Dynamic Characteristics Analysis of Blade of Fan Based on Ansys

Junjie Zhou, Bo Liu, Dingbiao Wang, Xiaoqian Li
School of Chemical Engineering Zhengzhou University Science Road NO.100 Zhengzhou 450001

Abstract: In this paper, the finite element model of blade of R40 axial-flow fan has been built, using this model, the dynamic characteristics of blade have been analyzed with Ansys software. We can get the first 10 natural frequencies of blade under rated and resonant operating conditions, and get the harmonic response of exciting force. The results show that R40 axial-flow fan runs stable under resonant operating conditions, resonance does not occur; the larger rotation speed can increase the natural frequencies of blade; the blade has the maximum response of the exciting force at 120Hz.

Key words: Blade; Finite Element; Dynamic; modal analysis; harmonic response

1 Introduction

Blade as an important component of fluid mechanical, its structure is reasonable or not directly affects the performance of the fan, while the advantages and disadvantages of blade performance are mainly reflected in the static and dynamic characteristics [1].

Blade will be affected by centrifugal force and steady or unsteady flow force, unsteady flow force is the main source of excitation among the all of the force. If the blade occurred bending and torsion deformation under the action of the exciting force, the deformation will lead to aerodynamic of blade change. When the interaction between air force and mechanical vibration is reduced, the motion is stable, otherwise vibration and unstable movement will occur. Blade Vibration will generate dynamic stress, resulting in blade fatigue, or even rupture [2-4]. Therefore, it is great significance to analyze the dynamic characteristics of the fan blades.

Structural Dynamics Analysis is to study the natural frequencies and mode shapes of blade [5], analyze and predict dynamic response of blade under the loads to avoid resonance. In this paper, the finite element model of blade of R40 axial-flow fan has been built, using this model, the dynamic characteristics of blade have been analyzed with Ansys software. We can get the first 10 natural frequencies of blade under rated and resonant operating conditions, and get the harmonic response of exciting force.

2 Blade finite element model and mesh

2.1 Study object

In this paper, the blade of R40 axial fan is used as researched object. Blade is CLARK-Y airfoil, its relative thickness is 12%. The speed of work is 1440rpm. The parameters of blade control section shown in Table 1. Material of blade is FRP, and Density is 2600kg/m3. Elastic modulus is $7.2 \times 10^7$ MPa, Poisson ratio is 0.3.

<table>
<thead>
<tr>
<th>parameters</th>
<th>control section</th>
<th>$r/R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chord C/m</td>
<td>0.356 0.4 0.5 0.6 0.7 0.8 0.9 1.0</td>
<td>0.1392 0.1280 0.1223 0.1103 0.0977 0.0869 0.0795 0.0724</td>
</tr>
<tr>
<td>Torsion angle</td>
<td>32.2° 25.0° 22.3° 18.4° 15.7° 13.8° 12.3° 11.1°</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. the parameters of blade control section

The model of blade is defined by parameters of control section, we can establish blade model by surface connection. Therefore, in the modeling process, using the point to a line and then to plane, to the body modeling [6]. The model of blade is shown in figure 1.

2.2 Finite element equation

In this paper, we selected Solid 186 to discrete unit of blade (The dispersed grid shown in Figure 2). Solid 186 is a high-end 3D solid unit which has 20-nodes, it with quadratic displacement model can better simulate
the irregular grid. Unit defined by 20 nodes, each node has three translational degrees of freedom along the xyz directions. Solid 186 can have any spatial anisotropy, unit support plastic, super-elastic, creep, and has the ability to simulate large deformation and large strain.

The balance equations of blade under the centrifugal force field are as follows:\(^\text{[7]}\):

\[ \sum \int [B]^T \sigma d\mathbf{v} - \sum \int [N]^T f d\mathbf{v} = \sum \int [N]^T p d\mathbf{x} + \sum [R]^e \]  

\[ (1) \]

- \( [B] \) — strain matrix  
- \( \{\sigma\} \) — stress vector  
- \( [N] \) — shape function matrix  
- \( \{f\} \) — inertia force vector per unit volume  
- \( [p] \) — pressure per unit area  
- \( \{R\}^e \) — node concentration loading vector  

The finite element equation is:

\[ [M]\{\delta\} + [C]\{\dot{\delta}\} + ([K] - \Omega^2 [M_c])\{\delta\} = [Q_c] + [P] - [F_{\alpha}] + [R] \]  

\[ (2) \]

- \( [M] \) — total mass matrix  
- \( [C] \) — damping matrix  
- \( [K] \) — stiffness matrix  
- \( [M_c] \) — centrifugal force matrix

2.3 Examination of grid independence

In the differential equations discrete process, the discrete error would be introduced. For the same discrete scheme, discrete error is usually reduced with the dense of grid increased\(^\text{[8]}\). As the computer resource constraints, we can not get very fine mesh, but the need to ensure that the result of numerical is independent to grid.

In this paper, three grid systems were used. Element edge length is 0.01, 0.0075 and 0.006; Spacing between two adjacent grid system level changes is large enough, the blade first mode and relative stress along X-axis is calculated. The results are shown in Figure 3 and Figure 4.

As can be seen from Figure 3, the result of first mode calculated using different nodes number not change significantly. With the increase of nodes number, the result of first mode calculated by two adjacent grid systems is more similar. Figure 4 shows that the result of relative stress along X-axis has a little difference, but the difference is very small when element edge length is 0.0075 and 0.006. Therefore, we believe that Element edge length = 0.0075 has been to meet the requirement of accuracy, and can be obtained the result independent to grid.

3 Result analyses

3.1 Static mode analysis

The root of blade was bound completely. Using
Lanczos method to calculate the first 10 natural frequencies of blade, the results shown in Figure 5.

Figure 5. The first 10 natural frequencies of blade

Figure 6 shows first two vibration mode and a relative stress of the leaf blade. As can be seen from figure, when the frequency of the leaf is 120.99Hz, first-order resonance will occur, the main form of first-order resonance is wave vibration, the closer to the tip of the site, the greater amplitude is, maximum dynamic stress appears in blade root; when the frequency of the leaf is 464.59Hz, second-order resonance will occur, the main form of second-order resonance is shimmy, the tip and the central of the blade have larger amplitude, dynamic stress will mainly concentrate in the location of near the blade root and from 1/3. Because the process of movement of the blade is affected by the first two bands vibration, roots and the upper is prone to fatigue and even appears crack or fracture. In practice, from the collected fracture fragments of leaves, we can see most of the fracture appear in the two places of above-mentioned\(^9\), the result is proved correct.

![](a First-order mode shape and relative stress (120.99Hz)

![](b Second-order mode shape and relative stress (464.11Hz)

3.2 Modal analysis of a pre-stress

In the process of rotation, blade is affected by centrifugal force. Load centrifugal force on blade as Pre-stress and calculate the first 10 natural frequencies of blade in different speeds. The result is shown in Table 2. As can be seen from Tab.2, with the speed increase, the natural frequency of blade also will become larger, which is due to stiffness matrix \( K \) increase.

The frequency of exciting force is: \( N \times \frac{n}{60} \) (3)

Where: \( N \) indicates the number of blade, \( n \) indicates the speed of fan per minute. As can be seen from the formula, when the working speed of the fan is 1440rpm, the frequency of the exciting stress is 96Hz, this frequency is difference more than 15% to first-order natural frequency(126.33Hz). The fan runs stable, resonance does not occur. With the increasing speed of fan, the frequency of the exciting stress gets larger, when the speed increased to 2000rpm, its frequency is 133.33Hz, this frequency is closer to the first-order natural

<table>
<thead>
<tr>
<th>speed order</th>
<th>0rpm</th>
<th>1440rpm</th>
<th>1750rpm</th>
<th>2000rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120.99</td>
<td>126.33</td>
<td>128.8</td>
<td>131.09</td>
</tr>
<tr>
<td>2</td>
<td>463.11</td>
<td>467.82</td>
<td>470.05</td>
<td>472.14</td>
</tr>
<tr>
<td>3</td>
<td>783.85</td>
<td>785.51</td>
<td>786.3</td>
<td>787.05</td>
</tr>
<tr>
<td>4</td>
<td>1033.5</td>
<td>1034.7</td>
<td>1035.3</td>
<td>1035.8</td>
</tr>
<tr>
<td>5</td>
<td>1269.6</td>
<td>1273.9</td>
<td>1275.9</td>
<td>1277.9</td>
</tr>
<tr>
<td>6</td>
<td>1963.0</td>
<td>1964.2</td>
<td>1964.7</td>
<td>1965.2</td>
</tr>
<tr>
<td>7</td>
<td>2218.0</td>
<td>2222.6</td>
<td>2224.8</td>
<td>2226.9</td>
</tr>
<tr>
<td>8</td>
<td>3048.3</td>
<td>3050.1</td>
<td>3051.0</td>
<td>3051.8</td>
</tr>
<tr>
<td>9</td>
<td>3157.7</td>
<td>3159.3</td>
<td>3160.1</td>
<td>3160.8</td>
</tr>
<tr>
<td>10</td>
<td>3563.9</td>
<td>3567.6</td>
<td>3569.3</td>
<td>3571.0</td>
</tr>
</tbody>
</table>
frequency \((131.09\text{Hz})\), blades will occur unstable vibration and affect the aerodynamic performance of the blade and reduce the efficiency of fan. If fan runs under this condition in long-term, the blade will fatigue and easily appear crack or even fracture. Therefore, when adjust to the speed in the actual operation process, we should take full account of the natural frequency of blade, avoiding resonance and extending the service life of fans.

3.3 Harmonic response analysis of exciting force

Application of computational fluid dynamics software Fluent to simulate the flow field, we can get the exciting force on blade is 140.9N. Load exciting force on blade and calculate response displacement and stress. The results are shown in Figure 7 and Figure 8.

As can be seen from the figure7 and figure 8, the maximum displacement response to exciting force is 0.919 mm, the maximum stress value of 14.8MPa. The maximum stress is lower than the allowable stress of the material and meets the design requirements.

With the changes of the exciting force frequency, Figure 9 shows us point A on the blade response displacement size, as we can see from the picture, when exciting force frequency increases from 110Hz to 120 Hz, point A radial response displacement increases dramatically, when exciting force frequency adds to 140Hz, point A radial response displacement decreases dramatically, so we can make sure that resonance occurs in nearby 120Hz and point A radial response displacement is 5.72mm now, it is 36.9 times of exciting force frequency in 96Hz correspondence response displacement(0.155mm). Figure 10 shows us point B on the blade response force size when exciting force frequency changes, its tendency is similar to Figure 9 and maximum response stress 25.7226Mpa, it is 27.65 times of frequency in 96Hz correspondence response stress(0.90423Mpa).

4 Conclusions

In this paper, the dynamic characteristics of blade have been analyzed with Ansys software. We can get the first 10 natural frequencies of blade under rated and resonant
operating conditions, and get the harmonic response of exciting force. The following conclusions can be drawn:

(1) R40 axial-flow fan runs stable under resonant operating conditions, resonance does not occur. The maximum stress is lower than the allowable stress of the material and meets the design requirements.

(2) The larger rotation speed can increase the natural frequencies of blade. In actual operation, we should fully consider the impact of natural frequency to avoid resonance.

(3) The blade has the maximum response of the exciting force at 120Hz.

References


