Dynamic Analysis of Test Frame of Railway Subgrade Dynamic Response Test System

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***Abstract*—In this paper, we take the railway subgrade dynamic response test system as the study object, the laboratory test reaction frame's model factors were analyzed through the finite element analysis software MSC.Patran/Nastran. The former six-order original frequencies and vibration modes of the frame were caculated and evaluated in detail. Then we studied its transient response under two working conditions: when it's fully loaded and suddenly unloaded, and the deformation displacement curves of the key points of the frame were obtained. These results provide a basis for the detailed study to the mechanical behavior of the frame and setting the proper working frequencies of the hydraulic servo excitation cylinder to avoid the resonance.**

***Index Terms*—Frame, Dynamic analysis, Railway subgrade, Original frequency.**

I. INTRODUCTION

Generally the light steel structures are mainly made of welded steel sheets or cold-formed steel members, which the typical light rigid structure is the portal frame [1]. As the steel portal frame are widely used, there are more and more new demands to the frames, such as higher anti-seismic, greater stability, and longer fatigue resistance, etc [2].

A laboratory test device of the high speed railway subgrade dynamic response test system was set up in a university laboratory [3-5], and the core of which is the servo hydraulic excitation cylinder, its maximum excitation force is 300kN and the maximum excitation frequency is 40Hz. In order to avoid resonance, prevent the servo hydraulic cylinder and the frame from being destructed, it is need to take the dynamic analysis to the frame to find out its natural frequencies and study the dynamic response under the typical work conditions, which may be help to set a reasonable frequency range of the servo hydraulic excitation cylinder and provide a basis for the later dynamic design.

II. FINITE ELEMENT MODEL OF THE FRAME

Compared with the ordinary cast structure, welded structures has the advantages of high strength and rigidity, light weight, short productive cycle and easy to construct, so we choose the welded assembly frame. Fig. 1 shows the laboratory test frame of the high-speed railway dynamic response excitation test system, which is mainly composed of the base, columns, beam and connection plate.

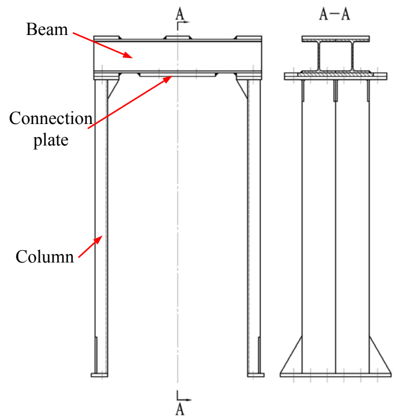


Figure 1. Structure of the frame

The base is the T-slot cast iron foundation (not appeared in Fig. 1).

The columns are respectively welded of two U-bars. The bottoms of them are bolted to the base.

The beam is made of two H-beam that welded together. The top and bottom of it are welded some strengthen plate. The beam is bolted symmetrically to the top of the columns.

The connection plate is of round shape and its upper surface is welded under the beam and the lower surface can mount the servo excitation cylinder through the screws.

The structure of the frame is complex, so its three-dimensional solid model is created in a graphics software firstly, and then import it to the MSC.Patran software [6]. The beam, column and base are connected with high-strength bolts that can be considered as the fixed connection. Considering each element must be continuous, so different solid elements should be meshed probably. Finite meshing adopts 10 nodes Tet element, and the frame is meshed into 73494 elements and 138201 nodes. The modulus of elasticity is set as 203 GPa, Poisson's ratioto is 0.3, the density is 7.8×10^3 kg/m^3.

III. THE FRAME MODAL ANALYSIS

A. Modal Analysis Theory

Modal analysis is the modern approach to study the dynamic characteristics of the structure [7]; it can be used to study the natural vibration performance of the mechanical structure. Each mode has a specific natural frequency, damping ratio and mode shapes [8]. When we study the natural frequencies and mode shapes of the reaction bracket, its damping can be ignored. As the external load is zero, the system dynamic equations can be expressed as:

$$[M]\{\ddot{x}\}+[K]\{x\}=0 \quad (1)$$

Where $[M]$ is the mass matrix, $\{\ddot{x}\}$ is the acceleration vector; $[K]$ is the stiffness matrix; $\{x\}$ is the displacement vector.

Its solution is:

$$\{x\} = \{\phi\}e^{iax} \quad (2)$$

So the characteristic equation will be:

$$([K]-\omega^2[M])\{\phi\}=0 \quad (3)$$

Where ω is the natural frequency of the system.

For the equation above, MSC.NASTRAN provides three types of solution: tracking method, changes method and the Lanczos method. They have their own advantages, comparatively speaking, Lanczos method could solve the very large eigenvalue problem, doesn't lose the roots, allows the singular mass matrix, and can get more feature values, so it is recommended.

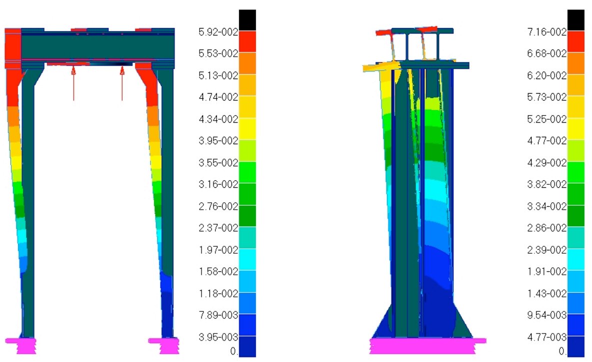
B. *Analysis and Discuss*

After being computed in MSC.Nastran, the former six-order natural frequencies and the amplitudes of the reaction frame are shown in Table 1.

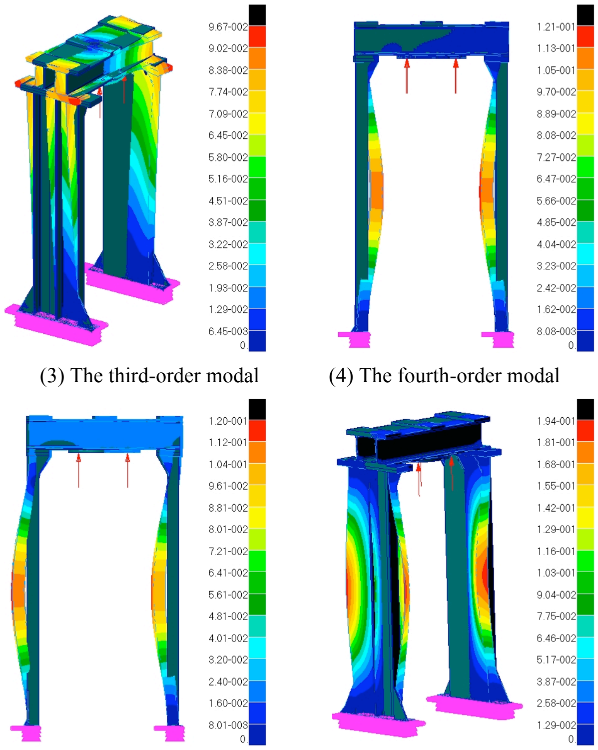
It can be seen from Table 1, the first order natural frequency of the reaction frame is low and under the working frequency; the second and third order natural frequencies are slightly larger than the servo excitation cylinder maximum operating frequency. Totally, the amplitude of each vibration mode shows that bottom of the columns where joint with the base and the beam are almost not distorted, however the amplitude of the columns is much greater, ranges from 0.06 to 0.19 m. The former six order modal vibration modes are shown in Fig. 2.

TABLE I.
FORMER SIX-ORDER NATURAL FREQUENCIES AND AMPLITUDE OF THE REACTION FRAME

Order	Natural Frequency (Hz)	Amplitude (m)
1	15.56	5.92×10^{-2}
2	42.85	7.16×10^{-2}
3	55.49	9.67×10^{-2}
4	119.46	1.21×10^{-1}
5	128.10	1.20×10^{-1}
6	136.28	1.94×10^{-1}



(1) The first-order modal (2) The second-order modal



(3) The third-order modal (4) The fourth-order modal

(5) The fifth-order modal (6) The sixth-order modal

Figure 2. The former six-order vibration modes of the reaction frame

The modal analysis shows that:

1) The stiffness of the column is relatively small; the former three order frequencies impact it obviously;

2) The first-three-order natural frequencies- 15.56Hz , 42.85Hz and 55.49Hz- are more sensitive to the load, they produce the swing and twist deformation in front-back and left-right direction;

3) The fourth, fifth and sixth vibration modes are lateral deformation and twist at the central of the column;

4) From the pictures, the frame may not only occur the bend deformation in front-back and left-right direction, but also the torsional deformation. It probably affects the strength and rigidity of the frame, raises the bolt stress, influences the output precision of the excitation hydraulic cylinders, aggravates the wear of moving parts of the servo hydraulic cylinders and reduces the cylinder and the frame's life. Therefore, in the future design it is necessary to increase the local stiffness and damping appropriately to suppress the vibration;

5) The distribution of the overall integral stiffness and mass is comparatively balanced, there is no noticeably weakness and excess, it will help to improve the dynamic characteristics of the frame.

IV. THE FRAME TRANSIENT RESPONSE ANALYSIS

The transient dynamic analysis (also known as time-history analysis) is used to analyze the response of the structure under time dependent load, including the static load, transient load or any combination of them [9-10].

In Nastran, there are two approaches to study transient response: direct and modal method. The direct method is of high precision, so it is chosen in this paper. Fig. 3 is the boundary condition of the transient analysis, Fig. 4 is the input stress-loading curve in 40Hz. In the picture, the sinewave curve in 0 ~ 0.08125s represents 3 1/3 cycles' excitation, and it inspects the response of the frame under the forced vibration; the after till 0.3s represents the unloaded state, it is used to study the response of the frame as it unloads suddenly.

Fig. 5 is the displacement curve in the Y-direction of the element 1 at the top of the beam. It shows that at the beginning, a slight vibration is occurred, and then it is relatively stable, the amplitude is about 4.4mm; as unloaded, there is a slight concussion, ranging about 1mm, but soon it becomes static. Fig. 6 presents the displacement curve in the Z-direction of the element 2 inside the column. At first it is in an irregular shape that within an approximately sinusoidal trend. The vibration amplitude is small, the maximum is about 0.36mm; there is a slight concussion after unloading, and the maximum amplitude is about 0.24mm.

V. CONCLUSIONS

In this paper, the dynamic response of the laboratory test frame of the high speed railway subgrade test system has been studied through the FEA software MSC.Patran/Nastran, and we can safely come to the conclusions:

1) The operation frequency range of the hydraulic excitation cylinder is of 0 ~ 40Hz, that may cover or approach the first two order natural frequencies of the frame and may resonate easily. To avoid this, it is recommended to set the excitation frequency band to 0 ~ 15Hz and 16 ~ 38Hz.;

2) If the excitation frequency is exactly close to the first or second order natural frequency of the rack, it is required to enhance the rack's structural rigidity, so that it is greater than 40 Hz to avoid the occurrence of resonance.

3) Under the conditions of the maximum force and frequency is applied and suddenly unload, the maximum displacements of the rack are all within the allowed limits, and the design is reasonable.

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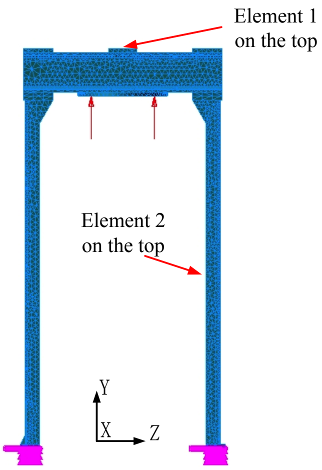

Figure 3. Boundary condition

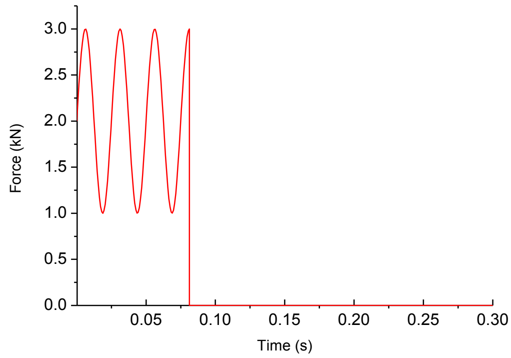

Figure 4. Input stress-loading curve

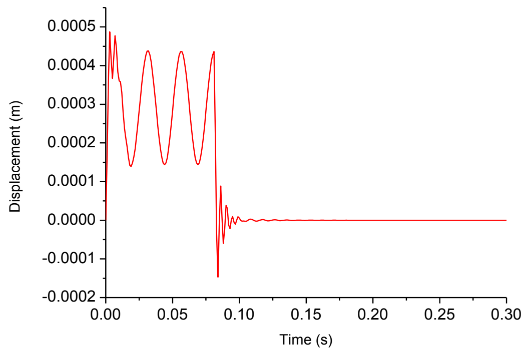

Figure 5. Time-displacement curves of element 1

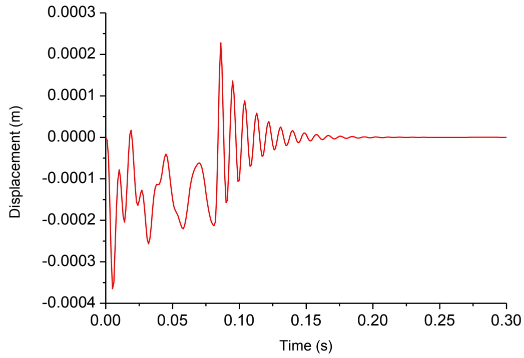

Figure 6. Time-displacement curves of element 2

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