EFRC Training Workshop
Basic training

Pulsations and Vibrations

Leonard van Lier & André Eijk – TNO

Outline

- Pulsations
- Vibrations
- Pulsation & vibration analysis according to the API 618 standard, 5th edition

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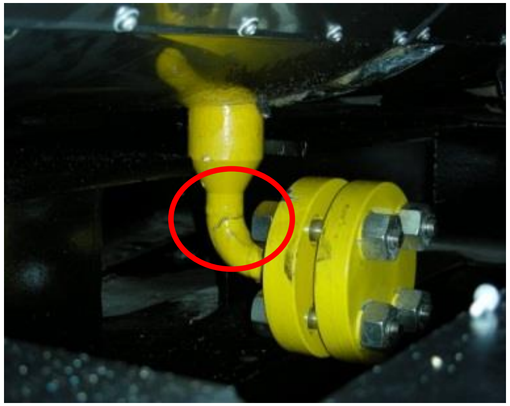
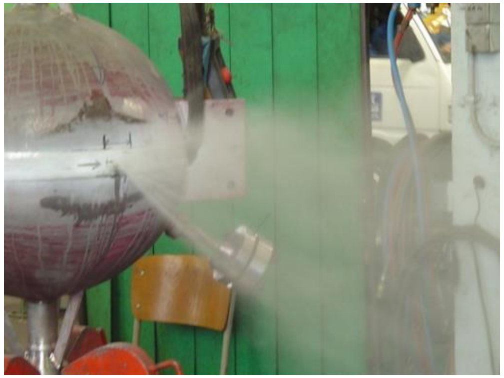
Why pulsation & vibration analysis?

- Pulsation & vibrations shall be minimized to avoid:
  - Integrity issues (fatigue)
  - Increased wear of compressor parts
  - Increased power consumption
  - Flow metering errors
  - Hammering of non-return valves





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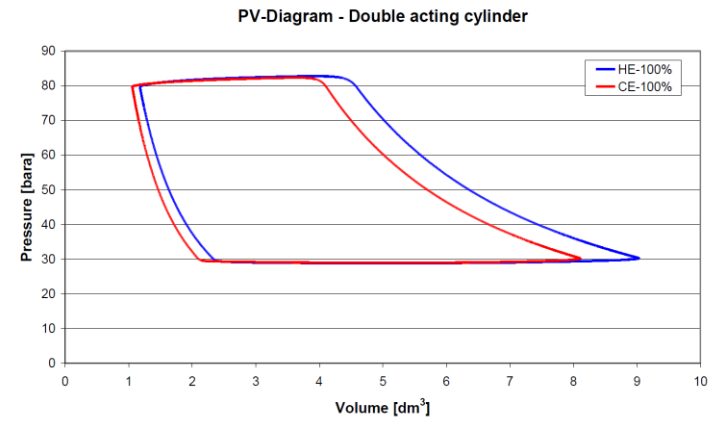
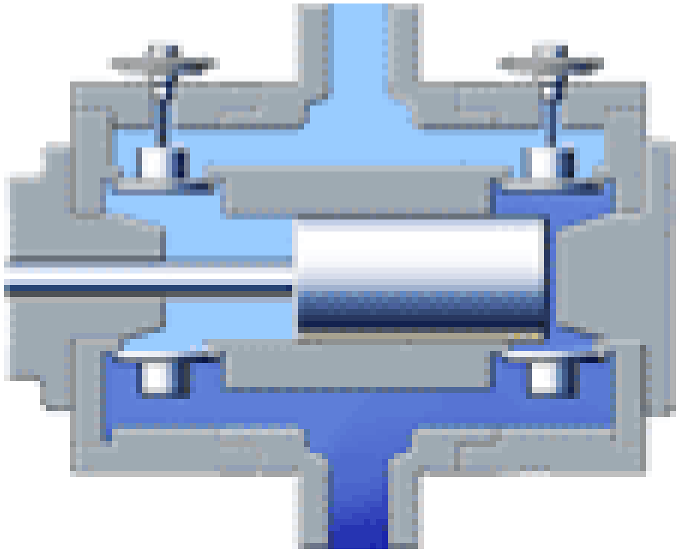
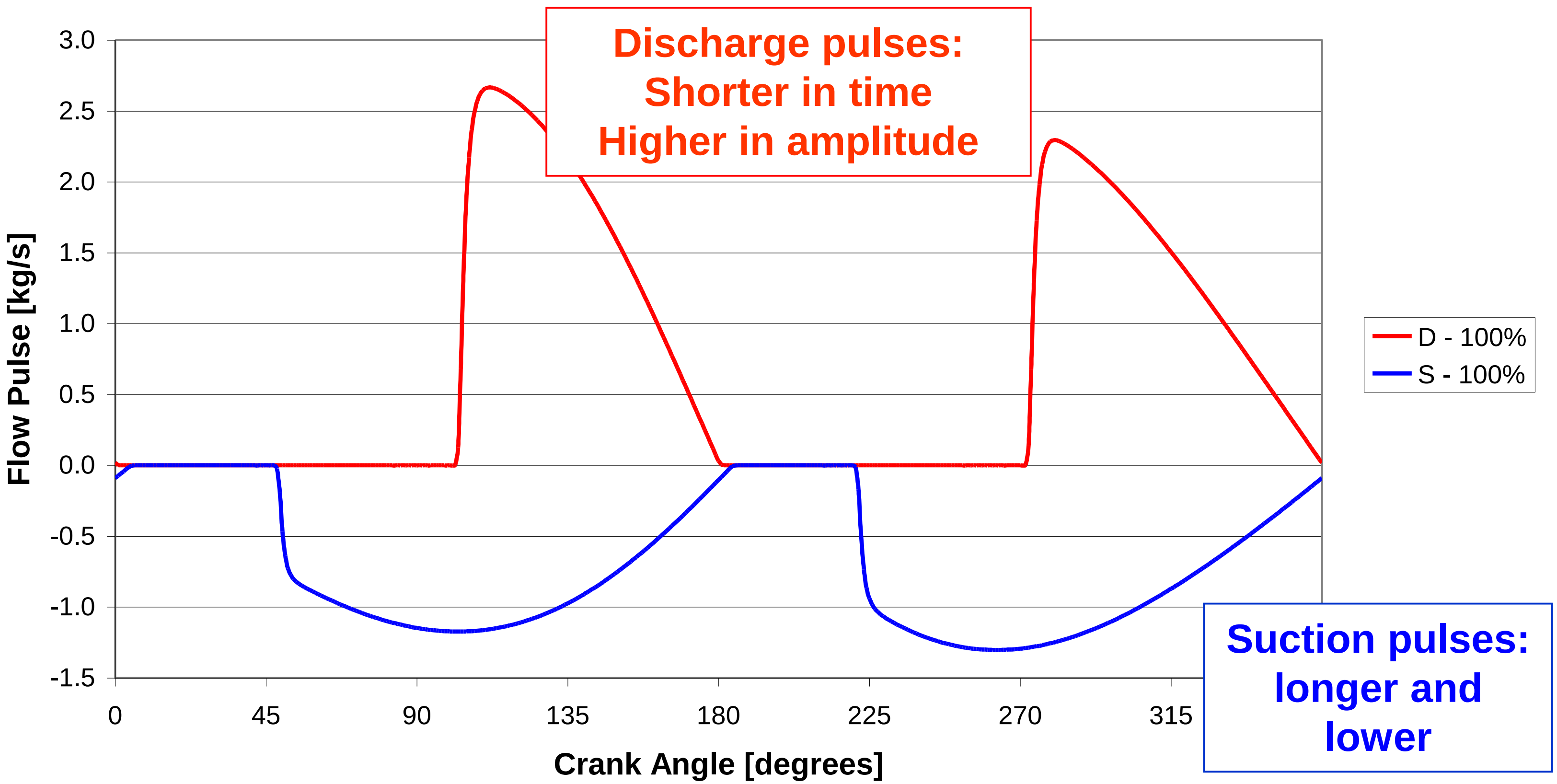
Pulsations

- Intrinsic feature of the reciprocating compressor
- Fluctuations of pressure and flow
- Suction and discharge
- Interaction with the piping system





Reciprocating, double-acting



Pulsation frequencies

- Fundamental = 1st order = RPM/60
- Frequency spectrum contains fundamental + higher orders
- Frequency content is essential for propagation to piping system and interaction with the mechanical structure

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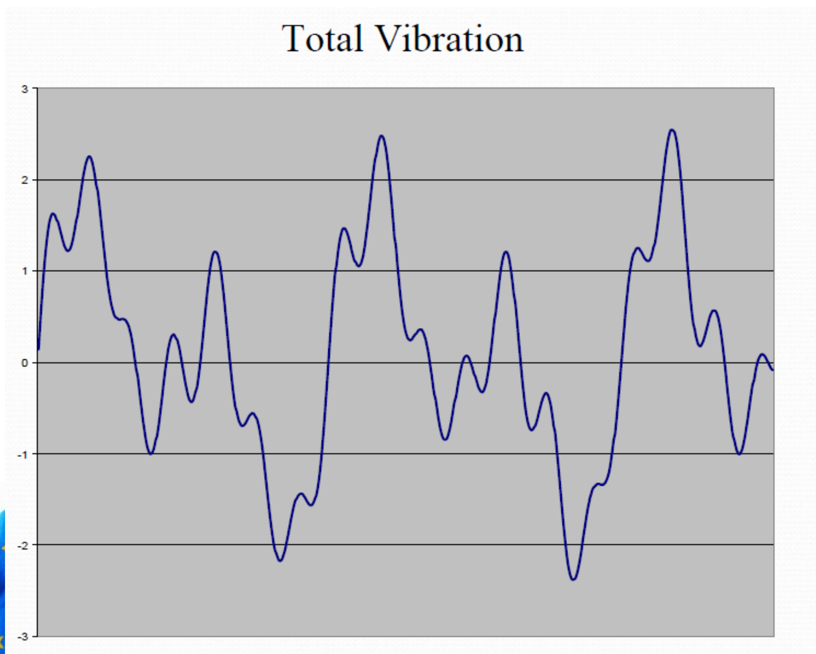
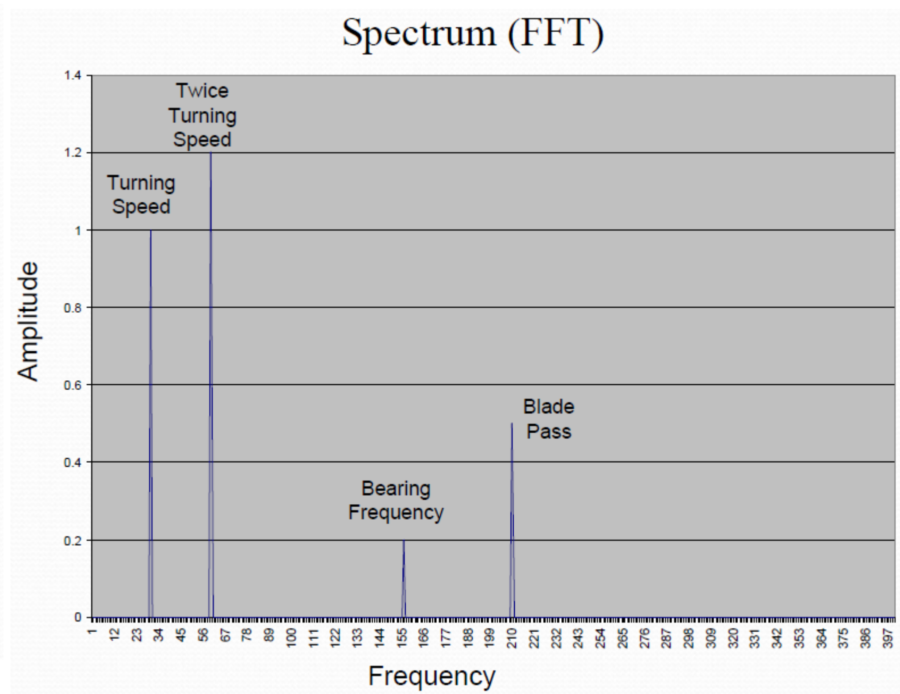
Fundamental and harmonics

- Pulsation time signal can be decomposed into harmonic components (Fourier analysis)





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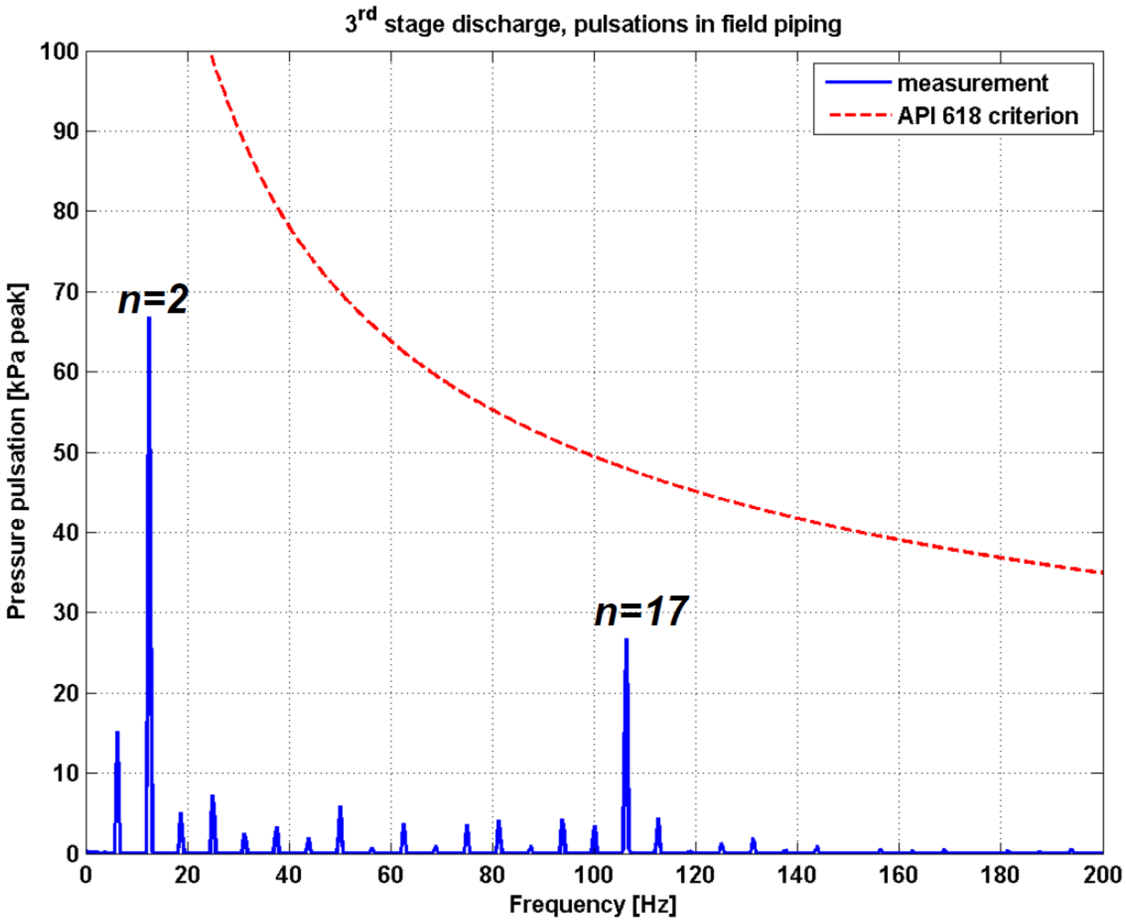
Spectral signature

- Double-acting: 2^{nd} order
- Single-acting: 1^{st} order
- Unloaded cylinder: 1^{st} order
- Step-less reverse flow capacity control: increased emphasis on higher orders

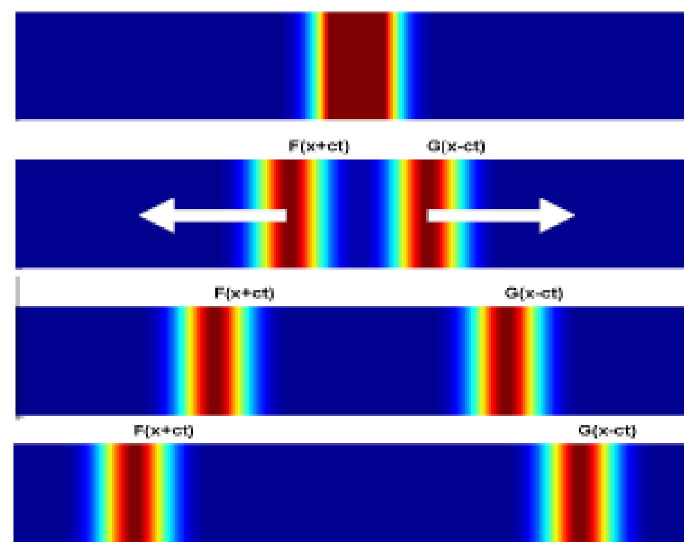
Illustration



Wave propagation

- Wave equation
- Pulsations are acoustic waves, propagating at the speed of sound
- Up- and downstream

$$\frac{\partial^2 p}{\partial t^2} - c^2 \frac{\partial^2 p}{\partial x^2} = 0$$



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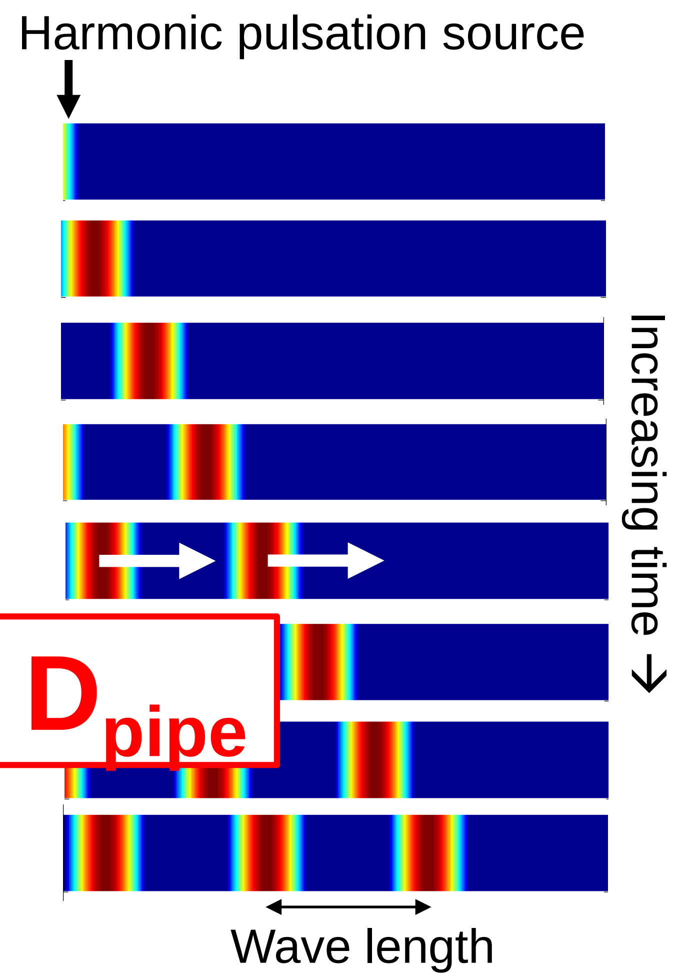
Speed of sound

- Increases with increasing temperature $$c \sim \sqrt{T}$$
  - Natural gas (20 ºC) → c=415 m/s
  - Natural gas (100 ºC) → c=475 m/s
- Decreases with increasing molecular weight of the gas $$c \sim \frac{1}{\sqrt{MW}}$$
  - Natural gas (MW=17) → c=415 m/s
  - Hydrogen (MW=2) → c=1350 m/s

Acoustic wavelength

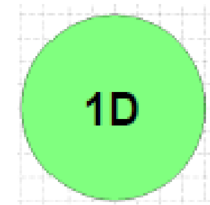
- Wavelength $\lambda = c/f$
- Speed of sound c (property of the gas)
- Pulsation frequency f (property of the source)



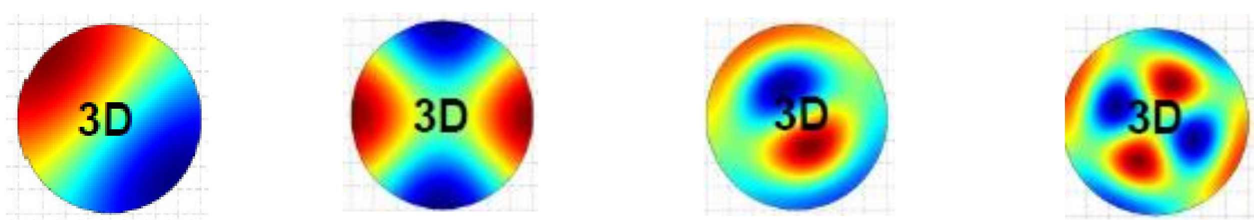
In general: $\lambda \gg D_{pipe}$

Plane acoustic waves

- If $\lambda >> D_{pipe}$: plane waves



- 1D acoustic theory and tools are valid
  - Reciprocating compressors: 1D theory is valid
  - Screw compressors, 1D theory may be valid
  - Pulsations of turbo compressors do **not** obey 1D theory!



Acoustic damping

- Damping mechanisms:
  - turbulence, wall friction, heat exchange with wall, viscosity …
- In general, damping effect is small
- Effective damping for L > 10-100*λ
- Pulsations propagate over large distances

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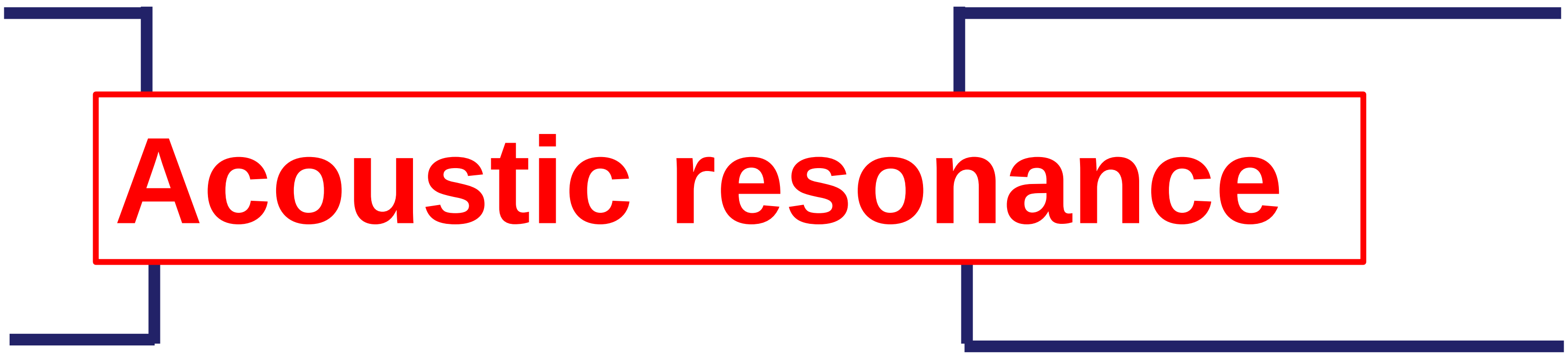
Reflection and transmission

- Acoustic waves reflect at ‘discontinuities’
  - Diameter changes
  - Temperature changes
  - Side branches

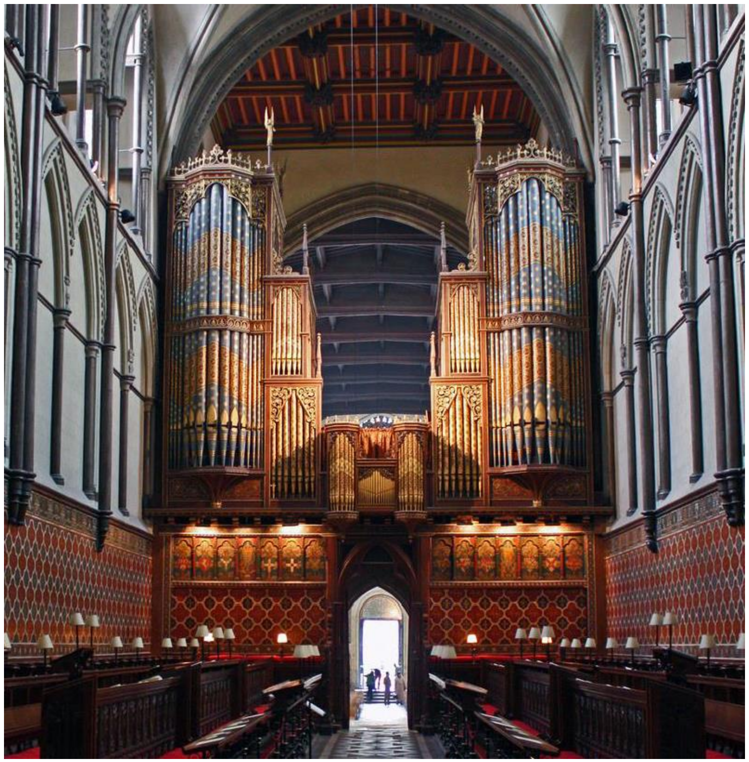
Interference of acoustic waves

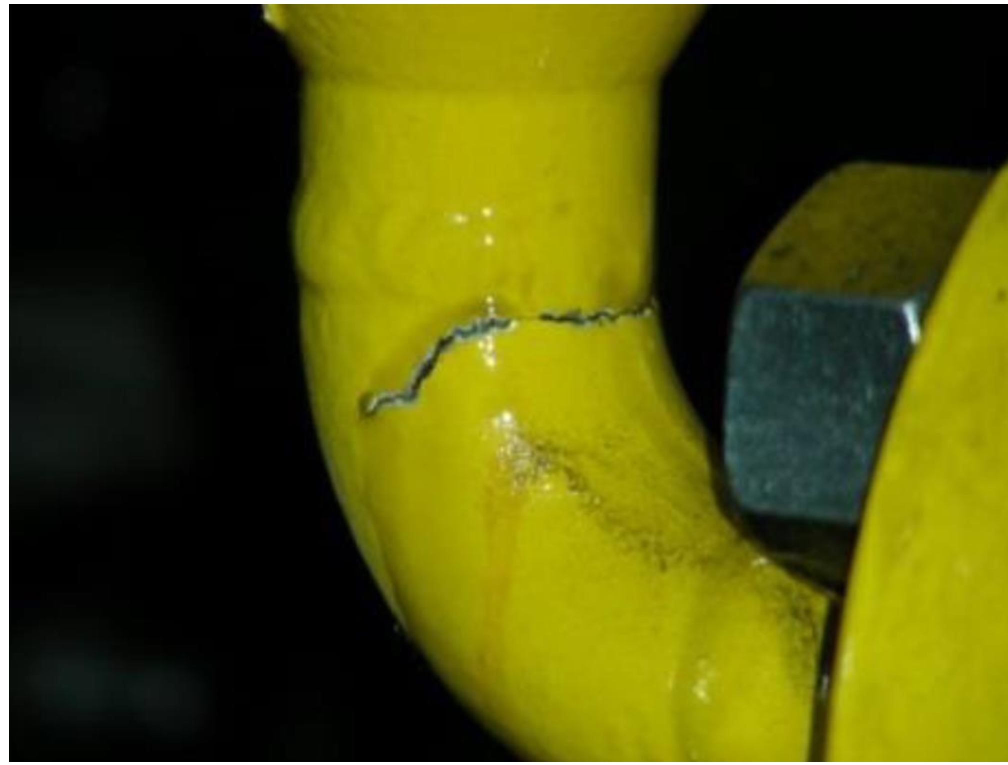
- Constructive / destructive interference

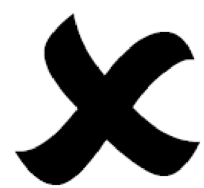


- Depending on the phase of the waves, occurrence of local minima (node) and maxima (anti-node) in the pulsation amplitude

Acoustic resonance

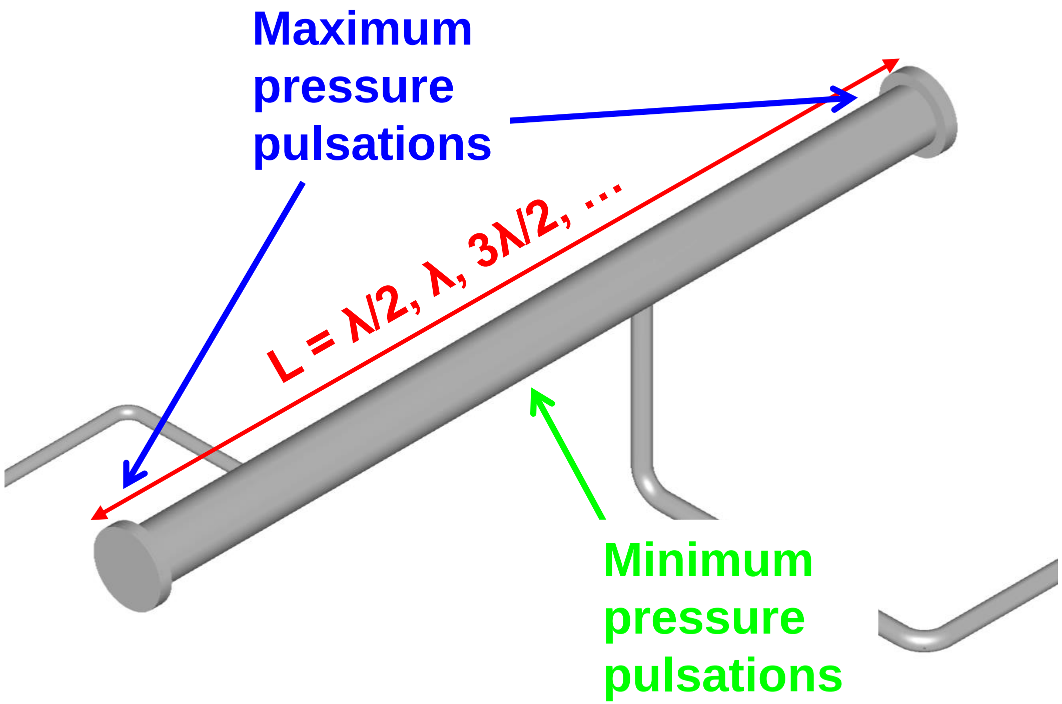




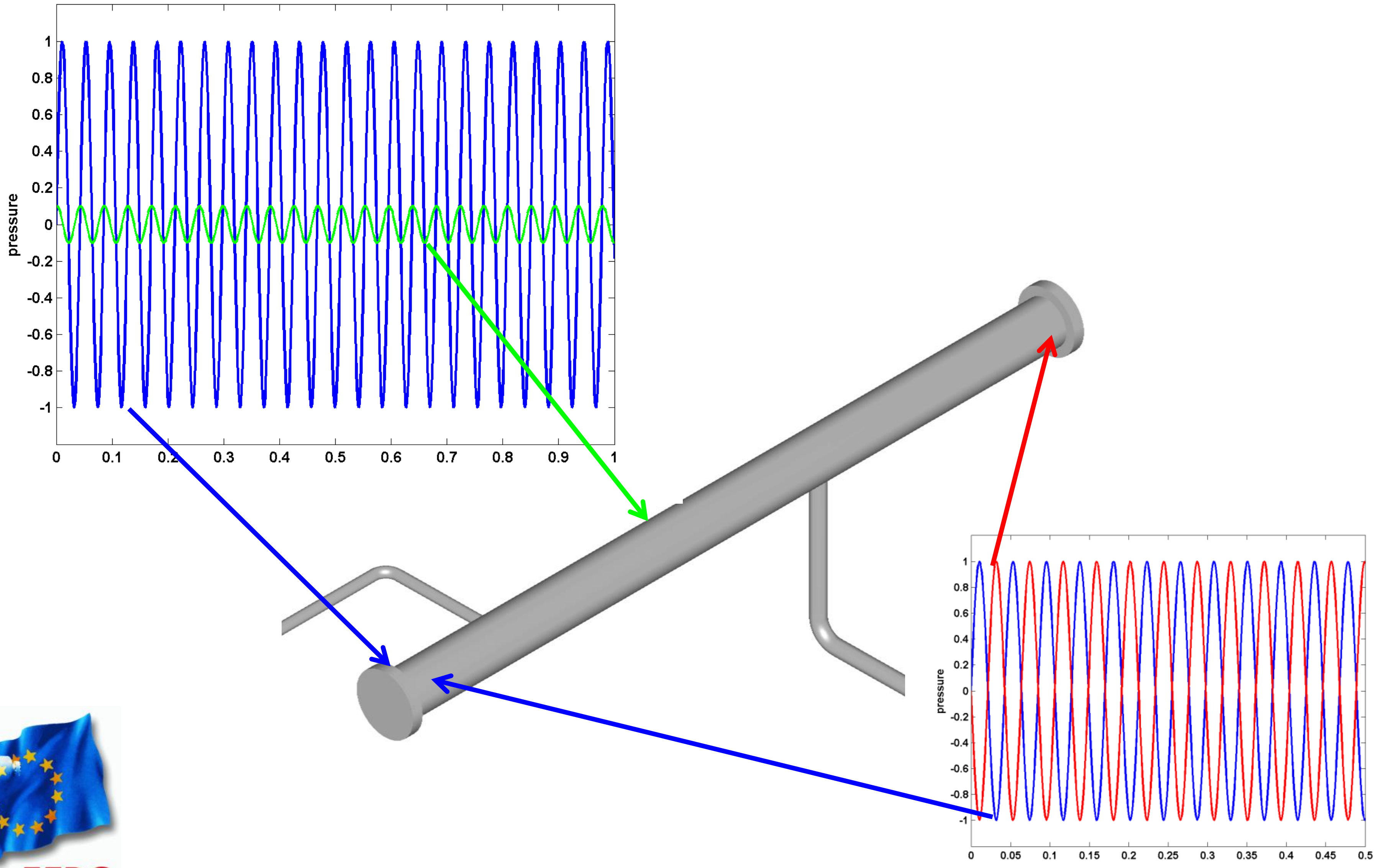


Standing waves

- Maximum amplification occurs when acoustic wave length matches the resonator pipe's length



Standing wave (½λ)



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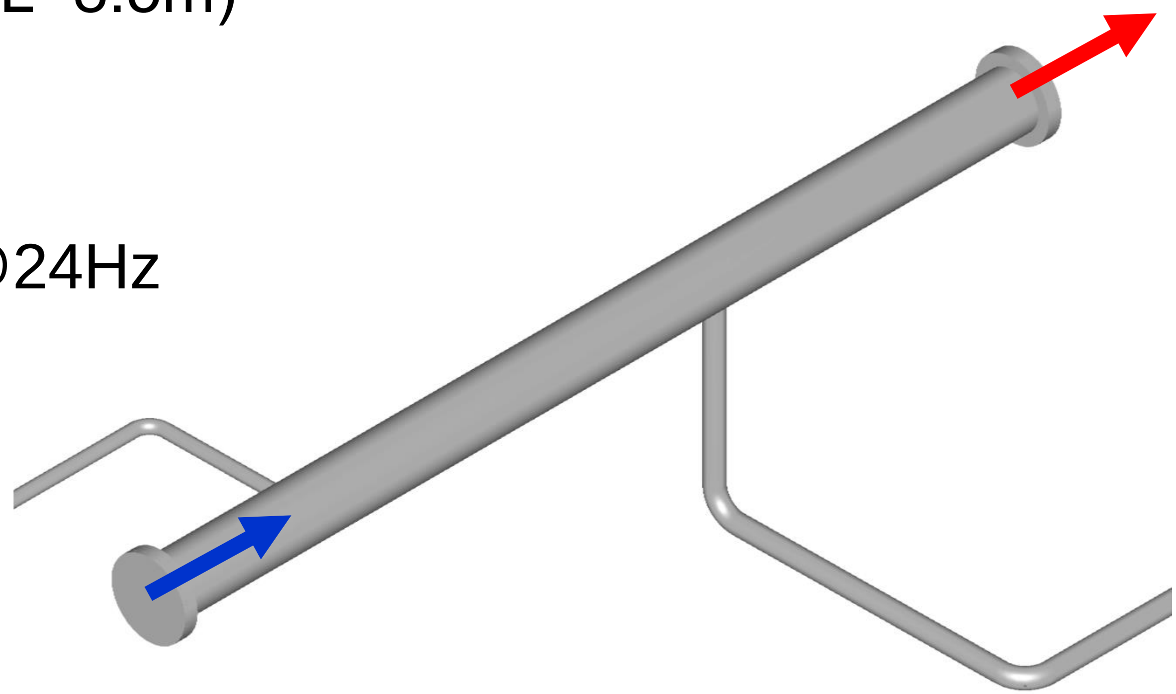
Shaking forces

- 20” header (L=8.5m)
- P=200 bar
- p’ = 1%
- F= 40 kN, @24Hz



Also acting on elbows, tee, reducers …

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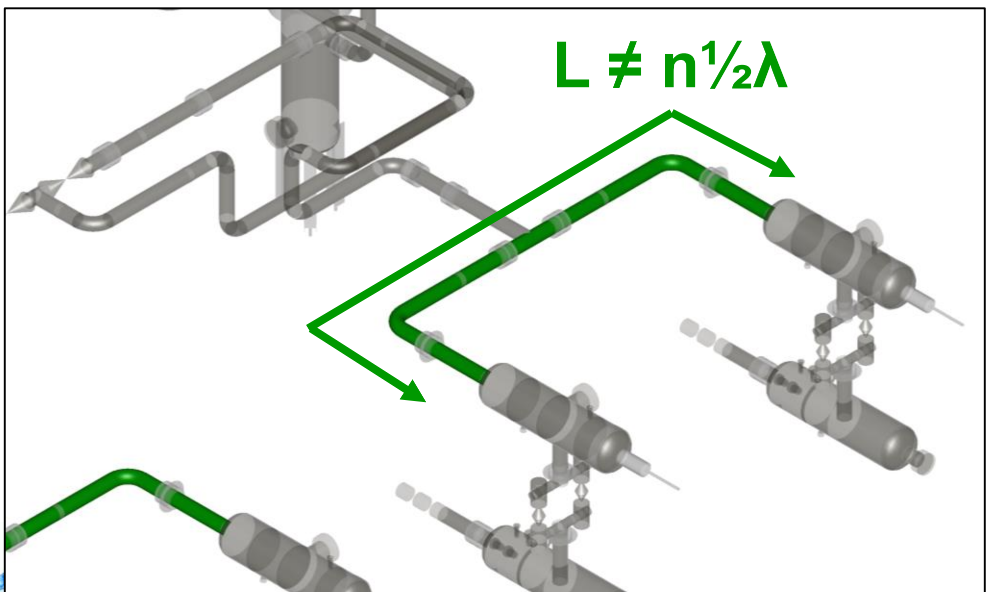
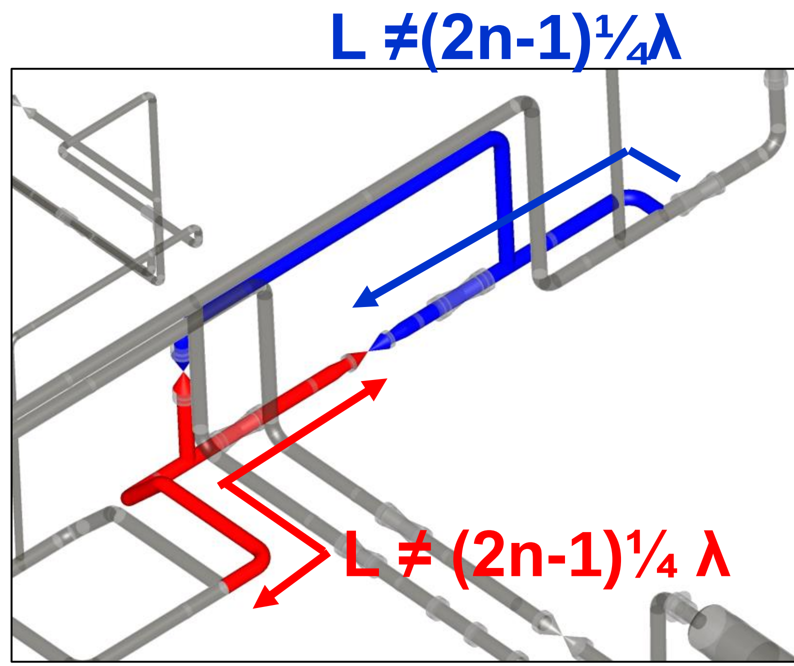
Control of pulsation issues

- Avoid coincidence of source frequencies with resonance frequencies





Not very realistic in case of variable compressor speed and fluctuating process conditions …

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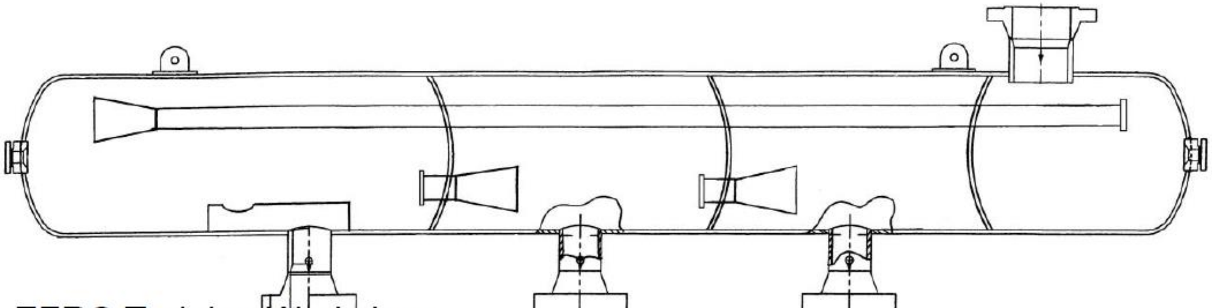
Pulsation dampers

- Mitigate the transfer of pulsations from compressor to piping
- While reducing:
  - Pulsations near the compressor valves
  - Shaking forces over the dampers
  - Pressure losses



Restriction orifice plates

- Supress acoustic resonances
- Essential for performance:
  - Pressure loss
  - Location in the system
  - Layout (for higher frequencies)