

Article

An Analytic Solution for the Dynamic Behavior of a Cantilever Beam with a Time-Dependent Spring-like Actuator

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Abstract: The purpose of this study is to derive an analytical solution for a cantilever beam with a novel spring-like actuator that behaves like a time-dependent spring and to study the dynamic behavior of the system. A time-dependent spring was set at the free end of the cantilever beam to model the novel spring-like actuator. First, the boundary conditions were transformed from being nonhomogeneous to being homogeneous using the shifting function method. The solution of the analytic series was then obtained by using the expansion theorem method. The correctness of the proposed analytical solution was verified by comparing the results with those obtained via the separation of variables in the special extreme case of a constant spring coefficient. We took the free end of a cantilever beam with harmonic spring stiffness and an external periodic unit load as an example. The influence of the actuator parameters, such as the effect of the magnitude and the frequency of the time-dependent spring stiffness on the resonance frequency, was investigated. An important new result was found, i.e., that the resonance frequency is clearly dependent on the magnitude and the frequency of the spring-like actuator in the first two modes, but not in the third and fourth modes. In practical engineering applications, system resonance can be avoided by adjusting the magnitude and frequency of the actuator.

Keywords: spring-like actuator; time-dependent spring; beam vibration; shifting function method; analytical solution

MSC: 35A25; 37N15; 70G60; 74H10; 74H45; 74K10



Citation: Chang, J.-R.; Tu, T.-W.; Huang, C.-J. An Analytic Solution for the Dynamic Behavior of a Cantilever Beam with a Time-Dependent Spring-like Actuator. *Axioms* **2023**, *12*, 500. <https://doi.org/10.3390/axioms12050500>

Academic Editors: Juan Francisco Solís, Zacharias A. Anastassi and Hans-J. Haubold

Received: 17 February 2023

Revised: 4 May 2023

Accepted: 16 May 2023

Published: 19 May 2023



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1. Introduction

With the rapid development of mechatronics, typical examples such as micro-actuators, micro-generators, micro-switches, and micro-beams have been used to manufacture the various structures and models of cantilever beams [1–6]. Meanwhile, smart materials have been developed in recent decades and these can be used to manufacture controller components [7–13]. With the development trend of mechatronics and smart materials, it is assumed that in the future researchers will be able to design and fabricate a new type of spring-like actuator (Figure 1), which can work like a time-dependent spring with a fast dynamic response (Figure 2). Therefore, a novel cantilever beam with a free end supported by a time-dependent spring is proposed. Several books [14,15] have presented and derived the governing equations of motion for beams with different boundary conditions; however, no analytical solutions have been presented for a cantilever beam with a time-dependent spring-like actuator. In this study, an analytical solution of the undamped forced vibration of a beam system with a time-dependent spring was achieved and its dynamic behavior and parameters were investigated in detail.

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