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Damping of flutter oscillations by dry friction contacts

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Self-excited flutter vibrations of turbine blades are very dangerous phenomena for the service life of turbines [1], [2]. The various design treatments are therefore applied for suppression of blades' flutter vibrations. The introduction of dry friction elements is one of the very effective methods. The dynamic behavior of a computational model of 30-blades turbine wheel is investigated in the proposed paper. The blades in the rotating cascade are excited by aerodynamic forces arising from the spatially periodical flow of steam through the stator blades cascade. This flow produces both forced vibration and self-excited vibrations – flutter. The application of dry friction elements on reduction of these dangerous vibrations is presented on several examples.

The computational model of thirty blades turbine wheel with elastic connections between neighbouring blades modelled approximately the experimental wheel investigated in our institute. A small blades' section is in Fig. 1. Spring connections between blades (stiffness k_1) model the elastic properties of disc.

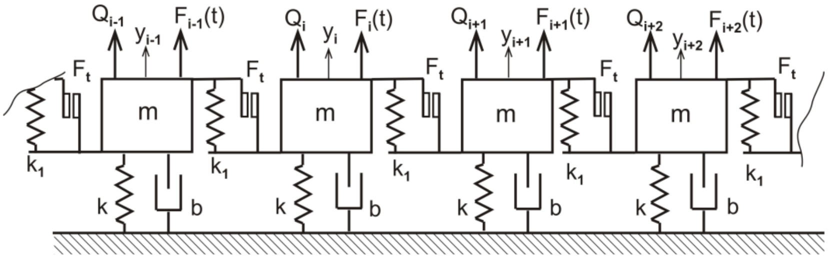

Fig. 1. Section of computational model of closed 30-blades cascade with dry friction inter-blades connections

Due to the different numbers of blades of stationary and of rotating wheels, the wakes from the stationary cascade flow excite the forced running waves. These forced waves serve as initial impulses for aero-elastic self-excited oscillations – flutter running waves. In order to investigate the behaviour of bladed cascade also in the unstable regions, the simple Van der Pol expression for description of self-exciting forces is used. These self-exciting forces are controlled by only one blade's motion parameters – similar as at aeroplane wing:

$$Q_i = -\mu(1-(y_i/r)^2)\dot{y}_i, \qquad i = 1, \ldots, 30,$$

where r is the displacement at which the negative aerodynamic force changes into positive one, μ is a scalar parameter indicating the intensity of this non-linear force.

The dry friction elements used for suppression of flutter vibrations are described by smooth modification of Coulomb law with arctangent function F_{ti}:

$$F_{ti} = fF_N \, arctg(\gamma(\dot{y}_i - \dot{y}_{i+1}))2/\pi \qquad i = 1, \ldots, 30,$$

with sufficiently high parameter γ.

The first step in study of bladed wheel dynamics is analysis of free vibration. This cyclic structure with parameters m = 0.182 kg, k = 105000 kg s^{-2}, k_1 = 10000 kg s^{-2} has 30 eigen-frequencies in the range 759.55 – 899.48 rad/s (majority twofold) and 15 modes with 0 –15 nodal diameters (nd). In this paper only 5 selected cases with 0, 4, 8, 12, 15 nd is presented. The aerodynamic forces of the interrupted steam flowing from stator cascade with *l*s blades produce spatial generally periodic forces, acting on the rotating blade cascade with different numbers *lr* of blades. These periodic forces have many components that can excite forced vibrations corresponding to all above mentioned natural frequencies.

Let us concentrate on the damping of flutter oscillation of bladed wheel with 12 nodal diameters at $\Omega = 880.74$ rad/s (140.17 Hz). Mode of un-damped flutter (F_{t0} = 0) vibrations are shown in Fig. 2. Using dry friction elements (F_{t0} = 0.93 N) between neighboring blades reduces flutter oscillations on acceptable value.

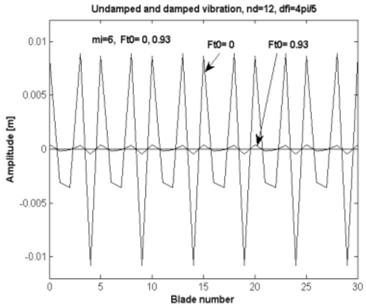

Fig. 2. Mode at 880.74 rad/s

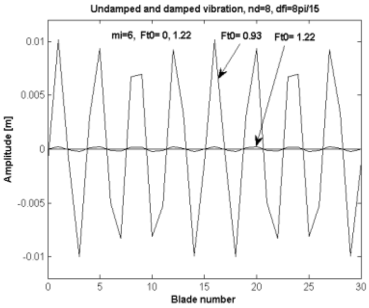

Fig. 3. Mode at 835.64 rad/s

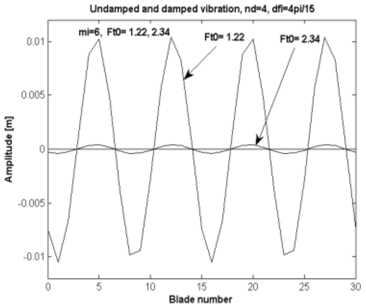

Fig. 4. Mode at 783.12 rad/s

However, this dry friction element does not suffice for suppression of bladed wheel flutter oscillation with 8 nodal diameters ($\Omega = 835.64$ rad/s, 133.00 Hz) as it is evident from record in Fig. 3, where the dry friction element (F_{t0} = 0.93 N) does not reduce the amplitudes and they stay roughly the same as of un-damped system. Only when the dry friction forces increase to F_{t0} = 1.22 N, the danger flutter oscillations disappear.

Similar damping properties have also the resonance vibrations with 4 nodal diameters ($\Omega = 783.12$ rad/s, 124.62 Hz) as it is seen from Fig. 4. Application of the same dry friction dampers as in previous case (F_{t0} = 1.22 N) does not reduce the flutter oscillations and the dry friction force has to increase to F_{t0} = 2.34 N in order that these oscillations are strongly diminished.

The same properties have all 15 resonances of investigated bladed wheel. The simpler is the mode of vibrations, the higher dry friction force is needed for suppression of the flutter vibrations. E.g. the lowest eigen-frequencies need very high dry friction for their reduction and the first frequency with umbrella mode (all blades vibrate in phase) cannot be suppressed by any value of dry friction situated between neighbouring blades.

This phenomenon is typical for all multi-degree-of-freedom systems, where damping forces act in another place than excitation forces work.

Acknowledgement

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References

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