Analytical predictions for vibration phase shifts along fluid-conveying pipes due to Coriolis forces and imperfections

Resonant vibrations of a fluid-conveying pipe are investigated, with special consideration to axial shifts in vibration phase accompanying fluid flow and various imperfections. This is relevant for understanding elastic wave propagation in general, and for the design and trouble-shooting of phase-shift measuring devices such as Coriolis mass flowmeters in particular. Small imperfections related to elastic and dissipative support conditions are specifically addressed, but the suggested approach is readily applicable to other kinds of imperfection, e.g. non-uniform stiffness or mass, non-proportional damping, weak nonlinearity, and flow pulsation. A multiple time scaling perturbation analysis is employed for a simple model of an imperfect fluid-conveying pipe. This leads to simple analytical expressions for the approximate prediction of phase shift, providing direct insight into which imperfections affect phase shift, and in which manner. The analytical predictions are tested against results obtained by pure numerical analysis using a Galerkin expansion, showing very good agreement. For small imperfections the analytical predictions are thus comparable in accuracy to numerical simulation, but provide much more insight. This may aid in creating practically useful hypotheses that hold more generally for real systems of complex geometry, e.g. that asymmetry or non-proportionality in axial distribution of damping will induce phase shifts in a manner similar to that of fluid flow, while the symmetric part of damping as well as non-uniformity in mass or stiffness do not affect phase shift. The validity of such hypotheses can be tested using detailed fluid-structure interaction computer models or laboratory experiments.

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