Theoretical and experimental modal analysis of a beam–tendon system

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ABSTRACT

Theoretical and experimental modal analysis of the system consisting of the Euler–Bernoulli beam axially loaded by a tendon is studied in the paper. The beam–tendon system is modelled using a set of partial differential equations derived by Hamilton's principle and the coupling between the beam and the tendon is ensured by the boundary conditions. Theoretical modal analysis is conducted using a boundary value problem solver and the results are thoroughly experimentally validated using a bench-top experiment. In particular, the effect of the tendon tension on the modal properties of the system is studied. It is found that by increasing the tension, the natural frequencies of the beam decrease while the natural frequencies of the tendon increase. It is also shown that these two sets of modes interact with each other through frequency loci veering. The effect of the tendon mass is also experimentally and numerically studied and it is shown that lighter tendon produces fewer vibration modes in the studied frequency region. Two further numerical studies are conducted to demonstrate the effect of the tendon on the torsional modes of the beam, and to study the structural stability. Overall, an excellent agreement between the numerical and experimental results is obtained, giving the confidence in the derived theoretical model.

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1. Introduction

Free vibration of beams and tendons (cables, strings) have been extensively studied, because they are two essential structural elements that are frequently used in many engineering applications. There is an overwhelming number of studies that focus on different aspects of beam and string modelling, application and testing. Many review papers and monographs have been written on the topic [1–4]. Often, the beam models are augmented to suit a particular application. For instance, beam models with pretension and under an action of a moving mass [5] are used as models of rail road tracks, bridges or machining processes, while the rotating composite beams are of interest in aerospace engineering where they represent rotorcraft blades [6]. A number of studies also investigated vibration of axially loaded beams [7] and their stability [8,9]. Tendons have also been used in a number of applications, often as actuators or a means of vibration control. A comprehensive review of active tendon control can be found in [10,11]. The beams and tendons are almost always used and modelled separately. In contrast, a coupled system that consists of a cantilever beam of a box cross-section that is axially loaded by a tendon that passes through the body of the beam is studied in this paper.

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