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Optimal design and experimental analyses of a new micro-vibration control payload-platform

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ABSTRACT

This paper presents a new payload-platform, for precision devices, which possesses the capability of isolating the complex space micro-vibration in low frequency range below 5 Hz. The novel payload-platform equipped with smart material actuators is investigated and designed through optimization strategy based on the minimum energy loss rate, for the aim of achieving high drive efficiency and reducing the effect of the magnetic circuit nonlinearity. Then, the dynamic model of the driving element is established by using the Lagrange method and the performance of the designed payload-platform is further discussed through the combination of the controlled auto regressive moving average (CARMA) model with modified generalized prediction control (MGPC) algorithm. Finally, an experimental prototype is developed and tested. The experimental results demonstrate that the payload-platform has an impressive potential of micro-vibration isolation.

1. Introduction

For high sensitive precision devices, such as astronomical telescopes, interferometers and laser communication equipment's, there exists urgent demand of precise positioning. However, one of the major technical challenges is to isolate the onboard micro-vibrations which typically occur at frequency from less than 1 Hz up to 1 kHz and are generated by various disturbance sources, for example, the control moment gyroscopes, reaction wheel assemblies, cryocoolers, etc. [1–4].

When it comes to the space micro-vibration isolation, passive isolation schemes, which can provide efficient attenuation when an excitation frequency is greater than the intrinsic frequency, are always regarded as the primary choice in high frequency vibration isolation (above 30 Hz), without requiring external power. Particularly in recent years, some new passive isolation schemes based on nonlinear dynamics theory, for instance nonlinear damping and quasi-zero stiffness, have been developed which have broadened the frequency band of vibration isolation and exhibited a better isolation performance than traditional linear passive isolation schemes [5–8]. However, even though those passive vibration isolation schemes possess the characteristics of high reliability and no energy transmission, it is powerless in facing low frequency disturbances [3,9,10]. Thus, active vibration isolation schemes have continuously received extensive attention from researchers. Two typical isolation schemes, referred to as vibration isolation and suppression system (VISS) and satellite ultra-quiet isolation technology experiment (SUITE), have been developed and utilized in space vehicle [11,12]. They consist of six struts in a hexapod configuration and the vibration isolation performances are more than 20 dB at all frequencies over 5 Hz, respectively. A six-axes active platform was used to explore a new precision pointing strategy which wisely combined

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up to three-axes pointing functions to reject low-frequency disturbances with six-axes passive isolation to attenuate high-frequency disturbances [13]. Since the pointing function only required up to three degrees of freedom, the platform had a built-in redundancy in case of actuator failures. Also, Active Structures Laboratory developed an isolator with a standard Gough-Stewart platform architecture equipped with voice coil motors, for precision payloads [4]. By using decentralized control based on force feedback, the isolator can be effective in a frequency band between 5 and 400 Hz, with a maximum attenuation of 40 dB in the vicinity of 100 Hz. Subsequently, considering that using the soft actuators led to difficulties in stability of the systems under normal loads, a stiff Stewart platform with stiff piezoelectric actuators was designed and softened in active ways by utilizing a simple proportional plus integral compensator for the purpose of vibration isolation [14]. In Ref. [15], a low frequency vibration isolation platform (LFVIP) for a deep space optical communication transceiver was discussed and the resonant frequency reduced into sub-Hertz region, thereby maximizing the passive isolation effect. This improvement could simplify the acquisition, tracking, and pointing control system and reduce the complexity of the optical communication system. Another active-passive hybrid isolation platform for micro-vibration of satellites was proposed with the folded continuous beams combining with piezoelectric actuators [16]. The results showed that lower frequencies could be achieved by increasing the number of folds and by decreasing the thickness of the blade. In addition, by incorporating the piezoelectric actuators and sensors, and adopting the optimal control algorithm, the harmonic disturbance could be well suppressed by this isolation platform. Similarly, a low frequency flexible isolation platform aiming at micro-vibration isolation of the onboard reaction wheel assemblies and momentum wheel assemblies was studied and significant isolation performance was achieved by using velocity feedback control [17].

However, few investigations have focused on isolating the micro-vibration in low frequency range below 5 Hz, such as the thermal flutter which mainly interferes with the *Z*-axis translation, the rolling movement and the pitching movement, and is discussed through experiment and simulation methods in our previous investigation, induced by the solar arrays. In addition, little attention has been paid to the giant magnetostrictive actuators which can be used as the active component of the micro-vibration control payload-platform. Compared with the piezoelectric actuators, the advantages of the giant magnetostrictive actuators lie in that the giant magnetostrictive materials not only possess a larger deforming length and output power in a compact space, but also can offer a more stable output in face of the complex variational temperature. What's more, the magnetostrictive actuators can be driven in low voltage which may be particularly suitable for use in aeronautics and astronautics fields. Hence, this study, which proposes a new precision payload-platform driven by giant magnetostrictive actuators and discusses the feasibility of micro-vibration isolation in low frequency region below 5 Hz, can be usable as a basis for further research. Unlike former schemes, the advantages for this platform of combining giant magnetostrictive actuators with displacement amplifiers connected with flexible hinges is that, on the one hand, the stiff payload-platform can possess higher stability under a relatively high load and achieve a larger stroke no less than those platforms driven by voice coil motor; on the other hand, adopting four sets of driving elements in symmetrical arrangement offers a unique feature of decoupled control for rotations around *X*-axis and *Y*-axis, as explained in the following section. Moreover, we conduct the optimization design based on the minimum energy loss rate for the single driving element in order to achieve high drive efficiency and reduce the effect of the magnetic circuit nonlinearity. Furthermore, for purpose of simulating the micro-vibration isolation response of the whole system, the dynamic models are built according to the Lagrange method ignoring the influence of nonlinear factors, and the modified generalized prediction control (MGPC) algorithm combined with the controlled auto regressive moving average (CARMA) model is designed. Finally, based on the configuration and structural parameters which have been optimized in Sections 2 and 3, an experimental prototype is manufactured and tested. It should be noted that the test results reveal impressive potential of micro-vibration isolation, and meanwhile, show a certain capability of micro-positioning owing to adopting the displacement signal as feedback. Although there are some other experiments to be done, it is still gratifying for us to find that the proposed payload-platform shows the expected performance.

This paper is organized as follows: In Section 2, we present a detailed description of the proposed payload-platform. The optimum design based on minimum energy loss rate is carried out in Section 3. Then, the dynamic models are built and the

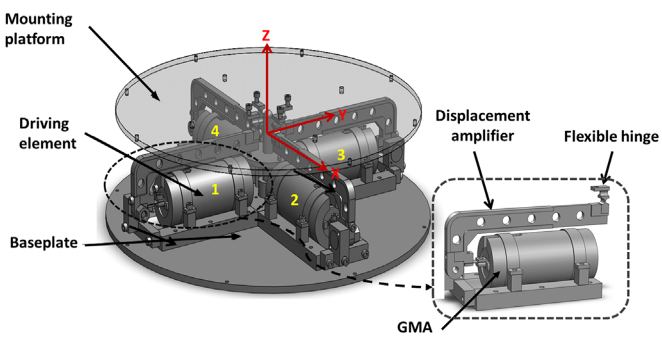

Fig. 1. Conceptual scheme of the payload-platform.