

Dynamic Analysis of Gantry Crane Pillar subjected to Industrial Base Excitation

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Abstract: This paper is concerned with the investigation of the dynamic behaviors of cranes under Base excitation. For this purpose, firstly we have performed an experiment on a 1/10 scale crane model and shaking table, then a multi-degree-of-freedom non-linear mathematical model is developed including the behavior of the gantry cranes. In this study, a prototype is prepared of a particular gantry crane and shaking table with comprehensive calculations and the base excitation is artificially produced by the means of vibromotors. The paper elucidates the analysis of dynamic motion behavior of the prototype using FFT Response, Time Domain Response and Orbit Plot tools, to understand the effect of industrial base excitation on the gantry crane and to provide a better layout for the setup of various machinery in the industry.

IndexTerms - shaking table , gantry crane, base excitation, dynamic motion behavior , FFT or Orbit Plot, modal analysis, mathematical model.

I. INTRODUCTION

Nowadays high-performance large size material handling and conveying machines, such as container cranes, huge gantry cranes, ship unloaders and ship loaders, etc., as well as construction and surface mining machines, such as e.g. bucket wheel excavators, spreaders, reclaimers, stacker feeding bridges etc., have found an extremely wide application in almost all areas of human running life activities. Overhead cranes are widely used to move the large/heavy objects horizontally for either manufacturing or maintenance applications in many industrial environments, such as ocean engineering, nuclear industries, and airports, etc. Also, there is a continuous scope for improvement in efficiency and performance of such systems. The effect of seismic excitation on these systems have previously been studied, C. Oktay Azeloglu studied seismic behavior of container cranes while Ahmet Sagirli investigated dynamic behavior of cranes under the impact of seismic excitation. Also, the use of shaking table test has been remarkable for understanding structural as well as dynamic behavior of cranes and buildings. However, the effect of industrial base excitation is highly dubitable and is always neglected and the focus is drawn upon improving the efficiency and reducing the effect of earthquake tremors.

Here, a prototype model of gantry crane has been prepared by using a 1:10 scale ratio. Scale ratio of 1:20 was used by C. Oktay Azeloglu, Ahmet Sagirli and the scaling method used here is according to Hamid Reza Tabatabaiefar and Bitam Mansoury. Further, shaking table tests are performed with the use of digital analyzer to understand the dynamic motion behavior under the impact of artificial base excitation. Hong-Seok Park and Ngoc-Tran Le researched on a virtual prototype by simulating the real behavior of harbor crane. Modal analysis on giant shipbuilding crane is also performed by Guojian Huang, Chengzhong He and Xinhua Wang and M.L. Chandravanshi and A.K. Mukhopadhyay compared results of theoretical analysis and modal analysis.

In this review, the modal analysis of a scaled prototype is performed to figure out the natural frequency of the setup to confirm the validity of the scaling method and also to assist in drawing a conclusion. All these methods together derive a better pattern for arranging the rotating machinery in industries using gantry cranes to minimize the effect of base excitation on the crane. Although noticeable work has been done in the field of shaking table and studying gantry crane, very little work is reported which combines the use of scaling and prototyping in addition to modal analysis for understanding the proper dynamic motion of Gantry crane.

1. COMPUTATIONAL MODELLING AND MODAL ANALYSIS

The proposed system is schematized in Fig 1. A prototype of E-series Gantry Crane is designed by scaling an original model manufactured by SPANCO Inc.

Knowing the required characteristics of the model, its three-dimensional numerical model has been created in SOLIDWORKS software using two-dimensional shell elements to model columns and beams as shown in Figure 1. The numerical model consists of a hoist beam, 2 square columns, 4 square pipe gussets, 4 casters with mounts and 2 steel plates. The material used for fabrication of crane is mild steel having density $7.70 \frac{g}{cm^3}$. The dimensions of the crane have been determined in the design process after taking a scaling ratio of 1:10 in order to fit the required natural frequency and mass. After the numerical modeling and design, detail drawings were prepared to reflect the design requirements of the prototype.

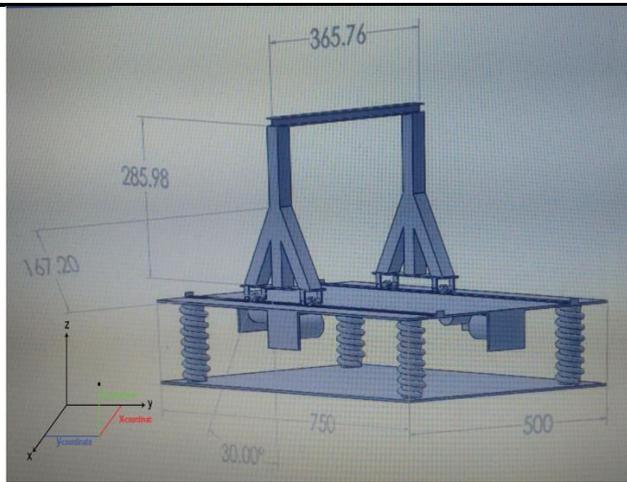


Fig 1 Computational model

Moreover, modal analysis of the setup was performed in ANSYS software to figure out the natural frequency. As illustrated in Fig 2 the natural frequency of the setup in mode 6 which is for the deformation in up and down swiveling motion of the table is 33.33 Hz.

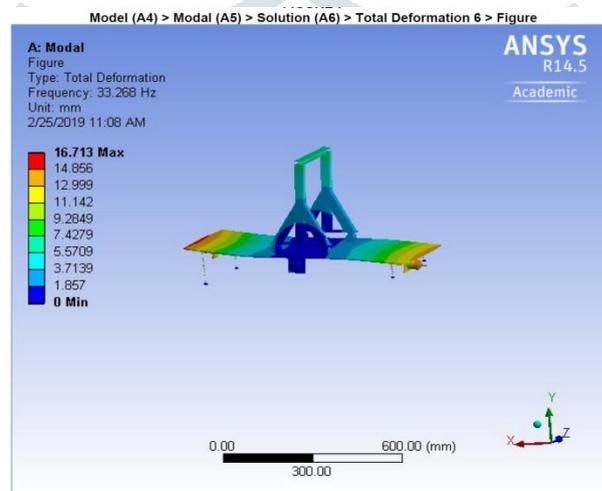


Fig 2 Modal Analysis

II. DEVELOPMENT OF EXPERIMENTAL SETUP

Construction details and arrangement of the prototype are illustrated in Fig 3. Thereafter, the detailed drawings were passed on to the engineering workshop where the steel plates and columns were cut and drilled according to the construction detailed drawings and they were welded together and the castors were mounted at equal distance on the bottom steel plates.

In the shaking table phase, a mild steel plate of 5mm thickness was procured and set as a top plate while a wooden plate of 19mm thickness was considered as the base plate. Afterward, the plates were assembled using 4 stainless steel springs (stiffness $K=5.38$ KN/m) at each corner using metal screws with 5-mm diameter and washers. Henceforth, to produce vibrations on the table, 4 D.C. motors with unbalanced weight on their shaft were clamped at the ends of 2 centerlines passing through the middle of the table. The maximum speed of the motors was 1000 r.p.m. and a D.C. controller was connected with them to regulate their speed. The mass of the model, without the wooden base plate, was measured to be 20kg.

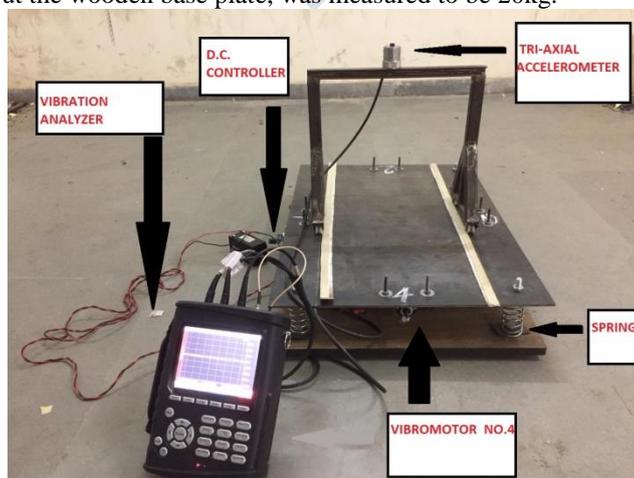


Fig 3 Experimental setup

Further, the industrial crane experiences base excitation from every direction and hence to create a similar situation the motors situated underneath the top plate of shaking table are switched on and off in various combination. As shown in Fig 1 the direction along the length of the table is an X direction and the direction along the width is Y direction. Motors are operated in sequence

(1,3), (2,4) and (1,2,3,4) and the speed is varied with the controller. Data acquisition has been done using the latest Vibration analyzer Coco80 which consists of one piezoelectric accelerometer (tri-axial) used for picking up the vibration signals from various stations on the test rig. This special piezoelectric pickup type of sensor has a frequency range of 1-30 KHz, measurement range +/- 500g peak, resolution of 0.005 g and a resonant frequency of 70 KHz. Both the sensor and vibration analyzer were installed on the set-up fabricated and a trial run was done. Vibration responses were acquired and analyzed by the analyzer with 3 input channels and a sampling rate of 3.2 KHz.

The accelerometer is firstly placed on the crane top and then on the table top and the vibration response analysis of developed shaking table with a prototyped crane at different operating conditions have been analyzed using FFT, Time Response and Orbit Plot.

III. RESULTS AND DISCUSSION

Data was gathered from the digital analyzer and FFT, Time Response and Orbit Plots for the crane and the table were prepared for 3 different combinations of the vibromotors. The 3 different combinations for generation of base excitation are,

- 1) Motors 1 and 3 are on,
- 2) Motors 2 and 4 are on,
- 3) Motors 1,2,3,4 are on.

Amplitude in x and z-direction along with the significant FFT response for each modulated base excitation frequency produced when a probe is placed on the crane for combination 1 (1,3) is depicted in Table 1. The modulated frequency (Mf) is the summation of the natural frequency of a prototype with the rotating frequency. Calculation of rotating frequency is based on the equation,

$$f = \frac{N}{60} \text{ sec, where } N=r.p.m$$

TABLE 1 CASE STUDY WHEN PROBE IS ON THE CRANE FOR POSITION (1,3)

MODULATED BASE EXCITATION FREQUENCY (Mf) (Hz)	AMPLITUDE (DISPLACEMENT) (mm)		SIGNIFICANT FFT RESPONSE (Hz)	
	<i>x- direction</i>	<i>z- direction</i>	<i>x- direction</i>	<i>z- direction</i>
50	18.3, -18.7	37.9, -37.3	21, 39, 92	21, 39, 92
46.66	12.4, -13.8	38.5, -41.9	19, 53, 98	19, 56, 201
41.66	8.91, -11.4	17.5, -16.7	11, 22, 91	11, 22, 44
36.66	13.8, -14.4	21.3, -19.8	20, 43, 90	43, 88, 170

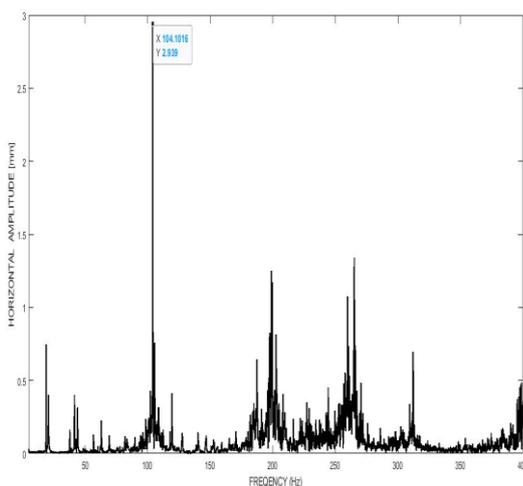


Fig.4 @49.93 Hz plate fft Z axis

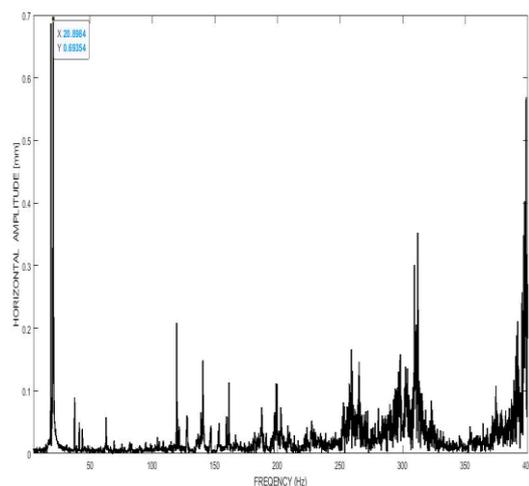


Fig.5 @49.93 Hz plate fft X axis

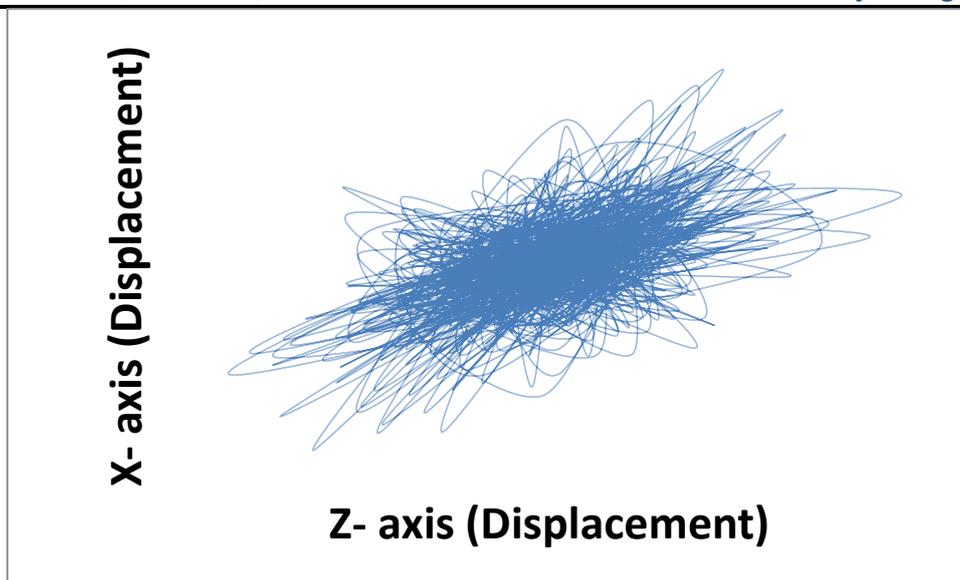


Fig. 6 Orbit Plot plate@49.96Hz Mf

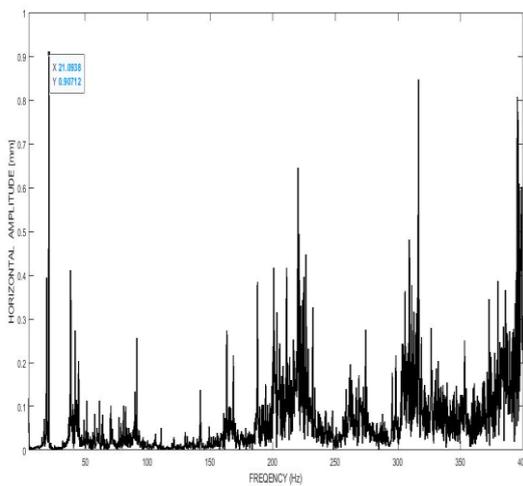


Fig. 7 @49.93 Hz Crane fft Z axis

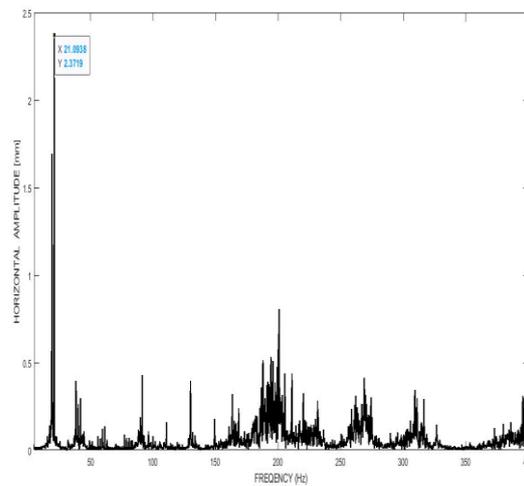


Fig. 8 @49.93 Hz Crane fft X axis



Fig. 9 Orbit Plot Crane @49.96Hz Mf

The FFT, Time Response and Orbit Plot graphs for each modulated base excited frequency were developed and after thorough analysis, several results were prepared. FFT and in the X direction at 49.96Hz are illustrated in Fig 4 and 5. Also, the trend followed in the Z direction for the same situation is similar to this trend which can be confirmed from Table 1 as well. Fig 6 is the FFT at Mf of 49.96Hz in an X direction. The maximum peak occurs at much high frequency which is a clear indication of abrupt chaotic motion of the system under this Mf. Moreover, the orbit plot in Fig 7 displays a scattered representation of the points which is unevenly distributed in 4 quadrants and hence it supports the previous result that the system is undergoing a chaotic motion.

IV. CONCLUSION

The conclusions in the study are summarized below

1. A significant response is observed at $(X+0.1W_n)$ Hz and it is harmonic.
2. From the above relation $(X+0.1W_n)$, the value of the base excitation can be determined. Where W_n is the natural frequency of the structure and X is the base excitation frequency.
3. It is recommended to design or maintain the structure to adjust the base excitation frequency above 8.33Hz till 16.67Hz.
4. As the base excitation increases from 8.33Hz to the 13.33Hz system shows chaotic behavior, so, the base excitation frequency of 13.33Hz should be strictly avoided.
5. Position 1-3 is recommended, as FFT on crane clearly shows $(X+0.1W_n)$ with super harmonic response.

Observing the FFT response in combination 1(1,3) @modulated frequency of 50Hz has shown super harmonic motion response, while the FFT response in combinations 2(2,4) and 3(1,2,3,4) @modulated frequency of 50Hz has shown a superharmonic route to chaotic behavior. Hence, it is advisable to design the layout of the structure to avoid the later combinations of base excitations.

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