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ON THE INFLUENCE OF MICRO-VIBRATION ON THE INTERFEROMETER STABILITY

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I. INTRODUCTION

The aim of spectral detection is to obtain the spectral information of the measured beam. Nowadays, the interferometric Fourier transform spectrometer detection technology is becoming the hot topic in spectral detection, especially in high spectral resolution infrared detection technology, due to its advantages such as large detection flux, multi-spectral band, and high spectral resolution.

The Fourier spectrum detection technology acquires the interference pattern signals of the measured beam through time or spatial modulation, and obtains the spectral information through an inverse Fourier transform. The spectral information quality of the measured beam depends on the interferences pattern signals, which are generated by the optical spectrum interferometer, thus the interferometer technology is the keyword in the spectral detection [1-4].

The high precision reciprocating swing of the interferometer mechanism is required to satisfy the uniformity of the scanning arm motion, which is the precondition of the high quality interferences signals. Yet, as to the space spectral detection, the disturbance of the micro-vibrations from the satellite platform generated by the reaction wheels and other disturbance source devices makes the precision swing of the mechanism complicated.

Generally speaking, the precision of the reciprocating swing, regard as the interferometer stability, depends on the mechanism control system, which is however always immature and indeterminate in the operational cases. In order to take a quick predication of the interferometer mechanism reliability affected by the disturbances from the satellite bus, a method on discussing the influence of micro-vibration on the space detection interferometer stability is introduced.

II. THE OPTICAL PATH DIFFERENCE (OPD) SPEED STABILITY

The optical path difference (OPD) speed stability of the spectrum interferometer is normally taken as the criterion on the interferometer stability and the high demand of it are required to meet the requirements of the spectrum detection accuracy. Meanwhile, the high stability of the OPD speed depends on the high precision reciprocating swing of the cube mirrors that are held by the just same rigid arm, thus the high demand of the interferometer stability is just the high precision of the cube mirror reciprocating swing.

In order to describe the motion of the cube mirror driven by the mechanism, the concept of the spectrum interferometer OPD is firstly introduced. An outline sketch of the basic instrument is shown in Fig.1, and the basic operation is as follows: the input radiation represented by the ray B is divided at the beam splitter into ray B1 and B2; each ray is returned to the beam splitter by the reflection of the cube mirrors, expressed separately in cube corner 1(CC1) and cube corner 2(CC2), and then ray B1 comes through the splitter, while ray B2 is reflected. The recombined beam is thus formed.

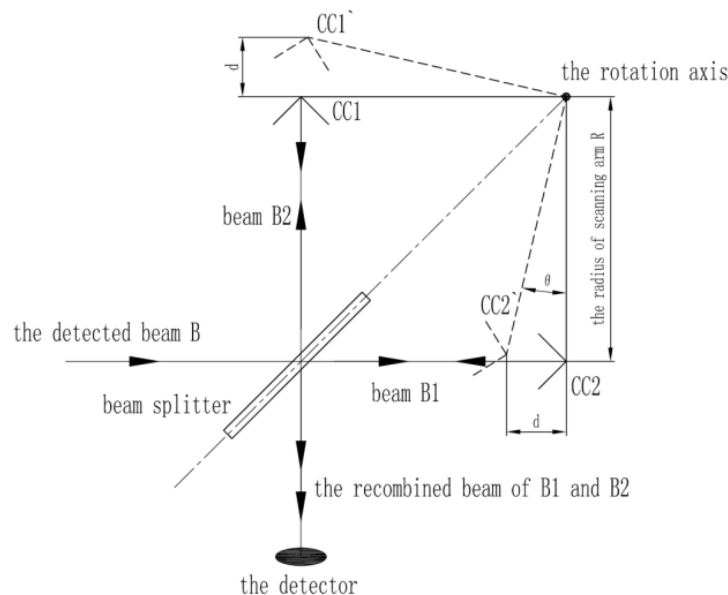


Fig. 1. The interferometer optical path difference (OPD)

The two scanning cube corners are normally displaced through an angle range $\pm\theta$ with a scanning arm radius R from an initial point of zero retardation such that the OPD, remarked in D , is

$$D = 4R \cdot \sin \theta(t), \quad \theta \in \left(-\frac{\pi}{4}, \frac{\pi}{4} \right) \quad (1)$$

Next is the introduction of the OPD speed. According to the identity that the velocity is the first derivative of the displacement with respect to time, the OPD speed, expressed by v , is

$$v(t) = \frac{d}{dt} D(t) = 4R \cdot \cos \theta(t) \cdot \frac{d}{dt} \theta(t) \quad (2)$$

This clearly shows that the OPD speed is completely characterized by the three parameters: the scanning arm radius R , the arm scanning angle $\theta(t)$ and the corresponding angular velocity $\frac{d}{dt} \theta(t)$.

The OPD speed is demanded to be homogeneous to satisfy the scanning modulation requirement, and the OPD speed stability is conveniently used to describe the uniformity of OPD speed. In order to confirm the OPD speed uniformity quantitatively, instead of the definition of the stability, the definition of OPD speed instability, written in α , is firstly given. The OPD speed instability is the ratio of the root-mean-square deviation and the equalizing value of the sampling OPD speed in the effective interferometer scanning optical path domain. As to the high demand of interferometer stability, α is generally required to be less than 1%.

Hence, the OPD speed stability is defined as $(1-\alpha)$, which is required to be more than 99%.

III. ON THE INFLUENCE OF MICRO-VIBRATION ON THE SWING OF SCANNING ARM

The micro-vibration affects the interferometer arm scanning angle $\theta(t)$ and the angular velocity $\frac{d}{dt} \theta(t)$. By analogy with the linear system, a reasonable hypothesis, as the base of the analysis of this paper, is proposed that the interferometer arm scanning angle under the influence of micro-vibration is the superposition of the angle under mechanism control system $\theta_c(t)$ and the angle with respect to the excitation of the micro-vibration $\theta_d(t)$, then

$$\theta(t) = \theta_c(t) + \theta_d(t) \quad (3)$$

It is important to note that the guarantee of the OPD speed stability is not included in the $\theta_c(t)$, which means that the external disturbance will operate onto the interferometer directly without any rectification from the control system. Obviously the stability deduced with this hypothesis is worse than the actual mechanism-control system case in which the control system does certify the deviation from the external disturbance, so the corresponding judgment of the interferometer stability would be conservative. However this is of importance to the operational cases that the control system rectification of deviation generated by the external disturbance is uncertain, since a conservative and quick estimation is always welcome to the engineering.

Hence, the arm scanning angle velocity is

$$\frac{d}{dt} \theta(t) = \frac{d}{dt} \theta_{\text{cntrl}}(t) + \frac{d}{dt} \theta_{\text{dsturb}}(t) \quad (4)$$

Substituting (3) and (4) into (2), the corresponding OPD speed expression becomes

$$v(t) = 4R \cdot \cos [\theta_c(t) + \theta_d(t)] \cdot \frac{d}{dt} [\theta_c(t) + \theta_d(t)] \quad (5)$$

This shows that the interferometer OPD speed under micro-vibration is the function of four arguments.

Within the arguments as stated above, the angle under mechanism control system $\theta_c(t)$ and its velocity $\frac{d}{dt} \theta_c(t)$ could be obtained with the definition of OPD and its speed. Equation (2) can be written in the form

$$\frac{v}{4R} \cdot dt = \cos \theta \cdot d\theta \quad (6)$$

Note that it is a constant with respect to the time that the OPD speed v is completely under the mechanism control system, so after the direct integration on both sides of the (6), one has

$$\frac{v}{4R} \cdot t = \sin [\theta_c(t)] + c \quad (7)$$

Where c is a constant, and it would be zero if we define that at the initial time, the interferometer arm is on the zero path difference, where the arm scanning angle is zero as is shown in Fig.1.

So the arm scanning angle under the mechanism control system $\theta_c(t)$ is

$$\theta_c(t) = \arcsin\left(\frac{v}{4R} \cdot t\right) \quad (8)$$

Since driven by the control system, here v is still a constant with respect to the time, so the arm scanning angle velocity $\frac{d}{dt}\theta_c(t)$ is

$$\frac{d}{dt}\theta_c(t) = \frac{v}{4R} / \sqrt{1 - \left(\frac{v}{4R}t\right)^2} \quad (9)$$

As to the other two arguments in (5), the angle and the angle velocity generated from the external micro-vibration $\theta_d(t)$ and $\frac{d}{dt}\theta_d(t)$, the analysis of them needs the finite element mode of the interferometer structure.

By means of the finite element model, $\theta_d(t)$ and $\frac{d}{dt}\theta_d(t)$ can be obtained with the structure response algorithm in discrete time domain.

IV. ANALYSIS OF INFLUENCE OF MICRO-VIBRATION ON A CERTAIN INTERFEROMETER

As is shown in Fig.2, the interferometer is fixed on the platform, on which the reaction wheels and other disturbance source devices such as scanning mechanisms and refrigerating engines are landed. The frequency of those external disturbance vibrations is tested to concentrate on 90Hz, 70Hz 50Hz and 30Hz. In order to make it clear that the influence of those above disturbances on the stability of the interferometer, the analysis of the OPD speed stability with the method introduced in section 3 is processed.

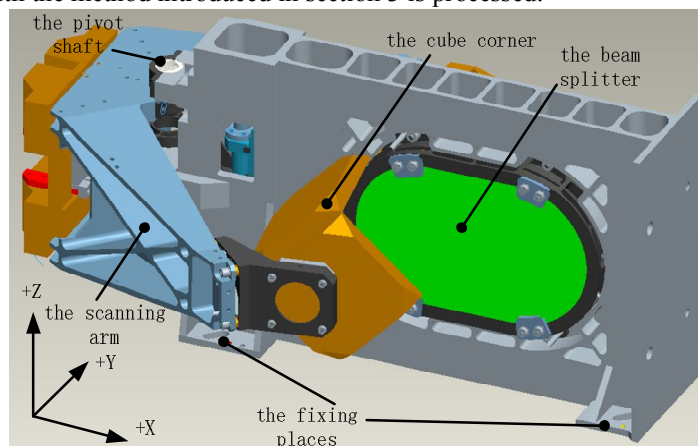


Fig. 2. Model of the interferometer

Both of the two different scanning modules of the interferometer are taken into consideration, and the relative parameters are listed in the following table.

Tab. 1. Parameters of the interferometer

Characteristics of the interferometer	Working module I	Working module II
Radius of the scanning arm R/mm	175	175
the maximum OPD Dmax/mm	25.2	25.2
OPD speed required v /(mm/s)	45.82	22.91

As the analysis method stated above, the arm scanning angle $\theta_c(t)$ and angle velocity $\frac{d}{dt}\theta_c(t)$ under the mechanism control system are firstly obtained with (8) and (9), shown in Tab.2.

Tab. 2. Movements of swinging arm in control system

Characteristics of the interferometer	Working module I	Working module II
$\theta_c(t)$ /rad	$\arcsin(0.065t)$	$\arcsin(0.033t)$
$\frac{d}{dt}\theta_c(t)$ /(rad/s)	$\frac{1}{\sqrt{1 - 4.28 \times 10^{-3} \cdot t^2}}$	$\frac{1}{\sqrt{1 - 1.1 \times 10^{-3} \cdot t^2}}$

Afterwards it is the calculation of the angle magnitude and angle velocity generated from the external micro-vibration $\theta_a(t)$ and $\frac{d}{dt}\theta_a(t)$. This is a solution procedure of structural finite element time domain response, in which the analysis object is the finite element mode of the interferometer structure, the displacement boundary condition is set to be fixed on 6 degrees of freedom at the installing place. According to the counteracting force frequency test of the reaction wheels and the disturbance source devices, the generalized force boundary condition of the finite element mode is series of disturbance accelerations cases that are arrayed with frequency on 90Hz, 70Hz, 50Hz, 30Hz, and amplitudes at $50 \times 10^{-3}g_n$, $30 \times 10^{-3}g_n$, $10 \times 10^{-3}g_n$.

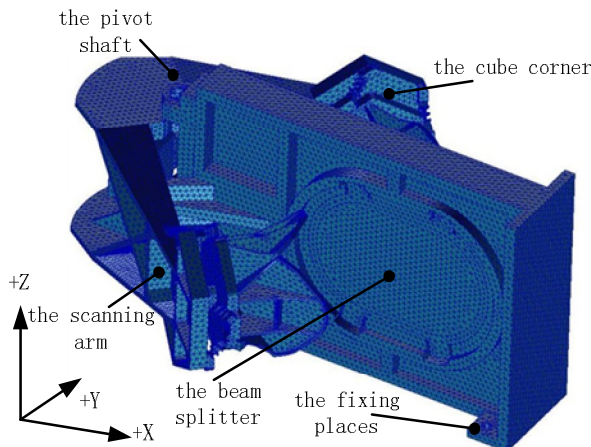


Fig. 3. Finite element model of the interferometer

The results of angle and angle velocity of the interferometer arm obtained from the finite element analysis are all about the discrete time, containing the influence of micro-vibration on the motion of the arm mechanism. Until now, all the arguments in the (5) have turned to be known, thus the OPD speed of the interferometer affected by the micro-vibration from its platform is rectifiable, yet in the form of $v(t_i)$, $i=1, 2, 3, \dots, N$. Here N is total number of the discrete time from the finite element discrete time domain.

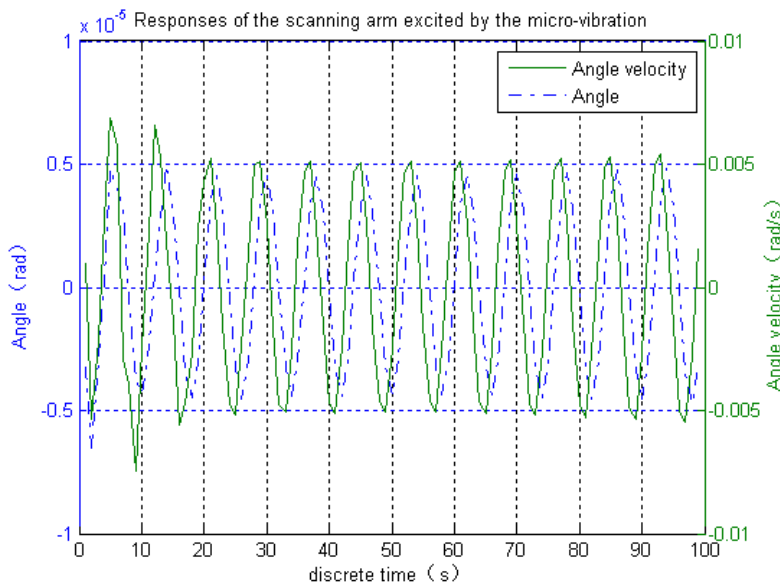


Fig.4. Analysis results in discrete time sequence

Using the identity, the equalizing value of the OPD speed from the finite element time domain sampling is

$$E = \sum_{i=1}^N v(t_i) / N \tag{10}$$

Then the root-mean-square deviation of the OPD sampling speed is

$$\sigma = \sqrt{\frac{\sum_{i=1}^N [v(t_i) - E]^2}{N}} \quad (11)$$

And the OPD speed stability about the 12 cases stated above is shown in the following,

Tab.3. The interferometer OPD speed stability subject to micro-vibration

Interferometer working modules	Frequency of micro-vibration / Hz	the OPD speed stability/%		
		50×10 ⁻³ gn	30×10 ⁻³ gn	10×10 ⁻³ gn
I	90	97.34	98.40	99.50
	70	97.93	98.76	99.59
	50	98.56	99.12	99.77
	30	99.14	99.48	99.83
	90	95.54	97.58	99.13
II	70	96.87	98.08	99.32
	50	97.93	98.74	99.58
	30	98.76	99.25	99.75

With the comparison of the data from the above, some regular pattern can be summarized that:

Firstly, when the frequency of the micro-vibration acceleration is given, the smaller the amplitude of the vibration is, the higher the OPD speed stability is.

Next, when the amplitude of the acceleration is given, the lower the frequency is, the higher the stability is.

Finally, the OPD speed stability will satisfy the requirement of no less than 99% with respect to all the discussed frequencies as to the amplitude of the micro-vibration acceleration is 10×10⁻³gn.

V. CONCLUSION AND OUTLOOK

A method on discussing the influence of micro-vibration on optical spectrum interferometer (in twin cube corners and swinging arm structure) has been introduced. According to the method, the interferometer structural response excited by the micro-vibration, obtained from finite element analysis is considered as an influencing factor in derivation of interferometer OPD speed stability, which could be taken as a criterion on interferometer stability. Considering micro-vibration disturbance, this OPD speed stability would be more accurate in the evaluation of interferometers on orbit stability, and more effective in determining the micro-vibration that interferometers could afford.

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