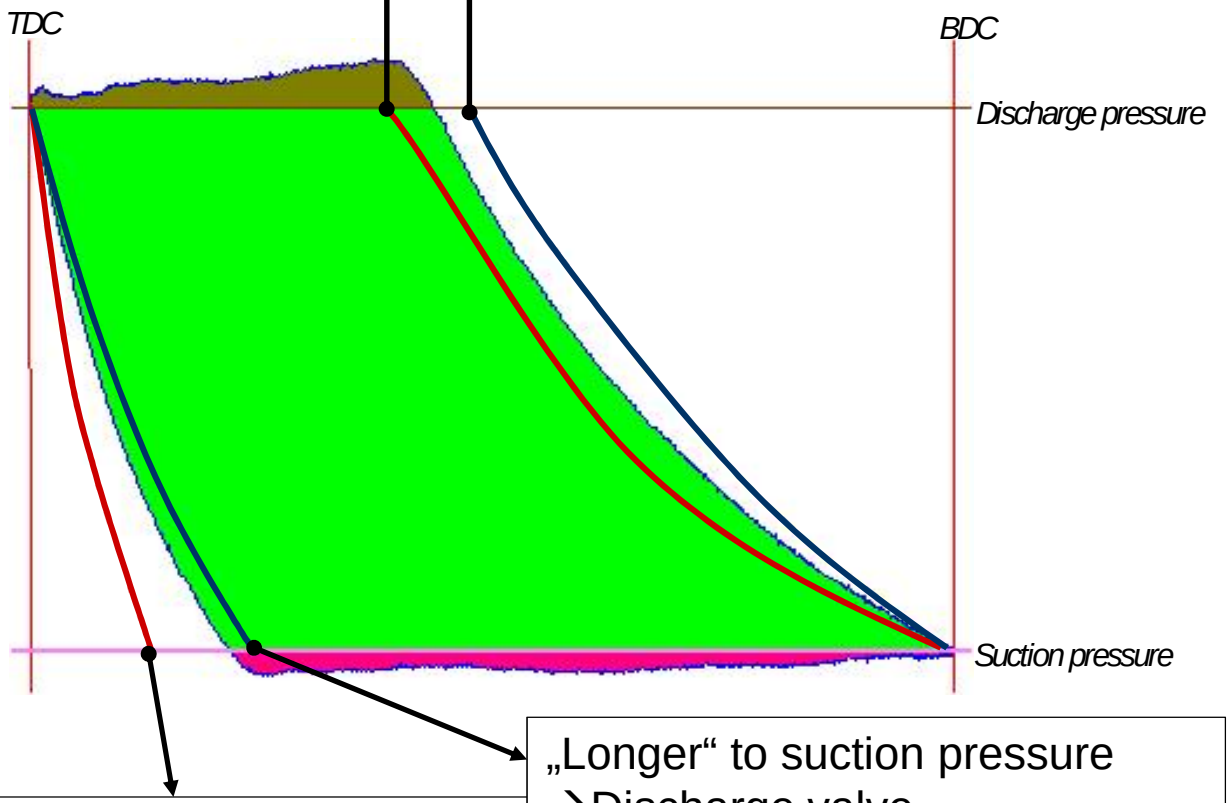
pV characteristic values



Exercise: Detection of leakages

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

„Shorter“ to discharge pressure
→ Discharge valves

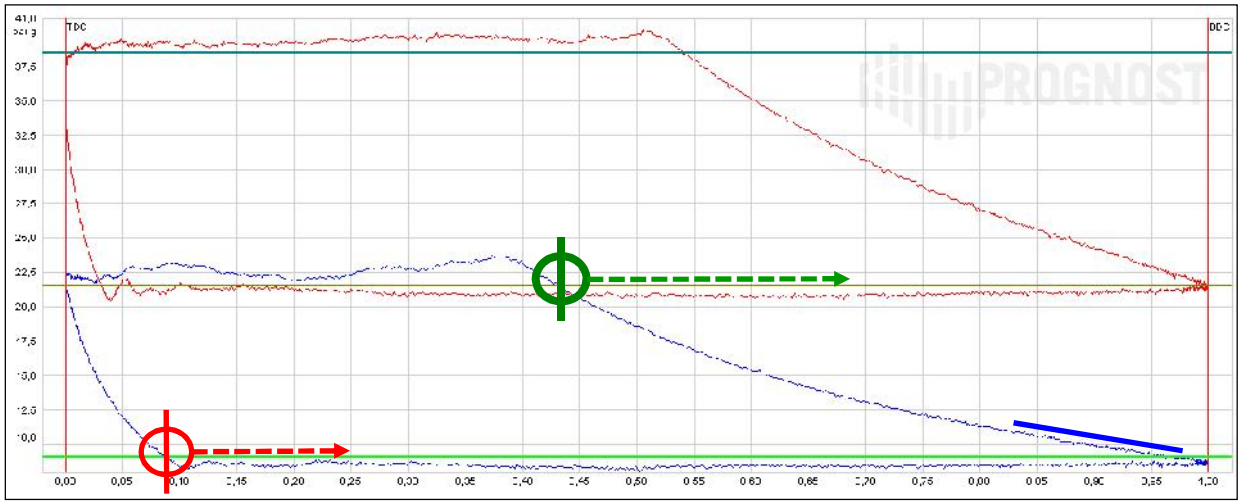


„Longer“ to suction pressure
→Discharge valve

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

Case 8: Valve failure

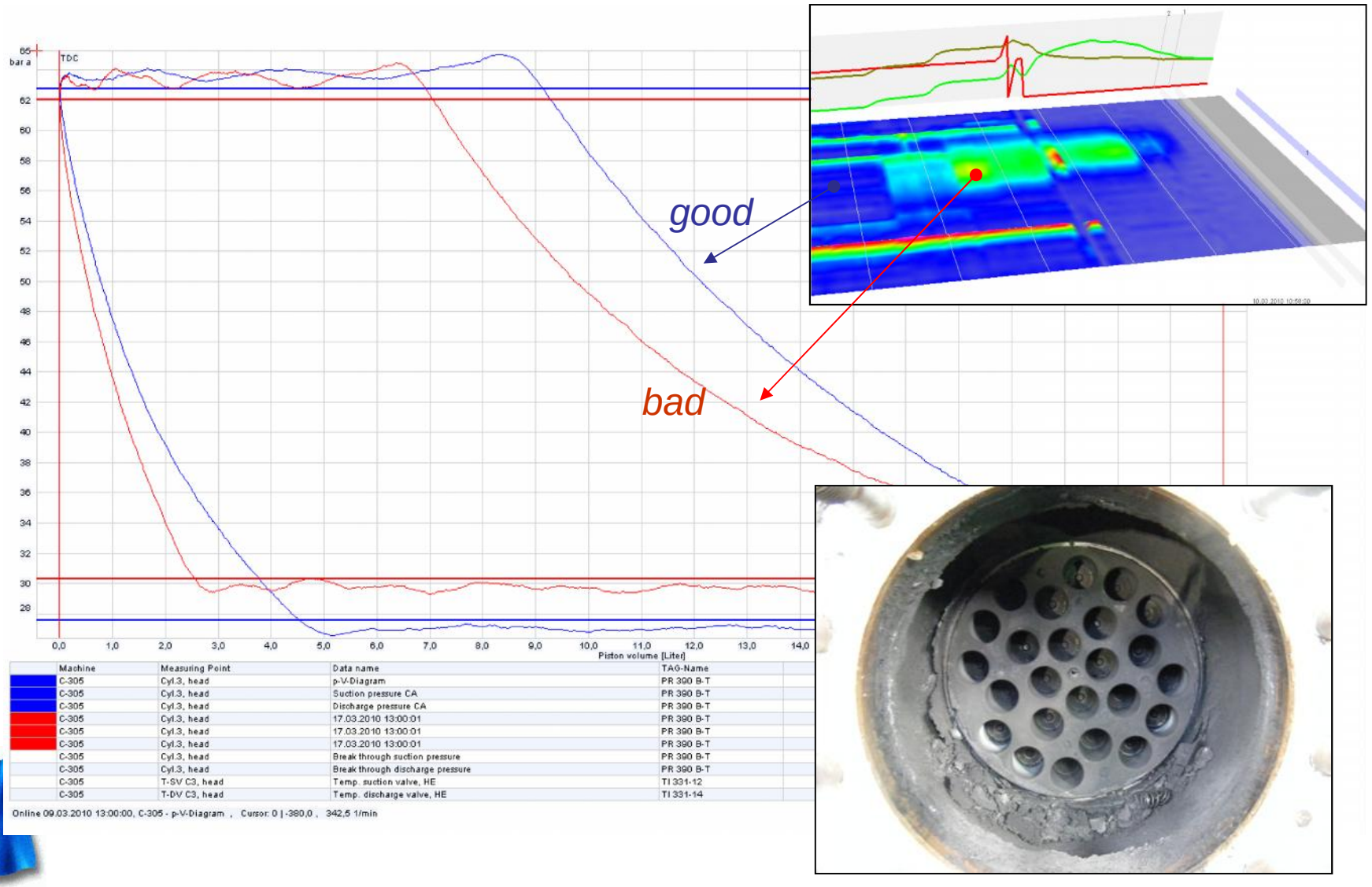
Good condition



Bad condition

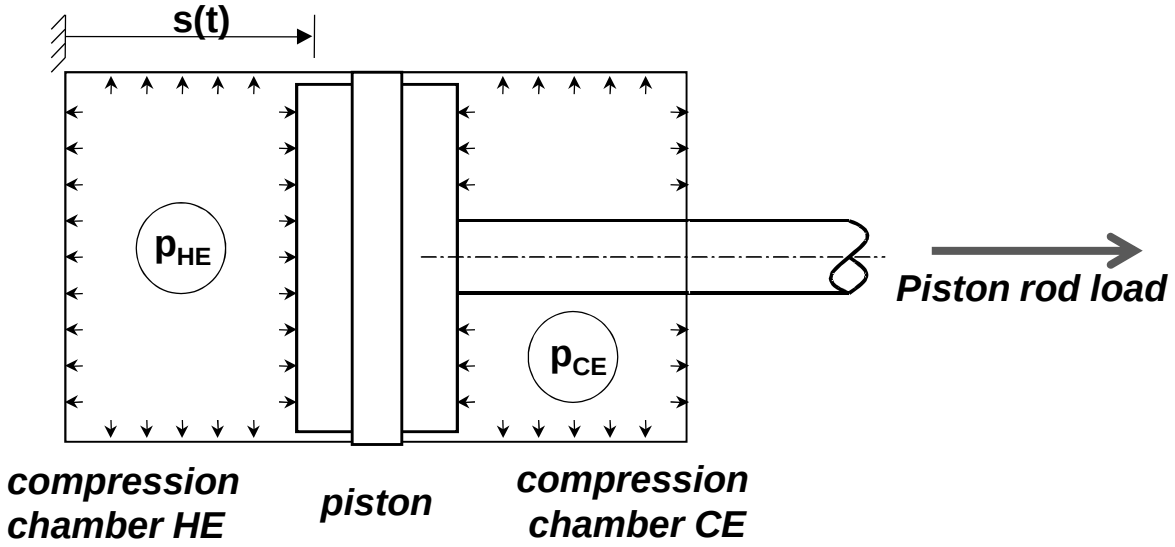
Line of compression steeper

Case 9: Bad suction valve



Piston rod load

- Calculation of piston rod load
  = ***Inertia*** force + **Gas** forces HE/CE

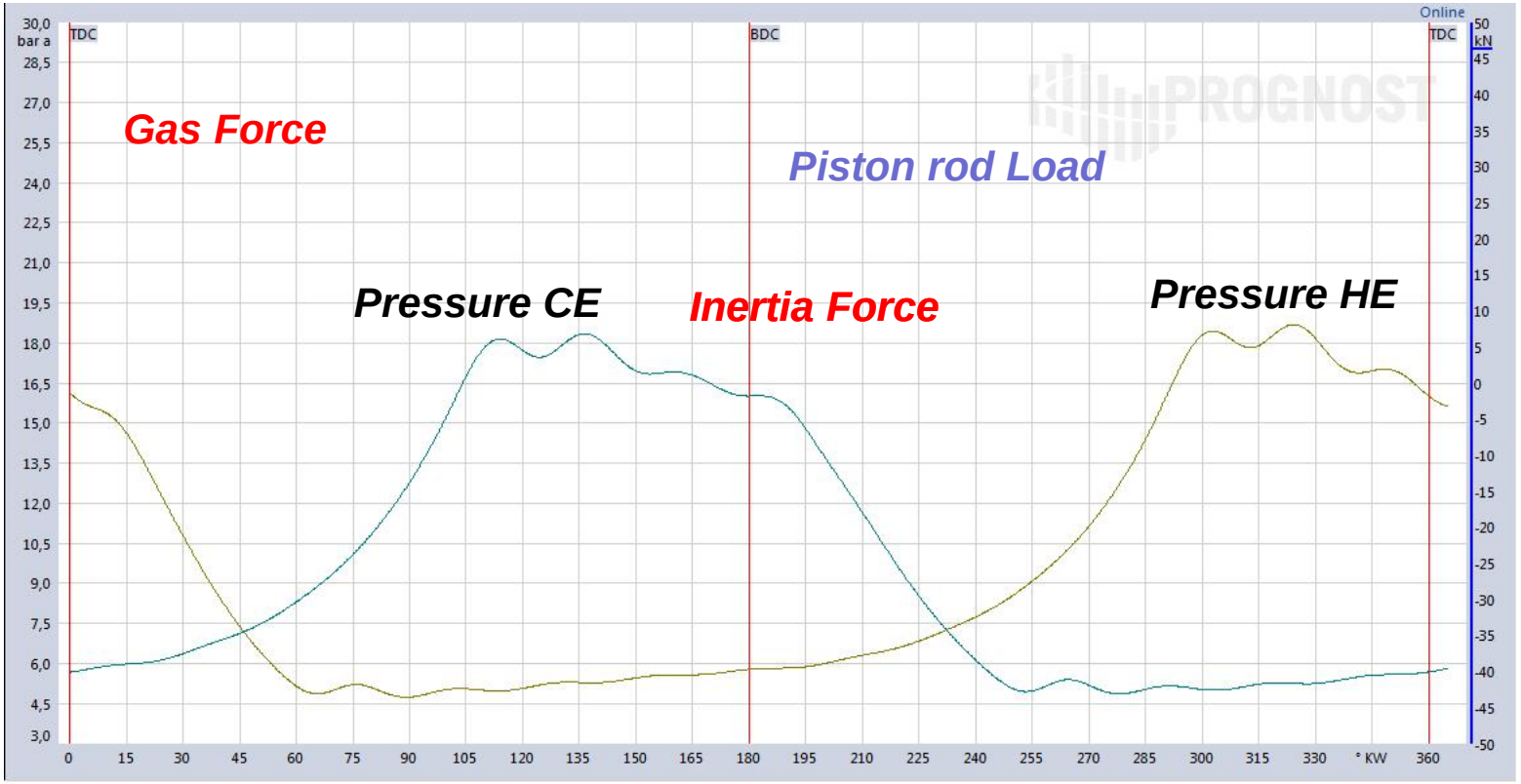


Inertia force - piston, rod and crosshead mass
- speed
- connecting rod ratio

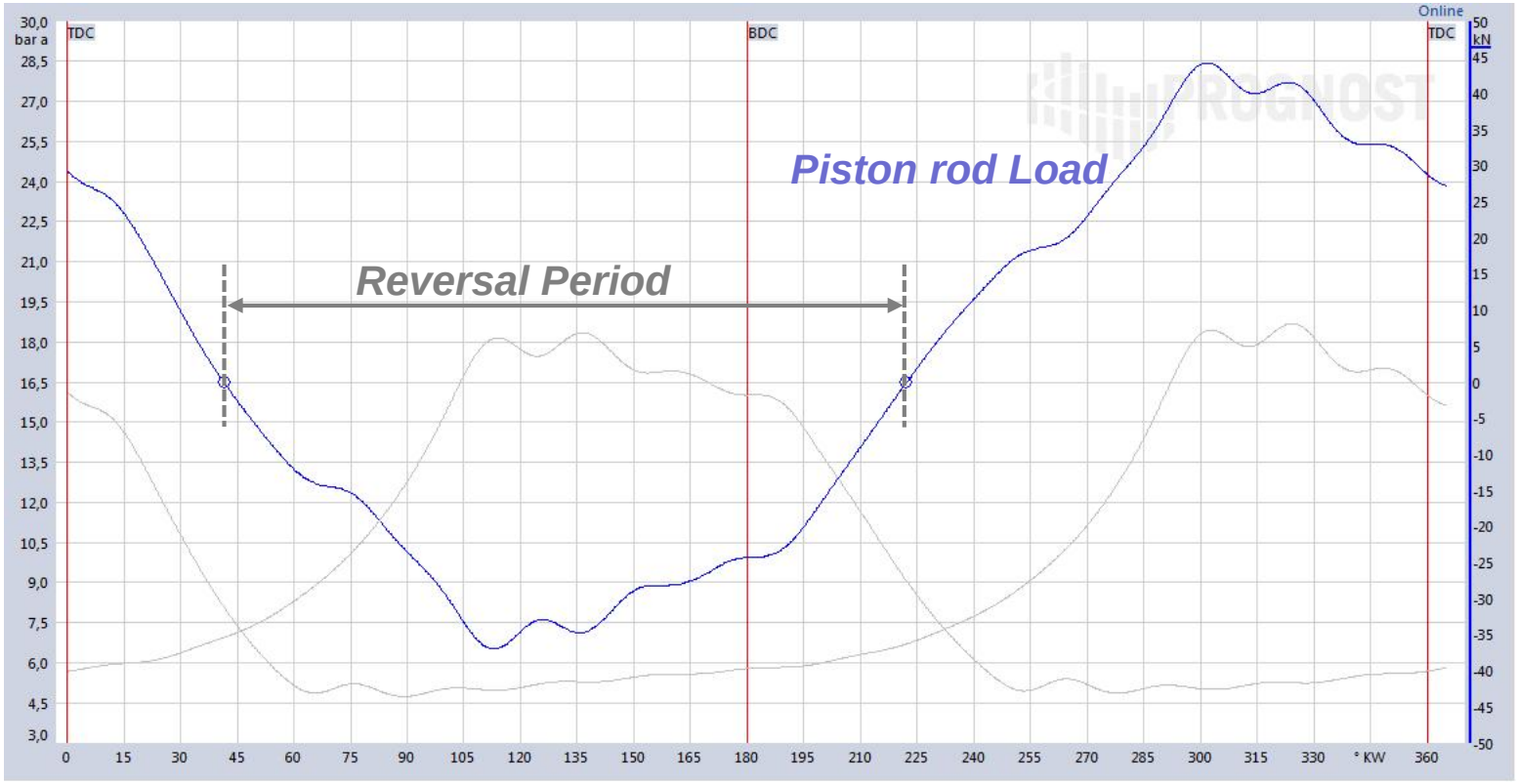
Gas force - dynamic pressure
- piston area

HE = head end
CE = crank end

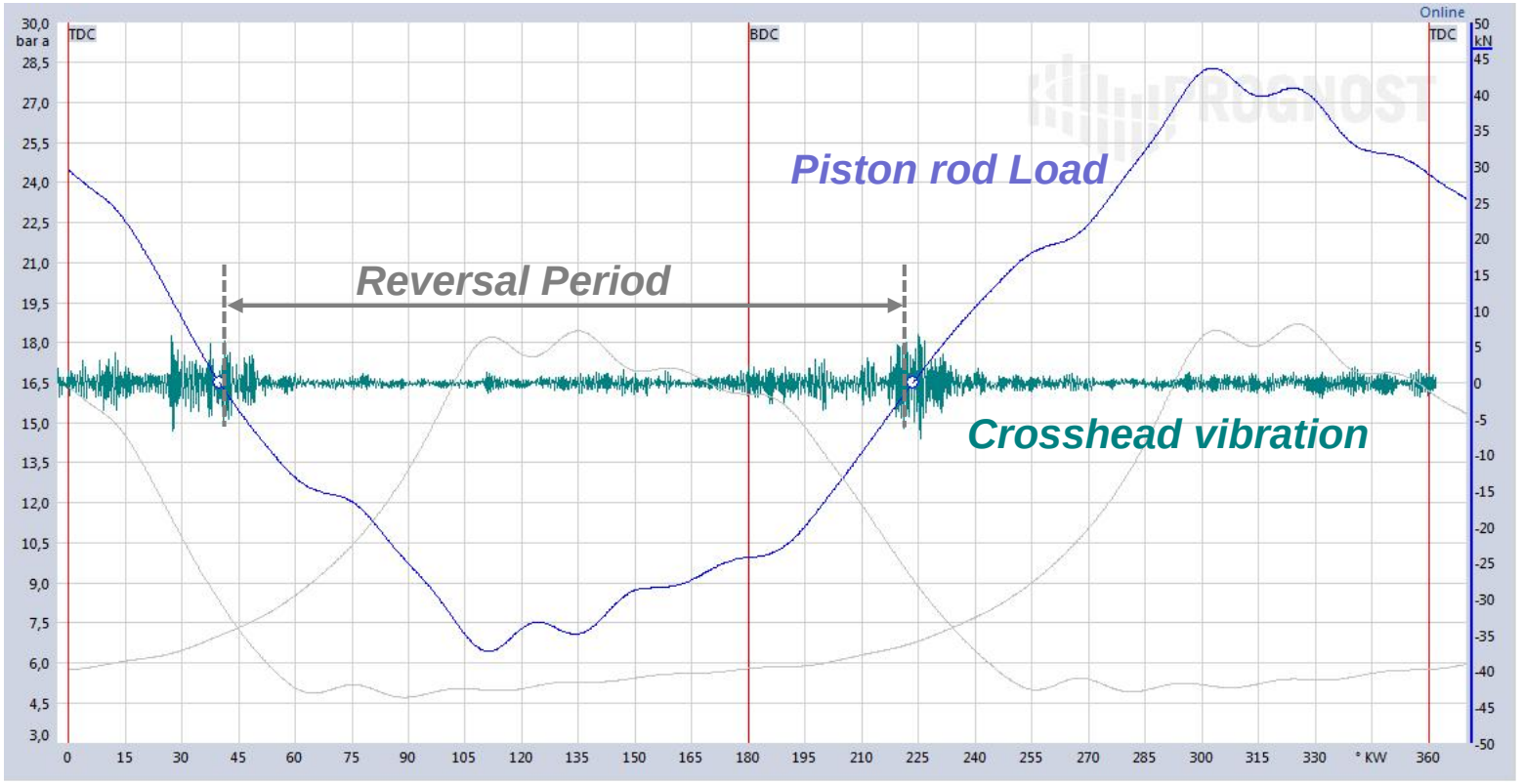
Piston rod load



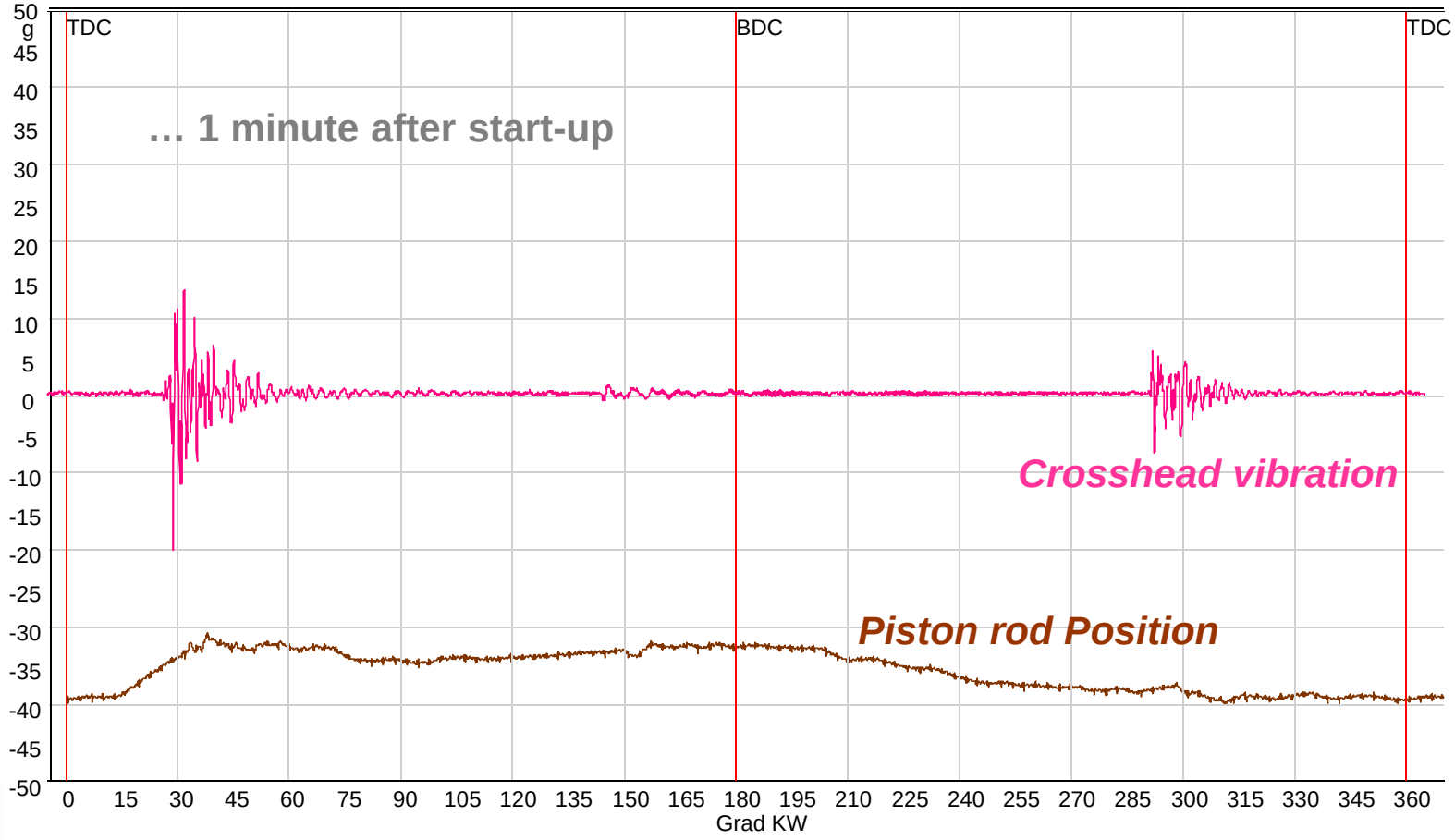
Piston rod load



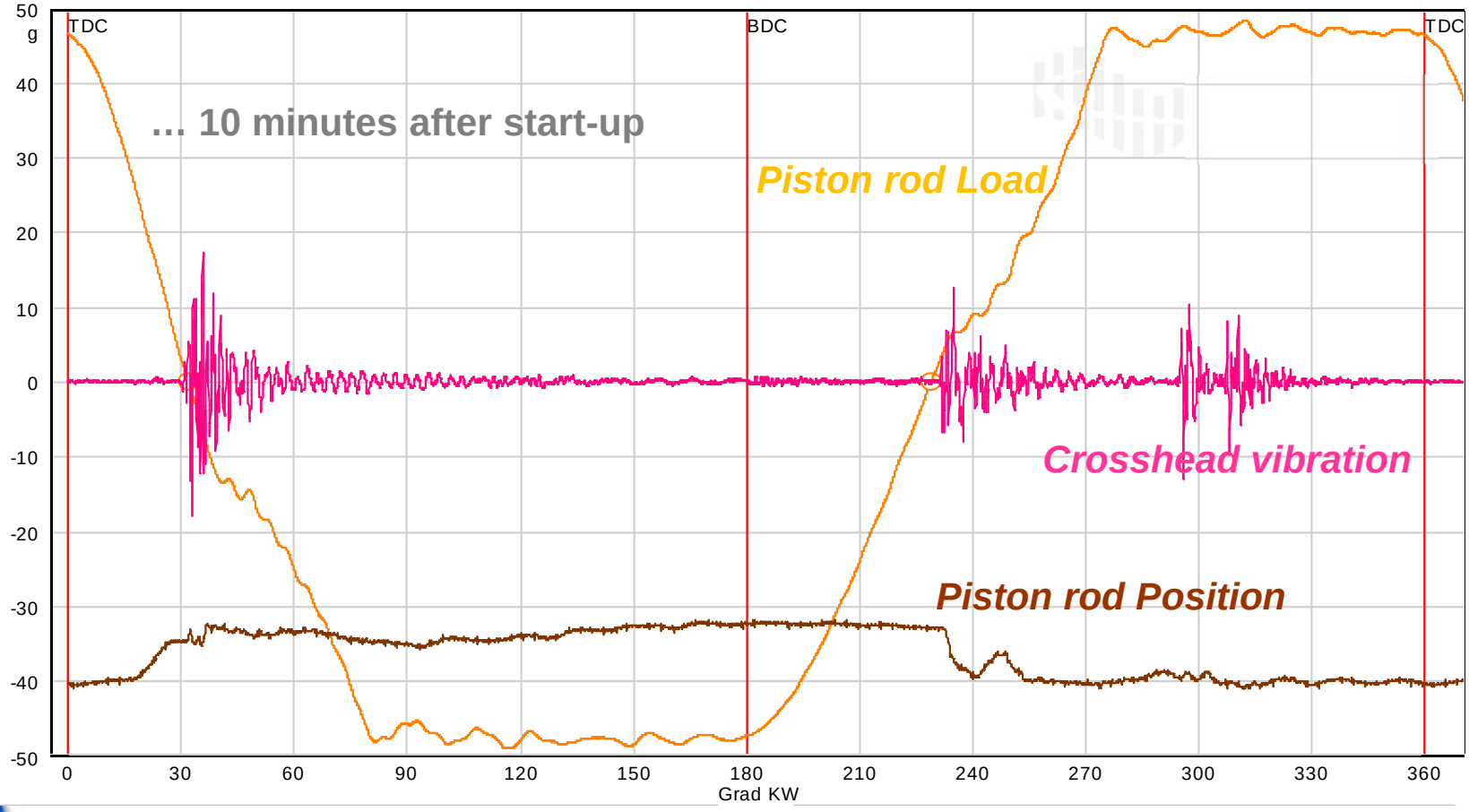
Piston rod load vs. Vibration



Case 10 : Loose connection during machine start-up

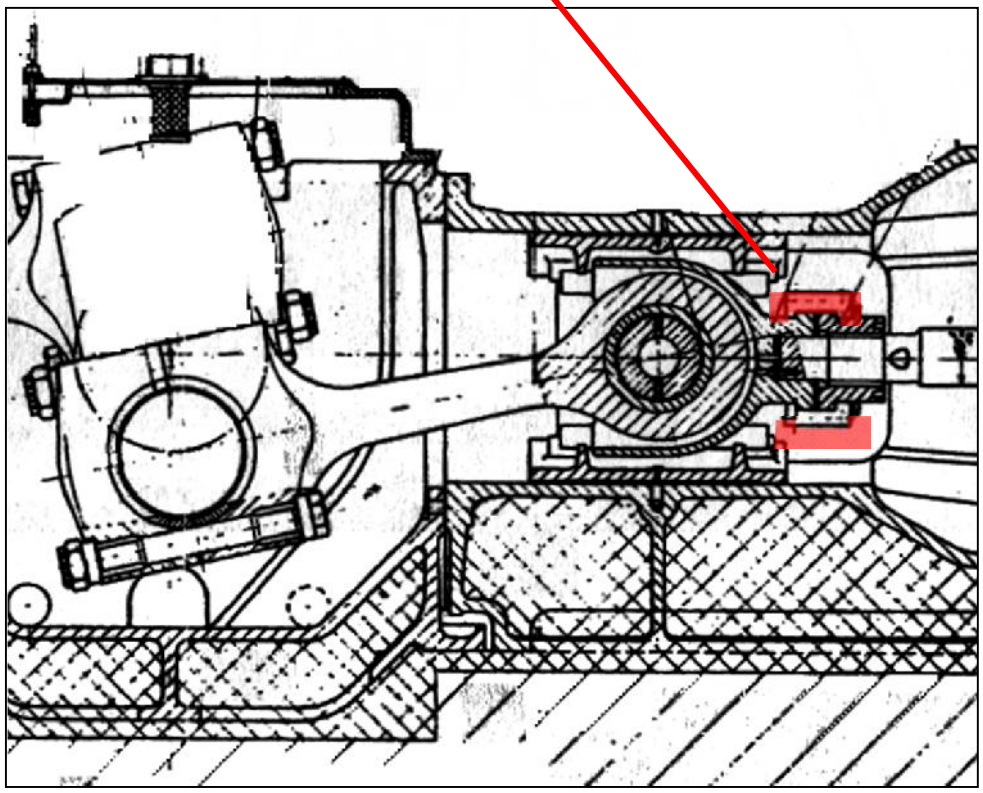


Case 10: Loose connection during machine start-up



Case: Loose connection during machine start-up

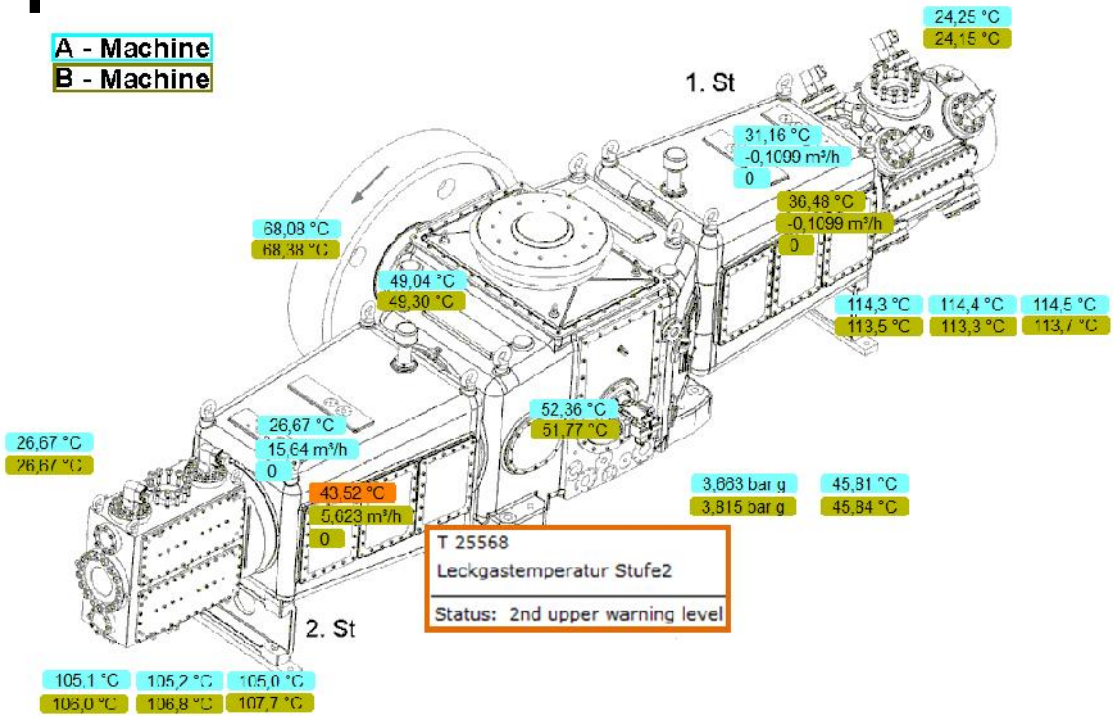
- Loose connection crosshead / piston rod after restart of a overhauled compressor



Temperatures

<u>Common</u>

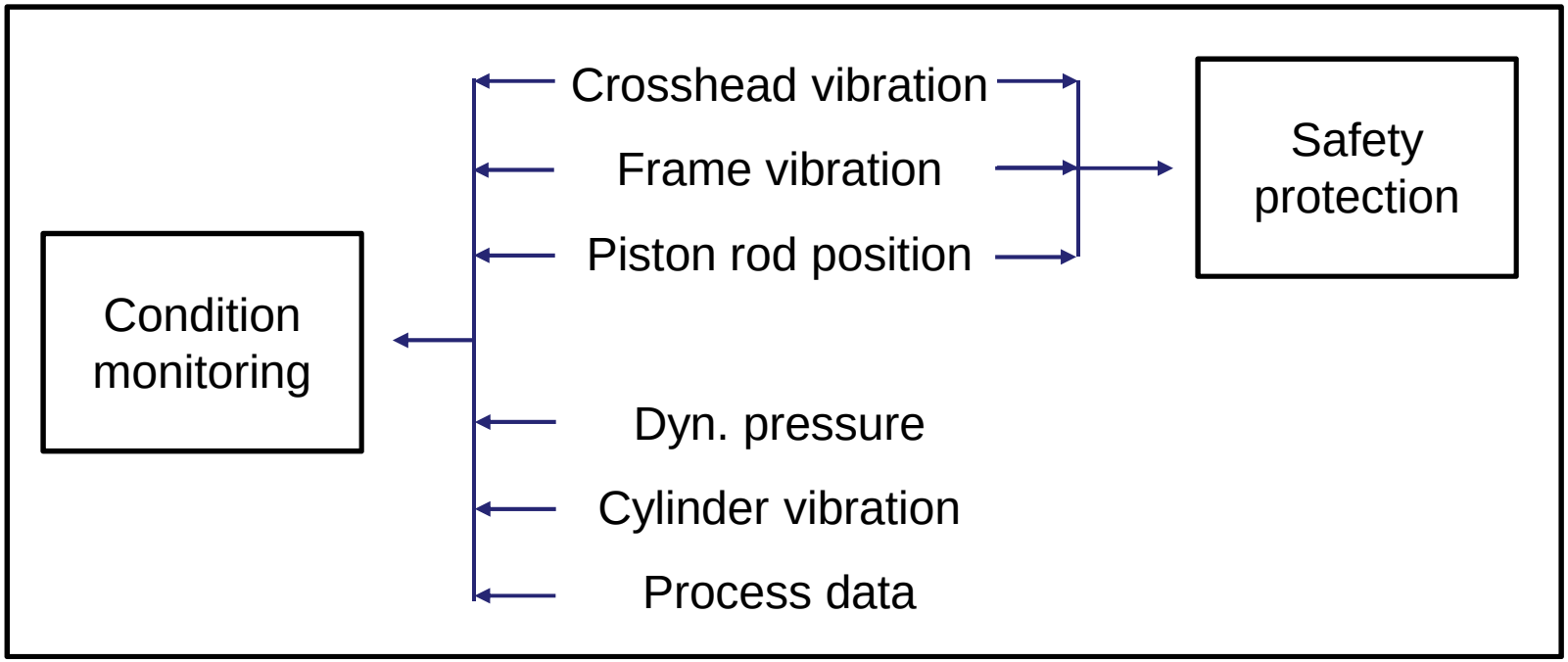
- Valve
- Gas
- Packing vent or case
- Bearings



<u>Uncommon</u>

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

Early failure vs. Safety



API 670

- Shutdown parameters for API 618 machines

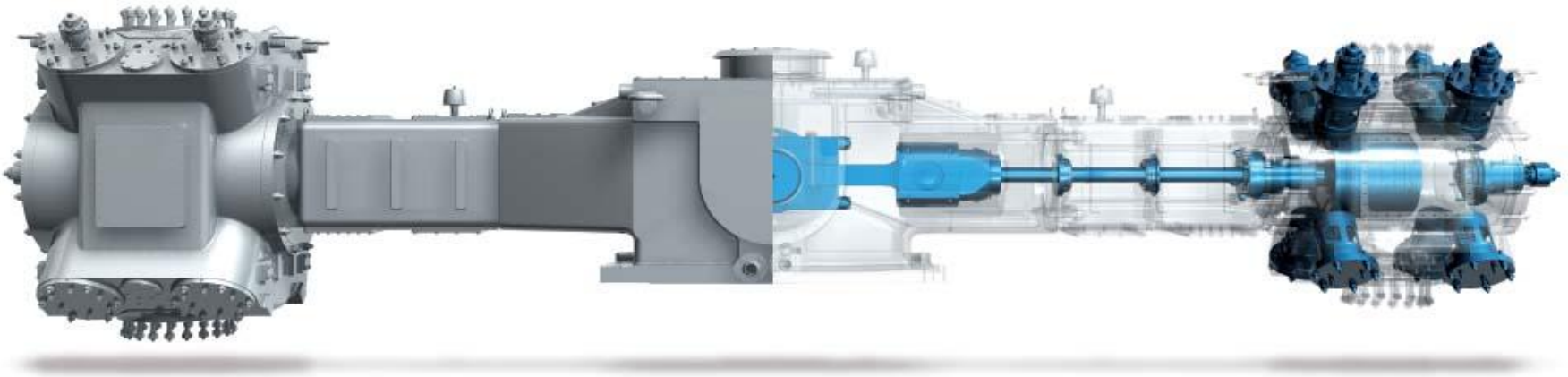
	Monitored Point	Signal Type
Protective Signals	Low Frame Lube Oil	Pressure
	High Frame Vibration	Accelerometer
	High Liquid in Separator	Level
Additional Signals	High Crosshead Vibration	Accelerometer
	High Gas Discharge Temp.	Temperature
	High Differential Gas Stage	Pressure

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



Thank you for your Attention!

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