Coupled vibration and parameter sensitivity analysis of rocking-mass vibrating gyroscopes

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Abstract

Vibrating beam gyroscopes are widely used to measure the angle or the rate of rotation of many mechanical systems. The vibration and parameters sensitivity analyses of a specific type of vibrating beam gyroscope namely rocking-mass gyroscopes are presented in this paper. These types of gyroscopes by far have a better performance than the conventional single-beam gyroscopes. The system comprises of four slender beams attached to a rigid substrate, undergoing coupled flexural and torsional vibrations with a finite mass attached in the middle. Two of the beams carry piezoelectric patch actuators on top, while the other two possess piezoelectric patch sensors. Using extended Hamilton’s principle, the resulting eight coupled partial differential equations of motion with their corresponding boundary conditions are derived. In spite of the need for a high computational power, the system is analysed in the frequency domain using an exact method and the closed-form characteristic equations for two cases of fixed and rotating base support are obtained. Furthermore, a detailed parameter sensitivity analysis is carried out to determine the effects of different parameters on the complex natural frequencies of the system. Results presented are valuable in the design of this type of gyroscope as the exact resonant conditions and the sensitivity of the system parameters play important roles in the dynamic performance of gyroscopes.

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1. Introduction

Due to the wide range of the applications of the vibrating mass gyroscopes; they are being used in many navigational applications, namely, aerospace, marine and automobile industries. Hence, the detailed study of such systems has always been of great interest to engineers and researchers.

In most of these types of gyroscopes, the bending and torsional vibrations are coupled. The theory of coupled flexural–torsional vibrations for thin–walled beams was first developed by Timoshenko and Young [1]. The free flexural/torsional vibration of an Euler–Bernoulli beam with a rigid tip mass was studied by Oguama [2]. He presented explicit expressions for the frequency equation, mode shapes and their orthogonality relationship and investigated the effects of different parameters on the fundamental frequencies of the system. Salarieh and Gorashi [3] continued his work, but used the Timoshenko beam theory. They studied the effects of the shear deformation and the rotary inertia on the free vibration response of a Timoshenko beam with a rigid tip mass. Gokdag and Kopmaz [4] extended the work of

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The present research undertakes the vibration analysis of a rocking-mass gyroscope, which comprises of a rotating rigid substrate and an assembly of four cantilever beams with a rigid mass attached to them in the middle, as shown in Fig. 1. The objective of the research is to develop a detailed mathematical modeling of the system. The governing equations of motion, using the extended Hamilton's principle, are derived. Since the closed-form solutions can serve as the benchmarks for validating the results obtained from either the numerical calculations or experimental results, the closed-form equations are developed for the frequency characteristic equations of the system for either a fixed supporting base or a rotating one. These exact equations are very important and useful, since their solutions would not only provide exact
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