Loads and vibrations affecting pump operations

Joni Järvenperä

What happens when a pump is not operating properly?

- Visible issues → e.g. noise or leakage
- Measurable values → e.g. vibration or temperature
  - These lead to limited operating times to avoid failure

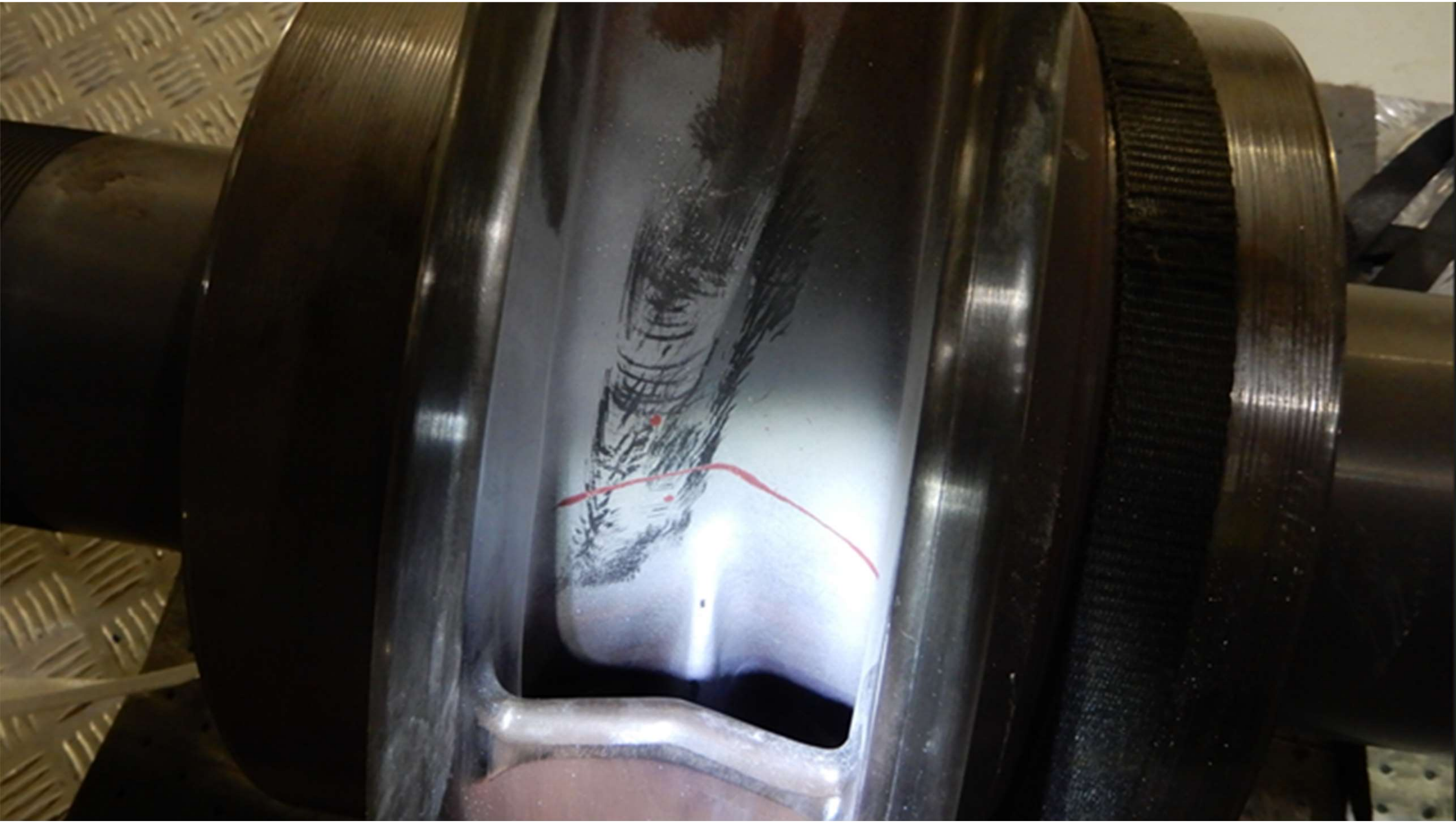
- **Limiting operating times is not a remedy!**

- Failure can occur nevertheless it might just not be visible
  - Leads to downtimes as repair is a must
  - Fatigue failure might be difficult to notice
- These issues require a dedicated investigation

Failures that can occur due to improper conditions

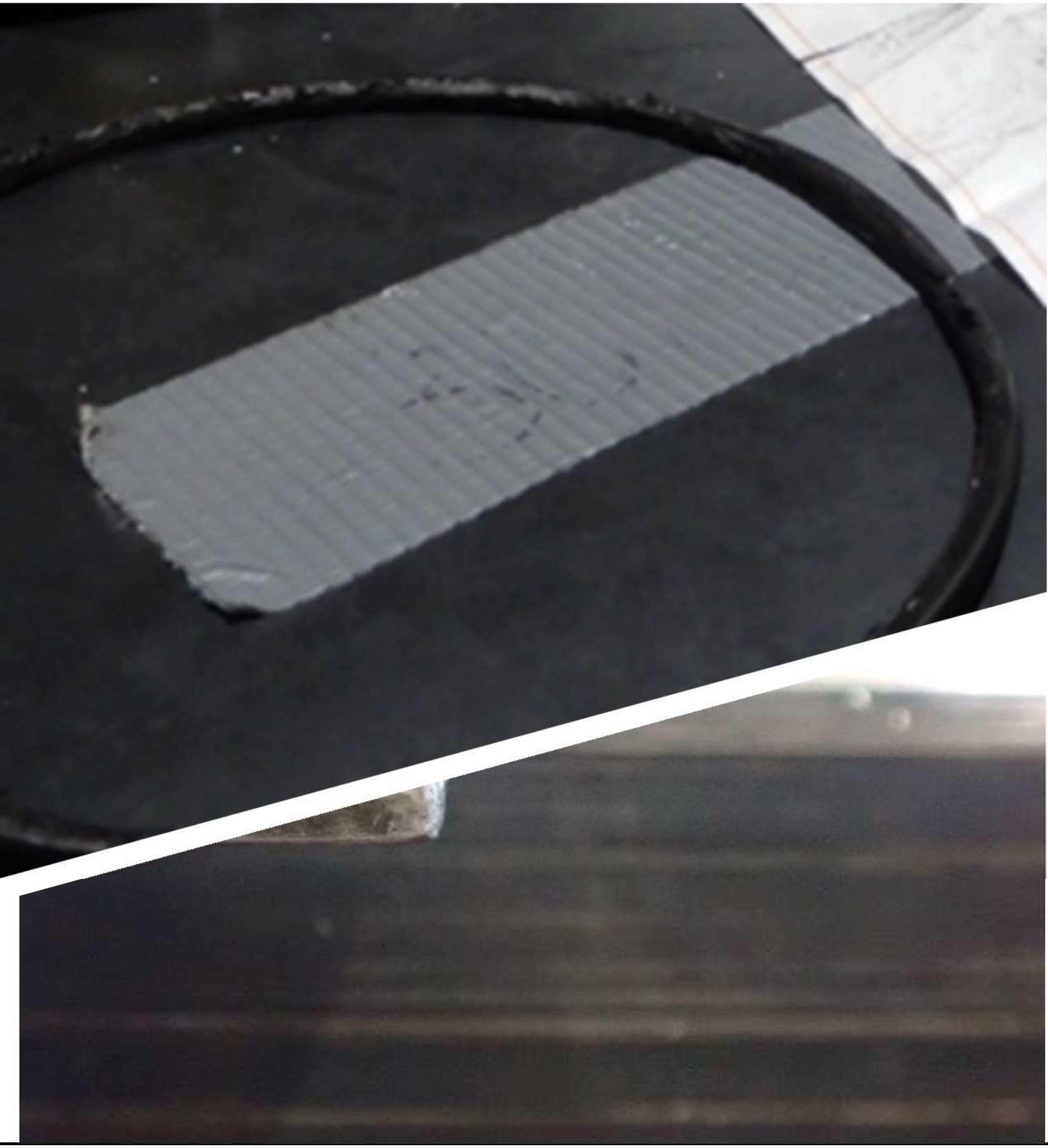
- High vibrations are troublesome for pump components
  - Seal and bearing failures
- Hydraulic forces can initiate a fatigue failure
  - Impeller cracking
- Pump rotor subjected to bending
  - Rubbing
- Thermal transients can burden the pump
  - Thermo-mechanical fatigue

Impeller failure

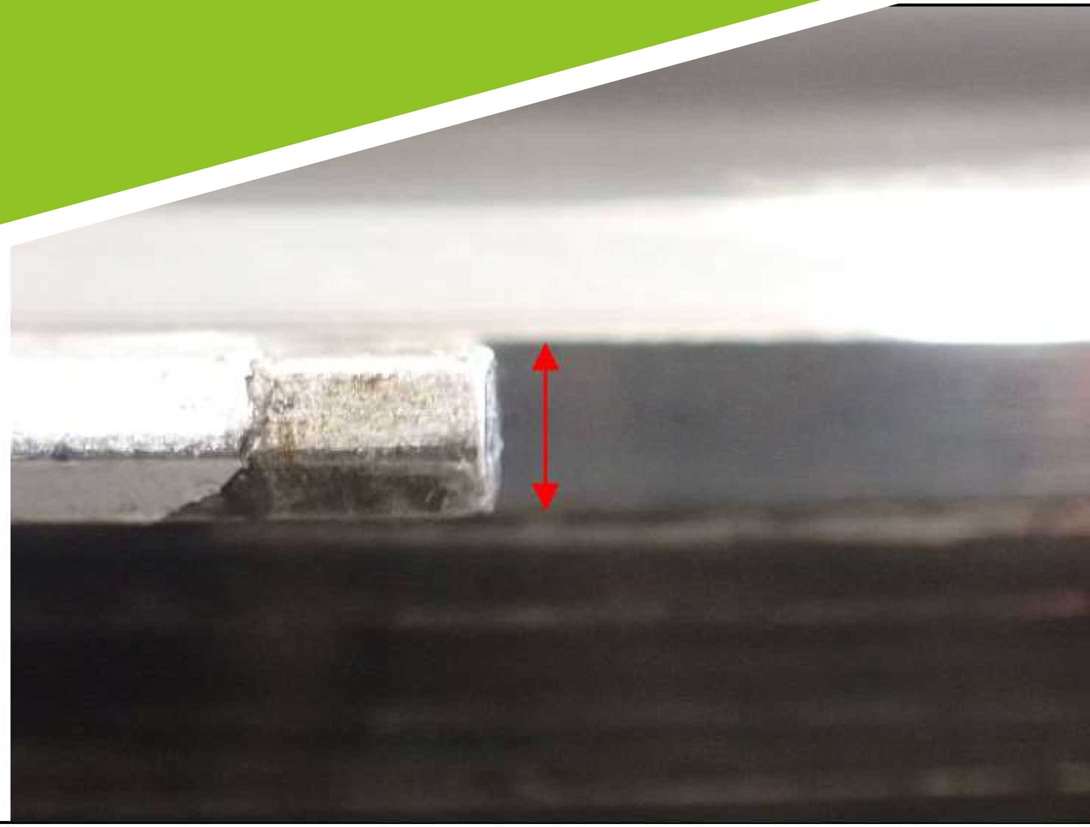


Contact marks

Mechanical seal failure



Approx. 1 mm



Approx. 2 mm

Possible reasons

- Thermal-mechanical fatigue
  - Thermal shock
- Hydraulic forces
  - Pressure pulsations, pressure distribution
- High vibrations
  - Many possibilities
- Fatigue failure
  - Design based

Thermal shock

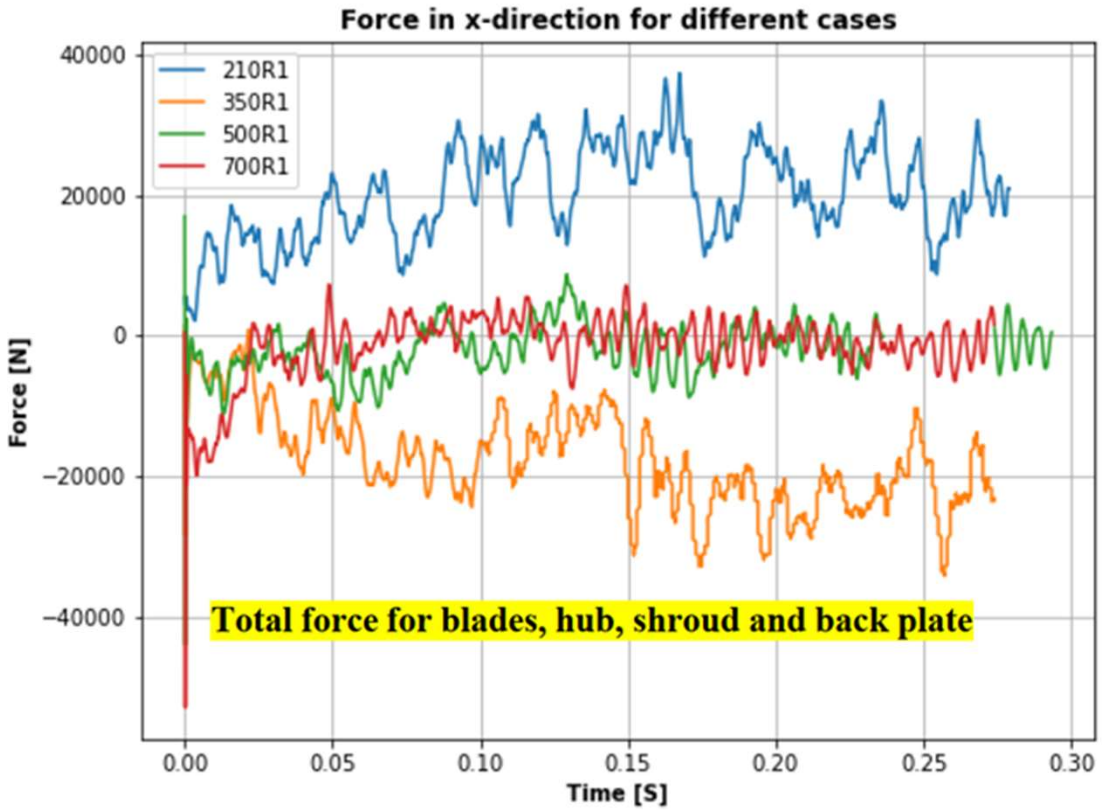
- Initiated crack grows cyclically
- Can be inspected but is very precise
- Is the crack growing at what rate and how the crack growth looks like

- CFD analysis is beneficial to understand generated stresses
  - Temperature transients and properties
- For this case not the reason of the cracks
  - Can sustain cycles in thousands before failure
  - Pump does not get that many starts on average
  - High temperatures can cause failure on some materials

Hydraulic forces

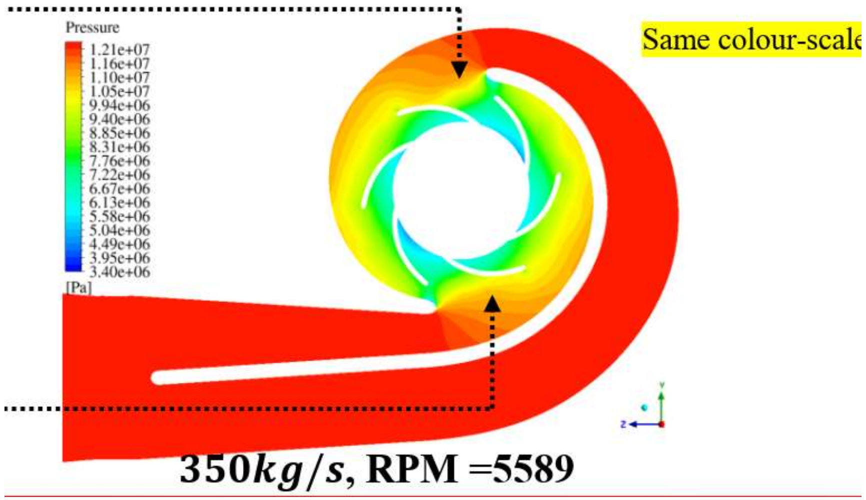
- Have a significant impact to the pump
- Affects in all directions (XYZ-plane)
- Especially meaningful on lower mass flows (left of BEP)
  - High fluctuations can occur
  - Higher force amplitudes and larger zero to peak difference

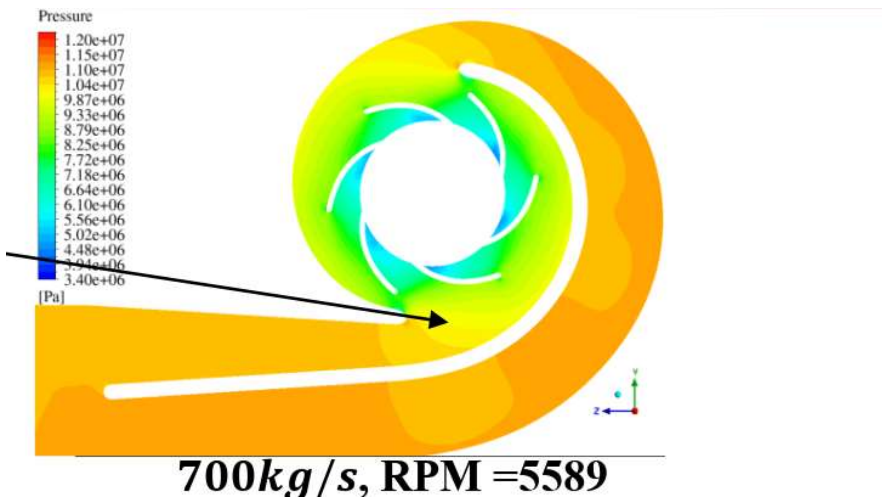
Difference from 210 kg/s minimum flow (blue graph) to 700 kg/s (red graph).



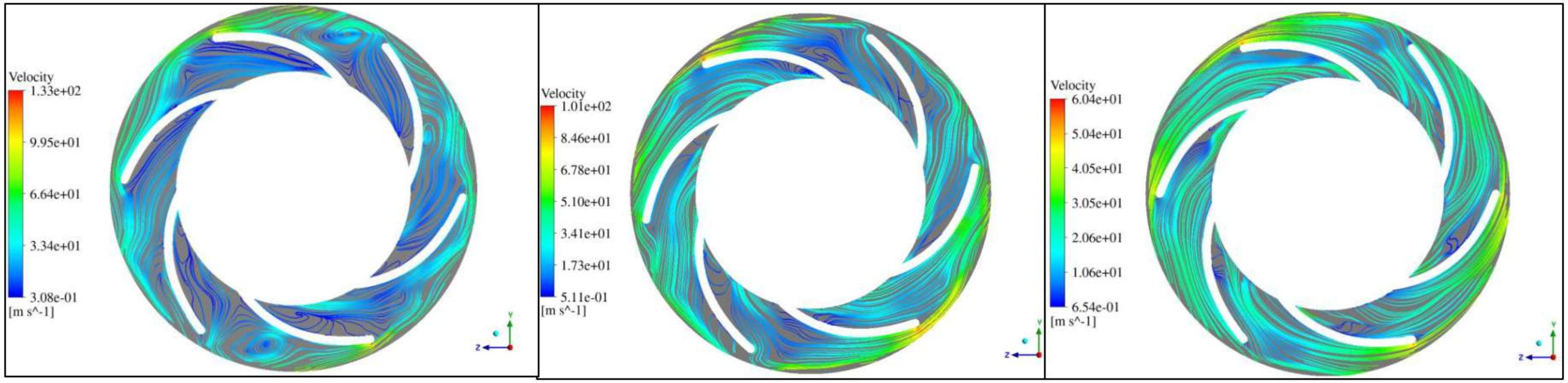
In this case, x is axial direction of the pump

Difference with mass flows





Vortex formation



$210 kg/s$, RPM =5589 **$350 kg/s$, RPM =5589** **$700 kg/s$, RPM =5589**

Impeller design has big impact

→ Sharp designs might be hydraulically optimal but they have their issues

In this case the sharp edged blade nose design had high stress intensity

→ limited lifetime and fatigue failure

Rounder design reduced stress from 233 MPa to 47 Mpa in crack initiation point

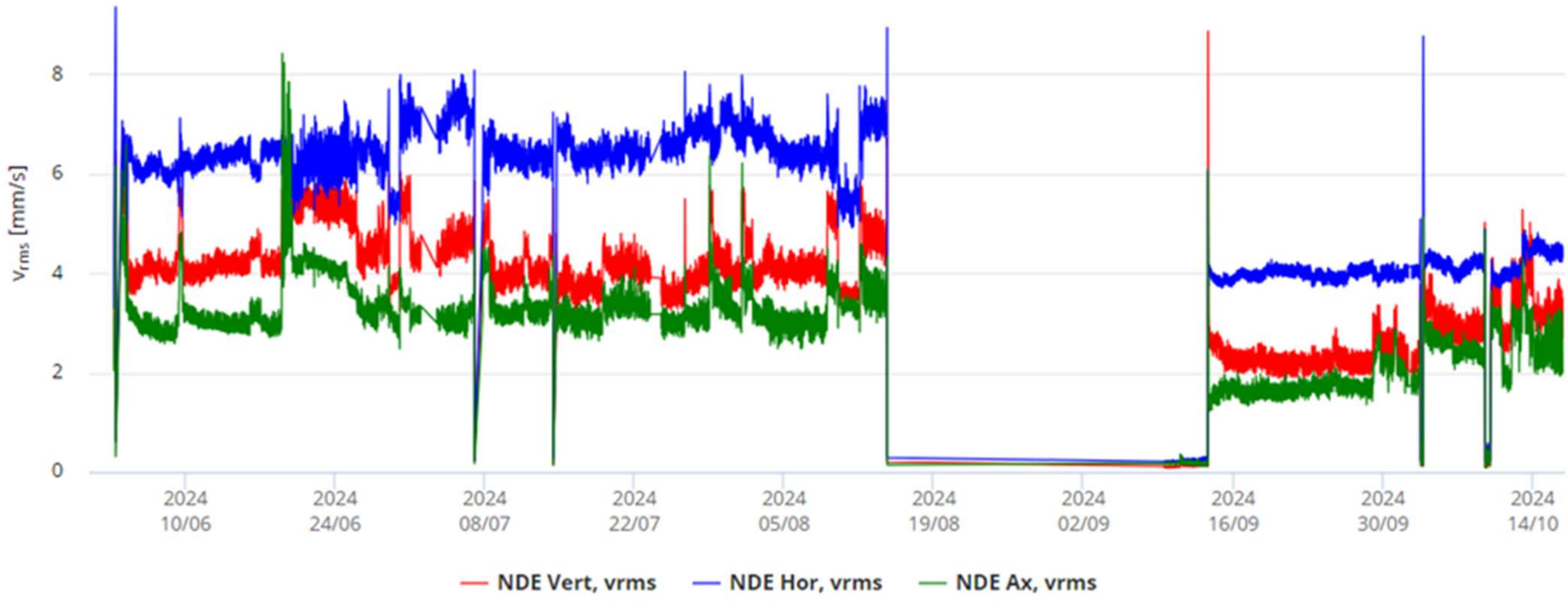
Forces cause loading every cycle → fast cycles = very limited lifetime

FATIGUE

Vibrations

- Basic measurements just notify about pump condition

- Precise information is required for analysis



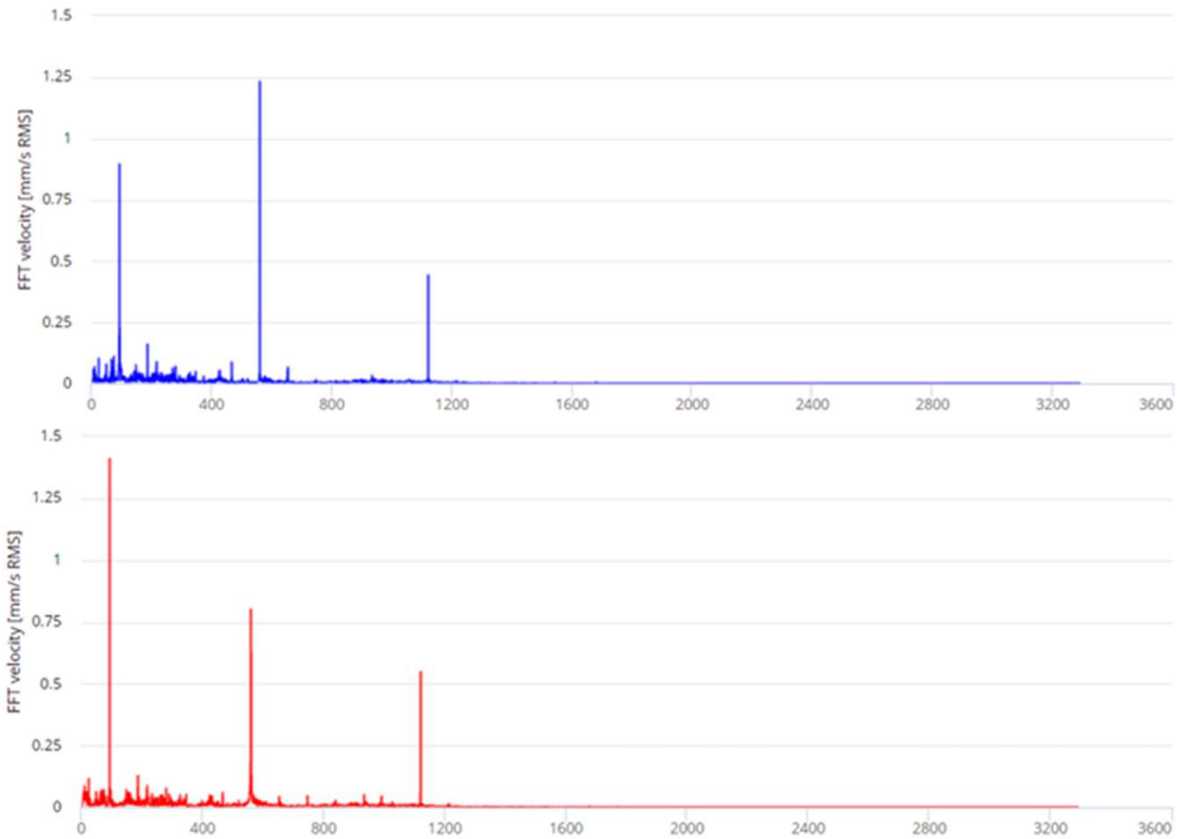
Frequency spectrum

- Good tool to understand what is possibly causing vibration issues
- Rotational speed and its orders
- Sub-synchronous, synchronous or non-synchronous

Frequency spectrum from NDE in vertical direction

80 % mass flow

95 % mass flow



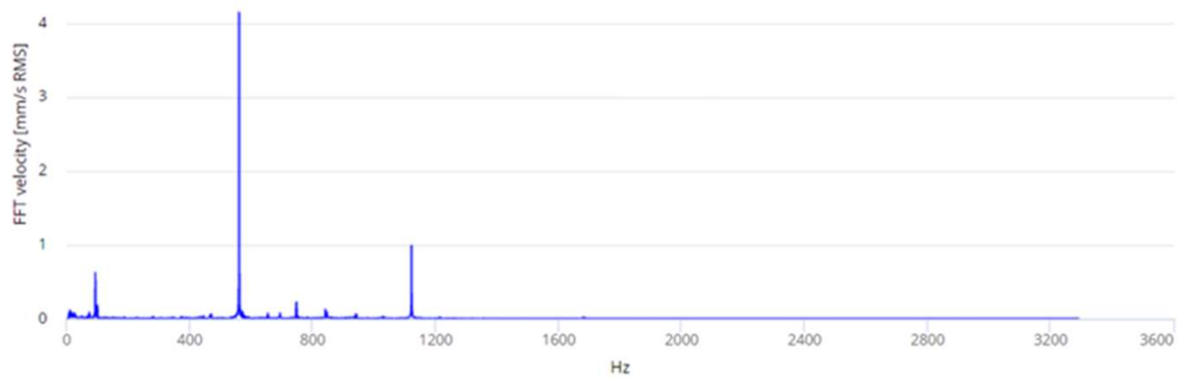
1*n 6*n 12*n

Excitation frequencies

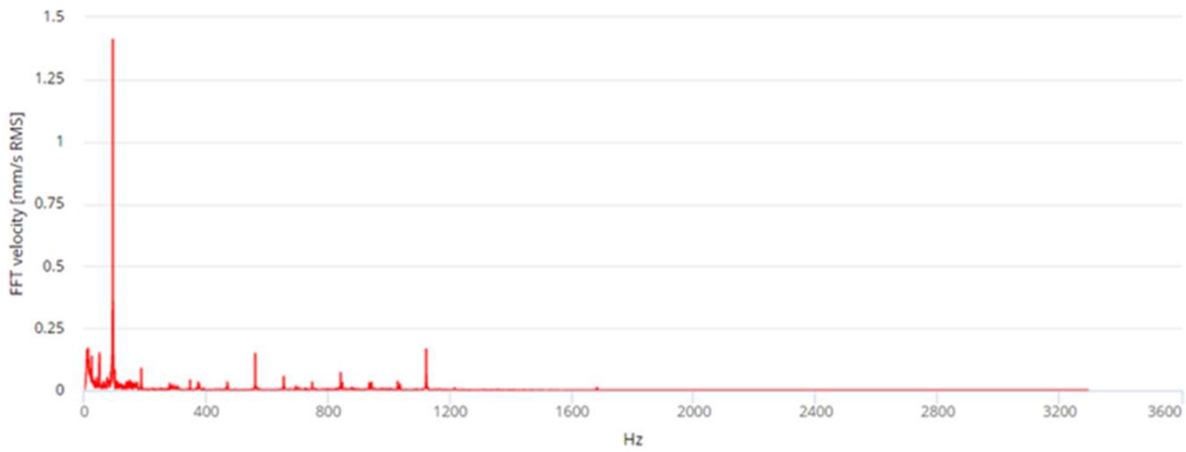
- First order is rotational speed
- Second order possible shaft misalignment
  - Not peaking → not causing elevated vibration levels
- Sixth order (in this case) is blade pass frequency
- Twelfth order (in this case) is 2x blade pass frequency from volute tongues

- First, sixth and twelfth order visible in spectrum
  - What are the possible reasons?
  - Are all measurement directions the same?

NDE axial



NDE
horizontal



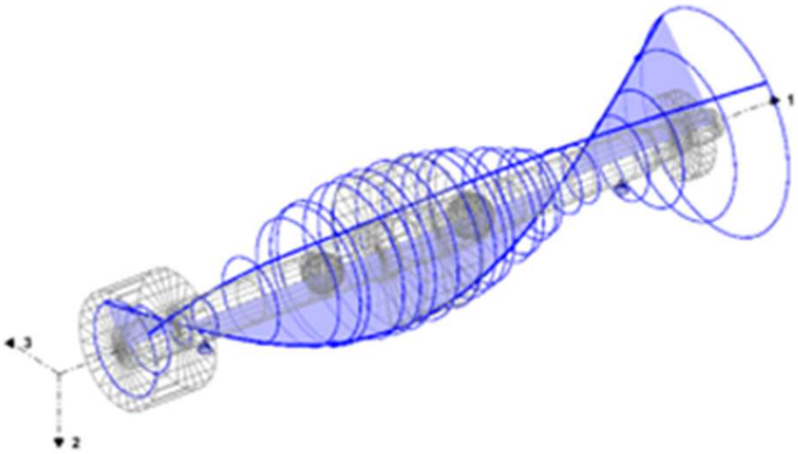
Why the spectrum looks as shown

- In this case axial direction impacted more by sixth and twelfth order
  - Would be more related to the blades
- Horizontal impacted more by rotational speed frequency
  - Could unbalance be the reason for this
- Good to inspect if there are natural frequencies close
  - Modal analysis is important for better understanding

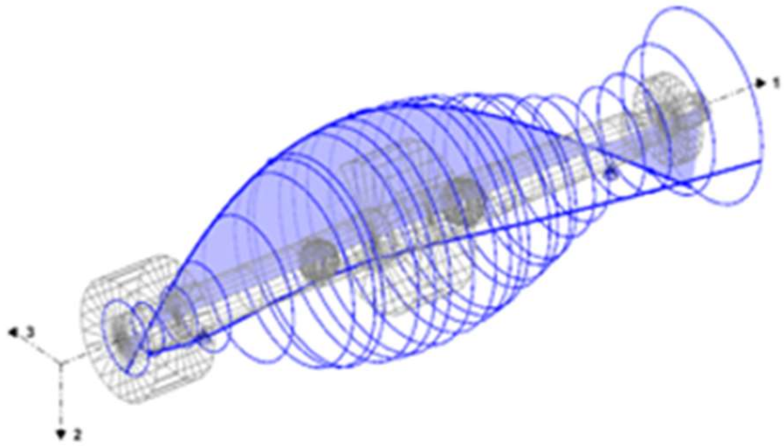
Modal analysis

- Separation margin should be 20 % with excitation frequency and natural frequency
- For this case, the impeller has three first mode shapes at the twelfth order in less than a 10 % range
- For the rotor, first, sixth and twelfth order are really close
  - First order at 93 Hz and natural frequency in the range of 105 Hz to 125 Hz
  - Sixth order at 558 Hz and natural frequency in the range of 540 Hz to 565 Hz
  - Twelfth order at 1116 Hz and natural frequency in the range of 1076 Hz to 1126 Hz
- Also, how the mode shape might affect

Might the bending modes load bearings or the seals



First bending mode



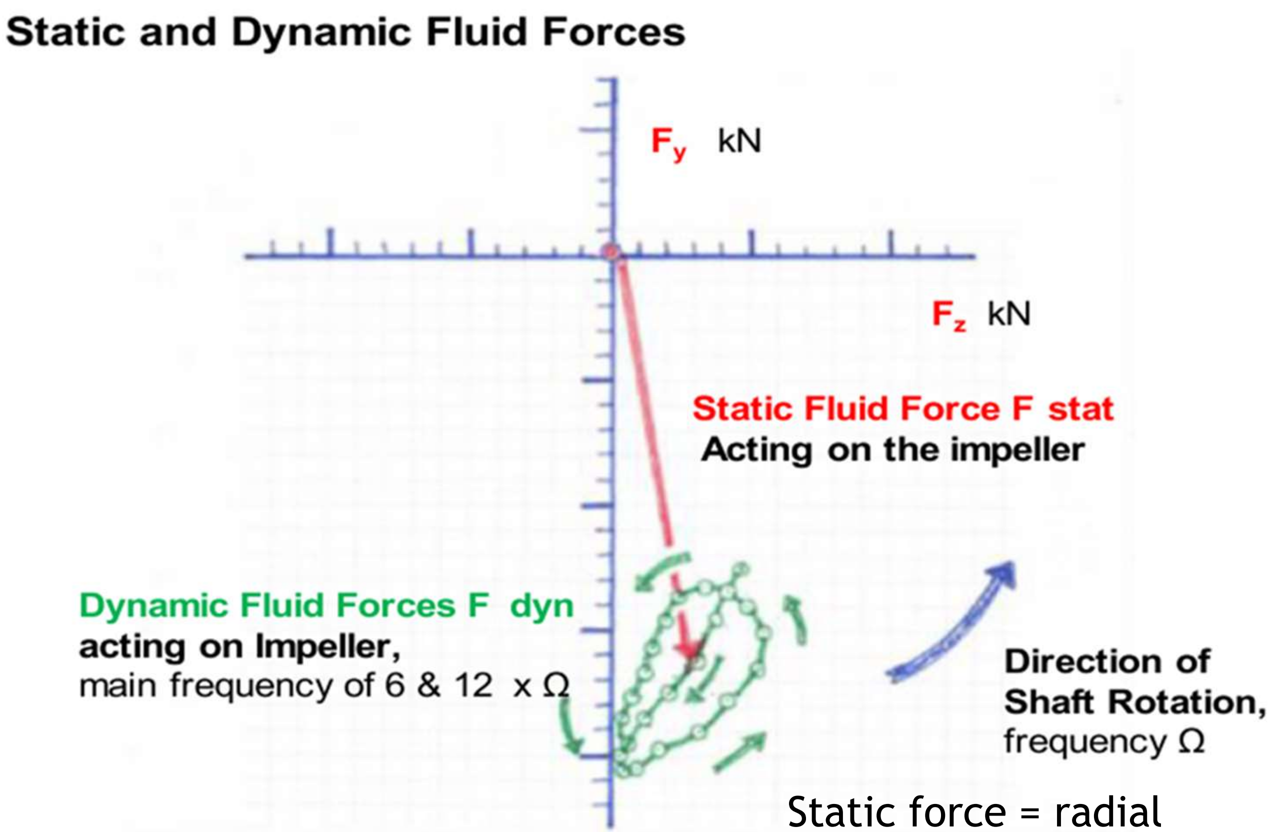
Second bending mode

Pump experiences static and dynamic forces
Depend on fluid flow rate and rotational speed

Lower mass flow increases static and dynamic loads

For this pump the min flow static load is 6x compared to full load

Dynamic load is 5x



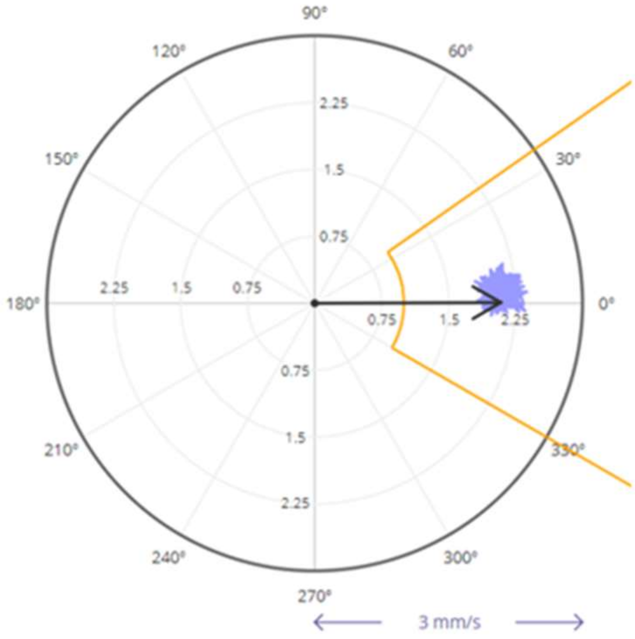
Dynamic force is time dependent

Static force = radial thrust (R)
R=K*ρ*g*H*D*B

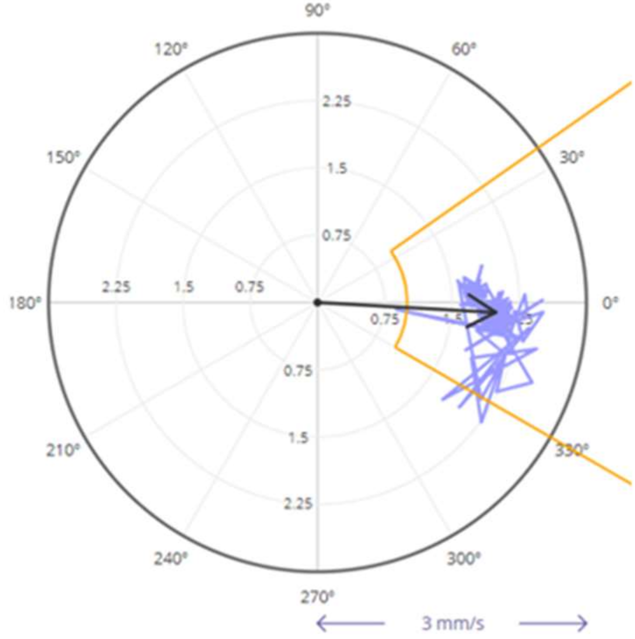
Rotational speed peak

- Unbalance is a probable reason
- Balancing of the shaft is important
  - Shaft deflection also to be accounted for
- Other possibilities e.g. include cavitation, looseness and flow turbulence
  - Not visible in the spectrum (background vibration levels or nonsynchronous)
- For this case balancing has been done multiple times and with different approaches → First order still very dominating
- Possibly hydraulic unbalance?
  - Appears as mechanical unbalance, but cannot be treated mechanically

Near full load



Flow reduction



Flow transients at rotational speed

What can be deducted of vibrations for this case

- Low mass flow increases vibration amplitudes on sixth and twelfth orders
  - Uneven pressure distribution, vortex formation, loading changes, natural frequencies
  - Most visible in axial direction and in this case has been highest at NDE
  - Troublesome for mechanical seals due to dynamic loading
- First order probably bothered by hydraulic unbalance
  - Natural frequency close by could pose issues
- Phase angle shows some changes but not too excessive for possible rubbing
  - Contact marks could have a different explanation

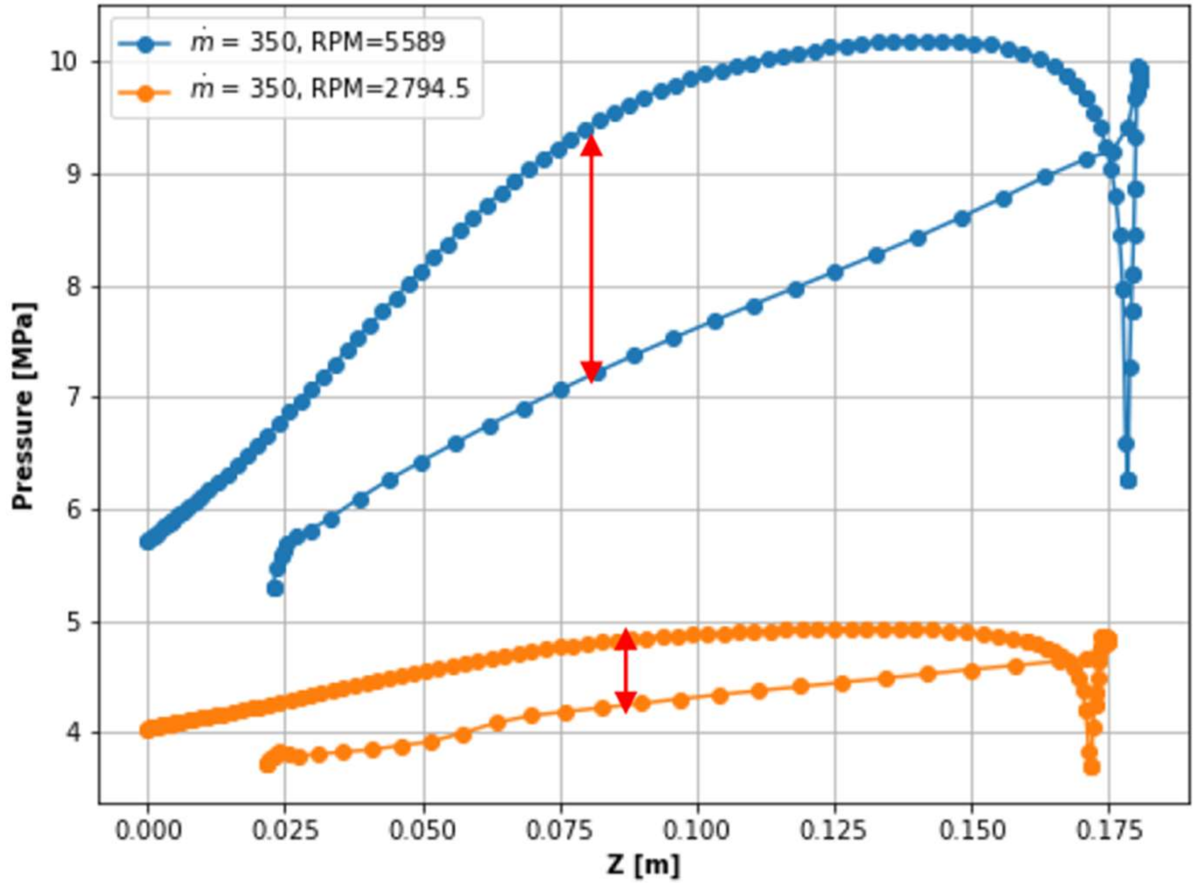
What can be improved

- Operate at higher mass flow (BEP)
  - Inconvenient for load regulation
- Gather more data
  - Does pump configuration affect the vibrations, especially on the three troublesome orders
- These pumps are throttled
  - Change rotational speed instead to optimize the flow
  - Increase mass flow → possibly bypass line

Blade pressure profiles

Decreased rotational speed has big difference with same mass flow

Not just overall pressure but difference over the blade itself



In short

- Hydraulically most optimal design might not be that in practice
  - Fluid forces can generate high stresses
- If thermal transients can be easily avoided, it should be done
- Vibrations can have multiple reasons
  - Not necessarily easy to solve
  - Minimum flow conditions cause excessive loading for the pump
  - System dependant vibrations are a bit harder to change
  - Natural frequencies could lead to resonances

- Thank You