The research micro-vibration detecting optical imaging system verification

Danyi Wang¹, Shanping Jiang⁴, Pengsong Zhang⁵, Bolun Zhang⁶
Beijing Institute of Spacecraft Environment Engineering, Beijing, China

*Corresponding author e-mail: jiangshp_cast@163.com, ⁴0089430@sina.com, ⁵zhpsong@126.com, ⁶optical511@163.com

Abstract. In order to reduce the influence of vibration on the imaging quality of space cameras, the ground simulation micro-vibration imaging detection optics is carried out, which is convenient for the off-line image recovery technology of measurement information. In this paper, the collimator system is selected as the optical system to simulate the characteristic target from infinity. The LIGHTTOOLS software is used to simulate the optical path. The system is studied through four experiments, namely camera excitation jitter test, target motion simulation optical axis jitter test, The wave-front distortion measurement test and the defocus measurement test analyze and compensate the optical error of the space camera through off-line image restoration. The test results show that when the camera is not excited, the camera outputs a clear image through the collimator system, which meets the requirements of the micro-vibration imaging test. In the micro-vibration imaging test, when the wave-front aberration reaches 0.21λ and 0.23λ, the imaging of the collimator system can meet the processing requirements of the recovery software. The result proves that the collimator system can be effectively applied to micro-vibration imaging. The detection system has the ability to successfully verify micro-vibration imaging detection tests.

1. Introduction
High-resolution space cameras can cause problems such as image quality degradation due to environmental conditions and changes in their own state. The most serious one is the degradation of image blur caused by on-board vibration, geometric distortion, etc., which will result in reduced image resolution, so spacecraft satellites Micro-vibration interference has an important impact on the quality of space camera imaging. At present, most of the detection of micro-vibration imaging is computer simulation proofreading, and it is rare to build a real micro-vibration imaging inspection optical platform. In this paper, a verification system is designed for the characteristics of micro-vibration imaging detection system to verify its performance and technical indicators such as optical axis jitter measurement, distortion measurement and defocus measurement. For the characteristics of the system, the collimator is selected as the optical system to simulate the characteristic target from infinity, select the vibration isolation platform and the exciter double jitter, simulate the optical axis jitter and other states, and more intuitively reflect the optical orientation of the camera, and simulate the space. The imaging situation of the camera under different vibrations in the environment.
2. Test plan

For the characteristics of the micro-vibration imaging detection system, two types of optical axis jitter generation methods are set here, namely target excitation and camera excitation. The target excitation simulates the camera defocus and the optical axis micro-vibration of the in-orbit camera through the target bracket and the translation stage respectively; two independent air floating stages are set in the camera excitation test, and the camera optical axis is directly passed through the exciter. The yaw direction and the pitch direction are excited to simulate such optical axis jitter.

The main components of the test verification system include: vibration isolation platform, parallel light pipe, target, camera, excitation device and so on. The layout of the test system has two forms:

(1) The camera and the collimator are respectively arranged on two vibration isolation platforms (test layout 1), which can excite the test camera without affecting the optical path of the collimator, and perform the "camera excitation simulation optical axis jitter test".

(2) The camera and the collimator are on the same vibration isolation platform (test layout 2). This layout minimizes optical axis jitter, and then performs “target motion simulation optical axis jitter test” and “wavefront distortion measurement test”. And "defocus measurement test".

Figure 1. Schematic diagram of test system (Test layout 1)

Figure 2. Schematic diagram of test system (Test layout 2)
2.1. Optical system

The optical system adopts a collimator system. The system is a reflective structure. The central area of the structure is not obstructed. It consists of an objective lens, a folding mirror, a reticle and a light source. Since the reticle is placed on the focal plane of the objective lens, the light source is used. After illuminating the reticle, the light from each point on the reticle passes through the lens and becomes a beam of parallel light that will be imaged at infinity. The system minimizes the refractive index, uniformity and fringe of the optical material. The effect on imaging, and no chromatic aberration, the system wavefront detection accuracy is better than $\lambda/4$ (rms).

(1) Main mirror

The primary mirror is used to receive light from the mirror and transmit the light path parallel to the camera. Its light aperture is $\Phi500 \text{mm}$ and the off-axis angle is $10^\circ$. The mirror silver-plated reflective film and SiO protective film have an average reflectance of not less than 95% in the range of 0.3 $\mu\text{m}$ to 14.0 $\mu\text{m}$.

(2) Folding mirror

The folding mirror reflects all the light emitted by the integrating sphere to the main mirror surface, the light aperture is $\Phi350 \text{mm}$, the surface accuracy is $\leq0.025\lambda$, the flatness is $<0.2\lambda$, the mirror silver-plated reflective film is added with SiO protective film, and the spectrum is 360nm~2600nm. The average reflectance in the range of the segment is not less than 95%.

(3) Integrating sphere

The integrating sphere emits uniform light to the collimator system, and its light exit has an effective diameter of $\Phi45 \text{mm}$ and an irradiance of one solar constant.

2.2. Vibration system

In this test, the vibration system adopts the exciter with excitation frequency range of DC~200Hz, which can generate sinusoidal fixed frequency excitation and random vibration mechanism. Finally, the "target motion simulation optical axis jitter test" and "wave-front distortion" are completed. Measurement test" and "defocus measurement test".

2.3. Target

According to the test requirements, the line-pair identification rate board is used to evaluate the imaging effect. In this system, 40 line pairs/mm is used as the reference evaluation. There are two kinds of target working states, one is that the target level moves back and forth to simulate the variable generated by defocusing; the other is to shift the target up, down, left and right to simulate the optical vibration of the in-orbit camera.

(1) Defocus measurement test

In the defocus measurement test, the translation stage is required to generate a micro-displacement simulation along the optical axis to generate a defocus amount, which is located between the integrating sphere and the collimator mirror.

Figure 3. The schematic diagram of target support and platform support
(2) Target motion simulation optical axis jitter test

The displacement stage is used to drive the target to generate vibration, and simulates the optical vibration of the on-orbit camera’s optical axis, that is, the horizontal and vertical vibration. The lateral vibration has the greatest influence on the imaging quality of the space camera, and the image jitter causes the diffusion spot when vibrating. When the amplitude is large, the receiver appears. The position relative to the target changes. The target is located between the integrating sphere and the collimator lens as shown.

![Diagram of displacement platform bracket](image)

**Figure 4.** Diagram of displacement platform bracket

### 2.4. Optical platform

The optical platform uses two independent vibration isolation platforms for environmental micro-vibration isolation. The base frequency of the platform is no more than 2Hz. The test camera is installed on the vibration isolation platform through the six-degree-of-freedom tooling, and the target and the collimator are installed in the tooling. Vibration isolation platform. The vibration isolation platform is supported by 6 sets of large damping air springs for automatic horizontal adjustment. The first-order frequency of the whole platform is not higher than 1.5Hz, the external vibration response amplitude is attenuated by 85% above 5Hz, and 90% can be attenuated above 10Hz, which satisfies the requirement of high-precision optical test for external environment vibration isolation.

### 3. Optical vibration test

#### 3.1. Parallel light pipe system imaging verification test

The camera is imaged as shown in the picture without applying excitation. The figure takes 40 pairs/mm and 20 pairs/mm. Figure a is the full field layout, and Figure b is the 20 line/mm detail picture.

![Image of parallel optical tube system](image)

**Figure 5.** The image of parallel optical tube system

It can be seen from the above figure that when the camera is not excited, the clear line pair is imaged by the parallel light pipe system output camera, that is, the parallel light pipe is clearly imaged, and the test requirements are met, and the micro vibration imaging test can be smoothly performed.
3.2. Micro-vibration imaging test

Taking the target vibration to simulate the micro-vibration of the orbital optical axis as an example, the two conditions of the target vibration, the target and the exciter at the same time are analyzed. When the target vibrates, only the micro-vibration of the optical axis of the orbit is simulated, and the image is obtained after being transmitted through the collimator, and the vibration image is restored. When the target and the exciter vibrate at the same time, the target is subjected to on-orbit optical axis micro-vibration simulation, and the exciter applies typical optical jitter to the contraction camera, image recovery method based on measurement information, and frequency domain analysis optical axis jitter imaging the quality impact is calculated.

(1) Target vibration imaging

When the target vibration is simulated, the micro-vibration exciter on the track optical axis does not shake, the optical mirror surface wavefront aberration is measured by the sensor to reach 0.21λ (rms<1/4λ), 1.28λ (PV), the layout of the field of view, the local details, the overall layout of the field of view and the local details obtained after image processing are shown in the table.

| Working condition | Vibration image | Restored image |
|-------------------|----------------|---------------|
| Full field        | Wave front aberration 0.21λ (rms<1/4λ) = 1.28λ (P-V) |               |

As shown in the table, it can be seen that the target vibration simulation is not blurred when the optical axis micro-vibration exciter is not shaken, the image is blurred (vibration image), and the image processed by the software is clear (recovered image), which is used for micro-vibration The collimator system for imaging inspection meets the requirements for pre-wave front distortion testing.

(2) Target vibration and camera shake imaging

When the target vibration simulates the micro-vibration of the optical axis of the orbit and the exciter vibrates, the optical mirror surface wave front aberration is measured by the sensor to reach 0.23λ (rms<1/4λ), 1.34λ (PV), the full field of view layout. The full view field layout, local details, the full view field layout and local details obtained after image processing are shown in the table.
Table 2. The Target vibration and camera vibration images and restoration images

| Working condition | Vibration image | Restored image |
|-------------------|----------------|---------------|
| Full field        | Wave front aberration 0.23λ (rms<1/4λ), 1.34λ (P-V) |               |
|                   | ![Vibration Image] | ![Restored Image] |
| Local details     |                |               |

As shown in the table, it can be seen that when the target vibration simulates the micro-vibration of the optical axis of the orbit and the exciter vibrates, the imaging is slightly blurred (vibration image) when the exciter is not shaken, and the image processed by the software is clearly imaged (The restored image), the collimator system for micro-vibration imaging detection satisfies the pre-wave distortion plus jitter test.

4. Conclusion

This paper analyzes the problem of imaging quality degradation caused by vibration in high-resolution space cameras. It is proposed to use the parallel optical tube optical system for ground vibration simulation test to simulate the characteristic target from infinity and select the vibration exciter. Cooperate with space camera wave-front distortion measurement and optical axis jitter on-orbit measurement test. The test results show that when the excitation is not applied, the output of the collimator system is clear, that is, the system requirements are met; when the target simulates the optical axis micro-vibration and the optical axis camera double vibration, the wave-front aberration reaches 0.21λ (rms< 1/4λ), 1.28λ (PV) and 0.23λ (rms<1/4λ), 1.34λ (PV), the collimator system can transmit the image completely to the camera, and the vibration image is processed by software to vibrate. The result image and the processed image were compared. The above series of test results prove that the collimator optical system can be effectively applied to the micro-vibration imaging detection system and has the ability to verify the micro-vibration imaging detection test.

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