Sound Radiation Pattern of the Sheng Pipes

Wei Kuang[1,2], Judit Angster[1], Zlatko Dubovski[1], Philip Leistner[1], Jun Yang[2] and Andras Miklos[1]

[1] *Fraunhofer-Institute for Building Physics, Nobelstraße 12, D-70569 Stuttgart, Germany*

[2] *Key Laboratory of Noise and Vibration Research, Institute of Acoustics, Chinese Academy of Sciences, Beijing, 100190, China, E-Mail: wei.kuang@ibp.fraunhofer.de*

Introduction

As a traditional Chinese mouth organ with lingual pipes, Sheng pipes are arranged in a round bundle. Therefore Sheng has pipe-dependent sound orientation. To get a better understanding on its sound radiation pattern, a B&K source identification system is used to measure the near field hologram of Sheng. Two measurements are presented in this paper. The first one investigates the active intensity distribution of 4 selected pipes as individual, while the second one measures the same pipes but as a component of the entire Sheng. Comparison of the active intensity distribution between the individual Sheng pipes and the labial organ pipes are also presented to explaining the result of the measurements.

Method

To measure the sound radiation pattern of Sheng pipes, a B&K source identification system which includes a type-3038 front end, a microphone array and ATC NS-STSF regular array software, is used in a semi-anechoic room of the Fraunhofer Institute for Building Physics, Stuttgart, Germany. The array contains 11*8 B&K 4195 microphones, while the distance of neighboring microphones is 7.5cm. Since the effective frequency range and spatial resolution depend on the array's dimension and on the distance between source and measurement surface [1], the analysis based on the system is in the range of [300, 2300] Hz and focuses on individual harmonics of the sound.

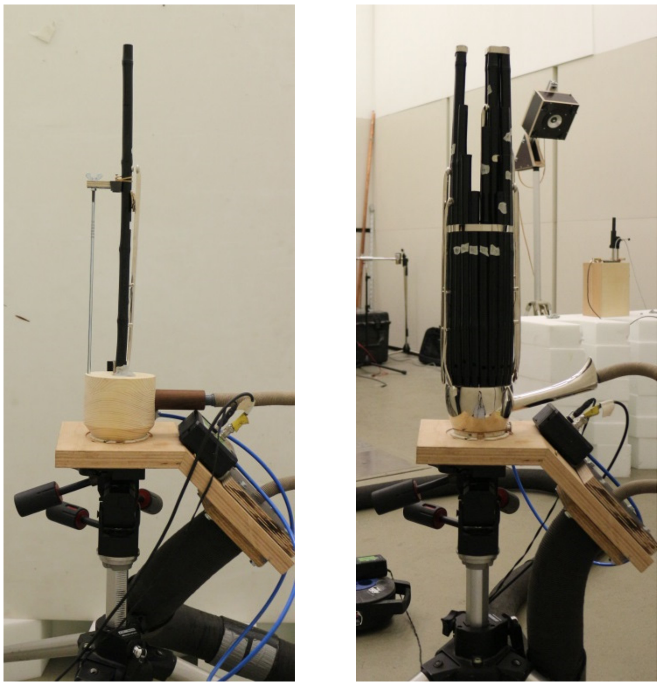
Two measurements are carried out. In the first measurement, as shown in Fig. 1(a), individual Sheng pipe is mounted on a cradle head which can rotate by 360° horizontally. The mouthpiece is supplied with constant wind pressure at 800 Pa. The microphone array is set with a distance of 27cm from the Sheng. Four pipes (No.1~ No.4) are chosen for their different geometric structures and orientations (Fig. 2). Their pitches and fundamental frequencies are listed in Table 1. As shown in Fig. 2(a), the black bar is the location of the tuning slot (pipe No.1~No.3) of the 1st type, the red bar is the tone hole (No.4) of the 2nd type. For the second measurement, the same pipes are measured again but only as components of the entire Sheng (Fig. 1(b)), while maintaining the other configuration parts as for the first measurement. Besides, 4 labial organ pipes of different pitches are measured as well for comparison (Fig. 3).

In both measurements, the sound pressure is recorded simultaneously by the array in 30° intervals. The active intensity of the first three harmonics is calculated as [2]

$$\bar{\mathbf{I}}(\mathbf{r},t) = \mathrm{Re}\{\mathbf{I}_c(\mathbf{r},t)\}$$

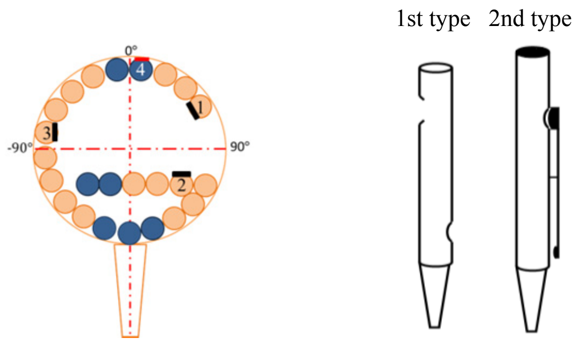
$$= \frac{1}{2}\cdot[\mathrm{p}(\mathbf{r},t)\cdot\mathrm{u}(\mathbf{r},t) + \hat{\mathrm{p}}(\mathbf{r},t).\hat{\mathrm{u}}(\mathbf{r},t)] \qquad [\mathrm{W/m^2}] \quad (1)$$

where $\mathrm{I_c}(\mathbf{r},t)$ is the complex instantaneous intensity, $\hat{\mathrm{p}}(\mathbf{r},t)$ and $\hat{\mathrm{u}}(\mathbf{r},t)$ are Hilbert transforms in time of the pressure $\mathrm{p}(\mathbf{r},t)$ and particle velocity vector $\mathrm{u}(\mathbf{r},t)$, respectively. Active sound intensity representing the net flow of energy therefore can be used to observe the sound radiation pattern.



(a) (b)

Figure 1: Experiment setup of two measurements: (a) the measurement of individual Sheng pipes; (b) the measurement of the same pipes as the 1st measurement, but the pipes are played as components of the entire Sheng. The measured object is fixed on a cradle head which can rotate horizontally. The Sheng mouth is supplied with 800 Pa blowing pressure.



(a) (b)

Figure 2: (a) The arrangement of Sheng pipes: each small circle is a pipe. Circles in orange are the pipes of the 1st type, while circles in blue are the pipes of the 2nd type. Black and red bars represent

the orientation of tuning slot and tone hole, respectively; (b) Two types of Sheng pipes: the first type (No.1~No.3) has an open end and a tuning slot, while the second type (No.4) has a closed end and a tone hole.

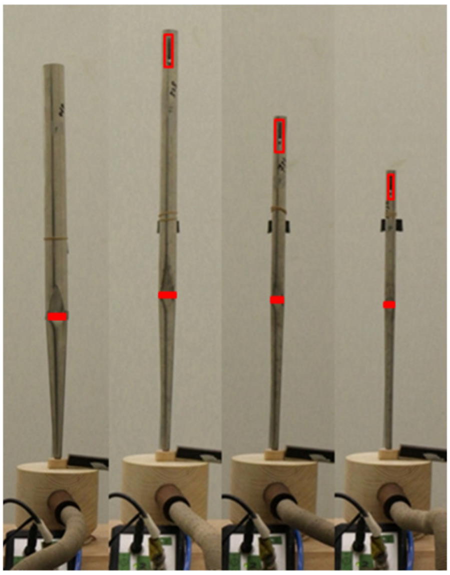


Figure 3: Four labial organ pipes.

Table 1: Fundamental frequency of pipe

	Pipe number	F0(Hz)	Pitch
Sheng pipes	No.1	627	#d2
	No.2	701	f2
	No.3	1124	#c3
	No.4	397	g1
Labial organ pipes	No.1	464	#a1
	No.2	528	c2
	No.3	752	f2
	No.4	1056	c3

Results of pipe of the 1st type

For the pipe of the 1st type, the holograms of the 1st and 2nd measurements are shown in Fig. 4. When the pipe is isolated as in Fig. 4(a), the first three harmonics of the sound radiate as a point source. The radiation center is close to the tuning slot and a bit upward shifting with frequency. When the pipe is played as a component of Sheng as in Fig. 4(b), the radiation pattern changes, especially for the 2nd and the 3rd harmonics. Two radiation centers are found: one is near the tuning slot, while the other is above the top of Sheng. It seems unreasonable to have a radiation above the instrument. However, the radiation center here is hardly the real sound source. Considering the measurement distance is 27cm, the upper radiation center can be explained as a result of the interference caused by reflected sound. That means: the superposition of sounds reflected by the Sheng body gets to its maximum amplitude at the upper center.

Similar conclusion can be drawn by analyzing the signals at the same column. Fig. 5(a) shows the arrangement of the microphone array. For the Sheng pipe of the 1st type that we chose to present as an example, its tuning slot is at the height of Row 5. The directivity pattern at three different heights ([R9, C4], [R5, C4], [R1, C4]) are plotted in Fig. 5(b). In the 1st measurement, this type of pipe radiates quite even at every measured height. Strongest radiation comes from the tuning slot ([R5, C4]). In the 2nd measurement, the radiation becomes uneven: it's strongest near 90° and weakest near -90°. Besides, the radiation at higher position ([R9, C4]) tends to be as strong as the middle position ([R5, C4]). This corresponds to the upper radiation center in Fig. 4(b).

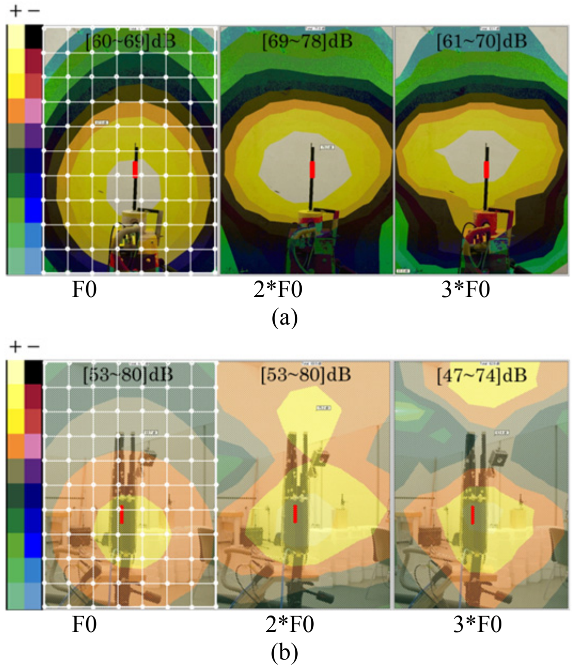


Figure 4: Active sound intensity holograms of the first three harmonics of Sheng pipe of the 1st type: (a) Hologram of the 1st measurement. Red bar is the location of tuning slot. (b) Hologram of the 2nd measurement.

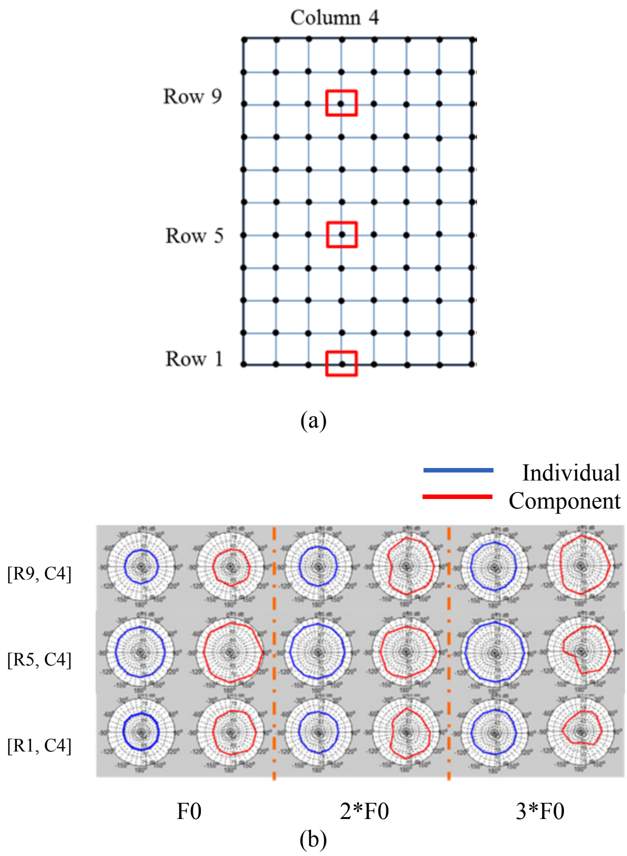
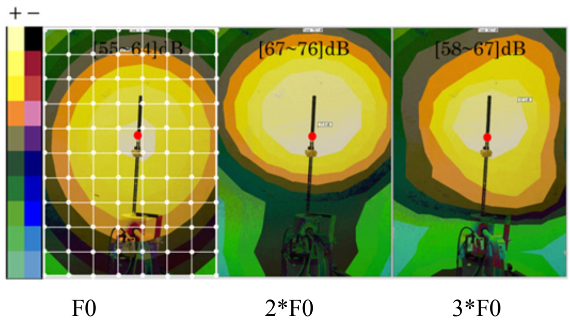


Figure 5: Directivity patterns of the Sheng pipe of the 1st type in two measurements: (a) The diagram of microphone array, three microphones are chosen to plot the directivity pattern in Fig. 5(b). The tuning slot of the pipe is close to Row 5. (b) Comparison of directivity pattern between two measurements and three harmonics. Blue curves are of the 1st measurement, while red curves are of the 2nd measurement. The coordinates on the left side represent the locations of the microphones.

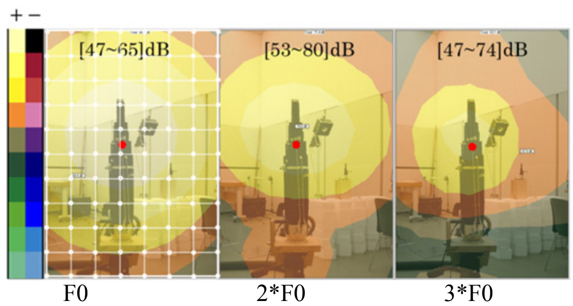
Results of pipe of the 2nd type

The Sheng pipe of the 2nd type only has a tone hole for sounding. It's opened when playing the pipe. Its holograms of two measurements are shown in Fig. 6. As the red dot shows, the radiation center is close to tone hole for the first three harmonics. Comparing Fig. 6(a) with Fig. 6(b), the patterns are similar, which means there's no complicated interference effect in the 2nd measurement.

The directivity patterns of the pipe at three different heights are plotted (Fig. 7(b)). The tone hole is near Row 6, where the radiation is strongest. Unlike the pattern in Fig. 5(b), the difference of radiation intensity is quite big between Row 2 and Row10. Especially, the intensity at Row 2 is much weaker. When considering the difference between two measurements, the pipe radiation when it's played as a component focuses near 0° and attenuates fast when coming to the back of the instrument (180°). Despite of that, two measurements are much similar to each other.

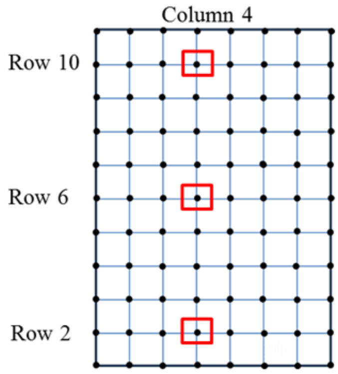


(a)

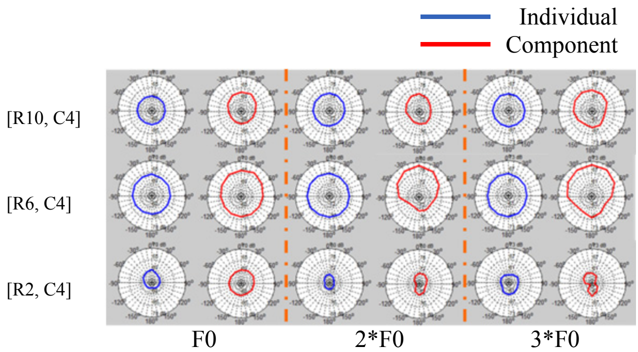


(b)

Figure 6: Active sound intensity holograms of the first three harmonics of Sheng pipe of the 2nd type: (a) Hologram of the 1st measurement. Red dot is the location of tone hole. (b) Hologram of the 2nd measurement.



(a)



(b)

Figure 7: Directivity patterns of the Sheng pipe of the 2nd type in two measurements: (a) The diagram of array and three microphones are chosen to plot the directivity pattern in Fig. 5(b). The tone hole of the pipe is close to Row 6. (b) Comparison of directivity pattern between two measurements and three harmonics. Blue curves are of the 1st measurement, while red curves are of the 2nd measurement. The coordinates on the left side represent the locations of the microphones.

Results of labial organ pipe

For comparison, four labial organ pipes are measured individually. They have similar fundamental frequencies and dimensions as the investigated Sheng pipes. According to previous research, the radiation of labial organ pipe comes from the mouth, the tuning slot and the end of pipe. What's more, the phase difference between the sound at mouth and at the end of pipe depends on the frequency. It's in phase for the 1st and 3rd harmonics, while it's out of phase for the 2nd harmonic.

As Fig. 8 shows, there's one radiation center for the 1st harmonic, two for the 2nd harmonic and three for the 3rd harmonic. The radiation center of the 1st harmonic is in between the mouth and the end of the pipe, which can be explained by the interference of two in-phase sound sources. At the same height, the intensity is at its minimum for the 2nd harmonic because of the interference of two out of phase sources.

Despite the differences of the physical sounding mechanism, some slight similarities of the radiation pattern of Sheng pipe inserted in a complete Sheng and an individual labial organ pipe can be found. That is, the 2nd and 3rd harmonic radiate stronger at the position of the real source and at a higher position. The Sheng pipe only radiates this way if it belongs to the first pipe type and if it is played in an entire Sheng.

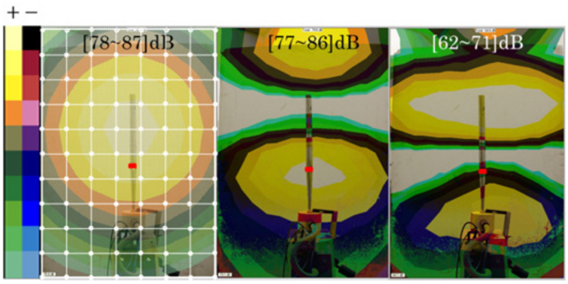


Figure 8: Active sound intensity holograms of the first three harmonics of a labial organ pipe. The red bar is the location of the mouth.

Discussion

In this paper, sound intensity measurements of two types of Sheng pipe are carried out in individual case and component case. For the Sheng pipe of the 1st type, radiation mainly comes from the tuning slot when the pipe is isolated. However, this type of pipe is usually inserted into the wind chamber in such a way that the tuning slot faces inward the instrument. This arrangement changes the radiation pattern of the pipe, especially for higher frequencies. The sound from the tuning slot is reflected by the other Sheng pipes. This results that the sound heard by people is the result of complicated interference of reflected sound.

On the other hand, Sheng pipe of the 2nd type isn't influenced by the arrangement of the entire instrument as much as the 1st type. This type is usually inserted into the wind chamber in such a way that the tone hole faces outward the instrument.

As individual, these two types of pipe radiate evenly only from one position (tuning slot or tone hole) though they're different in geometric structure. Nevertheless, the pipe arrangement and orientation of the opening make them behave differently. This should be taken into account in the subjective experiments because it will have an effect on the timbre perception.

Considering the measurement system used in this paper, it's not entirely suitable for musical instrument. The spatial resolution and frequency range, which are determined by the measurement distance and the dimensions of the array, turn out to be not high enough to meet the requirement. Therefore, for further experiments which are more accurate and precise, other possibilities are needed.

Acknowledgement

The first author thanks the National Natural Science Fund of China under Grant No.11174317 and the Sino-Euro Ph.D. Joint Training Program Scholarship of Chinese Academy of Sciences for the financial support of her research at the Fraunhofer IBP in Germany.

References

[1] Christensen J J, Hald J.: Beamforming. Brüel & Kjær Technical review 1(2004), 1-48

[2] Hald J.: Non-stationary STSF. Brüel & Kjær Technical review 1(2000), 1-36