Suppression of blade vibrations using a nonlinear absorption concept

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Long Abstract

Introduction

Blade vibrations lead to high cycle fatigue and pose a severe threat to the structural mechanical integrity of turbomachines. Several advanced means of vibration mitigation, such as active vibration control techniques involving piezo-electric material or dissipative coatings are of limited use here, due to the hostile conditions of high temperatures and centrifugal loading. The by far most established damping technology is still the passive dissipation provided by friction joints. Friction damping, however, has the inherent drawback of causing wear, and it can typically be designed to suppress only a single resonance.
Furthermore, impact dampers have been known for a long time as a possible alternative to friction dampers. An impact damper is a loose, comparatively lightweight mass inserted into a cavity of a vibrating structure. Under dynamical loading, the mass undergoes impacts with the cavity walls. Impact dampers were so far not successful in the area of blade vibration mitigation [1]. One reason might be that they were largely designed for maximum dissipation by using moderate damper weights and exploiting the inelastic character of the impacts, which is inherently associated with material damage and strictly limits the life span of damper or blade. Recently, this technology has regained attention [2], when it was shown that another working principle besides dissipation through inelastic impacts exists, termed "Impulse-Mistuning" [2]. Here, a considerable vibration mitigation effect can be achieved by perfectly elastic impacts and with much smaller masses, which is very promising in view of technical feasibility.
The purpose of the present work is to gain deeper insight into the nonlinear dynamics and provide a further perspective onto the working principle of the vibration suppression concept, by comparing it to the well-known concept of Nonlinear Energy Sinks (NES) [3,4]. Moreover, the effectiveness of this concept is compared with friction dampers and tuned mass dampers.

1. Model and simulation methods

A lumped-mass model of a turbine blade is considered. It consists of a four degree-of-freedom (DOF) blade model with an additional mass (termed NES) coupled to the main structure in an essentially nonlinear way as illustrated in Fig. 1 (left). Impacts between NES and the left and right cavity walls are modeled as perfectly elastic with a unilateral spring of finite stiffness, but comparisons with non-regularized contact laws are also shown. Owing to centrifugal forces in the rotating system, the NES is pressed against the top cavity wall and dry friction is accounted for with an elastic Coulomb model. The vibration response to a harmonic excitation force acting on the blade is analyzed using both time and frequency domain methods.

2. Results

The effectiveness of the vibration suppression concept is investigated for excitation frequencies in the vicinity of the first four blade modes. The maximum blade vibration response is defined as the highest magnitude of the displacement of DOF 4 reached during slow up and down sine sweep excitation. Thus, a single response level is determined for each excitation level. As reference, a friction damper is considered by simply setting the gap to a sufficiently large value so that no impacts occur. For the tuned mass damper, the 'NES' is attached only by a linear spring-damper element to the cavity, where the spring-damper element is designed according to den-Hartog's rule applied to the first vibration mode [5]. The same NES mass of 1% of the blade mass is used for all configurations.

It is found that the novel concept outperforms the friction damper for all modes, see Fig. 1 (right). As expected, the tuned-mass-damper shows optimum performance for the first mode. Its effect on the other modes, however, is negligible, which is a crucial drawback when considering application in turbomachines.

Additional insight into the rich dynamics of the essentially nonlinear system is gained. Particularly, it is demonstrated that a multitude of coexisting stable and unstable vibration states exists near resonance, including chaotic behavior, strongly modulated responses (SMR) and periodic responses on branches detached from the main frequency response branch.

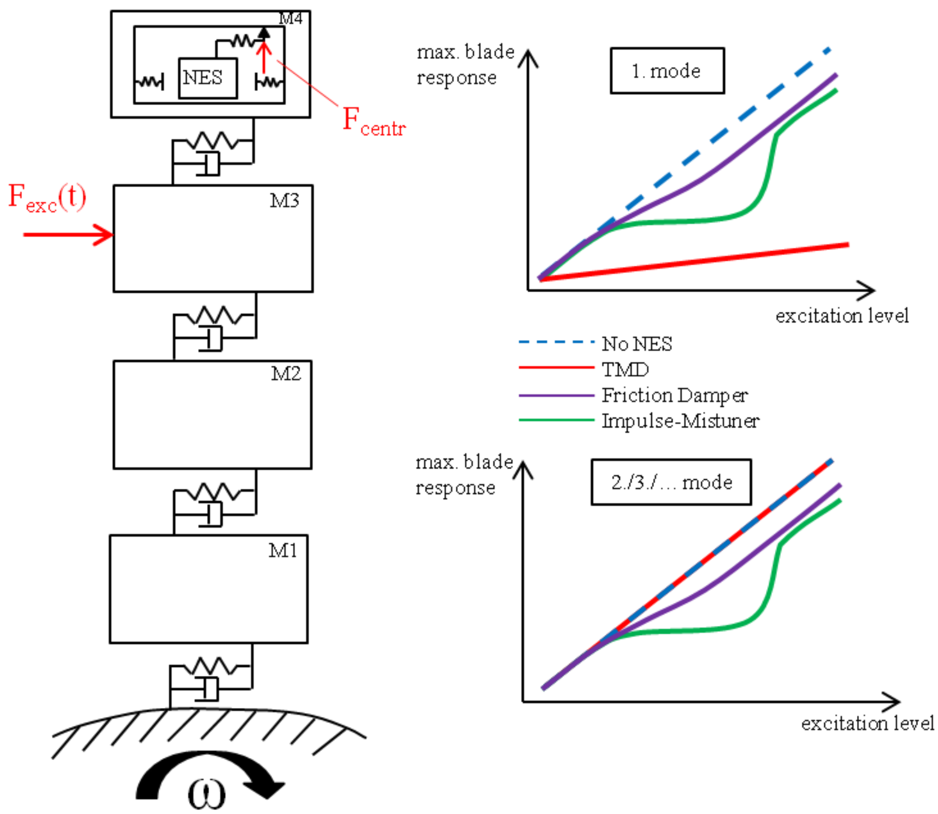

Figure 1: Model (left) and absorber effectiveness for various modes compared to tuned mass damper and friction damper (right)

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