

FDLV106 - Calculation of added damping in annular flow

Summary:

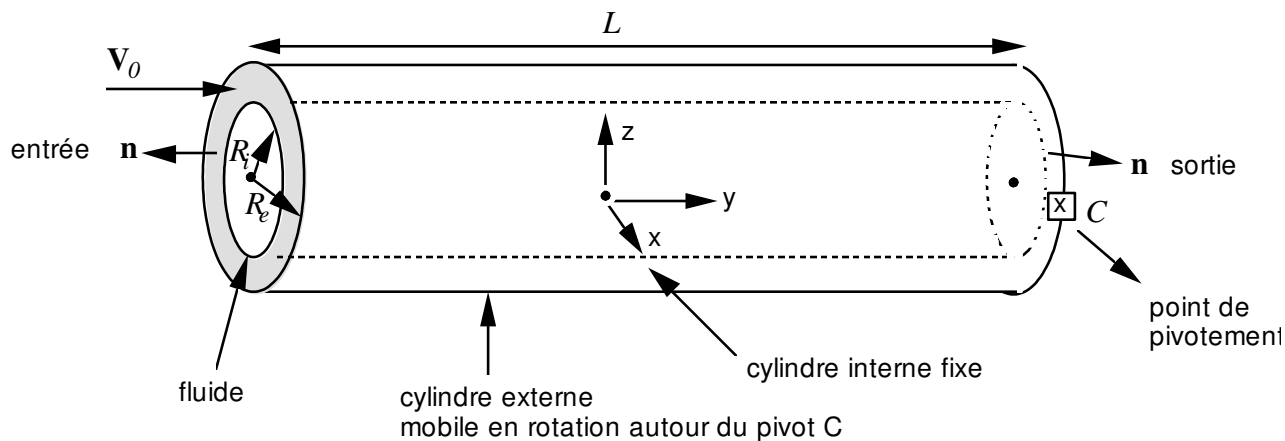
This test of the fluid field/structure implements the calculation of mass and damping added on a cylindrical structure subjected to an annular flow which one supposes potential. One calculates mass and damping initially added by the flow on the structure for various speeds upstream (4 m/s , 4.24 m/s and 6 m/s), this on a model 3D for the fluid and hull for the structure. The structure has a displacement of rotation around a pivot located at the downstream end of the cylinder compared to the flow.

The determined coefficients, one assigns them to a discrete model are equivalent to 1 ddl mass-arise-shock absorber, on which one carries out a modal analysis, in order to determine the complex Eigen frequencies of the system for the various rates of flow:

- 4 m/s : damping,
- 4.24 m/s : critical velocity, null damping,
- 6 m/s : negative damping, undulation.

1 Problem of reference

1.1 Geometry



$$L = 50 \text{ m}$$

$$R_i = 1 \text{ m}$$

$$R_e = 1.1 \text{ m}$$

C : not pivot of the external structure

1.2 Properties of materials

Fluid: density $\rho_g = 1000 \text{ kg/m}^3$ (water).

Structure: $\rho_s = 7800 \text{ kg/m}^3$; $E = 2.10^{11} \text{ Pa}$; $\nu = 0.3$ (steel).

1.3 Boundary conditions and loadings

Fluid:

- to simulate steady flow, one forces on the face of entry of the fluid a normal speed of -4 m/s (by thermal analysis, one imposes a normal heat flow equivalent of -4),
- to calculate the fluid disturbance brought by the movement of the external cylinder Dirichlet in a node of the fluid.

Structure:

one imposes on the external cylinder a displacement of the type $\vec{X}_i = \left[\begin{array}{c} L \\ 2 \end{array} - y \right] \vec{z}$ with the nodes of the grid of this cylinder.

2 Reference solution

2.1 Method of calculating used for the reference solution

For the calculation of the added coefficients:

it is shown [bib1] that the coefficients of mass and added depreciation depend on the permanent potential fluid speeds $\bar{\phi}$ as well as two fluctuating potentials ϕ_1 and ϕ_2 : these potentials are in the case of written the rotation movement of the external cylinder around the pivot C [bib1]:

$$\bar{\phi} = V_0 y$$

$$\phi_1 = \frac{R_e^2}{R_e^2 - R_i^2} r + \frac{R_i^2}{r} y + \frac{L}{2} \sin \theta \text{ avec } \mathbf{X}_i = \left[\frac{L}{2} - y \right] \mathbf{z}$$

$$\phi_2 = \frac{R_e^2 V_0}{R_e^2 - R_i^2} r + \frac{R_i^2}{r} \sin \theta$$

However the added modal coefficients projected on this mode of rotation are written:

$$M_a = \rho \int_{\text{cylindre externe}} \phi_1 \mathbf{X}_i \cdot \mathbf{n} dS$$

$$C_a = \rho \int_{\text{cylindre externe}} (\phi_2 + \nabla \bar{\phi} \cdot \nabla \phi_1) (\mathbf{X}_i \cdot \mathbf{n}) dS$$

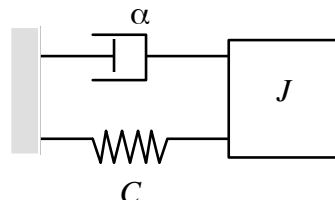
that is to say:

$$C_a = -\rho \frac{V_0 R_e^3 \pi}{R_e^2 - R_i^2} R_e + \frac{R_i^2}{R_e} L^2$$

$$M_a = +\rho \frac{R_e^3}{R_e^2 - R_i^2} R_e + \frac{R_i^2}{R_e} \frac{L^3 \pi}{3}$$

For the system with a degree of freedom are equivalent:

It is about a system mass-arise-shock absorber representing the rotation movement of the cylinder around the pivot C downstream.



- the inertia of the mechanical system subjected to the flow is written: $J = I + M_a$

where I is the inertia of the external cylinder swivelling compared to the axis Cx (cf appears Ci - below) in air.

It is shown [bib2] that this inertia is worth:

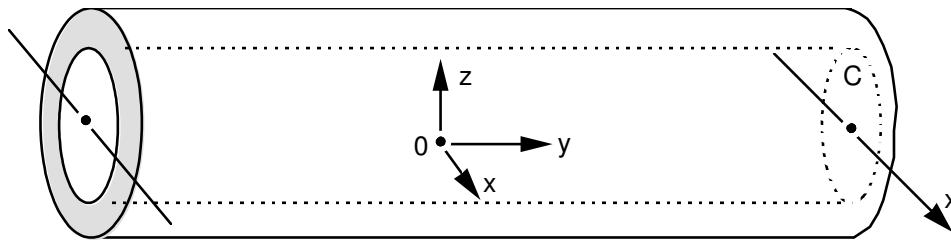
$$I = \frac{m}{6} (3 R_e^2 + 2 L^2)$$

where m is the mass of the cylinder:

$$m = 2 \rho_s \pi R_e e L$$

where e is the thickness of the cylinder, L its overall length.

ρ_s is the density of the cylinder.



$$\text{thus } J = \frac{m}{6} (3 R_e^2 + 2 L^2) + \rho \frac{R_e^3}{R_e^2 - R_i^2} \pi R_e + \frac{R_i^2}{R_e} \frac{L^3 \pi}{3}$$

- the damping of the mechanical system subjected to the flow is written: $\alpha = A + C_a$

where A is the damping of the mechanical system in air. Usually, A is equal to a few % of the critical damping of the system: $A = 2\xi\sqrt{IK}$.

where I is the inertia of the cylinder in air calculated above and K the rigidity of the spring at the point of swivelling C . Reduced damping is taken ξ equal to 1%.

Thus, the total damping of the system under flow is written:

$$\alpha = \xi\sqrt{IK} - \rho V_0 \frac{R_e^3 \pi}{R_e^2 - R_i^2} R_e + \frac{R_i^2}{R_e} L^2$$

- the rigidity of the mechanical system subjected to flow is written: $K = K + K_a$

where K is the rigidity of the spring in air. K_a is the rigidity added by the flow. It is shown [bib1] that this one is worthless on this mode of rotation.

$$K_a = 0$$

Thus the overall rigidity of the system is independent the rate of flow.

$$K = K$$

- One calculates then the complex modes of this mechanical system under flow (damped free vibrations):

$$J\ddot{\theta} + \alpha\dot{\theta} + C\theta = 0$$

The complex Eigen frequencies of this system are written [bib3]:

$$\Omega_{1ou2}^R = -\xi \omega \pm i \omega \sqrt{1 - \xi^2}$$

$$\text{with } \xi = \frac{\alpha}{2J\omega} \quad \text{et} \quad \omega = \sqrt{\frac{K}{J}} = \sqrt{\frac{K}{I + M_a}}$$

ξ : reduced damping of the system

ω : own pulsation.

- Digital applications:

One did three calculations of damping added correspondent to three rates of flow which involve three behavior vibratory of the structure:

speed with 4 m/s
speed with 4.24 m/s
speed with 6 m/s

The values of the mechanical system are:

$$e = 2.10^{-2} m \quad L = 50 m \quad R_i = 1 m \quad R_2 = 1,1 m$$

$$I = 4.5 \cdot 10^7 kg m^2$$

$$A = 4.24 \cdot 10^8 N.m rad^{-1}s$$

$$K = 10^{13} N.m rad^{-1}$$

The added mass and damping brought by the flow are worth:

$$I_a = 1.66 \cdot 10^{10} kg m^2 \quad (\text{independent of the value rate of flow})$$

According to the speed of entry of the fluid, one a:

$V_0 = 4 m/s$	$C_a = -4.00 \cdot 10^8 N.m rad^{-1}s$
$V_0 = 4.24 m/s$	$C_a = -4.24 \cdot 10^8 N.m rad^{-1}s$
$V_0 = 6 m/s$	$C_a = -5.94 \cdot 10^8 N.m rad^{-1}s$

Depreciation of the fluid system/structure is written:

- with $V_0 = 4 m/s$: $\alpha = 0.24 \cdot 10^8 N.m rad^{-1}s$

The flow does not amplify the vibrations. Structural damping interns is sufficiently important to dissipate the energy brought by the flow to the structure. The system is still deadened.

- with $V_0 = 4.24 m/s$: $\alpha \approx 0$ (vitesse d'écoulement critique)

The damping of the system is cancelled.

- with $V_0 = 6 m/s$: $\alpha = -1.5 \cdot 10^8 N.m rad^{-1}s$ (l'écoulement amplifie les vibrations)

The damping of the system at this last speed is negative: the system enters then in **instability of undulation**.

Corresponding reduced depreciation is written:

$V_0 = 4 \text{ m/s}$	$\xi = 1.1 \cdot 10^{-4}$
$V_0 = 4.24 \text{ m/s}$	$\xi = 0$ (en théorie) $\xi = 1.380 \cdot 10^{-5}$ (avec les erreurs d'arrondi)
$V_0 = 6 \text{ m/s}$	$\xi = -6.6 \cdot 10^{-4}$

The own pulsation remains as for it unchanged: $\omega = 12.5 \text{ Hz}$.

2.2 Results of reference

Analytical result.

2.3 References bibliographical

- 1) ROUSSEAU G., LUU H.T. : Mass, damping and stiffness added for a vibrating structure placed in a potential flow - Bibliography and establishment in *Code_Aster* - HP-61/95/064
- 2) BLEVINS R.D: Formulated for natural frequency and shape mode. ED. Krieger 1984
- 3) SELIGMANN D, MICHEL R: Algorithms of resolution for the quadratic problem [R5.01.02], Manuel de Référence *Aster*.

3 Modeling A

3.1 Characteristics of modeling

For the system 3D on which one calculates the added coefficients:

For the fluid:	480 meshes QUAD4 elements of hulls MEDKQU4
For the solid:	480 meshes QUAD4 elements thermics THER_FACE4 on cylindrical surfaces
	360 meshes QUAD4 thermal elements THER_FACE4 on the faces of entry and exit of fluid volume
	720 meshes HEXA8 thermal elements THER_HEXA8 in fluid annular volume

3.2 Values tested

Identification	Reference
N°1 mode	
with $V_0 = 4 m/s$ frequency	12.5 Hz
reduced damping	$1.1 \cdot 10^{-4}$
N°1 mode	
with $V_0 = 4.24 m/s$ frequency	12.5 Hz
reduced damping	$1,380 \cdot 10^{-5}$
N°1 mode	
with $V_0 = 6 m/s$ frequency	12.5 Hz
reduced damping	$- 6.60 \cdot 10^{-4}$

4 Summary of the results

The computational tool of damping under flow (potential assumption) was validated on the mode of rotation of a cylindrical structure subjected to an annular flow. It should however be noted [bib1] that the very good agreement between the semi-analytical model suggested for comparison and digital calculation is obtained only if the cylinder is sufficiently long.

Indeed, the semi-analytical model is in fact only one approximate solution of the posed problem.