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A TIME-FREQUENCY COUPLING ANALYSIS METHOD FOR DATA FROM MICRO-VIBRATION GROUND-TESTING

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Micro-vibration of spacecraft should be seen as small amplitude on-orbit disturbance. It's non-destructive on structure and is directly related to the precision of high-resolution remote imaging and laser communication. Response suppression and ground-test of micro-vibration become hot research areas. Based on ground emersion and high-resolution measurement, this article starts from spacecraft ground-test and proposes a time-frequency coupling method for micro-vibration of spacecraft ground-testing. Multi-angle analysis and identifications of key characteristic are realized. The method can be used to analyze structural design and assess micro-vibration of spacecraft.
Keywords: micro-vibration, angular displacement, high resolution, ground test, frequency domain

1. Introduction

The representative accuracy indicators of high performance spacecraft to earth observation continue to improve. However, with the continuous improvement of satellite targets, some of the issues need not be concerned in the past began to highlight, and have become a bottleneck factor that must be exceeded. One of the typical representatives is micro-vibration. Early structural design usually does not consider the influence of micro-vibration; however, for the need for high precision and stable directional control of the load, such as high resolution remote sensing imaging, laser communications, a small perturbation may also have a serious impact on the performance of the load [1]. Ground test of spacecraft micro-vibration environment become particularly important. First, it involves the simulation of zero gravity of spacecraft in orbit. Due to the low level of acceleration and displacement of micro vibration, the measurement sensor must have high precision, and try to avoid the additional influence on the vibration environment due to the installation of sensors. At the same time, the data processing of the ground test of micro vibration environment is different from the traditional mechanical environment test, which is based on the structural strength assessment, data processing [2-4]. In this paper, the method of temporal and frequency domain analysis will be used to study the ground simulation test of spacecraft micro vibration environment.

1.1 Free boundary simulation

The schematic diagram of the free boundary simulation used in the test is shown in Fig.1. The product is connected with ground through the free boundary simulation device. The basic principle of this device is to provide low frequency support for the product, and to realize the simulation of free boundary condition and isolation of the vibration. According to the requirements of vibration isolation, reliability and balance, the platform also has the main functions of vibration isolation, safety protection and system balance adjustment.

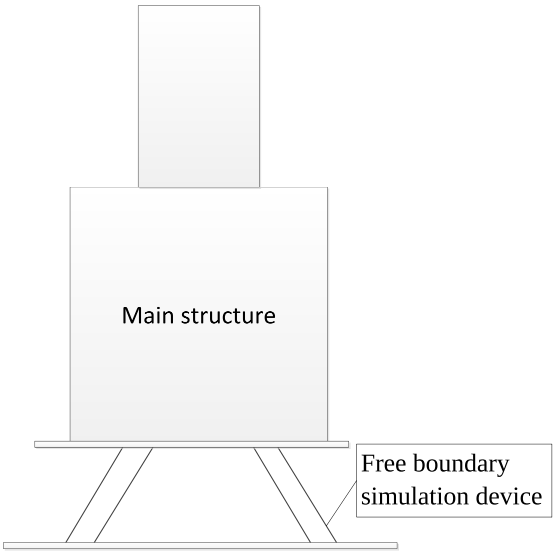

Figure 1: Schematic diagram of free boundary simulation device

1.2 Measuring device

The ground test device is shown in Fig.2. The ground accelerometer measures the background vibration of test environment. The accelerometer is mounted on the product to collect three axial vibrations. The laser measuring device collects the displacement of the target. The angular displacement sensors measure angle vibration data.

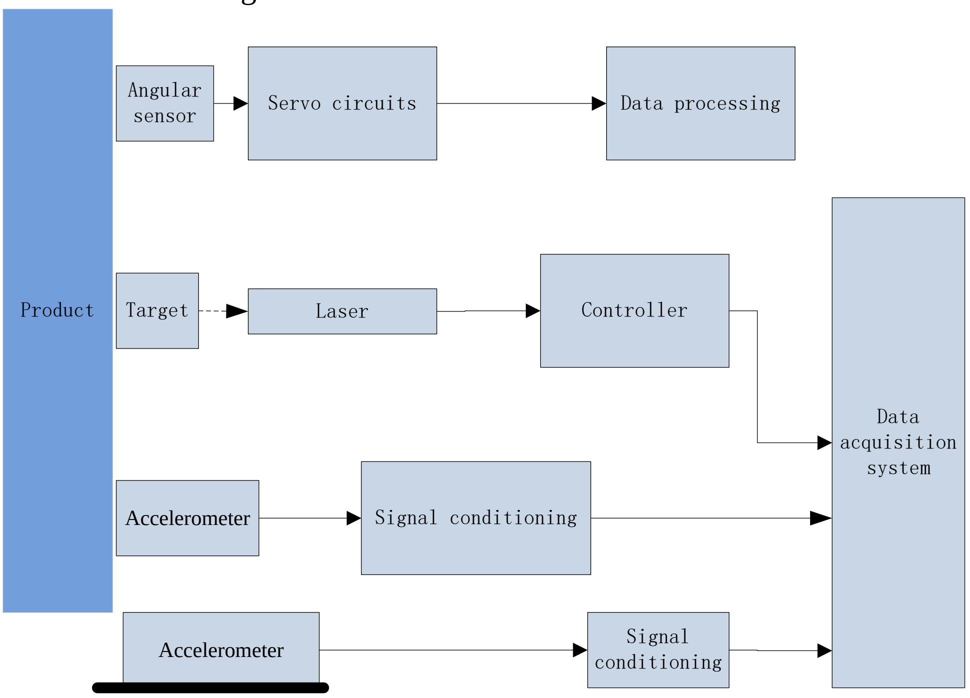

Figure 2: Schematic diagram of the principle of ground test

The angular displacement sensor uses a high resolution ring laser gyro because of the small magnitude of the angular vibration. Ring laser gyro is essentially a ring laser device, in the ring cavity there are two directions (clockwise and counter-clockwise) of the light wave. The output signal of the laser gyro is the beat frequency of two signals (clockwise and counter-clockwise interference). The angular displacement can be obtained by counting the number of interference fringes in the sampling interval, which is defined as angular increment in this paper. The angular increment represents the rotation angle of the measuring point in the sampling interval.

2. Analysis methods and results

2.1 Coordinate system definition

The vibration of the satellite can be divided into two parts: the vibration along three directions and the angular vibration around the three axes. Six degrees of freedom vibration coordinate system is defined as shown in Fig.3. The X, Y, Z three axes represent the rolling axis, the pitch axis and the yaw axis, respectively. The X axis is the direction of the satellite flight, the Z direction is the optical axis direction, and the direction of X and Y is perpendicular to the optical axis.

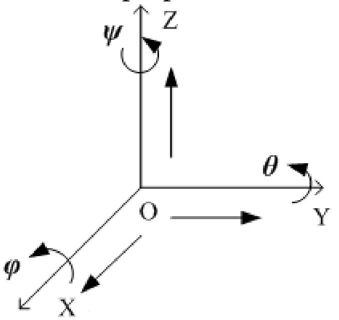

Figure 3: The definition of coordinate system

2.2 Translation analysis

It is assumed that the satellite is moving along the X axis, and the translational distance of the camera along the X direction is d, l and $l'$is the distance between the target image and the center of the field before and after the jitter :

$$D = l' - l = \frac{f}{H} d$$

f is the focal length of the lens, H is the height of the satellite orbit, and D is an image shift in the exposure time.

The translational displacement amplitude of X and Y is very small and can be ignored, and the same result can be obtained by Z analysis. Therefore, the amplitude of the time domain is of little significance to the translation, and the translation analysis needs to be carried out in the frequency domain.

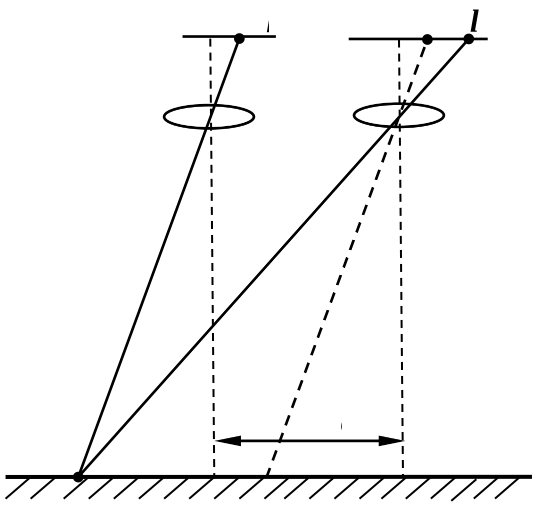

Figure 4: Schematic diagram of X and Y translation

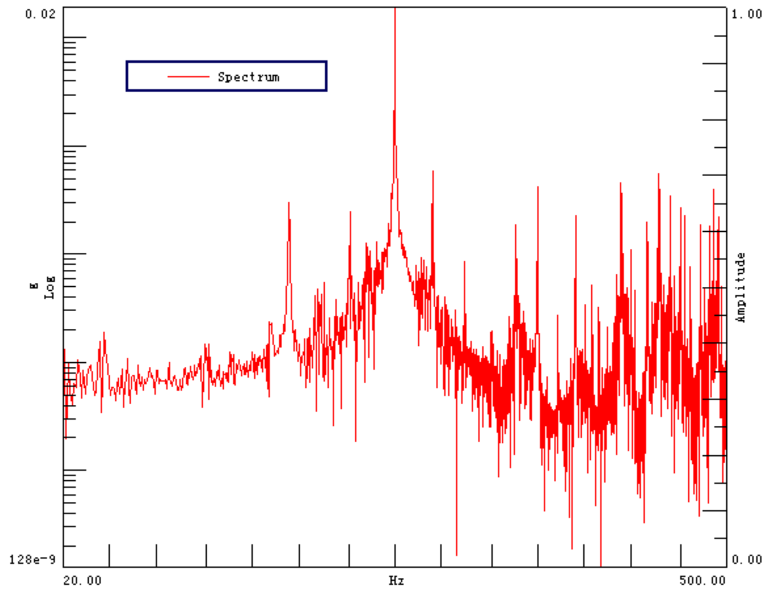

Figure 5: Spectrum of a key point

The above Fig.5 is the spectrum of a key point, the peak of the highest amplitude appears at 100Hz. 60Hz, 80Hz, 120Hz and other places also have a significant peak, where 100Hz is the characteristic frequency of the interference source.

According to the transmission path of disturbance, the number of measuring points can be arranged, and the attenuation and amplification of the structure can be obtained. The spectra of the measuring points on the transmission path are shown in Fig.6, the direction of the disturbance is from bottom to top, and the four measuring points are recorded as A, B, C, D. The sequence passing through the path is from A point to D point, the main frequency peaks concentrate in 60Hz, 100Hz. It can be seen that the structure of the product has little effect on the attenuation of low frequency, and the effect of high frequency attenuation is obvious. The structural design should pay attention to how to reduce the response near 60Hz and 100Hz.

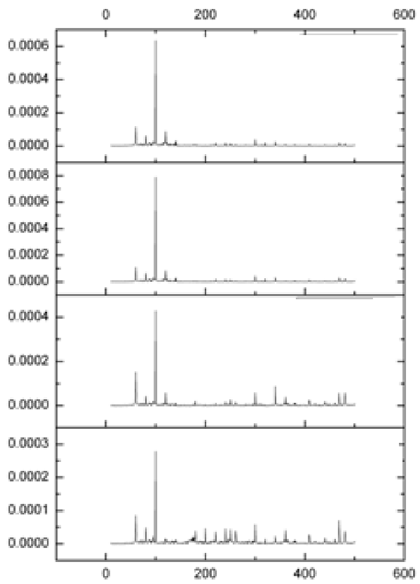

Figure 6: The spectra of the measuring points along the transfer path

3. Rotation analysis

By using the method of translation analysis, we can get the direction of the vertical optical axis, that is, the rotation around X and Y axis. The image motion produced by rotation is directly proportional to the focal length and rotation angle of the optical system, and the closer it is to the edge of the photographic device. Fig.7 gives the time domain curve of the angular increment when the source does not work. Fig.8 gives the angular increment time domain curve when the source works, the resolution of the laser gyro is sufficient to capture the vibration generated by the source.

The angular increment spectrum of a critical point is shown in Fig.9, the maximum peak value is still in 100Hz, 60Hz, 120Hz and other significant peaks are also obvious. In combination with the time domain curve, the vibration of 100Hz is dominant; the structural design should avoid the 100Hz mode as far as possible, and increase the damping in the source transfer path.

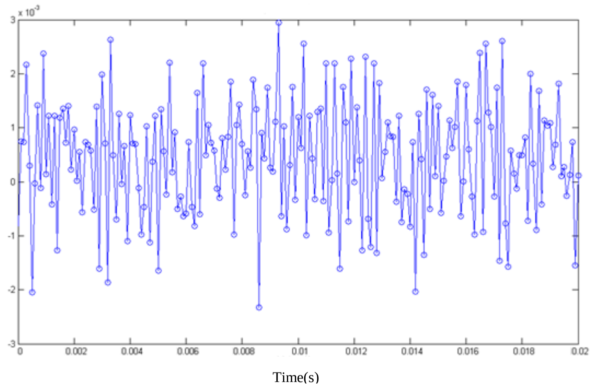

Figure 7: Angular increment without disturbance

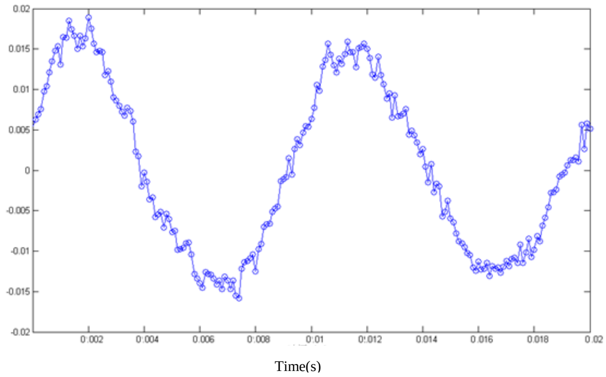

Figure 8: Angular increment under disturbance

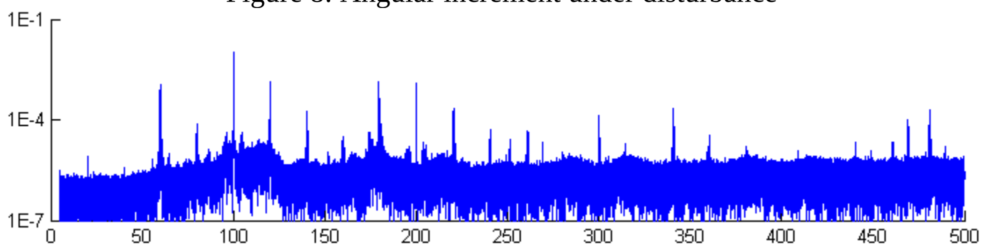

Figure 9: Angular increment spectrum

4. Conclusion

In this paper, based on the prediction of ground test, the temporal and frequency domain analysis method is used to study the translation and rotation response of the product under the influence of disturbance. According to the test results, the structural designing attentions are given.

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