Allowable Pulsation & Vibration levels for Fault Diagnostics

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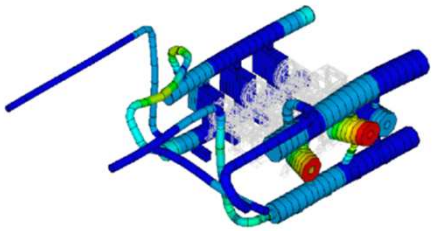

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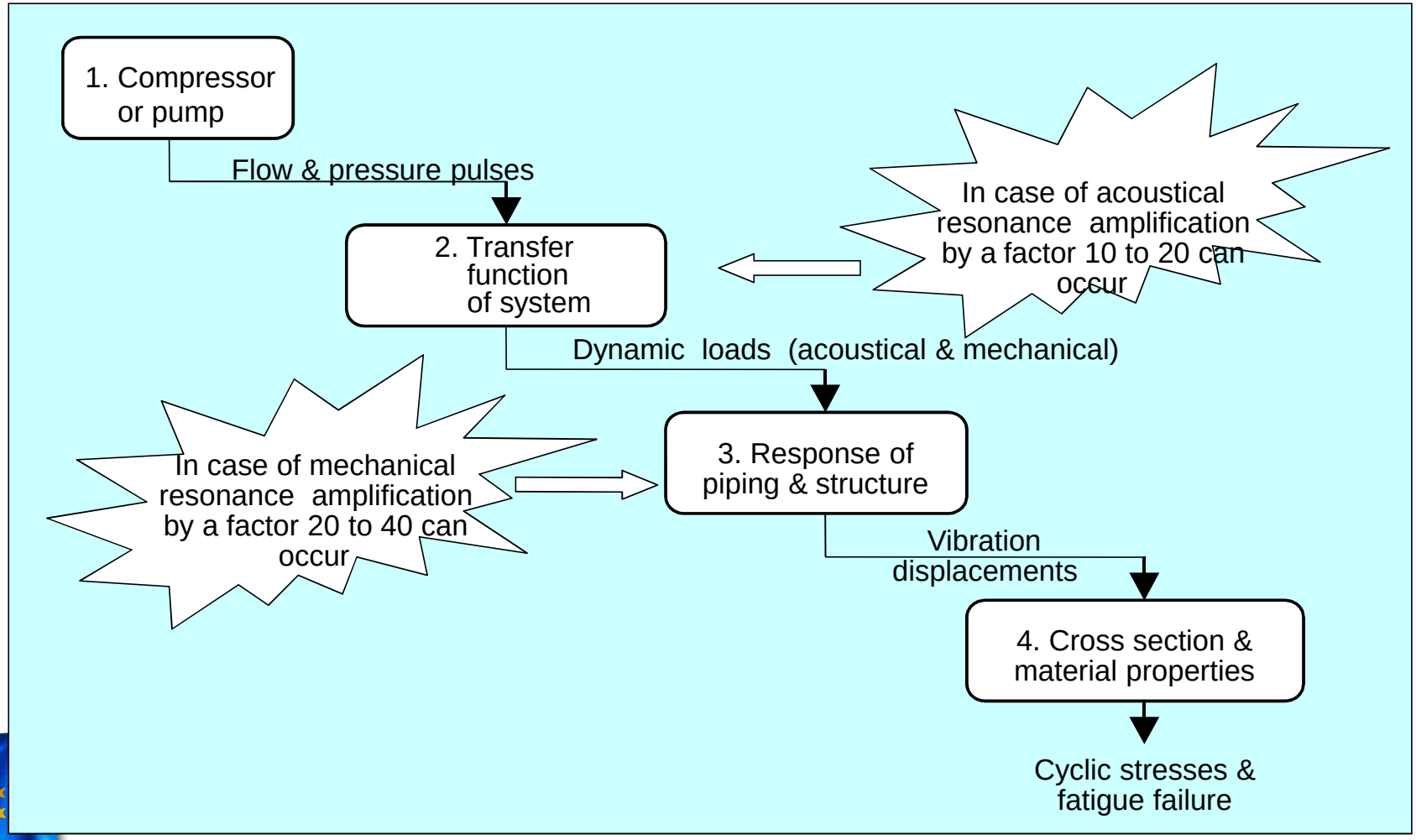
Introduction

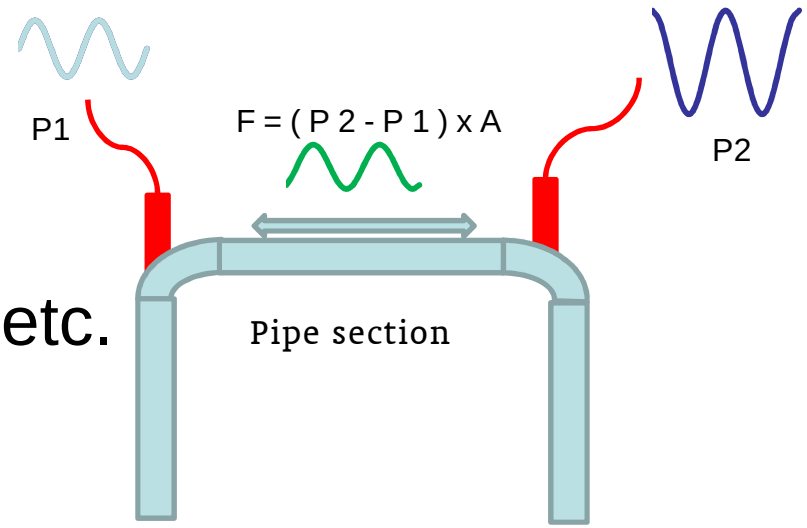


Introduction

- General parameters measured in a Root Cause Analysis:
  - Pulsations (amplitudes & frequencies)
  - Vibrations (amplitudes & frequencies)
  - Mode shapes, damping and sometimes: dynamic stresses
- This part of the course will focus on allowable levels of pulsations and vibrations

Pulsation Levels

- Dynamic loads: mechanical & acoustical
- Pulsation-induced (acoustical):
  - if pulsations “couple” (@flow & diameter change) to the structure e.g. bend, tee, reducer, closed valves etc.
  - caused by phase and amplitude differences on different locations



Pulsation Levels

- Measuring pulsation-induced forces is not feasible:
  - too much sensors required
- Measuring pulsations has proven to be a good (indirect) measure to judge if a problem can be caused by acoustical (pulsations) loads
- Two design standards for reciprocating compressors:
  - API Standard 618 (latest revision: 5th edition)
  - ISO 13707: latest revision: 1st edition which is identical to 4th edition of API 618

Pulsation Levels

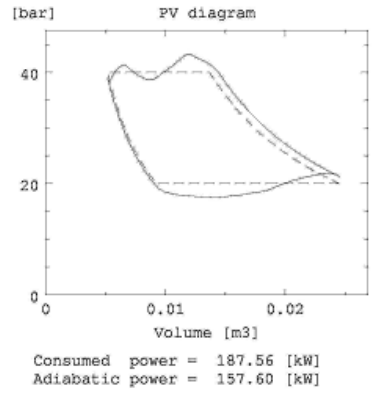
- Allowable pulsation levels in the piping according to 5th edition of API 618:

$$P_{all} = \frac{400}{\sqrt{P_{mean} * D * f}} * \sqrt{a/350} \quad [\%pp]$$

  - Pall= allowable level in % peak-to-peak of the mean static line pressure for each individual frequency
  - P_{mean}= mean static pressure [bar]
  - D= inner diameter [mm]
  - f= frequency [Hz]
  - a= speed of sound [m/s]

Pulsation Levels

- Too high pulsations at the compressor valves can cause:
  - valve damage (if acoustical and mechanical natural frequency coincides)
  - decrease in efficiency
  - high vertical acoustical forces



Pulsation Levels

- Pulsations at the compressor flange is an indirect measure of the pulsations at valves
- Allowable levels at the compressor flange according the 5th edition of API 618:
  - 7% (of mean static line pressure) or:
  - P_{cf}=3 x R (in % of mean static line pressure) whichever is lower

    R= stage pressure ratio

Vibration Levels

- Vibrations are used for many years to judge the integrity of the system during operation
- Several international standards (ISO, VDI) have been developed for vibration levels in reciprocating machinery
- Great variety of internal applied guidelines within OEM's and Operators (most of them have been derived from international standards)
- Standards consider the compressor as a separate part

Vibration Levels

- Most important standards which have been used the last decades for reciprocating compressors:
- **VDI 2056 (1964):**

  "Beurteilungsmassstäbe für mechanische schwingungen von Maschinen" (Judge criteria for mechanical vibrations of machines)

- **VDI 2063 (1985):**

  "Measurements and evaluation of mechanical vibrations of reciprocating piston engines and piston compressors"-> missing in VDI 2056

- **VDI 3838 (2004):**

  "Measurements and evaluation of mechanical vibrations of reciprocating piston engines and piston compressors with power rating above 100 kW"

Vibration Levels

- **ISO 10816-6 (1995):**

  “Mechanical vibration- Evaluation of machinery vibration by measurements on non-rotating parts”

  Part 6: Reciprocating machines with power ratings above 100 kW”
- **VDI 3842 (2004) :**

  “Vibrations in piping systems”
- **EFRC (2009)**

  ”Guidelines for Vibrations in Reciprocating Compressor Systems”

Vibration Levels

Allowable levels for Piping:

•have been derived from rotating equipment standards and experience

•Only available standard at this moment: VDI 3842 (2004):

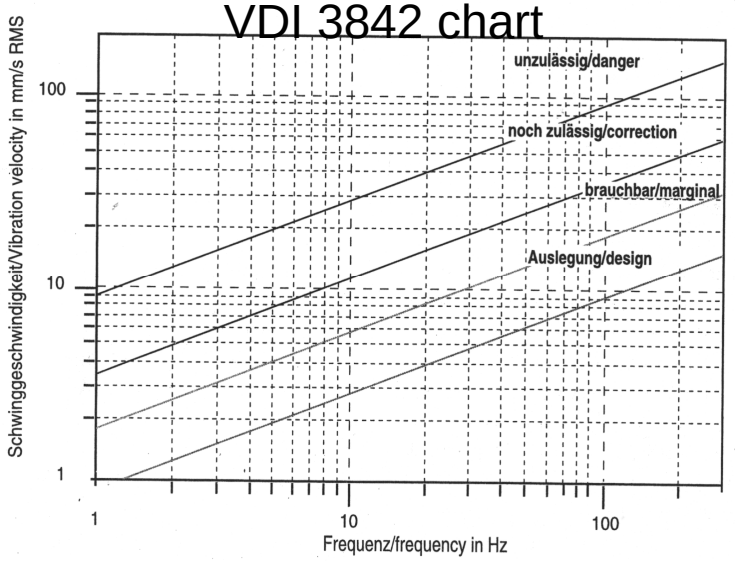
–rather high allowable levels, especially for high frequencies

•For higher frequencies generally higher stresses (higher mode shapes):

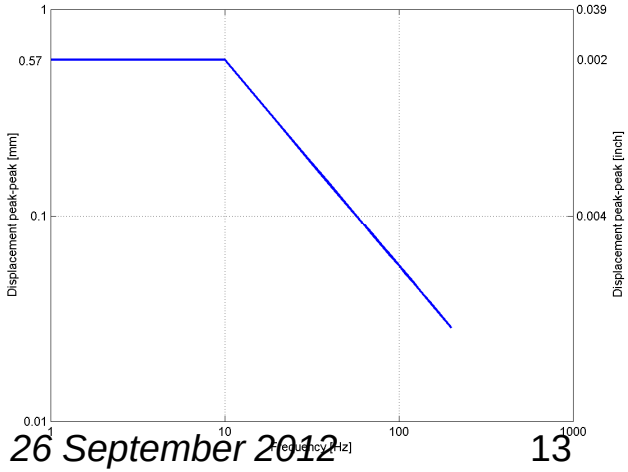
–lower values should be applied

•In API 618, 5th edition: chart for design purpose, not for measurements

VDI 3842 chart

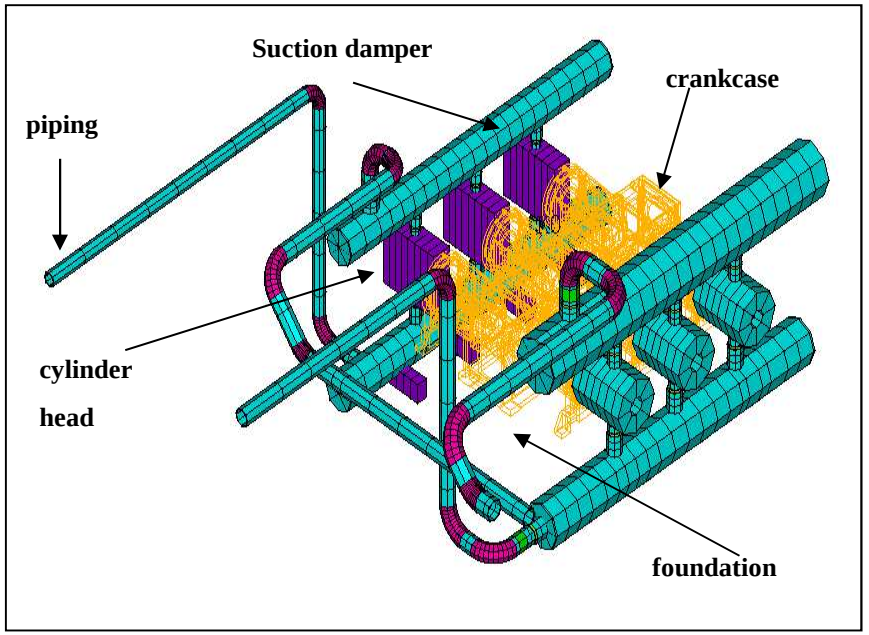


API 618, 5th edition chart



Vibration Levels

- Most international standards are not suitable to apply for reciprocating compressor systems: only for frame vibrations
- Higher permissible levels from foundation up to piping are more realistic due to flexibility of different parts—> This is the basis for the EFRC & ISO 10816-8 guidelines
- In a compressor system several parts should be distinguished with different permissible vibration levels:
  - Cylinder head
  - Frame
  - Foundation
  - Pulsation dampers
  - Piping



EFRC Guidelines (www.recip.org)

Scope of Standard:

- Vibration levels are defined primarily:
  - to classify the vibration of the compressor system and to avoid fatigue problems of foundation, compressor, dampers, piping and auxiliary equipment mounted on the compressor system
- Evaluation criteria may only have limited application when considering the effects of internal machine components; e.g. problems associated with valves, pistons, piston rings, etc. may be unlikely to be detected in the measurements.
- Guidelines are not for conditioning monitoring purposes

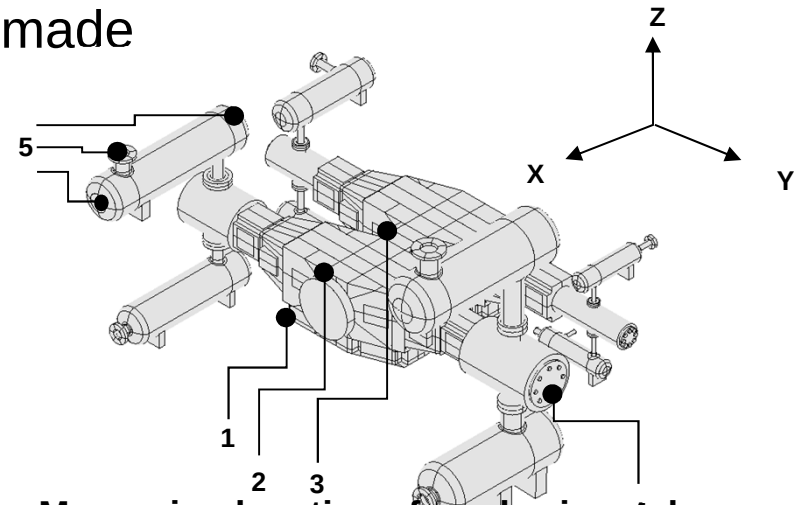
EFRC Guidelines

- Standard is not for hyper compressor systems
- Noise is outside the scope of this part of ISO 10816
- Rigidly mounted horizontal and vertical compressors
- Reciprocating compressors with speeds: 120-1800 rpm
- Compressors driven by: electric motors, gas & diesel engines, steam turbines, with or without a gearbox, flexible or rigid coupling
- Dry running and lubricated reciprocating compressors

EFRC Guidelines

Measurement procedure:

- Primary measurement: overall (2-1000 Hz) vibration velocity levels in mm/s r.m.s.
- For f<10 Hz: also measure vibration displacements
- For f>200 Hz: also measure vibration accelerations
- All levels should be within guidelines on all locations
- If one of the levels exceed the limit, a frequency spectrum should be made



Measuring locations for a horizontal compressor

1. All compressor frame foundation bolts
2: Each frame corner point
3. Each frame location between the cylinders (required for a compressor with more than 2 cylinders)
4: Each cylinder (cover flange at rigid location)
5: Pulsation vessels (only shown for one vessel in drawings)
6: Piping is not shown in picture (should be agreed upon with customer)

EFRC Guidelines

- Definition Key to zones as follows:

Zone	Measured Level	Qualification	Notes
A	Level < A	Good	1
B	A/B< Level <C	Acceptable	2
C	C< Level <D	Marginal	3
D	Level >D	Unacceptable	4

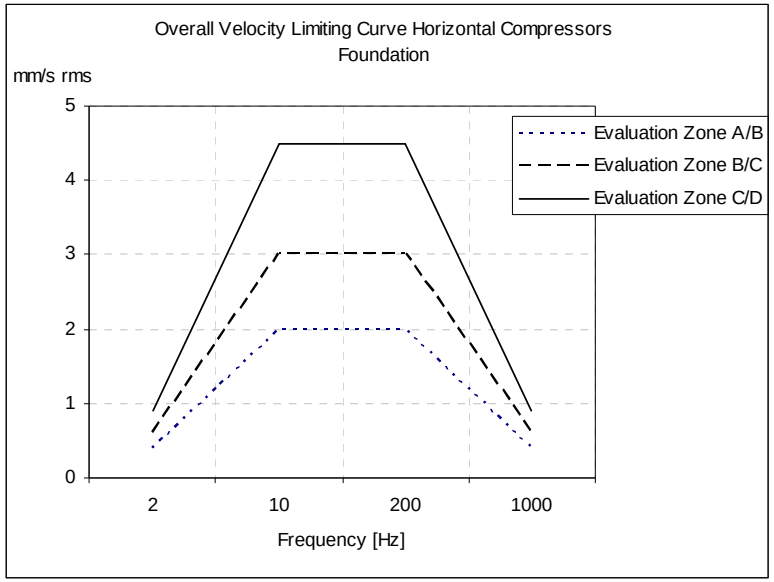
Notes:

- 1: Design
- 2: Field survey
- 3: Analysis and possible correction. Clarification between OEM and operator is necessary to ensure that the compressor is suitable for the long term operation
- 4: Urgent correction or shutdown
- Vibrations for reciprocating machines may tend to be more constant over life time than for rotating machines. Zone A and B have been combined therefore

EFRC Guidelines

- Summary of overall vibration velocity levels for different parts and key zones

Part	Vibration velocity levels horizontal compressors [mm/s r.m.s.]		
	A/B	B/C	C/D
Foundation	2.0	3.0	4.5
Frame (top)	5.3	8.0	12.0
Cylinder (lateral)	8.7	13.0	19.5
Cylinder (rod)	10.7	16.0	24.0
Dampers	12.7	19.0	28.5
Piping	12.7	19.0	28.5



Identical and graphs for displacements and acceleration

Zone A | Zone B | Zone C | Zone D

Coming ISO 10816-8

- ISO 10816-8 “Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 8: Reciprocating compressor systems”.

Main differences with EFRC Guidelines:

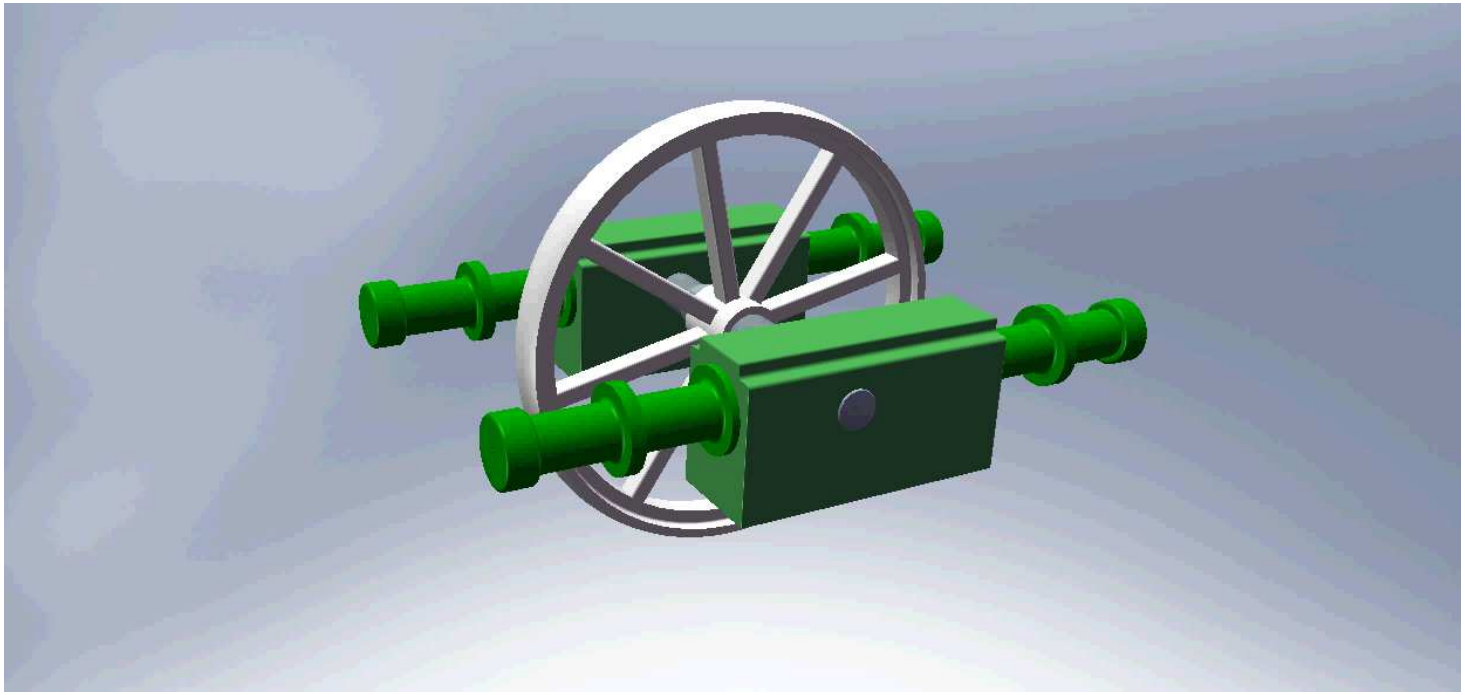
- L,V,W type compressors have been included
- Definitions of Key/Evaluation Zones have been extended and improved
- Improved Velocity Limiting Graphs (acc. to ISO definitions)

Coming ISO 10816-8

- Annex B (accelerometers) and C (post processing) have been removed. Reference to applicable ISO standards is sufficient.
- Improved drawings
- New informative Annex on Crosshead vibrations
- New informative Annex on Crest Factors (CF's):
  - r.m.s. values will not indicate high impact spikes
  - CF's can be used to calculate 0-peak value (indication for stress) from r.m.s. values
- Expected release date: 2014

Thank for your attention !

Any Questions ?



Appendix:
More detailed material on older vibration standards

VDI 2056

- **VDI 2056 (1964):** "Beurteilungsmassstäbe für mechanische schwingungen von Maschinen"
- Permissible vibration levels are a function of frequency for different type of machines: group K, M, G, T, D, S
- Examples of groups":
- Group K: small machines stiff mounted on foundation, e.g. electric motors up to15 kW.
- Group T: large machines with rotating masses mounted on low-tuned foundations (MNF < minimum 20% from excitation frequency)
- Group D and S: machines with reciprocating masses-> reciprocating compressors However: standard does not give values for group D & S

VDI 2056

Tabelle 2. Schwingstärkestufen und Beurteilungsbeispiele für Kleinmaschinen (Gruppe K), mittlere Maschinen (Gruppe M), Großmaschinen (Gruppe G) und Turbomaschinen (Gruppe T, gem. Definitionen auf S. 11)

Schwingstärke-Stufen		Äquivalente Amplituden an den Stufengrenzen		Beispiele der Beurteilungsstufen für einzelne Maschinengruppen *)			
Stufen-Bezeichng.	Effektive Schnelle v_{eff} in mm/s anden Stufengrenzen	Äquivalente Schnelle-Amplitude $\hat{v}_{äqu}$ in mm/s	Zu 50 Hz gehörige äquivalente Wegamplitude $\hat{s}_{50äqu}$ in µm	Gruppe K	Gruppe M	Gruppe G	Gruppe T
0,28							
0,45	0,28	0,4	1,25				
0,71	0,45	0,63	2	gut			
1,12	0,71	1,0	3,15		gut		
1,8	1,12	1,6	5	brauchbar		gut	
2,8	1,8	2,5	8		brauchbar		gut
4,5	2,8	4,0	12,5	noch zulässig		brauchbar	
7,1	4,5	6,3	20		noch zulässig		brauchbar
11,2	7,1	10	31,5	unzulässig		noch zulässig	
18	11,2	16	50		unzulässig		noch zulässig
28	18	25	80			unzulässig	
45	28	40	125				unzulässig
71	45	63	200				

*) unter besonderer Berücksichtigung von Abschn. 1, Gesichtspunkt 3

V=2.5 mm/s r.m.s.

Good

Acceptabl

Marginal

Unacceptа

- **Level of severity (13): maximum measured value at a certain location**

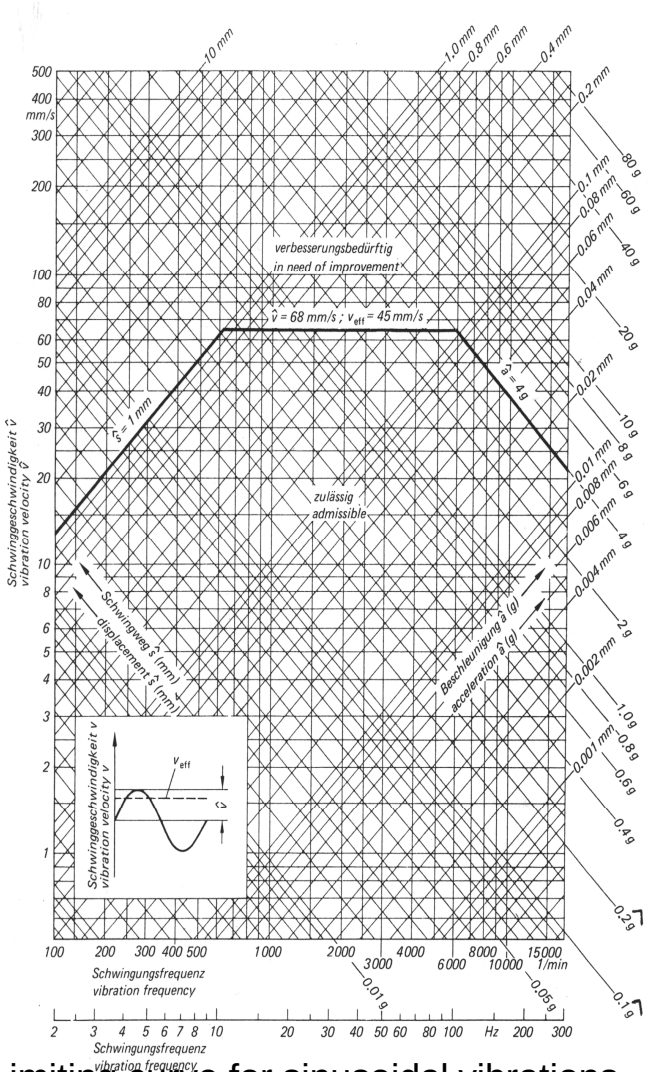
VDI 2063

- **VDI 2063 (1985):**
- "Measurements and evaluation of mechanical vibrati
- reciprocating piston engines and piston
- compressors"-> missing in VDI 2056

- Limiting line is only valid for vibration velocity in the case of sinusoidal vibrations (one freq.)

- If vibration contain several harmonics between
- 2 Hz and 10 Hz and/or between 100 Hz and 300 Hz should be considered for 2 Hz< f < 300Hz:
  - –v (overall velocity) ≤ 45 mm/s RMS
  - –s (overall displacement) < 2 mm peak-to-peak
  - –a (overall acceleration) < 8 g peak-to-peak

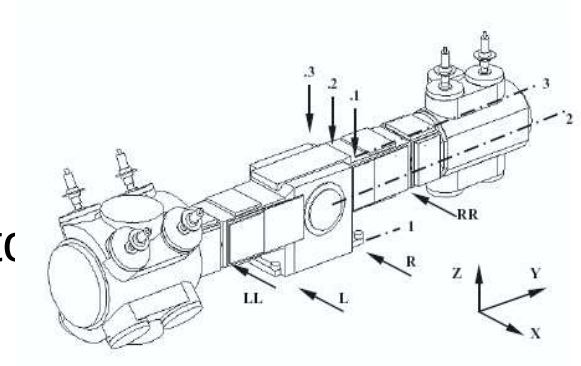
- Values are all rather high !!
- Standard gives only 2 grades:
  - –admissible and improvement



Limiting curve for sinusoidal vibrations

ISO 10816-6

•Most applied standards at this moment:
ISO 10816-6 and VDI 3838



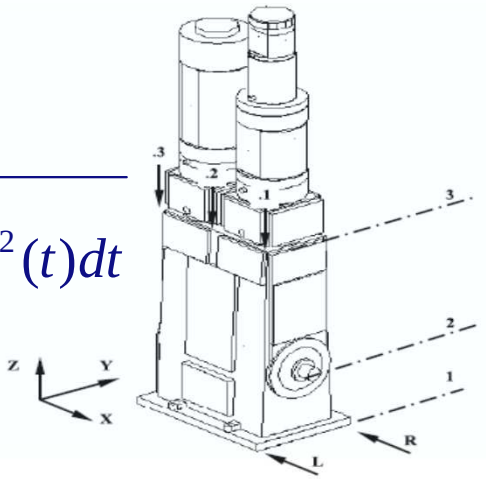
•Evaluation of the vibration of reciprocating pistc machines is based on the measurement of the r.m.s. (root-mean-square value) value of:

–vibration <u>displacement</u>
–vibration <u>velocity</u>
–vibration <u>acceleration</u>

•r.m.s. value is measure of energy:

$$V_{r.m.s} = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt}$$

•V(t) time dependent velocity,
•T sampling time
•Frequency range 2 - 1000 Hz



ISO 10816-6

- **ISO 10816-6 (1995):**

"Mechanical vibration- Evaluation of machinery vibration by measurements on non-rotating parts"

Part 6: Reciprocating machines with power ratings above 100 kW"

- More or less the same as VDI 2056
- Twelve levels of severity (13 for VDI 2056)
- 7 classes of machines (4 for VDI 2056)
- Does not give a classification for reciprocating compressors

ISO 10816-6

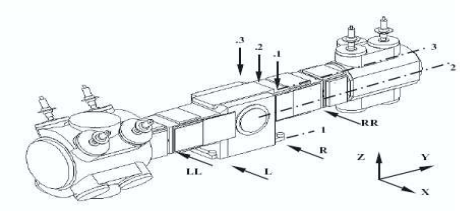
- Zone A: newly commissioned machines normally fall with this zone
- Zone B: normally considered acceptable for the long-term operation
- Zone C: normally considered unsatisfactory for continuous operation -> may be operated for limited time until next maintenance
- Zone D: normally considered to be severe -> machine will be damaged
- Vibrations for reciprocating machines may tend to be more constant over life time than for rotating machines. Zone A and B have been combined therefore

Vibration severity grade	Maximum values of overall vibration measured on the machine structure			Machine vibration classification number						
	Displacement µm (r.m.s.)	Velocity mm/s (r.m.s.)	Acceleration m/s² (r.m.s.)	1	2	3	4	5	6	7
				Evaluation zones						
1,1	17,8	1,12	1,76	A/B	A/B	A/B	A/B	A/B	A/B	A/B
1,8	28,3	1,78	2,79							
2,8	44,8	2,82	4,42							
4,5	71,0	4,46	7,01	C						
7,1	113	7,07	11,1		C					
11	178	11,2	17,6	D		C				
18	283	17,8	27,9		D		C			
28	448	28,2	44,2			D		C		
45	710	44,6	70,1				D		C	
71	1125	70,7	111					D		C
112	1784	112	176						D	D
180										

Classification numbers are not defined for reciprocating compressors

Most of the OEM's apply classification number 4 and Operators apply classification number 2 (depend on size, mass, foundation system etc.)

VDI 3838



- **VDI 3838 (2004):**
- Addition to DIN ISO 10816-6”
- Easier to understand, but rather high levels
- Values are maximum values of the locations as indicated in figures
- Missing location: cylinder covers
- Different levels for low and high tuned systems (coupled to speeds)
- Levels are upper limits of zone B, classification number 4 of ISO 10816-6
- Does not make a distinction between safe, correction and dang

Foundation	Speed rpm	Displacement µm (rms)	Velocity mm/s (rms)	Acceleration m/s^2 (rms)
High-tuned	120-3000	280	18	28
Low-tuned	300-3000	450	28	44