Study on the Relationship Between Material and Structure of Ancient Musical Instrument Resonator and Tone Quality

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Abstract: The acoustic vibration characteristics of ancient musical instrument resonator are vital factors to determine the tone quality of ancient instruments. In order to uncover the mystery of the relationship between the material and structure of ancient musical instrument resonator and tone quality, it is necessary to analyze the acoustic vibration of ancient musical instrument resonator scientifically. In order to analyze the acoustic vibration of the musical instrument, not only the structural characteristics of the musical instrument itself should be understood, but also the principle of vibration mechanics and acoustical principle should be mastered, with the finite element analysis and frequency analysis methods applied to all requirements. The testing and analysis technology of domestic acoustic vibration characteristics of musical instruments is still in its infancy, and most of the research objects are limited to the wood units or whole boards used in the production of musical instruments, which rarely involved the systematic analysis of the acoustic vibration characteristics of finished ancient musical instruments. This paper provides references for the quality control of ancient musical instruments and other resonating instruments in the process of manufacturing and the exploration on modification of instrument manufacturing material.

1. The Structural and Material Characteristics of Ancient Musical Instrument Resonant and Its Sound Principle

From the acoustic structure, ancient musical instruments can be divided into four systems: vibration system, excitation system, transmission system and the resonance system. Among them, the string is a vibration system, object that vibrates on ancient musical instruments; the excitation system of excitation vibration refers to human fingers, and the transmission system is the ponticello of ancient musical instruments; resonance system is a structural body that is able to quickly diffuse the vibration energy of vibration body structure. Although the structure specifications, length and width dimensions as well as appearance styles of various parts of the ancient musical instruments popular nowadays have their own systems, their differences mainly focus on the changes in the styles and radians of the neck and waist sections, which have little impact on the tone quality of the ancient musical instruments. Therefore, the differences in styles are beyond the scope of our discussion. The Chinese zither, the most all-pervading ancient instrument, was selected as the research sample here.

1.1 The Guqin Surface

The surface of the ancient musical instrument is a circle arc form, and the circular arc degree from the front end to the back end of each part of is different, a piece of soundboard with wide head and narrow tail. The thickness of the edge of the cambered surface of the Guqin is less than that of middle, that is, the middle arch is slightly thicker and gradually thinner around. [1] The middle arch part has the function of strengthening the pressure resistance and increasing the air volume in the cabinet and thinner edges are more conducive to vibration. The size of the instrument surface radian has close relationship with the timbre of the Guqin, and the surface shape of Confucius-style Guqin as shown in the figure 1.

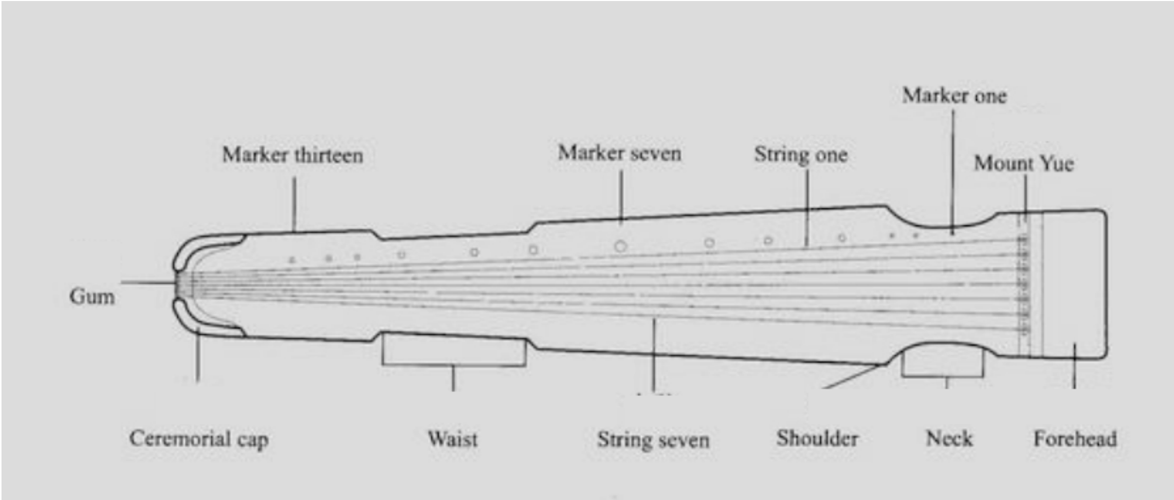

Figure 1: The Surface Map of the Guqin

1.2 Grooved Belly of the Guqin

The grooved belly of the Guqin generally refers to the hollowed-out part of interior of the instrument surface, which composes the sound box of the instrument body together with the bottom of the instrument. The common belly groove form today mainly consists of two main sounds and a dark groove. [2] Large sound from the start to the foot pool, includes the dragon pool na-tone; small sound from the foot pool to the end of the Guqin, includes the fongmarsh na-tone. The dark groove mainly refers to the sound pool at the head of the instrument and the structure shape of the grooved belly is shown in the figure 2.

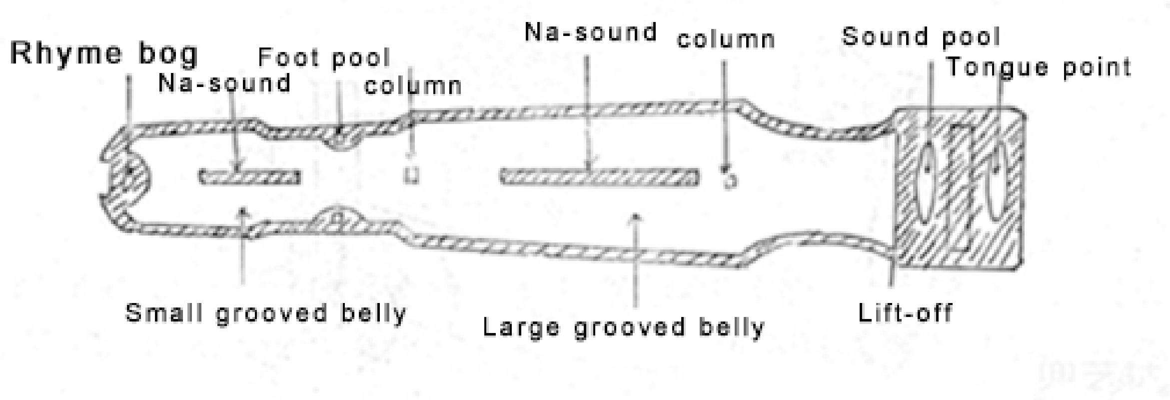

Figure 2: The Grooved Belly Map of the Guqin

The inner grooved belly structure of the Guqin is one of the key factors that influence the timbre of the Guqin, to which instrument makers throughout the ages attached great importance. In order to obtain the ideal timbres, the luthiers throughout the ages often explored the improvement of grooved belly structure, mainly focusing on the adjustment of na-tone and belly groove depth. The na-tone of the famous instrument handed down from ancient times is not high or low, or even no na-tone, because the setting of the na-tone also needs to be matched with the material of the panel and the thickness of the panel.

1.3 The Material Characteristics of the Guqin Resonant

In the study of the Guqin, the materials used in the panel and bottom plate of the Guqin are the most involved. The past generations also paid great attention to the selection of materials. The nature of the material has an absolute effect on the sound effect of the Guqin, and the combination of different materials will make different changes in timbre. The most commonly used materials of the Guqin are miantong (Chinese parasol) and bottom catalpa, namely candlenut is Yang wood, and catalpa is Yin wood, collectively known as “Yin and Yang woods”.

The different functions of the panel and the bottom plate determine the selection of their materials. In ancient times, there was a saying that "the surface takes sound while the bottom stiffens sound", and the instrument panel plays the role of sound transmission and vibration sound production, so the candlenut with light quality and good sound transmission is often chosen; the bottom plate of the instrument plays a sound supporting (plaque sound) role and vibrates with the panel, and therefore, the catalpa, which is relatively solid but not too hard, is often used for manufacturing. But the Chinese Guqin has always been mainly for self-entertainment (solo) or less songs accompaniment instruments, and unlike the violin and other instruments used in western symphony, it requires a relatively uniform (there are often dozens of stringed instruments such as violins in a band.) [3] sound and timbre, so no matter the instrument manufacturing is in royal court or the folk, it often based on local materials. Therefore, in addition to the materials such as candlenut and catalpa woods used in many ancient famous instruments, pine, Chinese fir, populus, willow, Catalpa bungei C.A.Mey., Tilia Tuan Szyszyl, mulberry, cypress and other materials are also commonly used.

1.4 The Sound Production Principle of the Guqin Resonant

The vibration source and resonance chamber are the main parts of the musical instrument, and they play different roles in different instruments. The pitch (sound frequency) of a string instrument is determined by the vibration source; the tone quality depends on the resonating chamber. The length of the Guqin resonating chamber is very long in a stringed instrument. According to the principles of physics, for a sound with a certain frequency to resonate in a resonating chamber, its wavelength can not exceed four times the length of the resonating chamber. It can be seen that the resonance peak range of the Guqin resonating chamber is very large, which can produce good resonance for most frequencies that can be emitted by the vibration source. Therefore, most of the sounds produced by the Guqin are not very "empty", but very thick. The sound production of the Guqin is not a simple vibration of the panel to drive the air vibration of the dragon pool and fongmarsh in the chamber, but actually the vibration of the panel to drive the air vibration, and at the same time, the bottom plate should also participate in the vibration, and then together constitute a longitudinal swing. [4] When the sound production is right, the sound goes down, and when the sound goes down, the sound must be a longitudinal vibration. In other words, the sound production vibration of the Guqin is actually a whole-body vibration.

2. Analysis of Acoustic Characteristics of Ancient Musical Instrument Resonator

2.1 The Theoretical Basis of Musical Instrument Acoustics

As is known to all, the vibration frequency domain of sound wave is from 10-4Hz to 1,014Hz, and the frequency range heard by human ear is roughly between 20Hz-20KHz. In this range, it is called audio frequency, and the frequency below 20Hz is called sub-frequency, while the high frequency above 20KHz is called ultrasound. Generally, the frequency range of music is roughly between 40Hz-15KHz. Sound waves from the production of vibration to the existence of human sense of sound, this process of sound production is a physical phenomenon, and the perception of sound is physiological and mental activities. So the characteristics of music sound contain both the characteristics of these two aspects in the meanwhile: physical and psychological characteristics. The physical characteristic elements mainly contain the frequency (fundamental frequency), sound intensity (sound pressure level) and waveform (frequency spectrum), and the psychological characteristic elements mainly include pitch, sound intensity, and timbre of sound. The three elements of psychological characteristics are respectively decided by the fundamental frequency, sound pressure level and frequency spectrum of sound.

2.2 Pitch and Fundamental Frequency

The human ear's perception of sound pitch is mainly related to the fundamental frequency of sound, but it is not proportional, and has a logarithmic relationship. In terms of the change of pitch, the vibration frequency of its objective physical quantity increases in geometric order, while the subjective psychological quantity is reflected in arithmetic order. For example, from the spectrum diagram, a tone with a single frequency of 440Hz is a spectral line (fundamental frequency), and the corresponding subjective perception of the human ear is the pitch Al of the sound. The actual musical sound is composed of fundamental frequency and harmonic (overtone), and the periodic vibration of each musical sound can be decomposed into the superposition of simple harmonic vibration of many different frequencies, phases and amplitudes. In these simple harmonic vibrations, the lowest frequency is called the fundamental frequency, and the energy of the fundamental frequency is often the largest; the frequency that is an integral multiple of the fundamental frequency is called harmonic partial tone, also known as overtone. [5]In general, the higher the frequency at which the sounding object vibrates, the higher the tone sounds; the lower the frequency at which the sounding object vibrates, the lower the tone sounds, but there is no strictly proportional correspondence between the tone and the frequency. It is generally believed that every time the frequency is doubled, the tone will sound one octave higher, which is only limited to the middle frequency band in the high-pitched part, and the audibility is low, that is, the doubling the frequency doesn’t sound an octave higher, but lower.

2.3 Sound Intensity and Sound Pressure Level

The vibration amplitude of sound rather corresponds to the physical concept of sound pressure level of sound, that is, the magnitude of sound pressure that can be measured by a device, but the human ear to the sound of the different frequency and same sound pressure level, the magnitude for the auditory sense is different, so this leads to the concept of “sound intensity” For musical instruments, it is refers to the magnitude of sound produced by the musical instruments, that is the volume, commonly marked by decibel value (dB). Generally, on the premise of keeping the sound quality unchanged, people want the volume of the instrument to be as high as possible. However, it should be noted that the volume of the instrument varies greatly in different regions of articulation. Therefore, high-quality instruments can always maintain good volume balance in different regions of articulation. The human ear is particularly sensitive to certain frequencies, which feels very loud with very little sound pressure. These frequencies are concentrated in the regions from 1,000Hz to 4,000Hz, while the most sensitive frequency is around 3,000Hz. Through research and measurement, an equal-sound curve chart is obtained. The sound of 100Hz must have a sound pressure level of nearly 40dB for human ears to hear, while the sound of 1,000Hz, greater than 0dB, can be heard by human ears. Therefore, when the volume of the listening sound is changed, the loudness of each frequency in the sound signal also changes, making people feel the change of timbre.

2.4 Timbre and Frequency Spectrum

Timbre refers to the sensory characteristics of sound. In physics, timbre is the three-dimensional perception of sound and can represent the quality characteristics of sound. The volume is determined by the vibration frequency of the sounding object, and the loudness is determined by the vibration amplitude of the sounding object. However, due to the different materials and structures of different sounding objects, the timbre of the sound production is also different, so different sounding objects can be distinguished by the difference of timbre. Timbre is mainly composed of the following physical factors: the number of partial tone, the distribution of partial tone, the relative intensity of partial tone, and the intensity of fundamental tone, etc. Changes in their combination or quantity value will change the waveform of sound waves. As can be seen from the above, the fundamental frequency (or called fundamental tone) of the vibration frequency determines the pitch; when the frequency is the sine of integer multiple of the fundamental frequency, the vibration is the harmonic, and when the frequency is the sine of twice the fundamental frequency, the vibration is the second harmonic. Musicians call the second harmonic the first partial tone, which is an octave higher than the fundamental frequency, and the third harmonic frequency is three times the fundamental frequency, also known as the second harmonic. Harmonic determines the waveform and make the sound of various musical sounds different, and even in the same tone, different timbres are constituted because of the different number and different strength relations of each harmonic. In other words, timbre is determined by the relationship between the vibration frequencies of objects and their characteristics. These characteristics related to the timbre include harmonic as well as resonance peak and the strongest harmonic is the central resonance frequency, which is also the resonance peak frequency.

Different from pitch and sound intensity, timbre itself has no corresponding physical quantity. Although the physical quantity data of pitch and sound intensity does not have a linear relationship with the subjective psychological feeling, at least the physical quantity data can provide reference for subjective feeling. Numerical change can be directly transformed into the subjective psychological feeling which can be expressed by simple words. But for timbre, due to different cultural backgrounds, language habits and professional fields, the term system used in the timbre evaluation by people is also not the same. At present, there is no a quantitative system that can provide objective reference. The analysis of timbre in modern music acoustics is generally adopted with the sound measurement method. Through the sound collection and analysis system, the sound is transformed into visible sound wave vibration images and frequency spectrum images, and then these images are analyzed to explore the characteristics of the sound they represent. The sound wave vibration images directly reflect the characteristics of sound change with time, while the spectrum diagram contains more information, which mainly reflects the number of partial tone in the sound and the intensity relationship between partial tone.

2.5 Evaluation Principle of Acoustic Characteristics of the Ancient Musical Instrument Resonator

For the Guqin, an ancient musical instrument, resonator can amplify the sound of the strings at different frequencies to different degrees according to its acoustic characteristics. The materials of the panel and bottom plate, the height of the na-sound, the height of the outer cambered surface of the panel, as well as the depth of grooved belly of the panel which will be discussed in the section are all relevant factors that affect the acoustic characteristics of the resonators. If the vibration frequency transmitted by the string to the resonator is consistent, that is, if the excitation conditions are consistent, the acoustic characteristics of the resonator will be reflected in the sound frequency spectrum that has been amplified by the resonator. From the sound frequency spectrum, we can analyze the different amplification degrees of the resonators to which frequency of the sound. Through the frequency spectrum comparison, we can understand the direct influence of the material parameters and size parameters of different resonators on the acoustic characteristics of the resonators.

By analyzing the frequency spectrum, we can not only understand the change of the acoustic characteristics of the resonator, but also find out whether the change trend is favorable or unfavorable to the timbre of the Guqin. Because we know from the acoustic fundamentals of musical instruments that the timbre of a compound sound depends on its frequency spectrum, or rather, on the number, combination, and intensity distribution of each harmonic (partial tone) in the frequency spectrum chart. In terms of acoustics, the basic requirements for the sound quality of an instrument are as follows: there are many resonance peaks, large amplitude of harmonious partial tone, small amplitude of disharmonious partial tone, and large number of partial tone in the tonic area. If the number of partial tone is large, and can basically be sorted according to the descending power of various partial tones, then the timbre is full. If the number of partial tone is not much, but the lower partial tone is strong, and the higher partial tone can reduce power, then the timbre is mellow.

Since the frequency range of the ancient instrument Guqin is from C2-65Hz to C6-1,046.5Hz, the frequency sampling range in this section is within 2,000Hz. It is divided into three regions of articulation: 1Hz to 800Hz as the main region of articulation, 800Hz to 1,600Hz as the middle region of articulation, and 1,600Hz to 2,000Hz as the high region of articulation. In the experiment, four strings of the Guqin were plucked for simulation to collect the hollow chord sound produced by resonance of the resonator of the Guqin, and the frequency spectrum of the sound was analyzed.

As a result of the vibration of the strings, the whole fundamental tone chord length constitutes the waveform to produce the fundamental tone, but also will produce the partial tone with the frequencies of twice, three times and four times the fundamental tone frequency, that is, the formation of the first harmonic, second harmonic, third harmonic and so on. In musical sound, the relation between fundamental wave and harmonic conforms to the relation between the partial tone series. Musical sounds are all compound sounds, so the characteristics of the frequency spectrum and the harmony degree of the partial tone series are completely consistent. The hollow chord frequency of the four strings of the Guqin is 98Hz, which is regarded as the fundamental tone (fundamental frequency) and the partial tone series are shown.

3. Conclusion

It can be seen from the above table, the partial tones that have harmonious interval of pure octave with the fundamental tone are the first, fourth, eighth and sixteenth partial tones, that have pure fifth harmonious interval with the fundamental tone are the third, sixth and twelfth partial tones, that have harmonious interval of major third and a half with the fundamental tone are fifth, tenth and twentieth partial tones, that have harmonious interval of minor third and a half with the fundamental tone are nineteenth partial tones, that have harmonious interval of major sixth and a half with the fundamental tone are thirteenth partial tones and the rest seventh, eighth, ninth, eleven, fourteen, fifteen, seventeen and eighteen are disharmonious partial tones. Among them, the relations between fourteenth and fifteenth, sixteenth and seventeenth as well as eighteenth and nineteenth partial tones are disharmonious. The partial tones with bass No. (1-6) are consonance, which are combined to make the sound rich. If the resonator of the Guqin can mainly generate resonance in this partial tone series to strengthen the partial tone with each bass No., the overall sound quality of the Guqin can be said to be good. If the resonance peak is obvious in the disharmonious partial tone series, it indicates that the sound is not pleased and dissonant, and the sound quality is not good.

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