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RESEARCH ARTICLE

Reducing the negative effects of flywheel disturbance on space camera image quality using the vibration isolation method

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Abstract Although the performance of space cameras has largely improved, the micro vibration from flywheel disturbances still significantly affects the image quality of these cameras. This study adopted a passive isolation method to reduce the negative effect of flywheel disturbance on image quality. A metal-rubber shock absorber was designed and installed in a real satellite. A finite element model of an entire satellite was constructed, and a transient analysis was conducted afterward. The change in the modulate transfer function was detected using ray tracing and optical transfer function formulas. Experiments based on real products were performed to validate the influence of the metal-rubber shock absorber. The experimental results confirmed the simulation results by showing that the negative effects of flywheel disturbance on the image quality of space cameras can be diminished significantly using the vibration isolation method.

Keywords micro vibration, modulate transfer function, vibration isolation, flywheel disturbance

1 Introduction

Space cameras are useful in studying the surface of the earth for their ability to obtain objective information that can be widely used in several domains, including topographic maps, geological survey, forest resources survey, urban design and renovation, railways, highways, and other transit exploration. The influence of micro vibration on image quality has become increasingly significant along with the continuous improvement of space cameras.

Satellites need movable parts to function, including attitude-controlling reaction flywheels, control moment gyroscopes, reaction jet devices, energy-providing solar panels, and other agencies. The movement of these parts generates various degrees of micro vibration [1]. Despite not damaging the satellite structure, such micro vibration affects the pointing accuracy and stability of a space optical remote sensing satellite, obstructs the transfer of the photo-inducing charge and the motion synchronization of the focal plane image, and affects the quality of camera images [2]. These effects restrict the developments in space optical remote sensing technology. Given that flywheel disturbance is the main source of micro vibration [3], eliminating the effects of the flywheel rotary actuator disturbance on space cameras has become a key technology of high-precision stabilized platforms for spacecraft.

The flywheel disturbance results from the imbalance of the flywheel rotor, which in turn can be attributed to the following factors:

1) uneven material quality, poor manufacturing precision, and structural asymmetry during fabrication,

2) poor installation, eccentricity, and loose parts during assembly and installation, and

3) shaft bending and deformation as well as wear, corrosion, fracture, or deposition of the rotating parts during the operation of the satellite [4,5].

Micro vibration changes the relative position of the optical element, the alignment of optical components, and the line of sight of the camera. In this case, micro vibration can change the imaging position, system aberration, and image quality. Micro vibration is a dynamic process, and the relative position of optical components changes with time. Therefore, the effect of micro vibration on the image

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quality of optical components also changes along with time [6].

By changing the surface shapes of the optical element, micro vibration directly affects image quality. The effects of micro vibration on the changes in surface shape also vary along with time. Previous studies show that the effects of the changes in surface shape on image quality are much smaller than the negligible effects of line of sight [7].

Provided an ideal optical system for imaging an object point, it should be formed a point. If micro vibration is generated during the imaging process, then the point in the imaging position will be changed. According to geometrical optics, the point will be imaged at several locations, thereby decreasing the light intensity, expanding the range of light distribution, lowering the image contrast, and reducing the resolution.

Flywheel disturbance has a relatively wide bandwidth, while the altitude control system has a generally small bandwidth. Therefore, flywheel disturbance cannot be easily measured and controlled. This study refers to the results of a computer simulation analysis. Only few studies have conducted a micro vibration test using an optical space camera with a long focal length. This paper investigated the influence of flywheel disturbance on the image quality of a camera by conducting a simulation and an experiment. A passive isolation method was adopted to reduce the micro vibration generated by the flywheel disturbance. A metal-rubber shock absorber was designed and installed in a real satellite. The main innovation of this paper lies in the fact that we have conducted an experiment based on real products to test the modulate transfer function (MTF) even if experiments of such nature are often difficult to realize.

2 Design of the metal-rubber shock absorber

Many isolation devices have been designed for different rockets, of which the Stewart platform is the most popular. This platform was introduced by the American scholar Stewart in 1965 [8] when he designed a flight simulator with six degrees of freedom. This platform is known for its simple design, large carrying capacity, high precision, and minimal components. However, if one actuator malfunctions, then the results will be catastrophic. This platform also requires specific assembling for decoupling control, and the centroid of load must be placed at the center of the platform. These requirements are difficult to achieve, especially for aerospace application.

A system with eight damping pads (metal-rubber shock absorbers) was designed based on the Stewart platform. These pads were uniformly distributed in a circle as shown in Fig. 1, and the system was mounted on the isolation structure. Apart from having two additional damping elements, this design has a higher reliability and carrying capacity than the original Stewart platform. Most importantly, this design only requires the centroid of load to be placed on the main axis of the platform.

Figure 2 presents the structure of a metal-rubber shock absorber [9–11], which comprises upper and lower parts with parallel stiffness. The axis load during flight is only applied on the lower part. The metal-rubber shock absorber has spring and damping features and can constrain the translation of the equipment by mounting the structure in three directions. The entire mounting structure of the camera is suspended on the platform of eight damping pads, and the vibration is reduced in three directions.

The thickness, area, and distribution diameter of the absorbers must be carefully selected to create an excellent dynamic environment and meet the requirement of roll stiffness.

The metal-rubber shock absorber comprises a metal wire with a 0.15 mm diameter. The wire is evaluated according to the structure of the absorber and by several circles of optimal design and experiment. The metal-rubber shock absorber has a diameter of φ = 50 mm, and its upper and lower parts have thicknesses of 25 and 15 mm,

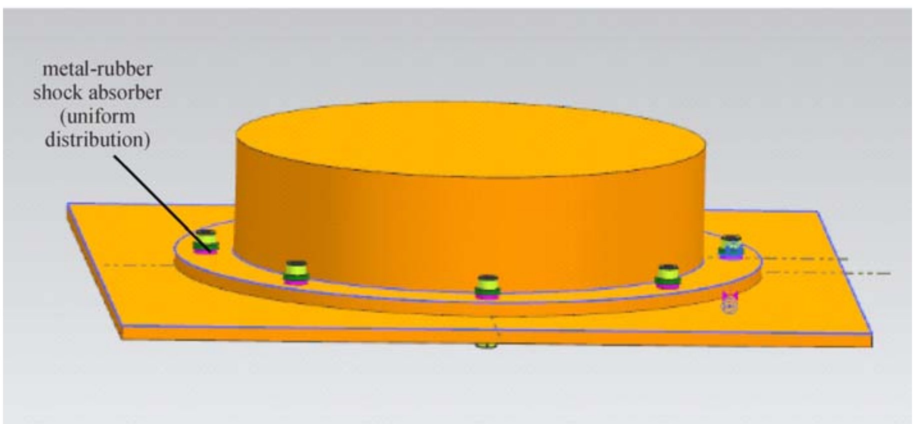

Fig. 1 Metal-rubber shock absorber with eight damping pads