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On the Application of Flow Simulation to Predict the Added Damping and Mass of Vibrating Water-Submerged Disc-Like Structures

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Abstract

Flow-induced vibrations are the main cause of fatigue damage in hydropower impellers. These vibrations may escalate to critical levels through resonance amplification. The dynamic properties of the vibrating system are significantly influenced by the surrounding fluid. On the one hand, resonance frequencies are significantly reduced by the fluid-added mass, which describes an increase in the inertia of the vibrating system. On the other hand, the amplitude of near-resonant vibrations is limited by the damping which is, in the case of hydraulic machinery, dominated by the fluid-added damping. Low-specific-speed hydroelectric impellers geometrically resemble discs and therefore exhibit bending modes with diametrical nodal lines. It is well-known that these modes can engage in near-resonant vibrations. Therefore, it is essential to quantify the fluid-added quantities to enable realistic fatigue life assessment.

As an abstraction of a low-specific-speed impeller, a submerged disc with a variable axial gap to a rigid wall is investigated. First, the added quantities of a nonrotating disc are computed for nodal diameter modes using the imposed modal motion approach in incompressible time-domain numerical flow simulations (1-way FEA-CFD coupling). Herein, the added quantities are extracted using a phase decomposition of the vibration-induced fluid reaction force. The requirements for CFD for accurate prediction of the added quantities are identified by validation against experiments. Next, key observations for added mass and damping are discussed. Finally, rotation is introduced to the disc, to study the mode split phenomenon. For different rotation speeds (Reynolds number ranging from 97880 to 489401 using the disc tip speed), pairs of forward and backward travelling waves are investigated. Herein, a novel efficient approach for the extraction of added quantities based solely on spatial information is presented.

For both the standing and rotating disc, accurate prediction of the added quantities is achieved. The results reveal that reliable computation of the added damping requires higher spatial and significantly higher temporal discretization than the added mass. The temporal discretization requirements are a direct result of the behavior of the phase lead of the fluid reaction force with respect to the imposed modal motion. Moreover, this phase lead explains the amplitude-dependency of the added damping and indicates an amplitude-dependent added mass. For the rotating disc, the accurate prediction of the split frequencies is also less challenging than predicting the split damping. Imposing the standing disc eigenfrequencies for the forward and backward travelling waves still delivers accurate added mass prediction even without any iteration.