Research on Modal Analysis of Qin Structure Based on Finite Element Technology

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Abstract. Qin is one of the traditional plucked musical instruments in China and has a history of more than 3,000 years. Qin has deep historical heritage and rich cultural connotation. It is often used for solo, but also for accompaniment. The timbre of Qin is quiet and the aftertaste is long. It is often used to express a person's interest and purity. It is a traditional musical instrument which puts emotions on it. Qin is loved by the public. Based on the finite element analysis method, this paper makes use of the Hypermesh finite element calculation and analysis software to obtain the finite element model of the Qin and analyze the modal of the Qin. [1] Through modal analysis, the effectiveness of the computer simulation method using in the production of Qin has been verified, which supplies data sustain and theoretical sustain for the study of the structure of the Qin and the other traditional Chinese national musical instruments.

1. Introduction
Qin is also known as Guqin, YaoQin, and Lyre. As one of the traditional Chinese plucked instruments, Qin has a history of more than 3,000 years. Qin is a traditional musical instrument which is respected by the refined scholars of all ages. [2] The structure of Qin is simple, but the production process is very complicated. Due to many shapes of Qin and different choices of the players for the materials, the high-quality Qin is basically made by hand. The production is time-consuming and labor-intensive. At the same time, there are also some Qin-making factories, which produce Qins by modern techniques to satisfy the market's needs. As a result, the quality of Qins often decrease. In order to stabilize the technical level of Qin making and promote the development of Qin art, in this paper, modal analysis provide effective ideas and methods in the process of production of Qin making.[3]

2. The structural characteristics of the Qin
The body of Qin is smooth and natural. The upper part of the body is a convex arc, and the bottom is flat, which corresponds to the "circle sky and square land" in traditional Chinese culture.[4] The materials of Qin select Kiriki and Chinese fir and surface paint with lacquer. The length of the body is about 36.5 inches (about 120-125 cm), which symbolizes 365 days a year; the width is about 6 inches (about 20 cm) and height is about 2 inches (about 6 cm). There are seven strings on the surface and emblem positions that is which are divided into Zhongni style, Fuxi style, Liezi style, and Luoxia style. As shown in the Figure 1:
Figure 1. Qin structure

The tone of Qin is pure and long, which is inseparable with Qin special structure. The Qin’s head is called "Yueshan", which is the highest part of the Qin made by hardwood. The strip on the side of Yueshan is called "Chenglu". There are two sound grooves at the bottom of the Qin, the larger called "Longchi" and the smaller called "FengZhao". The seven "string holes" beside YueShan use for wearing strings and seven "qin cymbals" use for tuning. Below the waist, it is called "QinWei". "QinWei" is supported the strings, which is inlaid hardwood "LongYin" engraved with shallow grooves. The strings path is "YueShan"—"LongYin"—"YanZu", "YanZu" is part at the bottom of Qin. In the body, there are two dark slots on the head, one is called "SheXue", anther is "YinChi". There is a dark slots on the end winch is called "YunZhao". The Qin characteristics is "clear, quiet, quiet, and far".

3. Qin Analysis description

3.1. Analysis instruction of Qin

Due to the continuous development of finite element technology, modal simulation analysis methods are widely used. Whether it is in the fields of aircraft, ship, or automobile and other mechanical engineering, the use of this analysis method has achieved significant results. The finite element-based modal analysis method has unparalleled superiority in solving structural vibration and noise. Qin has a complicated structure and involves many small manual structures. Generally, it is difficult to obtain the characteristics of its vibration through theoretical analysis. Therefore, the finite element analysis method is the best choice for studying the vibration structure of musical instruments. In the analysis process, the finite element analysis software is used to build a three-dimensional structure of the Qin finite element mesh model and create the properties of the wood material. It is obtained the Qin's mode shapes at different frequencies.

3.2. Modal analysis theory

3.2.1 Modal analysis. Modal analysis is the process of describing a structure based on its inherent characteristics, including dynamic properties such as frequency, damping, and mode shapes. The definition in the strict mathematical significance refers to transforming the physical coordinates in the vibrational differential equations of the linear stationary system into modal coordinates, and decoupling the equations into a set of independent equations described by the modal coordinates and modal parameters in order to find the modal parameters of the system. The transformation matrix of the coordinate transformation is a modal matrix, and each column is a mode shape. Therefore, modal transformation is the process of transforming equations from physical space to modal space through modal transformation equations. It is a process of transforming a set of complex, coupled physical equations into a set of single degree of freedom system and decoupled equations. The modal parameters are closely related to the mass and stiffness of the structure. In the finite element analysis process, a
uniform grid form is adopted as a whole [5].

3.2.2 Principles of Modal Analysis Algorithm. According to the vibration theory, the vibration form that a multi-degree-of-freedom system vibrates at a certain natural frequency is called a modal. After the structure of Qin is discretized and changed by the finite element, the vibration dynamic equation of Qin can be obtained as [6]:

$$M\ddot{X} + C\dot{X} + KX = F$$  \hspace{1cm} (1)\

Among them: $M$, $C$ and $K$ are mass, damping and stiffness matrices; $F$ is force vector; $\dot{X}$ and $\ddot{X}$ are displacement, velocity and acceleration vectors of Qin vibration.

The mode is independent of external loading conditions, that is $F = 0$, and ignores the influence of damping $C$. The free vibration equation of the system is:

$$M\ddot{X} + KX = 0$$  \hspace{1cm} (2)\

At free vibration, the points on the structure make simple harmonic vibrations. Suppose the simple harmonic vibration equation is:

$$X = \Phi e^{i\omega t}$$  \hspace{1cm} (3)\

Among them: $\Phi$ is mode shape vector; $\omega$ is modal frequency.

Substituting equation (2) into equation (3) gives:

$$\left(K - \omega^2 M\right)\Phi = 0$$  \hspace{1cm} (4)\

From the existence of a non-zero solution in the above formula, we obtain:

$$\left|K - \omega^2 M\right| = 0$$  \hspace{1cm} (5)\

Get the modal frequency of Qin $\omega_i(1,2,\cdots,n)$ and corresponding mode $\Phi_i(1,2,\cdots,n)$.

3.3. The modal extraction method

Modal analysis in Radioss software is linear analysis, that is, only linear behavior is effective in modal analysis. Any non-linear characteristics, such as plastic and contact (gap) elements, will be ignored even if they are defined, and they will be treated as linear. For example, if the contact element is included in the analysis, the system takes the stiffness value of its initial state and does not change the stiffness value. But material properties can be linear or non-linear, isotropic or orthotropic, constant or temperature-dependent. In modal analysis, it must specify EX and DENS.

3.4. Qin model and material parameters

Qin mathematical model is constructed using tetrahedral elements, the grid size is controlled at 3mm, the mesh order is second order. The elements and nodes is 724676 and 1083718, and the mass is 5.12 kg, as shown in Figure 2.

Figure 2. finite element model

Chinese fir material parameters shown in table 1. [1]
Table 1. Material parameters of Qin finite element model

| Material   | Elastic modulus (MPa) | Poisson's ratio | Density (T/mm³) |
|------------|-----------------------|-----------------|-----------------|
| Chinese fir| 5000                  | 0.33            | 5.4X10-10       |

4. Qin modal result

The goal of modal analysis is to identify the modal parameters of the system. In order to obtain the structural dynamic parameters of Qin, the solution provided by the Hypermesh software is used to calculate the first 12 free modes of Qin. The modal shapes are shown in Figures 3-5.

![Figure 3. 1 ~ 4 mode](image)

![Figure 4. 5~8 mode](image)
Figure 5. 9~12 mode

5. Conclusion
This paper uses ANSA software to pre-process the model of Qin, calculates the free mode of Qin by the Optistruct solver of the Hypermesh software, obtains the modal results of Qin, studies the vibration characteristics of Qin, and opens the beginning of Qin simulation research. Modal analysis is only part of the field of vibration and noise, and further exploration and research on the acoustic and timbral analysis of Qin is needed.

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