Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 144 (2016) 713 – 720

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Saturation control for a rotating thin-walled composite beam structure

Jerzy Warminski[a,*], Jaroslaw Latalski[a]

[a] *Department of Applied Mechanics, Mechanical Engineering Faculty, Lublin University of Technology,*
Nadbystrzycka 36, 20-618 Lublin, Poland

Abstract

A nonlinear saturation control method applied for reduction of oscillations of a rotating composite beam is presented in this paper. The flexible blade is treated as a thin-walled structure attached to a rigid hub driven by an external periodic torque. The beam model, derived in [1,2], takes into account a strong coupling between the flexural and torsional deformations due to the assumed specific reinforcing fibers perimeter orientation. The proposed saturation control method is used for the reduction of coupled torsional-flexural beam oscillations around the third natural frequency of the system. It is shown that for assumed structural parameters it is possible to find gains of the controller which may essentially reduce vibrations of the beam near the resonance zone.

Keywords: Nonlinear vibrations; bifurcations; rotating composite beam; nonlinear control

---

1. Introduction

Rotating structures play important role in aerospace, robotic or mechanical engineering. Due to a rapid development of composite materials technology the rotating elements of modern machines, for example wind turbines and helicopter blades, are manufactured as thin-walled elements [3–5]. By incorporating a proper engineering design approach we can manufacture an open or closed cross-section blades made of anisotropic materials exhibiting the assumed apriori mechanical properties [6].

Further enhancement of structural performance may be achieved by the concept of the so called smart structure. This idea requires integration of sensory capabilities and actuation authority within the host structure combined with an appropriate control strategy. This can be done by embedding active elements in the system, e.g. Macro Fiber Composite actuators [7,8], to react as required for varying operating conditions. More often than not the aim of the control strategy is vibration suppression. This effect can be achieved by a nonlinear coupling and a proper tuning of the controller with the main structure (the plant) [9–11]. The comparison of various nonlinear control methods with classical P, PID or PPF algorithms is presented in [12,13].

---

[*] Corresponding author. Tel.: +48-81-5384197; fax: +48-81-5384205.
E-mail address: j.warminski@pollub.pl

doi:10.1016/j.proeng.2016.05.073

In this paper we study dynamics of a flexible blade which is considered as a thin-walled closed cross-section box beam made of a multilayer composite material. The beam is attached to a rigid rotating hub (Fig. 1). The mathematical model of the structure assumes a specific fibres perimeter orientation which leads to a strong coupling of flexural (lead-lag plane bending) and torsional modes.

2. Mathematical model and governing equations

The model of the rotating structure is derived by means of the thin-walled composite beam theory developed by Librescu and Song [4]. The equations describing the dynamics of the combined hub-beam structure are formulated on the basis of the paper [1] and the following paper [2] where some additional terms necessary to properly represent the centrifugal force have been included.

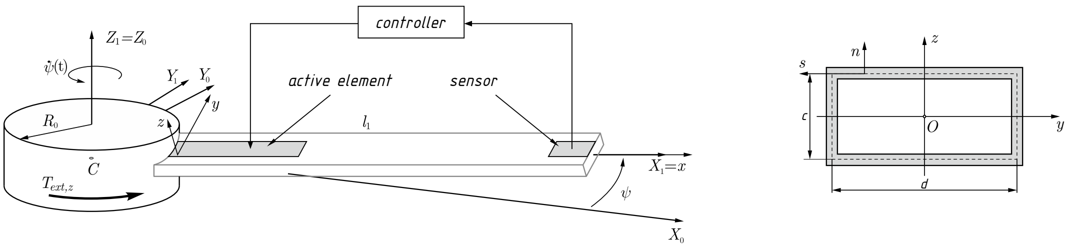

Fig. 1. Model of the rotating thin-walled beam structure.

The performed parametric analysis of the reinforcing fibres orientation and the observed deformation modes coupling shows that the strongest flexural-torsional vibration coupling takes place for circumferentially asymmetric stiffness (CAS) lamination scheme and fibres orientation angle $\alpha = 75$ deg. (measured from perimeter direction s) [2]. Considering a specific preset angle of the beam $\theta = \pi/2$, the general equations of motion [1,2] are simplified and the beam exhibits only flapwise bending-shear-twisting coupling. Then the motion of the system is expressed in terms of variables of the beam cross-section centre point (subscript 0) and current hub position $\psi(t)$ given in inertial reference frame $X_0\ Y_0\ Z_0$ (Fig. 1). Therefore, the dynamics of the rotating hub-beam structure is governed by a set of four mutually coupled partial differential equations (PDEs) and associated boundary conditions (BCs):

- beam lead-lag displacement w_0

$$b_1\ddot{w}_0 - 2b_1\dot{u}_0\dot{\psi}(t) - b_1 w_0\dot{\psi}^2(t) - b_1(R_0 + x)\ddot{\psi}(t) - a_{55}\vartheta_y' - a_{55}w_0' - (T_x w_0')' = 0 \tag{1}$$

with boundary conditions

$$w_0|_{x=0} = 0, \quad \left(\vartheta_y' + w_0'\right)\Big|_{x=l} = 0$$

- beam transverse shear angle ϑ_y

$$B_4\ddot{\vartheta}_y - B_4\dot{\psi}^2(t)\vartheta_y + B_4\ddot{\psi}(t) + a_{55}(\vartheta_y + w_0') - a_{33}\vartheta_y'' - a_{37}\varphi'' = 0 \tag{2}$$

with boundary conditions

$$\vartheta_y\Big|_{x=0} = 0, \quad \left(a_{33}\vartheta_y' + a_{37}\varphi'\right)\Big|_{x=l} = 0$$