Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **12**, No. 6, pp. 1542-1564

DOI: 10.4208/aamm.OA-2019-0180
December 2020

Transient Response of High Dimensional Nonlinear Dynamic System for a Rotating Cantilever Twisted Plate

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Received 17 June 2019; Accepted (in revised version) 20 April 2020

Abstract. Dynamic transient responses of rotating twisted plate under the air-blast loading and step loading respectively considering the geometric nonlinear relationships are investigated using classical shallow shell theory. By applying energy principle, a novel high dimensional nonlinear dynamic system of the rotating cantilever twisted plate is derived for the first time. The use of variable mode functions by polynomial functions according to the twist angles and geometric of the plate makes it more accurate to describe the dynamic system than that using the classic cantilever beam functions and the free-free beam functions. The comparison researches are carried out between the present results and other literatures to validate present model, formulation and computer process. Equations of motion describing the transient high dimensional nonlinear dynamic response are reduced to a four degree of freedom dynamic system which expressed by out-plane displacement. The effects of twisted angle, stagger angle, rotation speed, load intensity and viscous damping on nonlinear dynamic transient responses of the twisted plate have been investigated. It's important to note that although the homogeneous and isotropic material is applied here, it might be helpful for laminated composite, functionally graded material as long as the equivalent material parameters are obtained.

AMS subject classifications: 34A34

Key words: Cantilever twisted plate, rotating, blast loading, transient response, high dimensional nonlinear dynamics.

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1 Introduction

Rotating cantilever structures, such as blades, are the key components in aero engine, turbomachine and so on. The studies of nonlinear dynamic properties of them becomes more importance because they are always subjected to various external excitation in harsh service environments which may cause severe vibration of them inevitably and even result in the complex dynamics of overall unit. One of the threats to rotating cantilever structure is blast loads because blast loads not only may make a reduction in performance and failure of the blades [1, 2] but are the major safety hazard for them. In the past decade, the dynamics of the rotating cantilever structures were studied by several researchers. And in these studies rotating cantilever beams, rectangular plates, twisted plates or shallow shells were usually used.

Rosen [3] reviewed the dynamics of the pre-twisted beams and rods especially the dynamic models and solution methods. Vyas and Rao [4] derived the governing equations of motion of rotating disk-blade system and free vibrations were analyzed. Here the Coriolis forces, rotary inertia were taken into account. Lin [5] derived the governing differential equations of rotating non-uniform beam by energy principle but the Coriolis forces were not considered. To research the free vibration of pre-twisted blades, Yoo [6] applied the beam theory to obtain the motion of equations of pre-twisted blades and discussed the problem of loci veering and mode shapes variation. Chandiramani [7] researched the vibration of the anisotropic composite box-beam structure which was a simplified pre-twisted blade based on the extended Galerkin procedure. Librescu [8] studied the free vibration of functionally graded material per-twisted blades. The per-twisted blades were modeled as functionally graded material pre-twisted beams and the beams were made of metal and ceramic. Carrera et al. [9] applied finite element method and the Carrera unified formulation to rotating blades and free vibrations were analyzed. Yao [10] treated the blade as a cantilever twisted beam with pre-index angle and nonlinear dynamics of the twisted beam were studied. The chaotic dynamics were detected by numerical simulation. By using modelling method which employed hybrid deformation variables, Yoo [11] made modal analysis of the rotational pre-twisted blades by modelling method. Chortis [12] investigated the modal frequencies and damping of the beams and blades which were affected by stiffness and damping. Yang [13] established a shaft-disk-blades model and the blades were simplified as beams. On the basis of Rayleigh-Ritz technique, Chen [14] computed the free vibration of the blisk with NiCrAlY coating on the blades and the system damping were also computed. Sina [15] used geometrical nonlinearities and Hamilton's principle to analyzed the vibration of composite box beams. Chen [16] employed the variational iteration to calculate the natural frequency of the rotational tapered Timoshenko beams. In above studies, the dynamics of various simple beam structures were studied.

It is reasonable for the spindling structures but if the length-width ratio of the rotating cantilever structures is small the plate or shallow shell theories will be more appropriate and the in-plane inertia should be included. Sinha [17] pointed out that Dokainish and