Internal resonances of a rotating pre-deformed blade under a harmonic gas pressure

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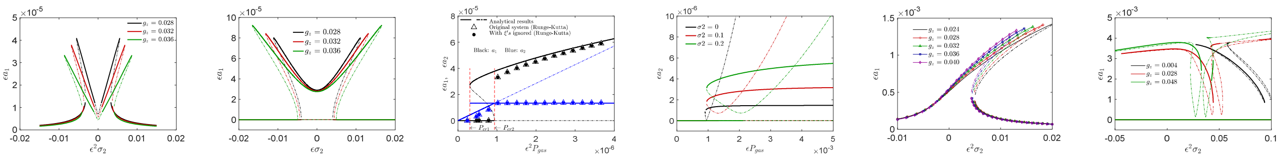
Abstract. The similarities and differences are analyzed for two types of internal resonance responses of a rotating pre-deformed blade under a harmonic gas pressure. The possibilities of different resonances (such as primary resonances, sub-harmonic resonances, super-harmonic resonances and even combination resonances) are determined via the method of multiple scales. The response curves and the stability ranges are compared for different types of resonances, respectively. A set of interesting findings are concluded in this study. The quadratic nonlinear terms introduced by the pre-deformation field due to the thermal gradient, not only introduce the rich phenomena through 2:1 internal resonance but also have dramatic effects on the dynamic response in the case of 3:1 internal resonance. The double jumping's and saturation phenomena can be only found in the 2:1 internal resonances. For some of the resonance cases, the frequency response curves or stable regions are quite similar with each other.

Introduction

The rotating blade plays an important role in the turbomachine. The investigations on the dynamic behaviours of a rotating beam can be traced back to 1940s [1]. Turbine blades are designed to operate diverging from the natural frequencies. Despite all that, the vibration failure of the blade still occupies a considerable proportion of the total failure of the turbine. Hence, it is of great importance to investigate further resonance mechanisms of the rotating blade, especially those introduced by nonlinearities. The turbine blades often serve under a huge thermal gradient which can deform the central axis of the blades. For the given nonlinear rotating blade dynamic models, a series of interesting phenomena arise when some of the natural frequencies are commensurable, namely, the existence of an internal resonance. In 2012, Lacarbonara et. al. [2] calculated the rotating speeds at which potential 1:1, 2:1, 3:2 and 3:1 internal resonances may occur for a rotating blade. After that, more and more researchers reported the different types of resonances based on various nonlinear models of rotating blade. However, the systematic comparisons and discussions on different internal resonances of rotating blade are rare in the literature. This is the motivation here.

Results and discussion

From the comparison among blade dynamic responses, following conclusion can be drawn. The multi-valued phenomenon exists in all resonance cases. For all the 2:1 internal resonances, the blade response experiences double jumping under excitation sweeps. This phenomenon indicates that the system experiences an evolution from softening to hardening behaviour near the 2:1 internal resonance. The frequency responses of 3:1 internal resonance bend to the right (primary resonance of 1st mode), similar to the case without internal resonance [3]. For some resonance cases, the frequency response curves are quite similar to each other, for example, 2:1 internal resonance in primary resonance of 1st mode and super-harmonic resonance of 1st mode. The saturation phenomenon [4] or quasi-saturation phenomenon (2:1 internal resonance combination resonances) are found in the 2:1 internal resonance. The stable regions in excitation parameters plane of 2:1 internal resonance super-harmonic resonance of 2nd mode are similar to those of primary resonance of 2nd mode. The stable regions of 3:1 internal resonances are different. Parameters effect differently on frequency response curves of different types of resonance. The 2:1 internal resonances depend only on the quadratic nonlinearities, while the 3:1 internal resonances depend on both the cubic and the quadratic nonlinearities [5].



(a) (b) (c) (d) (e) (f)

Figure 1: The blade response curves for different resonance types: (a) 2:1 internal resonance and primary resonance of 1st mode, (b)(c)2:1 internal resonance and primary resonance of 2nd mode, (d) combination resonance of summed type, (e)3:1 internal resonance and primary resonance of 1st mode, (f)3:1 internal resonance and primary resonance of 2nd mode.

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