4th Chemical Process Safety Sharing (CPSS)

"The Safety Design to Protect Vibration in Heat Exchanger"

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- Introduction to Vibration
- Vibration Mechanism
- Fluidelastic Instability
- Thermal design to avoid vibration problem
- Anti-Vibration Technologies
- Case study

Introduction to Vibration

- **Flow-induced vibration**
  - Be serious problem in many industries.
  - Causes mechanism tube failure and bring to another problem such as shutdowns of plant, tube damage in petroleum, and lost chemical production due to leaking tubes.

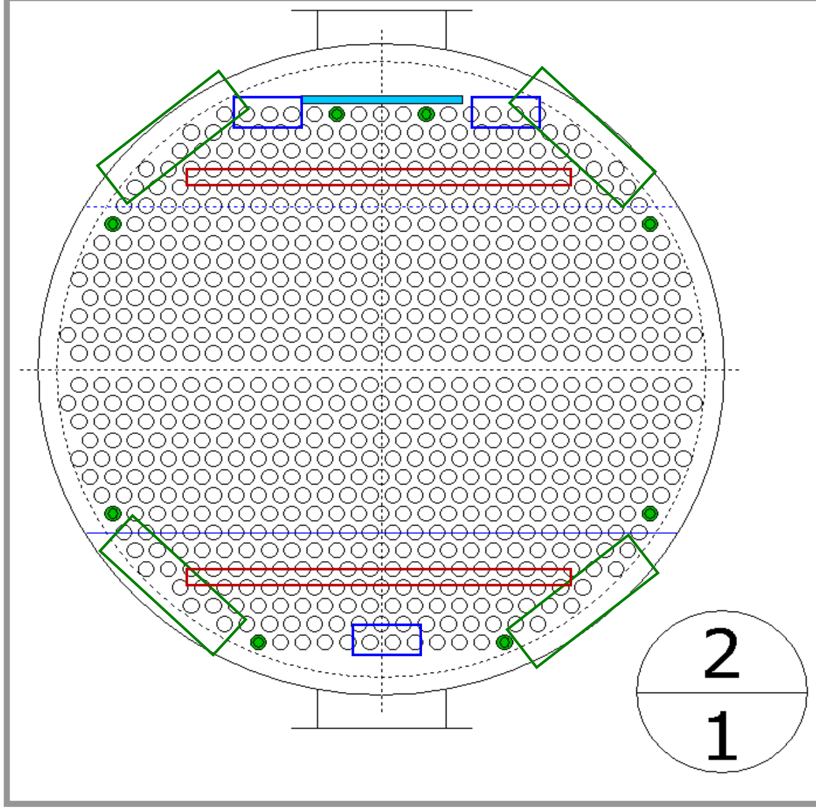
Tube damage from flow-induced vibrations

Introduction to Vibration

Tube failure locations

- Midspan of the longest unsupported span
- Window tubes near baffle tips (red)
- Tubes near inlet and outlet nozzles (blue)
- Tubes near outer periphery of bundle (green)
- Tubesheet joints and near tubesheet

Tube layout



Vibration Mechanism

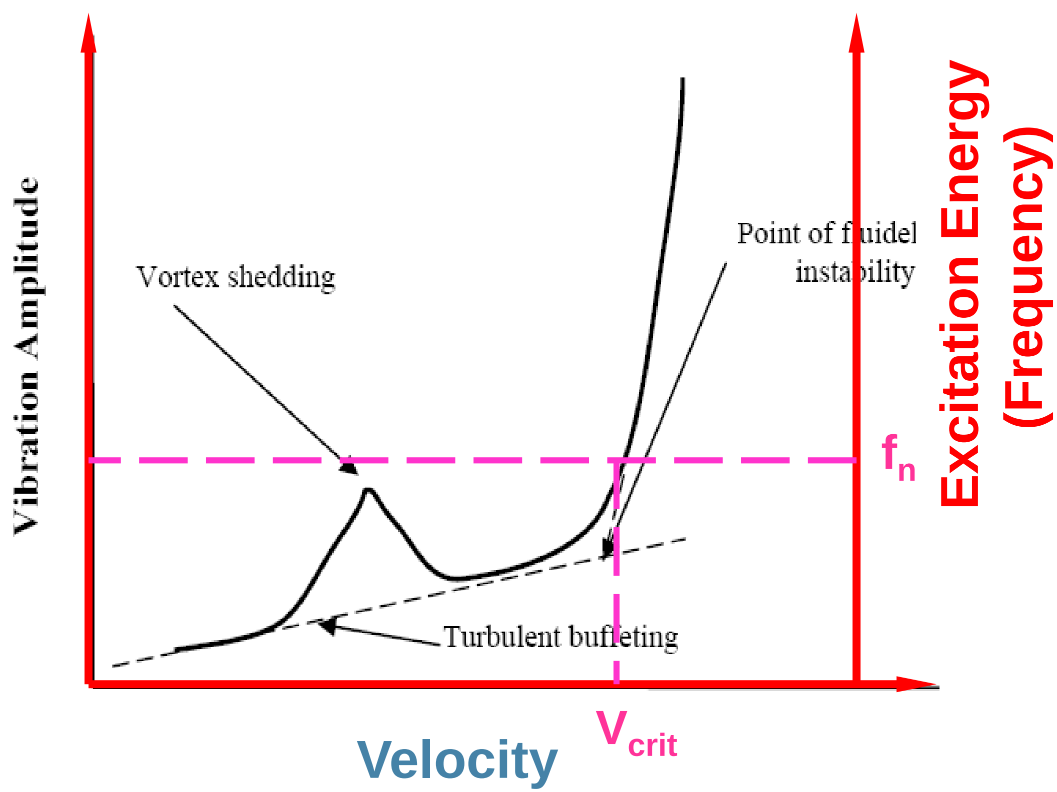
- Flow-induced vibration involves the coupling of some exciting forces with induced an elastic structure.
- Coupling occurs when the exciting frequencies match the tubes natural frequency.

Increasing shell side flowrate >> Excitation Energy >> match tube natural frequency >> Tube vibration

- **There are three vibration mechanism.**
  - Turbulence
  - Vortex shedding
  - Fluid Elastic Instability (FEI) → **Most problematic**

Vibration Mechanism

Mechanism of flow-induced vibration



$$V_{crit} = \beta f_n D_o \sqrt{\frac{W_o \delta_o}{\rho D_o^2}}$$

To avoid FEI, V_{crit} should be increased

Fluidelastic Instability

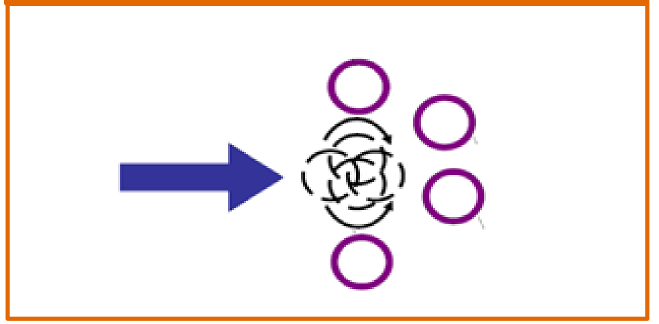
Tube vibrate in orbital motion

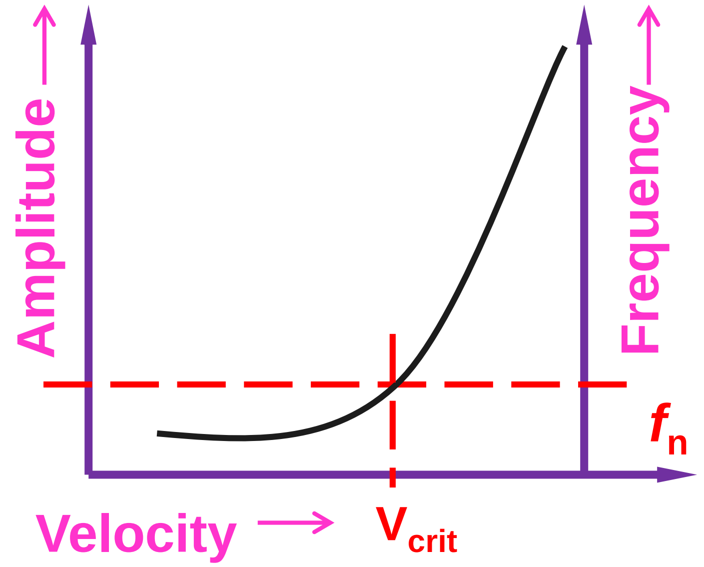
- Produced by combination of lift and drag displacements of tube at their natural frequencies

Can lead to "Runaway"

- If energy fed to tubes exceeds that dissipated by damping

FEI and tube movement





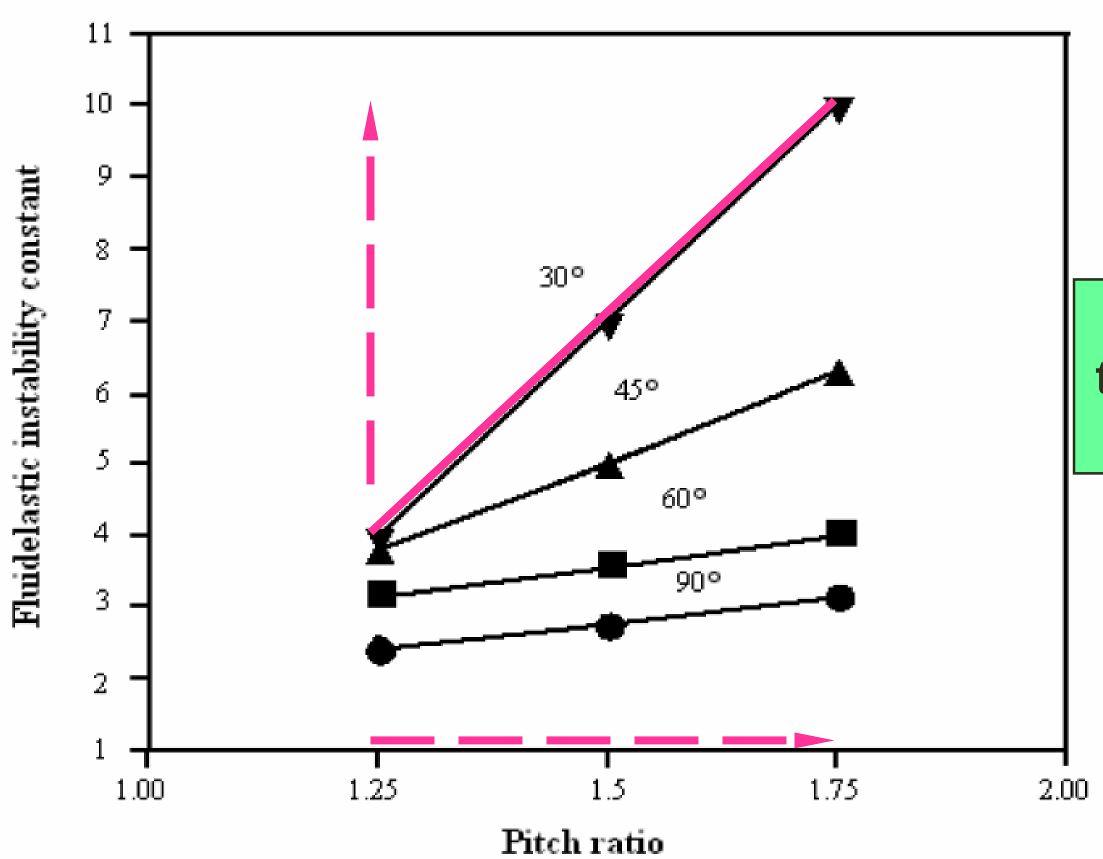
Fluidelastic Instability

$$V_{crit} = \beta f_n D_o \sqrt{\frac{W_e \delta_o}{\rho D_o^2}}$$

- β : FEI constant [Tube layout (30°, 45°, 60°, 90°) and pitch ratio]
- f_n : natural frequency [C_n (number of spans, end condition)]
- W_e : Effective weight per unit length
- δ_o : Log decrement as a measure of fluid damping [Tube properties, Support geometry, shell side fluid properties]

Fluidelastic Instability

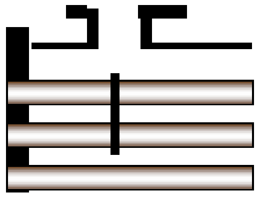
FEI constant for typical tube layout



Increasing β increases the critical velocity and therefore reduces FEI

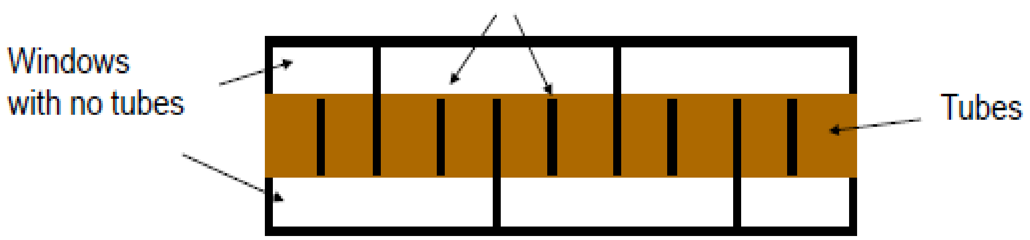
Thermal design to avoid vibration problem

- Use the inlet/outlet supports in first few tube rows under the nozzles in order to increase tube natural frequency.



Inlet support baffles

- Design by using NTIW baffle and intermediate support baffles.



No tubes in the window - with intermediate support baffles

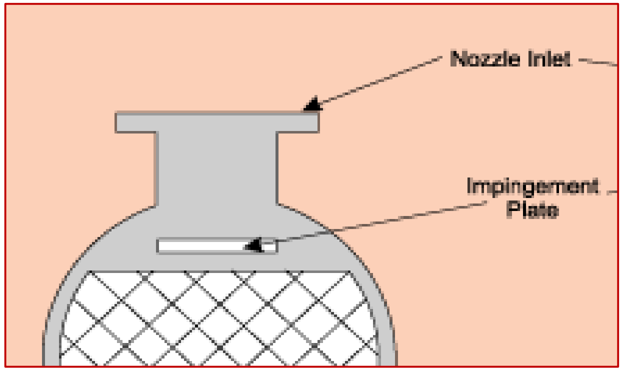
Thermal design to avoid vibration problem

- Increase the height under inlet/outlet nozzles
  (the height under inlet nozzle > 25% of Nozzle Dia.)

- Add full support at U-bend or rear head support plate for S,T type

- The U tubes should be well supported (In-bend U-bend support) and the maximum length of any bend should not exceed 80% of twice the baffle spacing (Especially, nozzle at U-bend or after U-bend). See TEMA for reference.

- Add impingement plate/rod at inlet nozzle for gases phase and two phase flow.
  See TEMA for reference.



Anti-Vibration Technologies

ExxonMobil Research and Engineering Company (EMRE) has developed and patented a suite of anti-vibration technologies that can be retrofitted into existing heat exchangers or used in new applications.

New technologies:

- Dimpled Tube Supports (DTS™)
- Saddled Tube Supports (STS™)
- Slotted Baffle Exchanger (SBX™)

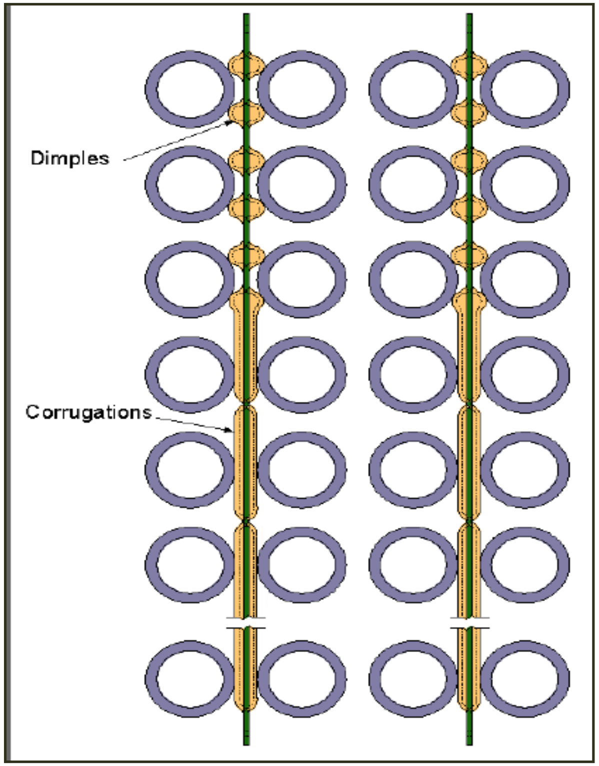
Expect there advantages:

- Increased energy savings by reduced pressure drop in compressor circuit
- Improve reliability of existing exchanger by elimination of tube vibration problem
- Increased throughput at same pressure drop in existing exchanger

Anti-Vibration Technologies

Dimpled Tube Supports (DTS™)

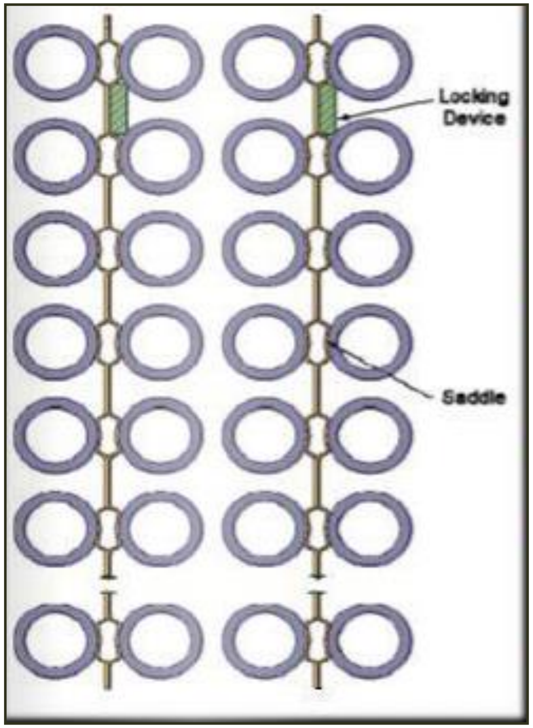
- Dimples lock into tubes avoiding accidental dislodging
- Suitable for all tube layout and vertical tube bundles
- Modified DTS strip used as U-Bend stiffener



Anti-Vibration Technologies

Saddled Tube Supports (STS™)

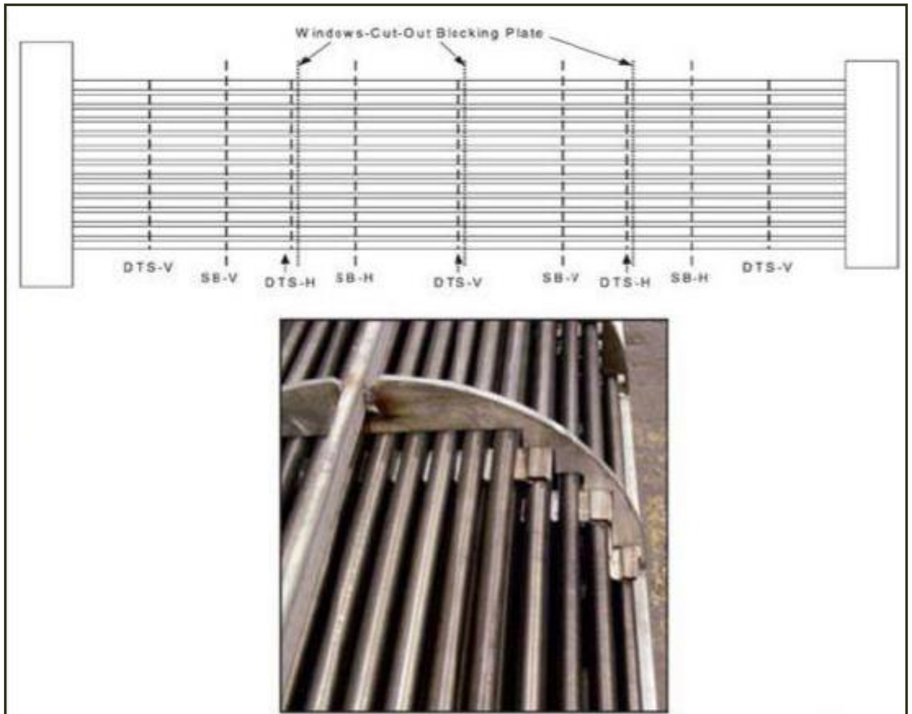
- A locking device prevents accidental dislodging of tube support
- Suitable for 45º and 90º tube layouts only



Anti-Vibration Technologies

Slotted Baffle Exchanger (SBX™)

- Suitable for 45º and 90º tube layouts only
- One tube support has horizontally arranged slots, while the next support has vertically arranged slots



Case study

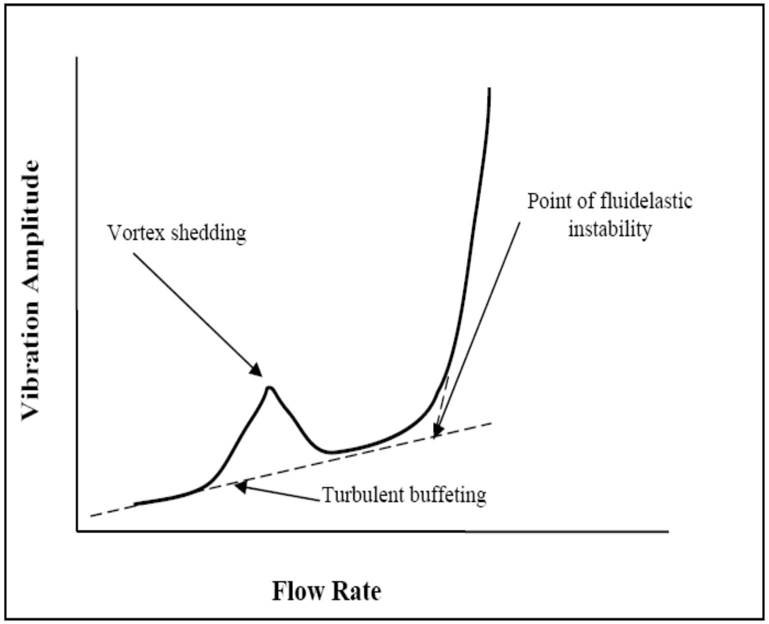
Application of DTS™ retrofit into Treat Gas Heater

- Current Case has no vibration problems
- Future operating case with 30% increase in capacity predicted to have vibration problems
- Use of DTS allowed re-use of existing equipment while eliminating vibration potential
- A new design would have required replacement of both shell and bundle and potentially piping modifications

Feed / Effluent Heat Exchanger	• TEMA BEU • 33" x 126", 1" tubes • 1,180 ft² • Segmented baffles		
	Design Conditions	30% Capacity Creep without DTS	30% Capacity Creep with DTS
Duty (MBtu/hr)	49.4	64.2	64.2
Δp (psi)	8.4	10.0	10.2
Vibration Problems?	NO	YES	NO

Thank you for your attention

Fluidelastic Instability



Note : C_{MF} depends on the ratio of forcing frequency and fn and the level of damping system.

Crossflow amplitude of tube vibration

-This amplitude depends on f_n, frequency and strength of the exciting mechanism, and system damping.

- Amplitude of vibration calculation

$$X_v = X_s C_{MF}$$

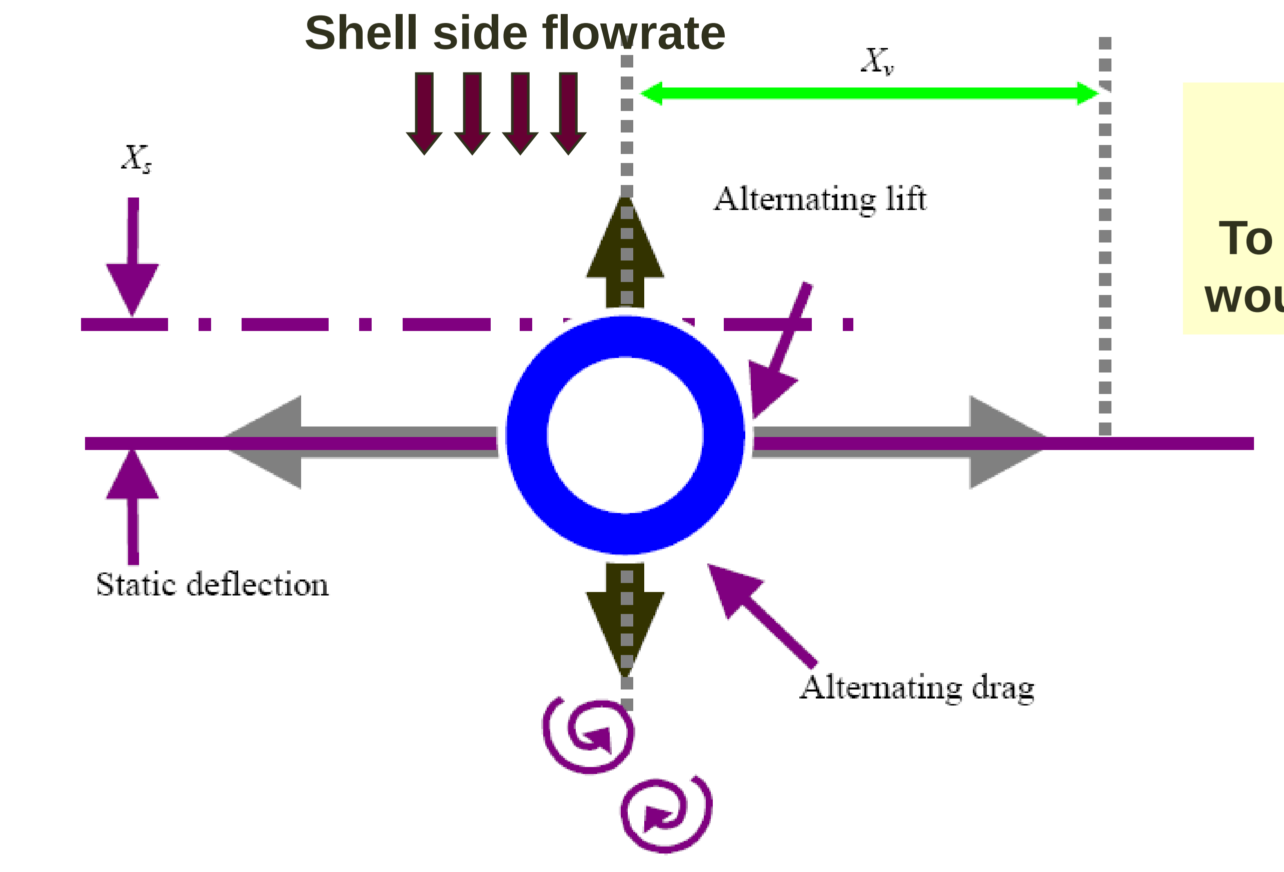
Where X_v : amplitude of vibration

C_{MF} : magnification factor

X_s : midspan static deflection

Fluidelastic Instability

Crossflow amplitude of vibration

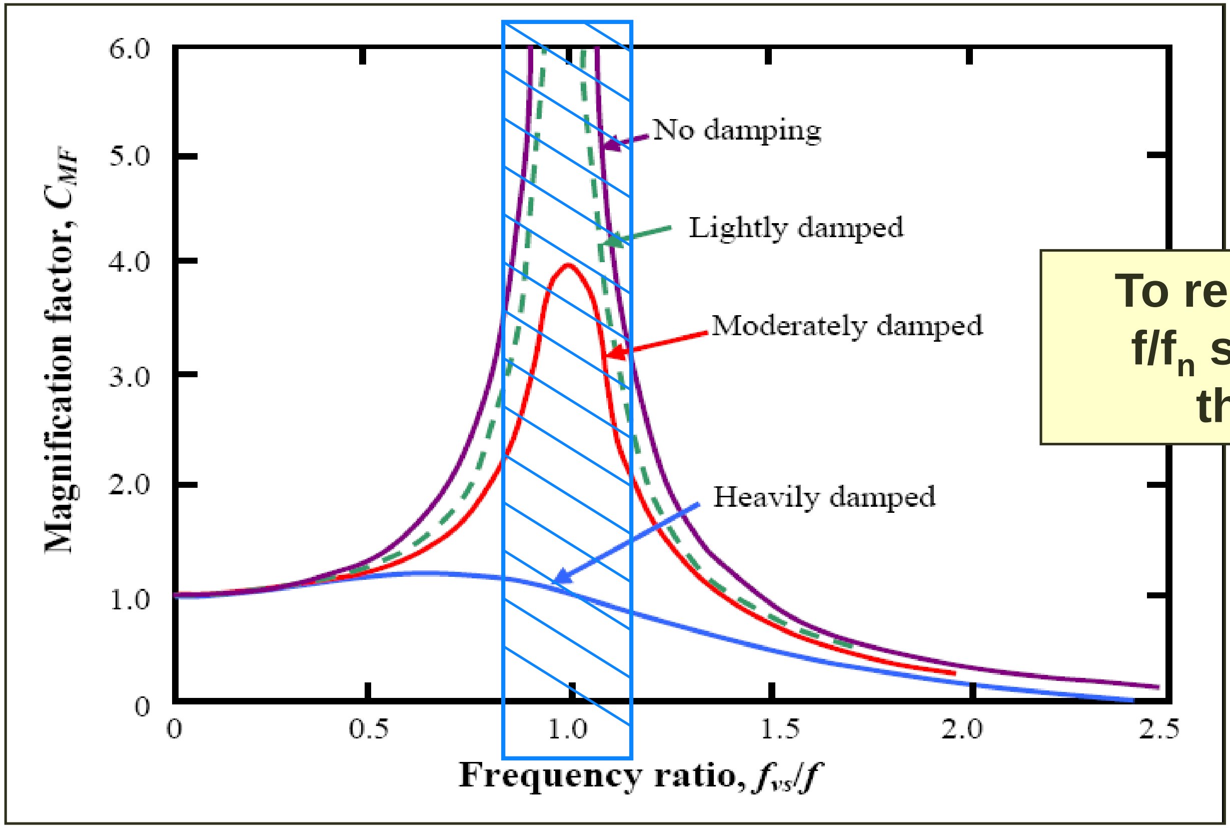


$X_v = X_s C_{MF}$

To reduce X_v, C_{MF} would be reduced.

Fluidelastic Instability

Crossflow amplitude of vibration



To reduce C_{MF} and X_v f/f_n should be lower than 0.8 – 1.2.

Fluidelastic Instability

From equation

$$V_{crit} = \beta f_n D_o \sqrt{\frac{W_e \delta_o}{\rho D_o^2}}$$

To avoid FEI vibration problem at design stage

- Tube natural frequency should be increased.
  - By decreasing baffle pitch or increasing baffle thickness
  - By increasing tube pitch or using 30°, 45° tube layout
  - By adding support
  - By using NTIW baffle
- The shell side velocity should be decreased.
  - By changing baffle type to double baffle
  - By changing shell type (E to J or X)
  - By increasing tube pitch
  - By increasing inlet and outlet height under nozzles.

Fluidelastic Instability

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