Research on Vibration Characteristics of Zither Based on Modal Analysis

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Abstract. Chinese Zither is one of the traditional Chinese national musical instruments. It has a clear tone and a wide range of plucked strings, which is comparable to Western instruments. In recent years, with the increasing number of zither students, the method of making zither has gradually changed from manual production to machine production. In the background of the mass production of musical instruments, it has become the consensus of the manufacturers to establish a more complete and scientific zither-making specification. Among them, the problem of zither noise and vibration is an urgent problem to be solved. This paper constructs a three-dimensional finite element model of Chinese Zither based on the principle of vibration and noise, and analyzes its vibration characteristics. The finite element model of the zither is established by combining computer simulation technology with traditional Chinese musical instrument manufacturing. It is obtained the zither dynamic characteristics through analyzing and provided data and theoretical support for the structure research and optimization of the zither.

1. introduction

Chinese culture has a long history and the Chinese traditional national musical instrument which is born with Chinese civilization also have a splendid history. Chinese traditional national musical instruments contain profound cultural heritage and distinctive national characteristics. There is inheriting the culture of our country for thousands of years and reflecting the crystallization of the wisdom of our working people. As one of the representatives of traditional national musical instruments in the country, the zither has distinctive features. It can not only express the artistic conception of flowing clouds and flowing water, but also show the majestic scenes. The zither is very popular.

With the rapid development of science and technology, more and more new technologies and methods are used in the research and improvement of musical instruments. Using the latest simulation technology, a complete and systematic simulation model is constructed from the perspective of the structural vibration of the zither. The modal calculation results of the zither is obtained by calculating zither vibration characteristics. It is provided reference data and samples which is optimized the structural stability of the zither and improved the sound and color of the zither Expressiveness.

2. The zither characteristics

The length of the zither is about 163cm. The body is composed of an arched panel, a back panel and a side panel. The body is the main resonance part of the instrument and acts as a resonance box. It makes
the air column resonate under the drive of the sound source and the sound is strengthened. There is a partition inside the body which connects the panel and the back plate to play a supporting effect. Most of the panels are made of paulownia, generally 9-12 years old paulownia wood is the best, which is good for sound transmission. There is a natural paulownia wood pattern on the panel. The grain spacing in the mid range is about 5-9 cm, and the spacing between the treble and bass areas is about 1.5-2.5 cm. The thickness of the panels in the high, middle and low range is different. The panel in the high range is about 9cm, and the panel in the mid range is the thickest part due to the slightly arched body, about 11cm. The bass panel is about 10 cm. The front, tail and four sides of the body are veneered with wood such as mahogany, old mahogany, golden nanmu, red sandalwood, etc. The body is decorated with shell carvings and gold foil by hollowing out and engraving. Those methods make the surface beautiful and durable. There are 21 strings on the panel. The strings are made of nylon steel wire strings, which increase the volume while ensuring the charm of the zither music. The strings are supported by 21 yards. The yards are mostly made of mahogany, rosewood, red sandalwood and other woods. The yards are embedded with beef bones to make a string slot for placing the strings.

Since the development of the Warring States Period, the zither has experienced 13-string, 18-string, 21-string and other forms. The zither has become an instrument with reasonable structure, stable sound, fine tone texture, and long charm. From the sound point of view, the instrument maker focused on the structure of the zither. They considered all aspects that make the sound perfect, such as the arched panel that maximizes the loudness of the sound. The sound hole on the bottom plate cooperates with the zither body to keep the air flowing and optimize the resonance. The movement of the yard can change the pitch position and sound. The front YueShan and the back YueShan can keep the strings passing through the threading holes in a stable state. This structure reflects scientific and rationality of zither production.

For musical instruments, sound stability and sound transparency are the most important characteristics. There are many reasons that affect the timbre and quality of zither. For example, the relationship between the piano code and the vibration of the piano board, the relationship between the string groove and the vibration of the strings, the relationship between the armour worn on the fingers and the vibration of the strings, the relationship between the performance techniques and the vibration of the strings, etc., these are all important factors that affect the sound quality. But the choice and production of wood is the most important key factor affecting zither and sound quality. Most of the zither are made of paulownia, and the expensive professional zither are also made of cedar. This is because if you choose other woods, you won’t be able to produce sound. The zither largest biggest resonance box uses paulownia or fir. Red sandalwood, mahogany and other precious woods are often used as the side panels or veneers of the zither, and are also used in the production of small parts such as zither codes.

3. Zither vibration characteristics
The main structure of the zither is relatively complicated. It is difficult to derive its vibration characteristics theoretically. In engineering applications, the finite element method is generally used to analyze such complex structures. For this reason, we use the structural finite element method to analyze the vibration response characteristics of the zither main structure. [2]

3.1. Modal analysis theory
Modal analysis methods include finite element method and experimental modal analysis. The parameters obtained from modal analysis are used to characterize the natural vibration characteristics of the structure, mainly including parameters such as modal frequency and modal shape. Most vibrating structures can be discretized as multi-degree systems, and their vibration differential equations are:

\[ M\ddot{X} + C\dot{X} + KX = F \]  

where \( M \), \( C \) and \( K \) are the matrix of mass, damping and stiffness. \( X \) is nodal displacement vector. \( F \) is nodal load vector.
In a linear system, it is written into a second-order constant coefficient differential equation. The structural characteristic equation is solved.

\[ [K] + \omega_i^2 [M](\varphi_i) = 0 \]  

(2)

In this equation, \( \omega \) is i-order frequency, \( \varphi \) is i-order mode shape.

3.2. Zither modeling
In the finite element analysis of the zither, it is necessary to construct the three-dimensional mathematical model of the zither according to the parameters, and then import the model into the finite element analysis software to establish the finite element mesh model structure and material parameters of the zither. Quality of zither paint, engraving and decorations are added in the model. When calculating the structural mode of the zither, there is a certain degree of camber because of special structure of the upper panel of the zither. In the analysis process, the model needs to be simplified. In the analysis process, the model needs to be simplified and established by solid modeling software. [3] As shown in Figure 1.

![Figure 1. zither model](image)

The model is imported into HyperMesh for meshing. Main structure is meshed with solid elements Tetra4. The finite element model is shown in Figure 2, which is divided into 612,725 units and 162,264 nodes.

![Figure 2. finite element model](image)

3.3. Zither modeling
At present, traditional zither mainly uses dry and loose paulownia. Because of paulownia belongs to wood, it is generally considered as an orthotropic material in finite element calculations. Material parameters are affected by factors such as moisture content, continuity, and wood defects. It is difficult to give a definite value [4]. Based on the requirements of simulation calculations, this paper refers to the material parameters of paulownia in the literature and uses the results of material test measurements to compare and correct them.[5,6] The final determination of the material parameters of the wood used for zither is shown in Table 1.

| Material  | Elastic modulus(MPa) | Poisson’s ratio | Density(T/mm^3) |
|-----------|----------------------|-----------------|----------------|
| paulownia | 5900                 | 0.15            | 2.7X10-10       |

4. Analysis result
Modal analysis is a common analysis method for studying the vibration characteristics of the zither. The free modes of the zither are calculated, and the first 8 modal results are obtained, as shown in Figure 3-5.
Figure 3. 1 ~ 4 mode

Figure 4. 5~8 mode
5. Conclusion

This paper uses the structural finite element analysis method to analyze the vibration characteristics of the zither main structure, deeply researches the vibration characteristics of the zither and combines computer simulation technology with the zither. It is calculating the 12th-order free mode of the zither model and verifying the feasibility and effectiveness of the method. This analysis provides solution for the subsequent structural improvement and optimization of the zither, and lays a solid foundation for further research on the acoustic characteristics of the zither.

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