Benefits and limitation of Vibration Standard for Rotating Machines

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Best Practices Webinar Series

Meet the Speakers

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Abstract

The ISO and API standards provide very useful information on evaluation criteria for evaluating rotating machinery. In most cases, applications are related to acceptance tests such as running test during first installation and more often during standard operating conditions.

The goal of this webinar is to provide additional and expert advice in order to use and apply those standards in the daily routinary vibration data evaluation.

1. **Why machines fail despite ISO standard is below alarm thresholds?**
2. **Why this machines still working in alarm zones for 2 years without any risk?**
3. **What are the criteria for selecting the better standard for my machines?**

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Why ISO 10816 is important for vibration measurement engineers?

The main target of condition monitoring and machinery protection systems is to ensure the health and continuous operation of the plant machinery. In this regard vibration measurement systems along with vibration transducers are installed for continuous measurement and analysis of machine vibrations. To this end users need a reference to compare machine vibration with it to evaluate the state of each machine. ISO 10816 provides a reference like allowable vibrations and alarm or trip conditions for various machinery based on some statistical analysis of historical data gathered by ISO TC 108.

ISO 10816 has been one of the first and mostly developed standards for vibration evaluation of machinery including different type of machinery like wind turbine, hydro turbine, gas turbine & steam turbines, reciprocating machinery, etc.

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Agenda

- ✓ ISO STANDARD
- ✓ Frequency Domain
- ✓ Absolute, Relative Alarm
- ✓ Band Alarm
- ✓ Case studies

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ISO STANDARD

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Data Management

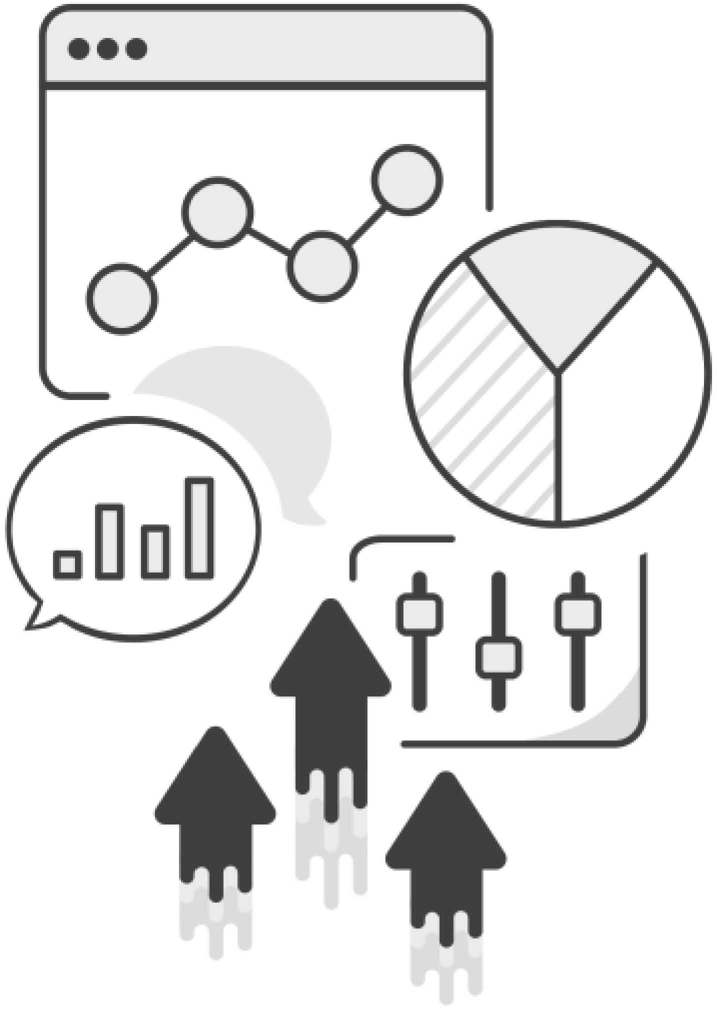
Large amounts of data are collected during the day to day process of running a predictive maintenance program.

But what should we do with all the data? How will we know if there is a problem?

All data coming from spectra and waveform needs relevant time consuming analysis.

One approach is to view the trend data; either trends of overall levels, specific bands, or of specific bearing measurements.

Alarm limits can be applied to RMS readings, Shock Pulse/HFD/Spike Energy readings, spectra, and even time waveforms.



Good alarm limits can save a huge amount of time!

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ISO Standard

Standard	Description
ISO 10816-1:1995	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 1: General guidelines
ISO 10816-2:2009	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min
ISO 10816-3:2009	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ
ISO 10816-4:2009	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 4: Gas turbine sets with fluid-film bearings
ISO 10816-5:2000	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 5: Machine sets in hydraulic power generating and pumping plants
ISO 10816-6:1995	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 6: Reciprocating machines with power ratings above 100 kW
ISO 10816-7:2009	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts
ISO 10816-8:2014	Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 8: Reciprocating compressor systems

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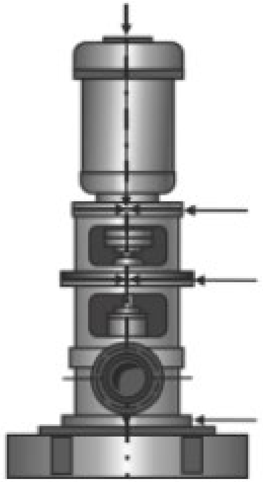
ISO 10816-1

General Machines

ISO 10816-1 is a basic document which sets out general guidelines for the measurement and evaluation of mechanical vibration of machines, as measured on non-rotating parts. The machine classifications are as follows:

Class I machines may be separate driver and driven, or coupled units comprising operating machinery up to approximately 15kW(approx 20hp).
Class I machinery (electrical motors 15kW (20hp) to 75kW(100hp), without special foundation, or Rigidly mounted engines or machines up to 300kW (400hp) mounted on special foundations.
Class III machines are large prime movers and other large machinery with large rotating assemblies mounted on rigid and heavy foundation which are reasonably stiff in the direction of vibration .
Class IV includes large prime movers and other large machinery with large rotating assemblies mounted on foundations which are relatively soft in the direction of the measured vibration (i.e.,turbine generators and gas turbines greater than 10MW (approx. 13500hp) output.

Velocity Severity		Velocity Range Limits and Machine Classes			
				Large Machines	
mm/s RMS	in/s Peak	Small Machines Class I	Medium Machines Class II	Rigid Supports Class III	Less Rigid Supports Class IV
0.28	0.02	Good	Good	Good	Good
0.45	0.03	Good	Good	Good	Good
0.71	0.04	Good	Good	Good	Good
1.12	0.06	Satisfactory	Good	Good	Good
1.80	0.10	Satisfactory	Satisfactory	Good	Good
2.80	0.16	Unsatisfactory (alert)	Satisfactory	Satisfactory	Good
4.50	0.25	Unsatisfactory (alert)	Unsatisfactory (alert)	Satisfactory	Satisfactory
7.10	0.40	Unacceptable (danger)	Unsatisfactory (alert)	Unsatisfactory (alert)	Satisfactory
11.20	0.62	Unacceptable (danger)	Unacceptable (danger)	Unsatisfactory (alert)	Unsatisfactory (alert)
18.00	1.00	Unacceptable (danger)	Unacceptable (danger)	Unacceptable (danger)	Unsatisfactory (alert)
28.00	1.56	Unacceptable (danger)	Unacceptable (danger)	Unacceptable (danger)	Unacceptable (danger)
45.00	2.51	Unacceptable (danger)	Unacceptable (danger)	Unacceptable (danger)	Unacceptable (danger)



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ISO 10816-2

ISO 10816-2 Steam Turbine and Generators

Velocity mm/s (RMS)	Speed(RPM)	
	1500	3000
	Damage Occurs	
11.8		
10		
8.5	Restricted operation	
7.5		
5.3	Unrestricted operation	
3.8		
2.8	Newly Commissioned	

Steam Turbine And Generators

ISO 10816-2 is used for measurement of vibrations by accelerometer or velocity transducers on fixed parts like bearing housings of large land based turbines &

generators over 50 MW & rotational speeds from 1500 to 3600 RPM

Displacement um (peak-peak)	Group 2		Group 1	
	Rigid	Flexible	Rigid	Flexible
	Damage Occurs			
396				
320				
255				
201		Restricted operation		
161				
127				
105		Unrestricted operation		
82				
62				
	Newly Commissioned			

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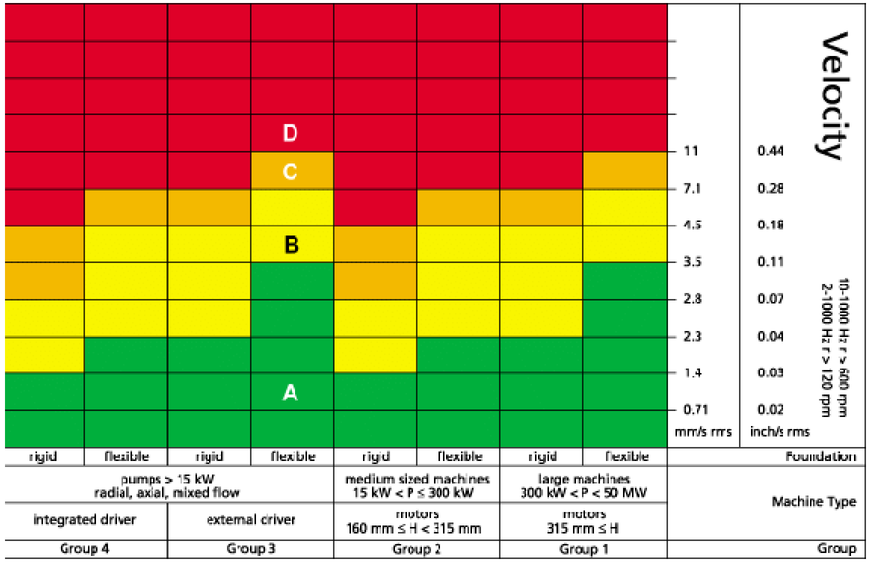
ISO 10816-3

ISO 10816-3		Group 1		Group 2	
		Large machines 300 kW < power < 50 MW		Medium machines 15 kW < power < 300 kW	
in/sec peak	mm/sec rms	Motor height >315 mm		Motor 160 mm < height < 315 mm	
0.61	11.0		Damage occurs		
0.39	7.1				
0.25	4.5		Restricted operation		
0.19	3.5				
0.16	2.8				
0.13	2.3		Unrestricted operation		
0.08	1.4				
0.04	0.7	Newly commissioned machinery			
0.00	0.0				
Foundation		Rigid	Flexible	Rigid	Flexible

Critical Machines

ISO 10816-3 is mainly applied to vibration measurement of industrial machines like electro motors powered above 15 KW and speed range (120 RPM-15000RPM)

by accelerometer or velocity transducers on fixed parts like bearing housings



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ISO 10816-6

Vibration Evaluation Standard - Reciprocating machine

Vibration Severity Grade	Overall Vibration measurment measured on the machine Structure			Machine Class*						
	Displacement in um - micron (rms)	Velocity in mm/ sec (rms)	Acceleration meter/ sec (rms)	1	2	3	4	5	6	7
1.1	≤ 17.8	≤ 1.12	≤ 1.76	A	A	A	A	A	A	A
1.8	≤ 28.3	≤ 1.78	≤ 2.79	A	A	A	A	A	A	A
2.8	≤ 44.8	≤ 2.82	≤ 4.42	B	A	A	A	A	A	A
4.5	≤ 71.0	≤ 4.46	≤ 7.01	B	B	A	A	A	A	A
7.1	≤ 113	≤ 7.07	≤ 11.1	C	B	B	A	A	A	A
11	≤ 178	≤ 11.2	≤ 17.6	D	C	B	B	A	A	A
18	≤ 283	≤ 17.8	≤ 27.9	D	D	C	B	B	A	A
28	≤ 448	≤ 28.2	≤ 44.2	D	D	D	C	B	B	A
45	≤ 710	≤ 44.6	≤ 70.1	D	D	D	D	C	B	B
71	≤ 1125	≤ 70.7	≤ 111	D	D	D	D	D	C	B
112	≤ 1784	≤ 112	≤ 176	D	D	D	D	D	D	C
180	≤ 1784	> 112	> 176	D	D	D	D	D	D	D

Zone A: Vibration of newly Commissioned Machines;
Zone B: Machines considered acceptable for unrestricted long-term operation
Zone C: Machines considered unsatisfactory for long-term continuous operation
Zone D: Vibration values normally considered to be sufficient severity to cause damage to the machine

Reciprocating Machinery

ISO 10816-6 specifies the general conditions and procedures for the measurement and evaluation of vibration, using measurements made on the non-rotating and non-reciprocating parts of reciprocating machines. It generally applies to reciprocating piston machines mounted either rigidly or resiliently with power ratings of above 100 kW. Typical examples of application are: marine propulsion engines, marine auxiliary engines, engines operating in diesel generator sets, gas compressors and engines for diesel locomotives. The general evaluation criteria which are presented relate to both operational monitoring and acceptance testing. They are also used to ensure that the machine vibration does not adversely affect the equipment directly mounted on the machine.

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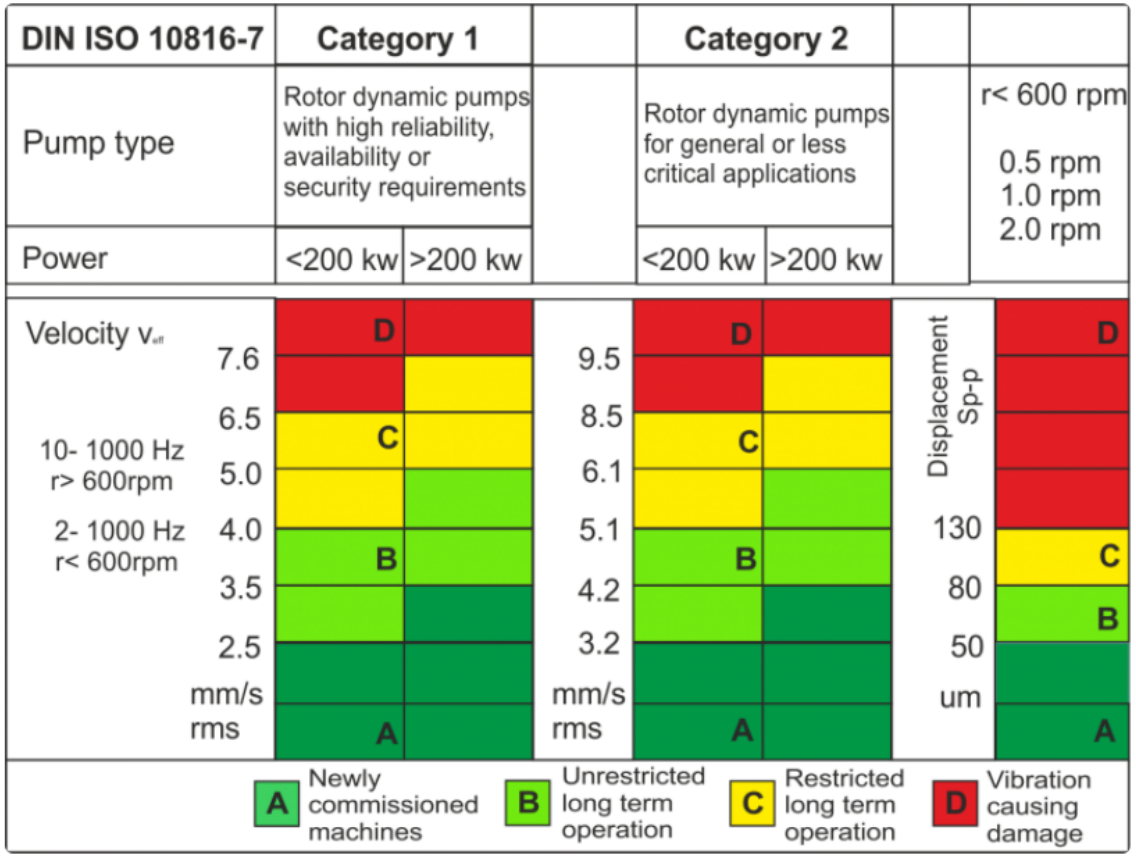
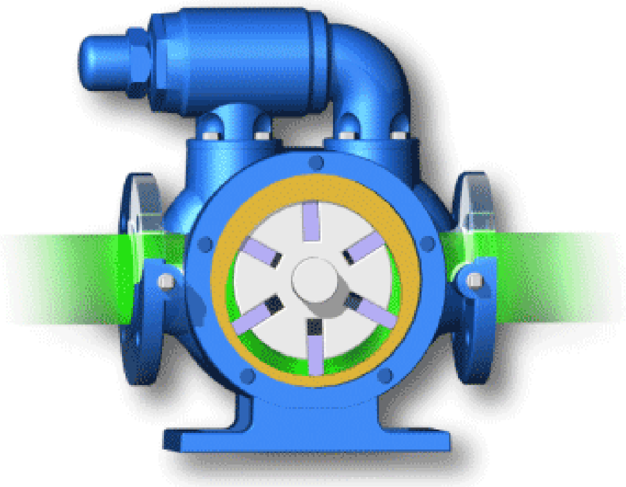
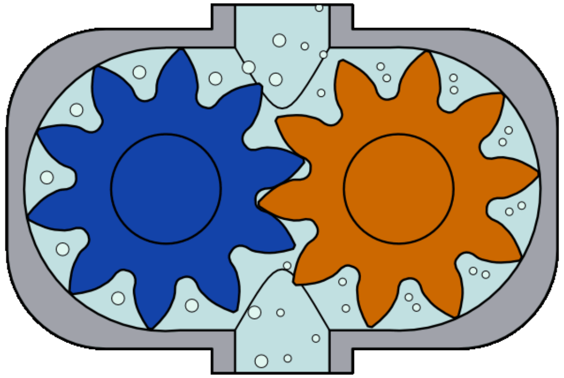
ISO 10816-7



Pump

ISO 10816-7 gives instructions for the evaluation of vibration on rotary pumps for industrial applications with nominal power above 1 kW. It defines the special requirements for evaluation of vibration when the vibration measurements are made on non-rotating parts (bearing housing vibration). It provides specific guidance for assessing the severity of vibration measured on bearing housings of rotary pumps in situ and for the acceptance test at the manufacturer's test facility or in the plant.





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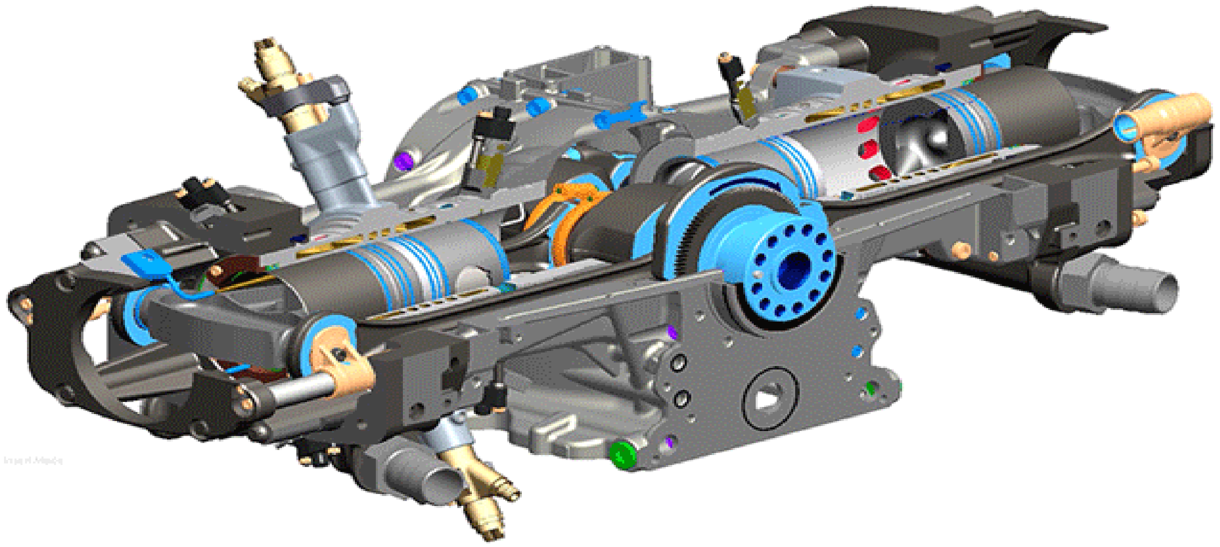
ISO 10816-8

Table 4 - Summary of overall constant vibration acceleration values for different compressor system parts

r.m.s vibration acceleration values for horizontal compressors m/s² — Evaluation zone boundary	Foundation	Frame (top)	Clyinder (lateral)	Clyinder (rod)	Dampers	Piping
35.8				D	D	D
30.2			D			
24.5					C	C
23.9				C		
20.1			C			
16.3					B	B
16.0						
15.1		D		B		
13.5			B			
10.9		C				
10.1						
6.7		B				A
5.7	D				A	
3.8	C			A		
2.5	B		A			
	A	A				

Reciprocating Compressors

This part of ISO 10816 establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating compressor systems. The vibration values are defined primarily to classify the vibration of the compressor system and to avoid fatigue problems with parts in the reciprocating compressor system, i.e. foundation, compressor, dampers, piping, and auxiliary equipment mounted on the compressor system.



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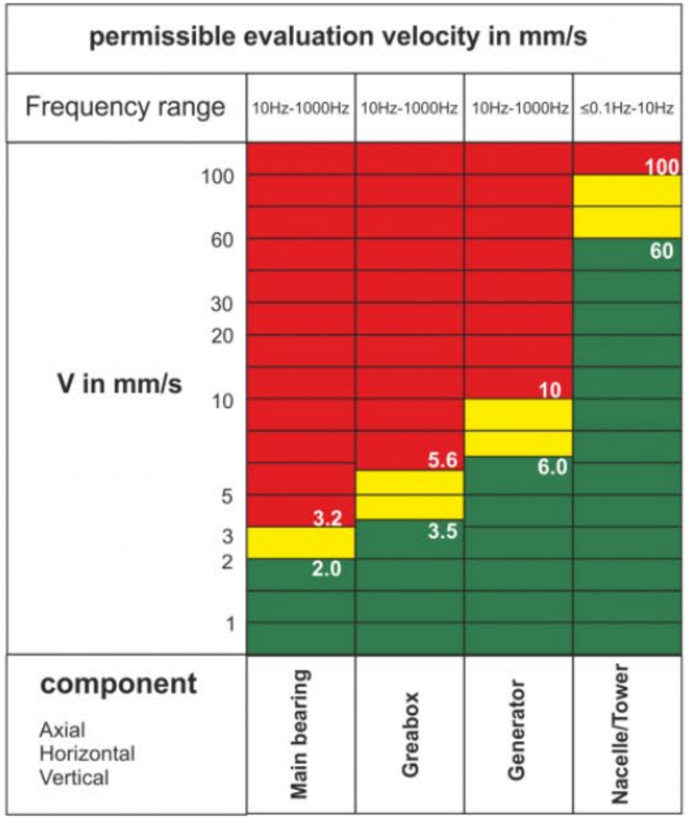
ISO 10816-21

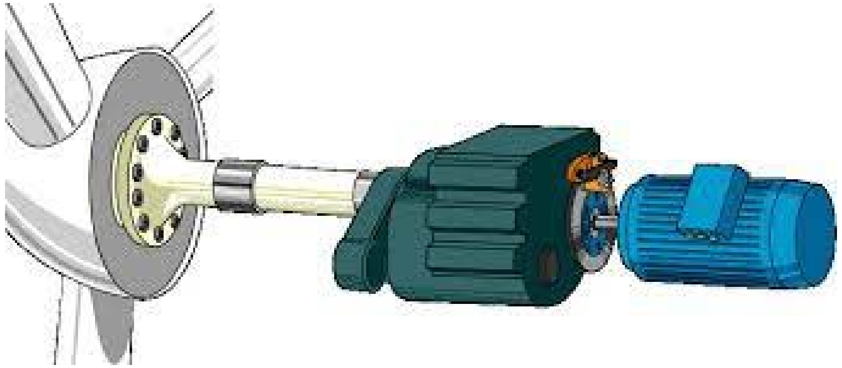
ISO 10816-21 onshore wind turbines with gearbox



Onshore Wind Turbines With Gearbox

ISO 10816-21 specifies the measurement and evaluation of mechanical vibration of wind turbines and their components by taking measurements on non-rotating parts. It applies to WTs with rated generator outputs exceeding 100 kW but less than or equal to 3 MW, and the following design and operational characteristics:

siting onshore, Installation on supporting systems (tower and foundation) made of steel and concrete, horizontal-axis rotor with several rotor blades, rotor bearing separate from or integrated into the gearbox, generators driven via gearbox, generators of the synchronous or asynchronous type with only a fixed pole number or which are pole-changeable for speed adjustment, generator coupled to the power grid via converter or directly.



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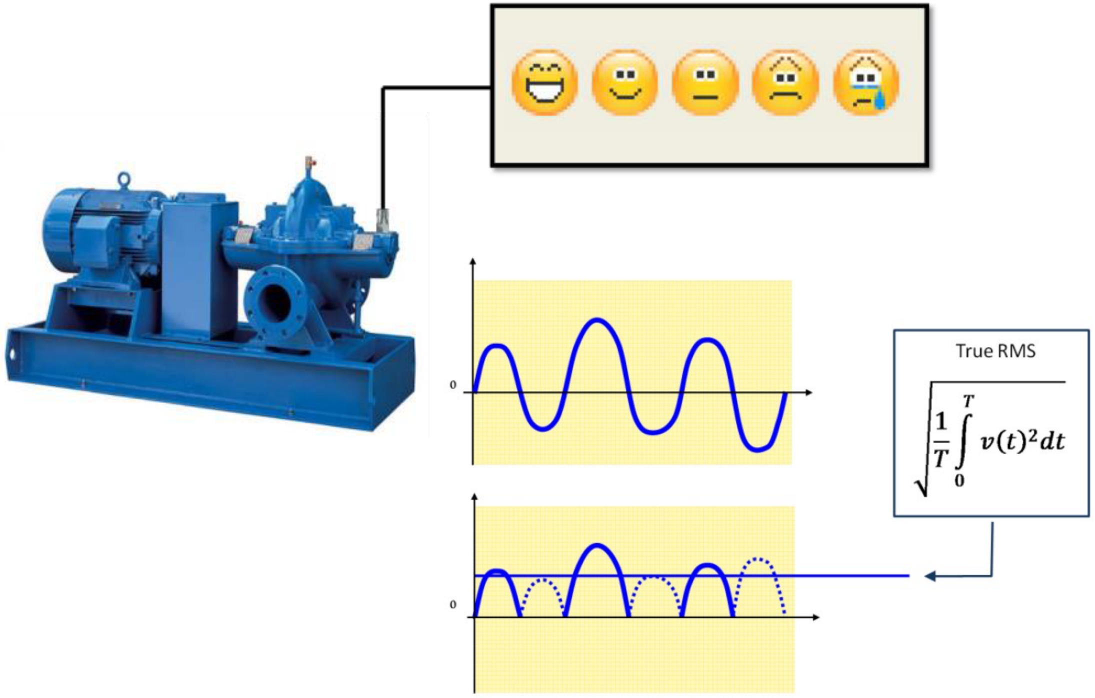
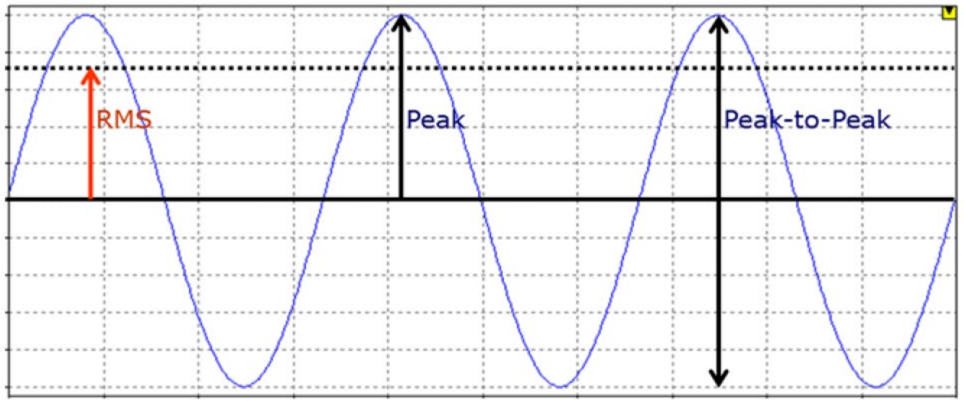
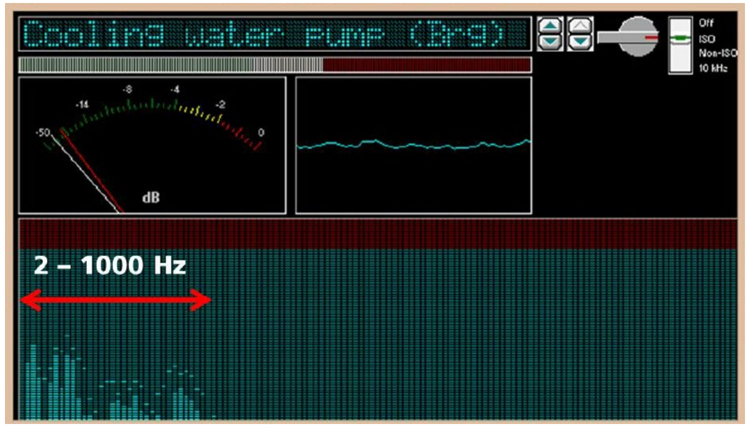
RMS Value

The ISO 10816 defines vibration severity as the RMS level of vibration velocity measured over a frequency range of 2 Hz to 1000 Hz.

Instead of measuring the amplitude of a transient at a single high frequency, the vibration severity reading represents an average of all vibration components within a wide and comparatively low frequency range.







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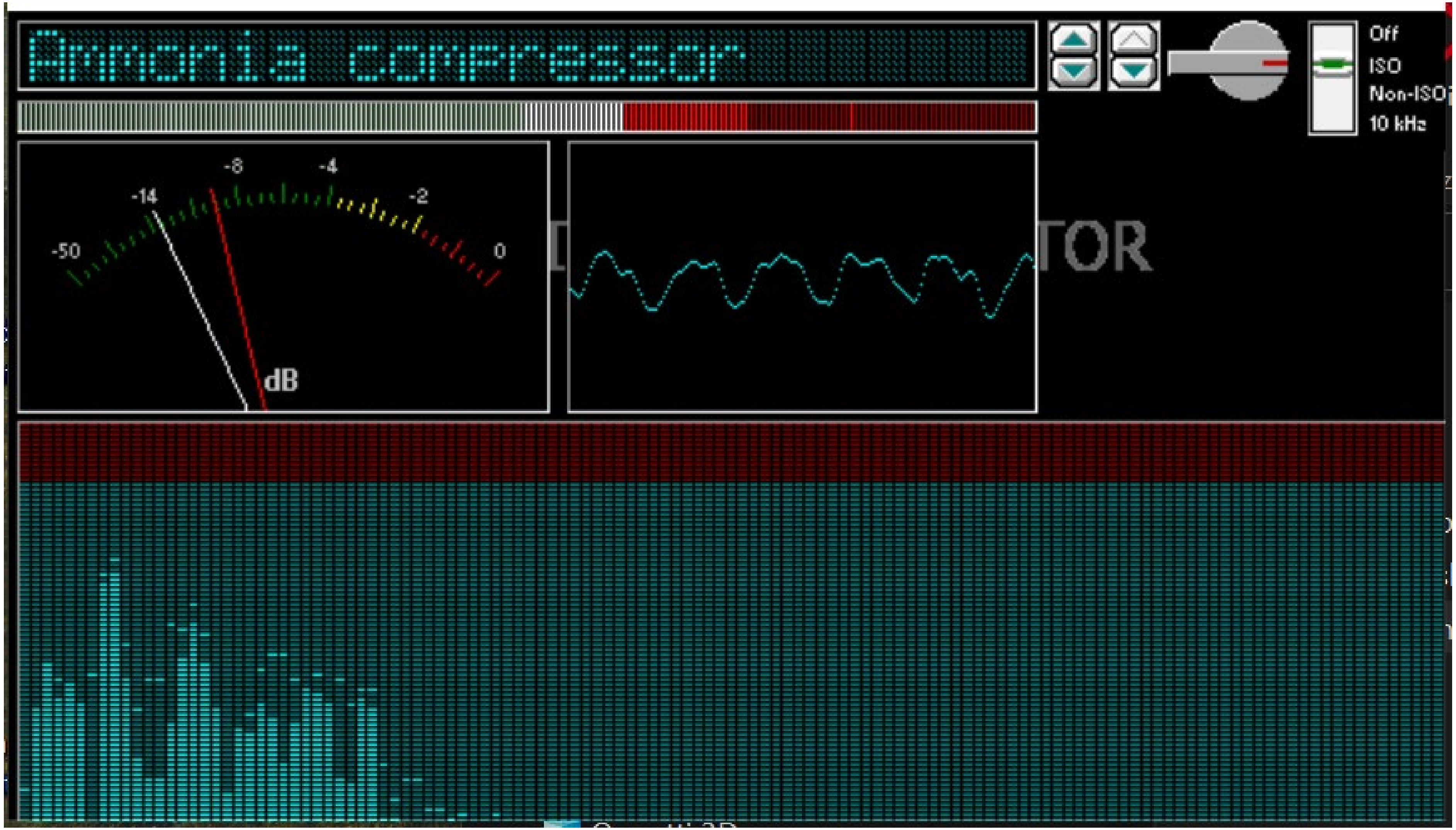
Simulations – live check



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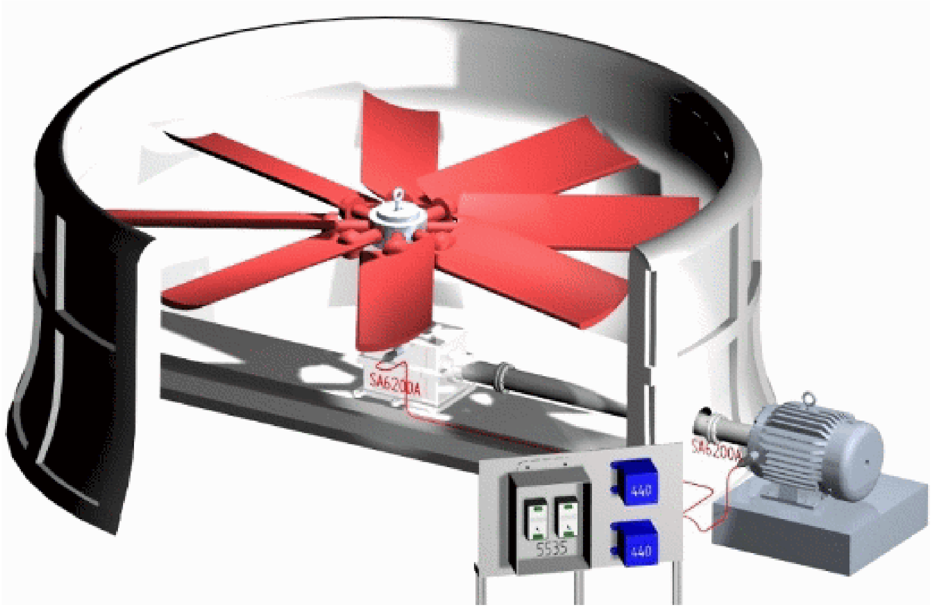
Macchine lente

Machines with operating speeds below 120 rpm are classified as low-speed machines

- These machines are usually the most critical elements of the production line, generally large and with high rotating inertia.
- If a breakdown occurs, downtime and replacement costs can be enormous, which can lead to huge production losses.
- Unlike medium-to-high-speed machines, monitoring the condition of low-speed machines is a challenge as standard sensors go into crisis.



Suitable methods and characteristics for a typical rotary bearing above 120 rpm cannot be effectively applied to identify abnormal bearing conditions at low rotational speed. This is due to the low emission of shock energy from the rotating elements, contact with a defective point may not show a noticeable change in the vibration footprint corresponding to the damage condition of the bearing and therefore become difficult to detect with conventional vibration analysis

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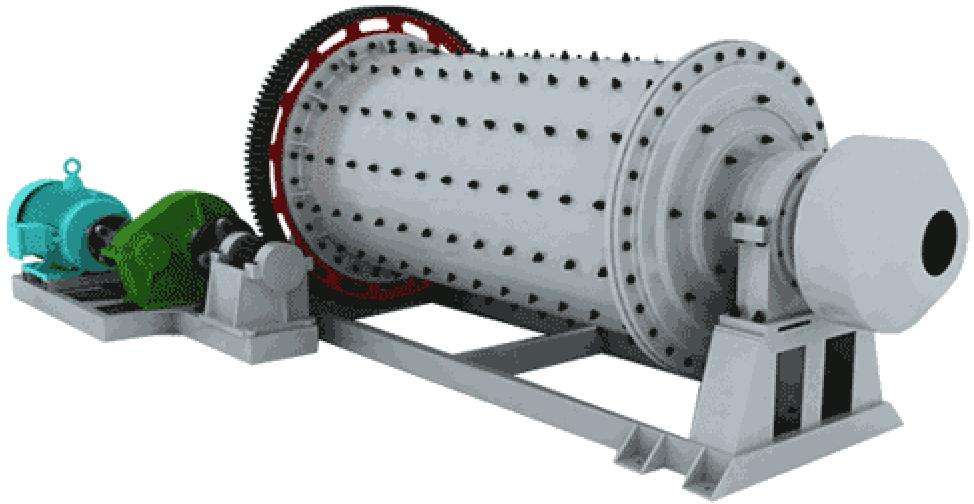
Machines that rotate at 6 rpm

Bearing fault detection for a 6-rpm shaft can be a real challenge for the following reasons:

- It may only be possible to detect a significant bearing failure but not the trend in advance.
- Very low values for frequency and acceleration amplitude for bearing failure frequencies.
- Bearing vibrations may not be detectable with high vibrations due to background noise.



- A long measurement time of 5 to 10 revolutions is required, which would be 50 to 100 seconds of data per measurement.

The vibration analyzer shall have a long-term recording measurement capability.

The ability to analyze the vibration signal should include the general level of peak acceleration, the time waveform, the FFT spectrum, and the demodulated spectrum (envelope).

An accurate measurement of shaft velocity that may require more pulses per revolution.

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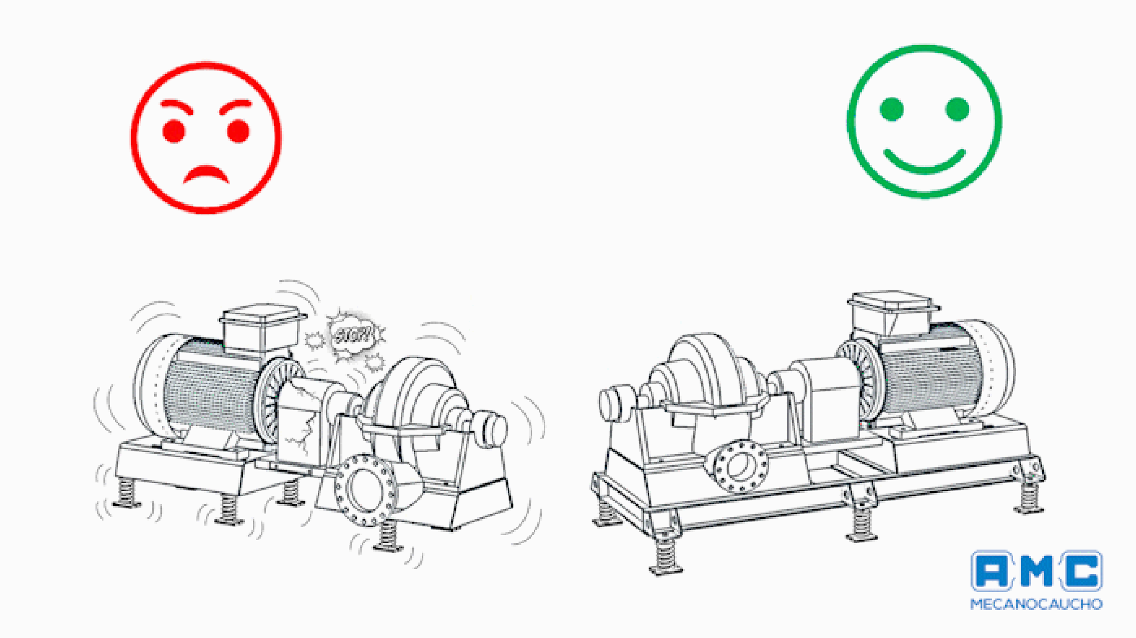
Common mistakes

Some common errors for low rev applications include:

- Incorrect use of low-frequency sensors
- Mounting the wrong sensor
- Incorrect selection of the sampling filter
- Inadequate measurement time
- Do not take into account any variable speed
- Do not take into account the loading area



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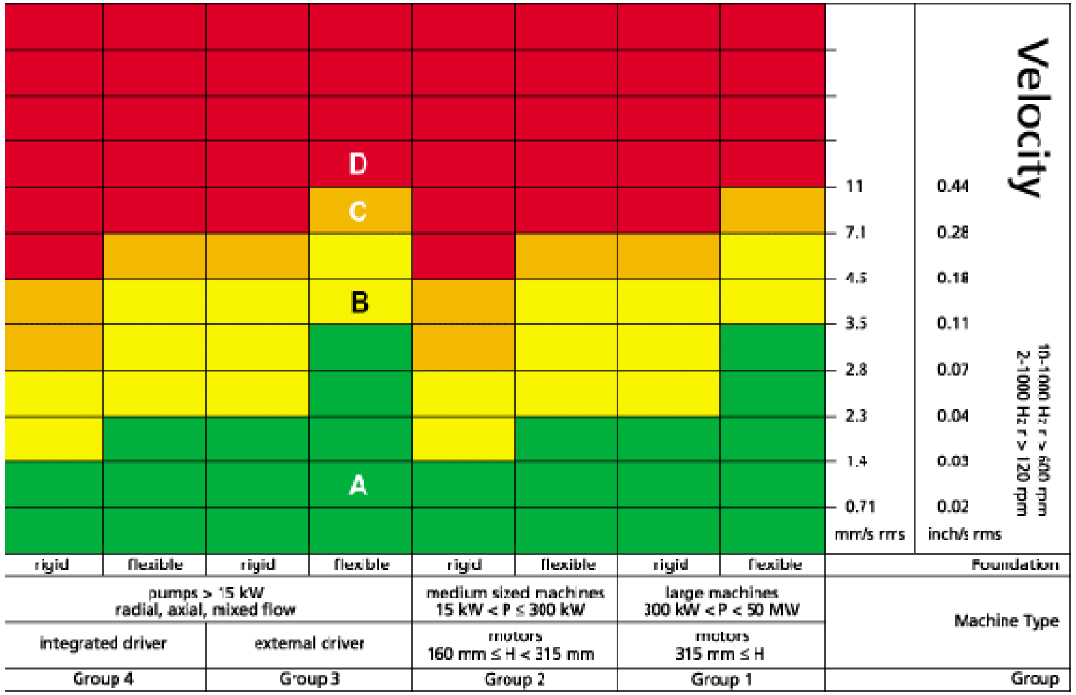
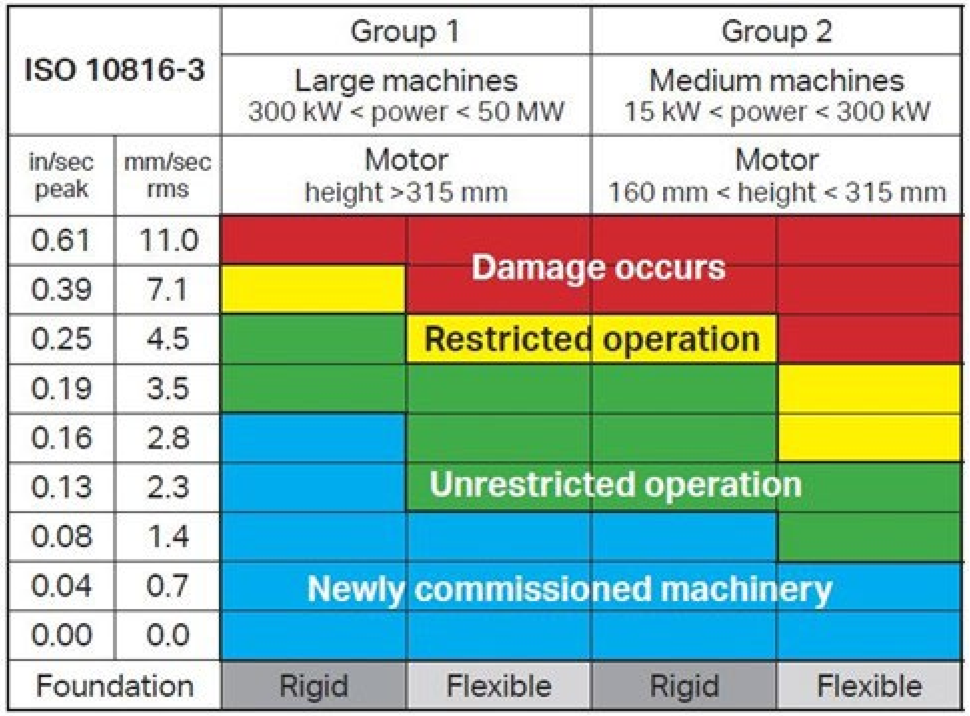
ISO 10-816-3 Regulatory Limits

ISO 10816-3 applies specifically to machine groups with power above 15 kW and operating speeds between 120 and 15,000 rpm. This category includes common industrial motors, pumps, generators, rotary compressors, fans and fans, and different types of turbines. Of course, some machines have power or speed requirements outside the scope of the norm.





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Frequency Domain

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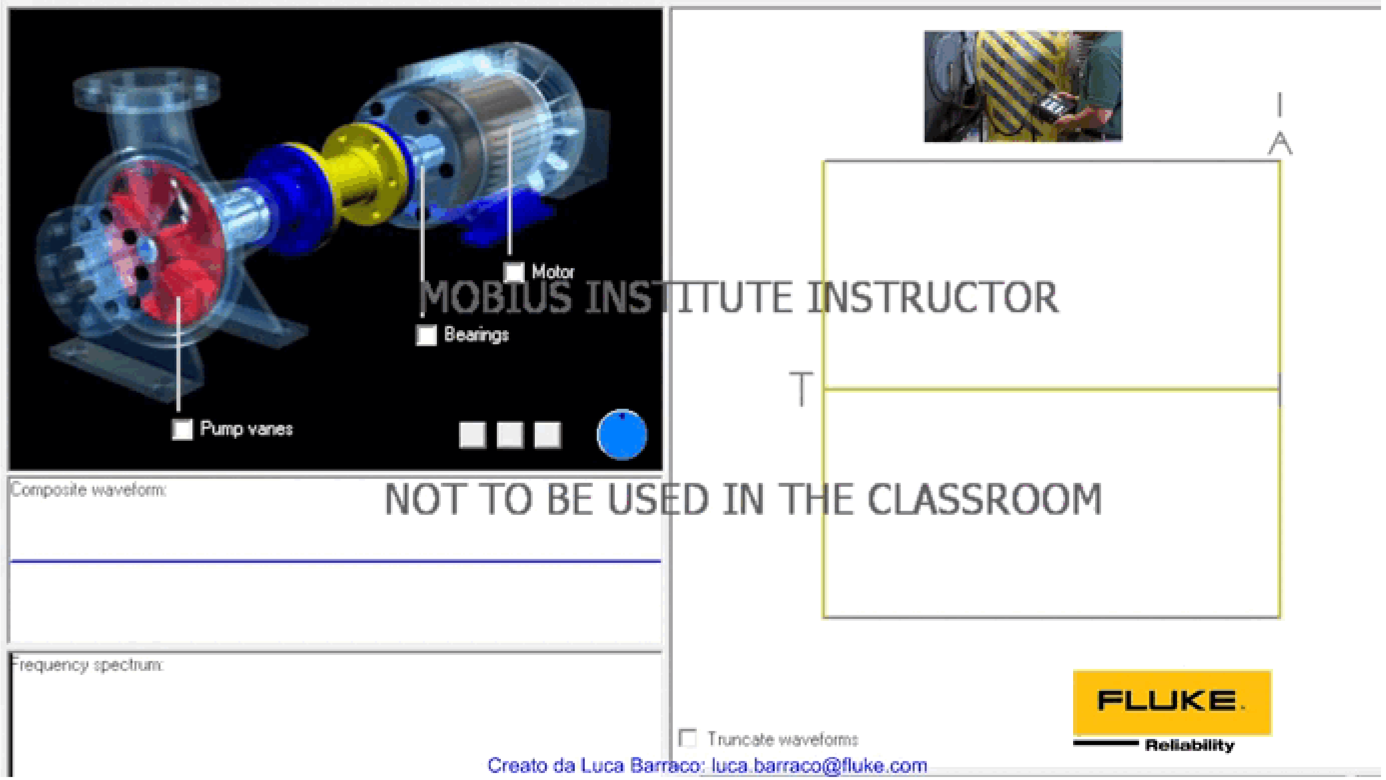
Frequency



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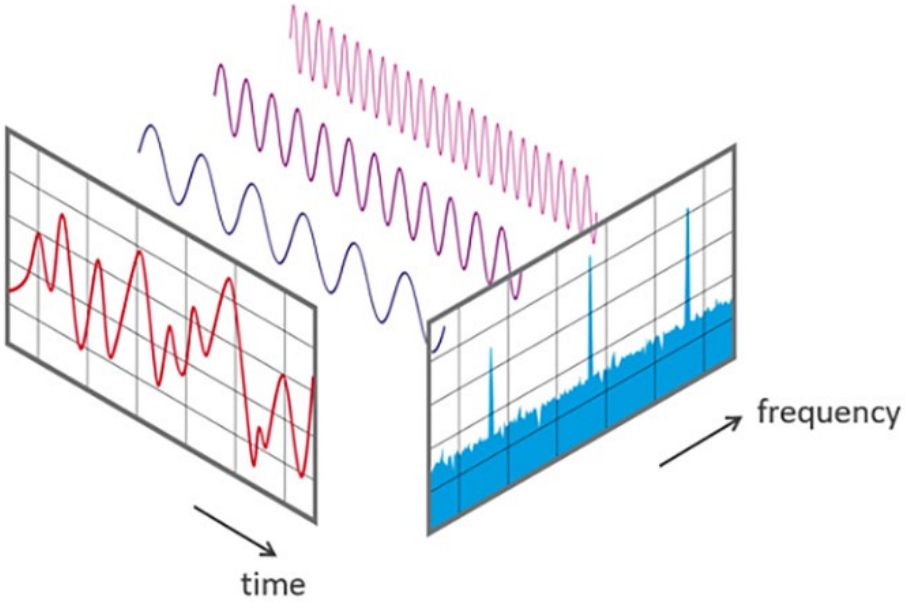

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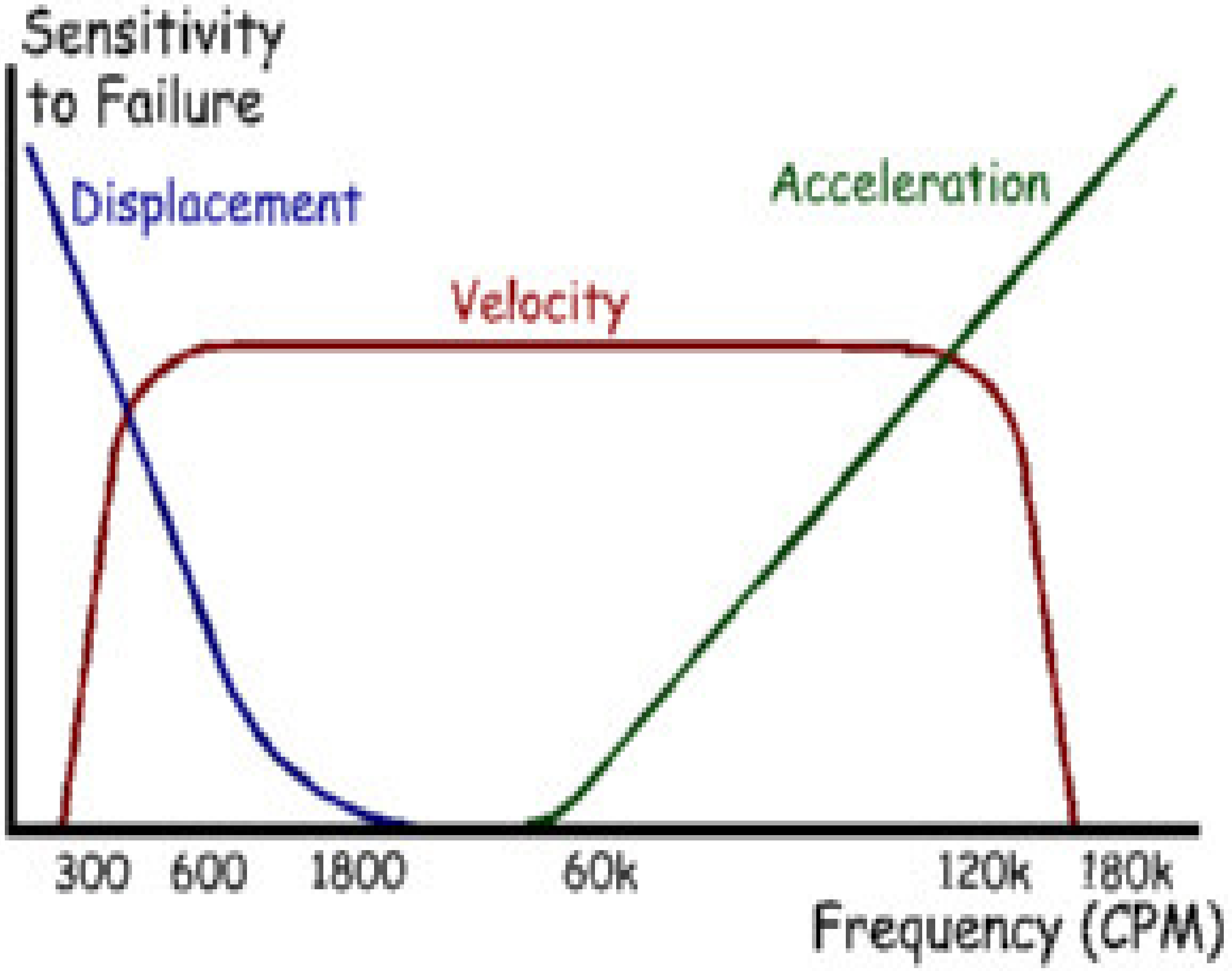
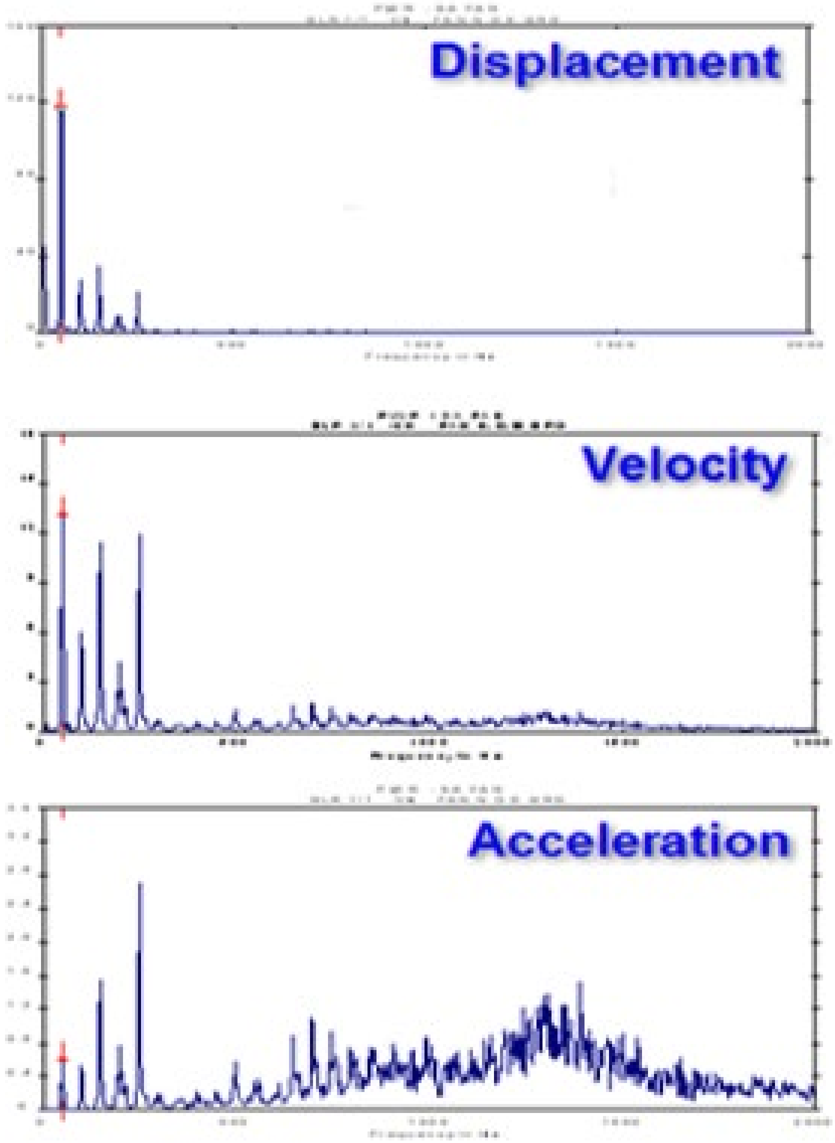
Frequency sensitivity





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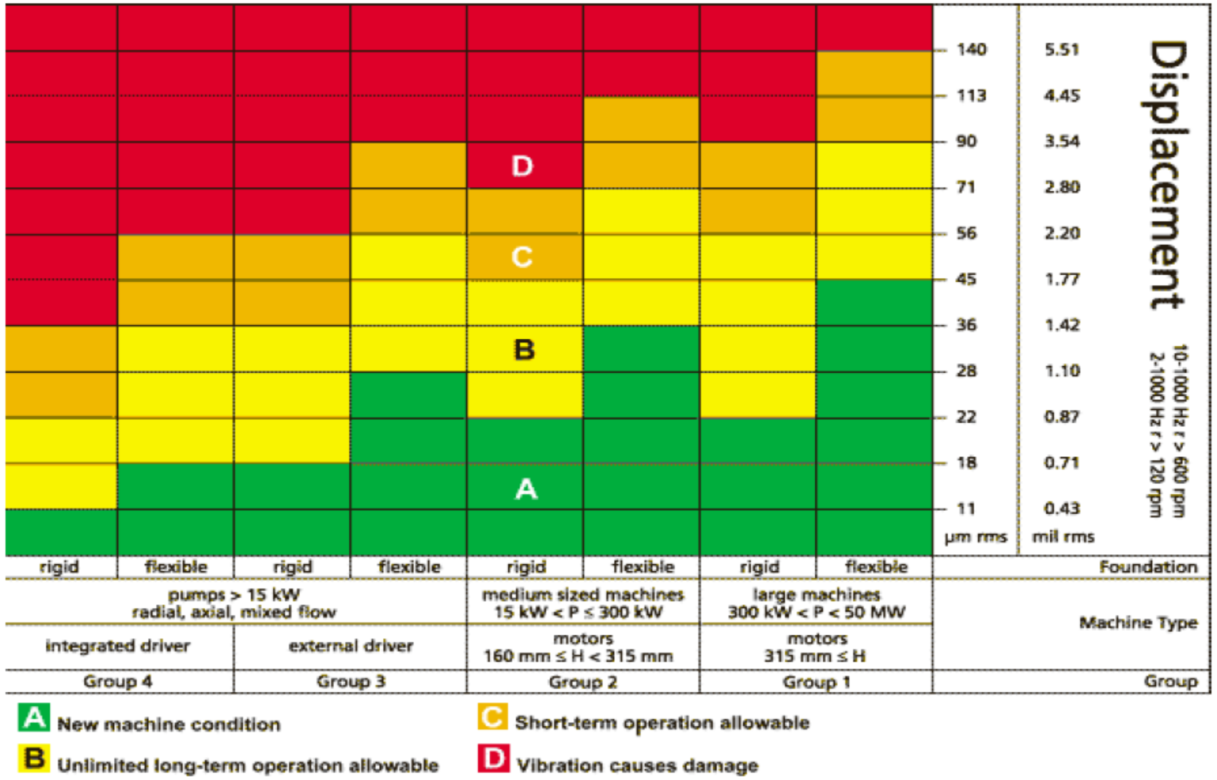
On-the-go integration

We can see that the quantity chosen to define the comparison thresholds is the Vibration Speed (RMS value), this is because it is the best compromise for the frequency range of interest (10 – 1,000 Hz for machines with revolutions > 600 RPM and 2 – 1,000 Hz for machines with revolutions > 120 RPM), also the thresholds are 3 that indicate respectively pre-alert (green), alert (yellow), alarm (red).



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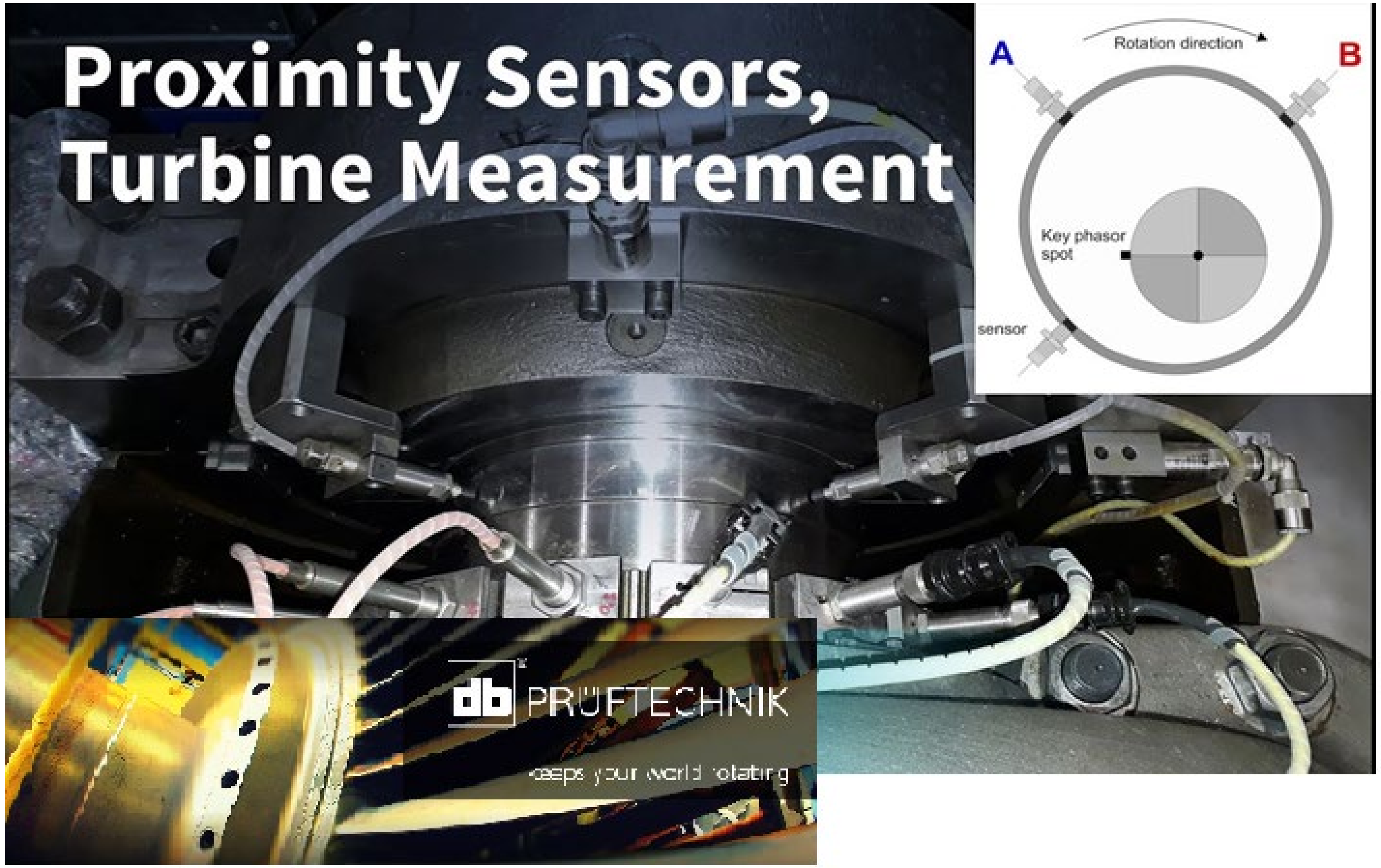
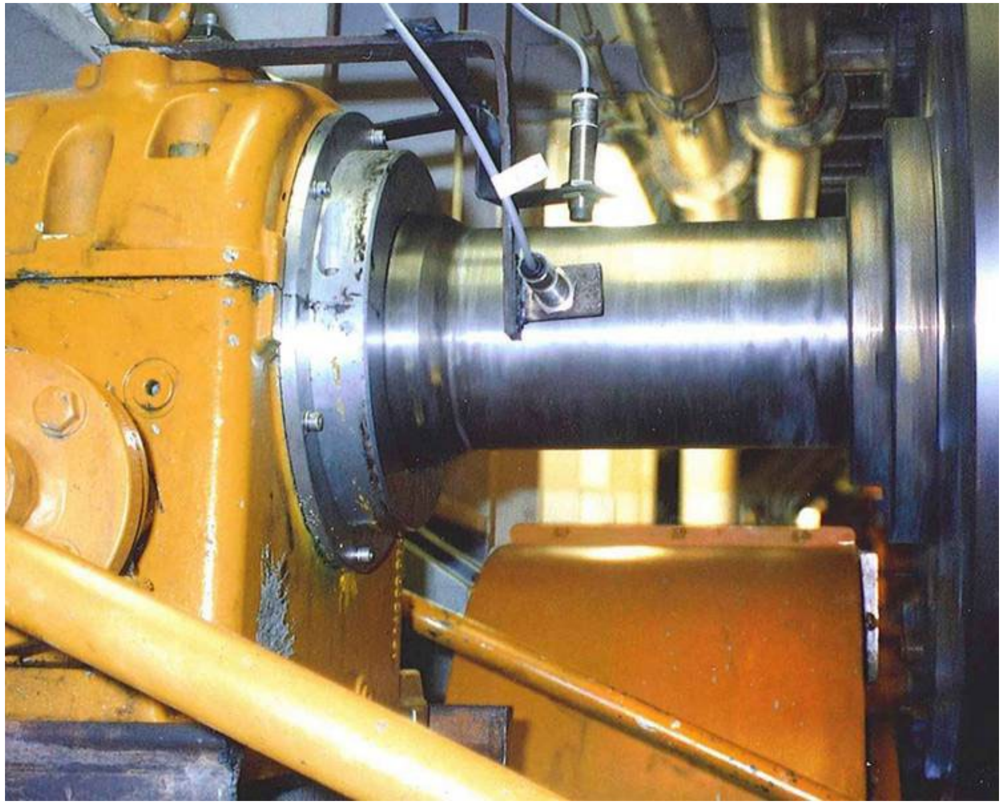
Displacement vibration measurements

Relative of the shaft to the case



Tree absolutes



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Accelerometer use

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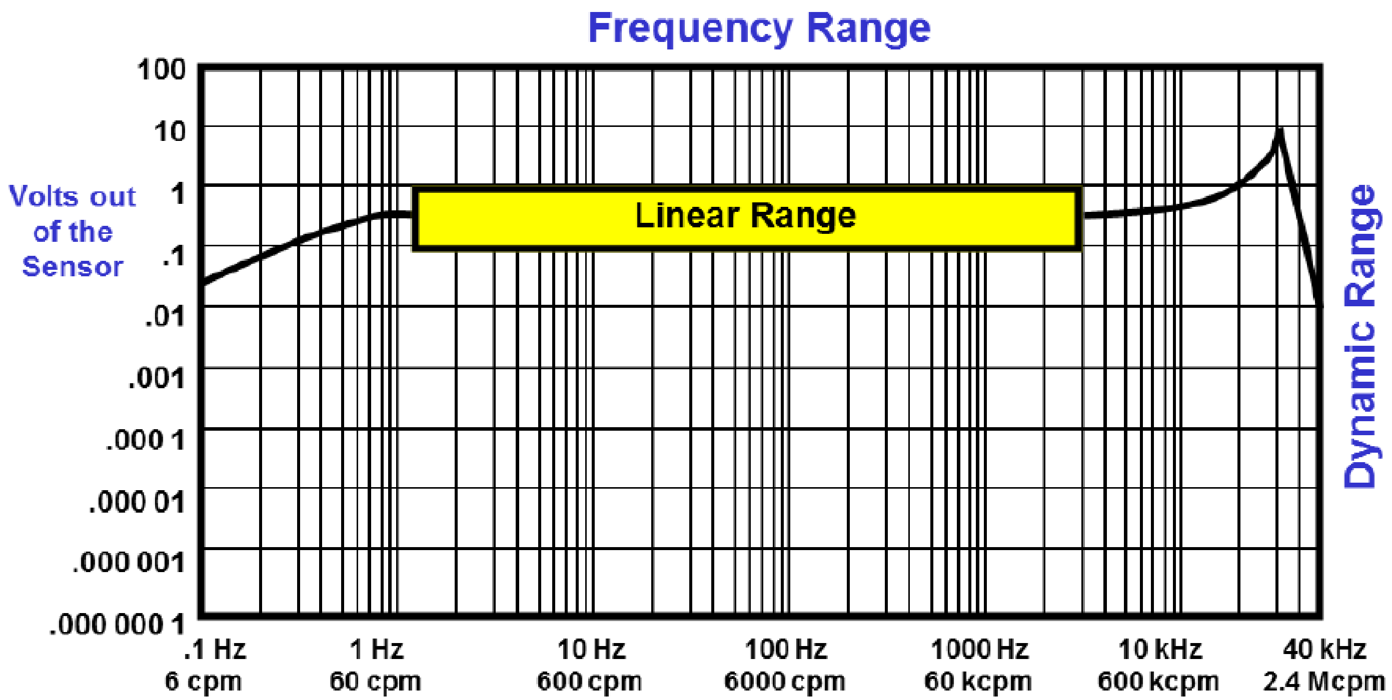
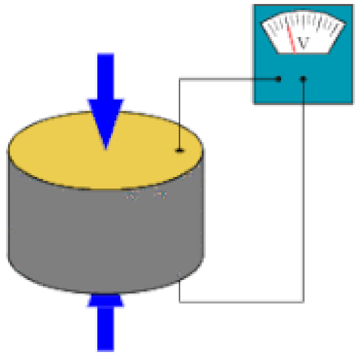
Accelerometer limits: Frequency and sensitivity response

Frequency range ± 5%	2.5 Hz to 13 kHz
Frequency range ± 10%	1.6 Hz to 17 kHz
Frequency range ± 3dB	1 Hz to 20 kHz



- 1 g at 10 Hz would generate 100 mV
- 1 g at 1,000 Hz would generate 100 mV
- 1 g at 10,000 Hz would produce 100 mV



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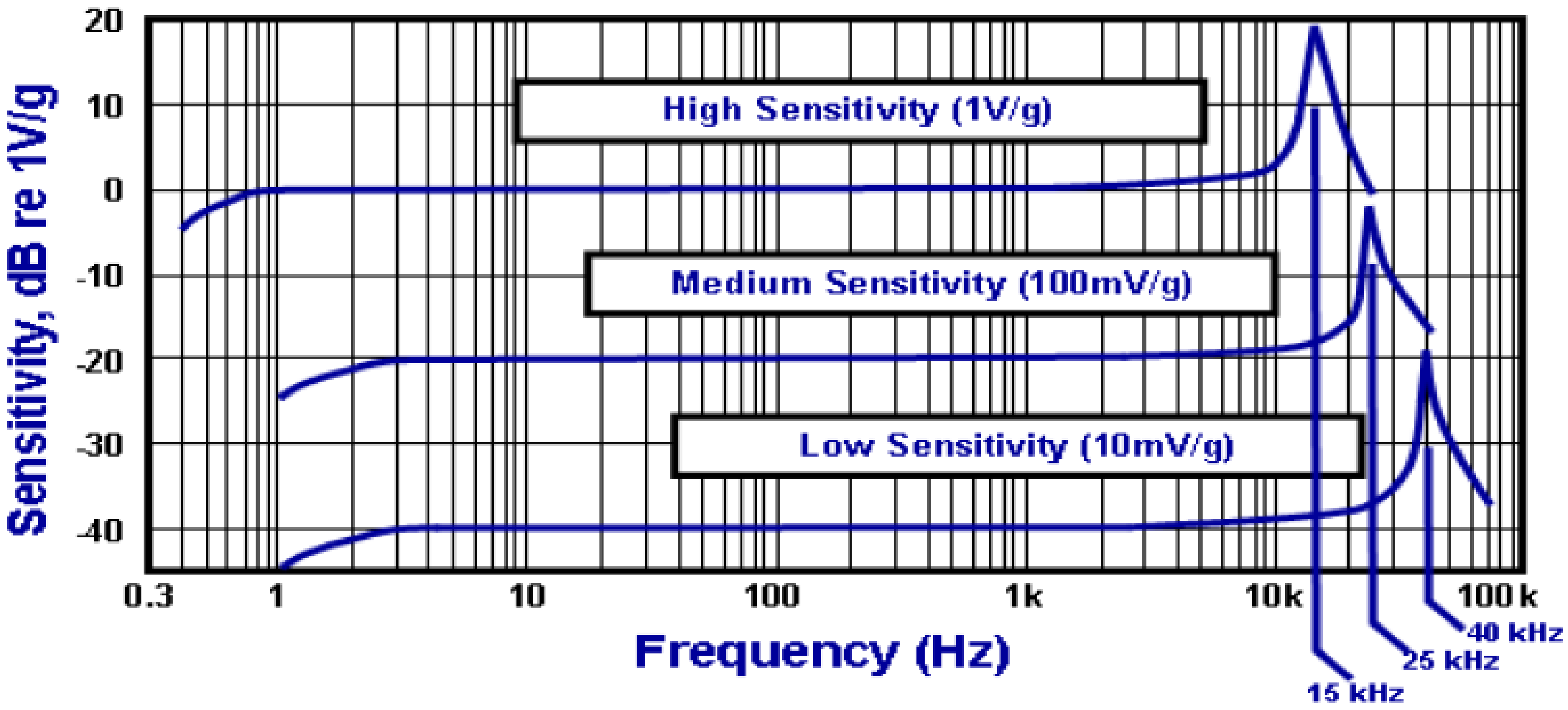
Frequency response variation with sensitivity



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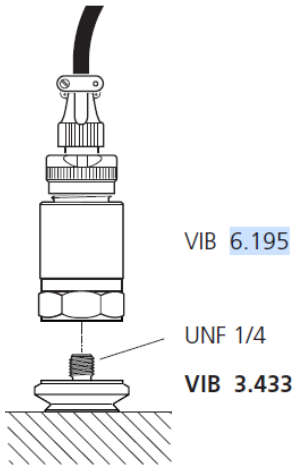
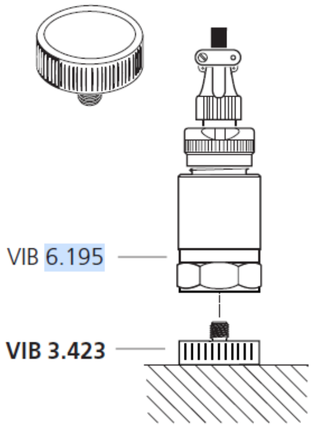
CLD accelerometers for low speeds

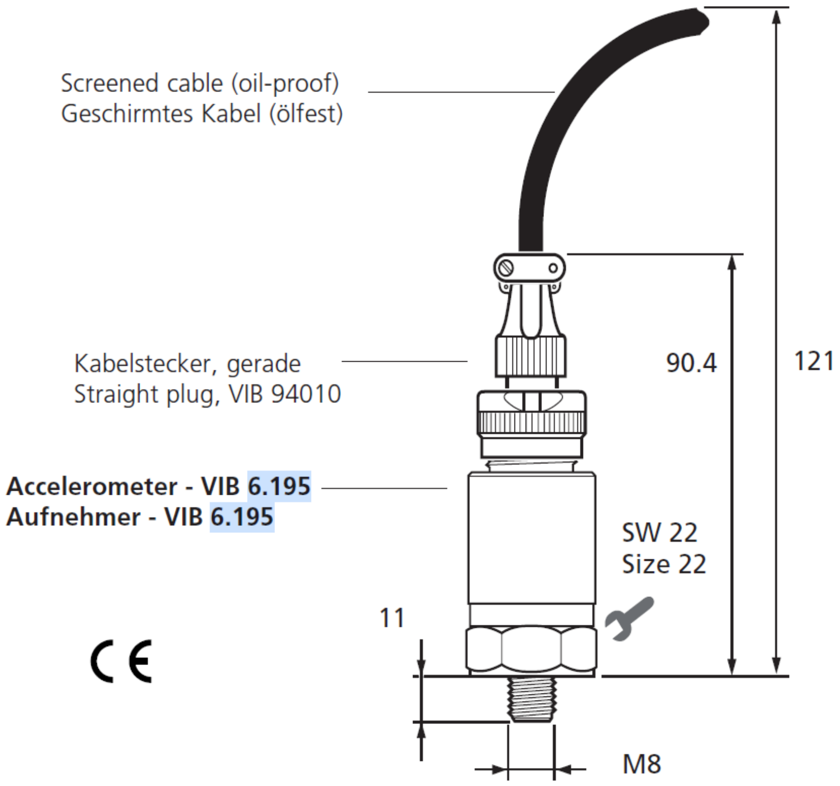
Technical data - VIB 6.195

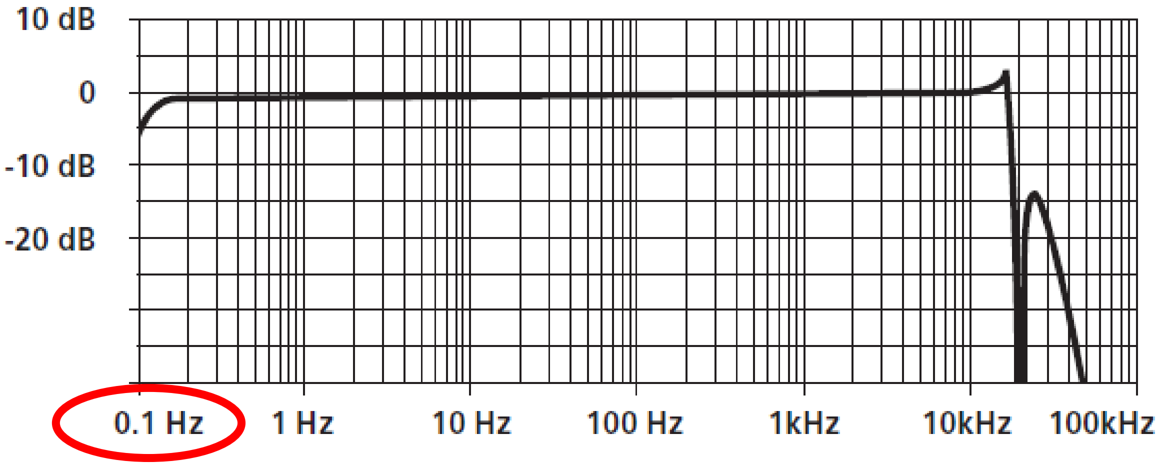
For vibration measurement up to 10 kHz on low speed machines (<60 rpm).

Signaling system	Current LineDrive, 3.5 mA closed current with superposed AC signal
Max. measurment range (r.m.s.)	up to 450 m/s² (46g)
Transmission factor ±4%	5.35 µA/ms^{-2} at 159 Hz, 25°C = 51.9 µA/g at 159 Hz/77° F
Frequency range ±3dB	0.1 Hz to 10 kHz
Resonant frequency	17 kHz; >20dB damped
Linearity range ±10%	±450ms^{-2} (±46 g)
Temperature range	-30°C to 80°C /-22°F to 176°F
Power requirement	>10 mA / 7-18 V DC
Transverse sensitivity	< 5% at 5 kHz
Temperature sensitivity	< 0.01 ms^{-2}/K
Magnetic sensitivity	<1 ms^{-2}/T (at 50 Hz)
Base strain sensitivity	< 0.01 ms^{-2}/µm/m
Electrical noise, rms	< 0.002ms^{-2} from 2 Hz
Output impedance	> 300 kOhm
Shock limit	50 kms^{-2} = 5 000g
Case material	VA 1.4305 (stainless steel)
Environmental protection	IP67
Weight	85 g / 3 oz.
Mounting	M8 thread
Connector type	Cable connector, 2 pin (Mil-C5015)









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Absolute and Relative Alarm

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Absolute and Relative Alarm

For many years the major software packages have included an "exception report". The software scans through all of the new vibration measurements, compare them to alarm limits, optionally compare them to previous readings, and then generate a list of machines with the results.

The results indicate the current level of the data, as well as the level of exceedance. The exceedance may be reported as a percentage (100% indicates the new level is twice the alarm limit) or less frequently in decibel (6 dB is the same as 100%).

The results typically also indicate how the latest readings have changed compared to the previous readings, and/or to a reference or baseline reading. Again, the results are presented as a percentage increase or a dB ratio.

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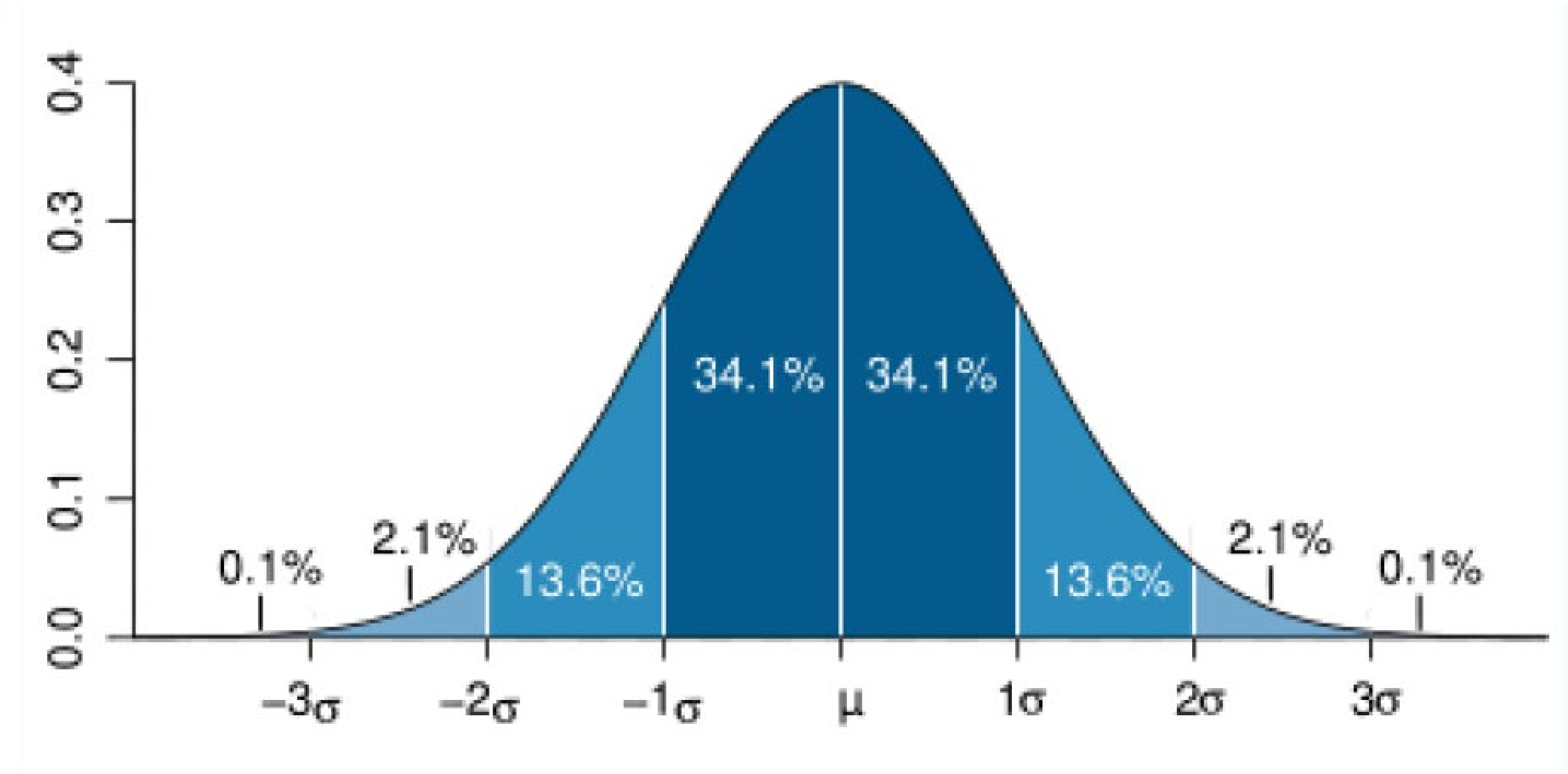
Statistics Allarm



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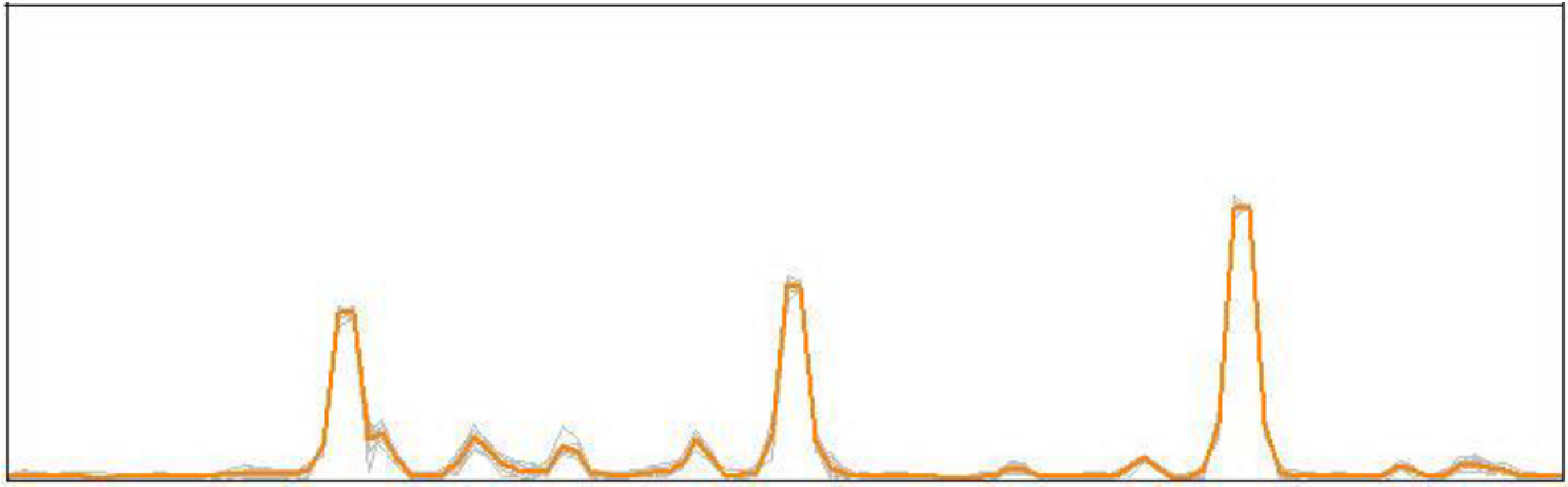
Historical data set



Zoom of three peaks in the spectrum – grey data represents the past readings and orange is the average

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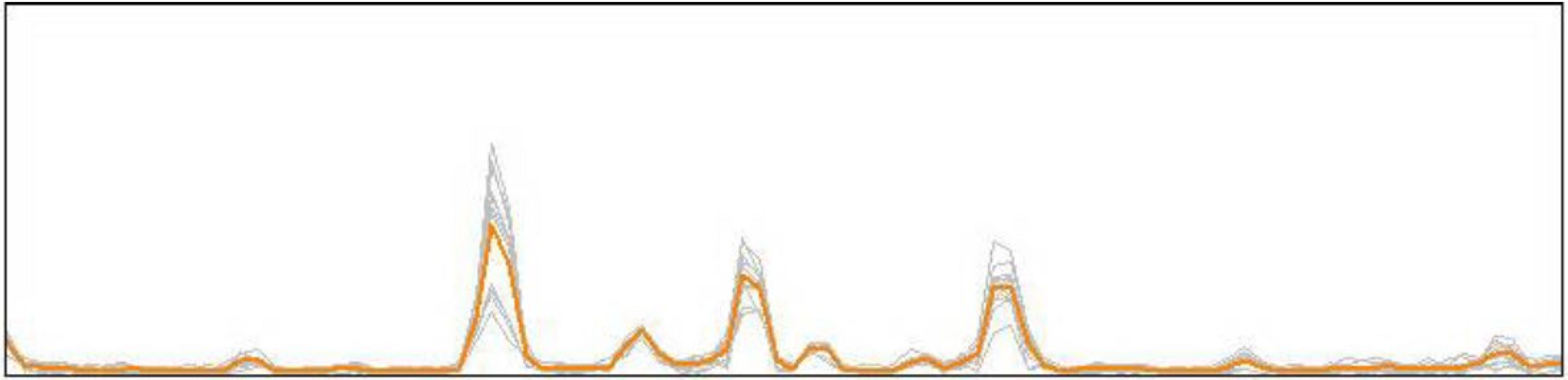
Statistics Allarm

Now the amplitude levels at each frequency varied by 10% then we would expect the eleventh spectrum to also vary by up to 10%.

Using average plus 2 sigma (i.e. μ ±2σ) as the reference, and then adding offsets to that calculated spectrum for alarm and alert values. By using average plus 2 sigma, you ‘believe’ there is a 95% probability that future readings should be below this limit.



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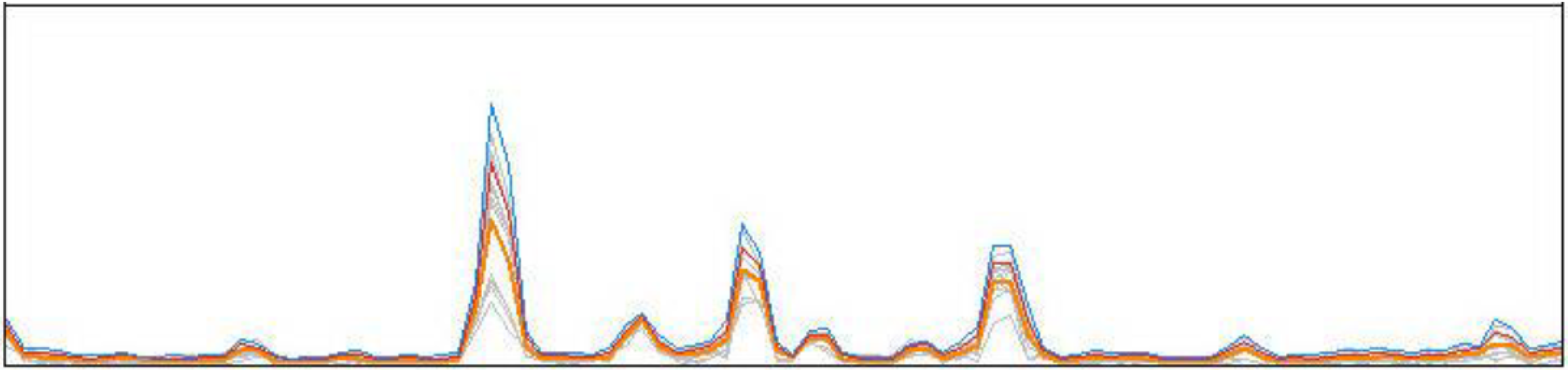
Statistics alarm



Grey is normal data, orange is average, red is average + one sigma, and blue is average + two sigma

In this set of data the average plus two sigma data is above all of the measured data. If we used this spectrum to set the alarm limits, then we could feel confident that only ‘unusual’ data would exceed the data.

Statistics can be used to protect different parts of the spectrum in different ways – all with the same effect – determine what is normal and set alarm limits accordingly.

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Band Alarm

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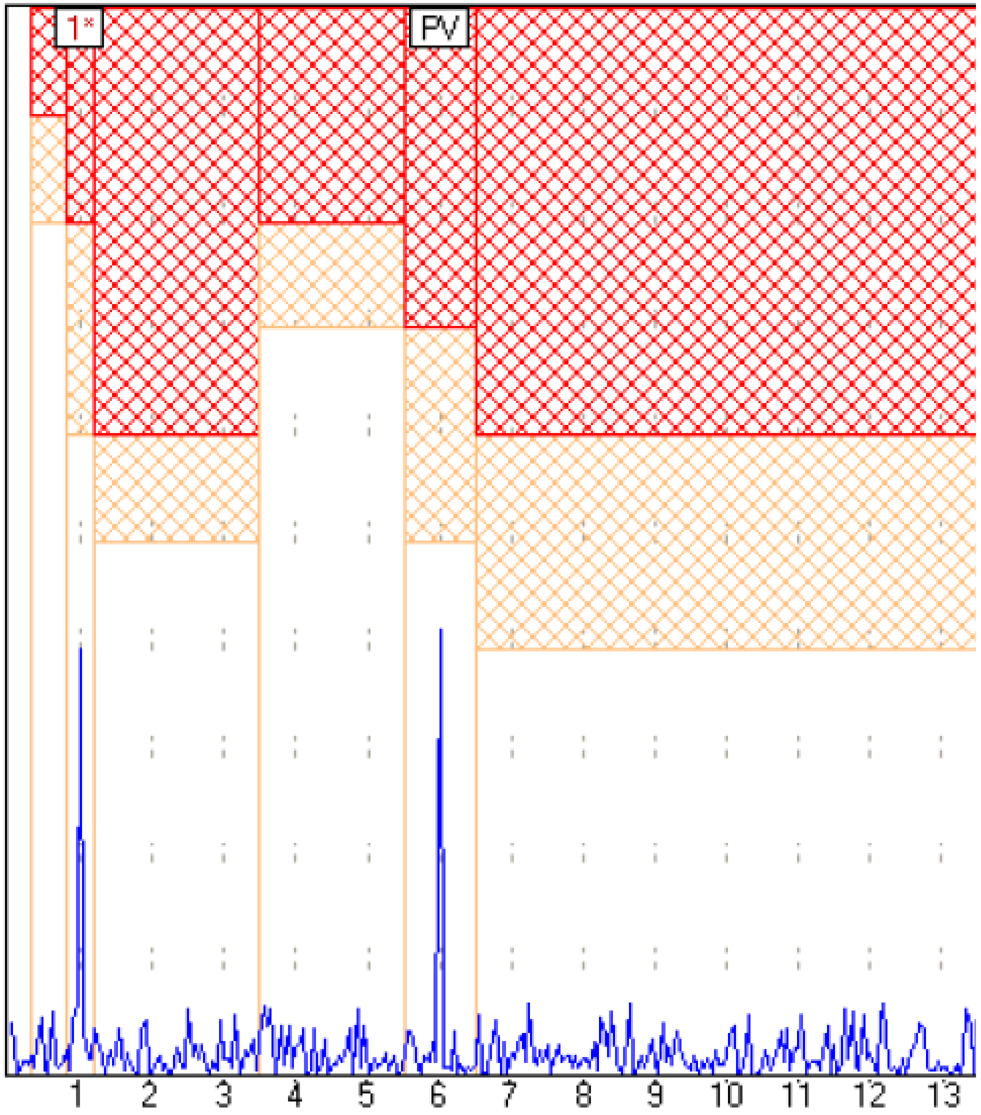
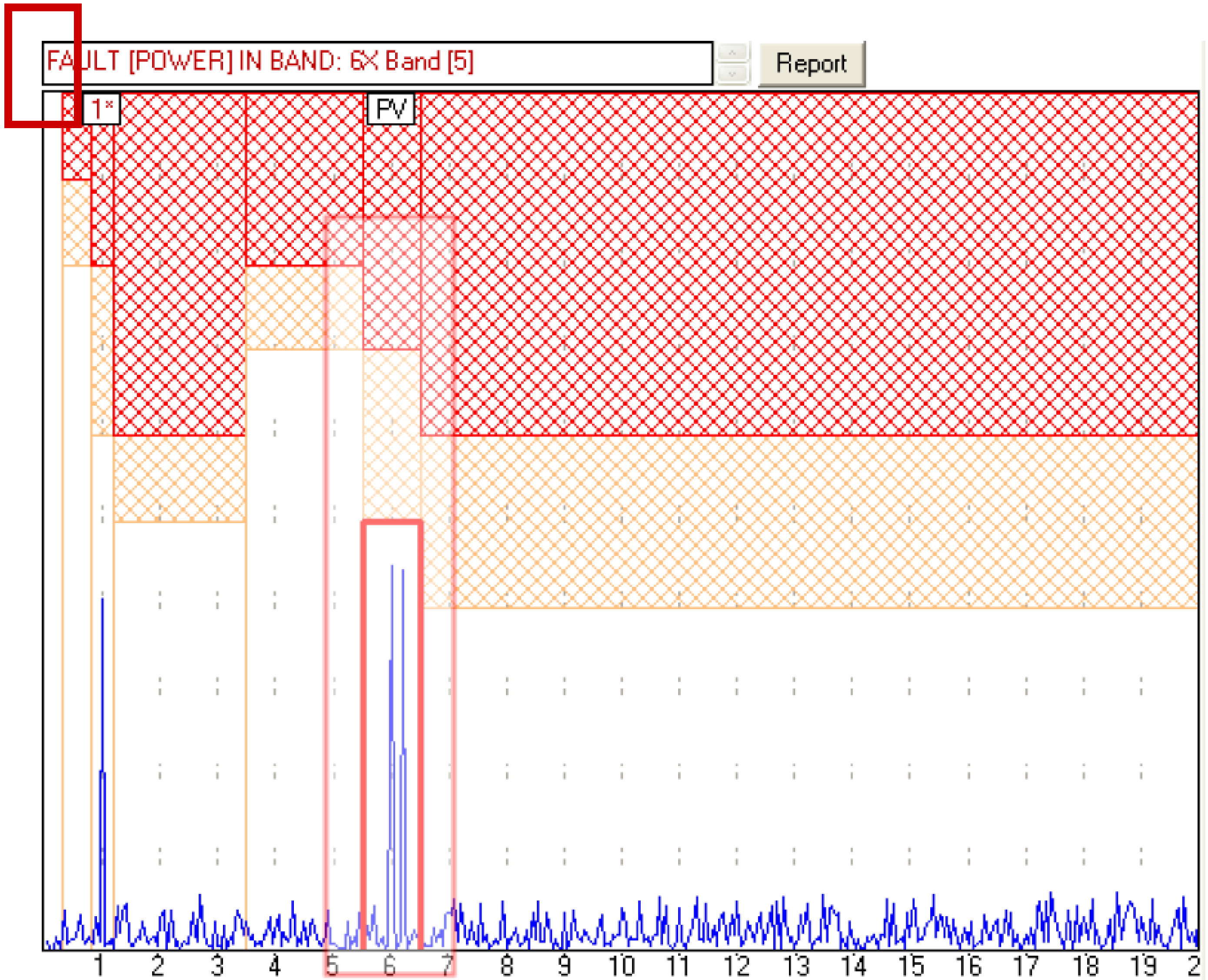
Allarm from FFT





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Frequency Bands

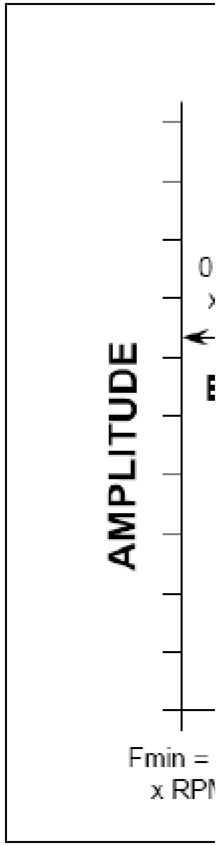

TABLE 9.4 MAXIMUM ALLOWABLE VIBRATION LEVELS FOR POSITIVE DISPLACEMENT AND CENTRIFUGAL PUMPS

LINE-AMPLITUDE BAND LIMITS

BAND	FREQUENCY RANGE Hz (CPM)	VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM	0.718	(0.04)
2	[0.8 → 1.2] x RPM	1.35	(0.075)
3	[1.2 → 3.5] x RPM	0.718	(0.04)
4	3.5 x RPM → 2,000 Hz (120,000 CPM)	0.54	(0.03)

BAND-LIMITED OVERALL AMPLITUDE LIMITS

BAND	FREQUENCY RANGE Hz (CPM)		ACCELERATION g's RMS	(g's PEAK)
1	0.3 x RPM → 5K Hz (300K CPM)	POSITIVE DISPLACEMENT	1.06	(1.5)
		NON-POSITIVE DISPLACEMENT	0.707	(1.0)

PUMPING FREQ. BAND (PF)	FREQUENCY RANGE Hz (CPM)		VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
BAND 5	5 Lines of resolution centered on PF.	PISTON	1.35	(0.075)
		VANE	0.89	(0.05)

ıs): 0.3 – 0.8x

ꞁx – 3.5 x

ing on the machine.

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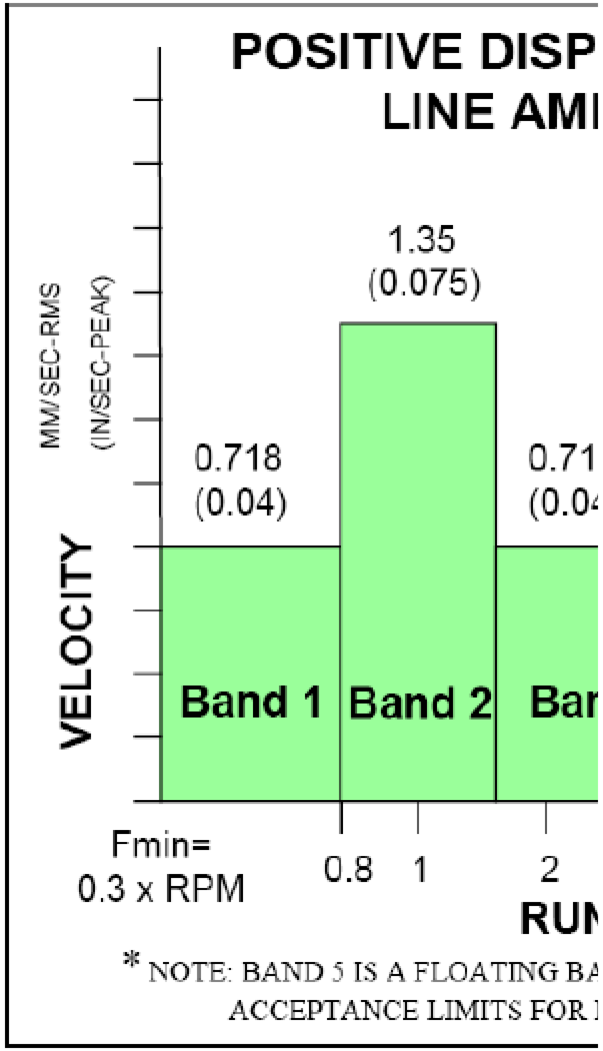
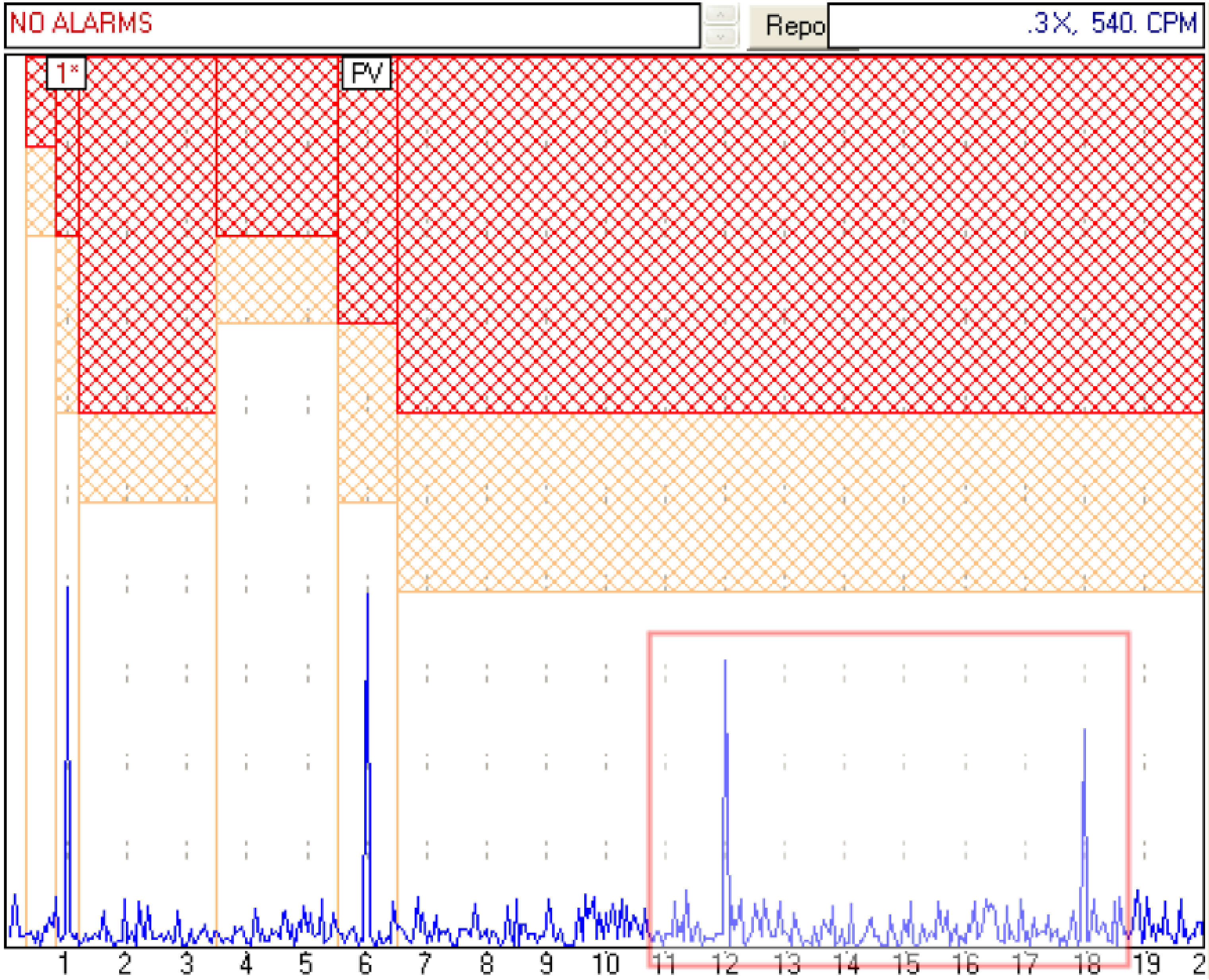
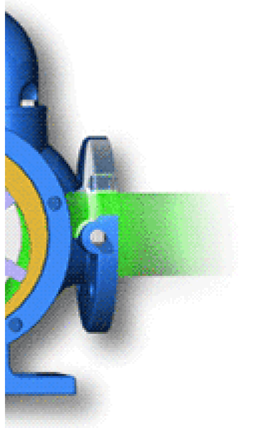
Centrifugal Pump







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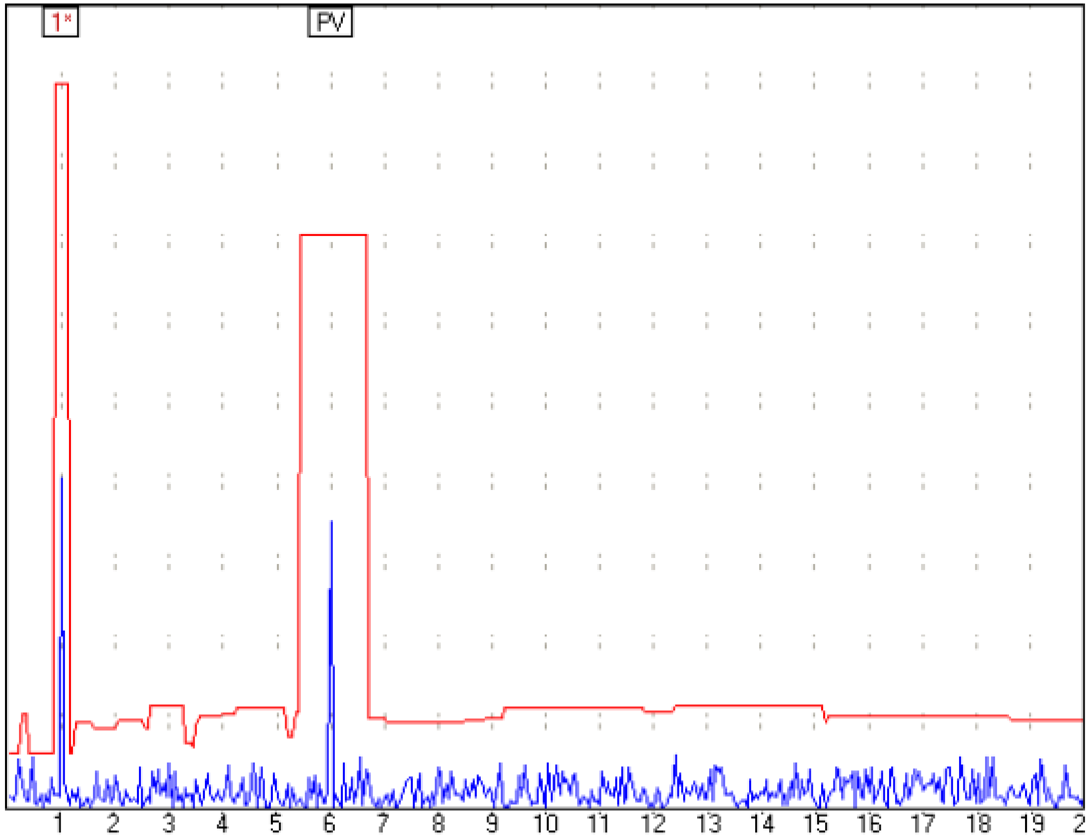
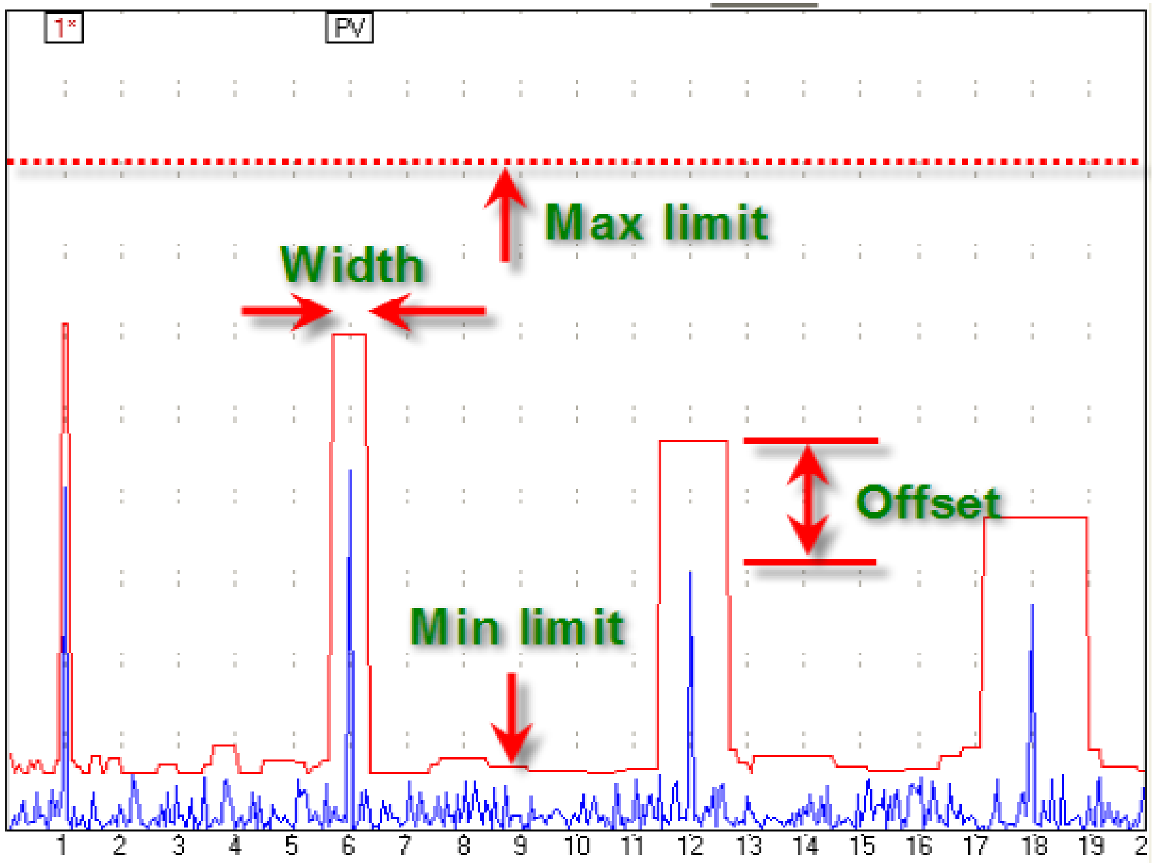
Band width and amplitude





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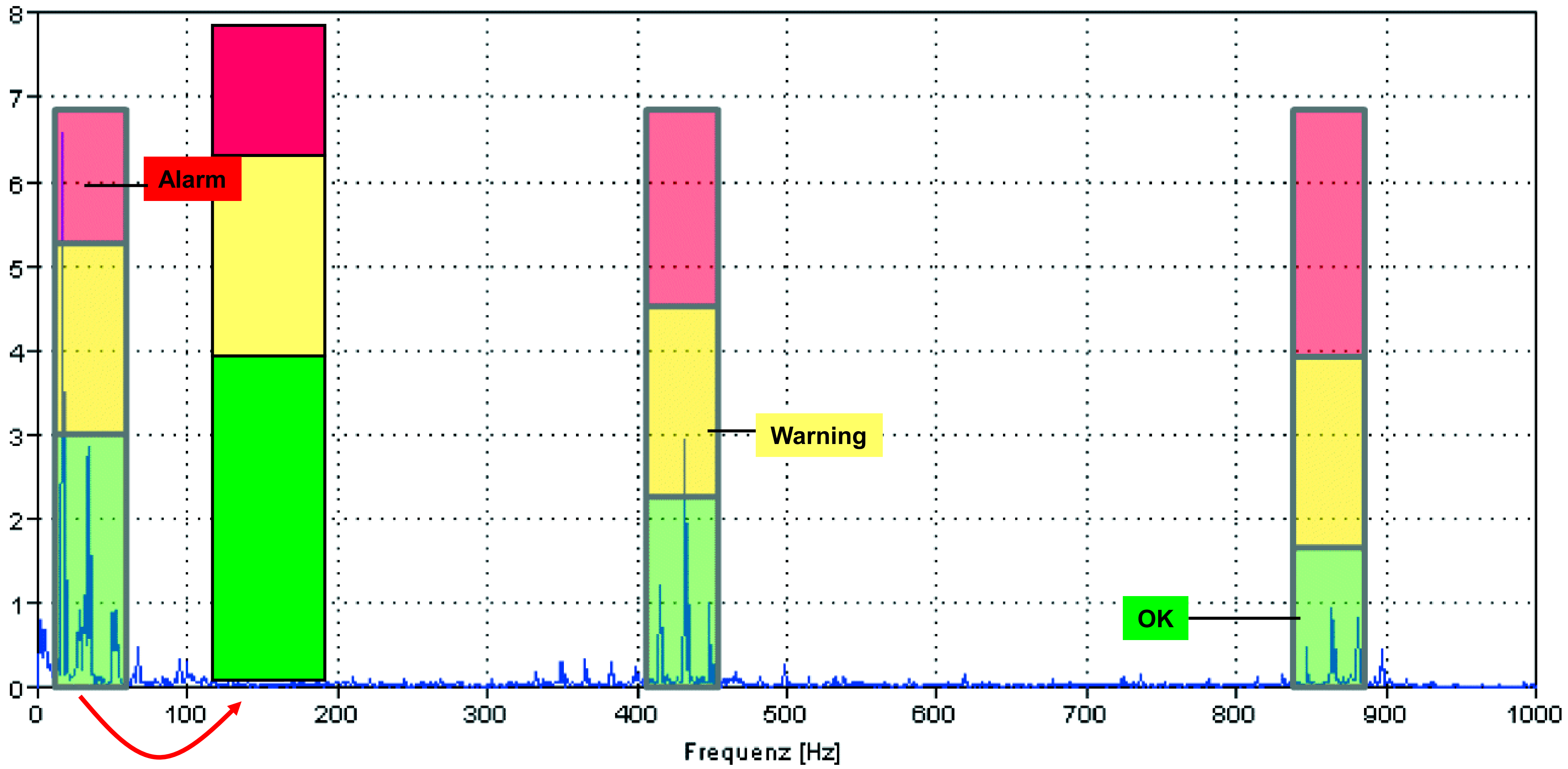
Speed and Load compensation



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Case Studies

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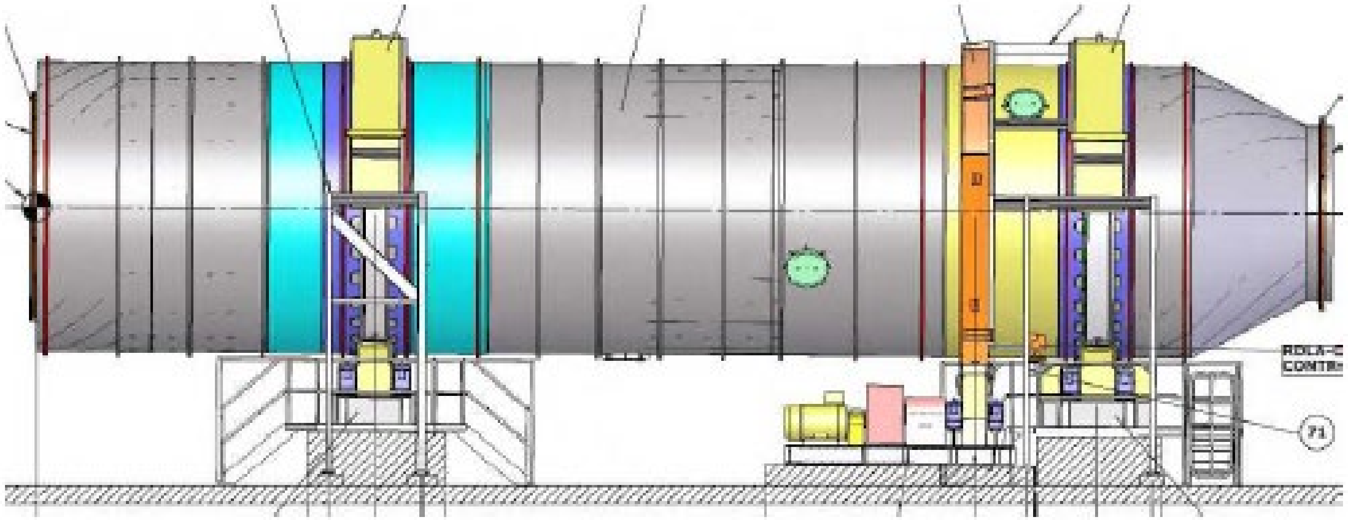
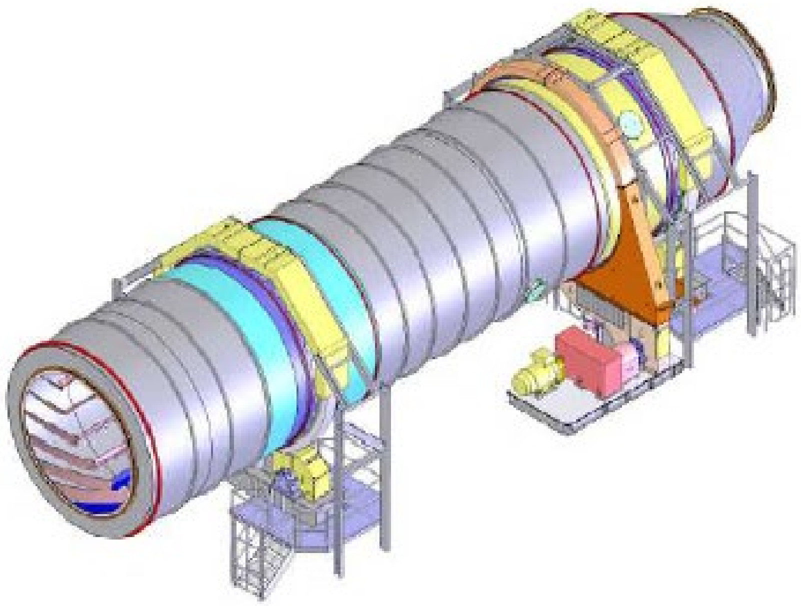
Case Study: Mill Dryer





Machine commissioned in 2021

Kinematics: Motor – Reducer – Sprocket Crowns

317 T Rotary Oven

8 holders with rolling bearings

Low speed

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Case Study: Mill Dryer

Low speed at 11.3 RPM

Envelopes with advanced filters

Continuous Condition Monitoring Program

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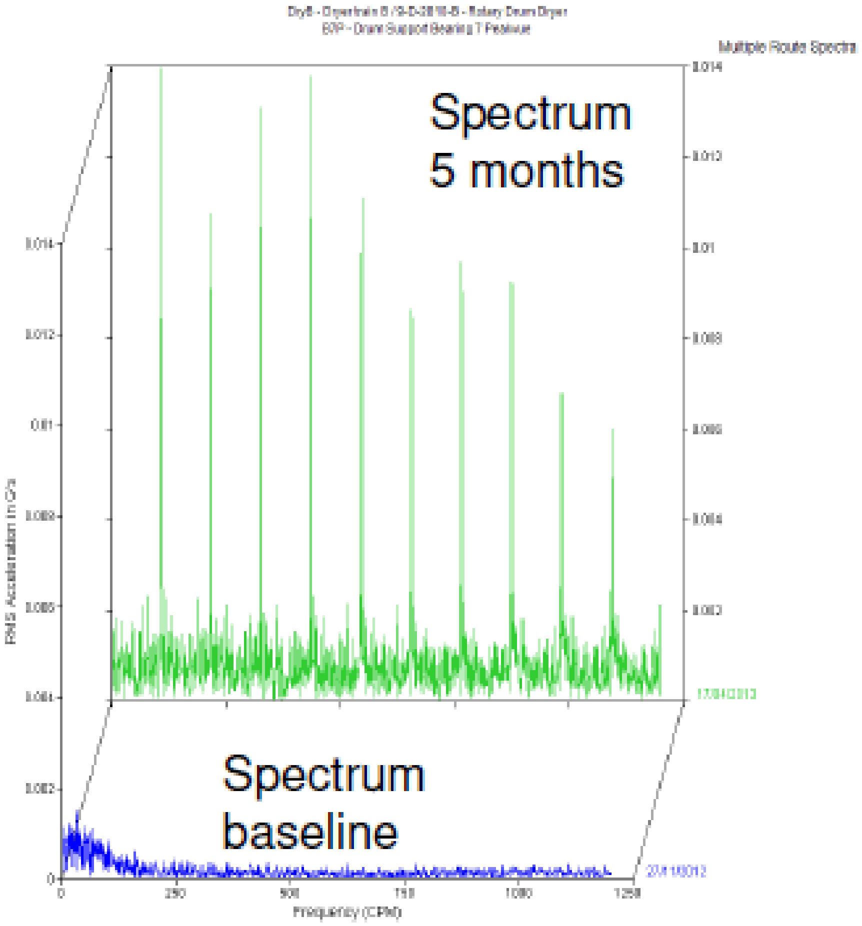
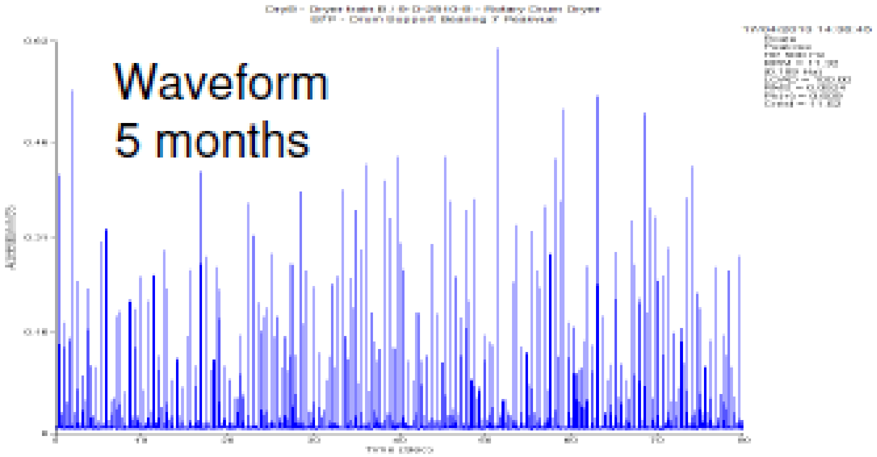
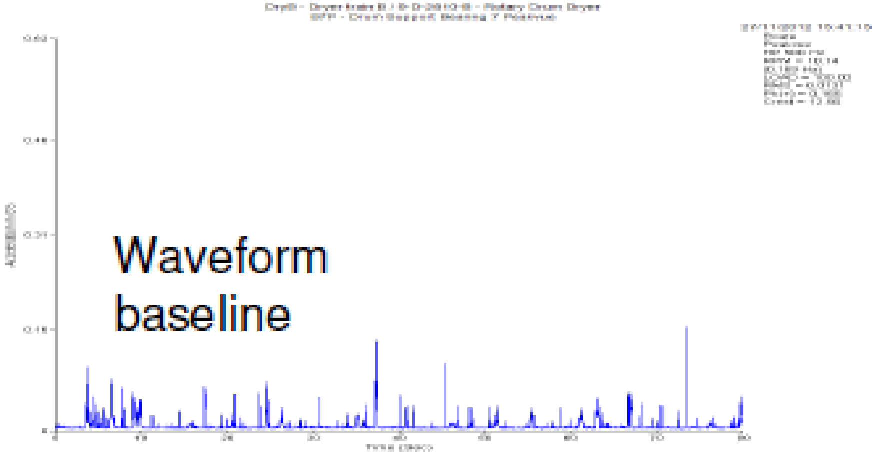
Case Study: Mill Dryer







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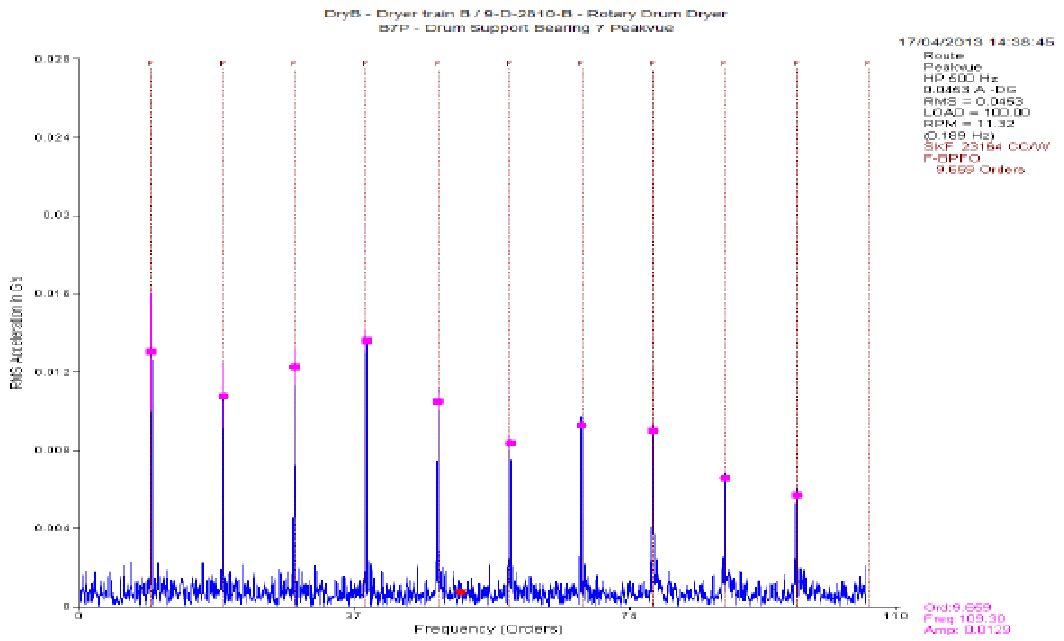
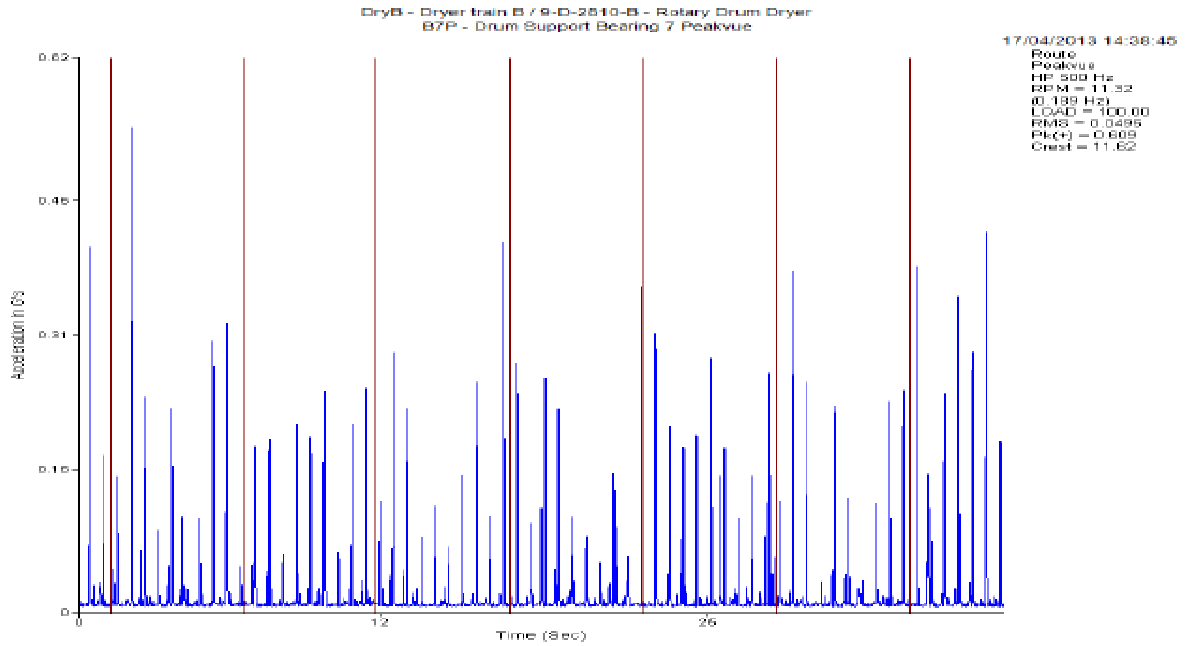
Case Study: Mill Dryer





Peak spectrum coinciding with external track frequencies bearing 23164 CC7W (9.65 orders)

Waveform impacts

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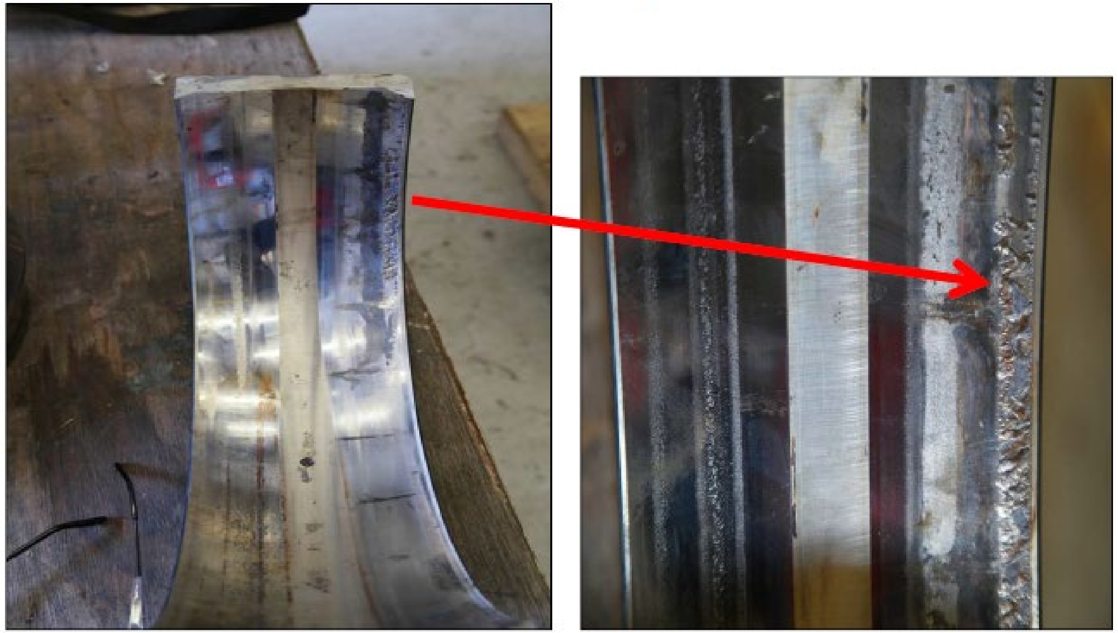
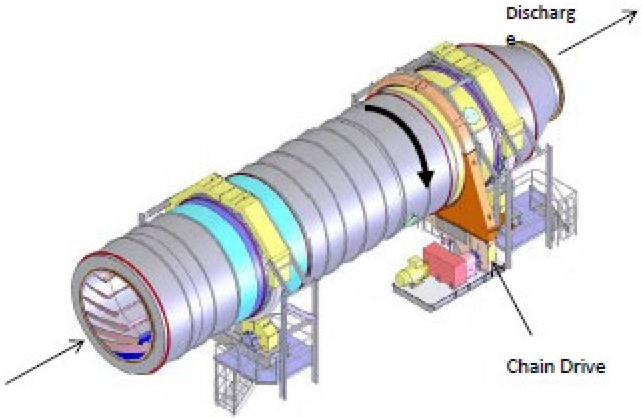
Case Study: Mill Dryer

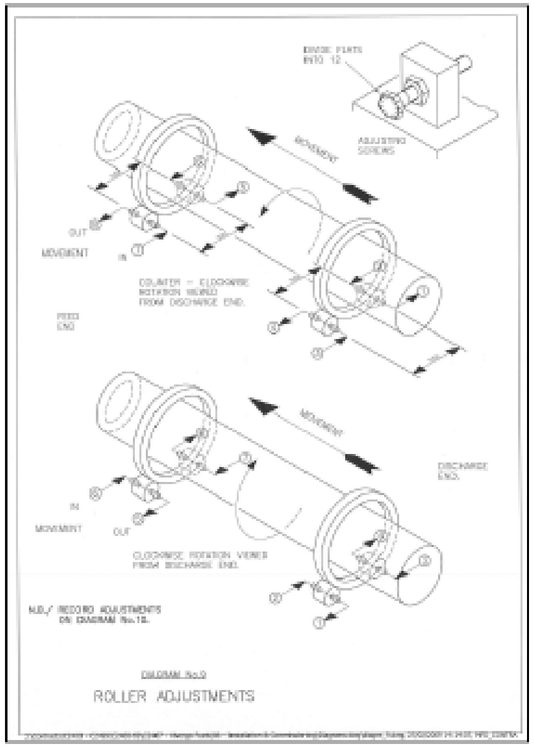




Advanced Spalling in the outer bearing track

Cause: High axial thrusts

Resolution: Kinematic alignment correction



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POLL QUESTION No. 1

Question?

(Click only one answer)

- Answer 1
- Answer 2
- Answer 3
- Answer 4

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Frequency Domain

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POLL QUESTION No. 2

Question?

(Click only one answer)

- Answer 1
- Answer 2
- Answer 3
- Answer 4

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Questions

QUESTIONS?

?

Thank you!

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