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Frequency lock-in phenomenon in structures with aeroelastic couplings

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Flexible structures exposed to the airflow can induce so-called *fluid-structure interaction* (FSI) – a complex process that needs highly sophisticated computational approaches to be dealt with. In some cases, shedding vortices can produce a phenomenon called *vortex-induced vibrations* (VIV). Moreover, if vortex frequency comes close to the natural frequency of the system, *frequency lock-in* possibly occurs in a small range of the velocity flow [1, 2]. This phenomenon is also often discussed e.g. in the field of rotating systems together with *crossing* or *veering* phenomena in Campbell diagrams.

The contribution focuses on the reduced phenomenological model of the flexible body exposed to airflow. The structure is represented by the damped linear oscillator and aero-elastic coupling is described by the van der Pol oscillator [3]. The linearized analysis is performed with respect to show interesting lock-in regimes as well as stability issues. These phenomena are studied considering a single-degree-of-freedom (sdof) system and a cyclic structure corresponding to the bladed disc exposed to the steam flow.

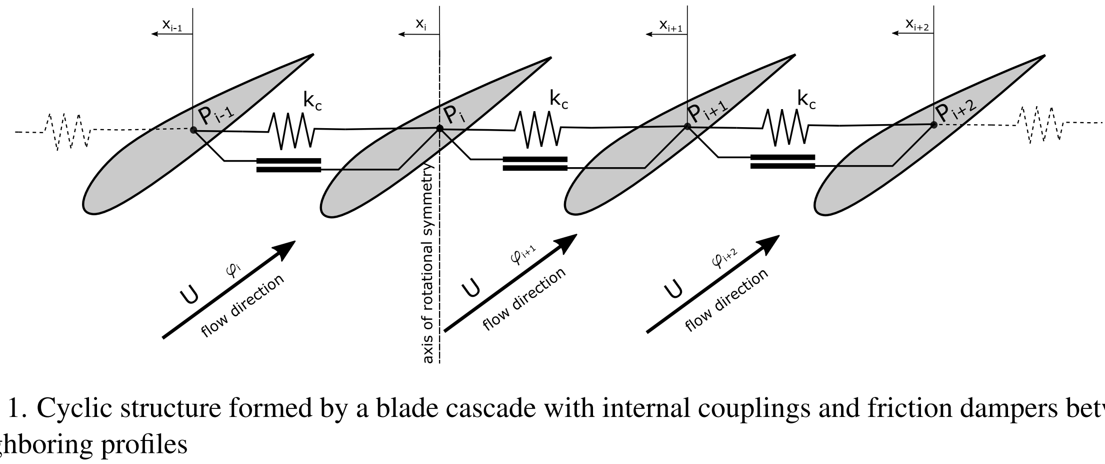

Fig. 1. Cyclic structure formed by a blade cascade with internal couplings and friction dampers between neighboring profiles

Let us focus on the multiple-degrees-of-freedom case shown in Fig. 1. A corresponding mathematical model is nonlinear due to the van der Pol terms. However, for the preliminary analyses and for the purposes of lock-in areas estimation, a linearized model is sufficient. A general mathematical model of the linearized and homogeneous system can be written in the form

$$\mathbf{M}_{BD}\ddot{\mathbf{q}}_{BD} + (\mathbf{B}_{BD} + \mathbf{B}_{fric})\dot{\mathbf{q}}_{BD} + (\mathbf{K}_{BD} + \mathbf{K}_{C})\mathbf{q}_{BD} = \mathbf{0}, \tag{1}$$

where $\mathbf{q}_{BD} = [\ldots, \varphi_i, x_i \ldots] \in \mathbb{R}^{2N_B}$ is vector of generalized coordinates which includes displacements x_i and van der Pol coordinate φ_i of i-th profile. $\mathbf{M}_{BD}, \mathbf{B}_{BD}, \mathbf{K}_{BD} \in \mathbb{R}^{2N_B,2N_B}$

are mass, damping and stiffness matrices, respectively, and $\mathbf{K}_C \in \mathbb{R}^{2N_B,2N_B}$ is coupling matrix representing elastic couplings between neighbouring profiles. Matrix $\mathbf{B}_{fric}) \in \mathbb{R}^{2N_B,2N_B}$ stands for equivalent linearized damping matrix corresponding to the friction couplings between neighbouring blades.

Modal analysis of such a system was performed with respect to the vortex shedding frequency which affects modal properties. For this purpose, system matrix $\mathbf{A}$ was defined in the form

$$\mathbf{A} = -\begin{bmatrix} \mathbf{0} & -\mathbf{I} \\ \mathbf{M}^{-1}(\mathbf{K}_{BD} + \mathbf{K}_C) & \mathbf{M}^{-1}(\mathbf{B}_{BD} + \mathbf{B}_{fric}) \end{bmatrix}. \tag{2}$$

Since stiffness and damping matrices are shedding-frequency-dependent ($\mathbf{K}_{BD} = \mathbf{K}_{BD}(\Omega_{aa})$, $\mathbf{B}_{BD} = \mathbf{B}_{BD}(\Omega_{aa})$), also eigenvalues of $\mathbf{A}$ are frequency-dependent. Moreover, due to the presence of damping forces, modal analysis produces complex values representing eigenfrequencies (imaginary part) and stability (real part). Results of the modal analysis are shown in Fig. 2 for two chosen values of the damping between profiles. It shows lock-in areas and its degeneration with changing damping.

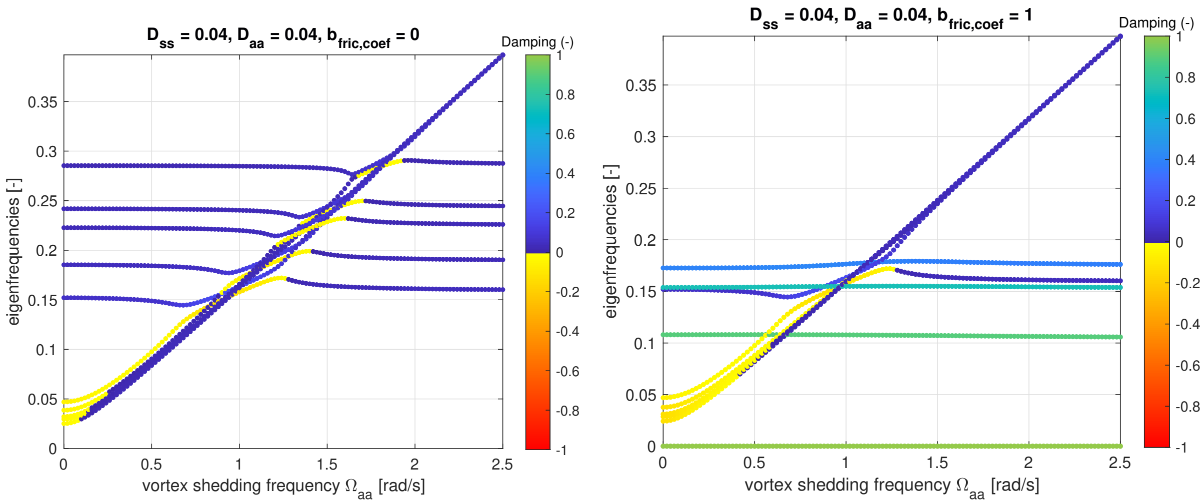

Fig. 2. Resulting eigenfrequency charts of the cyclic structure with five profiles; stability is denoted by the colour code

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