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Non-synchronous vibration in a bistable system induced by FSI

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Abstract: The aim is paid at the analysis of non-synchronous vibration along with frequency lock-in phenomena of a geometrically nonlinear bistable system induced by a reduced model of fluid-structure interaction.

Keywords: non-synchronous vibration, lock-in, bifurcation, bistable system

1. Introduction

The fluid-structure interaction (FSI) arises when an elastic structure interacts with the embracing fluid flow. In general, the FSI is a very complex process that requires highly sophisticated approaches from the mathematical and computational point of view. A particular case of FSI in which an alternate shedding of vortices forms the vibration of the structure is called a Vortex-Induced Vibration (VIV). The natural vortex shedding frequency is dependent on the velocity of the flow [1]. The vortex shedding exerts a periodic unsteady force on the body. As the vortex shedding frequency approaches the natural frequency of the body, the two frequencies could lock-in for a small range of the velocity flow, e.g. see [2-3]. The vibration connected with the lock-in phenomenon is often called a Non-Synchronous Vibration (NSV), which were observed in real applications [4]. Here, we deal with dynamic response of VIV of a single structural profile which can possess two stable equilibria. To model the FSI, a reduced, non-dimensional model is employed [4] and the resulting mathematical model can be written as follows

$$\begin{bmatrix} 1 & m_{as} \\ m_{sa} & 1 \end{bmatrix} \begin{bmatrix} \ddot{\varphi} \\ \ddot{x} \end{bmatrix} + \begin{bmatrix} -2D_{aa}\Omega_{aa} & c_{as} \\ c_{sa} & 2D_{ss}\Omega_{ss} \end{bmatrix} \begin{bmatrix} \dot{\varphi} \\ \dot{x} \end{bmatrix} + \begin{bmatrix} \Omega_{aa}^2 & k_{as} \\ k_{sa} & \Omega_{ss}^2 + 2\Omega_b^2 \end{bmatrix} \begin{bmatrix} \varphi \\ x \end{bmatrix} = \begin{bmatrix} -2D_{aa}\Omega_{aa}c_{asl}\varphi^2\dot{\varphi} \\ 2\Omega_b^2 \dfrac{l_0}{\sqrt{h^2+x^2}} \end{bmatrix}, \quad (1)$$

where the first equation describes the fluid-flow wake excitation employing the van der Pol term. The second equation corresponds to the structural behaviour and incorporates the geometric nonlinearity (see Fig. 1, left). All parameters are in detail described in [5].

2. Results and Discussion

The response of the structure is investigated in dependence on the vortex-shedding frequency Ω_{aa}. Here, two cases are analysed: (i) mono-stable nonlinear structure, i.e. $l_0/h=1$ and (ii) bistable nonlinear structure, i.e. $l_0/h>1$. These two systems have qualitatively different dynamical response. The system (i) shows NSV in main resonance and subharmonic areas which are accompanied by frequency lock-ins (see Fig. 1 top, the curves shows the response for $\Omega_b = 0, 0.3, 0.5, 0.7, 0.9$). Increasing changes the hysteresis region and shifts the lock-in frequency higher frequencies.

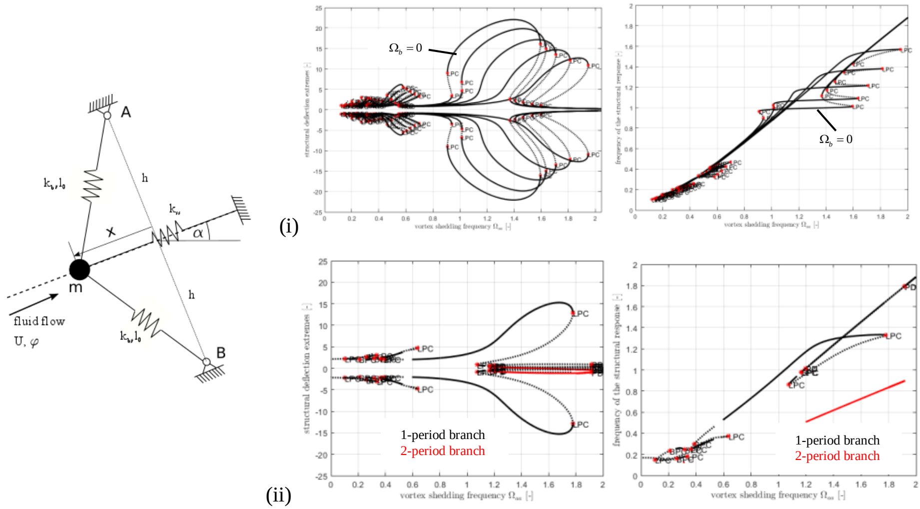

Fig. 1. Scheme of 1 DoF structural system, amplitude and frequency plots representing lock-in and non-synchronous vibration for $l_0 / h = 1$ (top) and $l_0 / h = 2.5$ (bottom)

Regarding the system (ii), the NSV area contains 2-period stable solution with significantly smaller amplitude (red colour). The frequency lock-in, which is present and which is connected with 1-period solution, should not be employed because of the high-energy level.

3. Concluding Remarks

Using a phenomenological model (1), the mechanism of NSV accompanied by frequency lock-in is numerically investigated. It can be seen, that the bistability changes qualitative properties of the dynamic response especially in the main harmonic area which can lead to vibration mitigation.

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