Radially Adjustable Perforated Vortex Controllers for the Suppression of Rotating Vortex Rope In Axial Turbines

***Doctoral Student**: Antariksh Nawander*

***Supervisors**: Michel Cervantes, Joel Sundström, Sandeep Kumar*

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Turbine Types

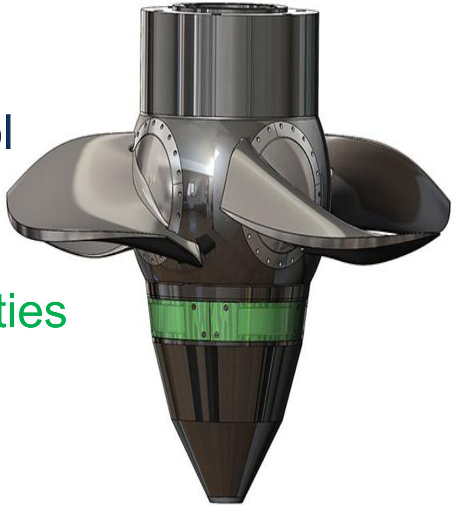
Single Regulation

- Guide vane control
- Fast Response
- Simple Mechanism
- Narrow Operating Range
- High Residual Swirl

Double Regulation

- Guide vane + blade pitch control
- Wide operating range
- Suppress swirl-induced instabilities
- Complex actuation (Expensive)
- Slower mechanical response

Double Regulation (Kaplan)



Hydropower and Turbine Types

- Renewable Intermittency → Wind, Solar
- Increased Grid Flexibility Demand
- Hydropower Compensates
- Operation Away from BEP
- Residual Swirl
- Rotating Vortex Rope (RVR)
- Pressure Pulsations
- Fatigue (Reduced Lifetime)

Nishi, M. "Flow regimes in an elbow-type draft tube." Proc.11th IAHR Symposium on Hydraulic Machinery and System, Amsterdam, 1982.1982.

Consequences for Single Regulated Turbines

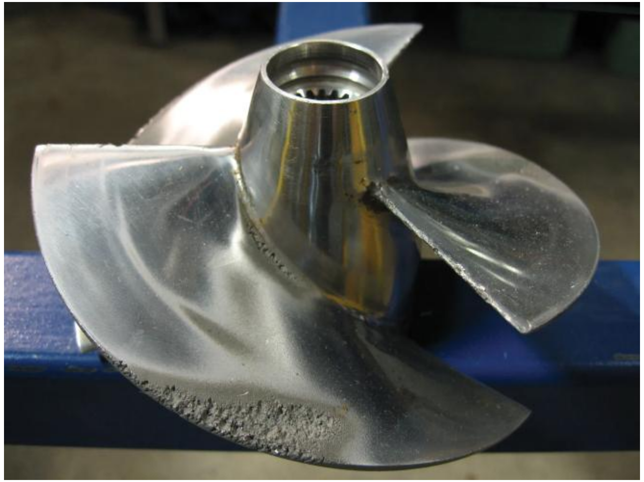
Residual Swirl

Increased Structural Fatigue

Reduced Lifetime

Maintenance Costs

Efficiency Drop



Cavitation Risk
(erosion on the blades)

Hydraulic Instabilities (RVR)
periodic pressure pulsations

Turbine Types

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Double Regulation (Kaplan)

In Propeller Mode

↓

Singly Regulated Turbine

Solve the RVR Problem!!

Vortex Controllers

- Solid bodies installed in the draft tube have been effective in mechanically disrupting the RVR structure.
- Rods offer the advantage of simple installation within the draft tube; however, they do not provide complete mitigation.

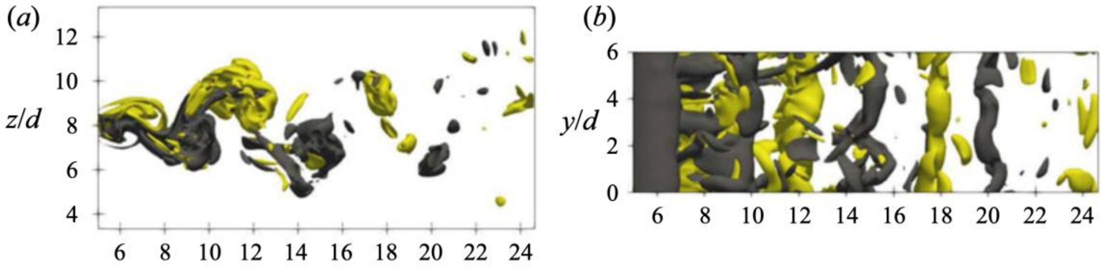
Novel Concept: Perforated flat plates

- ***Adjustable Protrusion Length (L/r_{DT})***
- ***Independent Porosity Control (φ)***

Relevance of Perforation

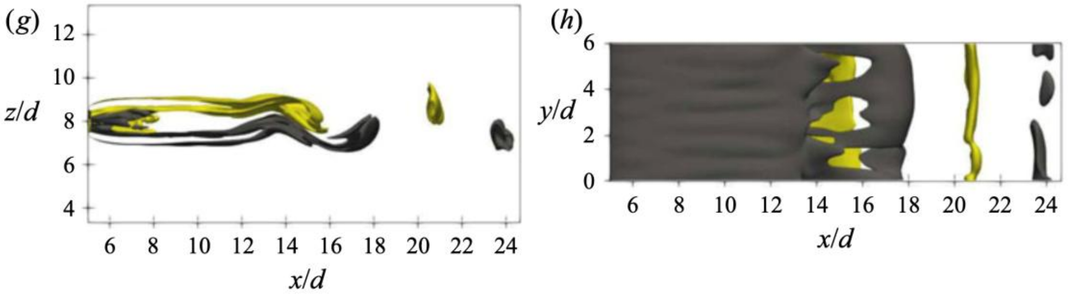
Non-perforated plate (β = 0%)

- Shear layers interact immediately
- Coherent Vortical Structures
- Large-scale shedding



Perforated plate (β = 25%)

- Bleed Jets
- Delayed shear layer interaction
- Disrupted vortex coherence



Singh A, Narasimhamurthy VD. Perforation effects on the wake dynamics of normal flat plates. Journal of Fluid Mechanics. 2022;947:A23.

Experimental Facility

Vattenfall R&D facility in Älvkarleby

IEC-certified 1:3.875 scaled-down model of the U9 Kaplan turbine

The distributor comprises 20 guide vanes and 18 stay vanes

Runner Diameter 0.4 m with six adjustable blades

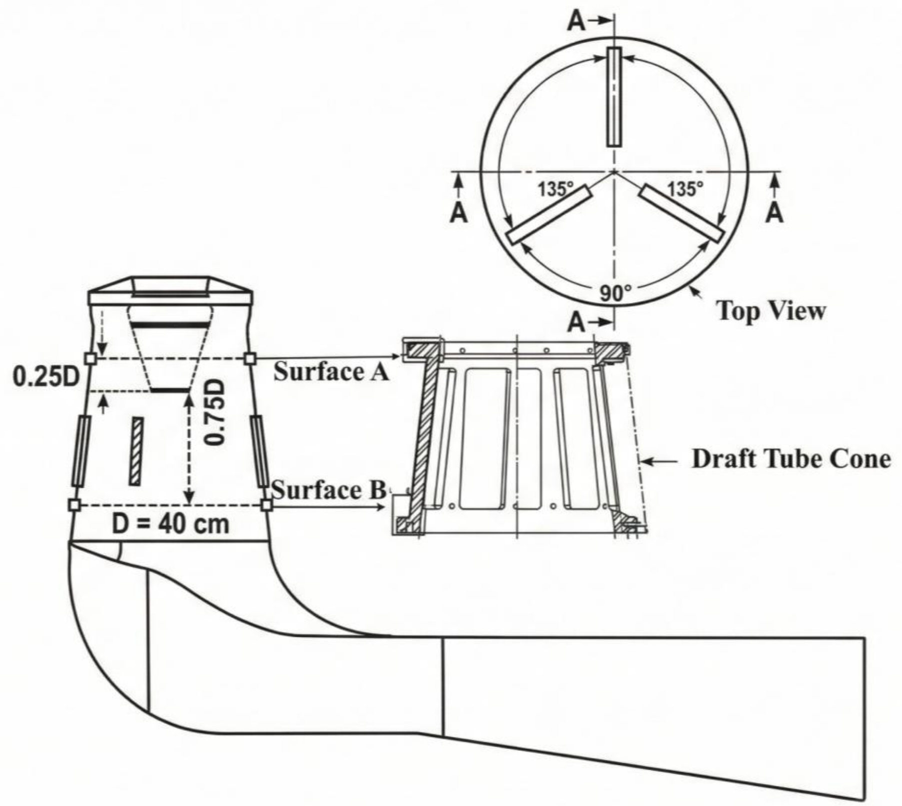
Cavitating conditions can be experimented with

Setup Schematic

Operating Conditions

Head: 5 m
Runner rotational Frequency: 11.84 Hz
Blade incidence angle: 0.8°

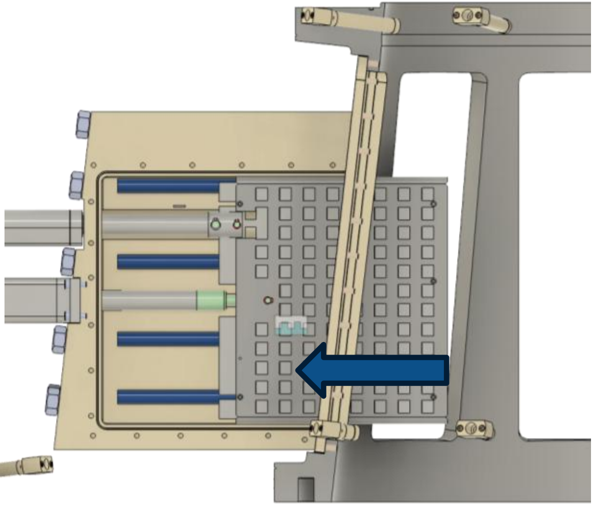
- OP 1: Q/Q_{BEP} = 0.86 (GV 20°)
- OP 2: Q/Q_{BEP} = 0.75 (GV 16°)

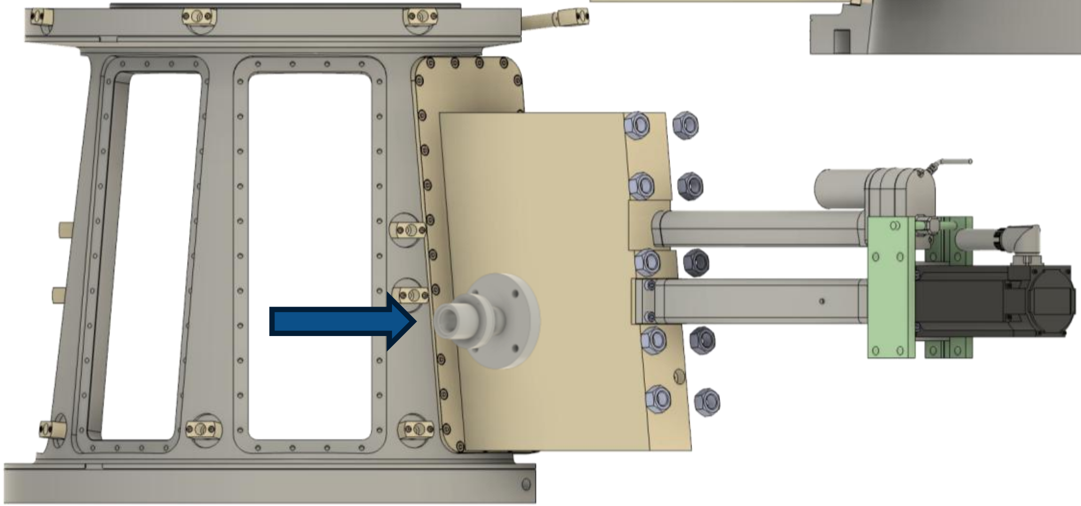


Pressure sensors located at surfaces A&B

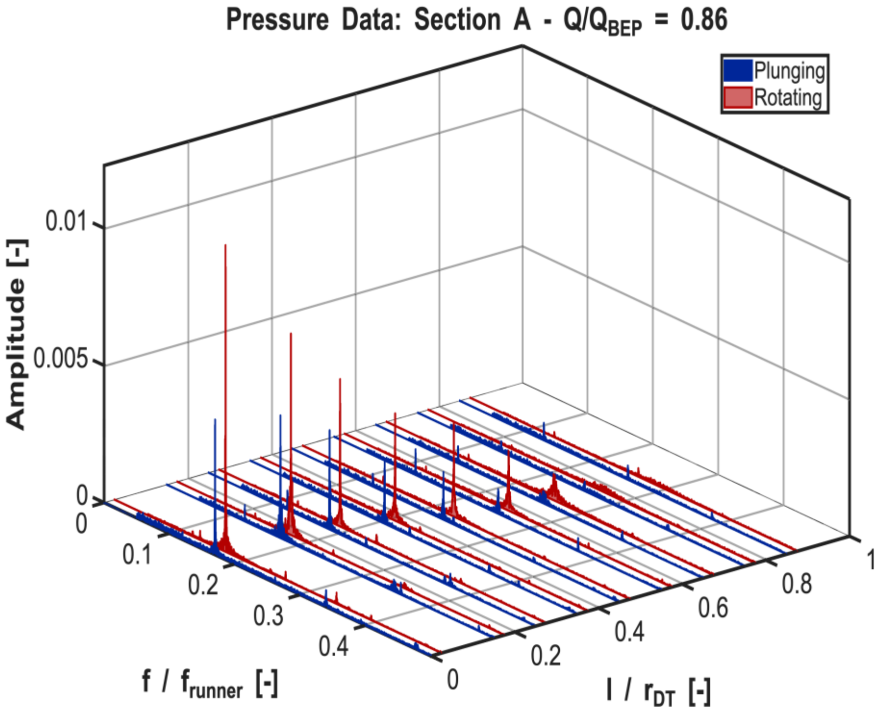
Accelerometer Placement

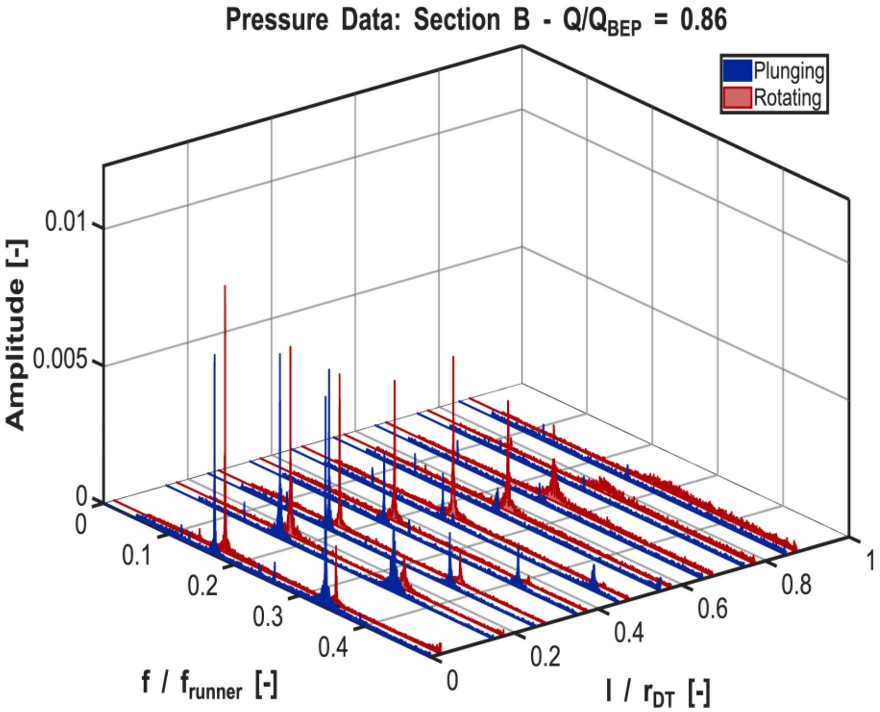
- The accelerometer is flushed against the vortex controllers with the help of a spring
- They are placed inside a holder enclosed in a sealed cavity for that purpose.





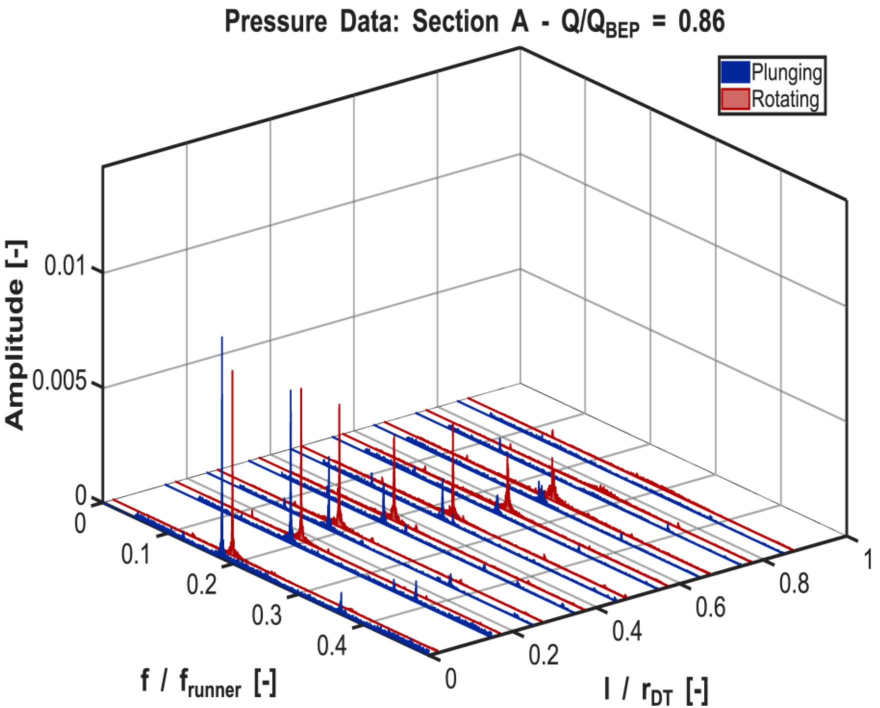
OP Q/Q_{BEP} = 0.86 (GV:20° Section A & B)

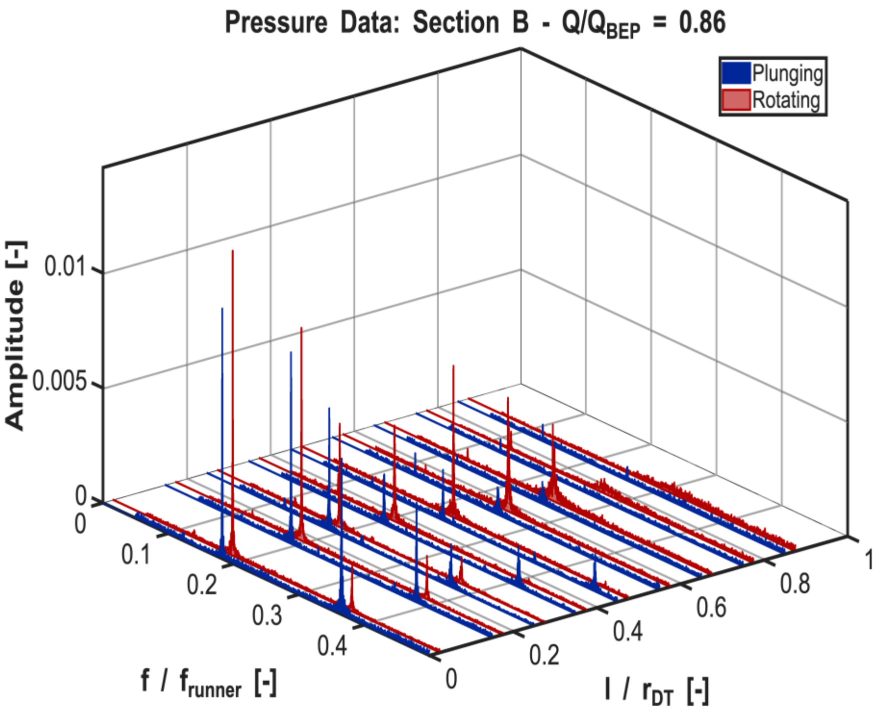




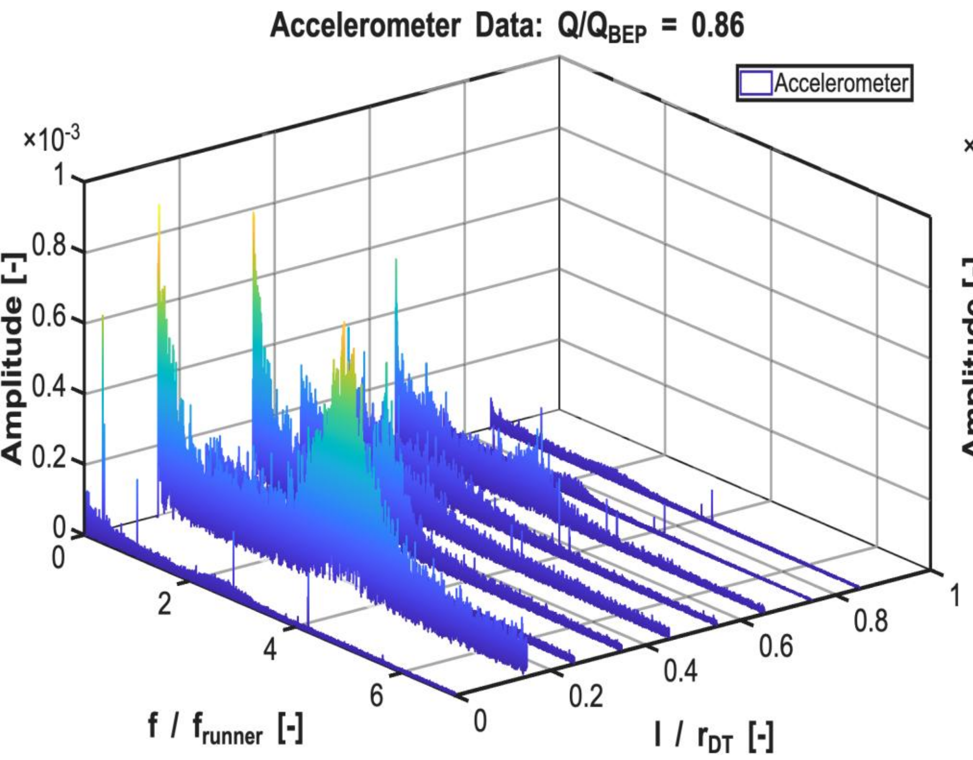
Fourier Spectra of pressure pulsations based on draft tube pressure measurements

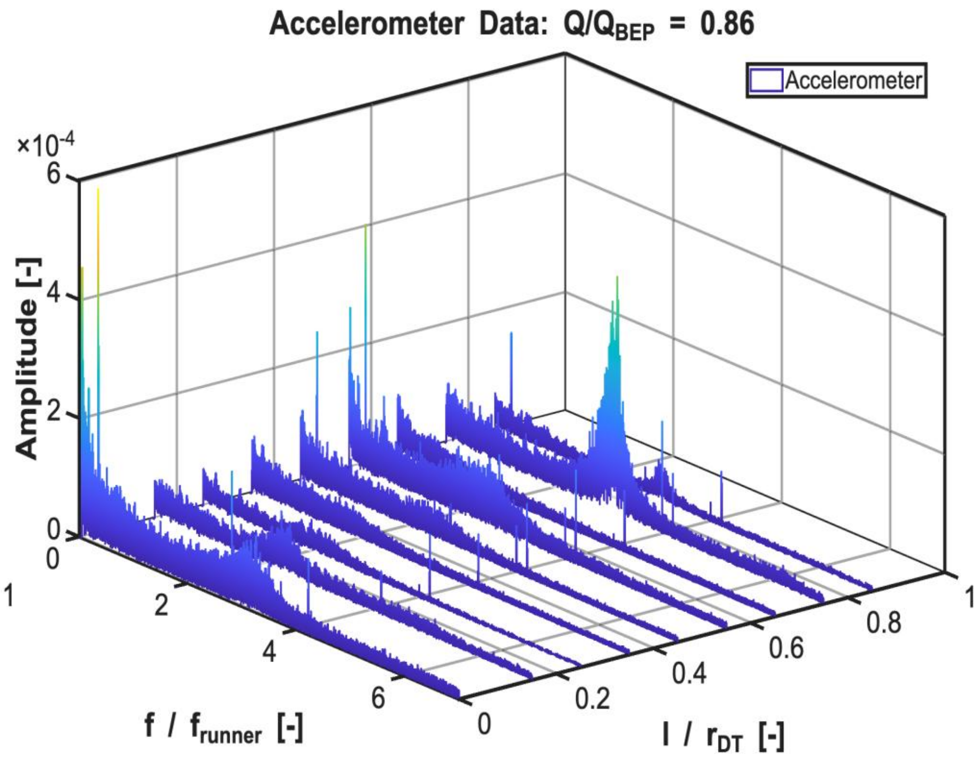
OP Q/Q_{BEP} = 0.86 (GV:20° With cavitation effects)



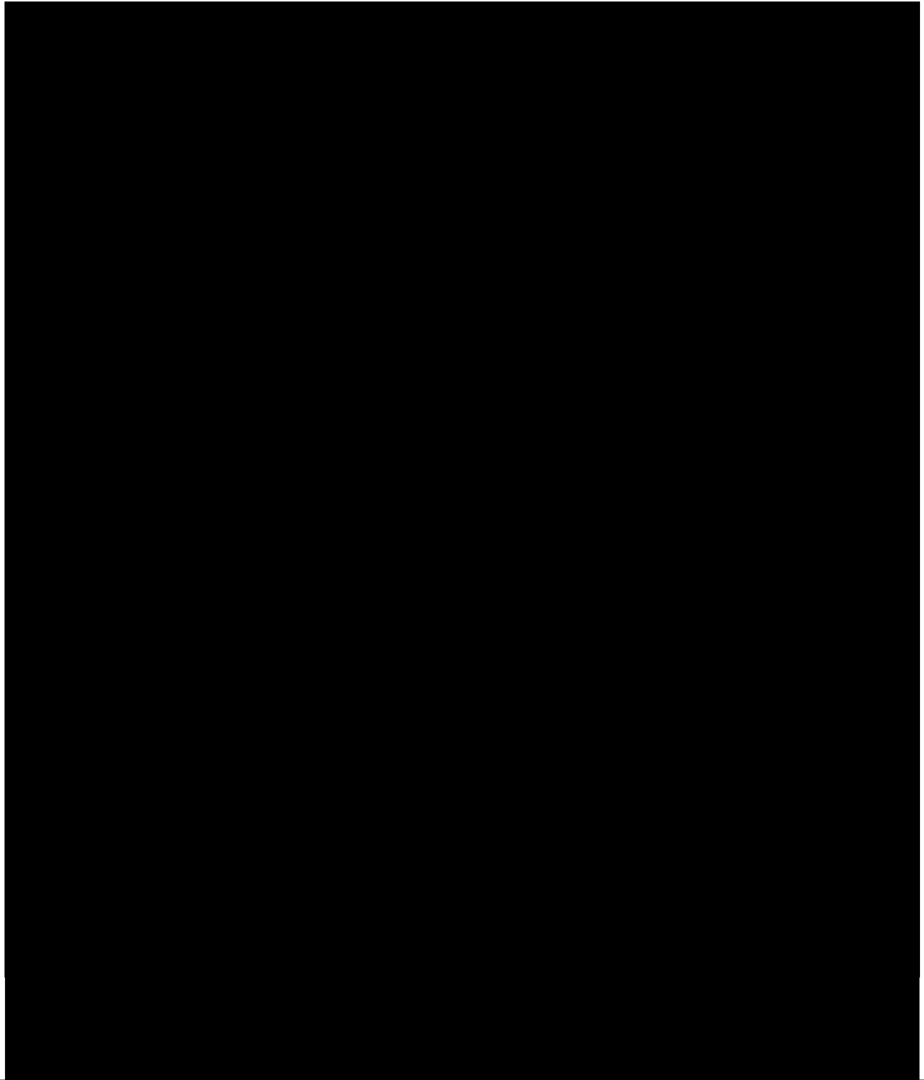


Accelerometer Data (GV:20° Without and with cavitation)

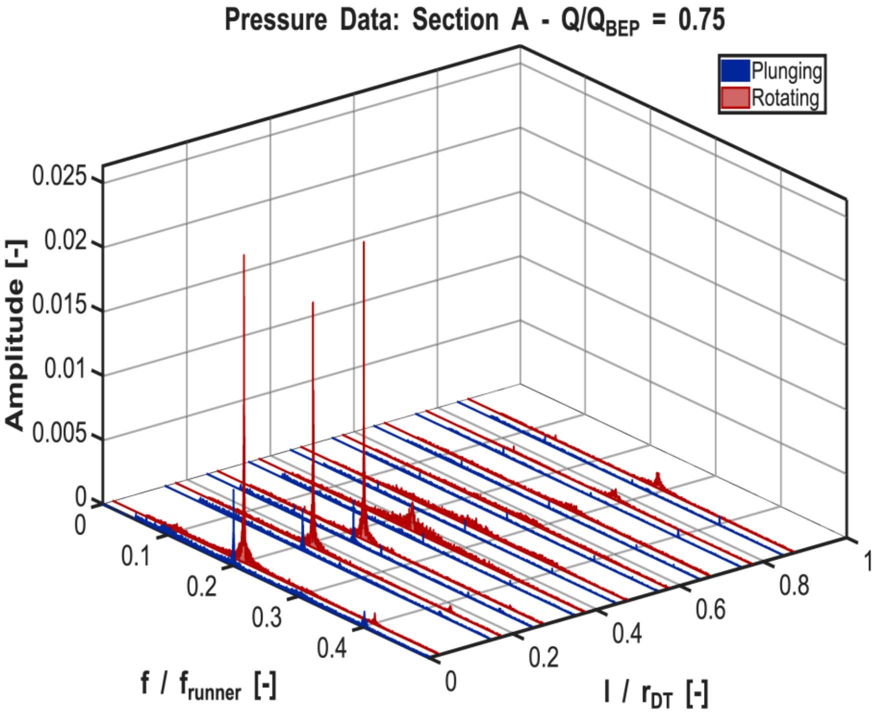


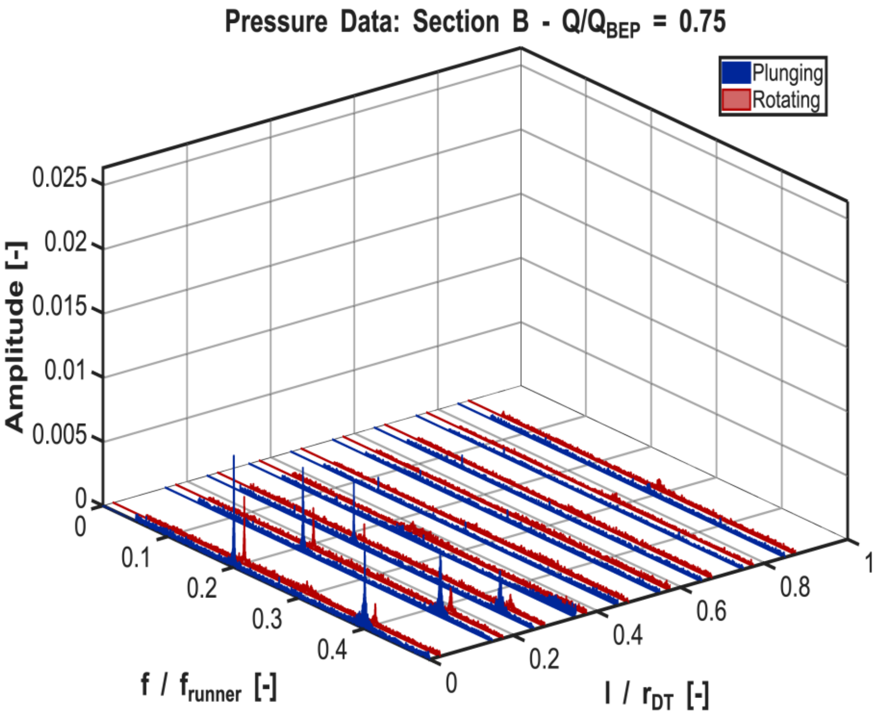


RVR Mitigation

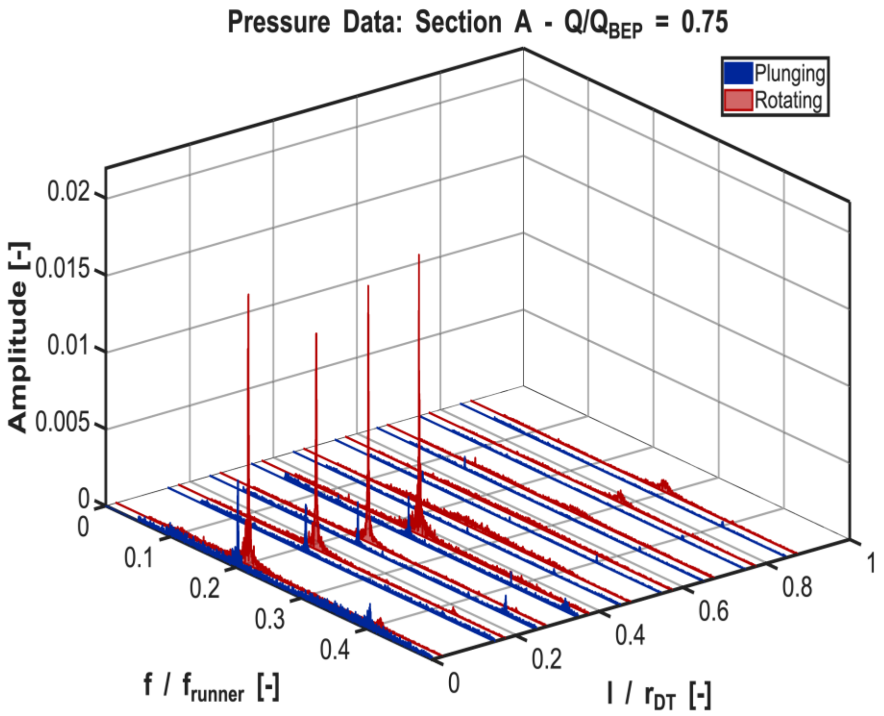


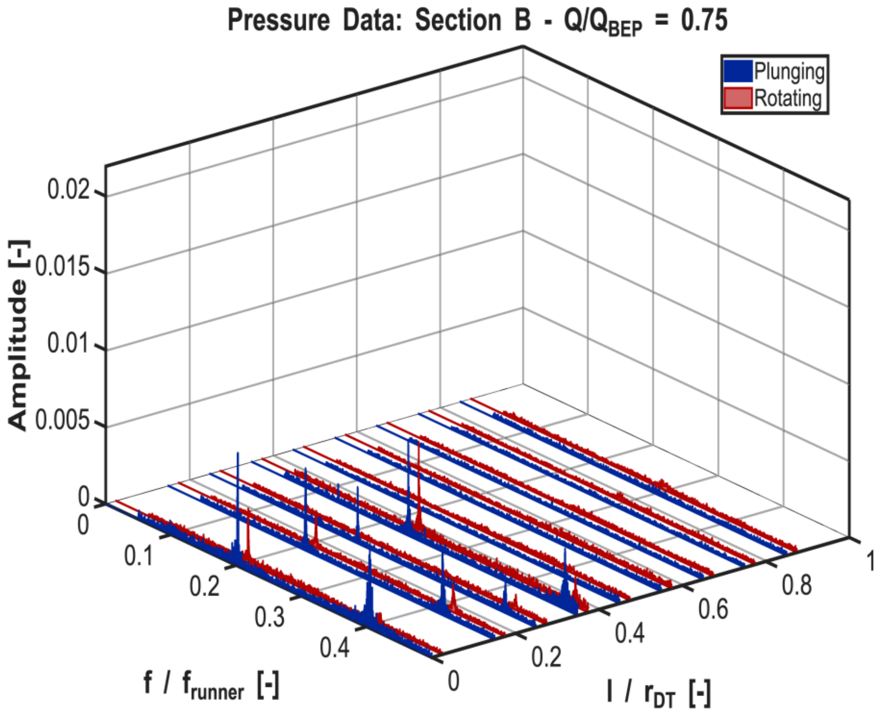
OP Q/Q_{BEP} = 0.75 (GV:16° Section A & B)



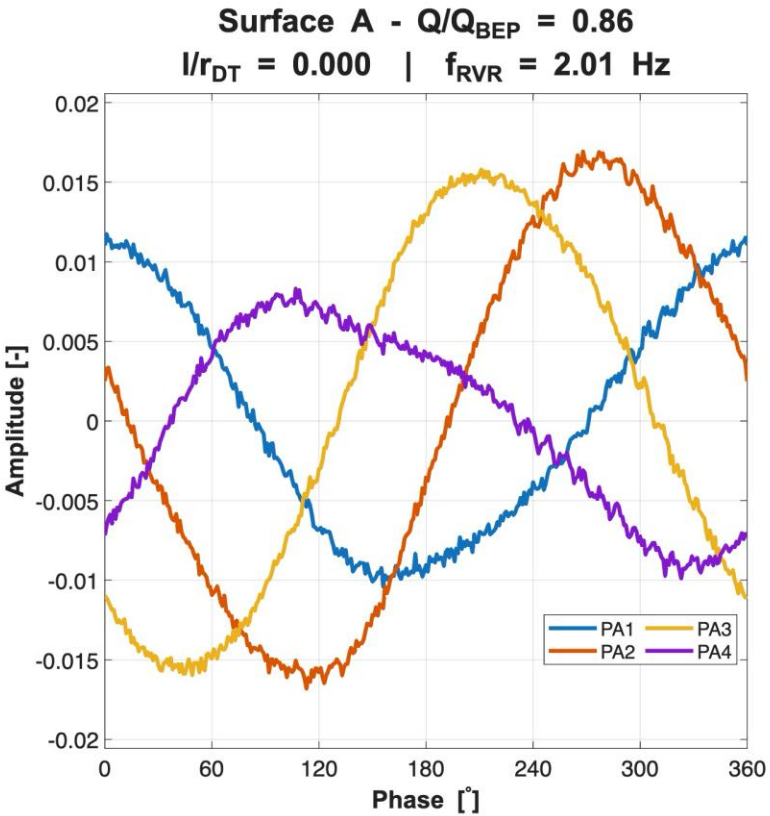


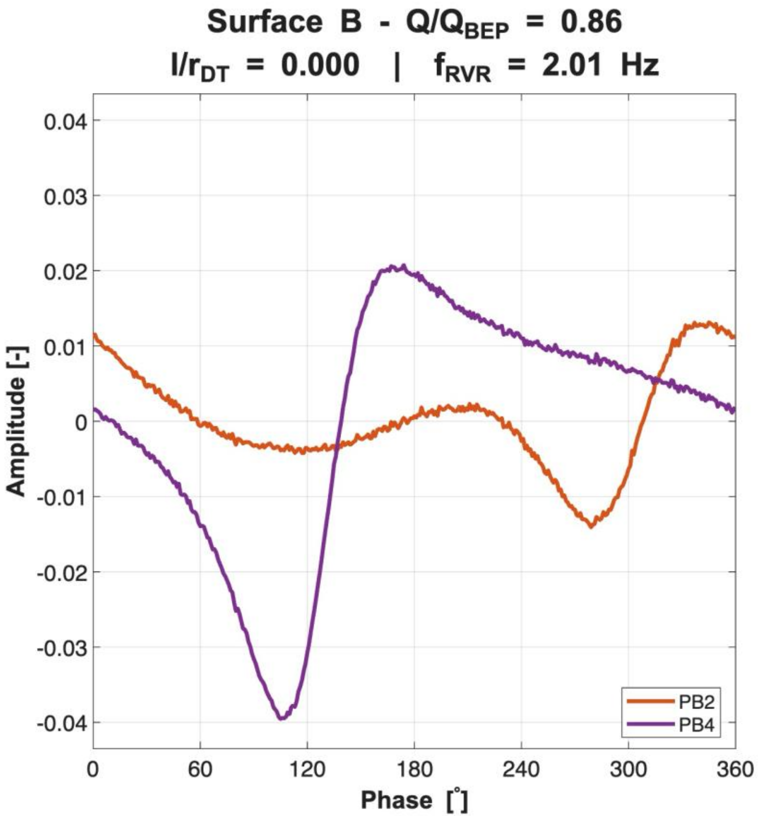
OP Q/Q_{BEP} = 0.75 (GV:16° With cavitation effects)





Phase Averaging OP $Q/Q_{BEP} = 0.86$ **(GV 20°)**





Key Results

Maximum reduction in RVR-induced pressure pulsations

OP 1 (Q/Q_{BEP} = 0.86)

- 65% protrusion disrupts the vortical structure and accelerates the remnant core
- At 75% protrusion, complete RVR mitigation (and harmonics) is observed
- At this protrusion, the entire bulk flow is obstructed and decelerated.

OP 2 (Q/Q_{BEP} = 0.75)

- 45% protrusion leads to complete mitigation of the RVR
- This mitigation is global: the same reduction in pulsations was observed by the pressure sensor in the plane downstream.

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Aquarium lab tour Thurday 12 March at 10:00

- 15-20 min
- 20 visitors at a time
- Departures at 10:05, 10:10, 10:15 (and 10:20 if needed)
- Find a guide at the posters (“12-torget”)
- Are you an eel, a trout, or a salmon?

Your guides

Team European eel

Team brown trout

Team salmon smolt

Emil Nordström

Sebastian Rock

Johan Watz