Sound Power Level Measurement of Zhonghu, a Chinese Bowed Stringed Instrument

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Zhonghu, as a Chinese alto bowed stringed instrument, is popularly used in Chinese national orchestra. As a part of the systemic measurement work of the sound power levels (SWL) radiated by Chinese musical instruments, the determination of the SWLs of the Zhonghu is reported. The measurement was performed in a reverberation chamber. Considering the differences among musical instruments and among musicians, two professional players were invited to play their own instrument respectively in the chamber. The radiated SWLs and the dynamic ranges of the Zhonghu instruments were investigated by 4 - channel acoustic measuring equipments. Typical sound power values of the Zhonghu instruments were obtained through averaging when melodies, music scale and single notes are performed under *pp*, *mp*, *f* and *ff* dynamics respectively. The SWLs of Zhonghu were compared with that of other Chinese two-bowed stringed instruments. Clear difference can be found from their SWL spectra.

Key words: Zhonghu, sound power level, measurement, Chinese bowed string instrument

1. INTRODUCTION

Zhonghu (Chinese Pinyin, Fig.1) is a Chinese two-bowed stringed instrument. 'Zhonghu'(中胡) is the shortened form of alto Erhu （中音二胡）in Chinese character. Its shape is quite like Erhu which is widely known in the west as "Chinese violin". At the base of the Zhonghu's neck there is a resonator, which is usually cylindrical or octagon prism and is made from boa skin stretched over a hollow wooden box on one side and some sound holes left on the other. Zhonghu is an indispensable alto musical instrument in the national orchestra.

Fig.1 Zhonghu

Since the 1960s, studies on the radiated sound pressure or sound power levels for the most important string and wind instruments of the Western orchestra have been published [1-3]. In 1990, Meyer summarized these measuring results, including his own sound power measurements, and derived a formula to calculate the mean forte sound power level L_{wf} for orchestral instruments [4]. Based on Meyer's work, a new criterion, the mean forte sound pressure level of tutti-sound, L_{pf}, was suggested for the evaluation of the loudness of concert halls [5]. In the formula for determining L_{pf}, the SWL data radiated by musical instruments are necessary.

Except of a minor study has been reported on the mean linear or A-weighted sound pressure levels and dynamic ranges of some traditional instruments performed in a studio [6], seldom works were done on the sound energy radiated by Chinese musical instruments. Since 2004 a systemic measurement on the sound power level radiated by Chinese national musical instruments was performed in the State Key Laboratory of Subtropical Building Science in China[7-12]. The sound power levels of more than 30 Chinese musical instruments were measured in the reverberation chamber and semi anechoic chamber of the lab. In this study, measurements for determining the SWL of the Zhonghu in a reverberation chamber are reported in details. The comparison between the sound power level measurement results of Zhonghu, Yehu, Gaohu and Erhu instruments are also given.

2. MEASURING PROCEDURE

For the SWLs measurement of Zhonghu, the same instruments and identical setup were arranged in the reverberation chamber of South China University of Technology as that used in the SWLs measurement of the Erhu[7]. Based on Meyer and Angster's work on the sound power measurement of violin [3], a change in source position causes only little effect on the measuring results. The standard deviation increased only 0.2 dB for lower frequencies and

0.1dB for frequencies above 800Hz. Therefore, in our measurements the sound source position was not changed.

The sound power of a musical instrument has a dynamic range which not only depends on the type of the instrument, but also on performing technique as well as on the performer's interpretation about dynamic markings. Considering that there are differences among musical instruments and among musicians, two professional players, each with 45 and 10 years experience respectively were invited to play their own instrument in the chamber. One of the Zhonghu was used for 6 years and the other was only half year old. Before measuring, the tuning was adjusted so that the pitch of the a^1 (A4) note was set to be 440 Hz.

The register of Zhonghu is g (G3 = 196Hz) - g^2 (G5= 784Hz). From the register three representative single notes, g, g^1 and g^2, which are representative notes for the low, medium and high registers respectively, and a special Chinese music scale consisting of 5 notes were selected for the sound power measurements. The music scale played was "g a c^1 d^1 e^1 g^1 a^1 c^2 d^2 e^2 g^2".

In each measurement round, a famous folk song "Molihua" (Jasmine flower) was first performed. The recording time was set to be 20 s. Then, the music scale was played with a recording period of 8 s. During this period, the scale could be repeatedly played with a speed about 2-3 notes per second. Finally, three notes g, g^1 and g^2 were played. In this case, 4 s was set for each tone. The players were asked to perform in a continuous style. The song, music scale and the three single notes were all played at four dynamic markings: pianissimo, mezzo-piano, forte and fortissimo (*pp, mp, f, ff*).

3. CALCULATING SOUND POWER LEVELS

For each case, the SWLs of each 1/3 octave band were measured. By taking an average, the sound pressure levels in each 1/3 octave band were obtained by Eq(1).

$$L_p = 10\lg(\frac{1}{N}\sum_{i=1}^{N}10^{0.1L_{pi}}) \quad (1)$$

Where L_p is mean sound pressure level in 1/3 octave band, dB; L_{pi} is sound pressure level in 1/3 octave band at each microphone position, dB; N is number of microphone positions, here N=4. And then the sound power level of each 1/3 octave band was calculated according to Eq(2) in accordance with ISO 3741.

$$L_{Wn} = L_p - 10\lg\frac{T}{T_0} + 10\lg\frac{V}{V_0} + 10\lg(1+\frac{S\lambda}{8V}) + 10\lg(\frac{B}{1000}) - 14 \quad (2)$$

Where L_{Wn} is the sound power level of n^{th} 1/3 octave frequency band from 100 to 10000 Hz [dB]; the number of bands being 21, n=1-21; T is reverberation time of the test chamber, s; $T_0 = 1$ s; V is volume of the test chamber, m^3; $V_0 = 1\,m^3$; S is total surface area of the test chamber, m^2; λ is wavelength of center frequency of the 1/3 octave frequency band, m; B is atmospheric pressure, mbar.

After obtaining the sound powers of each 1/3 octave band, the total sound power level L_W was calculated from

$$L_W = 10\lg(\sum_{n=1}^{21}10^{0.1L_{Wn}}) \quad (3)$$

Finally, the mean SWL and dynamic range for the two instruments were calculated through averaging.

4. RESULTS AND ANALYSIS

4.1 Sound Power Levels and Dynamic Range

Table 1 shows the mean sound power levels and dynamic ranges for Zhonghu sounding single notes, the musical scale and the melody, respectively. The mean sound power levels cover a span of 61-92 dB. The lowest mean level is observed for g^2 at *pp* level and the highest for music scale at *ff*. For 3 single notes, g^2 note has minimum SWL value when performed at *pp* and *ff* dynamics. But it has almost the same SWLs with g and g^1 note when performed at *mp* and *f* dynamics. Contrasting between the SWLs of music scale and melody performing, the SWL of Zhonghu has a larger dynamic range when music scale performed than that of melody performed, which can reach 20.5 and 15.7dB respectively. It is interested that the SWLs of Zhonghu are quite similar when melody and music scale performed under *mp* and *f* dynamics, Say 80.1 and 80.2, 88.7 and 87.8dB respectively. Although Zhonghu can radiate lower SWL when music scale is performed under *pp* dynamic, it will not be so weak for normal melody performing.

Table 1 Mean SWLs and dynamic ranges for both Zhonghus when single notes, music scale and a folk song are performed at *pp*, *mp*, *f*, and *ff* dynamic markings (dB)

Dynamics	Notes			Music Scale	Melody
	g	g^1	g^2		
pp	65.5	63.4	61.2	71.8	75.2
mp	74.7	73.7	75.7	80.1	80.2
f	83.6	83.5	82.7	88.7	87.8
ff	89.8	90.5	84.1	92.3	90.9
Dynamic Range	24.3	27.1	22.9	20.5	15.7

Table 2 gives sound power levels and dynamic ranges of the two Zhonghus when three single notes, music scale and melodies are performed at 4 dynamic markings. It is shown that there are wide discrepancies in the dynamic ranges of both Zhonghus.

Table 2 SWLs and dynamic ranges for two Zhonghus (A and B) when single notes, musical scale and a folk song are performed at *pp*, *mp*, *f*,and *ff* dynamic markings (dB)

Dynamics	Notes						Music Scale		Melody	
	g		g^1		g^2					
	A	B	A	B	A	B	A	B	A	B
pp	62.5	68.6	62.3	64.5	61.0	61.3	67.7	75.8	72.5	77.9
mp	74.6	74.7	76.7	70.7	76.6	74.8	78.3	81.9	79.8	80.7
f	84.7	82.6	85.6	81.3	85.0	80.4	91.0	86.4	88.7	86.8
ff	90.1	89.5	91.2	89.7	84.0	84.1	93.5	91.0	91.4	90.4
Dynamic Range	27.6	20.9	28.9	25.2	23.0	22.8	25.8	15.2	18.9	12.5

4.2 1/3 Octave Bands Sound Power Levels

The sound power levels of each 1/3 octave band of Zhonghu A and B when the music scale is played are shown in Fig.2. The sound radiation shows a peak appearing around the 1/3 octave band of 400 Hz. A clear secondary peak appears in the range of 1250-1600Hz for Zhonghu A. While Zhonghu B only shows a flat spectrum in the frequency band of 800 and 1250Hz. A sharp decrease appears at 2000Hz for Zhonghu A, and then a flat spectrum is shown in the frequency of 2000-2500Hz. While for Zhonghu B, this sharp decrease appears at 1600Hz, and a flat spectrum is shown in the frequency of 1600-2500Hz. For frequency higher than 3150Hz, the SWLs of both instruments show a quick attenuation. From Table 2 and Fig.2 one can see that Zhonghu A has wider dynamic range than that of Zhong B when music scale performed. The highest note in the music scale is g2 (784Hz). Thus the sound energy over 1000Hz must be radiated by harmonic resonance. This indicates that there are abundant overtones in the frequency range of 1000-2500 Hz.

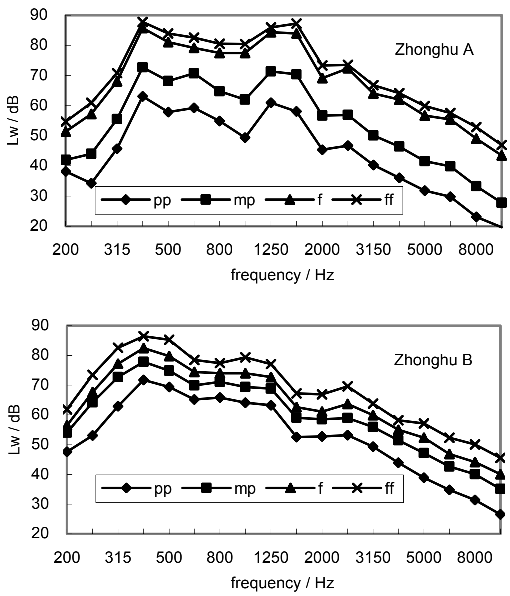

Fig.2. SWLs of Zhonghu A and B when music scale is performed at dynamic levels of pp, mp, f, ff.

The mean sound power levels in 1/3 octave bands of the two Zhonghus for music scale performed at pp and ff dynamics are shown in Fig.3, showing a dynamic range of nearly 20dB for frequency range between 250 and 10000 Hz.

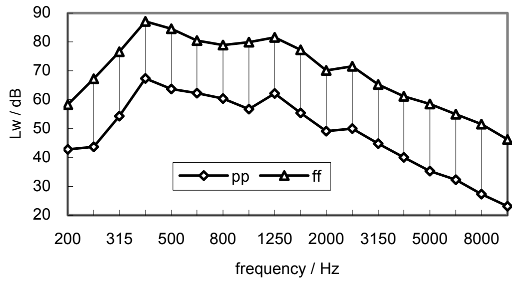

Fig.3. Mean SWLs of the two Zhonghus when music scale is performed at pp and ff dynamics.

The SWLs in 1/3 octave bands of both Zhonghus, when the three single notes are performed at *f* dynamic level, are shown in Fig 4. The frequencies of the note g, g^1 and g^2 are 196, 392 and 784 Hz and are located in the 1/3 octave bands of 200, 400 and 800 Hz, respectively. The fundamental frequency has not the largest sound power when tone g was performed. Its highest value appears in the 1/3 octave band of 400Hz. The sound power levels of tone g decrease for frequencies higher than 1250Hz for Zhonghu A. While for Zhonghu B, it decreases from the frequency of 1000Hz. Zhonghu A radiates more energy for frequencies higher than 1250Hz.

For g^1 note, the main peak appears in the 1/3 octave band of 400Hz in which the fundamental frequency (392Hz) exists. For both instruments the 2nd peak appears at 800Hz, which is corresponding to the 2nd harmonic frequency of tone g^1. And both instruments have similar values at main peak and the 2nd peak. As to the 3rd and 4th peaks, they appear at 1600Hz and 2500Hz for instrument A, and 1250 and 2000Hz for instrument B. Zhonghu A radiates more energy for those frequencies higher than 1000Hz.

For g^2 (784Hz) note, the SWL of the instrument B has three peaks at the frequencies of 400, 800 and 2500Hz respectively. The SWL spectrum of Zhonghu A shows two peaks appear at 800 and 1600Hz respectively. In the frequency range lower than 800Hz, instrument A shows a peak at 400Hz, while for instrument B, it shows a gradually increasing spectrum from 200-800Hz.

The differences shown in the SWLs spectra of the instruments can explain their timbre differences.

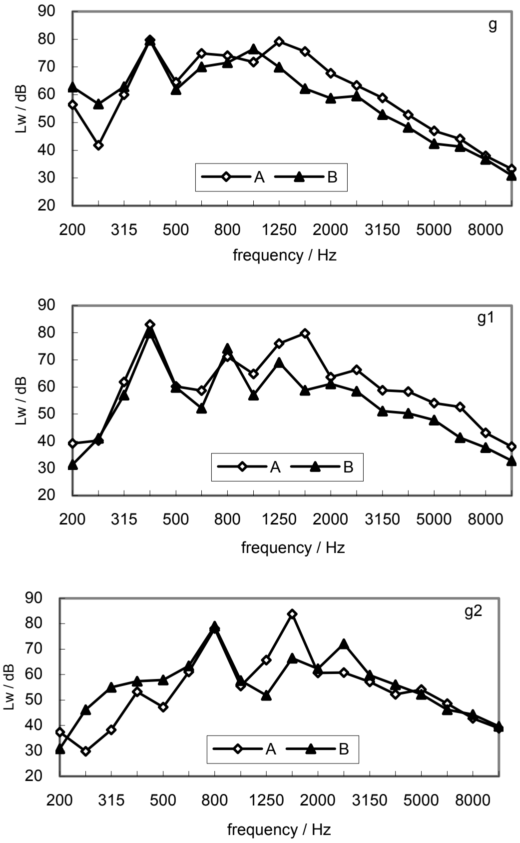

Fig.4. SWLs of Zhonghu A and B when three single notes (g, g^1, g^2) are performed at forte level

5. CONCLUSIONS and DISCUSSIONS

In this study, the SWLs of Zhonghu have been thoroughly determined. The dynamic range and 1/3 octave bands SWLs at *pp*, *mp*, *f* and *ff* are also obtained. The SWL differences between the two instruments are due to the combination of the instrument and its player. It is remarkable that the mean SWLs radiated by the two instruments are similar for melody and music scale performed at *mp and f* dynamic markings. While the instruments performed under *pp* dynamic markings, the mean SWLs when the music scale performed is 3.4dB higher than the SWLs when melodies performed. Which give a hint that, in melody performing, Zhonghu instrument cannot be played as weak as in music scale performings. For the instrument of Zhonghu, a less dynamic range can be expected when melody is performed than that of the music scale is performed with the same instrument.

The two performer were asked to perform the climax movement of < *The Moon reflects in Two Fountains* > and < *Floating clouds and flowing water* > for 20s with his own Zhonghu at normal dynamics. The SWL spectrum of the two melodies, and the SWL of each instrument and the mean SWL spectrum of both instrument when the music scale is performed under *f* dynamic, are shown in Figure 5. The SWL spectrum of instrument A and B when the melody of "Jasmine flower" is performed at *f* dynamic are also shown in this figure respectively. It can be seen that the shapes of the SWL spectrum for one instrument are similar even different melodies performed, and the SWL spectrum when the music scale is performed under *f* dynamic has a representative shape of melodies spectrums. Thus the SWL and its spectrum of one instrument can be represented by the value when music scale is performed. One also can conclude from figure 5 that SWL spectrum depends more on the instrument than the music. Thus the representative SWLs of the musical instruments can be obtained through measuring the SWL spectrum when a music scale is performed at *f* dynamic by several instruments and then calculating the mean SWL spectrum. Due to the good reproducibility of this value, it can be used in the SWL comparison among instruments.

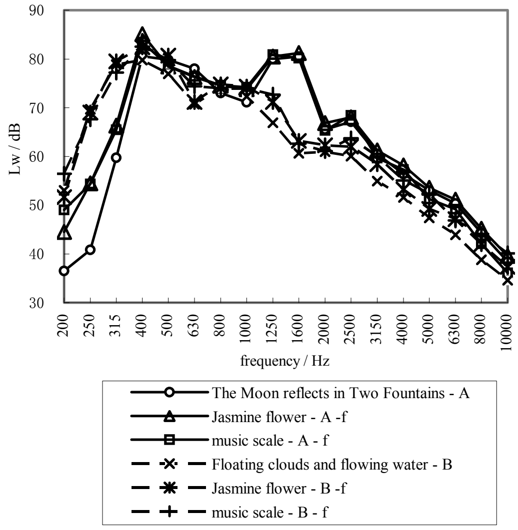

Fig.5 SWLs spectrum in 1/3 octave bands of Zhonghu when performing different music

The reproducibility of the musicians' performances is decisive for the usefulness of the results. Generally, repeated measurements show quite a high reproducibility which indicates that the players are qualified for their task and they acquainted with the reverberant environment and the recording conditions are satisfying. When playing at *f* level, the reproducibility is better than at other dynamics. The forte level in a concert hall has a high correlation with the subjective sensation of spatial impression and source broadening. We suggest that the forte SWL of performing a scale should be chosen as the most representative value of the sound power of an instrument [8]. In the case of Zhonghu, the mean forte SWL when playing a music scale can reach 88.7dB. The SWL spectrum is shown in

Fig.6. The sound power of the Zhonghu is radiated mainly from 315 - 1600Hz with levels over 70dB. Especially in the 1/3 octave bands of 315-500 Hz, the values are over 80dB. The radiated SWLs are 87.2 and 84.7dB respectively when the two performers were asked to perform the climax movement of < *The Moon reflects in Two Fountains* > and < *Floating clouds and flowing water* > with their own Zhonghu at normal dynamics. A SWL difference of 1.5dB can be found for Zhonghu A and 4.0dB for Zhonghu B from the suggested SWL value of 88.7dB.

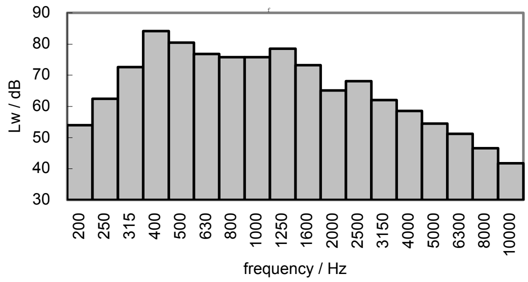

Fig.6. Mean SWLs in 1/3 octave bands of Zhonghu when the music scale is performed at forte level.

Since Zhonghu is not suitable for performing quick cadenza melodies, it always used with other bowed stringed instruments together in the Chinese national orchestra, such as Erhu, which is widely known in the west as “Chinese violin”, and Gaohu. The SWL spectrums of Zhonghu, Erhu and Gaohu are given in Fig.7. The SWL spectrum of Yehu is also shown in Figure 7. Yehu has the same register as Zhonghu and is usually used in Guangdong music. It can be seen that Zhonghu radiates more sound energy in 630- 2000Hz than that of Yehu. While Erhu can radiate more sound powers than Yehu for frequencies above 630Hz. Zhonghu and Yehu radiate more energy in 200-400Hz. Gaohu has the maximum energy in high frequency range of 2000-6300Hz.

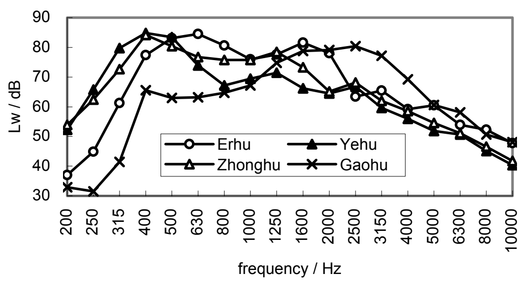

Fig.7 Mean SWLs in 1/3 octave bands of Erhu, Yehu, Zhonghu and Gaohu when music scales were performed at forte level.

The total sound power levels of Erhu, Zhonghu, Yehu and Gaohu instruments are 90dB, 88.7dB, 88.5dB and 85.8dB respectively when music scale is performed at forte level. Harmonious melodies can be expected if these instruments can be appropriately composed in an orchestra.

The measuring method discussed here is valuable for the sound power measurements of other musical instruments. The measurement of the sound power radiated by national musical instruments lays foundations for the investigation into the acoustics of national music halls.

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