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Influence of the Natural Frequency Mistuning and the Damping and Kinematic Properties of Blades on Subsonic Flutter Stability of Blading

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Abstract. The investigations of the subsonic flutter conditions in alternately mistuned blading, the blades of which differ in both the natural frequencies and the mechanical damping and vibration modes, are presented. The experimental aerodynamic influence coefficients for various attack angles are used for the stability calculations.

Introduction

It is known that one of the means to increase the stability of blading against self-excited vibration is its mistuning, which can be implemented by various ways:

– the mounting of blades with different geometric, elastic and damping properties;

– the use of dissimilar blade-to-disc interlocking joints;

– the introduction of changes of the flow in individual blade passages, e.g., by way of changing the blade spacing or angles of incidence.

Up to now, the effect of the differences in the natural frequencies of blades on the dynamic stability of blading has been studied most extensively. In this paper, the influence of the differences in the mechanical damping and vibration modes of the blades of the blade assembly is studied together with the frequency mistuning.

In case of alternating mistuning, the blade assembly can be considered as consisting of identical packets, and the packet blades differ from one another in the natural frequencies, vibration mode and mechanical damping, as shown in Fig.1 (the blades with different mechanical properties are denoted by different colors, whereas the identical packets of the blades are encircled).

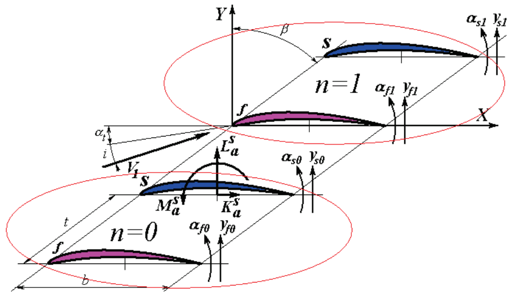

Fig. 1: Schematic of the blade assembly for alternating mistuning (i is the attack angle)

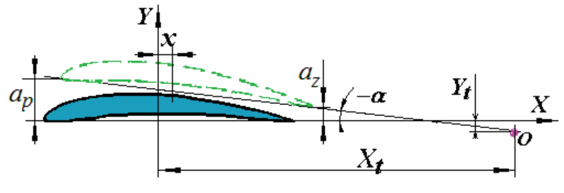

Fig. 2: Schematic motion of the blade tip section for the first vibration mode of the blade

Mathematical model

To calculate the flutter stability for the alternating distribution of mistuning, the following computational model of the blade assembly was adopted:

- there is no mechanical coupling between the blades;
- the inertial and elastic forces of the blade far exceed the aerodynamic forces;

- each blade has one degree of freedom, while the blade assembly consisting of 2N blades has 2N degrees of freedom and comprises N identical packets consisting of two blades that differ from one another in the elastic inertial and dissipative properties, etc.

We denote these blades by "*f*" and "*s*", their mechanical logarithmic decrements by δ_{fm} and δ_{sm}, the natural frequencies by Ω_f and Ω_s, and the detuning of the natural frequencies by $\gamma = \Omega_f / \Omega_s$.

The displacements of the cross-sections of the blades "f" and "s" in the first vibration mode will be considered as the angular displacements relative to the axes located at the distance X_{ft} and X_{st} from the center of the profile, as shown in Fig 2.

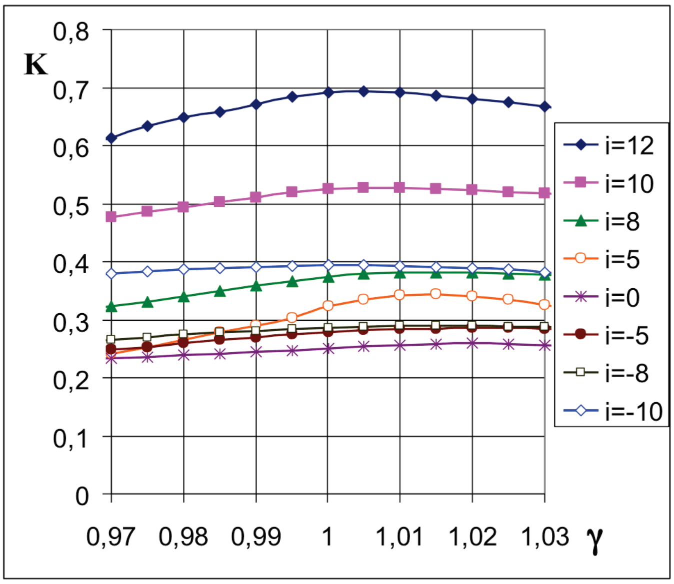

Fig. 3: Subsonic flutter stability boundaries for the first mode of vibration of the blade assembly

The aerodynamic force and moment influence coefficients $m_{n\alpha}, m_{ny}, l_{n\alpha}, l_{ny}$ obtained in the experiment make it possible to define the unsteady aerodynamic moments on the oscillating blades for an arbitrary value of X_t.

Substituting the unsteady aerodynamic moments into the equations of blade vibration, we find the eigenvalues. Next, we determine the flutter boundary of the mistuned blade assembly (the critical reduced vibration frequencies K_{cr} at which its stability is neutral). In-flow vibration of the blade assembly will be stable if its reduced frequency is higher than the critical one ($K > K_{cr}$).

Results

The stability boundaries of the first vibration mode of the blade assembly against subsonic flutter depending on the frequency detuning γ for different values for the position of the rotation axis of adjacent blade sections ($\overline{X}_{ft} = 1{,}79$; $\overline{X}_{st} = 2{,}29$) and different values of their mechanical logarithmic decrement ($\delta_{fm} = 0{,}003$; $\delta_{sm} = 0{,}03$) are illustrated in Fig. 3 for different angles of attack i. It is seen that the stability boundaries shown are non-symmetrical relative to $\gamma = 1$.

It can be concluded that with a simultaneous introduction of the alternating distribution of the natural frequencies, the position of the rotation axis of the blade tip sections and the mechanical logarithmic decrement, the effect of the joint variation in these parameters depending on their combination can be enhanced or diminished. For example, the blade assembly, whose blades with higher natural frequencies have a more distant position of the rotation axis of the sections and a higher mechanical damping, is more stable against subsonic flutter. That is, a blade assembly is more stable if $\Omega_f < \Omega_s$, $\overline{X}_{ft} < \overline{X}_{st}$, $\delta_{fm} < \delta_{sm}$.

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