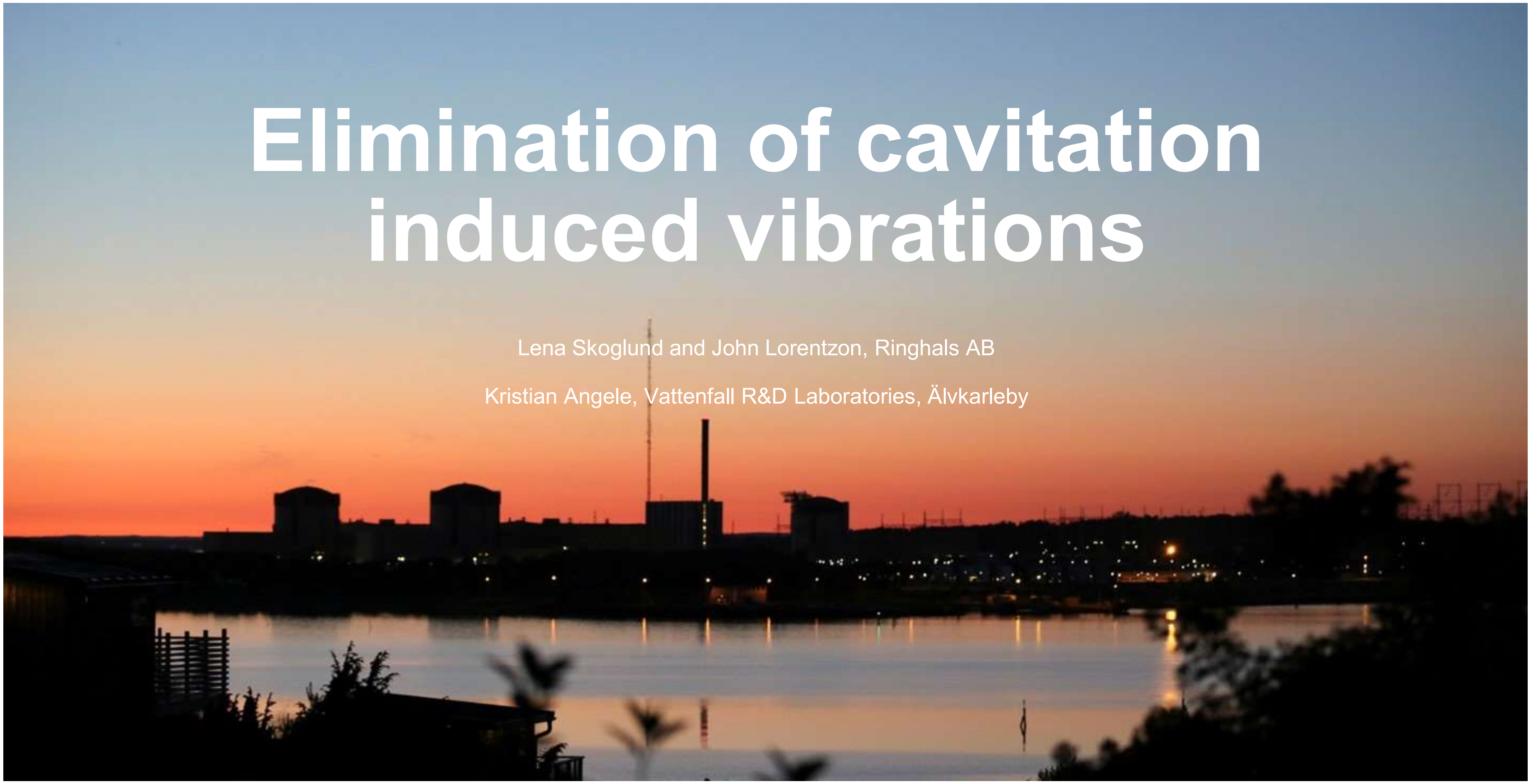


Elimination of cavitation induced vibrations

Lena Skoglund and John Lorentzon, Ringhals AB

Kristian Angele, Vattenfall R&D Laboratories, Älvkarleby

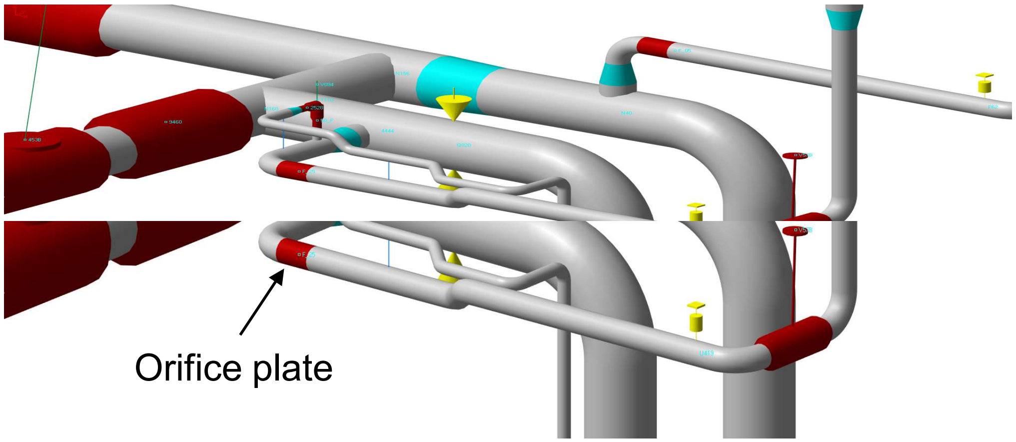
Background

- During outage of Ringhals unit 4 a small diameter piping started to leak at a weld
- The cause of the water leak was high cycle fatigue due to poor design with a large excentric mass combinied with high vibration levels
- The vibration level was above the acceptance criterion

Root cause of vibrations

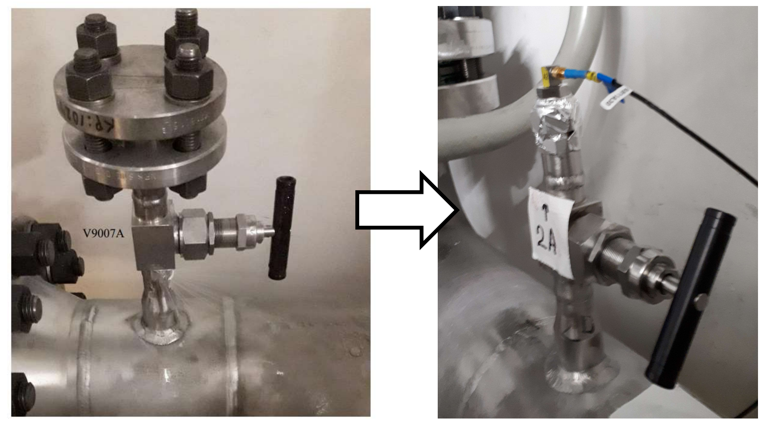
- The cause of the high vibrations was determined to be due to cavitation in an orifice plate

- Supported by the characteristic sound (like gravel through the pipe) and empirical correlations for cavitation in orifice plates.



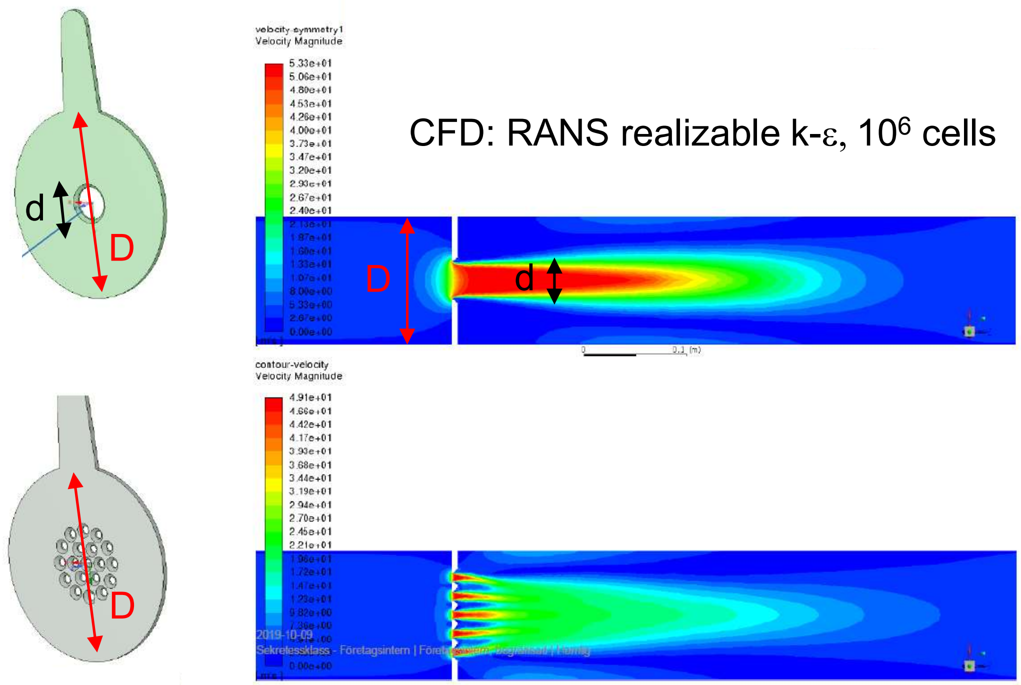
Actions taken

- To increase the robustness with respect to high cycle fatigue, the following measures were performed:
  - New design of the small pipe: the heavy flange was replaced with a plug
  - New orifice plate design
    - Design-CFD
    - Experimental verification



New orifice plate design: CFD

- **<u>Basic concept</u>**: divide the pressure drop in stages
- <u>Old design</u>: single-hole, <u>single-stage</u> orifice plate
- <u>Solution</u>: multi-hole, <u>multi-stage</u> (3 st) orifice plates



New orifice plate design: experimental verification

- Vattenfall R&D laboratory in Älvkarleby
- Old design
- New design

3 orifice plates

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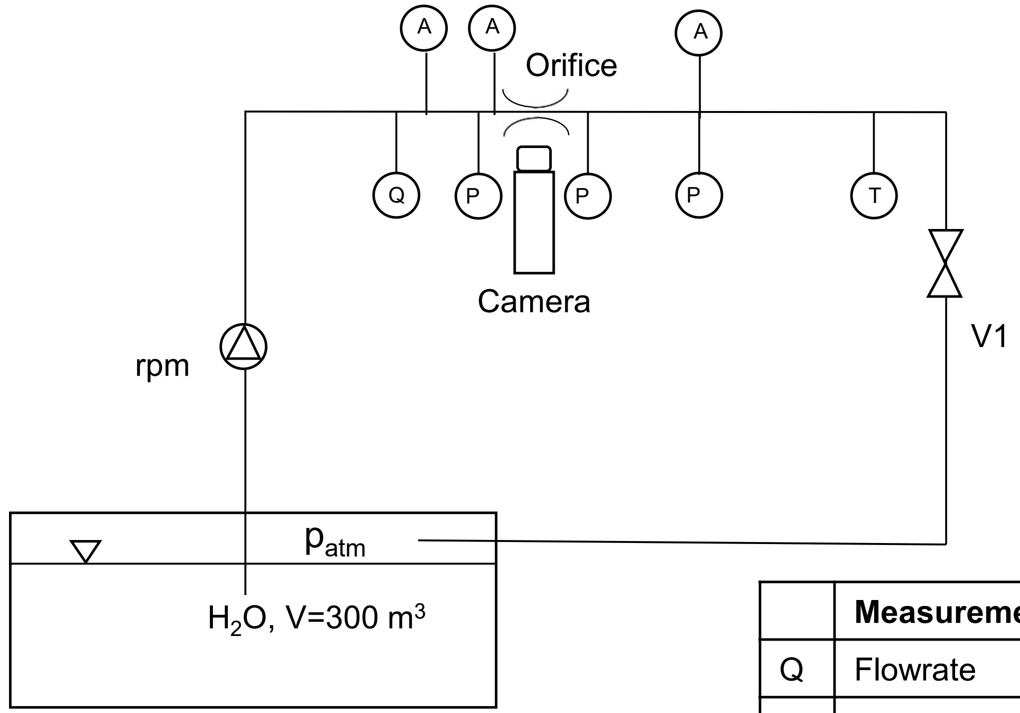
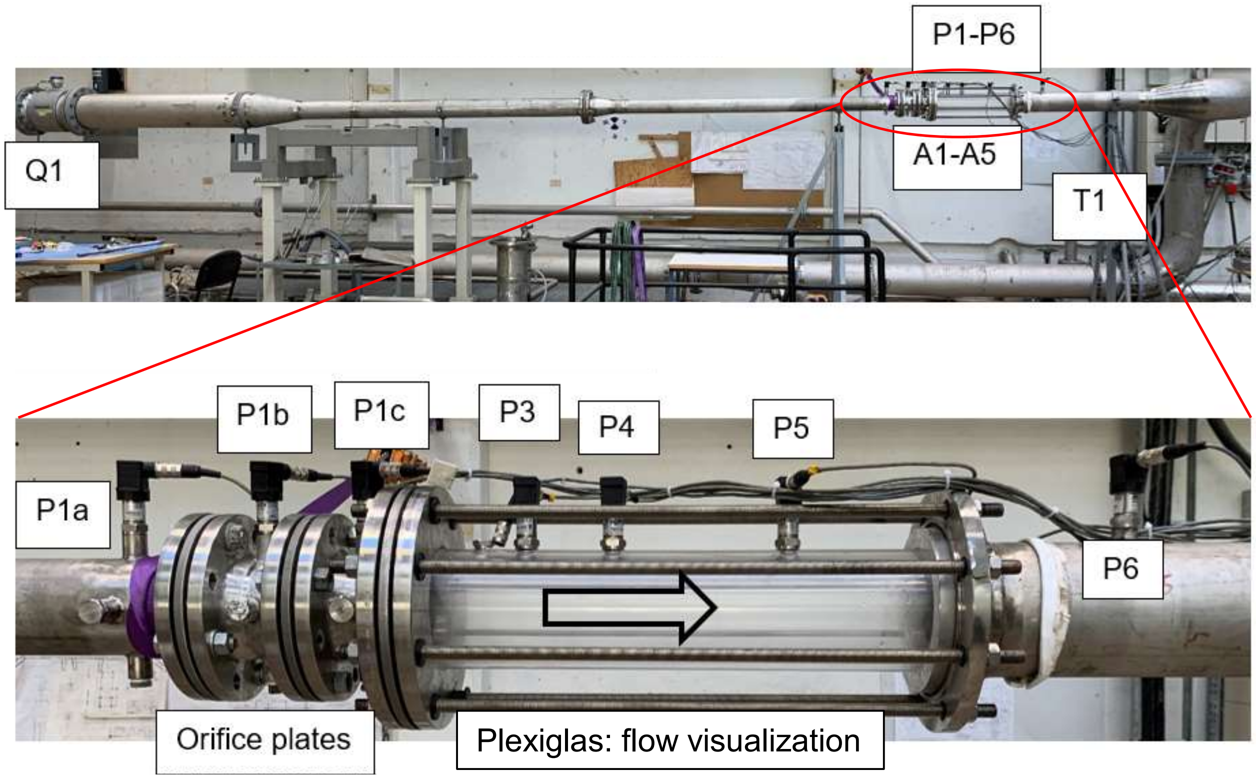
Flow chart, instrumentation and operation



- Flowrate (Q) and pressure (P) regulated by pump-speed (rpm) and regulation valve (V1)
- T=15.4±0.3°C (no regulation)
- $\rho(T)$, $\nu(T)$, $p_{sat.}(T)$

	Measurement	Instrument	Range	ε
Q	Flowrate	EMF	0-200 l/s	± 0.5 %
P	Pressure	Transducer	0-10 bar, g	< 0.5 %
T	Temperature	Pt100	0-50°C	± 0.1°C
A	Acceleration	Accelerometer	10-100 mV/g	< 1 %

Test rig and instrumentation



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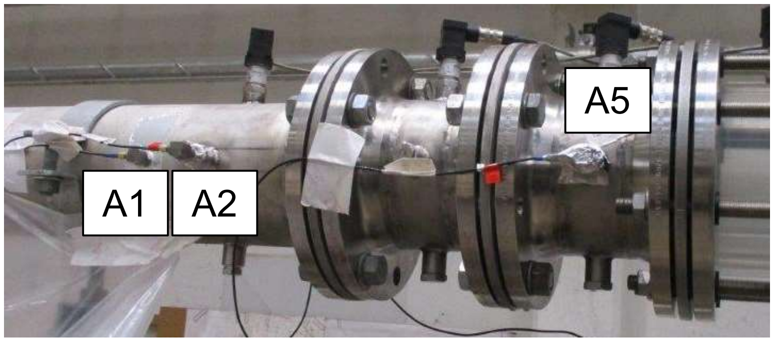
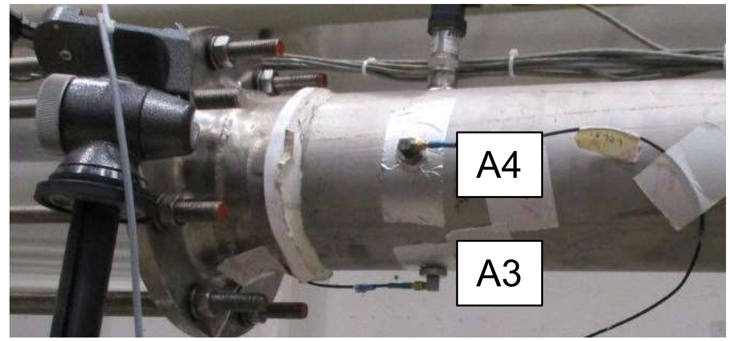
Vibration measurements

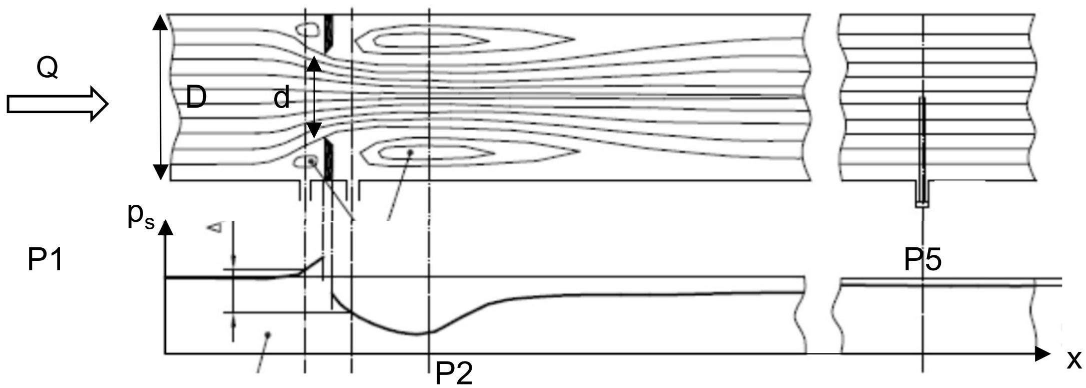




- Accelerometers Triax ICP (DYTRAN)
- Fixed using magnetic foot, Al-tape and washers
- Hardware: Dewesoft Sirius HD16
- Software: Dewesoft X3

	f (Hz)
Sampling	2000
Low-pass filter	780
High-pass filter (raw signal)	1
High-pass filter (integration)	4

Cavitation basics



Cavitation: local $p_s < p_{sat.}(T)$

$$\sigma = \frac{p_s - p_{sat.}}{\Delta P} \downarrow$$: increasing cavitation

$$\Delta P = P1 - P5 = \xi \cdot 0.5 \rho u^2$$

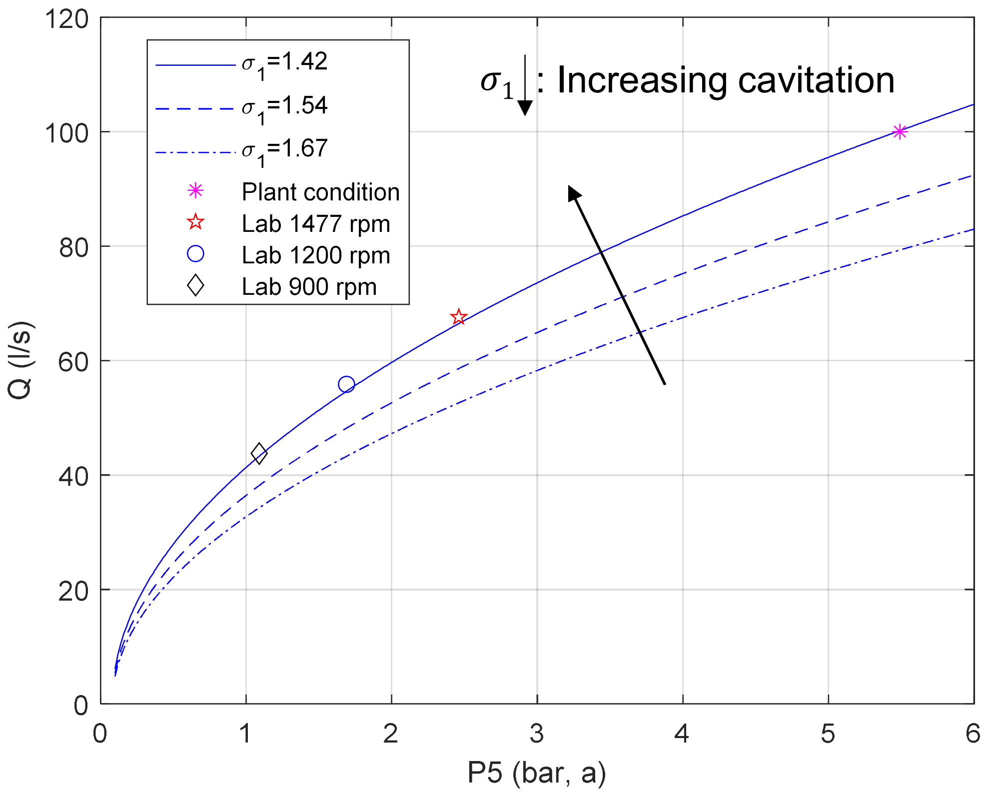
- p(x) pressure recovery: P5>P2
- Cavitation decreases in x-direction
- Implosion of cavitation bubbles
- Leads to vibrations

Conditions

	Plant	Lab
D (mm)	154.1	154.1
d (mm)	61.0	61.0
Q (l/s)	100	67.5
P1 (bar a)	18.7	8.4
P5 (bar a)	5.5	2.5
$\boldsymbol{\sigma_1 = \frac{P1 - p_{sat.}}{\Delta P}}$	1.42	1.42

- Geometrical scale 1:1
- Lower Q and P
- Same σ_1

Scaling: lab to plant



$\sigma_1 = 1.42$

$\sigma_1 = 1.54$

$\sigma_1 = 1.67$

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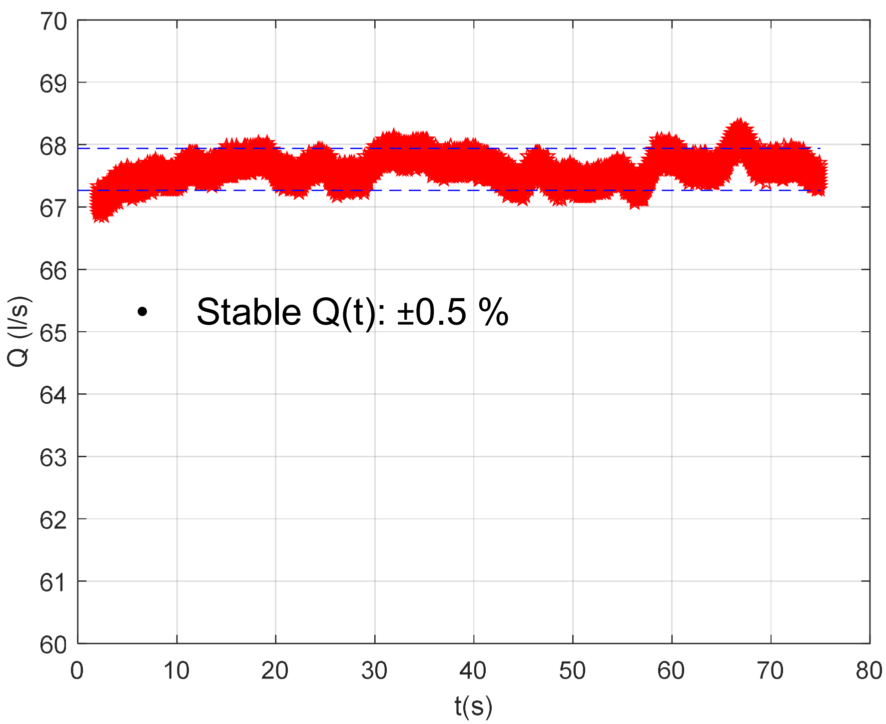
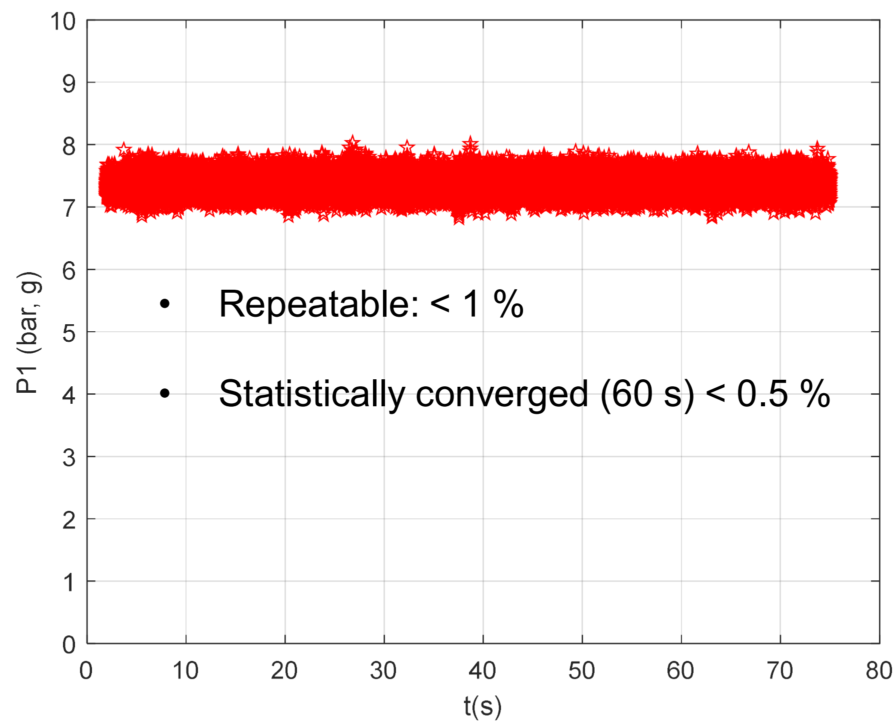
Stability, repeatability and statistical convergence





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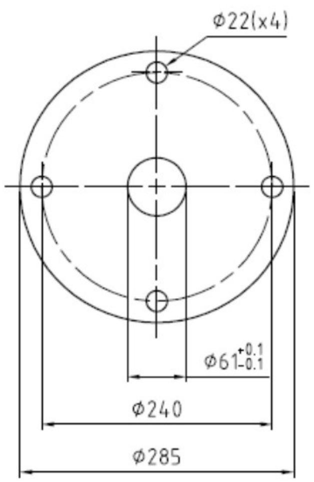
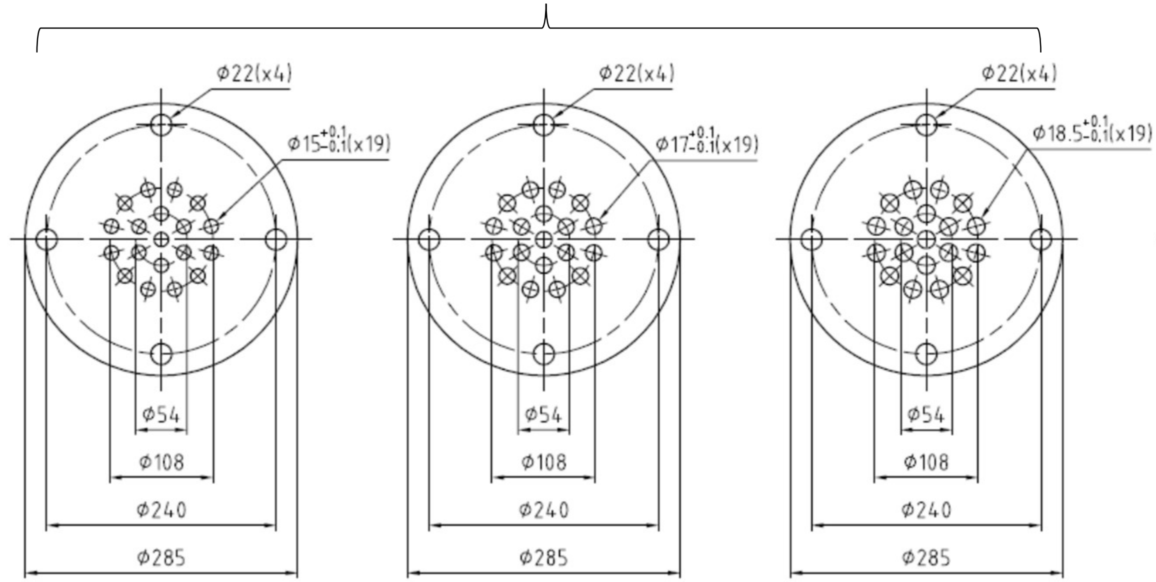
Strategy

Single-hole, single-stage orifice plate



Multi-hole, multi-stage orifice plates



$$\Delta P = \Delta P_a + \Delta P_b + \Delta P_c$$

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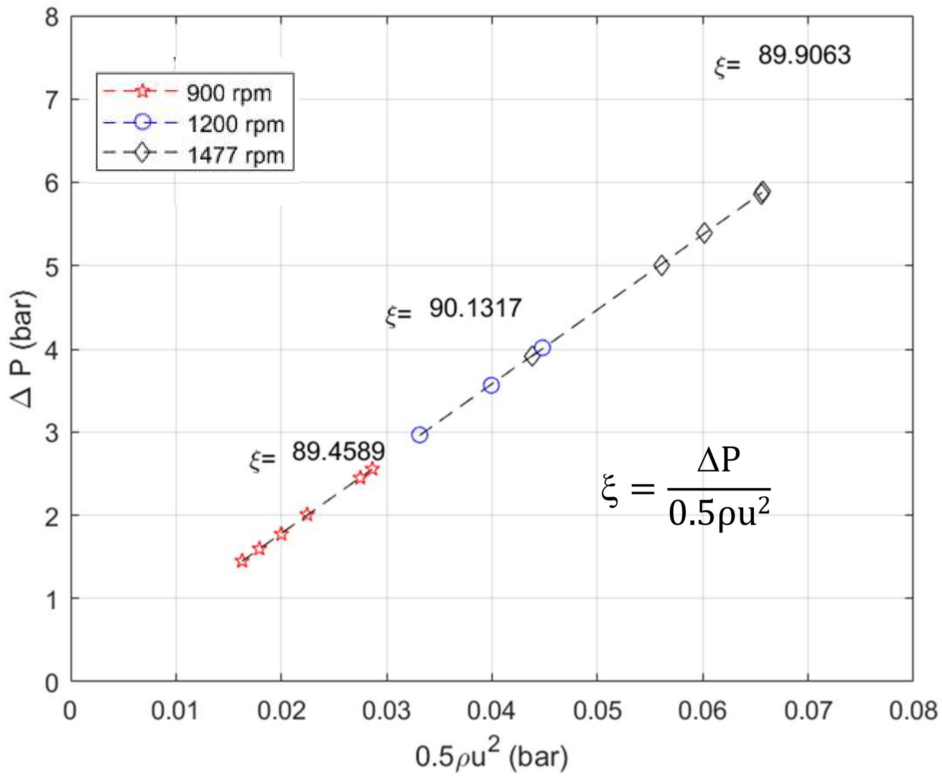
Open area ratio

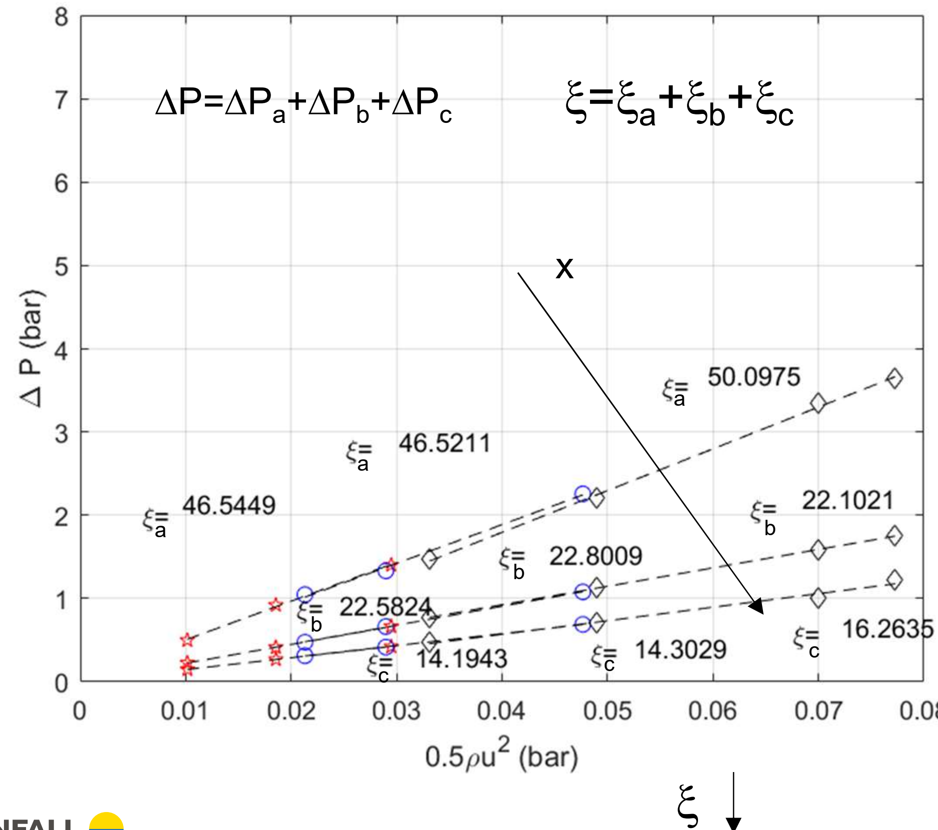
	n (st)	d (mm)	A_open (%)
Old orifice	1	61	15.7
Multi-hole_a	19	15	18.0
Multi-hole_b	19	17	23.1
Multi-hole_c	19	18.5	27.4

Pressure loss coefficient

Single-hole, single-stage orifice plate



Multi-hole, multi-stage orifice plates



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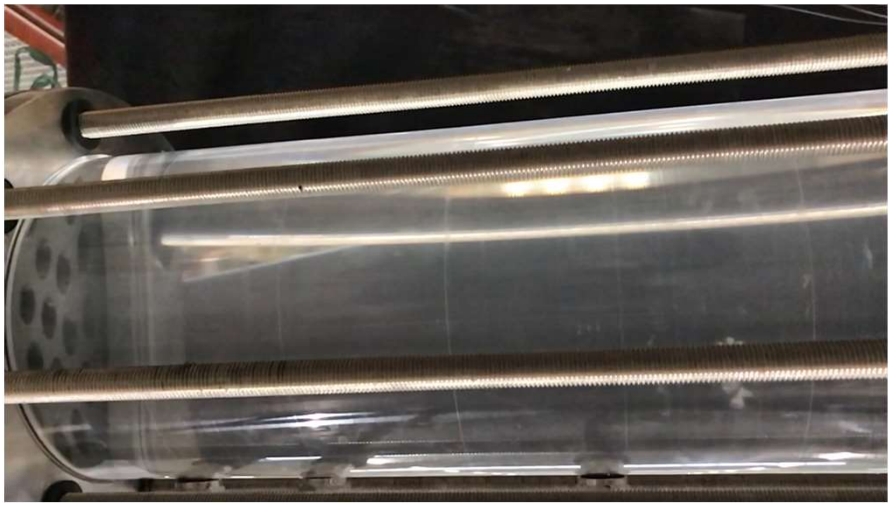
Cavitation vizualisation

Single-hole, single-stage orifice plate

Multi-hole, multi-stage orifice plates



Cavitation ↓

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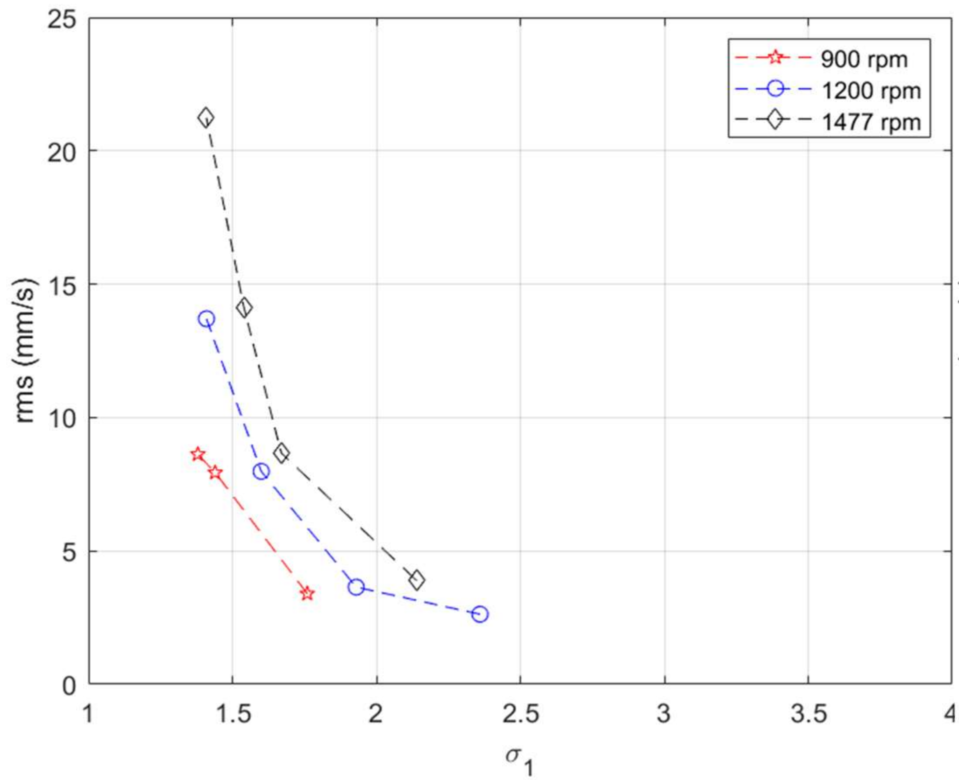
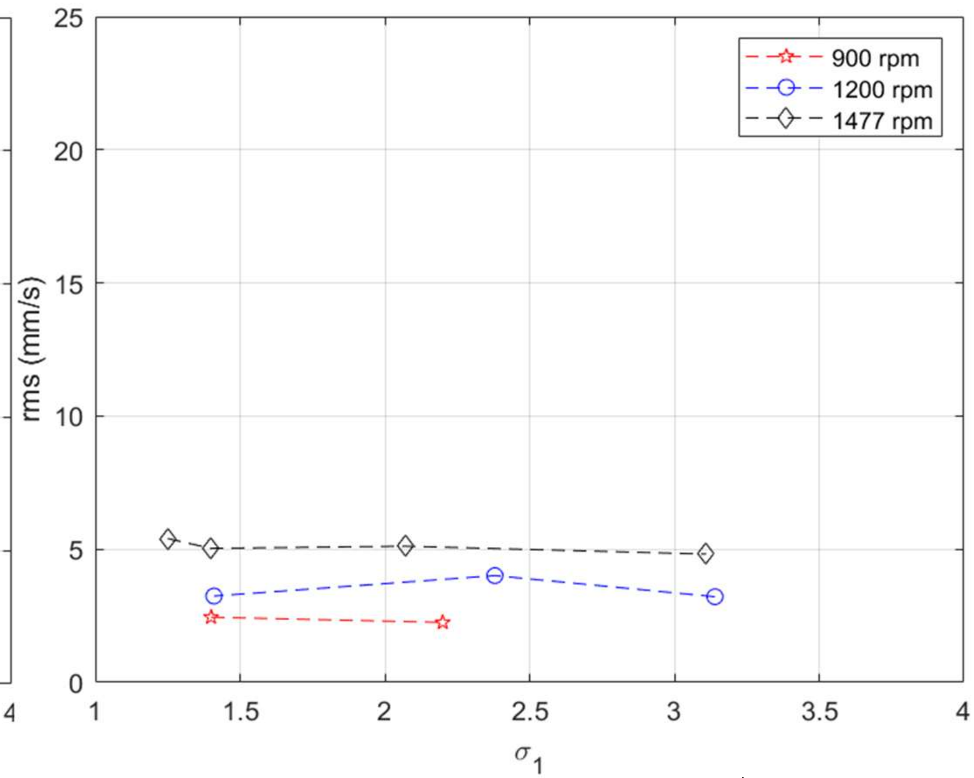
Cavitation induced vibrations

Single-hole, single-stage orifice plate



Multi-hole, multi-stage orifice plates



Vibrations ↓

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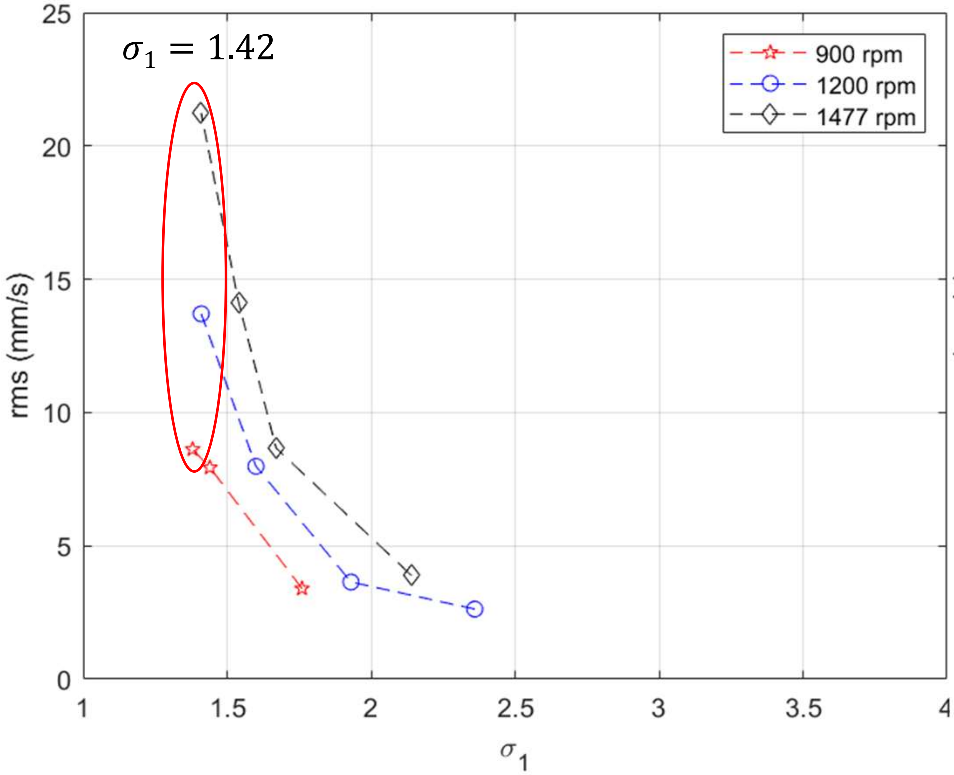
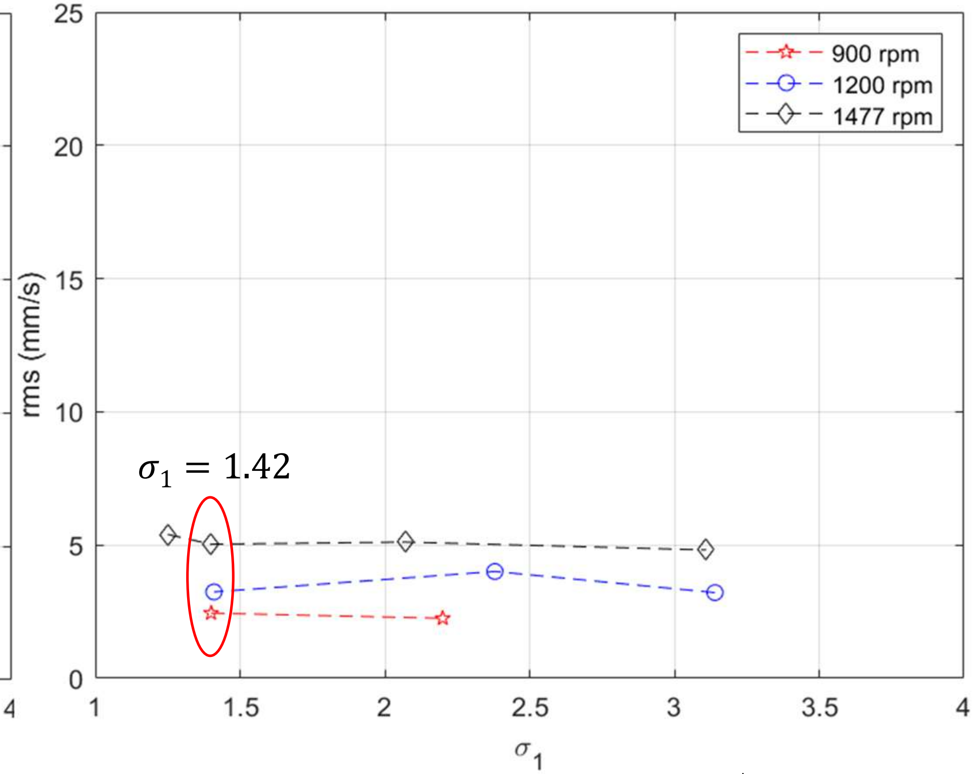
Cavitation induced vibrations

Single-hole, single-stage orifice plate



Multi-hole, multi-stage orifice plates



Vibrations ↓

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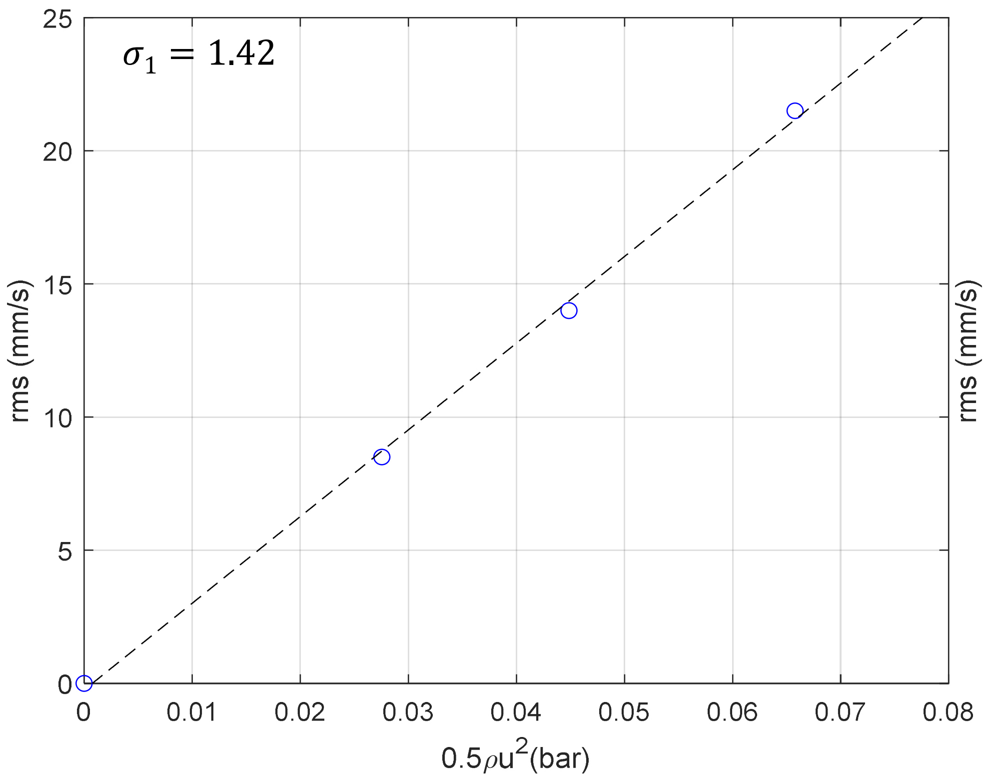
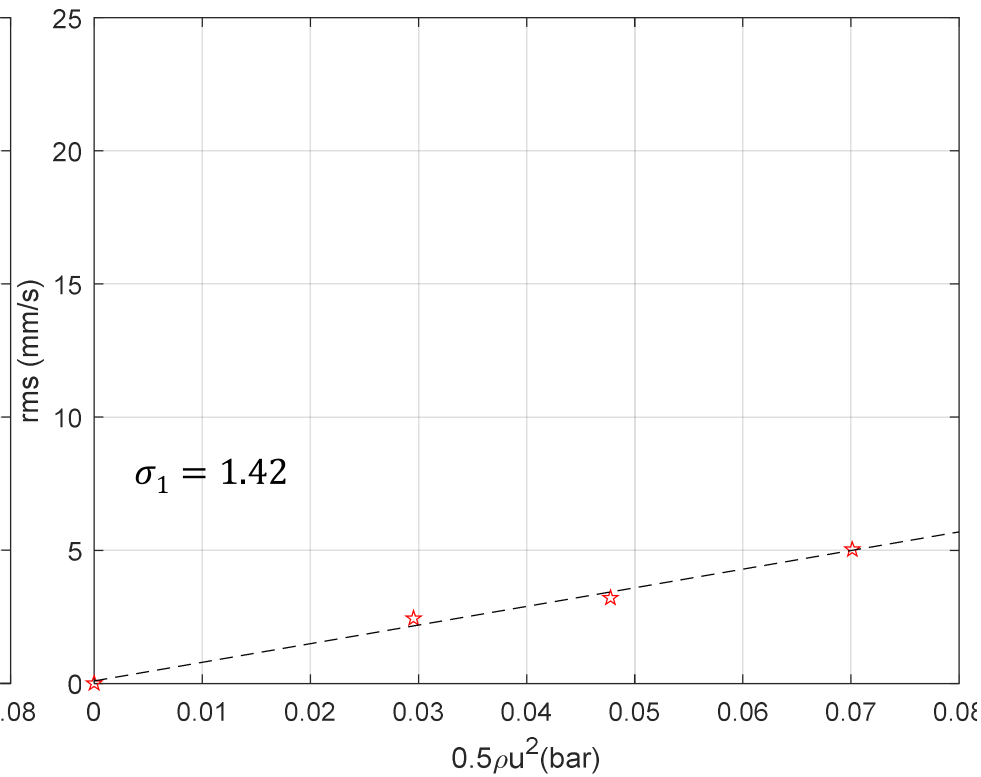
Cavitation induced vibrations

Single-hole, single-stage orifice plate



Multi-hole, multi-stage orifice plates



Vibrations ↓

Summary

- Problem: cavitation induced vibrations in single hole orifice plate at Ringhals 4
- Solution: Multi-hole, multi-stage orifice plates reduce cavitation and vibration levels
- Experimentally verified solution in the lab in Älvkarleby
- Results can be scaled up to plant conditions
- Solution installed during outage, May 2020