Passive Double-Layer Micro-vibration Control of Optical Spacecrafts

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Abstract. Aiming at the strict requirement of pointing stability and dynamic environment of optical spacecrafts with micro vibrations in reaction flying wheels or other attitude actuators, this paper presents a passive double-layer micro-vibration control concept. The proposed micro-vibration system comprises of two Stewart isolators. The first Stewart isolator is designed to suppress the micro vibrations of reaction flying wheels. To further improve the pointing stability, this paper designs another Stewart isolator to suppress the micro vibrations of spacecraft body. The proposed double-layer micro-vibration control system of a flexible optical spacecraft is analyzed using Patran/Nastran software. The simulation results demonstrate that the micro-vibration control system presents enhanced dynamic environment and pointing stability.

1 Introduction

The dynamic environment and pointing stability of optical payloads are increasingly strict[1]. The pointing accuracy and stability of space telescopes and inter-satellite are required to be in the order of μrad. The dynamic environment is also required in the order of μg. However, the reaction flying wheels of attitude control will deduce micro vibrations in the order of milli-g(mg). As a result, the imaging resolution of sensitive optical payloads will be degraded.

To enhance the dynamic environment and pointing stability of optical payloads, various vibration isolation approaches are proposed[2,3]. For example, the dynamic environment of the optical payload is less than 0.04μg, the pointing stability of JWST space craft is better than 0.02μrad.

In this paper, the double-layer micro-vibration control strategy is designed for optical spacecraft. The micro-vibrations of reaction flying wheels are first suppressed by the designed six-degree-of-freedom (DOF) Stewart isolator. The residual vibrations are further suppressed by the second Stewart isolator between the spacecraft body and the optical payload. The proposed double-layer micro-vibration control concept gives quiet dynamic environment and sufficient pointing stability.

2 Stewart Isolator Design

In order to isolate the vibrations of rotating attitude actuators in the optical spacecraft, vibration reduction mechanisms in six degrees of freedom (DOFs) are designed. Among these mechanisms, the Stewart platform isolator exhibits the most excellent performance [4, 5]. This paper thus designs Gough-Steward isolators with cubic configuration, which is got by shearing a cube using two planes，as shown in Fig.1. The proposed cubic Stewart isolator has two attractive features:

(1) The nearby legs are orthogonal to each other, which decouples the displacements in three directions of X, Y, Z. This special design further leads to an uniform performance of vibration isolation in six DOFs.

(2) It's easier to design and manufacture the cubic platform isolator because of the symmetrical structure as well as the identical legs.

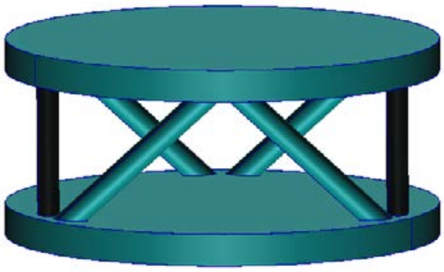

Fig.1 Gough-Stewart vibration isolation platform

3 Double-layer Micro-vibration Control Concept Design

The double-layer micro-vibration control strategy is illustrated in following Fig.2. The first Stewart platform isolator is placed between the flywheels and the spacecraft body. The flywheels are installed on the first Stewart platform isolator. The second Stewart is designed between the optical payload and the spacecraft body, and it is used to suppress the micro vibrations of the spacecraft body. The FEM model of the optical spacecraft is shown in Fig.3. The spacecraft mainly consists of spacecraft body, optical payload, solar panels, flywheels and the passive double-layer micro-vibration control system (contains two Stewart platform isolators).

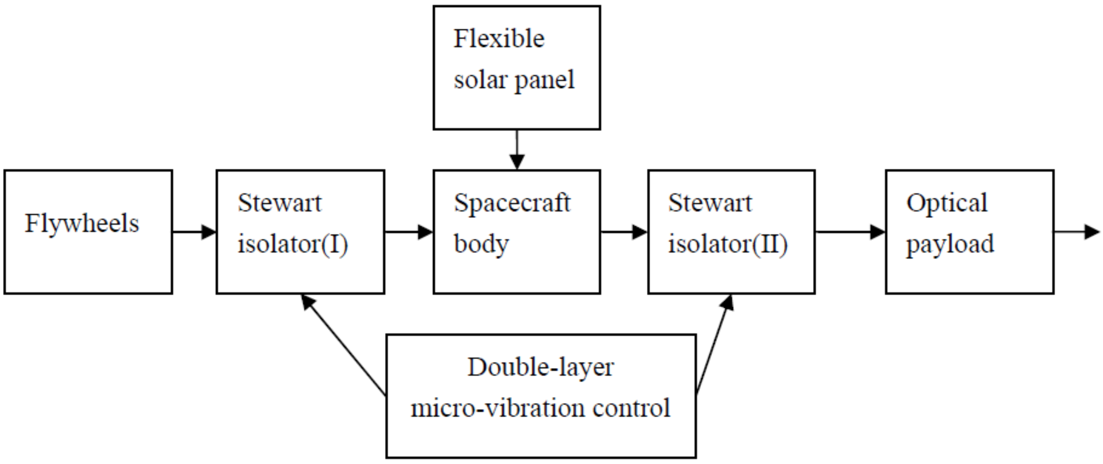

Fig.2 Double-layer micro-vibration control strategy

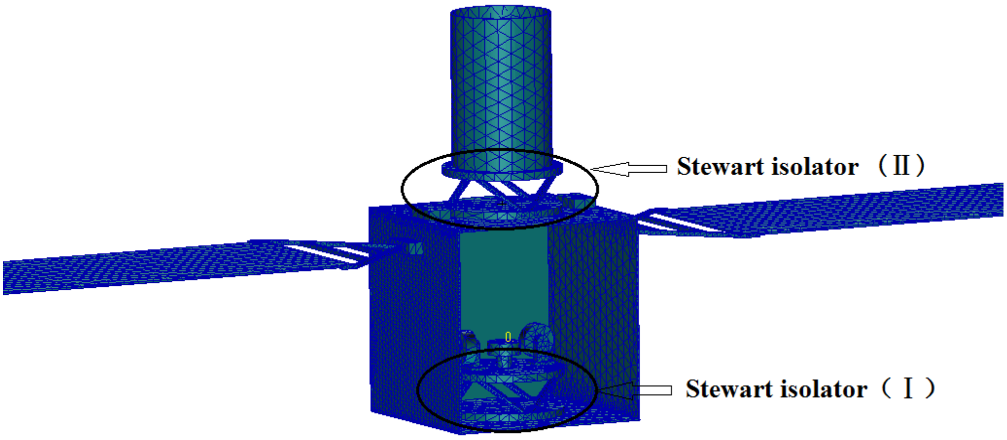

Fig.3 FEM model of optical spacecraft

In this paper, the masses of optical spacecraft body and optical payload are 2000 kg and 200kg respectively. The natural frequency of solar panels is set to 0.1Hz solved using Patran and Nastran software. The natural frequency of first Stewart platform installed with flywheels isolator is set to 0.5Hz. The natural frequency of the second Stewart platform installed with optical payload is set to 0.8Hz. The natural frequency of the spacecraft body (only the body structures without solar panels, optical payload and actuator module) is set to 40Hz. The micro vibrations of flywheels are set to the sinusoidal disturbing moments along three orthogonal axis with the same amplitude value of 0.5N·m and the same frequency value of 50Hz.

4 Dynamic Environment and Pointing Stability of the Optical Spacecraft

At first, the dynamic environment of the optical spacecraft is proposed. Fig.4 shows translational acceleration responses (two worse directions) with and without the double-layer micro-vibration control. It can be seen that the maximum acceleration without vibration isolation can be up to 1.5×10^{-3}m/s^2 (i.e., 0.15mg). The maximum acceleration with the proposed micro-vibration control is as small as 0.03×10^{-3}m/s^2 (i.e., 0.003mg, or 3μg). The dynamic environment has been enhanced. The proposed micro-vibration control strategy gives ultra-quiet dynamic environment.

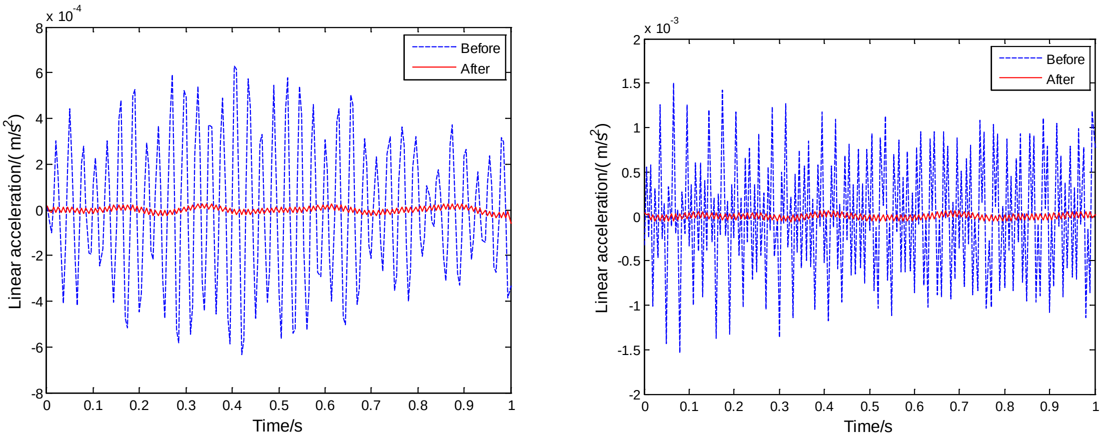

Fig.4 Dynamic environments in the two serious orthogonal directions

Then, the pointing stability of the optical spacecraft is simulated. Fig. 5 shows the pointing stability of the optical payload (the two serious directions) without vibration isolation. The maximum of the attitude rate (pointing stability) is as large as 6×10^{-5} (°/s). Moreover, the high frequency jitters of the optical payload are obvious.

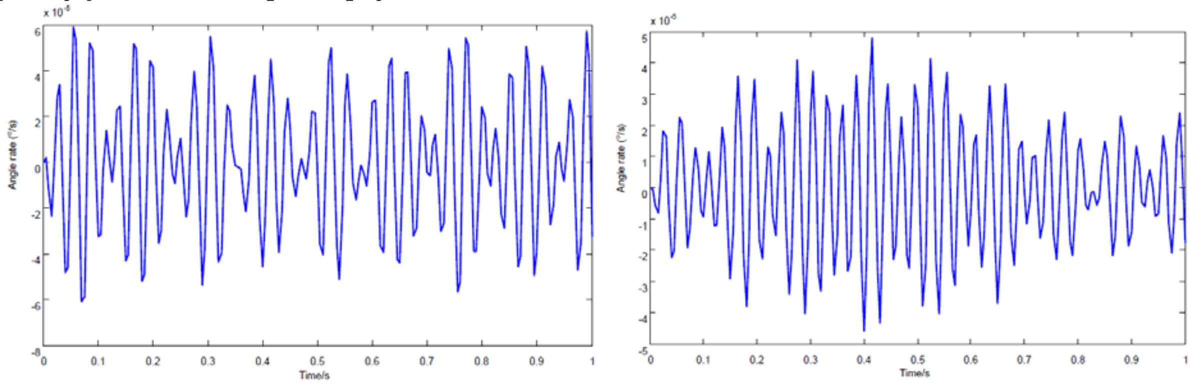

Fig. 5 Pointing stability (angle rates) of the optical payload without vibration isolation

Fig. 6 shows the pointing stability of the optical spacecraft with the proposed micro-vibration control strategy. The maximum attitude rate is as small as 1.5×10^{-5} (°/s). The pointing stability of the optical payload is enhanced by more than 75%. Furthermore, the high frequency jitters of optical payload are suppressed significantly. The residual low frequency jitters are deduced from the passive isolators and this could be overcome by active vibration isolation.

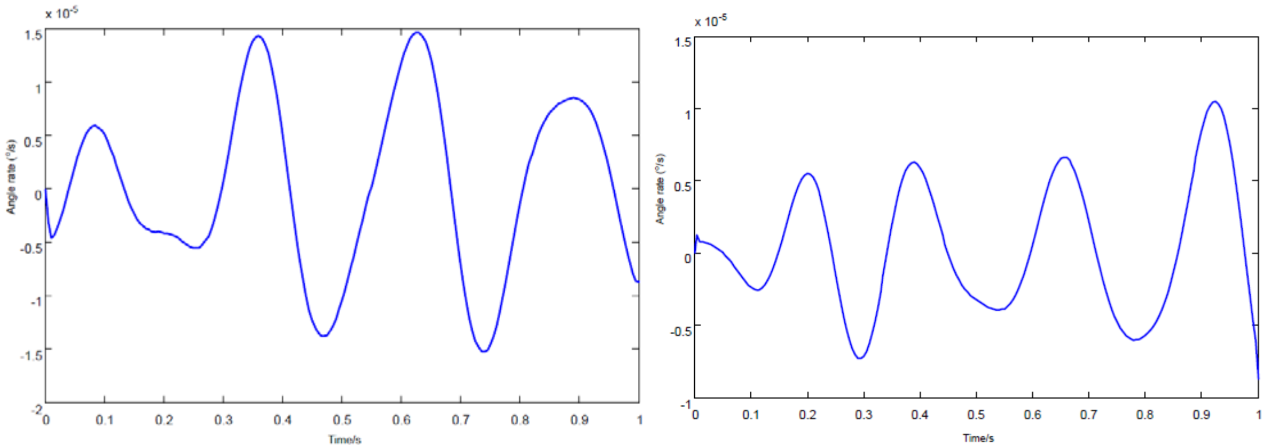

Fig.6 Pointing stability (angle rates) of the optical payload with the proposed micro-vibration control strategy.

5 Conclusion

This paper presents a passive double-layer micro-vibration control concept. The micro vibrations of optical payload are suppressed more than ninety percent compared with the flywheels module. The pointing stability of the optical payload is enhanced by more than 75%. The double-layer micro-vibration control presents quiet dynamic environment and sufficient pointing stability. The proposed micro-vibration control concept can provide a reference for vibration isolation design of optical spacecrafts.

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