Analysis of dynamic characteristics of thin-walled parts based on finite element method

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Abstract. In order to study the stiffness and dynamic characteristics of thin-walled parts of different types and sizes, this paper is based on the finite element method for modal analysis of thin-walled flat parts and thin-walled curved parts. According to the first four natural frequencies and mode shapes of thin-walled parts under different height and thickness parameters, a frequency comparison chart of thin-walled parts with different heights and thicknesses was drawn, and the influence of different types of thin-walled parts and different heights and thicknesses on the frequency and vibration mode of thin-walled parts was obtained. Experimental results show: (1) With the thickness increases, the natural frequency of thin-walled parts gradually increases and with the height increases, the natural frequency of thin-walled parts gradually decreases; (2) Under the same height and thickness, the natural frequency of curved thin-walled parts is greater than that of flat thin-walled parts; 3) The change of the height and thickness of the thin-walled parts has a greater influence on the frequency changes of the flat thin-walled parts than on the curved thin-walled parts.

1. Introduction
Aluminium alloy 6061 has good plasticity, good weldability and medium strength, and is widely used in aerospace, machinery manufacturing, precision instruments and automobile manufacturing industries[1,2,3]. However, due to the low rigidity and variability of thin-walled parts, it is easy to produce processing deformation and processing vibration in the actual milling process[3,4], and has a great influence on the tool life and the dimensional accuracy and surface quality of thin-walled parts[2,5].

Shi Dongyan[6] and others verified that the Lanczos algorithm is a faster calculation method than the subspace iteration method and mode shapes obtained in the modal analysis of the solid element and the shell element are basically the same based on ABAQUS. Wang Xiao[7] and others used ABAQUS to simulate and analyze the natural frequency and vibration mode of GH4169 superalloy thin-walled plate. Experimental results show that in the same model, the area of the vibration zone of thin-walled parts increases with the increase of thickness, and increases with the increase of height.

At present, in terms of rigidity and vibration characteristics of thin-walled parts, further analysis is needed to obtain the natural frequency and mode shape of mechanical parts. Based on ABAQUS software, using finite element method for analysis can improve the accuracy of analysis and increase processing efficiency. Based on the modal analysis module of finite element, in this article, the modal analysis of different heights and thicknesses and different types of aluminium alloy 6061 thin-walled parts was carried out and more accurate vibration characteristics of each thin-walled part were obtained.
2. Thin-walled parts model and finite element model processing

2.1. The establishment of three-dimensional model of thin-walled parts

Establish models of flat and curved thin-walled parts in CATIA, as shown in Figure 1(a) and Figure 1(b).

Figure 1 Outline drawing of thin-walled parts

In this paper, each type of thin-walled parts adopts 6 kinds of thin-walled parts with different heights and thicknesses. The specific workpiece dimensions are shown in Table 1.

| Numbering | Plane thin-walled parts size | Curved thin-walled parts size |
|-----------|-----------------------------|------------------------------|
| Base      | 150×60×8mm                  | 150×75×8mm                   |
| Blade     | 150×90×4mm                  | 150×90×5mm                   |
|           | 150×90×4.5mm                | 150×90×5mm                   |
|           | 150×110×4mm                 | 150×110×4.5mm                |
|           | 150×110×5mm                 | 150×110×5mm                 |

2.2. Finite element model establishment of thin-walled plate

In this paper, the modal analysis of thin-walled parts is based on ABAQUS software. Import the three-dimensional model of thin-walled parts built in CATIA into ABAQUS. The Young's modulus of aluminum alloy 6061 is 69GPa, the density is 2.700e-9T/mm³, and the Poisson's ratio is 0.33. The mesh is shown in Figure 1(c). Add constraints to the four holes of the thin-walled part.

3. Modal analysis results and analysis

3.1. Modal analysis of plane thin-walled parts

The modal analysis of thin-walled part 1-6 was carried out respectively, and the first four-order mode and frequency of thin-walled parts were obtained. The vibration shapes of the thin-walled part 1 are shown in figure 2. The thing to note here is that because the first four-order mode changes of workpieces 2-6 are similar to those of thin-walled parts 1 considering space limitations, it will not be given here.

Figure 2(a) shows the first-order mode of the thin-walled part 1. Its first-order frequency is 406.14 Hz, and its mode shape is first-order bending. Because the flat thin-walled part is a cantilever beam structure, according to the physical properties of the cantilever the farther away from the restraining end, the greater the deformation.

Figure 2(b) shows the second-order mode of the thin-walled part 1. Its second-order frequency is 682.95 Hz, and its mode shape is torsional deformation around the Z axis. Because the rigidity of the
two ends of the blade of the thin-walled part is less than the rigidity of the middle of the blade, the top of the two sides of the thin-walled part is easier to deform than the middle of the thin-walled part, and the largest deformation occurs here.

Figure 2(c) shows the third-order mode of the thin-walled part 1. Its third-order frequency is 1466.7 Hz. Because the position of the maximum rigidity of the thin-walled part is at the center of the connection between the blade and the bottom plate of the thin-walled part, the thin-walled part produces torsional deformation centered on the point of maximum rigidity and bending deformation along the Y-axis.

Figure 2(d) shows the fourth-order mode of the thin-walled component 1, and its fourth-order frequency is 2504.8Hz. The middle position of the thin-walled piece produces deformation along the Y-axis, and produces deformation at the top end of the thin-walled piece along the Z-axis.

Figure 3 is a comparison diagram of the corresponding natural frequencies of flat thin-walled parts with different heights and thicknesses, which can be analyzed from the diagram:

For a flat thin-walled part with a height of 90mm, when the thickness is increased from 4mm to 4.5mm and 4.5mm to 5mm, the first-order frequency increases by 11.38% and 9.95%, the second-order frequency increases respectively by 11.23% and 9.75%, the third-order frequency increased by 42.79% and 10.19%, and the fourth-order frequency increased by 8.66% and -1.54%. The natural frequency of each order of thin-walled parts increased nonlinearly with the increase of thickness. However, the increase in natural frequency of flat thin-walled parts from 4mm to 4.5mm is greater than the increase in natural frequency of flat thin-walled parts from 4.5mm to 5mm. For a flat thin-walled part with a height of 110mm, the natural frequency changes the same as that of a 90mm-height thin-walled part.

For a flat thin-walled part with a thickness of 4mm, when the height is increased from 90mm to 110mm, the first-order frequency decreases by 24.87%, the second-order frequency decreases by 14.22%, the third-order frequency increases by 25.27%, and the fourth-order frequency decreases by 23.69%. It shows that with the increase of the height of the thin-walled parts, the natural frequency of
the thin-walled parts decrease nonlinearly and has a larger drop. For a flat thin-walled part with a thickness of 4.5mm, as the height of the flat thin-walled part increases, the natural frequency of the thin-walled part decreases nonlinearly, but compared with a thin-walled piece with a thickness of 4mm, the difference in the decrease is smaller. For flat thin-walled parts with a thickness of 5mm, compared with the decrease in natural frequency of thin-walled parts with thickness of 4mm and 4.5mm, the decrease is obviously smaller. It shows that the thinner the workpiece, the greater the decrease in natural frequency produced by increasing the height of the workpiece.

3.2. Modal analysis of curved thin-walled parts

The modal analysis of thin-walled parts 7-12 was carried out respectively, and the first four-order mode and frequency of thin-walled parts are obtained. Figure 4 shows the vibration shape of the thin-walled part 7. It should be noted here that since the first four-order mode shape change law of the workpiece 8-12 is similar to that of the thin-walled part 7, considering the space limitation, it will not be given here.

Figure 4(a) shows the first-order mode of the thin-walled part 7. Its first-order frequency is 831.59 Hz. Because there is no support at the ends of the top of the thin-walled part, the stiffness is the least and the deformation is the most prone to produce. Therefore, bending deformation occurs along the normal direction at these two places. When the height and thickness are the same, the first-order frequency of curved thin-walled parts is higher than that of flat thin-walled parts. It shows that under the same conditions, the stiffness of the curved thin-walled parts is higher, and it is less prone to bending deformation.

Figure 4(b) shows the second-order mode of the thin-walled part 7, and its second-order frequency is 838.30Hz. Because the stiffness of the joint between the bottom plate of the curved thin-walled part and the blade is relatively large, and the height of the workpiece gradually decreases as the height increases, the two ends of the curved thin-walled part are prone to produce torsion deformation along the Z axis.

Figure 4(c) shows the third-order mode of the thin-walled part 7, and its third-order frequency is 1036.8 Hz. Because the maximum stiffness of the thin-walled part is at the four fixing holes of the thin-walled part, and the farther the bottom plate is from the fixing hole, the smaller the rigidity, and the higher the distance from the bottom plate of the thin-walled part, the smaller the rigidity, therefore, the thin-walled part produces deformation that rotates around the Z axis, and the closer the two ends and the farther away from the bottom plate, the greater the deformation.

Figure 4(d) shows the fourth-order mode of the thin-walled part 7, and its fourth-order frequency is
1338.00 Hz. At this time, the thin-walled part produces a second torsional deformation and bending deformation around the Y axis that are different from those shown in Figure 2(a).

Figure 5 is a comparison diagram of the corresponding natural frequencies of curved thin-walled parts with different heights and thicknesses, which can be analyzed from the diagram:

For curved thin-walled parts with a height of 90mm, when the thickness is increased from 4mm to 4.5mm and 4.5mm to 5mm, the first-order frequency increases by 3.28% and 2.23%, the second-order frequency increases by 6.17% and 4.53%, the third-order frequency increased by 0.93% and 0.57%, and the fourth-order frequency increased by 8.39% and 7.19%, respectively. Obviously, the natural frequency of a thin-walled part with a height of 90mm increases nonlinearly with the increase in
thickness. However, the increase in natural frequency of curved thin-walled parts from 4mm to 4.5mm is greater than the increase in natural frequency of curved thin-walled parts from 4.5mm to 5mm. That is, as the thickness of the thin-walled parts increases from 4mm to 4.5mm, the stiffness of the thin-walled parts increases more. For the curved thin-walled parts with a height of 110mm, the change law of natural frequency is the same as that of 90mm height thin-walled parts.

For the curved thin-walled parts with a thickness of 4mm, when the height is increased from 90mm to 110mm, the first-order frequency is reduced by 23.57%, the second-order frequency is reduced by 17.67%, the third-order frequency is reduced by 22.09%, and the fourth-order frequency is reduced by 10.46%. It shows that as the height of the thin-walled parts increases, the natural frequency of the thin-walled parts decreases nonlinearly and has a larger drop. And for the curved thin-walled parts with a thickness of 4.5mm, the natural frequency of thin-walled parts is reduced nonlinearly. However, the decrease of natural frequency of the thin-walled parts with a thickness of 4.5mm is less than that of the thin-walled parts with a thickness of 4mm. For a curved thin-walled part with a thickness of 5mm, the drop in natural frequency is relatively small.

4. Conclusion
1. The natural frequency of thin-walled parts increases nonlinearly as the thickness increases, and decreases nonlinearly as the height increases. The influence of height on the stiffness of thin-walled parts is greater than the influence of thickness on the stiffness of thin-walled parts. The stiffness of the thin-walled parts can be increased by decreasing the height of the thin-walled parts or increasing the thickness of the thin-walled parts.
2. Under the same conditions, the first-order frequency of curved thin-walled parts is higher than that of the flat thin-walled parts. And under the same conditions, the third-order and fourth-order frequencies of curved thin-walled parts are smaller than those of flat thin-walled parts. So, curved thin-walled parts are more prone to torsion deformation,
3. The influence of flat thin-walled parts and curved thin-walled parts on the natural frequency under the same conditions was analysed. When the height and thickness are constant, the size factor has a small effect on the deformation of flat thin-walled parts, meanwhile, has a greater effect on the deformation of thin-walled curved parts, and shows a nonlinear decrease trend.

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