

Element size effect on the analysis of heavy-duty machine cross-rail

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Abstract. Heavy-duty gantry machine plays an important role in the energy, shipbuilding, aerospace, transportation and military industry and other pillar industries, and is a manifestation of national equipment manufacturing capacity. Cross-rail is one of the key structural components, and its natural frequency affects the dynamic performance of the machine. It is difficult to obtain the accurate analysis of natural frequency by using the analytical method because of the complex internal structure. The finite element method is a general method to obtain natural frequency, but, is also difficult to obtain the precise result, because the analysis result depends on many factors, such as meshing manners, the constraint conditions, joint parameters, damping, and so on. The density of mesh is an important factor to affect the analysis result especially. Theoretically, the smaller element, the closer to the true result. But more dense grid could sharply increase the degree of freedom, and result in the insufferable solving speed in the analysis of the cross-rail. So to find a balance point between the speed and the accuracy becomes very meaningful. In this paper, the modal analysis was carried out on the cross-rail. The paper focus on exploring the influence of different element size on the results of the analysis. In order to verify the correctness of the modeling, the modal testing is carried on the cross-rail, and the experimental result is adopted to prove the correctness of finite element modeling.

1. Cross-rail free modal finite element analysis

1.1 The cross-rail profile:

Cross-rail on this study is about 15 meters, and the quality is 99.716 tons, as shown in figure 1-1. The global coordinate system is as following. Anti-gravity is the Z direction, Y is the longitudinal direction, front and rear direction is X direction.

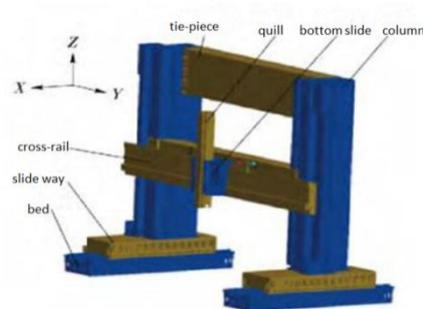


Fig. 1-1 CNC heavy-duty gantry machine and global coordinates

The cross-rail material is QT600. The property of the cross-rail material is as showing in table 1-1

Table 1-1 Cross-rail material parameters

Density (kg/m ³)	Young's modulus (GP)	Poisson's ratio
7200	174	0.275

1.2 FEM element selection:

The analysis tool of FEM is Ansys. Solid185 element is adopted to mesh the cross-rail. Solid185 entity structure applicable to the general three-dimensional structure modeling, it can be to prism, tetrahedron and pyramid for degradation, the element is shown in figure 1-2.

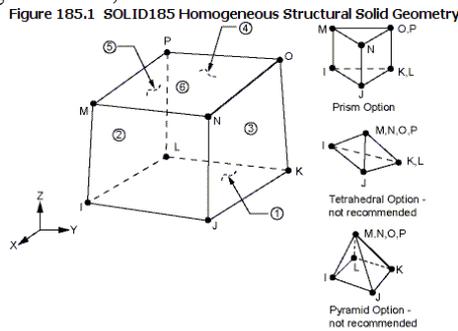


Fig.1-2 Solid185 element and degradation

Solid185 element is defined by eight nodes, and each node has the X, Y, Z three directions of the translational degrees of freedom. The element has a super elasticity, stress players, creep, large deformation and large strain capabilities. Stress output of Solid185 elements as shown in figure 1-3.

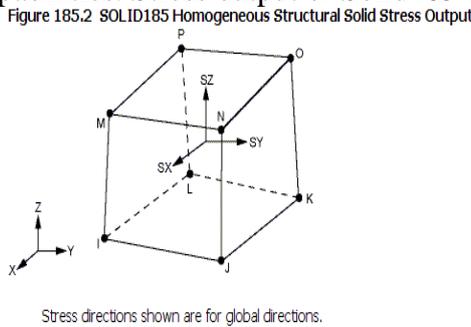
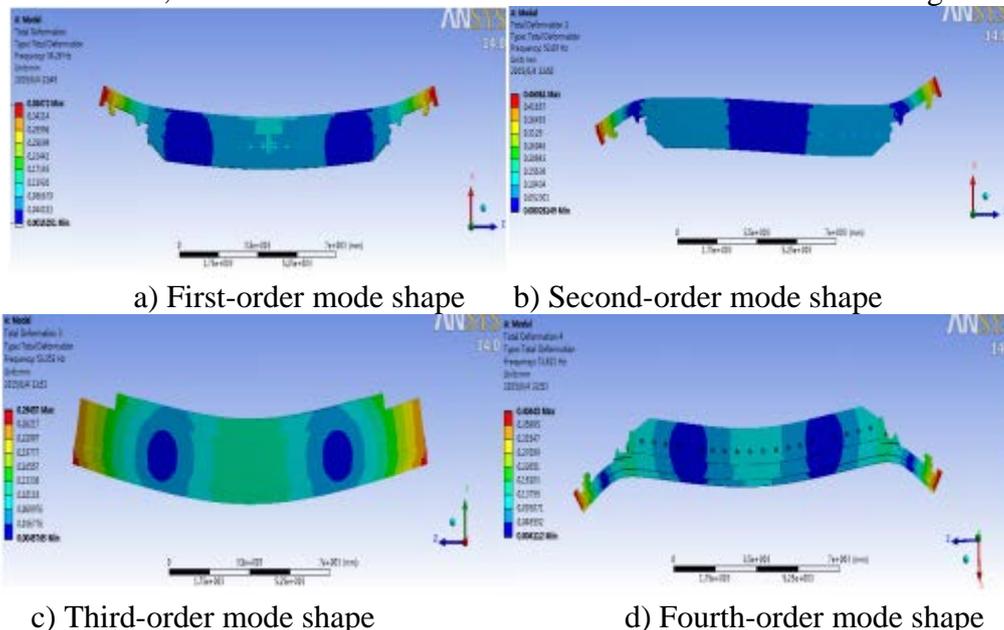
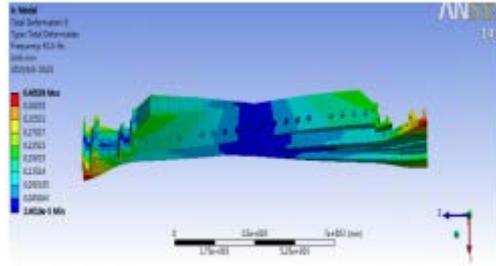


Fig. 1-3 Stress output direction of the Solid185 element (SX, SY, SZ)

1.3 Effect of element size on modal analysis:

Adopting the automatic meshing method. In the condition of completely free-free, modal analysis was carried out on the cross-rail, not imposed any constraint. Since cross-rail is in a free-free state, the first six orders vibration belongs to the rigid body motion, so the natural frequency is zero. Beginning with 7th frequency values, namely that the 7th order as the first order modal. Studies have shown that the size of the element will largely influence the finite element simulation result. It is necessary to control the grid size to achieve ideal result. At first , taking the element size of 30 mm , and the first 5 order modal simulation result is shown in figure1-4.





e) Fifth-order mode shape

Fig. 1-4 First 5 order mode simulation results of cross-rail

Then element size selection in turn: 200 mm, 150 mm, 100 mm, 90 mm, 80 mm, 70 mm, 60 mm, 50 mm, 45 mm, 40 mm, 35 mm, 30 mm. 12 groups of data is obtained by 12 kinds of element size. The element size on the result of modal analysis is shown in figure 1-5.

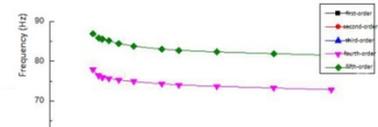


Fig.1-5 Cross-rail frequency change with element number

Simulation data shown in table 1-2.

Table 1-2 Modal frequency under different meshing method

Element size (mm)	Node number	Element number	Each order modal frequency (Hz)				
			1	2	3	4	5
200	300657	167383	35.955	54.911	57.033	78.808	87.228
150	325315	183397	35.781	54.989	56.256	77.895	86.860
100	359314	201989	35.483	54.707	54.994	76.367	85.826
90	387562	218533	35.396	54.625	54.713	75.906	85.509
80	422726	238682	35.290	54.402	54.512	75.649	85.107
70	493003	277825	35.142	54.121	54.302	75.264	84.441
60	582564	327561	34.984	53.851	54.072	74.911	83.777
50	739184	416595	34.767	53.359	53.829	74.327	83.035
45	878327	498193	34.656	53.066	53.727	73.997	82.717
40	1044618	595583	34.558	52.804	53.605	73.679	82.326
35	1339415	768650	34.426	52.480	53.466	73.277	81.891
30	1652491	950384	34.280	52.090	53.352	72.821	81.500

2. The experiment measuring cross-rail modal data

Test location: Some machine tool plant

Test content: The natural frequency, vibration mode and damping ratio of the cross-rail

Modal testing equipment: The experiment use the exciter method to motivate, vibration exciter can make uniform distribution of energy in the structure. Incentives for a point of the cross-rail, you can get multiple batches of response data, so you can get a very good response data in a very short period of time. Adopting sinusoidal scanning incentive structure, HEV - 200 vibration exciter – the largest exciting force is 200 N. Using LMS vibration test and analysis system and its supporting PCB acceleration sensor. The principle of testing is shown in figure 2-1.

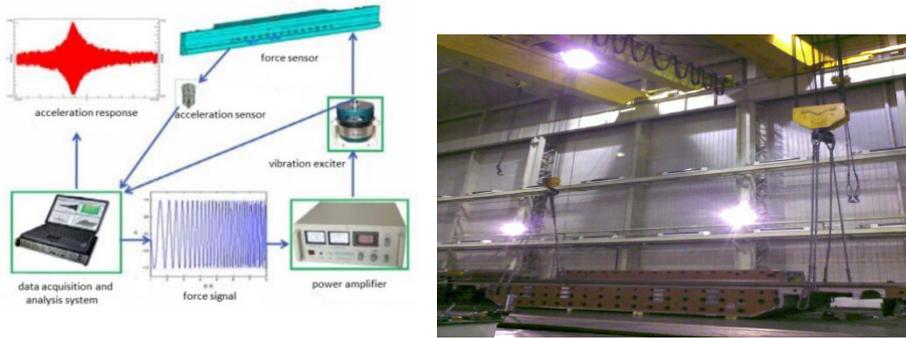


Fig. 2-1 Sine scanning excitation test principle

Cross-rail is lifted by the crane so as to make it in the free state . Incentive cross-rail with the front and rear position. The placement of the cross-rail、 exciting point and measuring points as shown in figure 2-2.

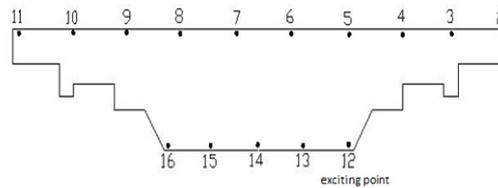


Fig. 2-2 The placement of the cross-rail、 exciting point and measuring points

Using the dynamic frequency sweep method for scanning cross-rail. First is sweep roughly, Set incentive frequency range as follows: 5 Hz - 100 Hz, exciting force is about 120 N, scanning speed is 0.08 Hz/s. Probably sweep time required to complete a measurement for 20 minutes. Through software for frequency response function of LSCE computing the natural frequencies of the cross-rail, further to the damping of the cross-rail at the natural frequency. Combining all the stimulation test results, the natural frequency of the cross-rail and damping ratio are shown in table 2-1:

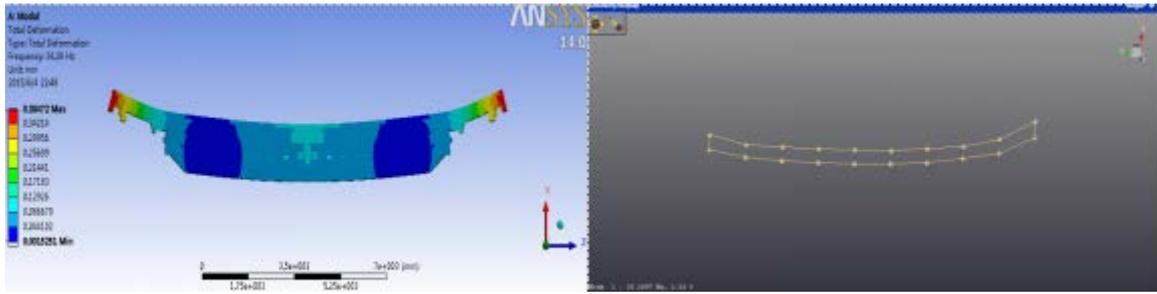
Table 2-1 Natural frequency and damping ratio

Natural frequency (Hz)	Damping ratio
31.72	0.0021
48.70	0.0053
54.76	0.0020
74.84	0.0013
82.12	0.0025

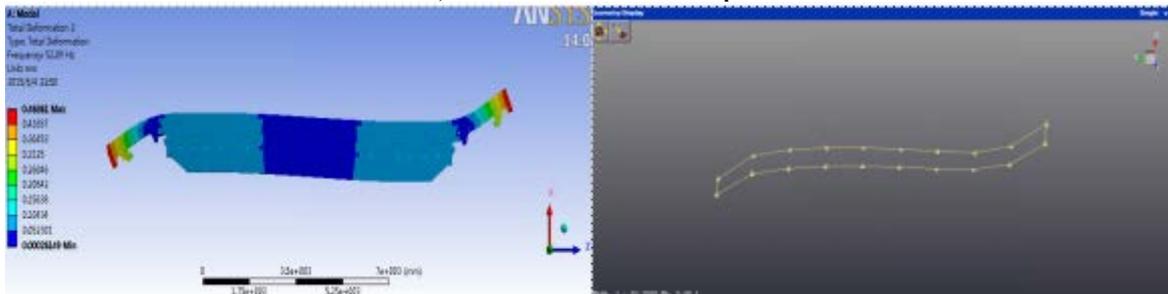
3. The experimental data and the simulation results

3.1 Contrast mode

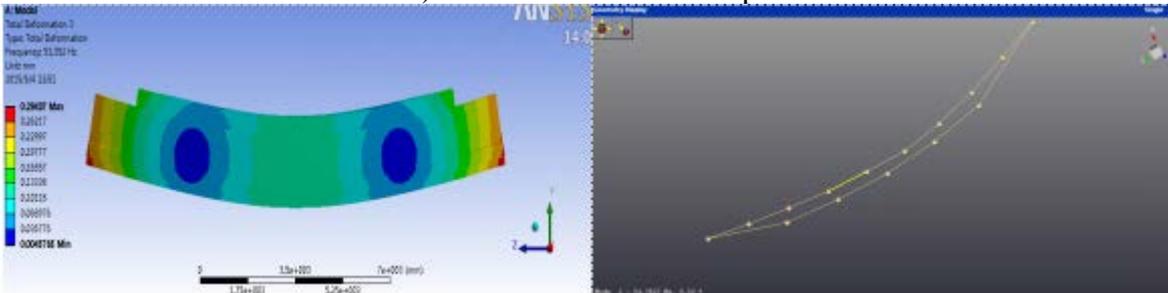
The result of the experiment and the simulation result are shown in figure 3-1. The left is the simulation result and the experiment result is on the right.



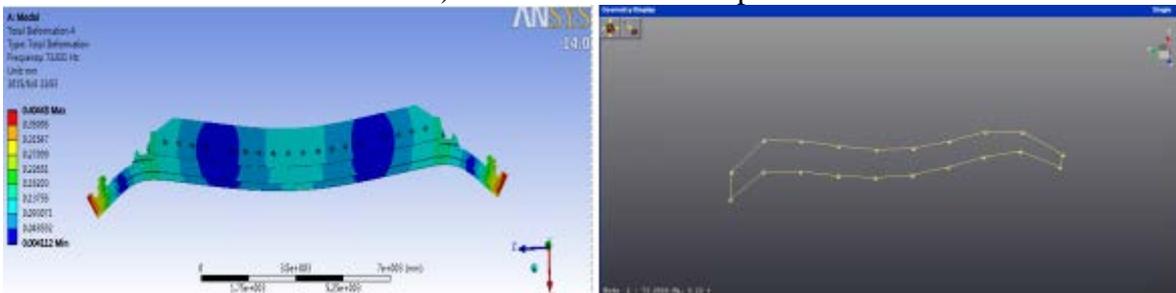
a) First order mode shape



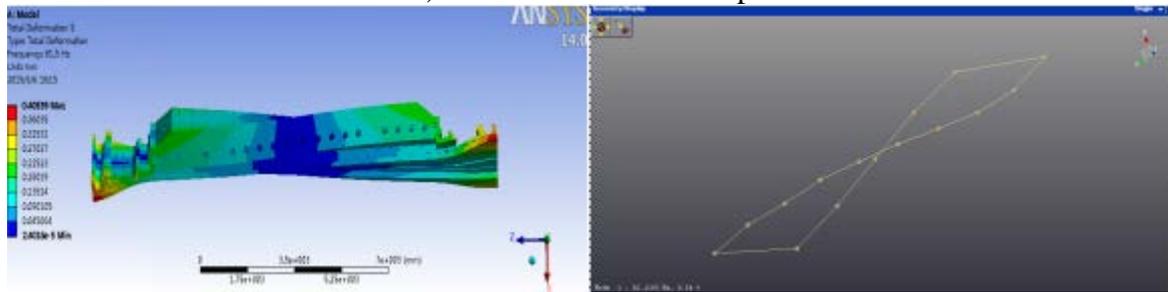
b) Second order mode shape



c) Third order mode shape



d) Fourth order mode shape



e) Fifth order mode shape

Fig. 3-1 Cross-rail first 5 order modal experiment and the simulation results

3.2 Contrast the simulation natural frequency and the natural frequency of the experiment

It is easy to see that two kinds of modes are basically the same. Then contrasting the natural frequency error obtained by simulation and experimental data, the results are shown in Table 3-1 and Table 3-2

Table 3-1 Element size is 30 mm simulation error

The experimental value (Hz)	The simulation value (Hz)	The percentage error (%)
31.72	34.28	8.07
48.70	52.09	6.96
54.76	53.35	-2.57
74.84	72.82	-2.70
82.12	81.50	-0.7

Table 3-2 Element size as the default simulation error

The experimental value (Hz)	The simulation value (Hz)	The percentage error (%)
31.72	36.92	16.39
48.70	55.45	13.86
54.76	60.89	11.19
74.84	83.51	11.58
82.12	89.61	9.12

It can be seen that the result between the experimental and simulation results match better, when the element size is equal to 30 mm.

4. Summary

The element size effect of modal analysis on the cross-rail is described. First, different element size is adopted to mesh the model of cross-rail, and then the cross-rail mode is analyzed. The analysis result is compared with the experimental results. When the element size decreases, namely the increase of grid density, each order natural frequency of the cross-rail will decrease, and more and more close to the experimental value. When the size is close enough, the simulation results will converge to the true value. When the element size is at the default value in Ansys, the first-order natural frequency and the error between the experimental value is as high as 16.39%. And when the element size is 30 mm, the natural frequency error fell by nearly half. Thus the element size had a great influence on the result of cross-rail modal analysis. At the same time, the simulation and experimental results in terms of natural frequencies or modes are basically the same, so the cross-rail finite element modeling method is feasible. The smaller the element size need the higher requirement for equipment processor, The element size of 30mm has been able to better match to the experimental results, and the subsequent analysis adopt the size of 30 mm.

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