Modelling and prediction of the fluid-induced quantities in the context of structural vibrations using the imposed modal motion approach

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Abstract A detailed mathematical modelling of the fluid-added quantities for flow-induced vibrations, i.e. the added mass, added damping, added stiffness and others, from a structural point of view is presented in the first part of this work, along with a graphical interpretation of the resulting forces. In the second part, the imposed modal motion approach (IMMA) is applied in conjunction with the theoretical foundation from the first part to derive equations that enable computing the fluid-added mass, damping, and stiffness. First, an approach based on the fluid force and the previously discussed graphical interpretation is introduced. It includes the case of coinciding modal and excitation frequencies which paves the way for applying the IMMA in operating regimes beyond best efficiency operation, where it has been commonly applied so far. Finally, the method is applied to a circular disc vibrating in spatially harmonic modes characterized by nodal diameters.

1. Introduction

Flow-induced vibrations are the main cause of the fatigue damage of hydropower runners. They occur in different operating regimes and can have a near-resonant character. The increased flexibility requirements of the power market and the consequently resulting wide operating range of single hydropower plants impede the avoidance of near-resonant regimes, as it is traditionally pursued. Therefore, reliable vibration prediction in these meanwhile unavoidable operating conditions has become paramount. In this context, it is a widely accepted concept that the surrounding fluid excites the structural oscillations on the one hand and shifts the dynamic properties of the structure on the other hand, that is, "retunes" it. While the flow-induced excitation can be predicted numerically by pure CFD simulations under certain assumptions, the shift in dynamic properties which is typically expressed in terms of added mass, added damping, and added stiffness requires a coupling between the structure and the fluid as it is the result of the fluid reaction force to the structural vibrations. In contrast to the fluid-added mass which has been studied extensively in the literature [1–10], there have been only a few works that address fluid-added damping and stiffness in hydraulic machinery. Most of these works focused on practical aspects of the numerical prediction or experimental measurement of these quantities whilst relying on a quasi-empirical physical modelling [11–16] with a few exceptions addressing the theoretical derivation [17–20]. However, a comprehensive theoretical foundation of the computed concepts enables a precise definition of the fluid-added quantities and thus a thorough understanding of their origin, their embedding in the structural models, and most importantly, the assumptions and