Dynamic Characteristics Analysis and Structural Noise Prediction of Bridge Crane

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Abstract. Taking the gear time-varying mesh stiffness, damping, transmission error and so on into consideration, and calculate stiffness excitation, error excitation, meshing impact excitation of every gear pair, to determine the internal dynamic excitation of gear system. Establish a dynamic finite element model of a coupled gear-rotor-bearing-housing gear system, and obtain the vibration displacement, velocity and acceleration of the gear system by modal superposition technique method, so as to predict structure noise accurately. The results show that the frequency response and the peak value of the structure noise all appear at gear meshing frequency and their multiples. In fact, this method can not only understand the comprehensive vibration characteristics of the bridge crane, but also provides a necessary foundation for the vibration and noise reduction design of gear system.

Introduction

Crane as the main loading and unloading machinery, widely used in machinery manufacturing, iron and steel industry, rail transport, port terminal, logistics and other departments and places. As a main type of crane, bridge crane, due to the small area, can be used in the whole plant area of the rectangular space within the crane and transport operations, is well received by users. The internal dynamic excitation of gear system caused by gear meshing stiffness, tooth surface machining error and installation error is an important reason for the vibration and noise, influence bridge crane comprehensive performance seriously. Therefore, research on dynamic characteristics of bridge crane has a great engineering value for vibration and noise reduction design of gear systems.

Since the beginning of the 20th century, the domestic and foreign scholars have adopted various methods to study the vibration response of the gear system. Parker [1] using finite element method to analyze the dynamic response of gear pair, the dynamic response of different speed and torque is analyzed, and the calculated results are in good agreement with the experimental results. Sun [2] using lumped parameter method to establish the 2K-L type planetary gear transmission nonlinear dynamics model coupling flexural and torsional, through the differential motion equations of the system, research a numerical harmonic balance method for solving the multi order harmonic response. Bonori [3] using the harmonic balance method to solve the nonlinear vibration of the normal gear and the defective gear, and the influence of the tooth profile error on the vibration is studied. Lin [4] uses the finite element method to calculate the internal dynamic excitation, and on this basis, the vibration response simulation is carried out. Wang [5] set up a multi degree of freedom dynamic model of spiral bevel gears, and the dynamic response of the transmission system is studied by numerical simulation. Liu [6] use finite element method to analyze the dynamic characteristics of a new type of small teeth difference reducer, and the results are in good agreement with the experimental results. Lin [7] establish the nonlinear dynamics model of cone parallel axes planetary gear, and the nonlinear vibration characteristics of the system were studied by Runge-Kutta method.

In summary, the domestic and foreign scholars have made a lot of research on the dynamic response of the gear system, and achieved a lot of valuable research results, but the research on the vibration of bridge crane is very little. Therefore, this paper establishes the finite element analysis model coupling dynamic of the bridge crane, and then studies the vibration noise, which provides the necessary reference for the vibration and noise reduction of gear system.
Simulation of Internal Dynamic Excitation

Bridge crane reducer using four parallel shaft helical gear transmission structure form, through the motor drives the input shaft to rotate, and through four stages of parallel shaft helical gear drives the reel to rotate, thus realize power output, as shown in Figure 1. In order to obtain the dynamic characteristics of the gear system, the internal dynamic excitation of each gear pair should be numerically simulated at first.

![Figure 1. Bridge crane structural diagram.](image1)

![Figure 2. Internal dynamic excitation.](image2)

The internal dynamic excitation can be calculated by the following formula:

\[
F(t) = \Delta k(t)\cdot e(t) + S(t),
\]

where \(F(t)\) is internal dynamic excitation, \(\Delta k(t)\) represents variable part of mesh stiffness, \(e(t)\) is gear transmission error, \(S(t)\) means meshing impact force. The internal dynamic excitation can be obtained, as shown in Figure 2, which is solved by ANSYS.

Mode Analysis of Bridge Crane

The intrinsic modes of bridge crane gear system will be analyzed in this section based on the Block Lanczos method. In this paper, the main object of modal analysis is to see whether resonance response would occur.

The solid model of coupling system includes gear-rotor-bearing-housing with a total of 296487 elements and 129587 nodes being established by ANSYS Parametric Design Language (APDL), as shown in Figure 3. The support between shafts and bearings, and the relationship of gear meshing are simulated utilizing the spring elements to build the bearing coupling between the internal geared rotor assembly and housing structure.

![Figure 3. Finite element model.](image3)

![Figure 4. Evaluation point.](image4)

The modal analysis of the gear system is carried out by applying the zero displacement constraint on the side of the motor and the support at both ends of reel. Table 1 shows the first 10 order natural frequencies of the system, Figure 5 shows the first three mode shapes.

![Figure 5. Mode shapes.](image5)

<table>
<thead>
<tr>
<th>Mode no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency [Hz]</td>
<td>45.6</td>
<td>51.6</td>
<td>53.6</td>
<td>56.4</td>
<td>85.3</td>
<td>94.2</td>
<td>107.6</td>
<td>143.2</td>
<td>150.7</td>
<td>161.0</td>
</tr>
</tbody>
</table>
The first three mode shapes of the gearbox system are shown in Figure 5. The input speed of the bridge crane is 980r/min, and the rotational and meshing frequency can be calculated according to the gear parameters, as shown in Table 2. Compared with the modal analysis results, it can be seen that the low order natural frequency of the crane can avoid the rotating frequency and meshing frequency of the gear system, and the resonance phenomenon will not occur.

Table 2. The rotational frequencies and meshing frequencies of gear system.

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>Input shaft</th>
<th>Middle shaft I</th>
<th>Middle shaft II</th>
<th>Middle shaft III</th>
<th>Output shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational</td>
<td>16.33</td>
<td>4.14</td>
<td>1.17</td>
<td>0.34</td>
<td>0.08</td>
</tr>
<tr>
<td>Gear mesh</td>
<td>294</td>
<td>78.68</td>
<td>23.49</td>
<td>5.70</td>
<td>-</td>
</tr>
</tbody>
</table>

Dynamic Characteristics Analysis of Bridge Crane

The vibration response analysis of crane is based on the finite element model, which is used in mode analysis as well. The internal dynamic excitation is applied on the nodes of contact line, and the dynamic response is worked out by mode superposition method. In order to achieve a steady vibration response, the total calculate time of interest is chosen to be 600 ms with the time step of $\Delta t=0.034$ ms. The node of the 4 different positions of the bearing seat is a dynamic response evaluation point, as shown in Figure 4. Table 3, Table 4 and Table 5 respectively illustrate the root-mean-square (RMS) value of displacement, velocity and acceleration. The vertical direction (Y) vibration response in both time and frequency domain of point 2 is shown in Figure 6.

Table 3. The RMS values of vibration displacement.

<table>
<thead>
<tr>
<th>Node no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-direction</td>
<td>0.947</td>
<td>1.449</td>
<td>4.592</td>
<td>5.249</td>
</tr>
<tr>
<td>Y-direction</td>
<td>1.820</td>
<td>4.571</td>
<td>16.243</td>
<td>11.428</td>
</tr>
<tr>
<td>Z-direction</td>
<td>6.450</td>
<td>15.296</td>
<td>15.110</td>
<td>7.274</td>
</tr>
</tbody>
</table>

Table 4. The RMS values of vibration velocity.

<table>
<thead>
<tr>
<th>Node no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-direction</td>
<td>0.431</td>
<td>0.890</td>
<td>1.306</td>
<td>1.223</td>
</tr>
<tr>
<td>Y-direction</td>
<td>1.047</td>
<td>2.089</td>
<td>4.964</td>
<td>3.738</td>
</tr>
<tr>
<td>Z-direction</td>
<td>1.432</td>
<td>3.322</td>
<td>3.378</td>
<td>2.199</td>
</tr>
</tbody>
</table>

Table 5. The RMS values of vibration acceleration.

<table>
<thead>
<tr>
<th>Node no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-direction</td>
<td>0.440</td>
<td>1.753</td>
<td>1.443</td>
<td>1.208</td>
</tr>
<tr>
<td>Y-direction</td>
<td>1.755</td>
<td>1.963</td>
<td>2.981</td>
<td>3.486</td>
</tr>
<tr>
<td>Z-direction</td>
<td>1.404</td>
<td>2.989</td>
<td>2.591</td>
<td>3.954</td>
</tr>
</tbody>
</table>
The results show that the vibration response of the bridge crane shown signs of cyclical, and the peak value of the frequency domain concentrates in the meshing frequencies and their multiples.

One of the main purposes of vibration response of bridge crane is to study the vibration severity which can reflect the degree of vibration intensity of gear system. It can be expressed as

\[ V_s = \sqrt{\left( \sum \frac{V_X}{N_X} \right)^2 + \left( \sum \frac{V_Y}{N_Y} \right)^2 + \left( \sum \frac{V_Z}{N_Z} \right)^2}. \]

where \( V_s \) is vibration severity [mm/s]; \( V_X, V_Y, V_Z \) are X-direction, Y-direction and Z-direction effective values of vibration velocity response respectively [mm/s]; \( N_X, N_Y, N_Z \) are respectively amounts of nodes in X-direction, Y-direction and Z-direction.

Based on formula (2) and Table 4, the vibration intensity of bridge crane is 4.044 mm/s.

**Structural Noise Prediction of Bridge Crane**

The structural noise of gear system is another expression of gear box surface vibration, which can be divided into velocity and acceleration of the structure noise, the one-third octave acceleration grade for structure noise is defined as

\[ L_a = 20 \log \frac{a}{a_0}. \]

where \( L_a \) is the acceleration level one-third frequency harmonic structure noise [dB]; \( a \) is the effective value of the acceleration in the frequency range as the center [m/s^2]; \( a_0 \) is reference acceleration, \( a_0=1E+08 \text{ m/s}^2 \).

Figure 7 gives the Y direction acceleration level structure noise of evaluation points 1 and 2.
The results show that Y direction structure noise maximum values of evaluation point 1 and 2 is 122dB and 120dB, appear at the frequency of 3150Hz, and at 31.5Hz, 40Hz, 63Hz, 80Hz, 250Hz, 500Hz, 800Hz and 3150Hz exists peak value, mainly reflected every gear pair meshing frequency and their multiples.

Summary

(1) The finite element model coupled gear-rotor-bearing-housing has been established to calculate each order natural frequencies and the corresponding modes, the results show that the resonance phenomenon will not occur.

(2) Based on the internal dynamic excitation, the dynamic characteristics and structural noise of bridge crane is calculated. The results show that the peak value of the vibration frequency response and structural noise mainly concentrates in the meshing frequencies and their multiples, and the vibration severity of gear system is 4.044 mm/s.

Acknowledgement

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References


