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Chinese suona timbre in the orchestral layers of Western symphonies

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SUMMARY: *Timbre is a complex and abstract multi-dimensional attribute, and together with other musical attributes such as pitch and loudness, it constitutes the basic elements of music. On the basis of analyzing the timbral properties of the suona and the duration and acoustic characteristics of the onset phase, this paper explores the use of the suona in practical training, as well as the way of collaboration between the suona and the orchestra, and analyzes the speed-strength visualization of three suona players. It was found that the fundamental and overtones of the soprano suona, alto suona, and bass suona showed an integer ratio of about 1:2:3:4 ...... and responded well to the frequency ranges of 1000-4000Hz, 700-3000Hz, and 250-1400Hz, respectively, with their resonance peak ranges decreasing in descending order according to frequency. The resonance peak range decreases in descending order of frequency. The law of the resonance length of suona instrument is that the resonance length becomes shorter with the elevation of the sound area in a single instrument, and in the same kind of instrument, the low, middle and high voices also have this law, and the resonance length becomes shorter with the elevation of the sound area. In addition, in symphonic concerto, the collaboration between suona and orchestra mainly has the requirements of tempo, air mouth, non-homogeneous rhythmic phrases and so on. This paper makes an important exploration for realizing the creative transformation and innovative development of suona music.*

KEYWORDS: *suona; timbre characteristics; starting duration; orchestral concerto; visualization analysis*

1 Introduction

Since ancient times, people can not live and work without music, dance and musical instruments, which are the cultural symbols of a nation and a country. Musical instrument is the bearer of national music and cultural heritage, which shows the musical life of a nation, records all aspects of national music, and thus reflects the musical culture, craft technology and even the symbiotic natural and cultural ecology of the nation [1-3]. The suona, which has flourished since ancient times, has been loved by all ethnic groups in China, and it is also the musical instrument with the widest popularity, the largest audience and the closest connection with the general public [4-7]. The suona is a Chinese national musical instrument with different names in different regions. In addition to being popular in various regions of China, the suona is no less popular in many other countries and regions, but the study of the suona currently remains in the material composition, cultural ecology of the music and morphological characteristics [8].

Symphony is a large-scale, acoustically rich and expressive genre of large-scale orchestral

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suite in Western music, which can reflect the contradictory conflicts in the society and human emotional experience through various depictions of musical images, and has a wide range of artistic generalization [9]. With the deepening of Chinese and Western cultures, “symphony”, as a genre of music, gradually showed a clear development trajectory, from which we can appreciate the sparks of multicultural collision [10]. Among them, suona concerto is the result of the collision. As one of the forms of western symphonic music genre, “concerto” has a different artistic charm after combining with Chinese traditional folk instruments [11-13]. For example, in 1983, the composer Zhu Yi wrote the symphony “Farewell My Concubine” for suona, which utilizes the traditional suona in G key to describe Xiang Yu's complex psychology before the war, and the traditional suona in C key to portray the aesthetic image of Yu Ji, which makes the music's emotion sincere and touching. Composers organically combine Chinese traditional instrumental music with western compositional techniques to create a classic work of art, which give new life to Chinese traditional instrumental music and also make great contributions to the development of Chinese instrumental music, which is an important force in the development of national music [14-16]. However, most of the current studies on the Chinese suona focus on the performance techniques of the suona or the analysis of a single work, and although compatibility in the orchestra has been mentioned, there is a lack of systematic theoretical support, and the study of adaptation for the Western orchestral orchestration method is still weak. Therefore, by systematically exploring the performance of Chinese suona timbre in western symphonies, the theory of orchestration method of national orchestral music can be enriched to a certain extent, so as to increase the controllable components of the creation of national orchestral works, and to improve the reasonableness, effectiveness, and diversity of the orchestration process.

In this paper, the Chinese suona instrument is selected as a research object, and the performance of its timbre in the orchestral hierarchy of Western symphonies is explored. First, based on the three categories of soprano suona, alto suona and bass suona, the timbre characteristics of suona are analyzed. Secondly, the duration and acoustic characteristics of these three types of suona in the vibrato phase are analyzed. Then, the tonal characteristics of the suona, a wind instrument, are explored in terms of its use in practical orchestral training, as well as the requirements for collaboration between the suona and the orchestra. Finally, the speed and strength of the three suona players, Guo Yazhi, Wang Zhanzhan, and Zhang Qianyuan, during the performance of “Calling the Phoenix” are visualized and analyzed.

2 Physical acoustic characterization of Chinese suona timbre

2.1 Basic characteristics of musical signals

Sound can usually be described by four basic but important parameters, instant duration, pitch, amplitude and timbre.

(1) Duration

Duration is the most direct way to characterize the duration of a pure tone or sound event, and is measured in units such as seconds, minutes, and hours.

(2) Pitch

Pitch is the auditory perception of the periodic or quasi-periodic character of a sound. A higher pitch means a higher frequency is perceived. Similarly, the lower the pitch means the lower the perceived frequency, and the unit of frequency is Hz. When frequency is used to express pitch, it is inversely related to time. The ratio of the frequencies of neighboring pitches in music is a constant value of 3/13/2. Modern music uses seven letters of the alphabet, C, D, E, F, G, A, and B, to mark the names of the basic pitch levels. These seven basic pitch levels are indicated by ascending or descending signs when a semitone change occurs. The same pitch corresponds to more than one tone name, e.g., another tone name for C# can be Db. Usually a semitone is used as a unit of pitch, and an octave consists of 12 semitones. An octave is the distance from the present level to the eighth tone of the same name above or below it, and the frequencies of neighboring octaves are related by a factor of two.

(3) Amplitude and Sound Level

Amplitude, that is, the strength of the signal, the greater the amplitude of the sound, and vice versa. Sound signals are often used dB as a unit of measurement of amplitude. The intensity of the sound of a musical instrument is often referred to as the loudness of the sound, with the amplitude of vibration and change, giving a visual sense of the size of the sound is different.

(4) Timbre

Tone is a kind of characteristic information different from other musical instruments. Musical instrument tone consists of the base note and overtone, the base note is the lowest frequency sound, in addition to the base note collectively referred to as overtones. The human auditory system can distinguish which instrument the sound comes from, because the high-frequency overtones of the instrument's sound are not the same, and the proportion of overtones varies from instrument to instrument. Musical instruments usually produce sound waves of integer multiples of a frequency called harmonics or overtones. In addition to the fundamental frequency, the ratio of these harmonic components determines the timbre, also called tonal timbre. In this paper, the timbre characteristics are parameterized in detail to achieve a characterization of the timbre of the Chinese suona.

2.2 Musical Signal Tone Related Characteristics

2.2.1 Time domain characteristics

The temporal structure is closely related to the timbre, which affects the dynamics of the timbre. In the sound design of electronic music instruments, the concept of “ADSR” is often used to describe the time envelope curve of music, i.e., Attack time, Decay time, Sustain time, Release time, which represents a transitional stage of change in the sound from nothing to something, and then from something to nothing. a transitional phase of change from nothing to something and back again. Among them, Decay time occurs in those systems where there is a continuous supply of energy after the transient phase. Since this study is aimed at the monophonic sounds of the suona instrument, which is basically not involved in this phase, it is analyzed and investigated only with respect to the onset time, the steady state time, and the release time of the timbre.

(1) Onset time

Rise time refers to the period of time from the beginning of the sound to its stabilization, and also refers to the phase in the amplitude envelope when it rises from zero to its maximum value, reflecting the characteristics of the sound at the moment of voicing. The larger the value of the onset time, the slower the sound rushes towards the highest point of energy. For example, in stringed instruments, the moment of maximum energy refers to the moment of maximum dynamic equilibrium between the restoring force from the strings and the force exerted on the bow when it reaches a friction-limited moment, a process that can take up to a few seconds. The smaller the value of the onset time, the shorter the time it takes for the amplitude to reach its maximum point, and the more resonant the sound sounds.

(2) Steady state time

Steady state time reflects the effective duration of signal perception. It is defined by detecting the onset and release phases of the signal, and then selecting the time of the portion of the curve that exceeds a certain threshold of the signal amplitude in that phase. Later, after many empirical tests, the threshold is usually set to 40%.

(3) Release time

The release time is similar to the starting time and refers to the process of sound decaying from steady state to zero.

(4) RMS Energy

The time-domain envelope reflects the change in the overall energy of the signal of a musical tone during the playing time, which can be represented by taking the root mean square of the square of the amplitude, i.e. the RMS energy:

$$RMS = \sqrt{\frac{1}{L}\sum_{n=1}^{L} x^2(n)} \tag{1}$$

where $x(n)$ is a frame of discrete time domain signal and L is the frame length. After the signal is divided into frames, the short-time RMS energy of each frame is calculated, and then the time-dependent amplitude envelope is obtained, and then the time-dependent amplitude envelope is obtained. We obtain a characteristic parameter by finding the mean and variance of the RMS energy envelope for all frames.

(5) Over-zero rate

The zero crossing rate refers to the number of times the signal passes through the zero point in each frame. This feature is mainly used to indicate the noise of the sound, if the ZCR is more, it means the noise is bigger. This feature can also be used to distinguish between percussion and pizzicato strings, as well as for endpoint detection to exclude those useless signals with zero energy. The expression is as follows:

$$ZC_i = 0.5\sum_{n=1}^{N}\left|\operatorname{sgn}\left[x(n)\right]-\operatorname{sgn}\left[x(n-1)\right]\right| \tag{2}$$

where ZC_i represents the over-zero rate of the signal in the i th frame. The $\operatorname{sgn}\left[\cdot\right]$ is the sign function, i.e.:

$$\operatorname{sgn}(x) = \begin{cases} 1, & x \geq 0 \\ -1, & x < 0 \end{cases} \tag{3}$$

2.2.2 Frequency domain characteristics

Tone color is closely related to overtones, the spectral components of sound. Differences in timbre depend mainly on the number of overtones, their position in the whole spectrum, and changes in their relative intensity. At the same time, the auditory system of the human ear is similar to a spectrum analyzer, so the study of frequency domain characteristics is the key to exploring the timbre of the suona instrument.

(1) Spectral center of mass

Spectral center of gravity is an important information about the frequency distribution and energy distribution of the signal, reflecting the frequency region where the energy is concentrated, which can also be considered as a characteristic parameter measuring the shape of the spectral waveform and the size of the center frequency, and can be considered as the expectation of the frequency based on the distribution of energy from the statistical method. The larger the value of the spectral center of mass, the richer the high-frequency component of the tone, the brighter it sounds, and conversely, if the value of the spectral center of mass is smaller, it means that the high-frequency component of the tone is less, and it sounds lower. The expression formula is as follows:

$$f_1 = \frac{\sum_{n=1}^{N} f(n) \cdot E(n)}{\sum_{n=1}^{N} E(n)} = \sum_{n=1}^{N} f(n) \cdot p(n) \tag{4}$$

where $f(n)$ is the frequency corresponding to the short-time Fourier transform of the discrete time domain signal $x(n)$, $E(n)$ is the spectral energy of the corresponding frequency, N is the length of the DFT, and $p(n) = E(n) \Big/ \sum_{n=1}^{N} E(n)$ is the normalized value of the spectral energy $E(n)$.

(2) Spectral Dispersion

Spectral dispersion reflects the degree of dispersion of the signal frequency energy distribution, which can be considered as the standard deviation of the data from the statistical method. If the spectral amplitude near the center of mass is large, the spectral dispersion is small. If the spectral assignment near the center of mass is smaller, the spectral dispersion is larger. The expression is as follows:

$$f_2 = \sqrt{\frac{\sum_{n=1}^{N} (f(n) - f_1)^2 \cdot E(n)}{\sum_{n=1}^{N} E(n)}} = \left(\sum_{n=1}^{N} (f(n) - f_1)^2 \cdot p(n) \right)^{1/2} \tag{5}$$

(3) Spectral Skewness

Spectral skewness describes the degree of asymmetry of a spectrum's distribution around its mean and is defined by the ratio of the third-order central moment of the distribution to the third power of the standard deviation. I.e:

$$f_3 = \frac{\sum_{n=1}^{N} (f(n) - f_1)^3 \cdot E(n)}{\sum_{n=1}^{N} E(n) \cdot f_2^3} - 3 = \left[\sum_{n=1}^{N} (f(n) - f_1)^3 \cdot p(n) \right] \Big/ f_2^3 - 3 \tag{6}$$

The spectral skewness $f_3 = 0$ indicates a symmetrical spectral shape. The spectral skewness $f_3 > 0$ indicates that the energy is mainly concentrated in the low frequency, the main body of the distribution is concentrated in the left side, and the tail of the right side is longer than the left side, and the larger the spectral skewness, the larger the degree of positive bias, i.e., the higher the energy of the fundamental frequency.

(4) Spectral Cliff

Spectral cliff is defined by the ratio of the fourth-order central moment of the distribution to the fourth power of the standard deviation, which describes the degree of flatness of the spectrum and is very sensitive to non-smooth signals. The smaller the value, the flatter the spectrum. Its expression is as follows:

$$f_4 = \frac{\sum_{n=1}^{N} (f(n) - f_1)^4 \cdot E(n)}{\sum_{n=1}^{N} E(n) \cdot f_2^4} = \left[\sum_{n=1}^{N} (f(n) - f_1)^4 \cdot p(n) \right] \Big/ f_2^4 \tag{7}$$

(5) Spectral flatness

Spectral flatness is defined by a simple ratio of the geometric mean to the arithmetic mean and is used to characterize whether the distribution of the spectrum is smooth or spiky. To wit:

$$f_5 = 10\log_{10} \frac{\left(\prod_{n=1}^{N} E(n) \right)^{\frac{1}{N}}}{\frac{1}{N} \sum_{n=1}^{N} E(n)} \tag{8}$$

Its value ranges from $(0,1)$, and the closer to 1, the flatter the signal spectrum.

(6) Spectral Entropy

Spectral entropy represents the "chaos degree" of the spectrum, and it can also be considered that the characteristic value reflects the flatness of the spectrum. The larger the value is, the flatter the signal energy spectrum is, and vice versa, the larger the ups and downs of the spectrum is. The expression is as follows:

$$f_6 = -\sum_{n=1}^{N} \left(\frac{E(n)}{\sum_{n=1}^{N} E(n)} \times \ln \frac{E(n)}{\sum_{n=1}^{N} E(n)} \right) \tag{9}$$

(7) Spectral Irregularity

Spectral irregularity reflects the degree of variation of the spectral peaks and is related to the smoothness of the spectral envelope. The larger the difference between neighboring spectral peaks, the larger the value of spectral irregularity, indicating that the spectral regularity is poorer, and the noise characteristics of the sound are more obvious. The expression is as follows:

$$f_7 = \frac{\sum_{n=1}^{N} \left[E(n) - E(n-1) \right]^2}{\sum_{n=1}^{N} E^2(n)} \tag{10}$$

(8) Spectral Decline

The spectral fall-off value is the point at which the energy of a sound begins to fall, i.e., the frequency below which a portion of the total energy is contained, and suggests how quickly the spectral amplitude decays with frequency, and can often be used to distinguish between percussive or transient sounds. Most studies have chosen 85% as the threshold, i.e., the critical frequency at which the amplitude decreases to 85% of the total spectral energy. The expression is given below:

$$f_8 = C \cdot \sum_{n=1}^{N} E(n) = 0.85 \cdot \sum_{n=1}^{N} E(n) \tag{11}$$

2.2.3 Characterization of the inverted spectral domain

The spectral peak corresponding to the resonant frequency in the spectral envelope of speech is called the resonance peak. The resonance peaks are not only determinants of speech timbre, but also reflect the physical characteristics of the resonant cavity, and the cepstrum coefficient is a way to represent the resonance peaks. The cepstrum coefficient containing the signal quantity $y(n)$ is defined as:

$$c(n) = F^{-1}\left\{\log\left|F\left\{y(n)\right\}\right|\right\} \tag{12}$$

where F denotes the discrete Fourier transform.

Two commonly used features for cepstrum-based improvements, linear predictive cepstrum and Mel-frequency cepstrum, will be described below.

(1) Linear prediction cepstrum coefficients

The main idea of Linear Prediction (LP) [17] is to use a linear combination of sampled values from several past moments to represent the sampling at the current moment.

The basic principle of linear prediction is to represent the analyzed signal by a model, i.e., to view the signal as the output of a certain model, so that the signal can be described by the model parameters. The linear prediction model is shown in Figure 1.

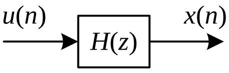

Figure 1: Linear Prediction model

where $u(n)$ denotes the model input and $x(n)$ denotes the model output. When $x(n)$ is a deterministic signal, the model input is a sequence of unit shocks; when $x(n)$ is a stochastic signal $u(n)$ can be a white noise sequence.

The transfer function $H(z)$ of the model can be written in the form of a rational fraction:

$$H(z) = G\frac{B(z)}{A(z)} \tag{13}$$

Among them:

$$\begin{cases} A(z) = 1 - \sum_{k=1}^{p} a_k z^{-k} \\ B(z) = 1 + \sum_{k=1}^{q} b_k z^{-k} \\ H(z) = \sum_{k=1}^{p} h(k) z^{-k} \end{cases} \tag{14}$$

where a_k, b_k and the gain factor G are the parameters of the model, while p and q are the orders of the selected model.

The cepstrum of the speech signal can be obtained by doing a Fourier transform of the signal, taking the logarithm of the mode, and then solving for the Fourier inverse transform. Since the frequency response $H\left(e^{jw}\right)$ responds to the frequency response of the vocal tract and the spectral envelope of the analyzed signal, the linear prediction cepstrum coefficients (LPCC) obtained by doing the Fourier inverse transform with $\log\left|H\left(e^{jw}\right)\right|$ is also considered to contain the information about the signal's spectral envelope, and thus it can be regarded as an approximation of the original signal's short-time cepstrum. of the original signal.

The system function of the synthesized filter obtained by linear prediction analysis is $H(z)=1\Big/\left(1-\sum_{i=1}^{p} a_i z^{-1}\right)$, and its shock response is $h(n)$. A recurrence relation between the inverse spectrum $\hat{h}(n)$ of $h(n)$ and a_i can be obtained by inference, knowing that $\hat{h}(1)=a_1$, one has:

$$\hat{h}(n)=a_n+\sum_{i=1}^{n-1}\left(1-\frac{i}{n}\right)a_i\hat{h}\left(n-i\right)\ 1<n\le p \tag{15}$$

$$\hat{h}(n)=\sum_{i=1}^{p}\left(1-\frac{i}{n}\right)a_i\hat{h}\left(n-i\right)\ n>p \tag{16}$$

According to the above equation, the inverse spectrum $\hat{h}(n)$ can be obtained directly from the prediction coefficient a_i. This cepstrum coefficient is obtained according to the linear prediction model, and utilizes the minimum phase property of the system function $H(z)$ in the linear prediction, so it avoids the trouble of seeking the complex logarithm in the general homomorphic treatment.

(2) Mel frequency cepstrum coefficient

The analysis of Mel Frequency Cepstrum Coefficient (MFCC) is based on the human auditory mechanism, i.e., the spectrum of speech is analyzed based on the results of human auditory experiments with the expectation of obtaining good speech characteristics.

1) Auditory Mechanism

There are two auditory mechanisms on which MFCC analysis is based:

First, the delineation of human subjective perception frequency domain is not linear with the following formula:

$$F_{mel}=1125\log\left(1+\frac{f}{700}\right) \tag{17}$$

where F_{mel} is the perceived frequency in Mel and f is the actual frequency in Hz. If the spectrum of the speech signal is transformed into the perceptual frequency domain, the processing of the auditory process can be better modeled.

Second, the critical band. Frequency groups corresponding to the human ear's base membrane is divided into many very small parts, each part corresponds to a frequency group, corresponding to the same frequency group of those frequencies of the sound, in the brain is superimposed on each other for evaluation. According to the division of the critical band, the speech is divided into a series of frequency groups consisting of a series of filter banks, i.e., Mel filter banks.

(2) Mel filter bank

A number of bandpass filters $H_m(k)$ are set up in the spectral range of speech, $0 \le m < M$, M is the number of filters. Each filter has a triangular filtering characteristic with a center frequency of $f(m)$, and these filters are of equal bandwidth in the Mel frequency range. The transfer function of each bandpass filter is:

$$H_m(k) = \begin{cases} 0 & k < f(m-1) \\ \dfrac{k - f(m-1)}{f(m) - f(m-1)} & f(m-1) \le k \le f(m) \\ \dfrac{f(m+1) - k}{f(m+1) - f(m)} & f(m) < k \le f(m+1) \\ 0 & k > f(m+1) \end{cases} \tag{18}$$

where $f(m)$ can be defined in the following way:

$$f(m) = \left(\frac{N}{f_s}\right) F_{mel}^{-1}\left(F_{mel}(f_l) + m\frac{F_{mel}(f_h) - F_{mel}(f_l)}{M+1}\right) \tag{19}$$

where f_l is the lowest frequency of the filter frequency range. f_h is the highest frequency of the filter frequency range. N is the length of the Fourier transform. f_s is the sampling frequency. The inverse function F_{mel} of F_{mel}^{-1} is:

$$F_{mel}^{-1}(b) = 700\left(e^{\frac{b}{1125}} - 1\right) \tag{20}$$

3) MFCC feature extraction

MFCC feature extraction includes the following steps: preprocessing, Fast Fourier Transform, calculating the spectral line energy, calculating the energy through Mel filter, and calculating the DCT cepstrum.

Step 1: Preprocessing: Preprocessing includes pre-emphasis, frame-splitting and windowing. The speech signal $x_i(m)$, where the subscript i denotes the ith frame after framing.

Step 2: Fast Fourier Transform: Perform FFT transform on each frame signal $X(i,k) = FFT\left[x_i(m)\right]$.

Step 3: Calculate the spectral line energy: $E(i,k) = \left[X(i,k)\right]^2$.

Step 4: Calculate the energy passing through the Mel filter: $S(i,m) = \sum_{k=0}^{N-1} E(i,k) H_m(k), \quad 0 \le m < M$.

Step 5: Calculate the DCT cepstrum: Calculate the DCT discrete cosine transform after taking the logarithm of the energy of the Mel filter, and the resulting MFCC features are shown below:

$$mfcc(i,n) = \sqrt{\frac{2}{M}} \sum_{m=0}^{M-1} \log\left[S(i,m)\right] \cos\left(\frac{\pi n(2m-1)}{2M}\right) \tag{21}$$

2.3 Tonal characterization of the suona

The structure of the Chinese suona is shown in Figure 2, which usually includes a soprano suona, an alto suona, a tenor suona, and a bass suona.

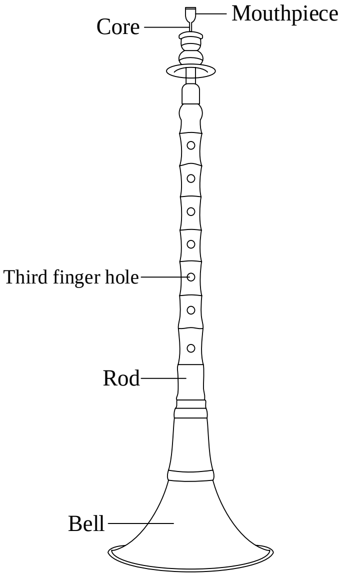

Figure 2: The structure of suona

Through the data analysis and visualization software MATLAB to calculate the full range frequency response of the suona, in which the full range frequency response of the soprano suona, alto suona, bass suona are shown in Figures 3~5, respectively.

Through the frequency response diagram can be seen suona group of instruments have some of the following characteristics:

(1) The soprano suona, alto suona, bass suona have a major resonance peak.

(2) The soprano suona, alto suona, bass suona responds better to the frequency range of 1000-4000Hz, 700-3000Hz, 250-1400Hz, respectively, and the resonance peaks of the three instruments decrease in descending order according to the frequency.

(3) The soprano suona and the alto suona responded well to the frequency ranges with full tones.

(4) The bass suona, in general, has a poor response to the fundamental frequency, a relatively high overtone component, and a lower volume than the soprano suona and the alto suona.

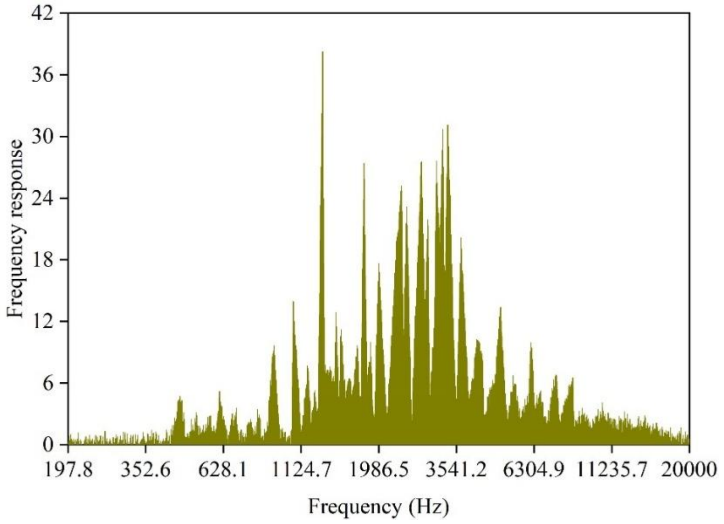

Figure 3: Frequency response of the high-pitched suona

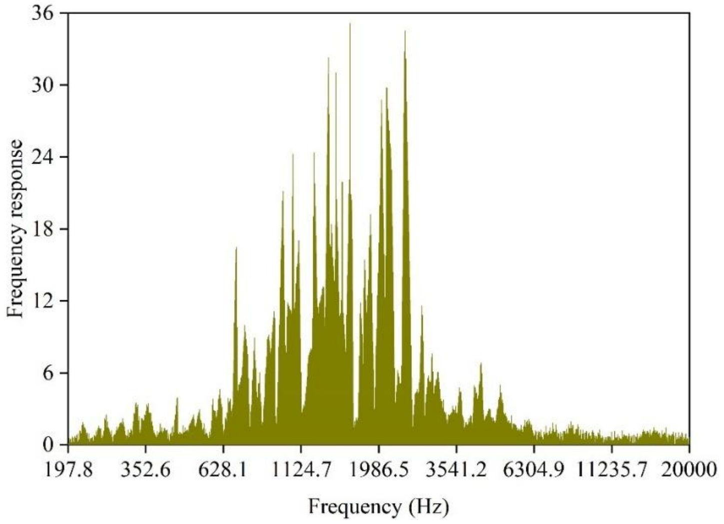

Figure 4: Frequency response of the alto suona

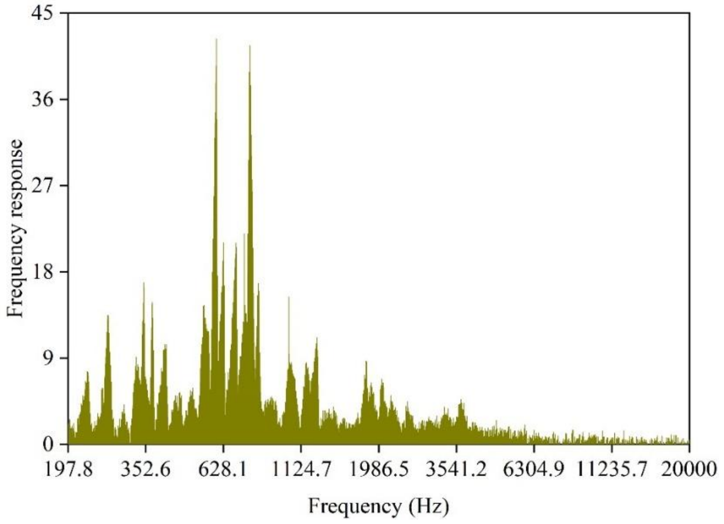

Figure 5: Frequency response of the low-pitched suona

Through the GMAS audio analysis software on the intercepted soprano suona were in the low, middle and treble areas of A4 (a^1), A5 (a^2), A6 (a^3) to analyze, to obtain the soprano suona harmonic frequency data as shown in Table 1.

It can be seen that the soprano suona spectrum has some characteristics as follows:

(1) The fundamental and overtones of the soprano suona are about 1:2:3:4 ...... integer ratio relationship, so its overtone column has the nature of harmonic column, with a clear sense of pitch.

(2) The harmonics of the soprano suona are rich and the tone is full.

(3)The soprano suona's odd-numbered harmonics are dominant in the bass region, bringing a slightly dull covering effect.

(4) The soprano suona's middle and soprano fundamental energy is relatively weak compared to the second and third harmonics, which is an important timbre feature of the double-reed instrument, and there is an obvious “nasal” effect.

(5) The number of harmonics in the soprano area is relatively small, and the tone is relatively thin and sharp.

Table 1: The phonetic frequency of the high-pitched suona

Homophonic serial numbers	A4			A5			A6		
	Frequency (Hz)	Sound group	Sound intensity (dB)	Frequency (Hz)	Sound group	Sound intensity (dB)	Frequency (Hz)	Sound group	Sound intensity (dB)
1	453.26	A4-2	21.12	895.32	A5+4	-23.56	1905.47	A6+40	-15.63
2	904.73	A5+19	16.16	1785.64	A6+4	-15.02	3785.38	A7+33	-6.32
3	1347.45	E6+14	16.28	2714.83	E7+22	-13.41	5624.86	E8+37	-0.98
4	1796.38	A6+19	13.24	3601.44	A7+16	-17.08	7417.68	A8+33	-21.05
5	2257.41	#C7+1	14.35	4475.96	#C8+0	-21.03	9226.29	#C9+20	16.24
6	2693.62	E7+21	0.21	5362.31	E8+14	-23.59	11685.34	E9+35	-18.93
7	3145.17	G7-15	-7.86	6238.54	G8-20	-20.14			
8	3583.59	A7+13	-22.94	7153.62	A8+16	-28.31			
9	4027.84	B7+20	-12.43	8039.53	B8+19	-26.84			
10	4495.34	#C8+1	-9.78	8924.75	#C9+0	-24.32			

The intercepted alto suona was analyzed by GMAS audio analysis software in the low, middle and treble areas C4(c^1), C5(c^2) and C6(c^3) respectively, and the alto suona harmonic frequency data were obtained as shown in Table 2.

Observation of the harmonic frequency table shows that the alto suona spectrum has some characteristics as follows:

(1) The fundamental and overtones of the alto suona are in the relationship of 1:2:3:4 ...... integer ratio, so its overtone column has the nature of harmonic column, with a clear sense of pitch.

(2) The harmonics of the alto suona are rich, and the tone is full.

(3)The even harmonics are dominant in the bass of the alto suona, which brings open sound effect.

(4) Similar to the soprano suona, the fundamental energy in the middle and treble areas of the alto suona is weaker than that of the second and third harmonics, which gives it an obvious “nasal” effect.

(5)The number of harmonics in the soprano area of the alto suona is less, and the tone is relatively thin and sharp.

Table 2: The phonetic frequency of the alto suona

Homophonic serial numbers	C4			C5			C6		
	Frequency (Hz)	Sound group	Sound intensity (dB)	Frequency (Hz)	Sound group	Sound intensity (dB)	Frequency (Hz)	Sound group	Sound intensity (dB)
1	274.53	C4+18	22.85	538.54	C5+6	29.24	1090.57	C6+49	27.21
2	539.25	C5-6	29.46	1072.73	C6+15	29.46	2164.86	C7+41	31.63
3	805.59	G5+4	28.62	1591.38	G6+14	35.02	3247.54	G7+46	6.24
4	1086.21	C6-6	35.27	2143.19	C7+15	25.41	4329.31	C8+45	14.05
5	1354.85	E6-15	17.21	2662.82	E7-1	15.78	5418.35	E8+29	-0.92
6	1612.27	G6-4	28.54	3194.73	G7+17	11.67	6502.76	G9+46	0.56
7	1886.71	#A6-33	14.52	3728.44	#A7-18	1.46	7595.59	#A8+9	-4.69
8	2148.35	C7-6	4.86	4261.75	C8+17	-15.33	8678.63	C9+45	-4.73
9	2420.93	D7+1	21.02	4786.49	D8+20	0.95	9765.78	D9+43	-4.73
10	2691.42	E7-19	6.59	5321.32	E8+1	5.18			

The intercepted bass suona was analyzed by GMAS audio analysis software in the low, middle and treble areas B2(B), B3(b) and F4(f1), respectively, and the bass suona harmonic frequency data were obtained as shown in Table 3. Analysis shows that the characteristics of the bass suona spectrum are as follows:

(1) The fundamental and overtones of the bass suona are in the relationship of 1:2:3:4 ...... integer ratio, so its overtone column has the nature of harmonic column, with a clear sense of pitch.

(2) The harmonics of the bass suona are richer and fuller in tone.

(3)In the low register of the bass suona, the fundamental energy is weak, and the strongest harmonics appear in the fifth harmonic or the harmonics after it, which brings a slightly hard and rough sound effect.

(4) The middle register of the bass suona has the typical spectral characteristics of a double reed instrument, the fundamental energy is weaker than the second and third harmonics, with a “nasal” color.

(5) The soprano of the bass suona has the dominance of the fundamental, the number of harmonics is less, the sound is strong, but relatively thin.

Table 3: The phonetic frequency of the low-pitched suona

Homophonic serial numbers	B2			B3			F4		
	Frequency (Hz)	Sound group	Sound intensity (dB)	Frequency (Hz)	Sound group	Sound intensity (dB)	Frequency (Hz)	Sound group	Sound intensity (dB)
1	131.24	B2-28	0.06	262.53	B3+39	32.06	364.75	F4+29	45.61
2	262.15	B3-28	33.51	523.41	B4+22	33.17	729.81	F5+29	42.43
3	393.27	#F4-27	34.76	785.25	#F5+29	40.24	1118.49	C6+31	15.16
4	524.22	B4-29	24.64	1043.87	B5+22	25.83	1459.53	F6+29	1.34
5	656.44	#D5-36	41.05	1307.54	#D6+11	-4.18	1825.21	A6+15	23.28
6	789.48	#F5-21	34.15	1571.38	#F6+29	-3.46	2176.18	C7+29	15.31
7	922.63	#G5+45	30.31	1832.04	A6-7	14.92	2554.14	#D7-2	7.57
8	1055.71	B5-24	18.62	2095.69	B6+26	9.87	2915.72	F7+27	9.42
9	1182.74	#C6-21	8.75	2354.53	#C7+27	4.73	3262.76	G7+31	-5.11
10	1316.59	#D6-39	-4.28	2609.38	#D7+11	-2.84	3643.62	A7+14	1.12

2.4 Duration and acoustic characterization of the suona's vibration stage

This section analyzes the duration and acoustic characteristics of the soprano, alto and bass suona in the vibration stage on the basis of the suona's timbre characteristics.

2.4.1 Duration and acoustic characteristics of the soprano suona

In the onset phase of a musical instrument, the Physical onset represents the energy of the sound from the presence to the absence of the sound, and the Energy peak represents the energy peak. In this paper, all the measured onset times are from Physical onset to Energy peak.

(1) Vibration onset statistics

Five samples were selected from the soprano suona audio, namely, A4 and D5 in the bass region, A5 and D6 in the middle region, and B6 in the treble region, and the vibration durations of the five suona samples at three strengths, namely, weak (p), medium (f), and strong (ffff), are shown in Table 4. It can be seen that under the strength of p, the middle zone samples A5 and D6 have the longest duration of 69 ms. Under the strength of f, the bass zone samples A4 and D5 have significantly longer duration than the other samples, while the middle zone samples have the shortest duration. Sample B6 in the treble region has the longest onset time of 53ms at ff intensity.

Table 4: The starting duration of the suona single-note sample

	A4	D5	A5	D6	B6
p (ms)	35	64	69	69	46
f (ms)	55	79	20	32	50
fff (ms)	29	36	47	11	53

(2) Correlation analysis of vibration duration and pitch

The descriptive statistics of the vibration duration and pitch of the five soprano suona samples in 15 tests under three kinds of strengths are shown in Table 5. As shown in Table 5, the mean value of the oscillation length of the soprano suona was 46.33 ms, and the mean values of the oscillation lengths of the bass, midrange and soprano regions were 49.67 ms, 41.33 ms and 49.67 ms, respectively.Because the original data did not pass the ANOVA chi-square test, a one-way ANOVA analysis could not be carried out to determine the correlation between the oscillation lengths and the pitches.

Table 5: Descriptive statistics of initiation duration and pitch

	N	Mean	Standard deviation	Standard error	The 95% confidence interval of the mean		Minimum value	Maximum value
					Lower limit	Upper limit		
Low pitch	6	49.67	19.613	8.795	27.689	68.521	29.00	79.00
Alto	6	41.33	24.598	11.152	13.427	65.064	11.00	69.00
High pitch	3	49.67	3.512	3.136	38.654	56.288	46.00	53.00
Total number	15	46.33	19.316	5.248	33.963	55.273	11.00	79.00

(3) Correlation analysis of vibration duration and tone intensity

The descriptive statistics of vibration duration and tone intensity are shown in Table 6, and the results of one-way ANOVA are shown in Table 7.

The results of the correlation between the vibration duration and tone intensity of the soprano suona show that the average vibration duration of the three kinds of strengths of p, f and fff are 56.60ms, 47.30ms and 35.20ms respectively, and the mean values show that the vibration duration becomes shorter with the increase of tone intensity. The significance result was obtained according to one-way ANOVA with a significance result of 0.231.

Table 6: Descriptive statistics of initiation duration and sound intensity

	N	Mean	Standard deviation	Standard error	The 95% confidence interval of the mean		Minimum value	Maximum value
					Lower limit	Upper limit		
P	5	56.60	15.339	7.625	36.276	73.524	35.00	69.00
F	5	47.30	22.643	11.274	17.284	73.718	20.00	79.00
FFF	5	35.20	16.438	8.427	13.177	53.815	11.00	53.00
Total number	15	46.33	19.316	5.248	33.963	55.273	11.00	79.00

Table 7: One-way analysis of variance

	Sum of squares	df	Equal square	F	Sig.
Between groups	1046.724	2	584.195	1.822	0.231
Within the group	3928.412	12	348.195		
Total number	4975.136	14			

(4) Analysis of measurement results

The average duration of vibration of the soprano suona was measured to be 46.33ms, with a standard deviation of ±19.316. According to the results of the one-way ANOVA on the correlation between the sound intensity of the soprano suona and the duration of vibration, we don't think that the sound intensity of the soprano suona has an effect on the duration of vibration. In addition, by analyzing the three-dimensional spectrograms of the onset stage, we found that the first harmonic of the soprano suona was never the strongest harmonic component in the low, middle, and high registers, and that the second, third, and fourth harmonics gradually became the strongest harmonics with the increase of time. Comparatively speaking, the harmonic component of the middle zone is more obvious, the noise component is less, and the presence of non-harmonic component noise in the treble and bass zones is also more obvious, which is related to the coupling process of the resonance cavity, the middle zone is in the resonance band and gets better resonance, and the harmonic component is also amplified.

2.4.2 Duration and acoustic characteristics of the alto and bass suona

Based on the duration of the soprano suona and the method of acoustic characterization, this paper analyzes the alto and bass suona in turn. The average duration of oscillation of the alto suona and bass suona were measured to be 79.37ms and 93.47ms, with standard deviations of ±29.42 and ±13.54, respectively.According to the results of the one-way analysis of variance (ANOVA) on the correlation between sound intensity and oscillation duration and pitch and oscillation duration, it was found that the sound intensity and the pitch did not have an effect on the duration of oscillation of the two kinds of suona, the alto suona and the bass suona. In addition, the first harmonic was not the strongest harmonic component in the low, middle and treble regions of the alto suona and bass suona, and the higher harmonics became the strongest harmonic component as time increased.

3 Analysis of suona timbre performance in western symphony orchestral performance

This chapter first introduces the use of the timbral characteristics of Chinese suona and other wind instruments in practical training, then explores the ways in which the suona collaborates with the orchestra in orchestral performance, and concludes with a tempo-strength visualization of the performance of three suona players.

3.1 Use of wind instrument characteristics in practical training

In the instrumentation of the modern national orchestra, the wind section is the most singable and breathable section, and its acoustic width and loudness are also very prominent. Its acoustic width and loudness are also very outstanding. Especially the rendering of emotion is incomparable to other voices.

Take the fragment of the wind section in the national orchestral music “Legend of Shadir” made by Liu Yuan as an example. This piece is a description of the exploits of the Uyghur hero Shadir, and is written with a heroic theme. The heroic thematic melody of this fragment is very obvious, unfolding in the mood of mission with sorrow and grief. In practice, special attention should be paid to the balance of this passage and to the breathing and fluidity of the melodic line. The heroic theme is firstly narrated by the soprano sheng in the flute part, supplemented by the suona group and the sheng group's wailing, which makes the theme even more tragic. The melodic line and the weaving of the fragment are staggered by one bar, simply because the melodic line is caused by the weak start of the bar, but the blowing from the breath is staggered by one bar. This requires the melody and the weave to alternate breathing in different breathing positions, resulting in an audible continuity. The breathing measures for the flute are 5, 5, 3, 3, 1, 1 while for the suona they are 5, 3, 3. In terms of acoustic balance, the flute and soprano sheng need to play with an F to keep the melody line going, while the suona plays with an MF or the suona will overshadow the melody.

3.2 Collaborative approach between suona and orchestra

This section takes the suona concerto “Calling the Phoenix” as an example to explain the way of collaboration between suona and orchestra. The whole piece of “Calling the Phoenix” is in a single movement, which can be divided into six themes: the awakening of the young phoenix, the rising of the sun in the east, the spreading of the wings and crowing, the phoenix in the fire, the phoenix in nirvana, and the rebirth of the firebird. The work's paragraph structure is shown in Table 8.

Table 8: Themes of the six paragraphs of Summoning the Phoenix

Paragraph	Location	Theme
1	Rehearsal numbers 1-3	Chufeng awakens
2	Rehearsal numbers 4-5	The sun rises in the east
3	Rehearsal numbers 6-14	Spread its wings and cry
4	Rehearsal numbers 15-25	Phoenix in the fire
5	Rehearsal numbers 26-28	The phoenix's rebirth
6	Rehearsal numbers 29-31	The rebirth of the firebird

3.2.1 Intonation control

The intonation of suona has always been a difficult point of cooperation, in order to achieve the difference between Chinese and Western instruments' intonation to accurately grasp the intonation in the cooperation with the symphony orchestra, the most important thing is to control the behavior of consciousness to achieve the unity of knowledge and action.

Such as the rehearsal number 3-4 part of the work, pay special attention to this part of the performance of the previous rehearsal number 1, 2 orchestra is not into the C suona performance of the intonation grasp needs to be used by the players in the percussion section of the pitch as a reference for the intonation of the performance. If you study the score, you will find that at the end of each phrase of the solo in rehearsal No. 3, there is a sol tone in the bells as an echo, so it is especially important to catch this pitch standard at the end of each phrase. The last phrase of this section falls on the re note for an extended treatment, leading to the entry of the re note in the string section of the orchestra's concerto. At this point, the soloist needs to pay attention to maintaining volume balance and intonation unity with the concert band. The soloist should be careful to maintain the balance of volume and intonation with the concerto part. The performance will become weaker and weaker, and the extended volume will gradually disappear above the strings, giving the effect of carrying on the top and starting the bottom, and gradually moving away from the top and bottom.

3.2.2 Technical coordination of the suona with the orchestra

There are several aspects of solo and orchestra coordination required in concert works.

(1) Tempo. Accuracy and uniformity in the tempo of both represent the quality of the finished work. Such as rehearsal number 11 on the score, in a large run of thirty-two notes, contains irregular ornamental notes and playing methods, such as tongue push tone, flower tongue, legato, broken. In this intricate melodic flow, the ability to maintain a well-coordinated relationship with the orchestra while expressing the solo voice at the original speed is a difficult problem in front of the soloist. First of all, it is necessary for the player to be familiar with the fast section, and the speed of his own playing should be judged according to the speed of the large and complex variations in rehearsal number 11, and the speed of rehearsal number 10 should be determined after ensuring that the speed and accuracy of the variations are clear and precise. This multi-faceted considerations, in order to achieve this section of the orchestra, soloist, conductor of the three unity.

(2) The air. The soloist can fully utilize the body language prompts on the air mouth processing. Such as rehearsal number 14 in the final phrase, there is a long phrase is free to show off part, fast and complex changes in the sound of the performance of the author to deal with the slow and fast, from far and near, from low to high effect, and in the last c to join the suona characteristics of the “Huoyin” technology. The performance of “Huoyin” can be made a fast to slow technical processing, just like the phoenix irregular fluttering wings, and then naturally connected to the rehearsal number 15, and then make a larger air mouth, mainly for the conductor and the orchestra speed tips, let them know the solo next speed requirements, in the body language action signal need to be decisive not to Hesitation. An excellent performer should let the conductor and the orchestra fully understand the speed, strength and expressiveness through body and gesture hints, so that the music can be expressed in a perfect and unified way.

(3) Non-homogeneous rhythmic phrases. The Allegro section of Rehearsal Numbers 15-25 is a showy fragment consisting of large, rapid double spit changes. The non-homogeneous rhythmic phrases can also be interpreted as accent shifts. In the penultimate six bars of rehearsal number 19, the soloist alternates between the eighth note do, sol, and la, with the same tone and the same rhythmic change of accent, adding skipping and legato, flutter tonguing and fingerpunching, and matching the percussion's accents to create a vivid image of dancing and swaying. During the rehearsal process, the soloist needs to train with the conductor and the

percussionist individually, paying special attention to the time difference in the speed of sound propagation due to the different positions of the two players, so the soloist needs to pay attention to aligning the beat with the conductor when playing phrases, and the percussionist needs to pay attention to the treatment of the phrases and the point of percussion to be as positive as possible, point forward, so as to ensure that the alignment of the phrases in the non-harmonized rhythmic phrases is accurate. The same treatment is applied to the solo after rehearsal number 23, where the solo switches to a small e-flat soprano oboe in a large, fast, double spit ostinato passage, and the solo is mirrored below by the interaction of the brass section. Solo treatment from the volume of the beginning should not jump too much, each phrase of the breath at the attention of the brass section to listen to the counterpoint phrases, while the brass echo phrases need to be made in advance, breathing and spitting should be active, so as to accurately counterpoint the logical accents of the score, to the rehearsal number 24 will be the volume of all the timbre release, a breath of air and together pushed to the climax of the showboat part of this song.

3.3 Velocity-intensity visualization for three suona players

The visualization results of Guo Yazhi, Wang Zhanzhan, and Zhang Qianyuan, three suona players, are shown in Figures 6~8 for their performance of “Calling the Phoenix” in terms of speed and intensity, respectively.

Comparing Figures 6~8, it can be seen that Guo Yazhi did not repeat the part A, but Wang Zhanzhan and Zhang Qianyuan both repeated the part in strict accordance with the score. The average speed of Guo Yazhi's performance is the fastest, while Wang Zhanzhan and Zhang Qianyuan's speeds are similar.

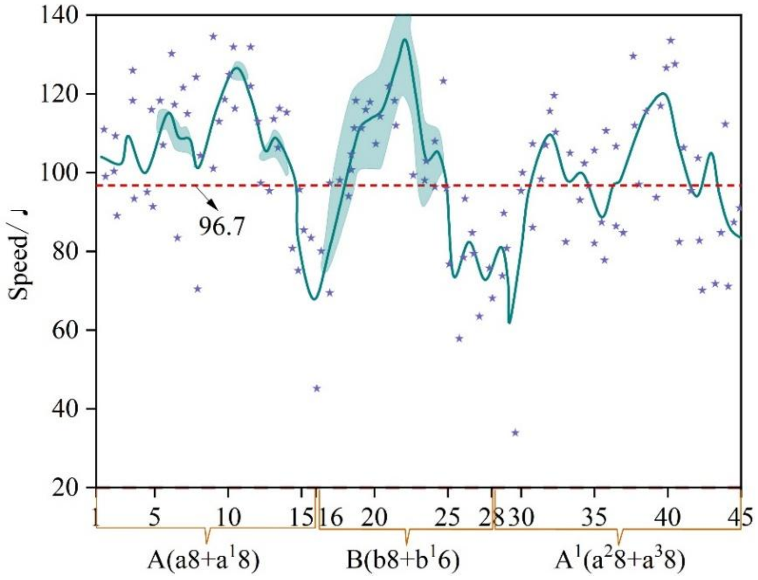

Figure 6: Speed-force visualization analysis of Guo Yazhi Wang

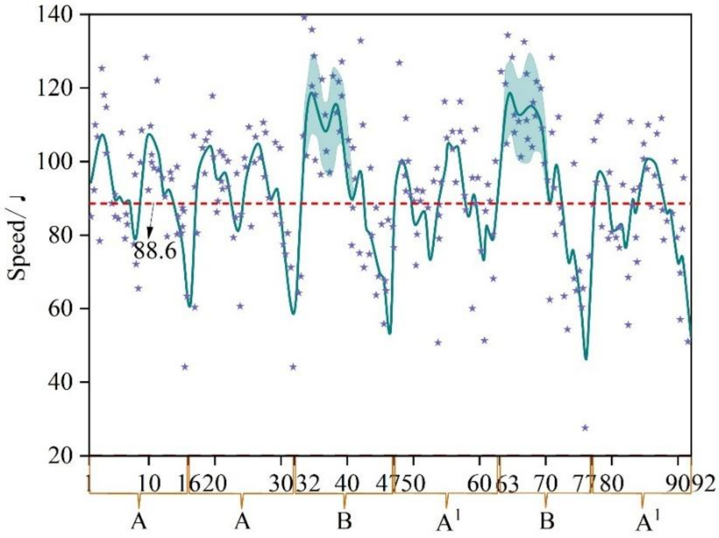

Figure 7: Speed-force visualization analysis of Wang Zhanzhan

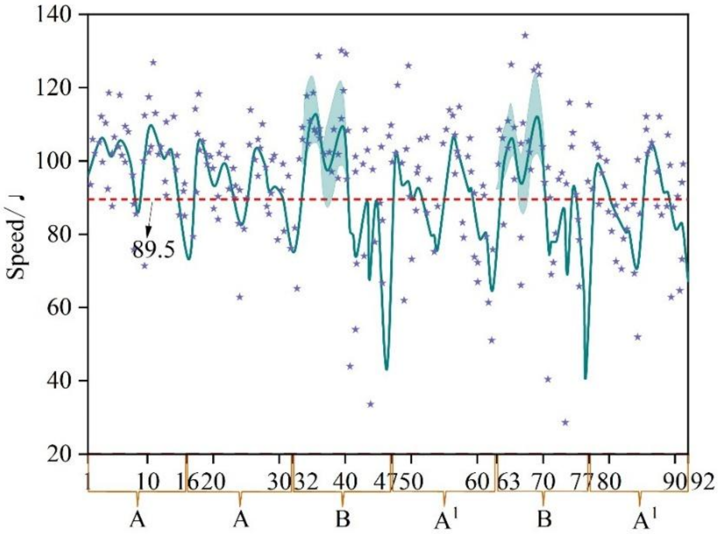

Figure 8: Speed-force visualization analysis of Zhang Qianyuan

The speeds of the three players, the fastest speed, the slowest speed and the difference between the fastest and slowest speeds and the average speed are shown in Table 9. Comparison of the speeds of the three players

Table 9: Comparison of the speeds of the three players

Performer	Average speed	The fastest speed	The slowest speed	The difference between the average speed and the fastest speed sheet	The difference between the slowest speed and the average speed
Guo Yazhi	96.7	133.5	61.8	36.8	34.9
Wang Zhanzhan	88.6	118.7	46.2	30.1	42.4
Zhang Qianyuan	89.5	112.7	40.7	23.2	48.8

Guo Yazhi played at an average speed of ♩=96.7, the fastest of the three players. Guo Yazhi's fastest tempo is in the middle of section B in measure 22, where the tempo reaches ♩=133.5, separated from the average tempo by ♩=36.8. The two tempo valleys are in measures 15-16, where the tempo is ♩=67.8, and 29, where the tempo is ♩=61.8, separated from the average tempo by ♩=34.9, which are at the end of the section. The A section consists of two 8-bar parallel phrases, both above the average tempo, with a noticeable crescendo between the two phrases, and with the second phrase slightly faster than the first. From the four-bar phrases, Guo Yazhi's last note of each phrase appears a little later and is emphasized a little bit in volume to highlight each small phrase; the B section has the most pronounced tempo fluctuations, with the speed of the b phrase jumping to the highest point of the whole section, and then slowly dropping back down to the lowest point of the whole section; the A1 section is similar in structure to the A section with two 8-bar parallel phrases, slightly slower than the A section overall. The A1 section is similar in structure to the A section in that it has two 8-bar parallel phrases, slightly slower than the A section in terms of tempo, but the tempo layout is the same as the A section, i.e., the second phrase is faster than the first phrase.

In terms of intensity, Figure 6 shows that the first phrase of the B section continues to grow in intensity and begins to weaken in the second phrase, and the A section is weaker than the A1 section. Although the layouts of the A and A1 sections are basically the same from the visual perspective, the two phrases of the A1 section end slower and weaker than those of the A section in terms of speed and intensity, thus reflecting a sense of the end of the passage and adequate preparation for the next section with a completely different style.

Wang Zhanzhan played at an average speed of ♩=88.6, the slowest of the three players. Like Guo Yazhi, the fastest tempo was in the first phrase of the B section, at ♩=118.7, separated from the average tempo by ♩=30.1, and the slowest tempo was at the end of the second phrase of the B section, at ♩=46.2, separated from the average tempo by ♩=42.4. The two 8-bar parallel phrases of the A section were basically the same tempo, and the recurring section did not have any major changes. Because the tempo is slower than that of Guo Yazhi, the overall feeling of the B section is more solemn than that of Guo Yazhi. However, in terms of the tempo changes, they were basically the same: the repeated section A1 was slightly slower than the first time they played it, with fewer ups and downs. Wang Zhanzhan's 4 bars of music were not as emphatic as Guo Yazhi's, and the tempo was arranged more in phrases. In terms of intensity, both Guo Yazhi and Wang Zhanzhan placed the strongest intensity in the first phrase of the B section according to the score. Although pp is marked at the beginning of the score and in the A1 section, both players coincidentally use a weaker intensity in the A1 section than at the beginning of the whole piece.

The average speed of the A section played by Zhang Qianyuan was ♩=89.5, which is basically the same as Wang Zhanzhan's speed. Like the other two, the fastest speed was in the first phrase of the B section at ♩=112.7, separated from the average speed by ♩=23.2, and the slowest speed was near the end of the second phrase of the B section at ♩=40.7, separated from the average speed by ♩=48.8. Zhang Qianyuan's speed and strength changes are basically the same as Guo Yazhi's and Wang Zhanzhan's, but there are two major differences between Zhang Qianyuan and the other two. The first point is in the passage connection, Guo Yazhi and Wang Zhanzhan's speed in the two passage connections is not much different, but Zhang Qianyuan's speed in the A passage connection to the B passage is obviously faster than the speed in the B passage connection to the A1 passage. The second point is that Zhang Qianyuan uses the same strength of pp for both A and A1, unlike Guo Yazhi and Wang Zhanzhan, who use the strengths of p and pp to form a contrast between the two passages.

4 Conclusion

This paper explores the performance of the suona in the orchestral hierarchy of Western symphonies based on the physical acoustic characteristics of the suona's timbre. The conclusions are as follows:

(1) The soprano suona, the alto suona, and the bass suona all have a major resonance peak, which responds well to the frequency ranges of 1000-4000Hz, 700-3000Hz, and 250-1400Hz, respectively, and the range of resonance peaks decreases in descending order from high to low frequency.

(2) The fundamental and overtones of suona are 1:2:3:4 ...... integer ratio, and the overtone column has the nature of harmonic column, with a clear sense of pitch. The harmonics as a whole are rich, and the timbre is full. The middle register has the typical spectral characteristics of a double-reed instrument, with a weaker fundamental energy than the second and third harmonics, with a “nasal” color. The number of harmonics in the upper register is relatively small, and the tone is relatively thin and sharp.

(3) In the low register, the odd-numbered harmonics of the soprano suona are dominant, bringing a slightly dull covering effect. The even numbered harmonics of the alto suona are dominant, bringing an open acoustic effect. The bass suona has a weak fundamental energy and the strongest harmonics appear in the fifth harmonic or the harmonics after it, bringing a slightly hard and rough sound effect.

(4) The average duration of vibration of the soprano suona, alto suona and bass suona were 46.33ms, 79.37ms and 93.47ms respectively, and there was no significant effect of sound intensity and pitch on the duration of vibration. And the first harmonic of the three kinds of suona was not the strongest harmonic component in the low, middle and high registers, and the higher harmonics became the strongest harmonic component with the increase of time.

(5) In orchestral performance, the way of collaboration between suona and orchestra mainly includes tempo, air mouth, non-homogeneous rhythmic phrases and so on.

(6) Among the three suona players, Guo Yazhi's arrangement of speed and intensity is very logical and rationalized, while Wang Zhanzhan and Zhang Qianyuan are more emotional and spontaneous. Aurally, Wang Zhanzhan's performance emphasizes the solemnity of the harmonic progression, while Guo Yazhi and Zhang Qianyuan emphasize the flow of the melody.

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