AFM Measurements of Fluid Induced Vibrations

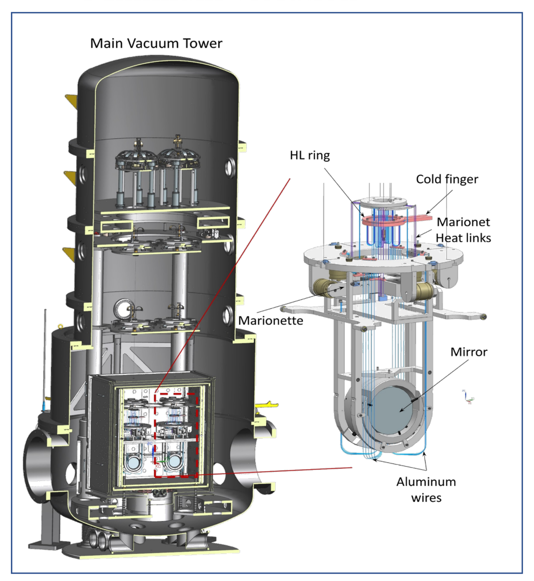
Characterizing of Sorption based J-T Cryocoolers Emitted Forces

Arvi Xhahi [1,2], Markus Schremb[1], Sebastiaan Haartsen[1], Michiel van Limbeek[1], Henk Jan Bulten[2], Pantelis Bampoulis[1], Marcel ter Brake[1]

Background

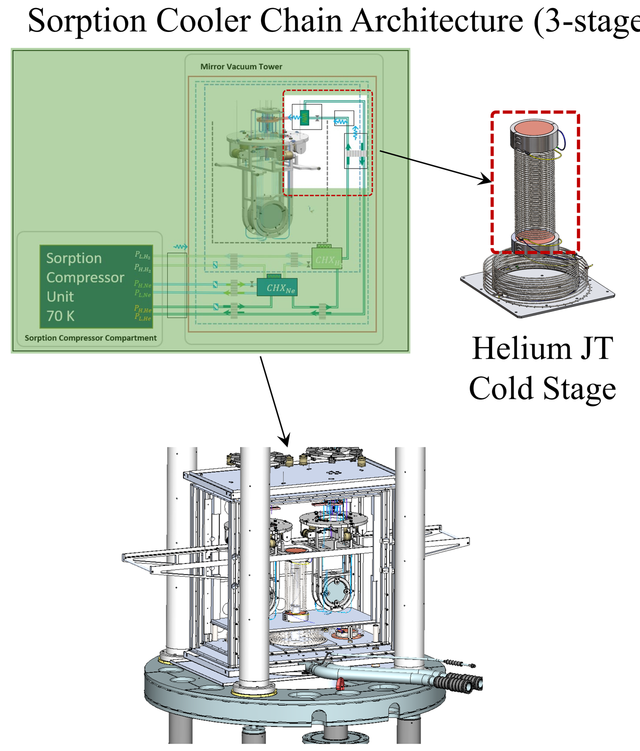
Gravitational Wave Detectors Test Facility:

- Einstein Telescope
- Cryogenic detectors (<10 K)
- Minimum vibration



ETpathfinder Environment [a]

Sorption Cooler Chain Architecture (3-stages) [a]

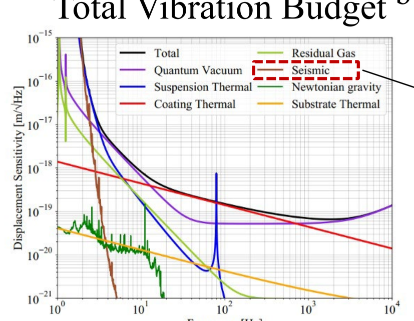


Helium JT Cold Stage

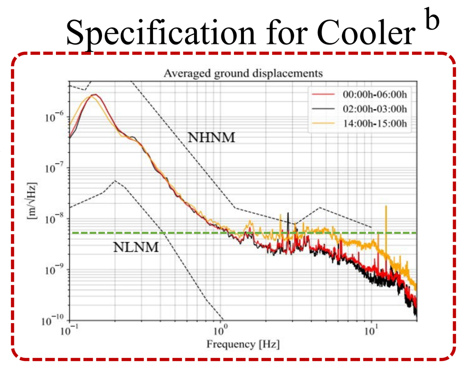
Sorption Cooler Chain Mounted in Cryostat [a]

Requirements

Total Vibration Budget [b]



Seismic Vibration Level: Vibration Specification for Cooler [b]

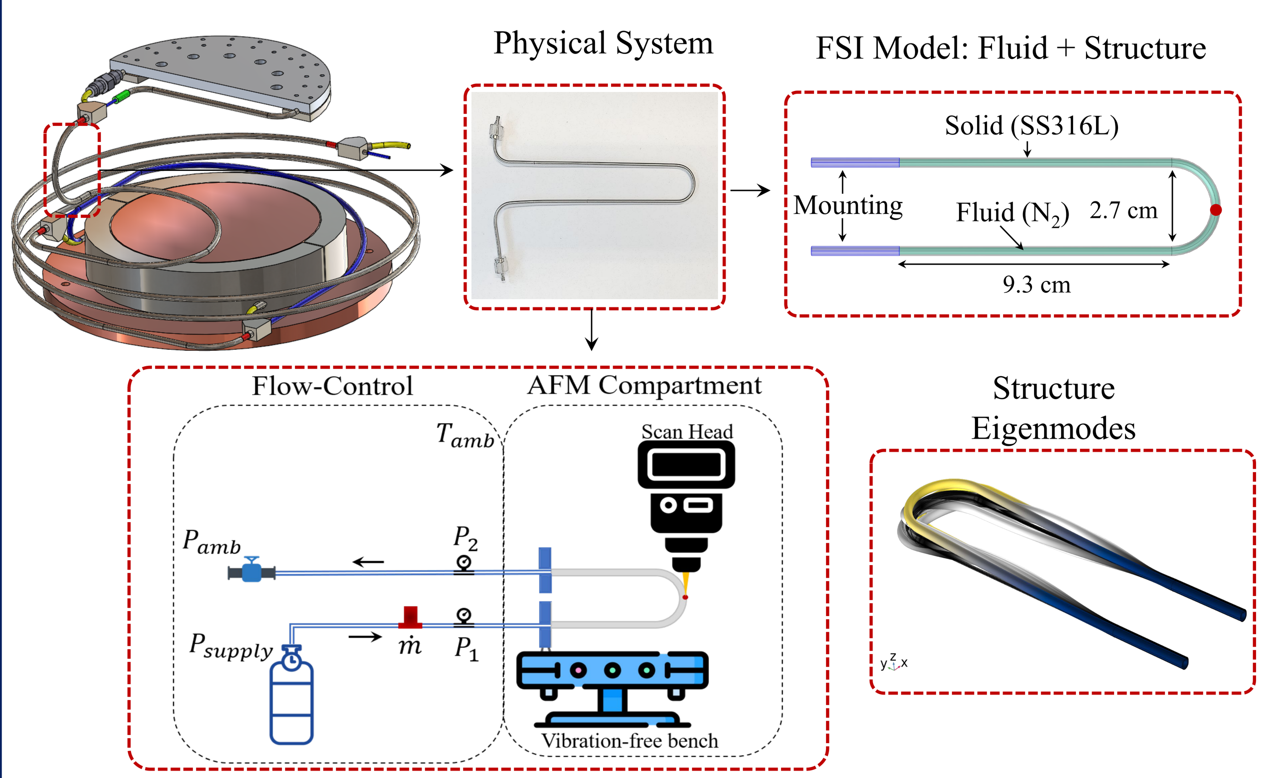


The forces emitted by the cooler must not surpass the excitation levels caused by background seismic vibrations at the cryogenic payload interface (cold finger): $4\ nm/\sqrt{Hz} \rightarrow 11\ nm\ @\ 2-20\ Hz$

Method –FSI & Experiments

Predict fluid forces on the structure (validation) :

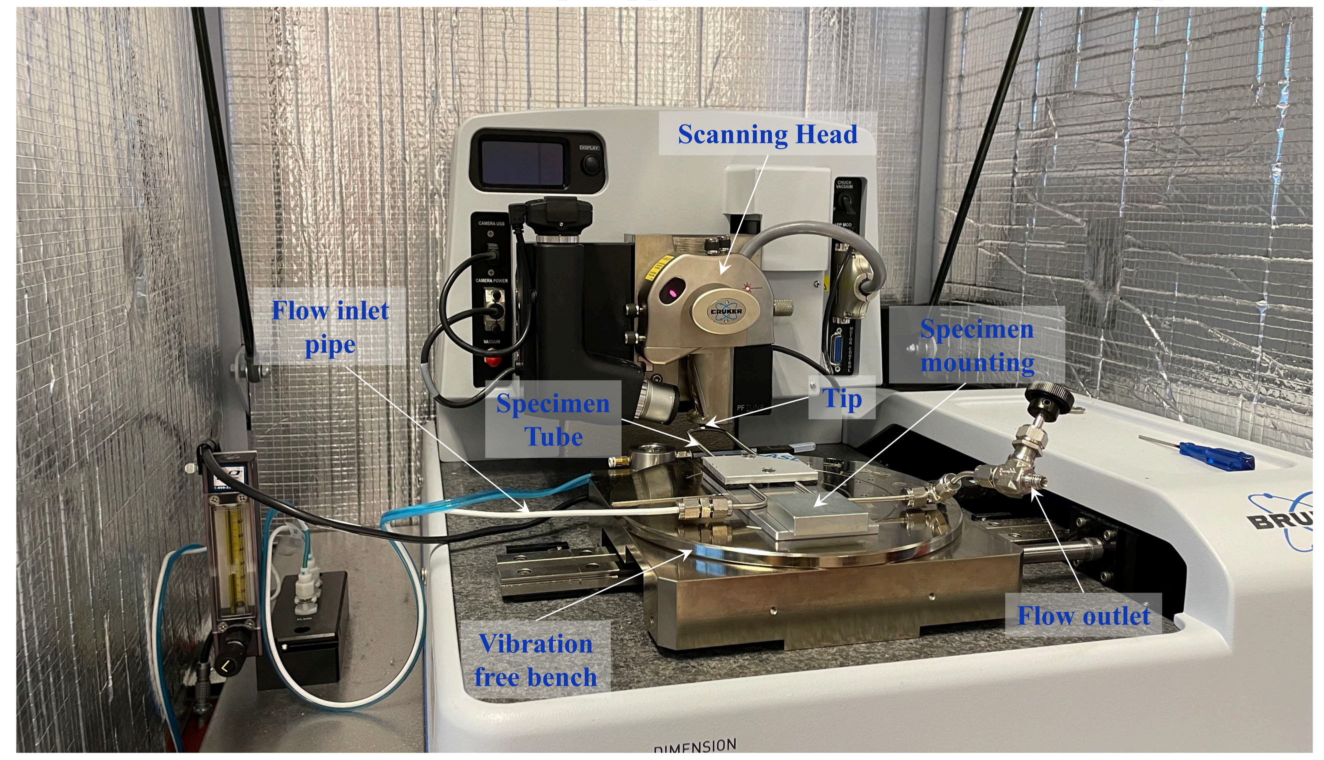
- Evaluate flow induce vibration in cooler representative geometry (tube bent)
- Compute structure eigenmodes and frequencies
- Fluid-Structure-Interaction modeling (LES fluid model and structural model)
- Vibration measurements (at room temperature)



Experimental set-up

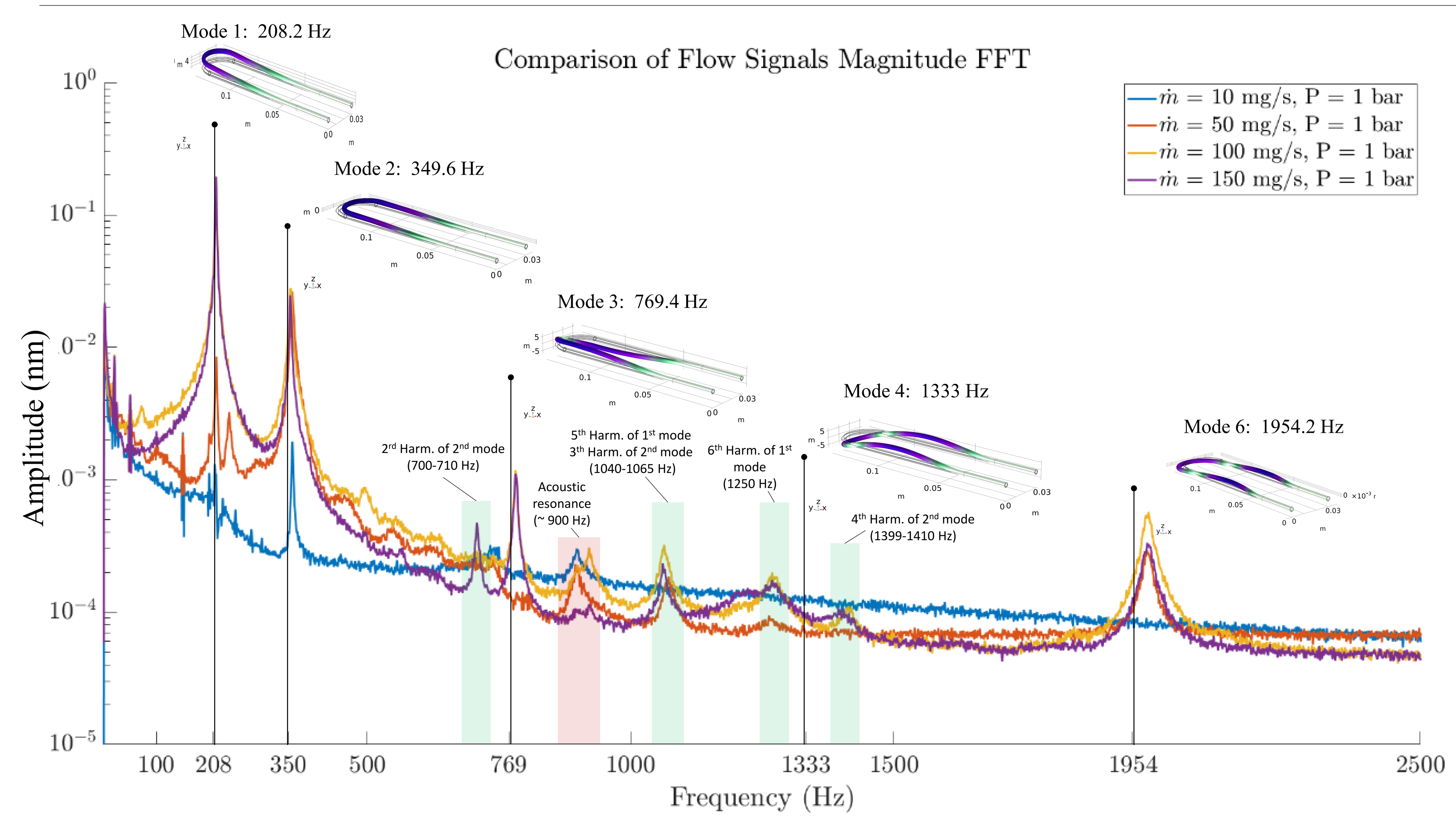
Apparatus- Measurements

Atomic Force Microscope Apparatus - Measurement of U-Shaped tube



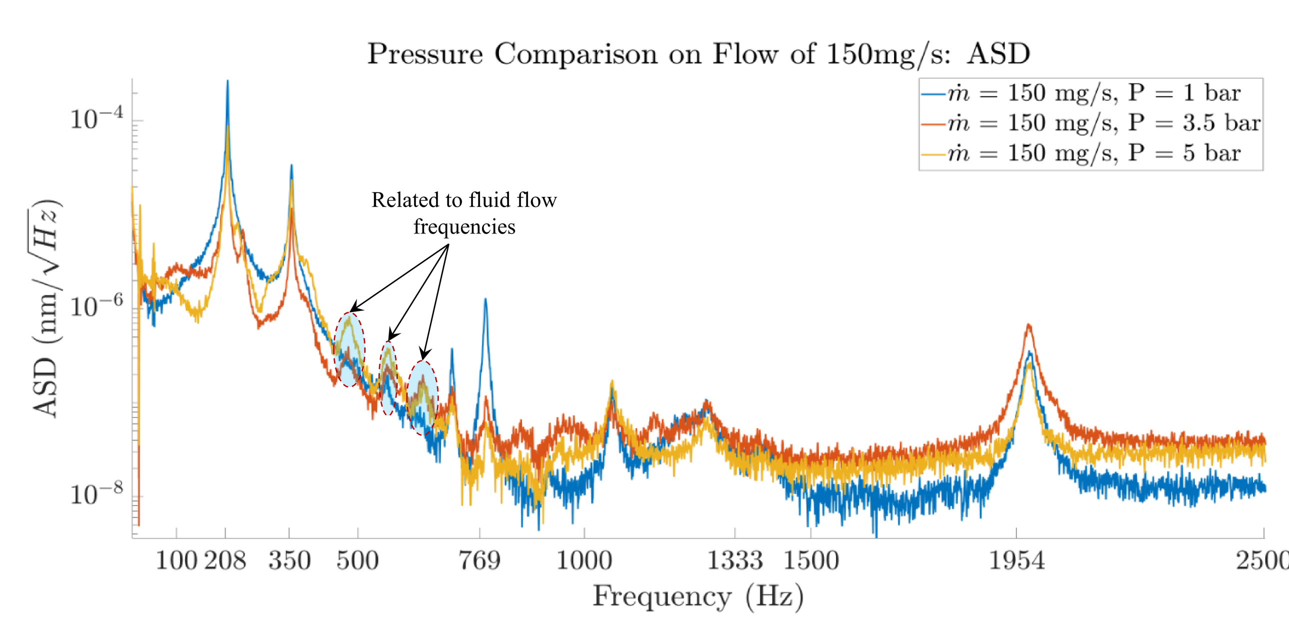
- One point displacement measurement at the mid-point of the tube bent.
- Controlled mass flow of N_2 in the range of 10 to 150 mg/s.
- Pressure control at the outlet via back-pressure regulator for 3 pressure levels: 1, 3.5 and 5 bar.
- Contact mode measurement period of 90 sec with a time step of 0.0001 sec.
- Max peak-to-peak displacement of ~3 nm for 150 mg/s flow at 1 bar.

Mass flow rate effect (Spectral Amplitude plot)



- 10 and 50 mg/s are laminar flows with 300 and 1513 Reynolds.
- Fully turbulent flow is resulted for flows above 100 mg/s.
- Amplitudes for turbulent flows are significantly higher.
- For turbulent flow additional frequency peaks are present.
- The second mode at ~350 Hz is the in-plane deformation in the direction of flow momentum change at the bend is present for all flow regimes.
- Complex interaction of modes harmonics and induced fluid frequencies are identified.

Pressure effect (ASD plot)

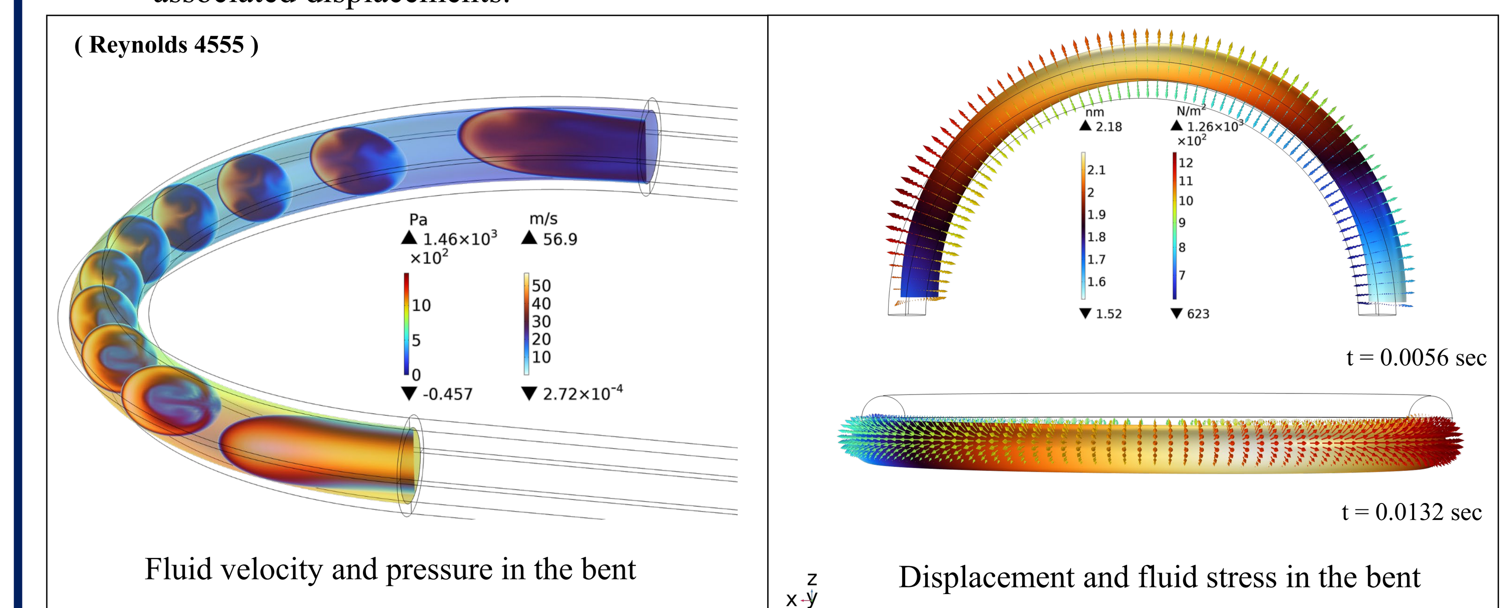


- Pressure effect on 150 mg/s flow : 1 bar, 3.5 bar and 5 bar.
- Spectral fundamental peaks tend to decrease with increasing pressure as the flow velocity and kinetic energy of the flow decreases (for the same mass flow rate).
- Three additional spectral peaks (between 480 – 645 Hz) are present for the 3.5 and 5 bar flows with respect to the 1 bar flow which are speculated to be related to particular flow frequencies (vortex shedding).

Simulations (FSI)

FSI results for 150 mg/s case :

- Simulation period of 0.1 sec with a time step of 0.0001 sec.
- Flow patterns and structures show formations of secondary flow and eddies in the bend.
- The traction vector distribution acting along the tube boundaries shows high stress concentrations at the bend, directly indicating areas of noticeable fluid-induced stresses and associated displacements.

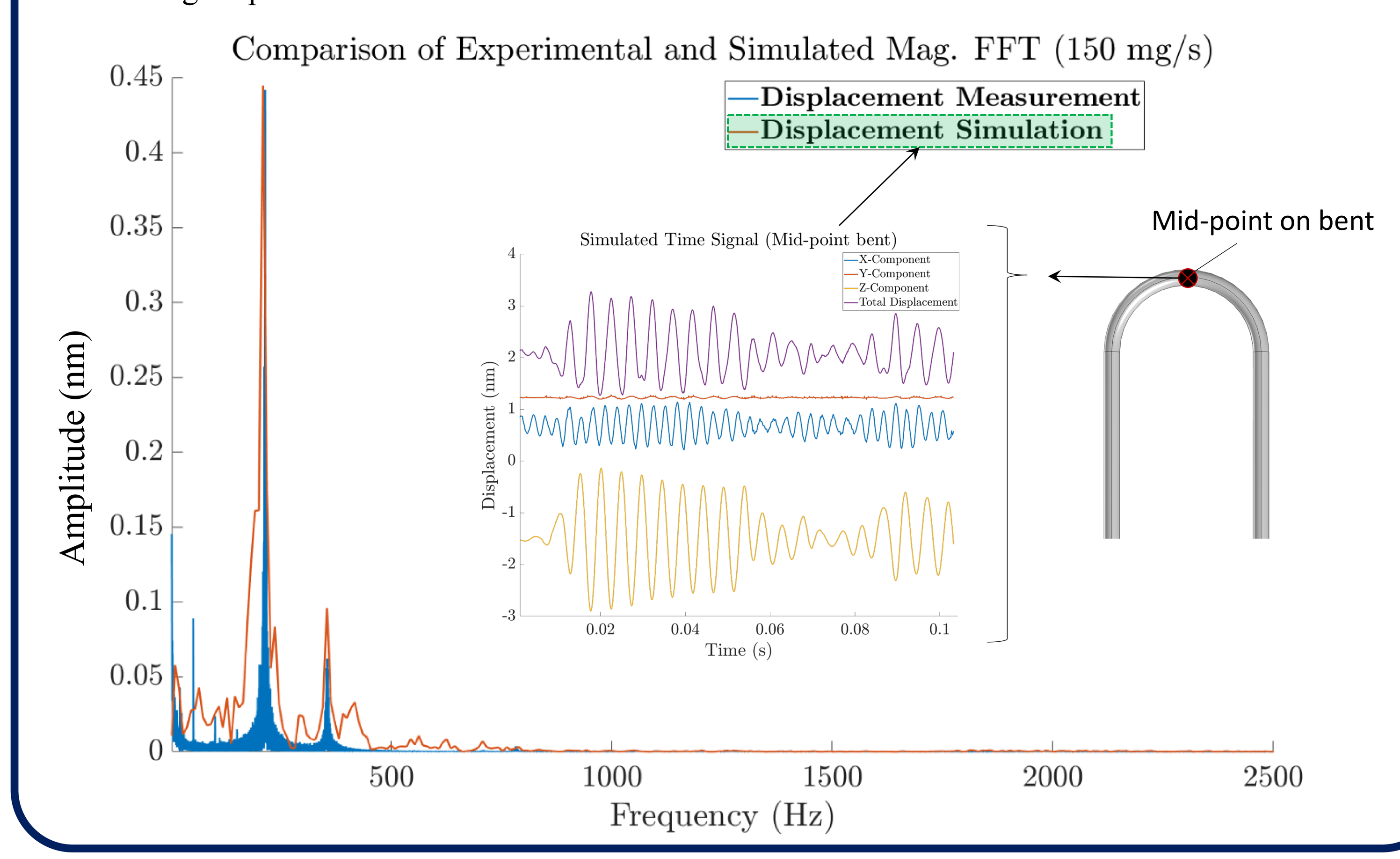


Fluid velocity and pressure in the bent

Displacement and fluid stress in the bent

Spectral analysis and comparison of point displacement at 150 mg/s case :

- The displacement spectra of the mid-point at the bent is considered.
- Comparison with measurement signal shows good agreement on first mode and slightly higher peak on the second mode for simulated results.



Conclusion

- Displacement measurements (point) of internal flow via AFM is a promising way forward for fluid induced vibration measurements in the nm range.
- The presence of fluid acts as a damping agent in the fluid-structure system, altering the observed structural spectral peaks. Additionally, fluid pressure affects the observed displacement spectra for the same mass flow rate.
- Point displacement comparison between measurement and FSI simulation show good agreement in frequency however further model validation with new measurements for amplitude validation is required.
- Additional AFM measurements with J-T throttling device are planned.

1. University of Twente, Faculty of Science and Technology, P.O.Box 217, 7500 AE, Enschede, The Netherlands
2. NWO-i Nikhef, P.O. Box 41882, 1009DB Amsterdam, The Netherlands.

a,b

Nikhef

UNIVERSITY OF TWENTE.