Experiment on Nonlinear Response Characteristics of Photoelectric Theodolite under Servo Driven

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Abstract. The dynamic response characteristics of the structure are affected by the nonlinear term in the theodolite structure with supporting shaft and bolt fixed connection. The harmonic term caused by nonlinear response has important influence on the measurement accuracy of optical system and the tracking stability of servo system. The harmonic response term is obvious by analysing the experiment data. The experimental study on the excitation of the cantilever beam model which fixed by single bolt shows that the nonlinear harmonic response is one of the source of the nonlinear dynamic characteristics of the system, and the harmonic response is much more obvious under special excitation condition

Introduction

Linear structural dynamic method which analysed be FEM is used to evaluate the effect of time-varying loads on the entire structure. And the simulation of dynamic response characteristics can clearly indicate the state of motion and the performance different conditions. Usually liner modal simulation method can deal with most engineering problem but joint fixed connections and rotating shafts which exist in the photoelectric theodolite structure make difference between simulation result and actual dynamic response characteristic[1]. Furthermore, the nonlinear response term in the photoelectric theodolite affects the stability of the optical system and the reliability of the measured data[2-6]. Therefore, it is necessary to further analyse the response of actual mechanical structure system of the photoelectric theodolite[7].

Characterization and Resonance Theory of Structural Nonlinear System

The equation of motion of the system with nonlinear excitation under harmonic excitation can be expressed as follows[8]:

$$M\ddot{x}+C\dot{x}+Kx+f_d\left(\dot{x}\right)+f_s(x)=F\sin(\omega_0 t+\phi) \tag{1}$$

$$f_d\left(\dot{x}\right)=c_2\dot{x}^2 \tag{2}$$

$$f_s(x)=\alpha x^2+\beta x^3+\gamma x^4 \tag{3}$$

where M is the mass matrix, K is the damping matrix and C is the stiffness matrix of the system; $f_d(\dot{x})$ is the nonlinear damping term; $f_s(x)$ is the nonlinear restoring force for the system. Equation 2 means the common quadratic damping term and Equation 3 shows the common stiffness expression. The α , β and γ are the nonlinear coefficient. The system mar occur super-harmonic response when the external excitation frequency can be written as follows:

$$\Omega\approx\omega_0/n \tag{4}$$

where ω_0 is the system natural frequency and n is the non-positive integer.

Analysis of Servo Experiment Result of Support Frame

The experimental system contains structure system of photoelectric theodolite, three axis acceleration sensor which made by PCB and data acquisition and control system (YMC 9232Dynamic Data Acquisition System). Figure 1 shows the sensor layout and the channel define about acceleration sensor are summarized in Table 1. The vertical direction of structure is defined as X direction of the measured coordinate. The horizontal axis direction of structure is defined as the Y direction of the measured coordinate and the Z direction is formulated using right hand law. And the system is excited by the vertical axis servo motor which using switching motors to achieve 0-300Hz sweep excitation the sampling frequency is 2Khz

Table 1. Channel define about acceleration sensor

Sensor1		Sensor2		Sensor3		Sensor4	
X	Channel_1	X	Channel_4	X	Channel_7	X	Channel_13
Y	Channel_2	Y	Channel_5	Y	Channel_8	Y	Channel_14
Z	Channel_3	Z	Channel_6	Z	Channel_9	Z	Channel_15
Sensor5		Sensor6		Sensor7		Sensor8	
X	Channel_16	X	Channel_19	X	Channel_22	X	Channel_25
Y	Channel_17	Y	Channel_20	Y	Channel_23	Y	Channel_26
Z	Channel_18	Z	Channel_21	Z	Channel_24	Z	Channel_27

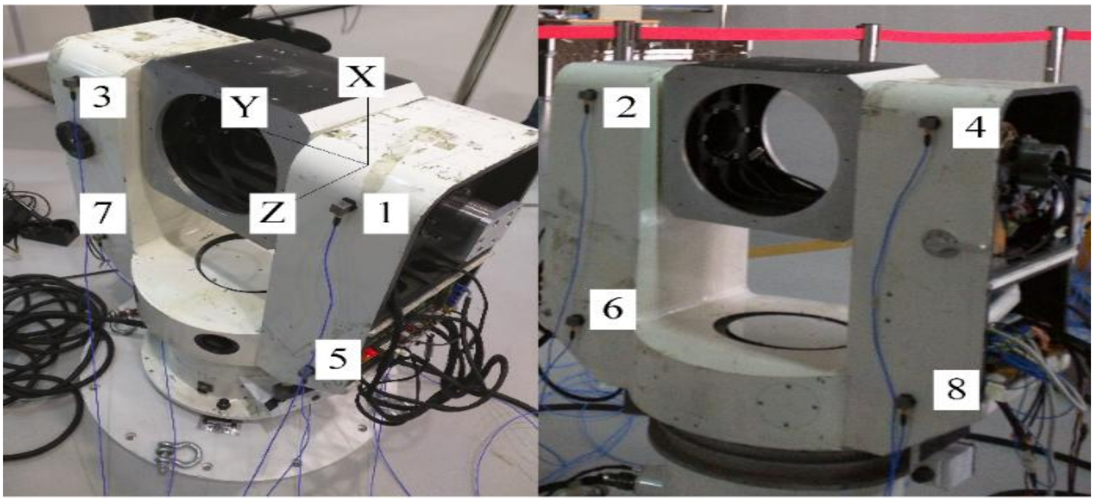

Figure 1. Define about acceleration test machine

Under the excitation frequency of $f_0=45Hz$, the frequency of the main response of y-direction and z-direction of structure is $f_1=55.66Hz$. Corresponding to the time-frequency curve from Figure 3, the harmonic response existed and the interval between each line of Figure 3 is $f=11.23Hz$. And there is a more obvious response at $5f_0=77.83Hz$. Therefore, the motion state of the system changes clearly in $t=35s$. The experimental data of the servo measurement of the structure of photoelectric theodolite indicate that the nonlinear term exists in the response and has a great influence on the dynamic response of the structure.

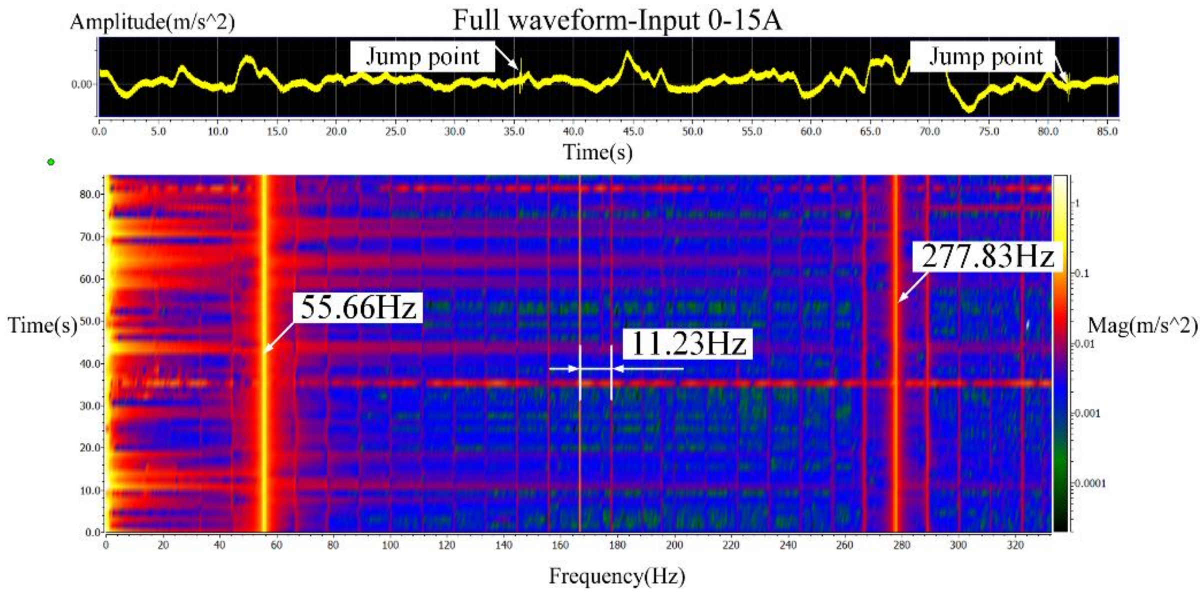

Figure 2. Full waveform (Time-Frequency curve) (Z direction)

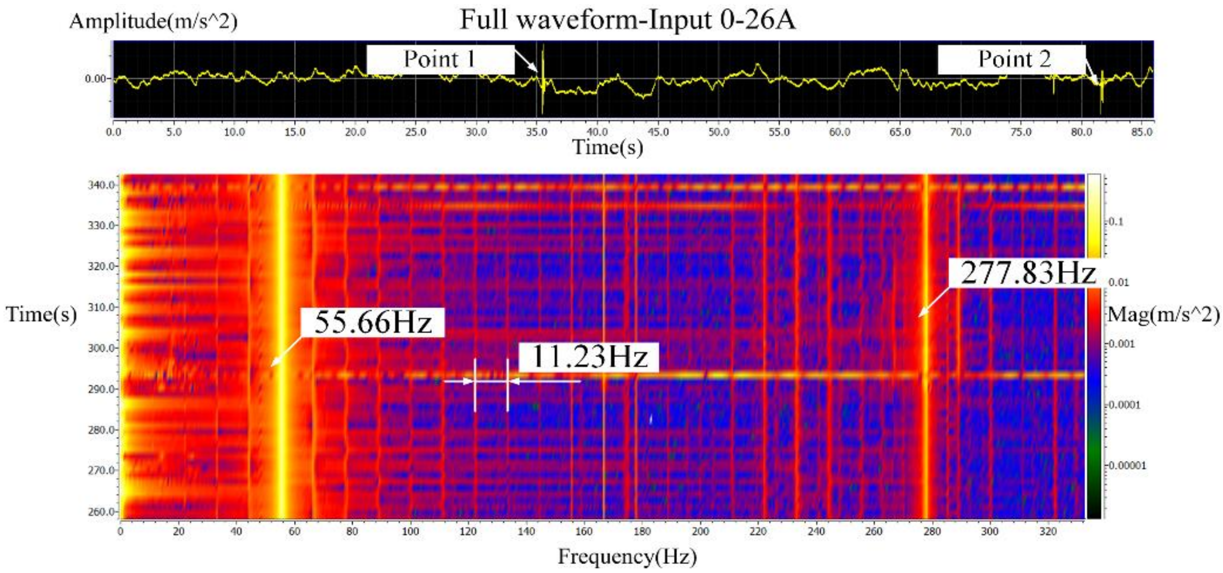

Figure 3. Full waveform (Time-Frequency curve)(Y direction)

Under the excitation frequency of $f_0=45Hz$, the frequency of the main response of y-direction and z-direction of structure is $f_1=55.66Hz$. Corresponding to the time-frequency curve from Figure 3, the harmonic response existed and the interval between each line of Figure 3 is $f=11.23Hz$. And there is a more obvious response at $5f_0=77.83Hz$. Therefore, the motion state of the system changes clearly in $t=35s$. The experimental data of the servo measurement of the structure of photoelectric theodolite indicate that the nonlinear term exists in the response and has a great influence on the dynamic response of the structure.

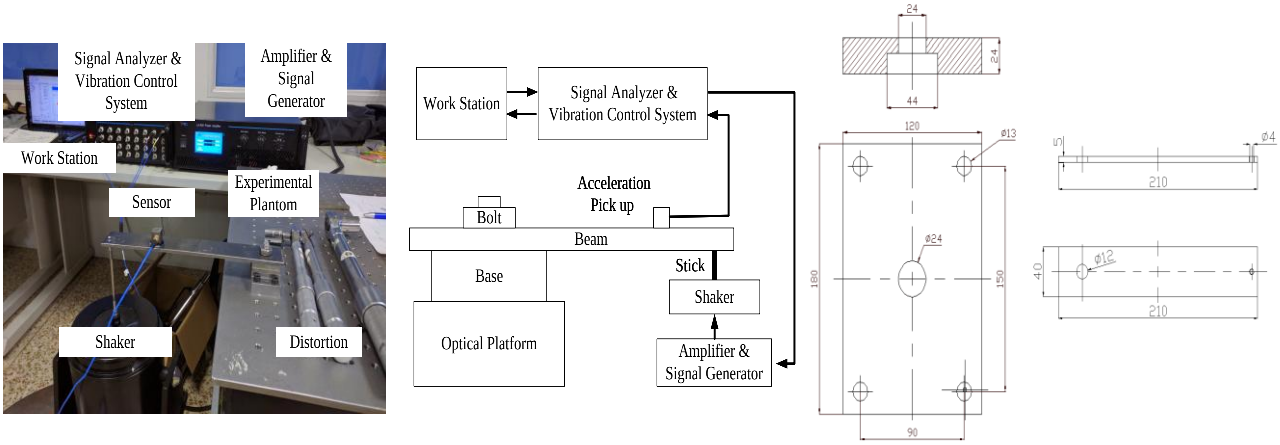

Figure 4. Vibration test sketch

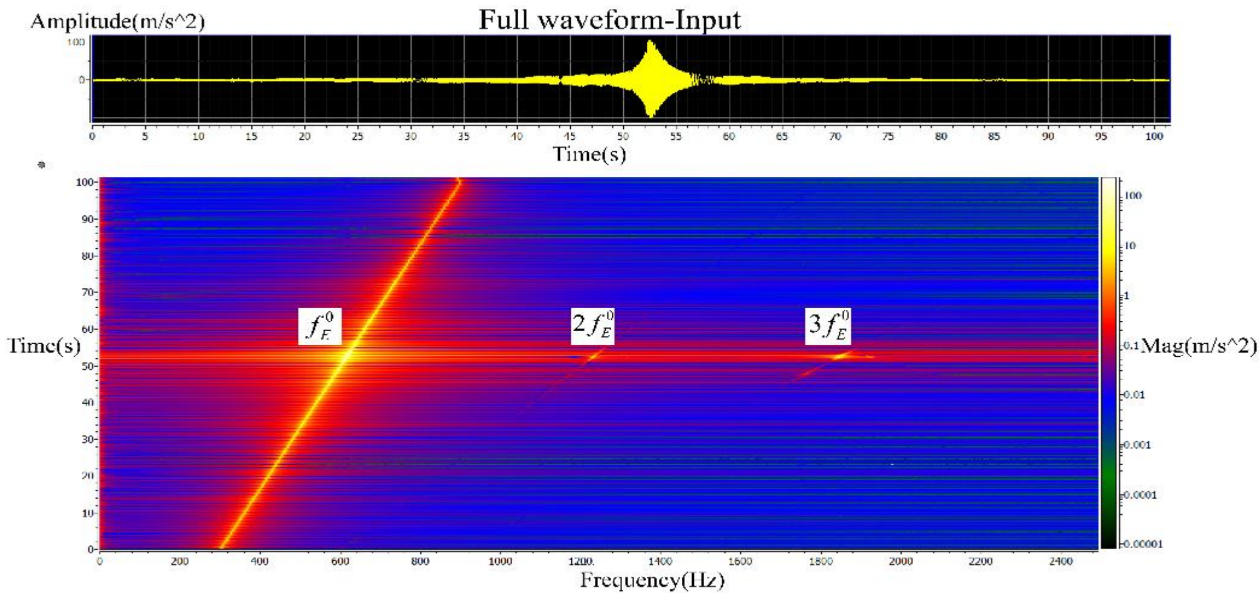

Figure 5. $Q^0 = 1N \cdot M$, $F_E = 300mv$, Result about sweeping load of full waveform (Time-Frequency curve)

Experimental about Bolt Fixed Cantilever beam modal

In order to analyze the source and response characteristic of the structure of photoelectric theodolite, a single bolt fixed cantilever beam experiment is established to analyze the effect of local nonlinearity caused by bolted connections on the dynamics response of the structure. The vibration control system is the same as the tracking structure servo experiment. And the exciter is YMC MS-200 series exciter, the maximum amplitude is 10mm, the excitation frequency range of which is 0-4000Hz under DC model. Amplifier of the system is YMC-LA-500 and the full power frequency range is between 20-5000Hz Figure 4 shows the specific sketch of the beam and the composition of the test system.

The whole sweep time is *t=200s*, sampling frequency is f_s*=10000Hz*. The amplitude-frequency characteristic of the Z direction acceleration data is analyzed by the vibration analysis platform YMC9800, and the Fast Fourier Transform method (FFT) is used as the analysis method. The length number of the sampling data is *N=8K*, the number of spectral lines is *M=3200*. The average method is peak holding method. The frequency resolution is $f_s/(2.56*M)=1.22Hz$. The preamplifier gain remains same during the experiment. Figure 5 shows the sweep analysis color chart and the depth of color represent the amplitude. The start frequency of the sweep experiment procedure is $f_{begin}=300Hz$, the end frequency of the sweep experiment is $f_{end}=900Hz$. The bolt fixed cantilever beam resonance at $f_E^0 = 617.70Hz$, and the amplitude of the resonance peak is

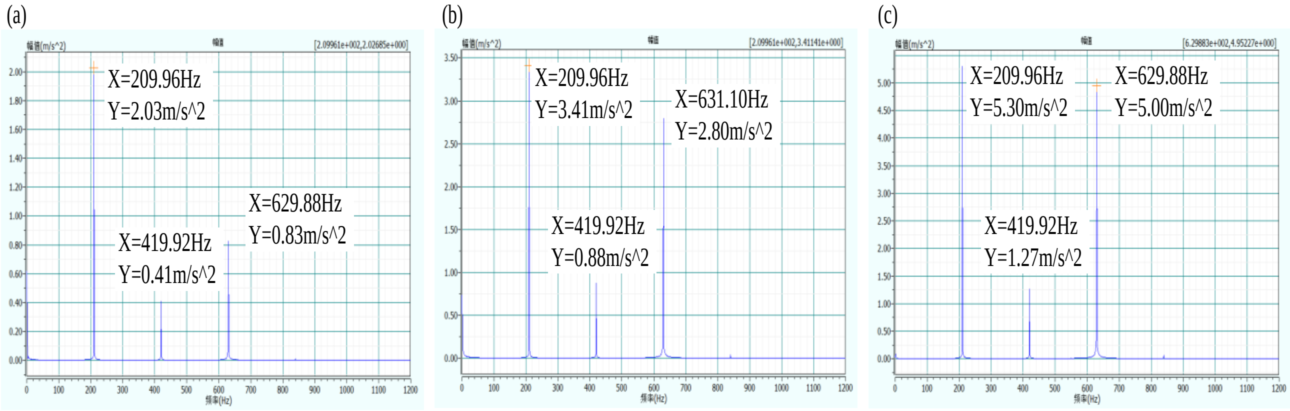

Figure 6. $Q^0 = 5N \cdot M$ (a) $F_E = 300mv$,Frequency-Amplitude curve; (b) $F_E = 600mv$, Frequency-Amplitude curve; (c); $F_E = 900mv$, Frequency-Amplitude curve

$H_a(f_E^0) = 96.13m/s^2$. The amplitude of the response is obvious when the excitation is f_E^0 and the response is also clearly under frequency of $2f_E^0$ and $3f_E^0$.

When the preload torque changes to $Q^0 = 5N \cdot M$, the resonant frequency of the bolt fixed cantilever beam changed to $f_E^0 = 630.05Hz$. Figure 6 shows the different response characteristic under excitation of sinusoidal frequency $f_E = f_E^0/3 = 210.00Hz$ and excitation voltage changes between 300mv to 900mv. In Figure 6.a, we can get the conclusion that the amplitude $H(f_E^0/2)$ and $H(f_E^0)$ increase with the external excitation load increase In Figure 6.b, the ratio $H(f_E^0)/H(f_E)$ also increase when F_E increase but the $H(f_E^0/2)/H(f_E)$ keeps the same. The experiment result shows that the cantilever beam is mainly three times nonlinearity when the preload torque is $Q^0 = 5N \cdot M$. It can be seen that the structural nonlinear effect of the bolt-connected cantilever beam model has an effect on the structure.

Conclusion

Based on the servo experiment data of theodolite structure, the harmonic response of the structure under servo excitation are analyzed. The local nonlinearity existed in the system, such as the shafting contact and bolting in the structure, which makes the harmonic response under servo excitation more obvious. Therefore, jump phenomenon existed when the structure of photoelectric theodolite is excited under motor from harmonic response time-frequency curve. It can be seen that there is a strong nonlinear term in the resonant frequency region of the structure using the excitation experiment of cantilever beam. The third-order response of the system is obvious. And the bolt do have strong effect to the dynamic response of the system.

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