General Design Elements of Protection, Condition Monitoring and Diagnostic Systems

Albert König & Tobias Ahlert
PROGNOST Systems GmbH

Contents

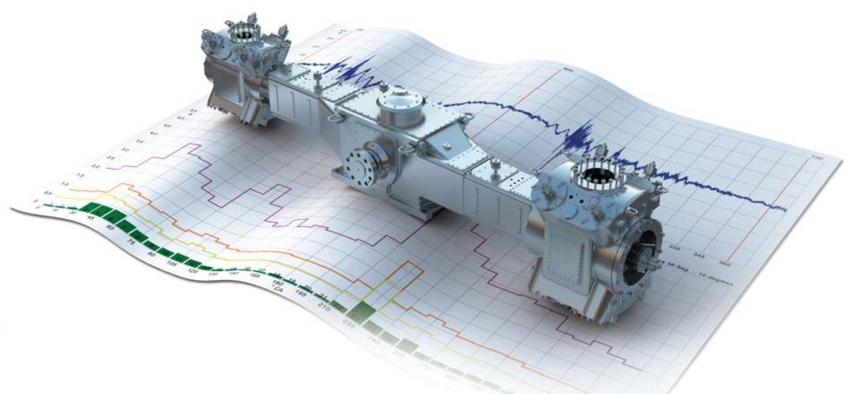
1. Introduction

General Concept of Compressor Monitoring

- Periodic or permanent monitoring of the machine condition by measuring and analysing physical quantities
- Objectives: - Health and safety
  - Integrity and reliability
  - machine efficiency

Steps:

- Data acquisition of the different sensors
- Comparison of actual value with reference value (Thresholds or Safety limits)
- Warning -> Alert/Shutdown
- Root cause analysis



1. Introduction

In the past:

- Minor priority on reciprocating compressor monitoring
- Focus on centrifugal compressor as main machine
- Maybe because of “felt” smaller damage risk and redundancy

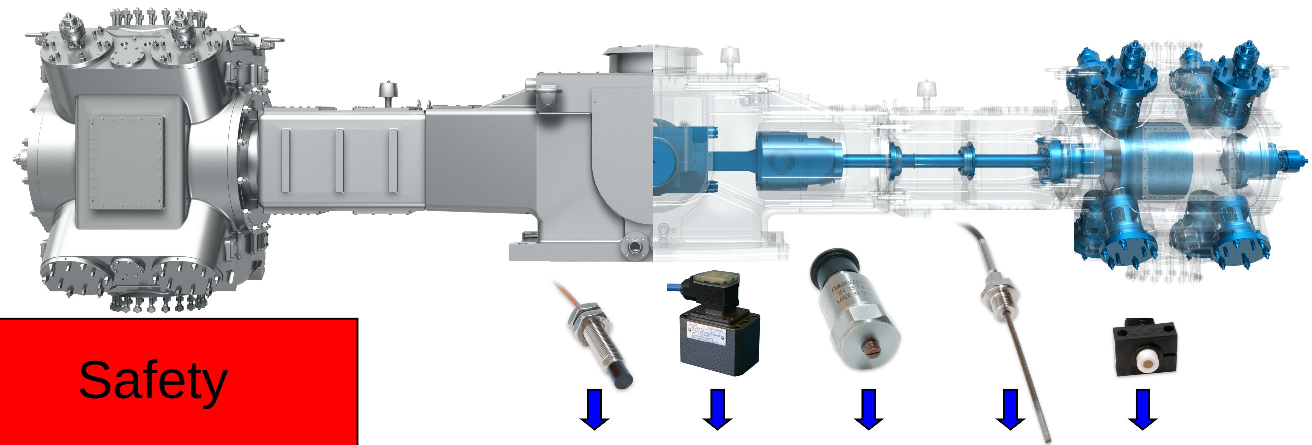
Today’s fact:

- Extensive damages with influence on whole production process/ plant
- In most cases no redundancy because of capacity increase

Over the time 3 kinds of systems became obviously:

- **Protection System**
- **Condition Monitoring System**
- **Diagnostic System**

1. Introduction



Alert
Shutdown

HMI
- Trend
- On-line
- Alarm history
- Dailly snapshot
- Ring buffer

Warnings

Clear text messages based on
-Pattern recognition
- Calculations

Safety Protection

Signal processing

Condition Monitoring

Diagnostic system

Data storage

Dynamic (Fast) signals

Speed, Frame Vibration (API requirement)
Rod Position, Crosshead Guide Vibration (API optional)

Cylinder Vibration, Dynamic Pressure (pV), Motor Vibration

DCS values

High Liquid Level KO Vessel, Low Frame Lube Oil Pressure (API requirement)
Pressures, Temperature& Rod load/reversal (API optional)

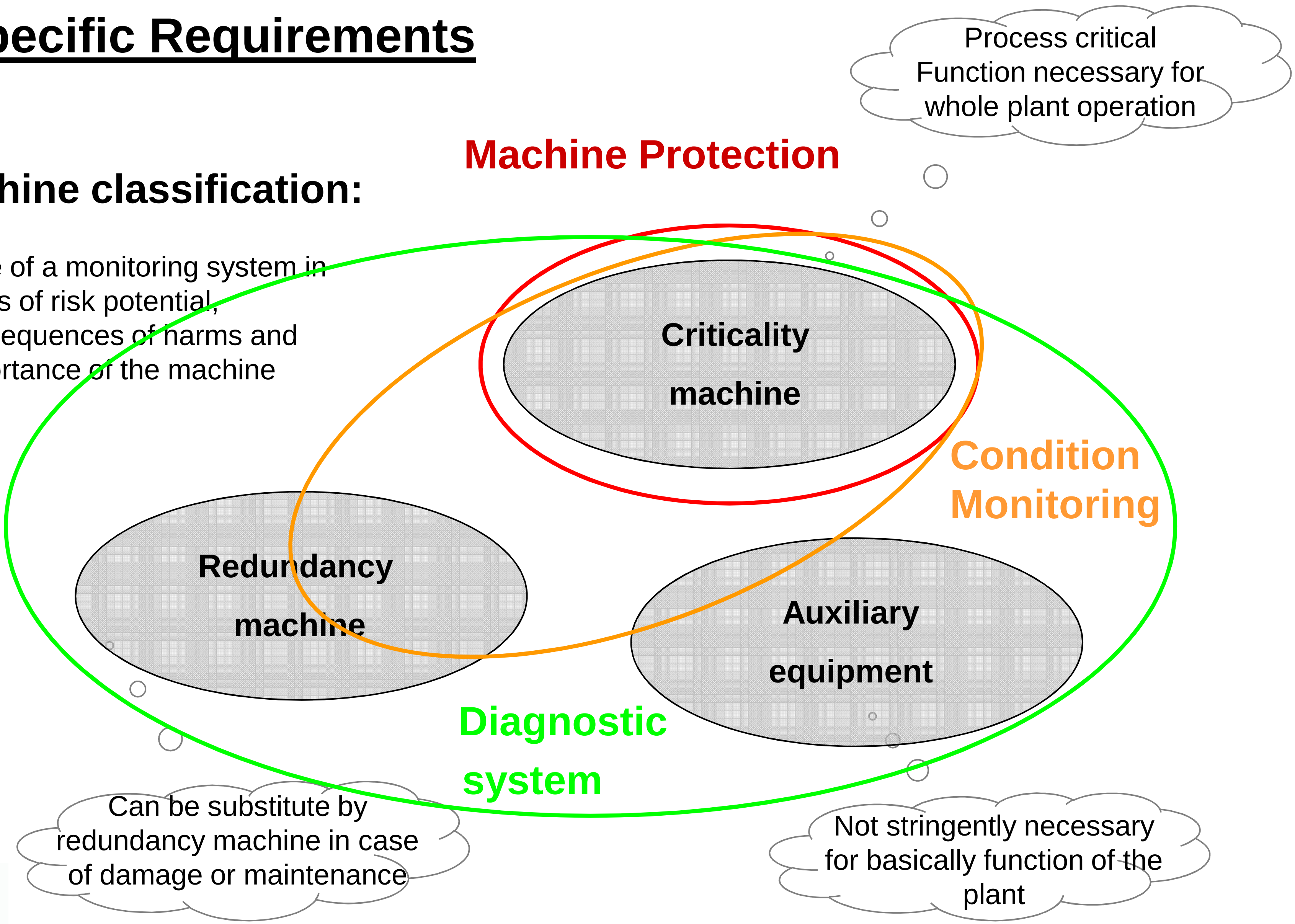
Intermediate Pressure/ Temperature, Lubrication Values, Flow Capacity, Regulation Data, Winding Temperature,…

- **Protection System**
- **Condition Monitoring System**
- **Diagnostic System**

2. Specific Requirements

Machine classification:

… for use of a monitoring system in terms of risk potential, consequences of harms and importance of the machine

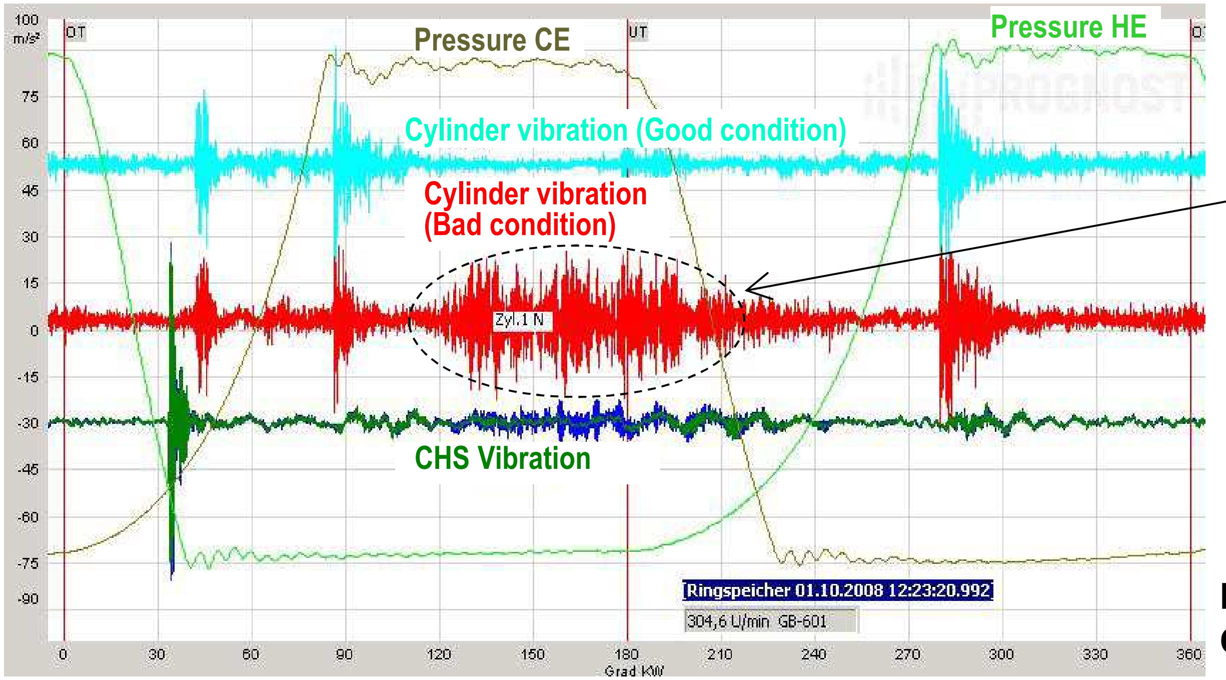


2. Specific Requirements

Additional benefit of Condition Monitoring & Diagnostic system

➔ **Process dependent:**

-Example for discovering of process related issues-



Gas contamination

Isolated revolutions show high and wide vibration amplitudes close before and after BDC: hints for gas impurity (liquids, dust)

Dynamic pressures & vibrations Comparison „Good“ / „Bad“

2. Specific Requirements

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-Example for discovering of process related issues-

Gas contamination

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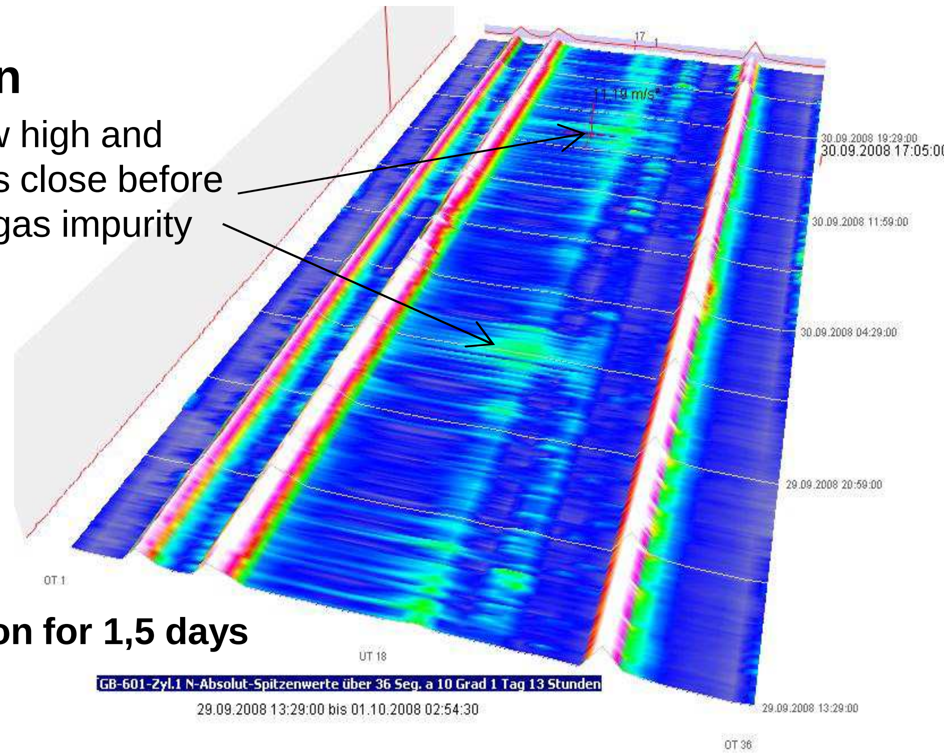


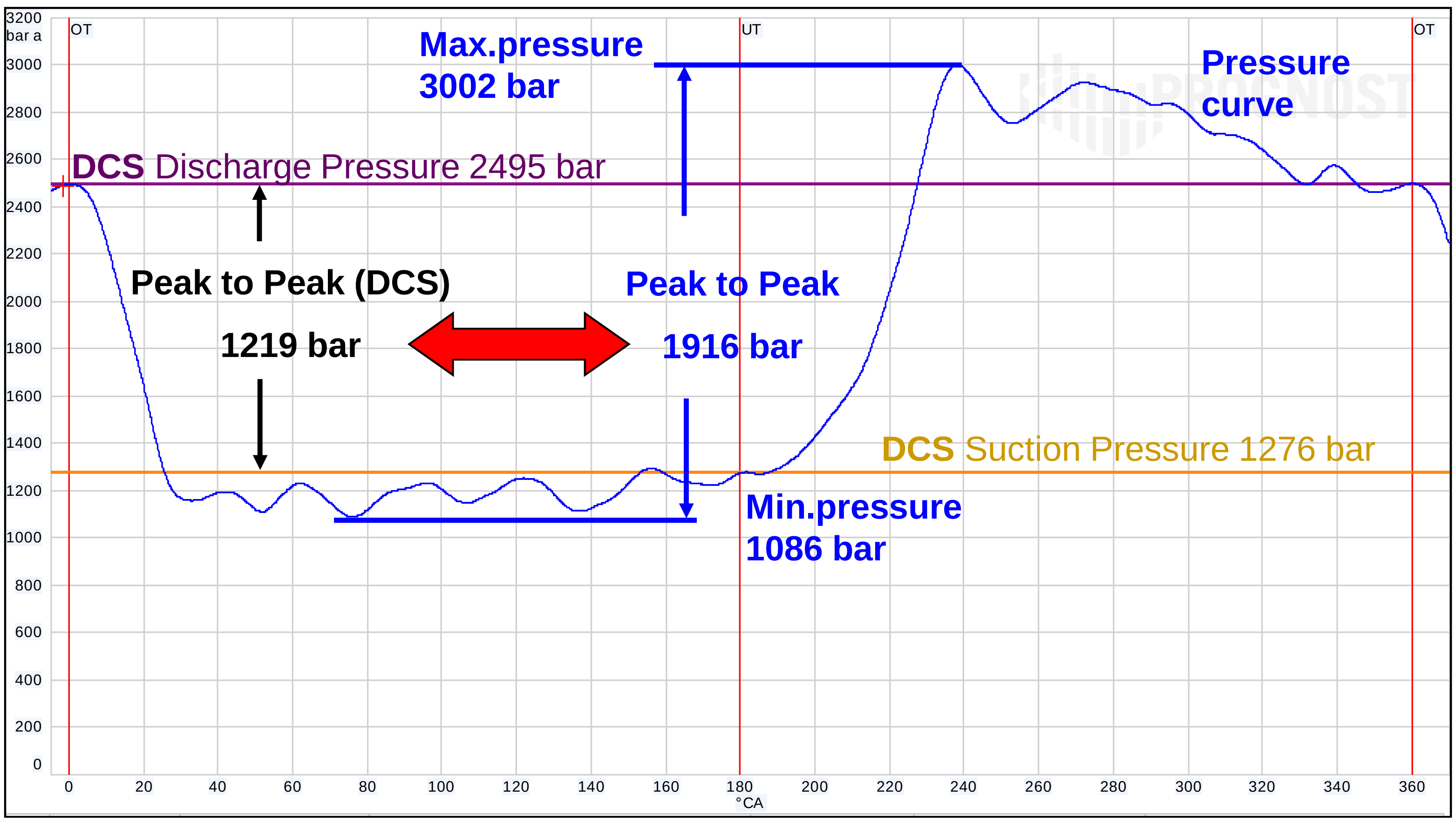
3D Trend
Cylinder Vibration for 1,5 days

2. Specific Requirements

Additional benefit of Condition Monitoring & Diagnostic system

➔ Difference to Distribution Control System (DCS):

-Example real pressure measurement vs. DCS values-



2. Specific Requirements

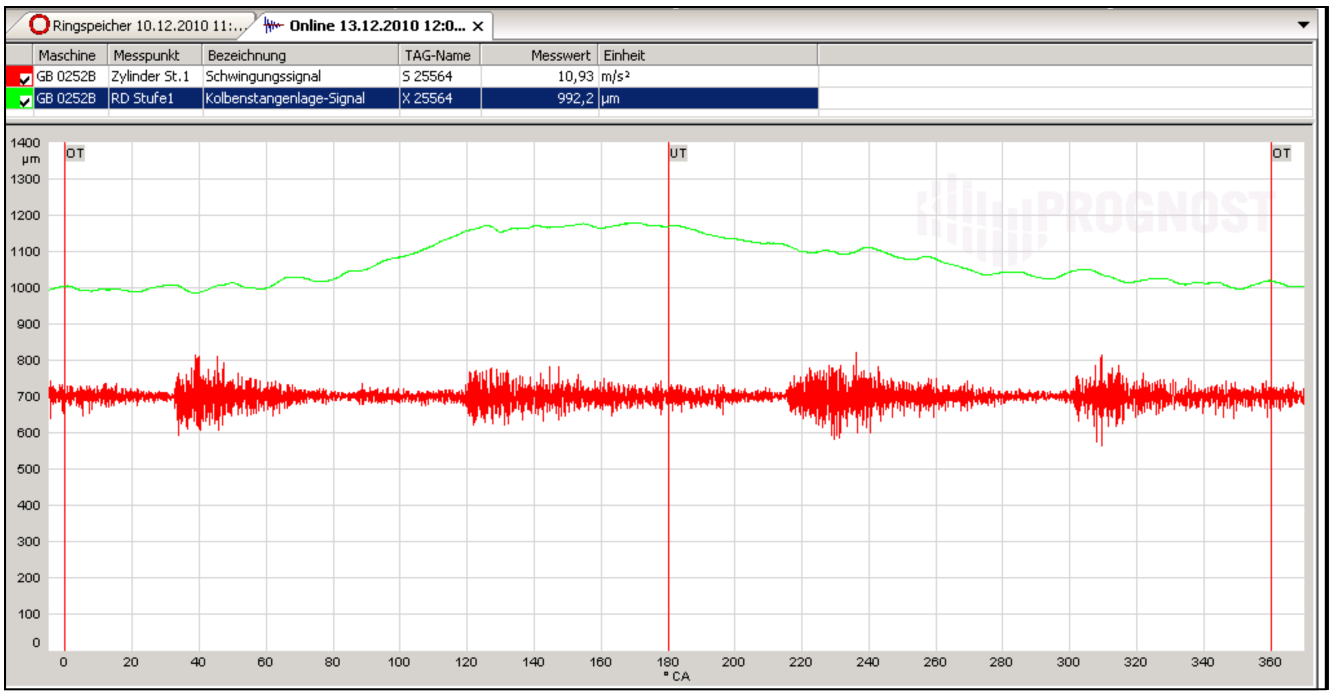
Additional benefit of Condition Monitoring & Diagnostic system

➔ **Snap-shot Measurement** versus **Continuously Monitoring:**

Snap-shot measurement:

Data at a defined and limited period of time

… Like a certain number of photos!



2. Specific Requirements

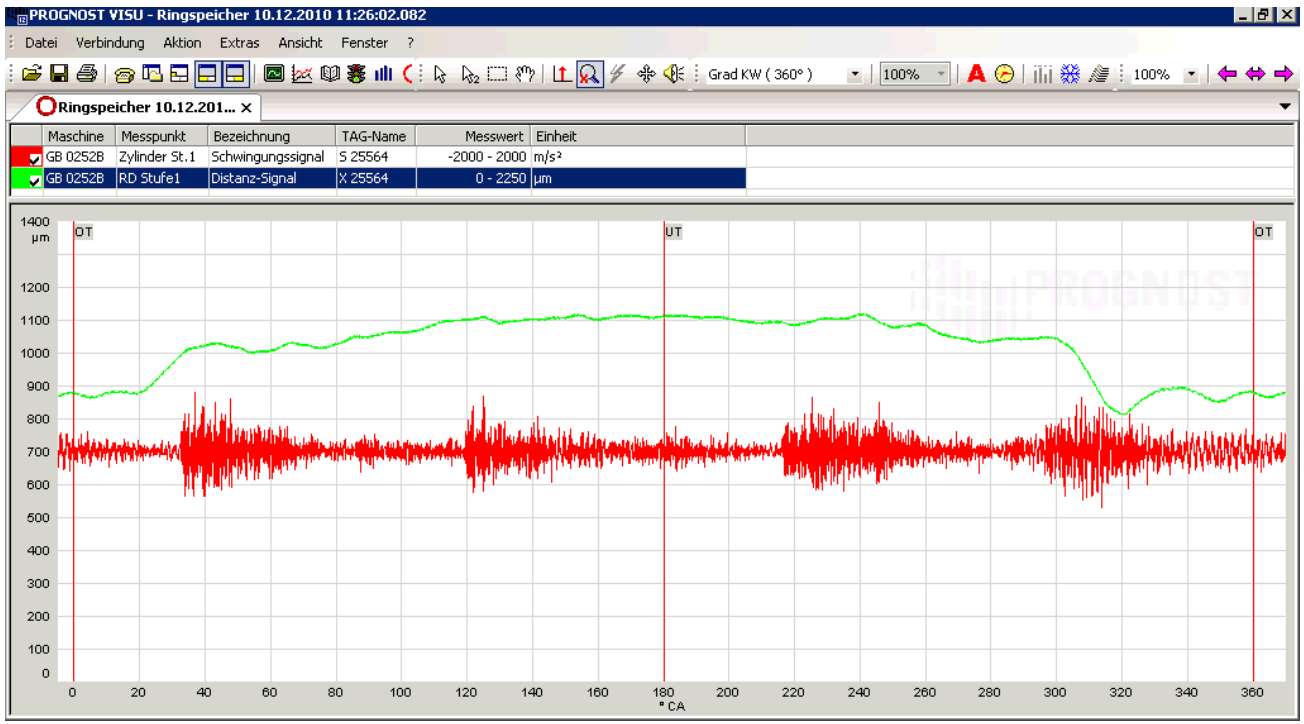
Additional benefit of Condition Monitoring & Diagnostic system

➔ **Snap-shot measurement versus Continuously monitoring:**

Continuously monitoring:

Data without a gap, every detail is available

… Like a movie!



3. Functional Safety

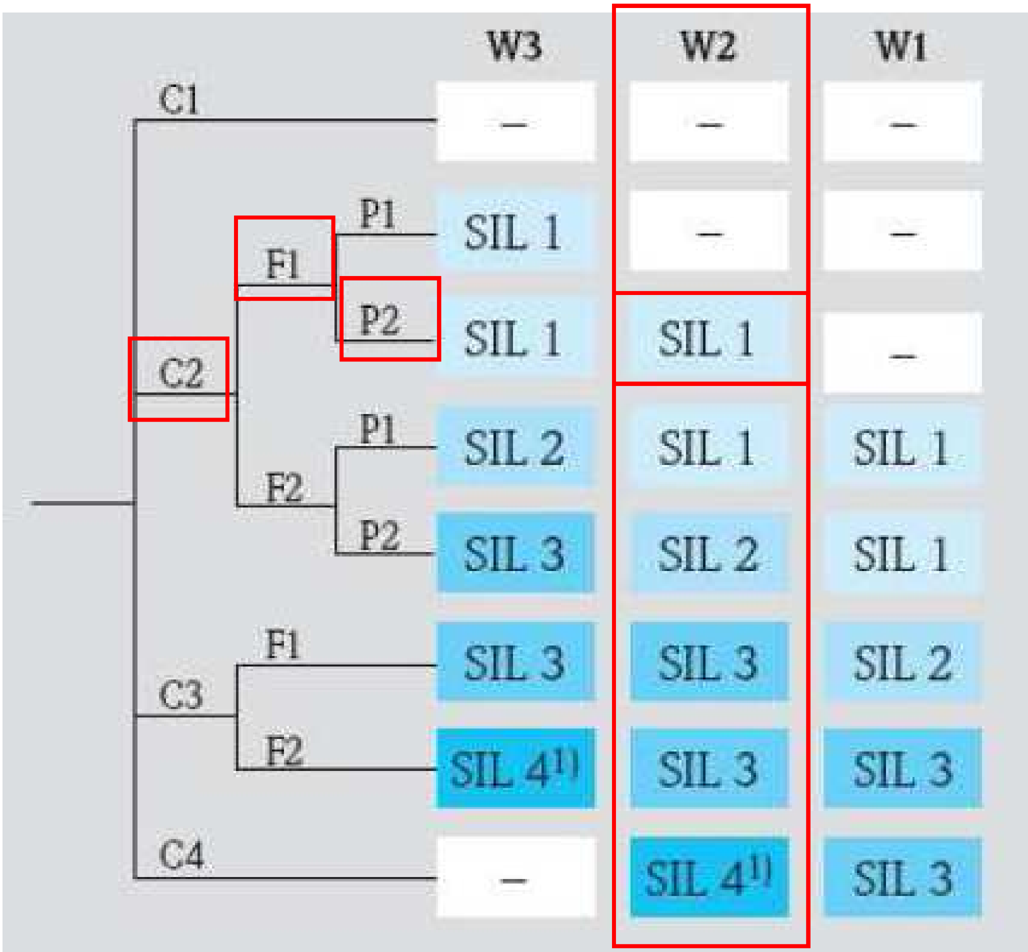
SIL – Safety Integrity Level

The probability that a safety-related system performs its necessary safety-relevant function under all given conditions within an established period of time“.

Relevant Standards for Protection Systems:

IEC 61508 (for vendors)	Functional Safety of Electrical/Electronic Programmable Electronic Safety Related Systems.
IEC 61511 (for operator)	Functional safety - Safety Instrumented Systems for the process industry sector
IEC-62061	Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems
ISO 13849	Safety of machinery – Safety-related parts of control systems
ANSI/ISA 84.00.01-2004 (IEC 61511 Mod)	Functional safety: Application of Safety Instrumented Systems for the Process Industries

3. Functional Safety: Risk Graph (IEC 61511)



Risk parameters:

W-Occurrence Probability
W1: very low probability
W2: low probability
W3: relative high probability

C-Extent of damage
C1: slight injury
C2: severe irreversible injury to one or more persons or death of a person
C3: death of several persons
C4: catastrophic consequences, multiple deaths

F-Exposure time
F1: seldom to relatively frequent
F2: frequent to continuous

P-Hazard Avoidance
P1: possible under certain conditions
P2: hardly possible

Example: Low probability (W2) + death of a person (C2) + seldom exposure (F1) + hardly possible (P2) ⇨ **SIL 1**

3. Functional Safety: Definition PFD

$$\textbf{PFD} = \frac{\text{Frequency of justifiable risk}}{\text{Failure rate of unprotected process}}$$

[Probability of failure on Demand]

Safety Integrity Level		Availability Required	Probability to Fail on Demand	1/PFD
IEC 61508	4	>99.99%	E-005 to E-004	100,000 to 10,000
IEC 61508, ISA S84	3	99.90-99.99%	E-004 to E-003	10,000 to 1,000
IEC 61508, ISA S84	2	99.00 - 99.90%	E-003 to E-002	1,000 to 100
IEC 61508, ISA S84	1	90.00 - 99.00%	E-002 to E-001	100 to 10

3. Functional Safety: How to calculate the pfd value?

$$\mathbf{pfd_{System} = n \times \lambda_{du} \times PTI/2}$$

Input: n = Safety channels

λ_{du} = Rate of dangerous undetected failures per channel [1/h]

PTI = Proof test interval [h]

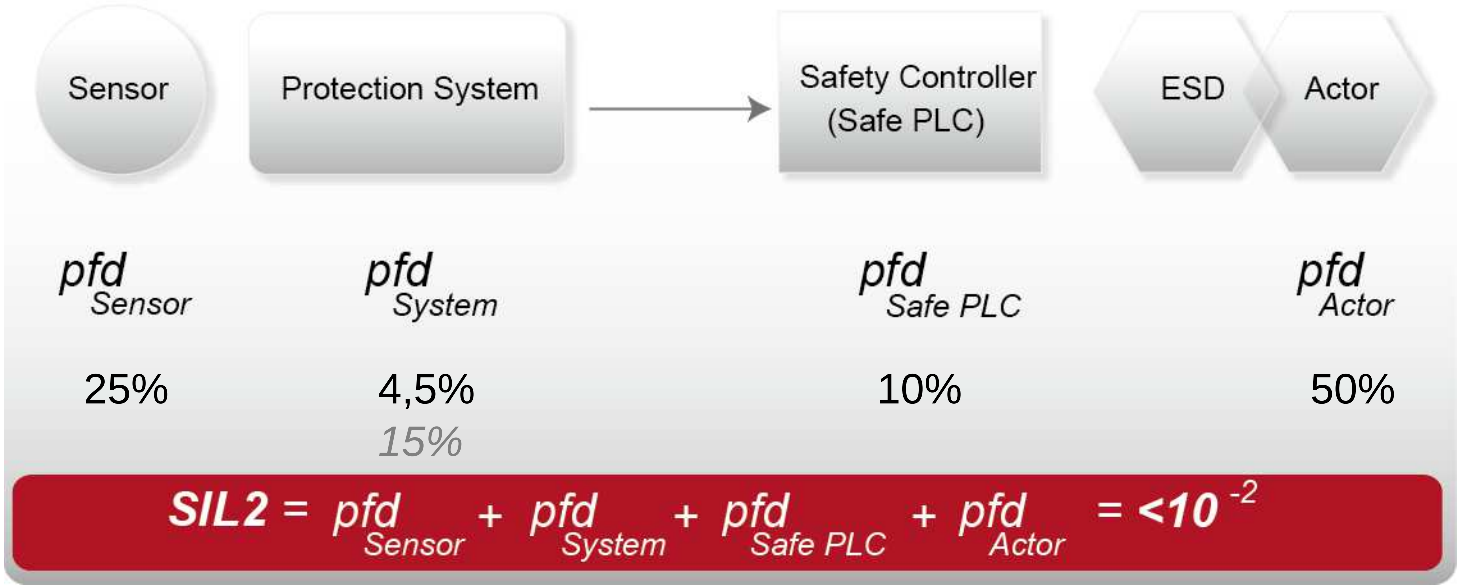
Example: $n = 23$, $\lambda_{du} = 1{,}5 \times 10^{-9}$ 1/h, PTI = 3 years = 3x8760h = 26280h

p*robability of* ***f****ailure on* ***d****emand* $\mathbf{pfd_{System}} = \mathbf{23 \times 1{,}5 \times 10^{-9} \times 26280 / 2}$

$= \mathbf{0{,}045 \times 10^{-2}}$

Note: The lower „n“ and „PTI“, the lower pfd!
Low pfd value equals a high SIL level!

3. Functional Safety: Loop of instrumented system



= 89,5%

= 100%

Low pfd value (equals **high SIL level**) does <u>not</u> mean: The system **protects effectively**!

….. but it’s the first step of your homework!

4. Available Standards

API 610, 611, 612, 613, 616, 617, 618 are machine specific standards. Mainly deal with aspects of machinery design, installation, performance and support systems.

Central document for all aspects for machinery protection increasingly becoming

API 670 Machinery Protection Systems (4th edition from 2000)

→ Widely used and most mentioned standard. Based on the accumulated knowledge and experience of manufacturers and users of monitoring systems.

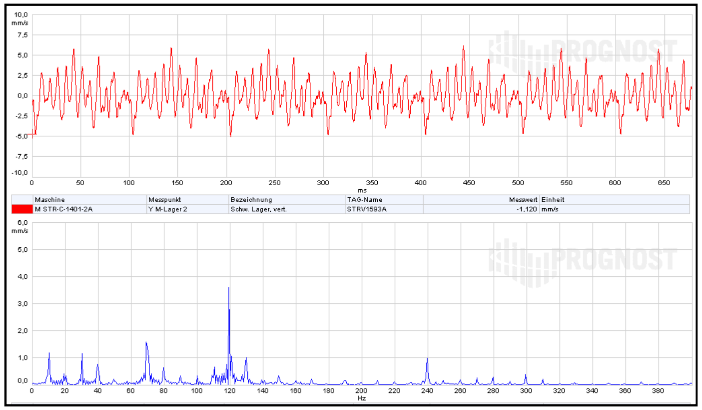
History:

API 670 1st edition	1976	focused on the application of proximity sensor based machinery monitoring
API 678 1st edition	1981	Parallel standard: „Accerlometer-based Vibration Monitoring System“
API 670 2nd edition	1986	
API 670 3rd edition	1993	-Extension and update of API670 -Incorporated and replaced API678
API 670 4th edition	2000	-still valid today -Renamed: „Machine Protection system“ to better reflect its safety relevant character
API 670 5th edition	2012 (to be released)	At first time the 5th Edition will offer valuable information and guidance on how to effectively protect reciprocating compressors

4. Available Standards

Until the 4th edition the API Standard 670 focused very much on technical requirements of centrifugal equipment. Reciprocating compressors have never been a focus.

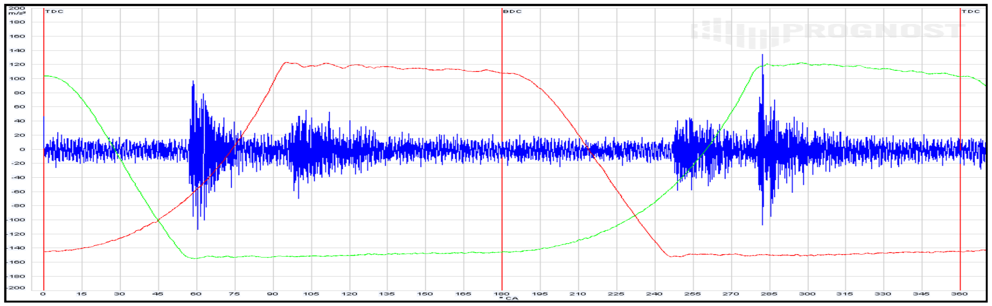
- axial, radial shaft position
- speed and surge
- bearing and frame vibration



In comparison:

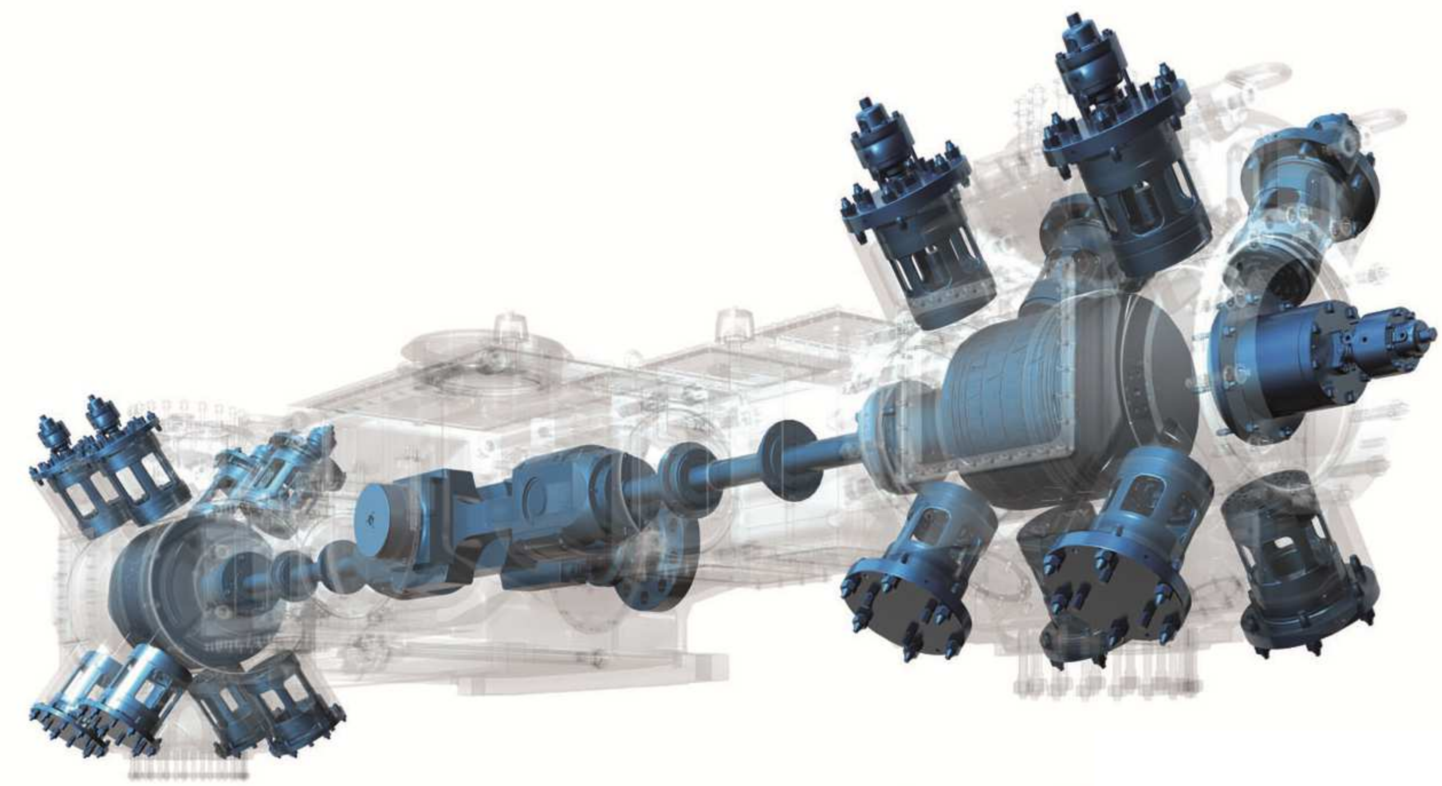
Impact driven signal of a

piston compressor



➔The 5th Edition will offer valuable information and guidance on how to effectively protect reciprocating compressors!

Thank you!



Albert König & Tobias Ahlert
PROGNOST Customer Support