Influence of friction damping on frequency lock-in in cyclic structure

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Summary. The paper deals with modelling and investigation of lock-in phenomena in bladed cyclic structure which is further influenced by friction damping couplings. The investifation is focused on how the friction can affect the unstable behaviour during frequency lock-in regimes.

Introduction

The fliud-structure interaction (FSI) phenomenon arises when an elastic structure interacts with the embracing fliud flow. A particular case of FSI in which an alternate shedding of vortices forms the vibration of the structure is Vortex-Induced Vibration (VIV). The natural vortex shedding frequency is dependent on the velocity of the flow. The vortex sheddding exerts a periodic unsteady force on the body. As the vortex shedding frequency approaches the the natural frequency of the body, the two frequencies lock-in for a small range of the velocity flow [2]. Experimental characterization of lock-in is performed in [1].

The FSI plays significant role in modern aerofoils and turbine blades which are designed for higher efficiencies and higher power under higher operational temperatures and flow rates. Higher operational safety and economical demands force the designers to be more precise during phase of design with respect to operational condition laying out of the area with loss of stability [3, 4, 5]. The fluid-induced forces create an aero-elastic couplings between the aerofoils and the fluid flow. Moreover, in the case of periodical structures (gas or steam turbine blades in bladed disks) the aero-elastic coupling influences not only the single blade but the adjacent blades as well. There are many experimental works investigating experimentally the conditions of instability origin, e.g. [7, 8]. The paper deals with the modelling and dynamical analysis of a periodic blade system influenced by VIV and friction-damping in inter-blade couplings.

Cyclic structure of blade profiles influenced by VIV

Further, it is assumed the cyclic structure formed by a bladed disk has N_B blades which are created by identical airfoil profiles. Each blade is modelled by the approach presented in the previous section, i.e. it comprises two degrees of freedom (bending and torsion) and moreover these two motion are mutually coupled by so called bending-torsion coupling, see [6]. Usually, in steam turbine applications, the bladed disks are equipped with different kinds of shrouding, which causes that the system of blades mounted on a rotating disk become more stiff, especially with respect to axial flow direction.

The time-varying vortex force due to the alternating sheddin of vortices in the wake causing the VIV is modeled by the van der Pol equation. The van der Pol model has two significant properties: i) self-sustained stable limit cycle oscillation and ii) the lock-in with the frequency of external forcing [2].

In Fig. 1, the blade cascade of a bladed disk is depicted in a plane view. The axis of rotational symmetry designates the axis of rotor symmetry which is the bladed disk attached to. Further, it is assumed that the flow direction is parallel with the blade chords. The shrouding is supposed to be mounted at tips of the blades and it is modelled by means of two lumped springs representing bending k_{shb} and torsional k_{sht} stiffness of each shrouding section between two adjacent blades.

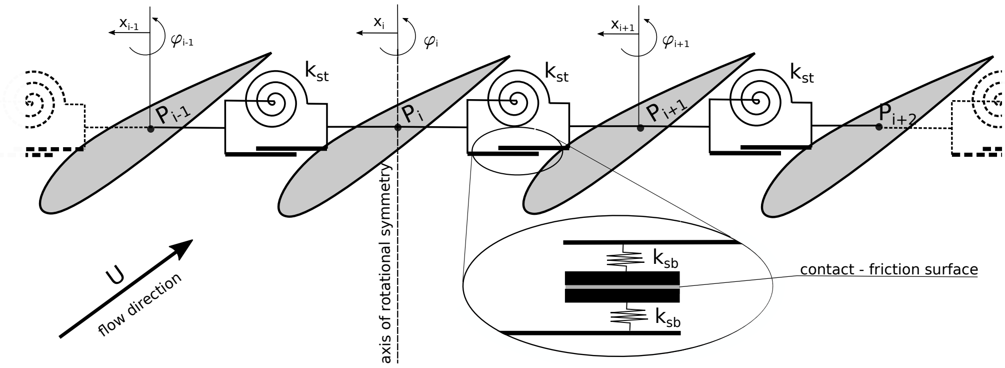

Figure 1: Bladed cascade section with contact-friction shrouding coupling modelling.

The derivation of the linearized mathematical model of a bladed disk with the influence VIV is based on the methodology presented in [2]. Here, it is extended for a cyclic structure and completed by the influence of interblade damping-friction forces which are incopororated in shrouding coupling. It can be advantageously written in matrix form

$$\mathbf{M}_{BD}\ddot{\mathbf{q}}_{BD} + \mathbf{C}_{BD}\dot{\mathbf{q}}_{BD} + \mathbf{K}_{BD}\mathbf{q}_{BD} = \mathbf{f}_{BD}^{E} + \mathbf{f}_{BD}^{FC}, \tag{1}$$

where $\mathbf{M}_{BD}$, $\mathbf{C}_{BD}$ and $\mathbf{K}_{BD}$ are rectangular of order $3N_B$ mass, damping and stiffness matrices of a complex bladed disk model. Right hand side of (1) contains force vectors of friction coupling $\mathbf{f}_{BD}^{FC}$. Vector of generalized coordinates is of following form $\mathbf{q}_{BD} = [\ldots, x_i, \varphi_i, q_i, \ldots]^T \in \mathbb{R}^{3N_B}$, where index $i = 1, \ldots, N_B$ designates the particular blade. The coordinate q_i is governed by van der Pol equation which is used for the wake dynamics.

Lock-in in the cyclic structure

The figures below show multiple frequency lock-in reagarding different mode shapes of the structure (left). Real parts of the eigen values witness of the stability. It is clear that when the frequency lock-in happens, the system exhibit can unstable vibration.

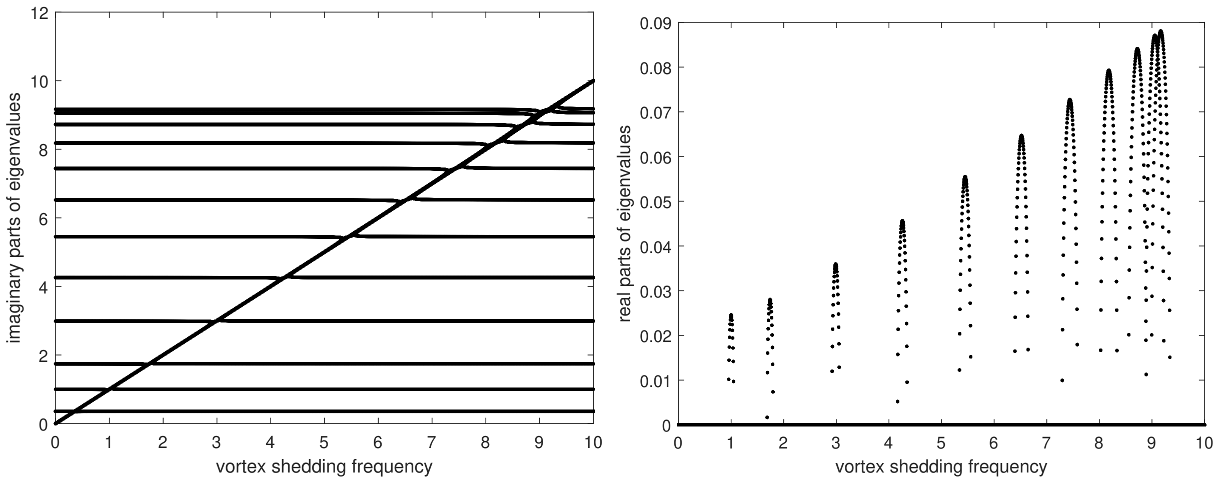

Figure 2: Frequency lock-in areas and stability charts for cyclic structure created of identical air-foil profile connected by shrouding.

Conclusions

The paper presents phenomenological model of vortex-induced vibration in a cyclic structure which is formed by blade profiles. The attention is paid on the investigation of lock-in phenomenon using linearized model, which will further completed by nonlinear friction terms based on LuGre friction model. There is obvious in the presented results, that the system losses its stability during the lock-in phases. The future aim is to propose suitable damping mechanism which is based on friction dampers and complete the analyses with experimental data.

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