FS DYNAMICS

Structural Effects of High-Velocity Flows in Heat Exchanger Barrier Systems

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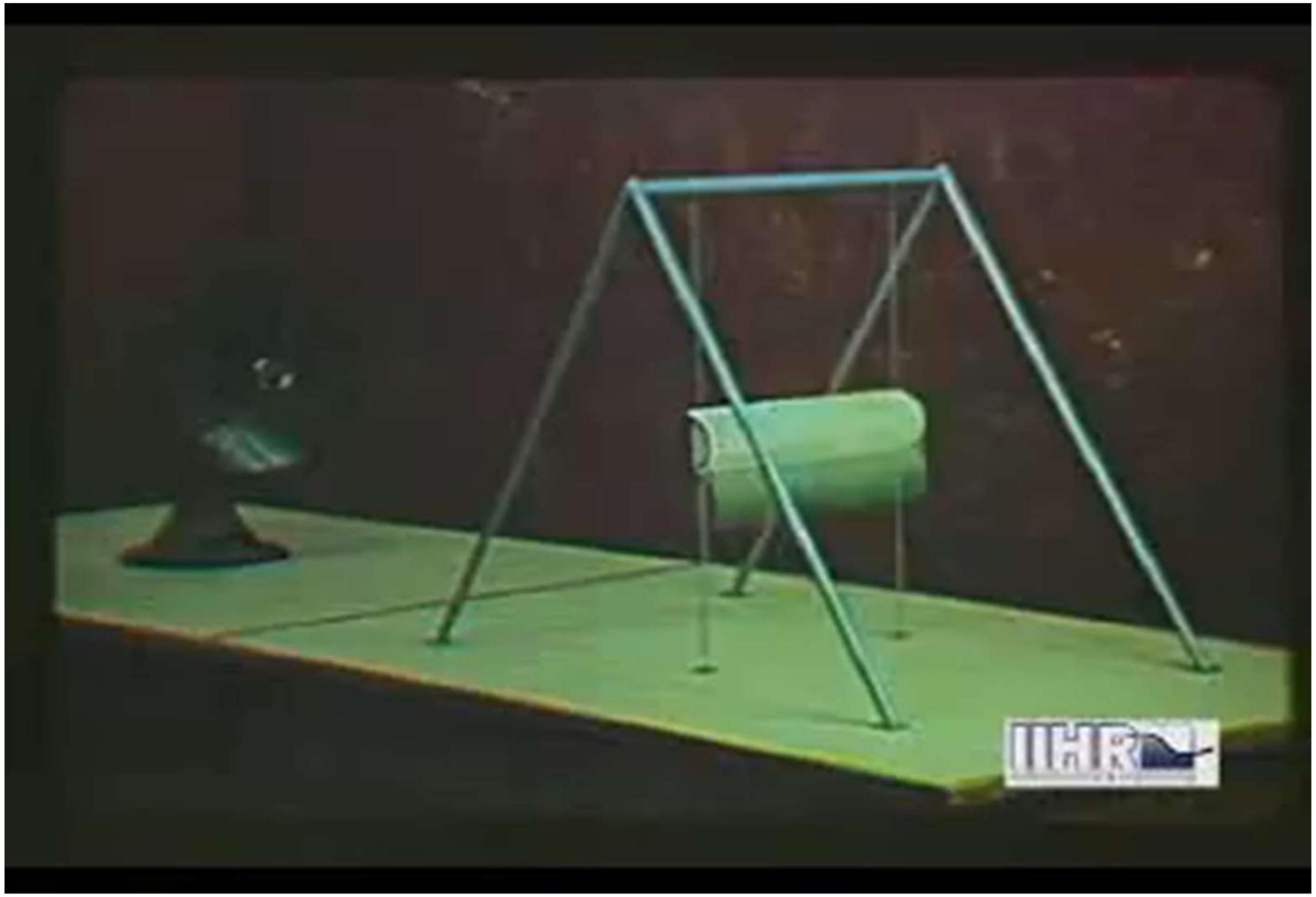
FS Dynamics

What is flow-induced vibration?

It is a phenomenon where fluid flow generates vibrations in structures that interact with and may cause significant stresses and lead to fatigue, wear, or even failure of components over time.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Flow induced vibration mechanisms

Vortex shedding or flow periodicity →
Turbulent buffeting →
Acoustic resonance →

Resonance phenomena

Fluid elastic instability (FEI) →

Failure due to a critical flow velocity.
Cross-flow below the critical flow,
FEI will not take place.

Since the problem involve variables and parameters complex to determine, most of the methods assume the flow conditions as follows

1. The flow is uniform and steady.
2. The incident of the flow is either axial or normal to the tubes.
3. The tube motion is linearized, and it is assumed that the frequencies are well defined
4. The baffle supports provide a simply supported condition.

Methods

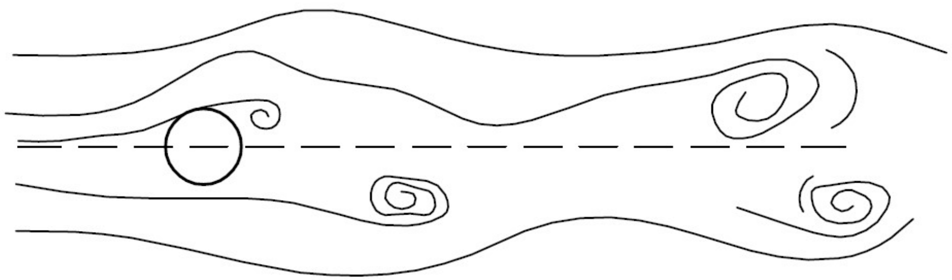
CRITERIA

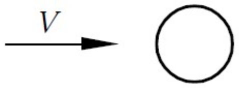
Criterion 1: Vortex shedding - EN 1991-1-4 annex E (single bar)

The effect of vortex shedding need not be investigated when

$$v_{crit\_i} \geq 1.25 \cdot v_m$$

$St. := 0.18$





$$v_{crit\_i} := \frac{b \cdot n_i}{St.}$$

v_{crit_i} *Critical velocity for vortex shedding*

v_m *Flow velocity*

b *Bar diameter*

n_i *Bar frequency*

$St.$ *Scruton number*

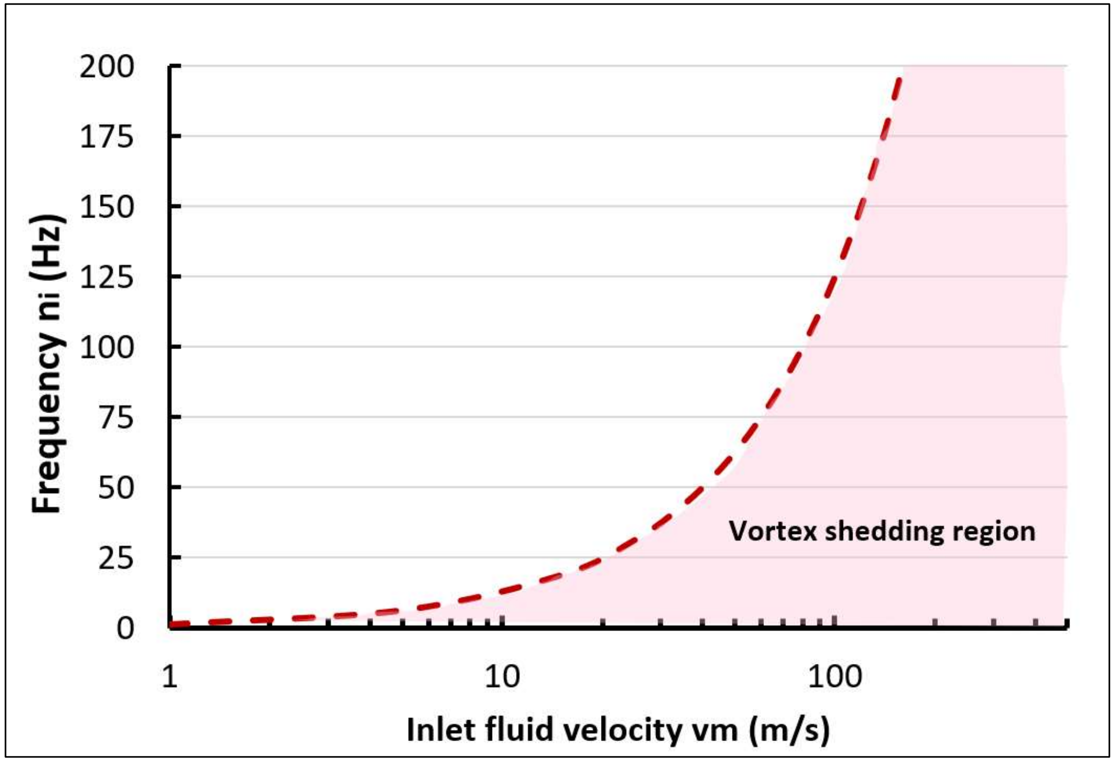
Criterion 1: Vortex shedding - EN 1991-1-4 annex E (single bar)

$$v_{crit\_i} := \frac{b \cdot n_i}{St.}$$

$$v_{crit\_i} \geq 1.25 \cdot v_m$$

b	*0.02 m*	*Bar diameter*

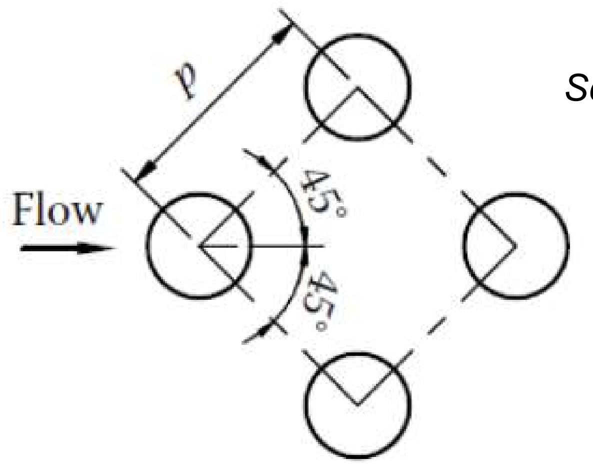
$$St. := 0.18$$



Criterion 2: Pettigrew and Gorman (vortex shedding bar array)

The criterion to avoid resonance due to vortex shedding is as follows

$$\frac{n_i \cdot b}{v_m} \geq 2 \cdot S_{u\_Array}$$



Scruton number for array

$$S_{u\_Array} = 0.333$$

b *Bar diameter*

n_i *Bar frequency*

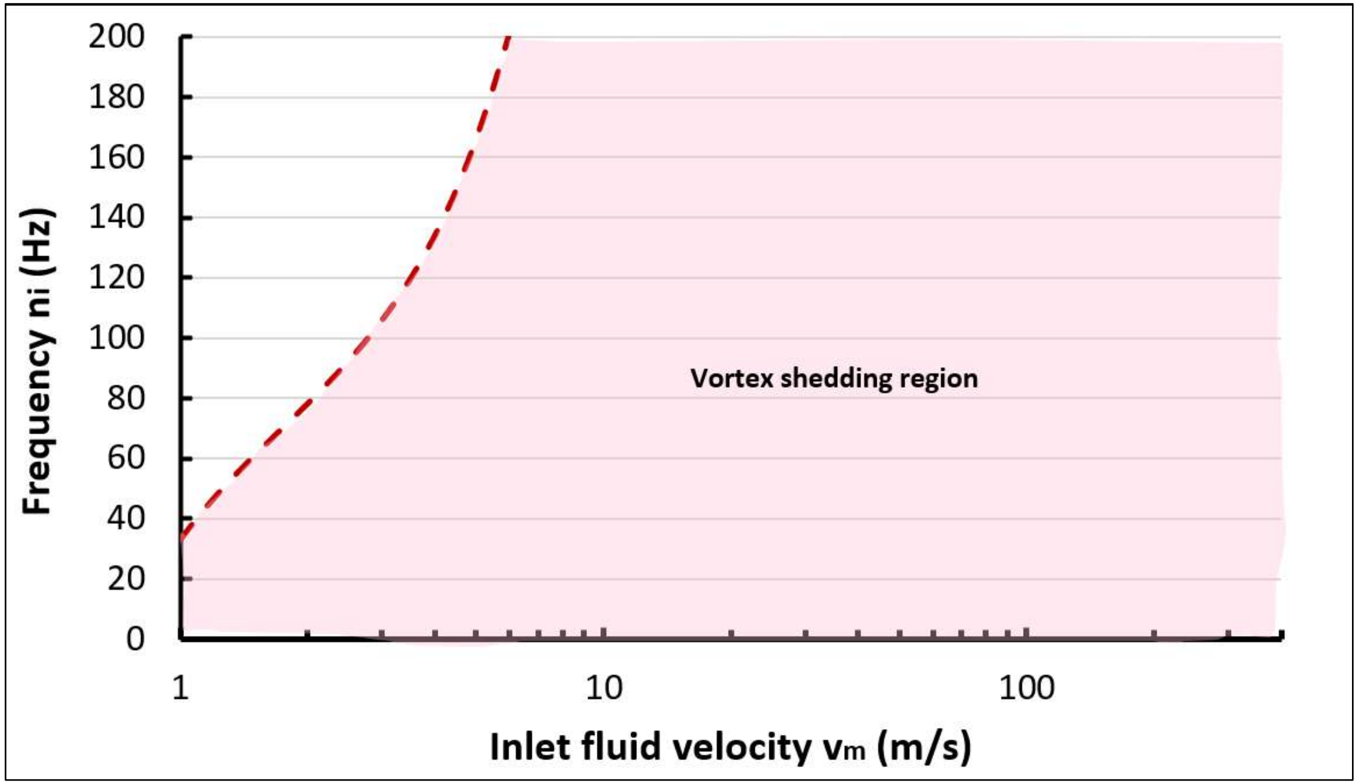
v_m *Flow velocity*

Criterion 2: Pettigrew and Gorman (vortex shedding bar array)

$$\frac{n_i \cdot b}{v_m} \geq 2 \cdot S_{u\_Array}$$

$$S_{u\_Array} = 0.333$$

b *0.02 m*



Criterion 3: ASME-Section III (Vortex shedding in bar array)

To avoid lock-in phenomena due to vortex shedding in tube arrays, ASME suggests the following empirical equation

$$0.7 < \lambda < 1.3$$

$$f_w := \frac{0.33 \cdot v_m}{b}$$ *Vortex shedding frequency*

$$\lambda := \frac{f_w}{n_i}$$ *Frequency ratio*

v_m *Flow velocity*

n_i *Bar array frequency*

b *Bar diameter*

Criterion 3: ASME-Section III (Vortex shedding in bar array)

$$0.7 < \lambda < 1.3$$

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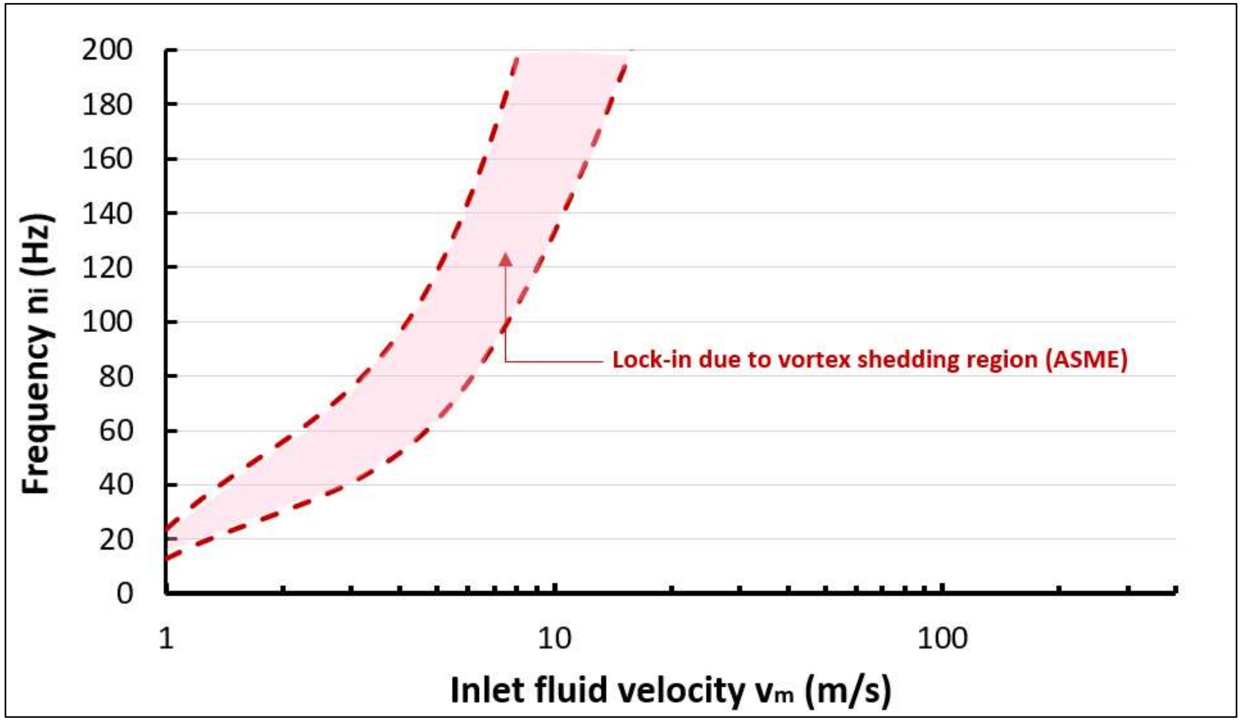
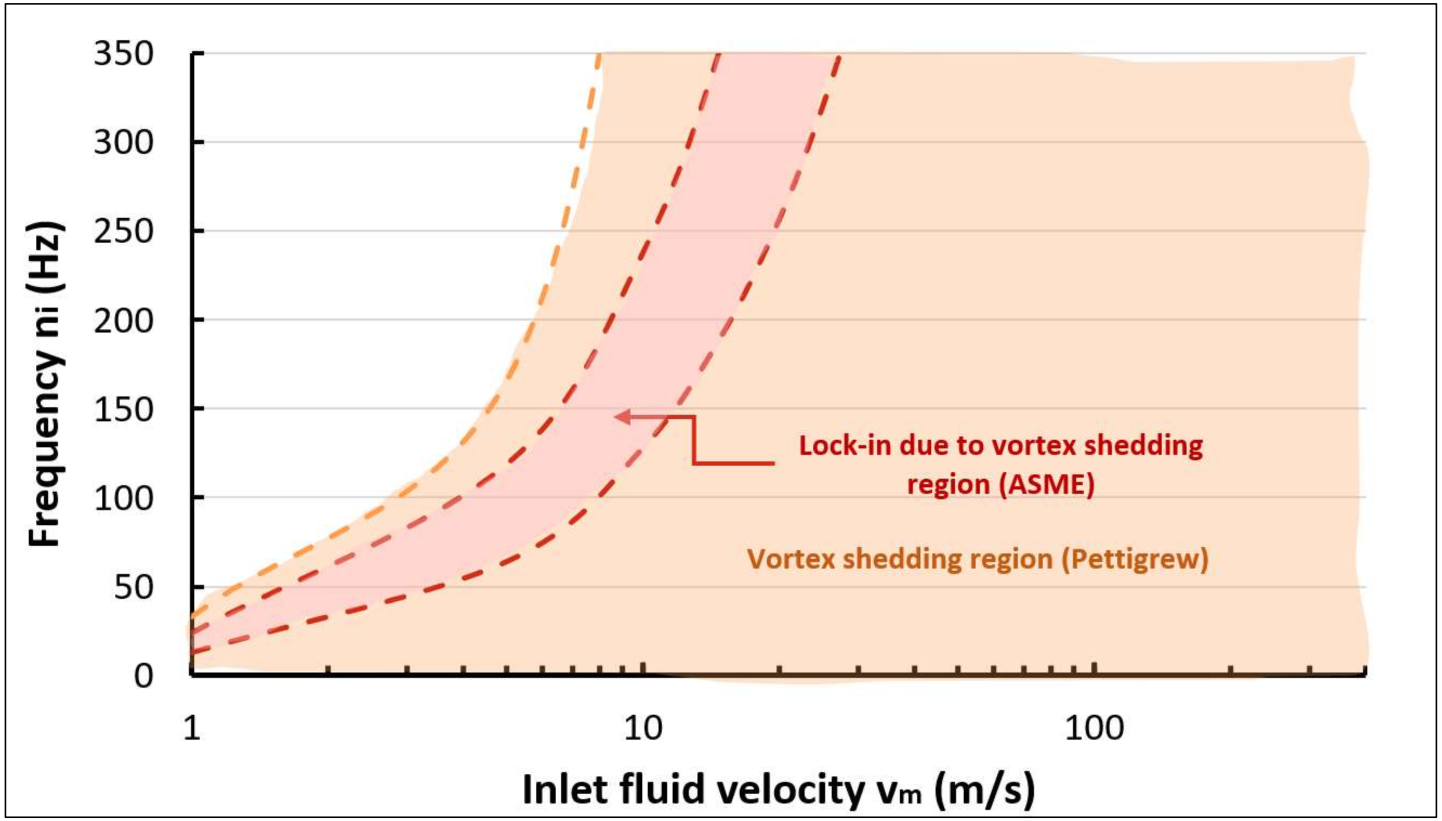


Combination of criteria 2 and 3



Criterion 4: Galloping - EN 1991-1-4 annex E (single bar)

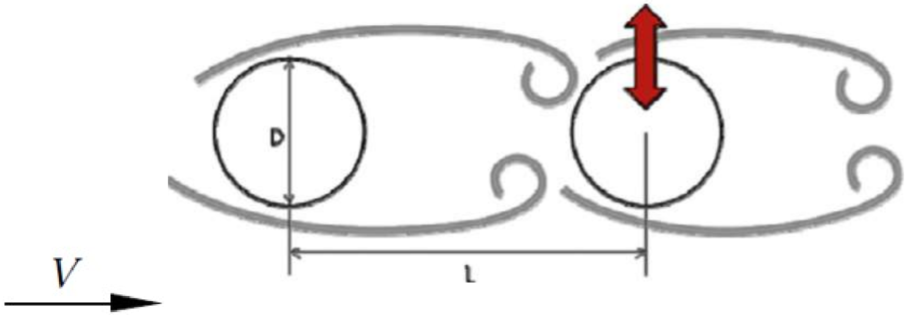
The galloping effect (self-induced vibration) need not be investigated when

$$v_{cg} \geq 1.25 \cdot v_m$$

v_{cg} *Critical velocity for galloping*

v_m *Flow velocity*

Dynamic instability due to lift and drag forces caused by high cross-flow.



Criterion 5: Interaction between vortex shedding and galloping

Interaction between critical vortex velocity and galloping velocity needs to be investigated when

$$0.7 < \frac{v_{cg}}{v_{crit\_i}} < 1.5$$

Criterion 6: Au-Yang criteria - ASME (Fluid elastic instability)

A bar array under the effect of a crossflow can be subjected to dynamic instability (fluid elastic instability). Fluid elastic vibration sets in at a critical flow velocity and can become of large amplitude if the flow is increased further.

$$v_m < U_{cr}$$

U_{cr} *Critical velocity for vortex shedding*

$$U_{cr} := n_i \cdot b \cdot 2.1 \left(\frac{m_{ie} \cdot 2 \cdot \pi \cdot 0.005}{\rho \cdot b^2} \right)^{0.5}$$

v_m *Flow velocity*

b *Bar diameter*

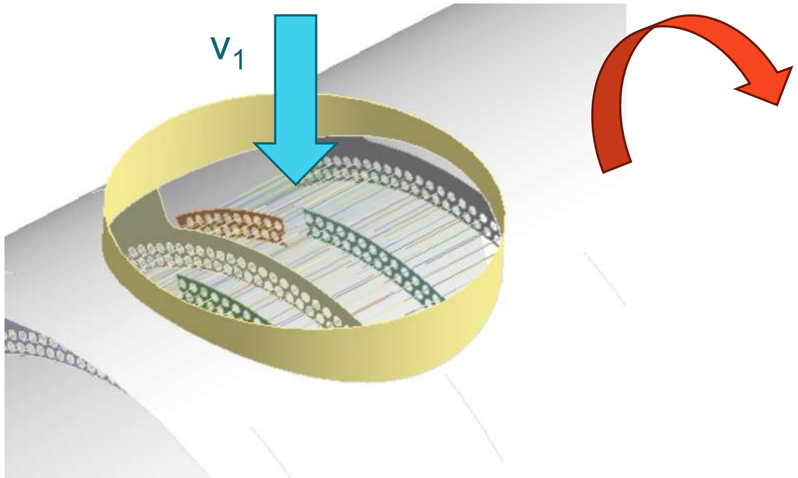
m_{ie} *Distributed mass*

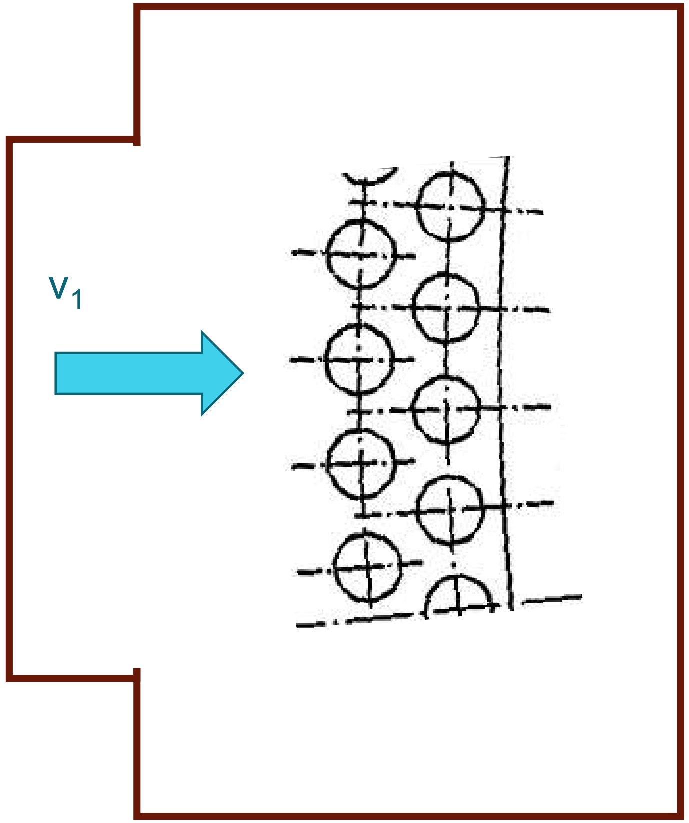
n_i *Bar array frequency*

Methods

Load cases (heat exchangers units)

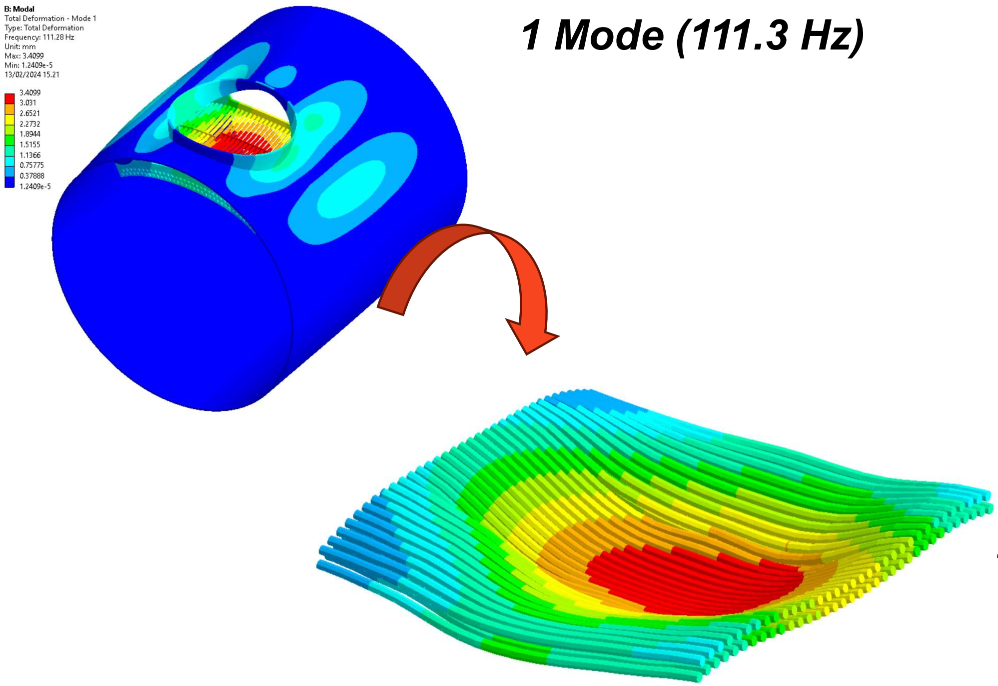
Single outlet approach for mass balance



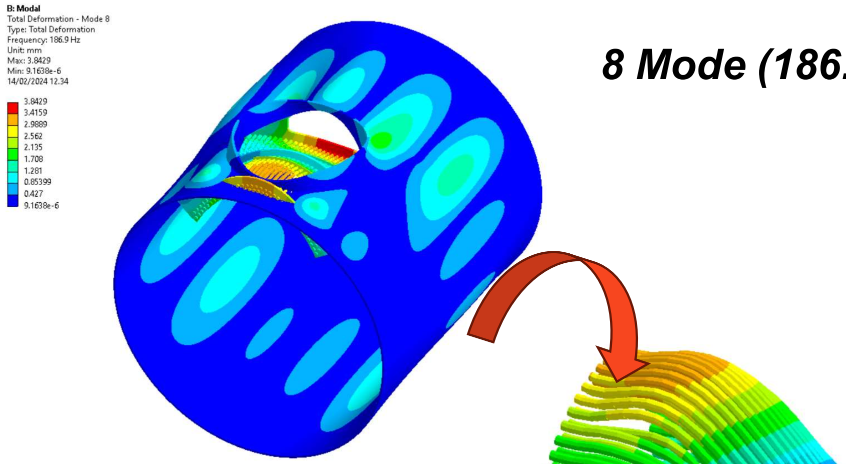


Eigenfrequencies results Unit 2 (FE-model)

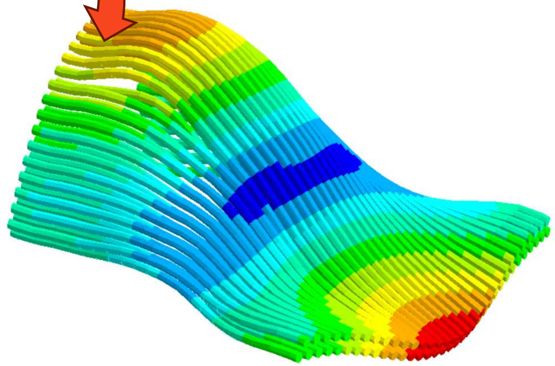
Range: 111.3 – 776.3 (200 modes) Hz



1 Mode (111.3 Hz)



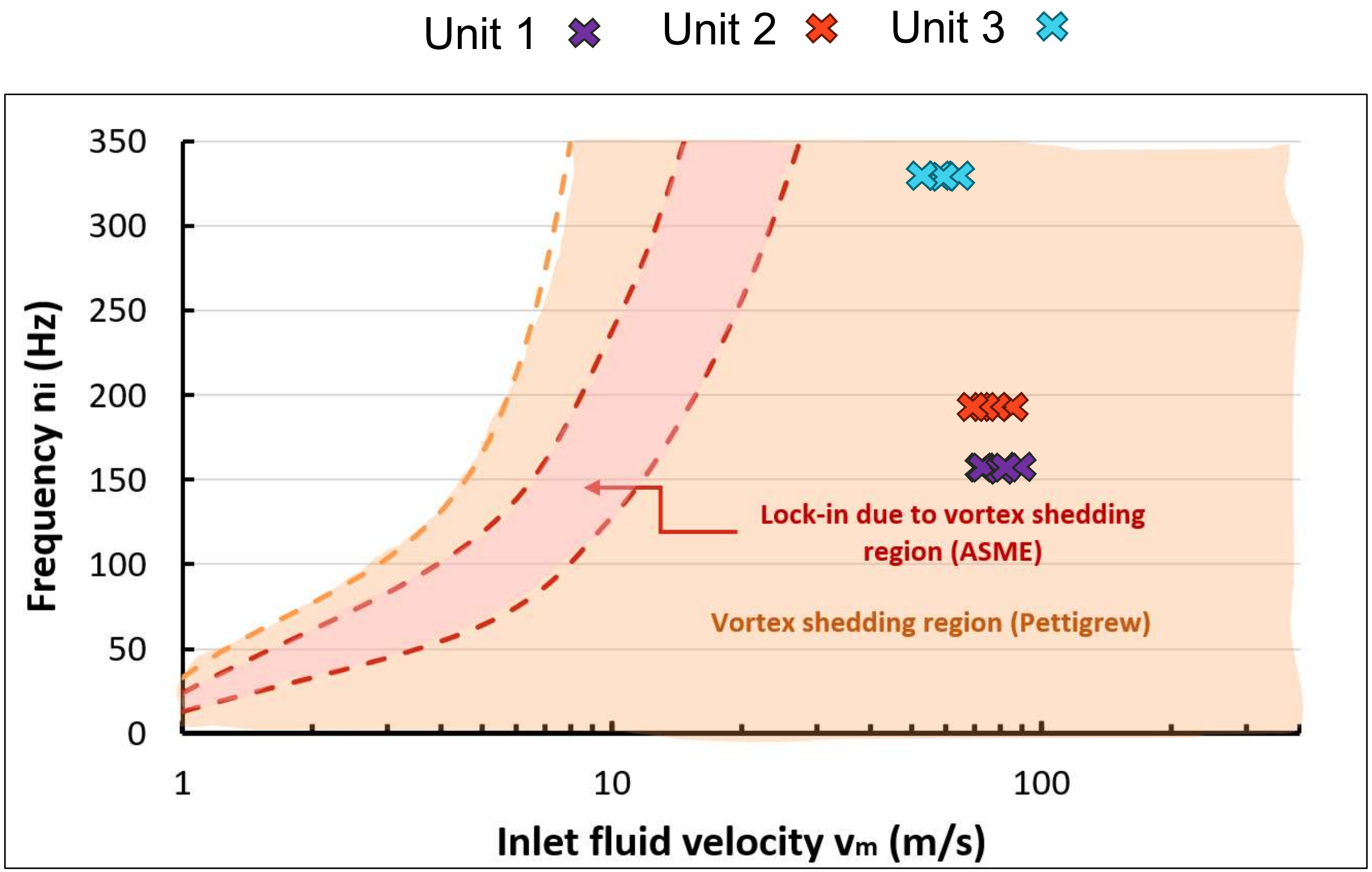
8 Mode (186.9 Hz)



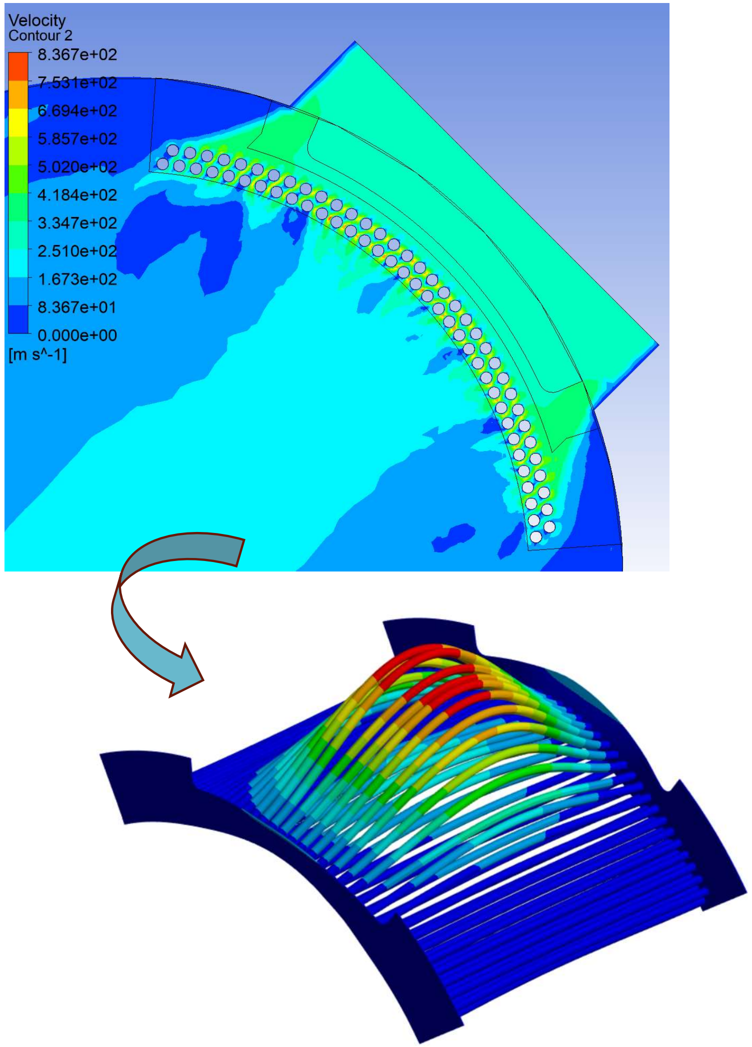
The frequencies are between the extreme values obtained from 2-support/3 support bar analysis

Results

Vortex shedding risk (multiple outlets)



Conclusions



A flow-induced vibration analysis was conducted in the barrier system due to higher flow in the heat exchangers.

Critical flow velocities for the barrier system were determined for each working conditions in each heat exchanger and compared with Vortex shedding, galloping, and fluid elastic instability (ASME).

Results suggest that the barrier system may experience vibration problem due to high flow velocities in the heat exchangers following to potential fatigue issues.

We would like to make additional analyses such as in site noise and vibrational analysis and fluid-structure interaction models to identify structural problems beforehand.

References

- EN 1991-1-4 (2005) (English): Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions
- Heat Exchanger Design Handbook, Second Edition, Kuppan Thulukkanam, CRC Press, 2013.
- Flow-Induced Vibrations Classifications and Lessons from Practical Experiences, Shigehiko Kaneko, Tomomichi Nakamura, Fumio Inada, Minoru Kato, Elsevier, 2008.
- Thermodynamics, An Engineering approach, Yunus A Cengel, McGraw Hill, 2023.
- Website for extracting steam properties: https://www.spiraxsarco.com/resources-and-design-tools/steam-tables/

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