A Harmonic Balance Method for unsteady Aerodynamics and Flow-Induced Vibration

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We present a harmonic balance (HB) method to model lock-in effects during vortex-induced vibration (VIV) of elastically mounted circular cylinder and a flexible riser section in a freestream uniform flow. The fluid flow and structure are coupled by a fixed-point iteration process through a frequency updating algorithm. By minimizing the structural residual in the standard least-square norm, the convergence of HB-based fixed-point algorithm is achieved for a range of reduced velocity. To begin with, the HB solver is first demonstrated for a periodic unsteady flow around a stationary circular cylinder. A freely vibrating circular cylinder is then adopted for the reduced-order computation of VIV at low Reynolds number of Re=100. The results show that the HB solver is able to predict amplitude of vibration, frequency and forces comparable to its time domain counterpart, while providing significant reduction with regard to overall computational cost. The proposed new scheme is then demonstrated for a fully-coupled analysis of flexible riser undergoing vortex-induced vibration in the lock-in range.

The present work aims to develop an efficient and fast reduced-order model for VIV response in the frequency domain. Of particular interest here is the lock-in situation where the vortex shedding process itself occurs at a frequency near to a resonant frequency of the structure. During the lock-in process, the cylinder wake is able to adjust itself to the structural frequency. Such coupling can lead to large amplitude vibrations which can in turn lead to fatigue failure of structures. A HB method is adopted to address the problems in the paper. As far as the authors are aware, it is the first attempt to use HB method for VIV prediction. The method is demonstrated for a stationary circular cylinder undergoing alternate vortex shedding. This will be followed by implementation of the HB method for VIV computation of a circular cylinder and flexible riser vibrating transversely in the flow at Reynolds number Re=100. To assess the accuracy and efficiency of HB solver, the results are compared against its time domain counterpart. Through the vortex contours and the maximum amplitude of vibration, the predictive performance of HB is demonstrated for reduced-order modeling of VIV. The basic hydrodynamic features are well captured and the numerical technique is an improvement over the existing empirical and experience-based methods.

Keywords: Vortex Induced Vibration, Harmonic Balance, Reduced Order Model