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Design and dynamic analysis of micro-vibration isolator for Single Gimbal Control Moment Gyro

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Abstract

Control moment gyros (CMGs) are widely used for attitude control in spacecraft. However, micro-vibrations generated from these high speed spinning actuators has a significant impact on high-sensitivity space mission. Based on the energy dissipation mechanism of viscoelastic material, this research puts forward a passive isolator for Single Gimbal CMG (SGCMG). Dynamic model of this proposed isolator is developed and analyzed, and then isolation performance is improved through parameters optimization. Numerical simulations indicate that disturbances with frequency above 40Hz can be isolated in all six degrees of freedom. In addition, the resonant peak in transmissibility has been greatly suppressed due to the structural damping that provided by viscoelastic material.

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1. Introduction

Micro-vibration (or jitter) on spacecraft is a special kind of vibrations which has low amplitude and high frequency. It has no damage impact on the spacecraft structure, so it receives no concerns in the past. However, it brings about bad impacts on space missions such as Earth observing, laser communication between satellites through degrading the performance of sensitive devices [1]. Therefore, high-precision spacecrafts have very strict requirements for micro-vibration. With the development for higher performance, it is necessary and imperative to mitigate its disturbance effects.

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As the major actuators for attitude control in spacecraft, control moment gyros (CMGs) are generally thought of the prominent source of micro-vibration disturbance. When they provide moment for controlling the attitude of the spacecrafts, undesirable high frequency forces or moment appear during these operation. The micro-vibration disturbance of CMGs mainly resulted from their high speed spinning rotors. Among the approaches of attenuating disturbances of CMGs, mounting an isolator between vibration sources and the spacecraft bus is an effective and practical one in aerospace engineering [2]. It allows the low frequency attitude control torques to pass through to the spacecraft bus while filtering out the higher frequency disturbances. So far, substantial researches have been conducted on the micro-vibration isolation. Honeywell Company [3] manufactured a flywheel isolator for Hubble Space Telescope. The viscosity fluid flow through the orifice provided the damping. Springs were included to provide the desired isolator stiffness. Karl J. Pendergast et al. [4] proposed a passive isolation system for the Advanced X-Ray Astrophysics Facility. Six damping struts were configured in a Stewart platform arrangement, which is one of the most effective conformations for isolators. D. Kamesh et al. [5] designed a flexible platform consisting of four folded continuous beams arranged in three dimensions. Hyun-Ung Oh et al. [6,7] studied semi-active vibration isolators using liquid-crystal type electro-rheological (ER) fluid and shape memory alloy.

Based on the energy dissipation mechanism of viscoelastic material, this research puts forward a newly designed passive isolator for a typical Single Gimbal CMG (SGCMG) which has a constant spinning speed generally beyond 6000 rev/min. Dynamic model of this proposed isolator is developed and analyzed, and then isolation performance is improved through structure optimization.

2. Micro-vibration characteristics of SGCMG

A simplified SGCMG to be isolated in our work is depicted with a global Cartesian coordinate O - XYZ in Fig. 1. The SGCMG consists of two major parts: high-speed spinning rotor and outer gimbal. The origin of coordinate is defined at the centre of upper surface of the outer gimbal and axes are defined accordingly. Let ω and Ω denoting the spinning speeds of rotor and outer gimbal respectively. The rotor spins at a constant high speed mostly beyond 6000rev/min (100Hz) while the outer gimbal rotates with a much lower speed ($\ll 1$ rev/sec) according to the command of attitude control.

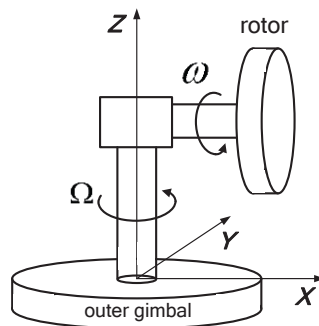


Fig. 1. Simplified configuration of the SGCMG

Many researches [8,9,10,11] have shown that disturbances of high-speed rotor mainly result from its residual static and dynamic unbalances. The unbalance disturbances are synchronous with the rotor and have the same frequency of its rotating frequency. The amplitude of unbalance disturbance is much smaller than the working moment provided by SGCMG during attitude control. Because of the movement of rotor and outer gimbal, disturbance force and moment exist along and around the X , Y , Z axis. Fig. 2 shows the attitude control moment of a SGCMG with micro-vibration disturbance (jitter) in X -axis.

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