Modal analysis of a rotating pre-twisted beam axially loaded by an internally guided tendon

Jun Wu*, Branislav Titurus

Department of Aerospace Engineering, University of Bristol, Bristol, BS8 1TH, UK

A R T I C L E   I N F O

Article history:
Received 13 November 2020
Revised 10 January 2021
Accepted 23 January 2021
Available online 28 January 2021

Keywords:
Beam-tendon system
Rotating pre-twisted beam
Modal analysis
Frequency loci veering

A B S T R A C T

A guided tendon concept in the context of rotating helicopter blades is proposed to modify their dynamic characteristics, so that the rotorcraft can operate under a wide range of working conditions. In this paper, a rotating pre-twisted beam with bending-bending-torsion coupling axially loaded by a tendon is used to model the proposed system. An internally guided tendon is attached to the beam at several spanwise locations to avoid the resonant vibrations due to insufficient separation between the rotor harmonics and natural frequencies of the beam. A set of orthogonal polynomials that satisfy the geometric boundary conditions is used to represent the deflections of the beam and tendon. The equations of motion are derived by means of the Lagrange’s equation of the second kind combined with the appropriate energy expressions. In vacuo modal analysis is then carried out after the modal properties of the rotating pre-twisted beam without the tendon are validated against the reference. The effect of the attachments and rotation on the free vibration of the beam-tendon system is studied. It is found that the attachments and rotation can improve the structural stability of the system significantly, so as to allow a significantly larger axial force to be applied. The natural frequencies of all studied modes increase with rotation due to the centrifugal stiffening effect. The tendon-guiding attachments cause an increase in the natural frequencies of the tendon-dominated modes because of their reduced effective length but decrease the frequency reduction rate of the beam-dominated modes with the applied axial force. The beam part of the mode shapes of the beam-dominated modes is not significantly sensitive to the varying axial force, rotor speed or number of attachments expect when the studied modes enter the modal veering regions with other neighbouring modes.

© 2021 Elsevier Ltd. All rights reserved.

1. Introduction

Novel and reconfigurable helicopter rotor configurations can achieve significant performance advantages, e.g., reduced noise emissions and improved fuel efficiency. However, there are some inevitable drawbacks associated with these increasingly complex systems. One of the main drawbacks is the resonant vibration can arise when changing the configuration due to the insufficient separation between the rotor harmonics and the natural frequencies of the blade.

The problems of excessive loads and other dynamic responses have been extensively studied and addressed in the contemporary fixed rotor configurations such as aeroelastically tailored composite blades developed under the BERP IV project.

* Corresponding author.
E-mail addresses: junwu.wu@bristol.ac.uk (J. Wu), brano.titurus@bristol.ac.uk (B. Titurus).

https://doi.org/10.1016/j.jsv.2021.115980
0022-460X/© 2021 Elsevier Ltd. All rights reserved.