Fluid-structure interaction problem of two coaxial flexible cylinders vibrating in a viscous fluid

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ABSTRACT

In this paper, we investigate the vibration of two coaxial finite-length cylinders separated by a viscous Newtonian fluid with a small-amplitude forced beam. A new theoretical approach based on an Helmholtz expansion of the fluid velocity vector is carried out, leading to a full analytical expression of the fluid forces and subsequently of the modal added mass and damping coefficients. Our theory shows that the fluid forces are linear combinations of the Fourier harmonics of the vibration modes.

The coefficients of the linear combinations are shown to depend on the aspect ratio of the cylinders, on the separation distance, and on the Stokes number. As a consequence, the linear fluid forces do not have, in general, the same shape as the forced vibration mode, so that the fluid makes it possible to couple vibration modes with different wave-numbers. Compared to previous works [1, 2, 3], the present theory includes the viscous effects of the fluid, accounts for the finite length of the cylinders, does not rely on the assumption of a narrow annulus, and covers in a unique formulation all types of classical boundary conditions for an Euler-Bernoulli beam.

The self-added mass and damping coefficients are shown to decrease with both the Stokes number and the separation distance. The cross-added mass and damping coefficients tend to increase with the Stokes number and the separation distance. We show that the aspect ratio of the cylinders has a strong effect on the magnitude of the fluid forces, whereas the Stokes number mainly affects the phase shift between the fluid forces and the imposed modes of vibrations.

To assess the validity of the theoretical predictions, we perform numerical simulations with the open-source code TrioCFD [4]. The fluid-structure interaction problem involving moving boundaries is solved in this code using an Arbitrary Lagrange-Eulerian technique. We show that the numerical simulations successfully corroborate the theoretical predictions for all types of classical boundary conditions, different confinements, and different aspect ratios of the vibrating cylinder [5].

Keywords: Fluid-Structure Interaction; Coaxial cylinders; Vibration modes; Viscous theory; Fluid forces, Modal added-coefficients

REFERENCES

[1] Beam vibrations of coaxial cylinders separated by a fluid gap of arbitrary size. Inviscid theory and numerical assessment of the fluid forces, R. Lagrange, L. Lorand, and M. A. Puscas. *Journal of Fluids and Structures, 2023.*

[2] R. Lagrange and M. A. Puscas. Hydrodynamic interaction between two flexible finite length coaxial cylinders: new theoretical formulation and numerical validation. *Journal of Applied Mechanics, 2022.*

[3] R. Lagrange, M. A. Puscas, P. Piteau, X. Delaune, and J. Antunes. Modal added-mass matrix of an elongated flexible cylinder immersed in a narrow annular fluid, considering various boundary conditions. New theoretical results and numerical validation. *Journal of Fluids and Structures, 2022.*

[4] D.Panunzio, M. A. Puscas, and R. Lagrange. FSI–vibrations of immersed cylinders. Simulations with the engineering open-source code TrioCFD. Test cases and experimental comparisons. *Comptes Rendus. Mécanique, 2022.*

[5] R. Lagrange and M. A. Puscas. Viscous theory for the vibrations of coaxial cylinders. Analytical formulas for the fluid forces and the modal added coefficients. *Journal of Applied Mechanics, 2023.*