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SIMULTANEOUS DETECTION AND ANALYSIS OF REED VIBRATION AND SOUND OF SHENG PIPES

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Framed by a common research program of Chinese Academy of Sciences and of the Fraunhofer Gesellschaft a cooperation project on the acoustics of Chinese and European wind instruments has been established. A first set of experiments is dedicated to reed vibration and sound of individual pipes of a sheng, a typical Chinese free-reed instrument. The investigated pipe of the sheng was mounted in a tailored transparent boot, which allowed the measurement of the velocity of reed vibration by using a laser vibrometer. Simultaneously, the sound of the pipe was detected by a microphone located in the near field of the sound source. The pressurized air for exciting the sheng pipe was provided by a bidirectional laboratory wind system, developed originally for driving organ pipes. Both the reed velocity and sound pressure signals were synchronously sampled by a four channel AD board and recorded by a laptop. The measurements were carried out in a semi-anechoic chamber. Reed velocity and sound pressure as functions of wind pressure and air consumption were studied experimentally. Spectra of reed velocity and sound pressure were calculated from the recorded signals by a special sound analysis software. The attack transients which are very important for the perceived sound of the instrument, were also analyzed. The results presented in this paper will provide a better understanding of the sound generation mechanism of sheng pipes and can be applied for support further research activities with directly applicable potentials.

1. Introduction

The sheng is a traditional Chinese free reed mouth organ which has a history of more than 3000 years. It consists of several bamboo pipes inserted into a metal wind chamber and this makes the sheng ideal as an accompaniment instrument in Chinese orchestra. Normally, for each pipe, there are a finger hole for playing, a window for tuning and a free reed which is attached to the foot of the pipe for excitation. The reed is cut and chiselled from a single plate so it can vibrate in both directions. Therefore, each pipe sounds with the same pitch whether in exhaling or inhaling condition.

Although the sheng is an ancient instrument, only little acoustic research has been performed and reported on it. To the author's knowledge, the acoustic model and the sounding condition of individual sheng pipe was theoretically investigated in small vibration approximation. The acoustic spectra of four different pipes in blowing condition were also given and discussed.[1] According to

previous research, the sheng reed behaves as 'blown-open' reed: the playing frequency is higher than both the natural frequency of the reed and the first pipe resonance.[2] However, the reed movement as well as the coupling between reed and resonator is rather complicated and still not clear.

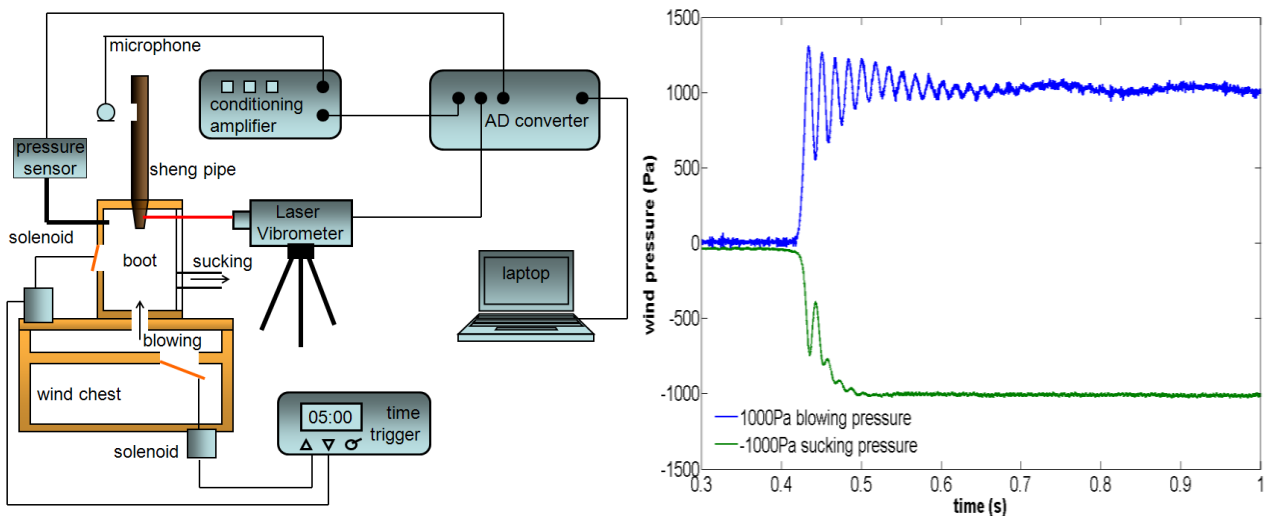
In order to understand better how sound is produced in the sheng pipe, this study investigated the reed vibration with resonator and sound spectra of different types of individual pipes in various sounding conditions through a set of experiments. The results of the measurements are presented and discussed in this paper. Section 2 gives a description of the experimental setups and method. The results of the measurements are presented in Section 3, and are discussed in Section 4.

2. Experimental method

2.1 Measurement system

All measurements were carried out in a semi-anechoic room of the Fraunhofer Institute for Building Physics, Stuttgart, Germany. To simulate the typical condition of the sound production of sheng pipe, a bidirectional wind system was applied (see Fig. 1(a)). The blowing wind system, which simulates a church organ's wind system was used in organ pipe measurements before; while the vacuum system was built specifically for sheng pipes. The blower and bellow as well as the vacuum pump were installed outside the semi-anechoic room in order to prevent the measurement from noise interference. The wind chest was installed in the semi-anechoic room. Electromagnetic wind valves, controlled by a timer, switched the air flow on and off. The wind pressure was controlled through the opening of slider valves and measured by a pressure sensor. The rise times of both wind system are less than 50ms (see Fig. 1(b)). The fluctuation at the beginning is probably caused by mechanical vibrations of the electromagnets. Since these oscillations didn't influence the measured reed vibration and sound pressure, no further investigation of this phenomenon was performed. According to the normal playing pressure and preliminary investigation, the wind pressure of measurement was set to ± 600Pa, ± 800Pa, ± 1000Pa and ± 1200Pa.

In order to observe the reed vibration of the reed, the sheng pipe was mounted on a wood adapter (boot) with transparent window at one side. The velocity at the tip of the reed was measured by a Polytec OFV 3000 laser vibrometer. Besides, the sound of the pipe was measured with a one-half inch B&K 4165 microphone near the sound source. As we will see in Section 2.2, the location of the main sound source differs in various types of pipe. The wind pressure, reed velocity and sound wave form were sampled synchronously by a four-channel AD board and recorded by laptop.



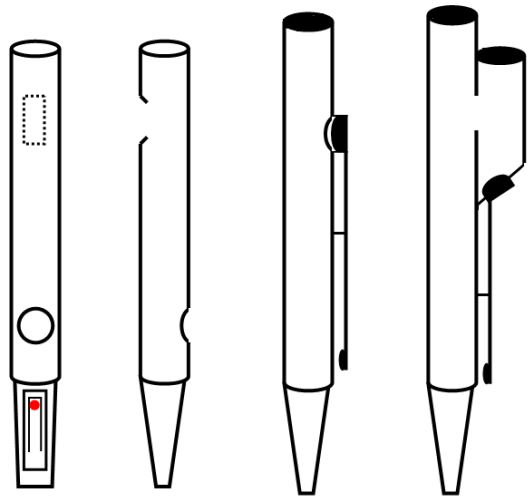
(a) (b)

Figure 1. Schematic of experiment on sheng pipe and wind pressure comparison

2.2 Selection of sheng pipes

The sheng for experiment is a 24-pipes traditional sheng for performance. Its register spreads from A_3 to F_6 sharp. In addition, the pipe structure differs in register.[3] There are three types in this sheng and their shapes are shown in Fig. 2. Figure 2(a) and (b) show the front and left view of the first type which is also the type of most pipes with medium and high pitches. A finger hole and a window are carved in the pipe. The end of the pipe is open. The pipe sounds only when the finger hole is covered. The second type (see Fig. 2(c)) is equipped by a metal key for playing, but without window. On the contrary, this pipe sounds when the hole is open by pressing the key. The last pipe (see Fig. 2(d)) is similar to the second one in sounding but it has a folded structure for the aesthetics of the whole sheng and better sound. This pipe has the lowest pitch and the longest resonator. The second and the third pipe have closed end. We have assumed that these differences in resonators may have an effect on the reed vibration and the timbre. Therefore, we have chosen one pipe from each type to measure and analyze. For notation, we assigned each pipe a number as shown in Fig. 2. The notes are D_5 sharp, F_4 sharp and A_3 corresponding to pipe No.19, No.4 and No.24.

To determine the sound source location of different types of pipe, a preliminary measurement of the complete sheng was carried out with a HEAD VISOR system in an anechoic room. Here we conclude the result in brief: the sound source of pipe No.19 locates at the window, while the other two locate at the hole which is opened by pressing the key. Therefore, microphone position was set near the source in our experiments.



(a) (b) (c) (d)

Figure 2. Three types of experimental sheng pipe. (a-b): pipe No. 19; (c): pipe No.4; (d) pipe No. 24

3. Results

3.1 Reed vibration and sound generation

After comparing the recordings of three pipes it was realized that the reed velocities are similar and have approximately sine waveforms. Typical attack waveforms of reed velocity and sound pressure are shown in Fig. 3. (Here the reed velocity is positive when the reed moves towards the laser vibrometer; i.e. away from the pipe). At the very start, both the sound pressure and reed velocity oscillates like a sine wave and the amplitude is very small. While the reed vibration is getting stronger, the sound waveform changes and peaks and valleys appear. Finally, the difference be-

tween peak and valley becomes bigger and the sound keeps stable. In the stationary signal two peaks can be seen in one period of the sound pressure signal.

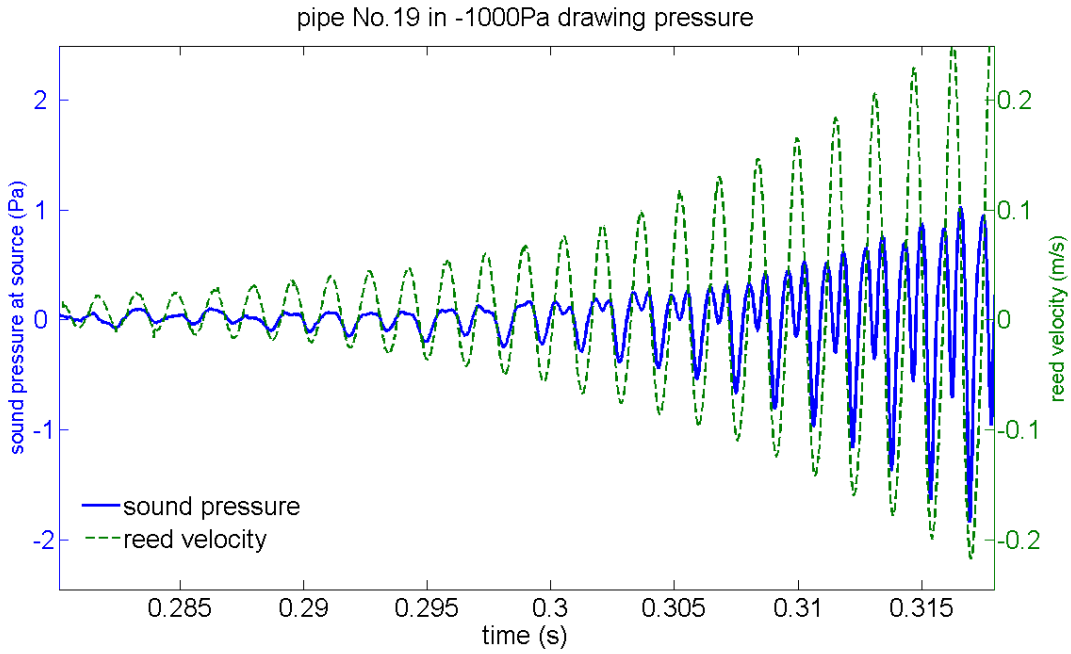


Figure 3. Process of sound generation

In Fig. 4 the waveforms of reed velocity and acceleration are shown in blowing and sucking condition. There are several common features in all the pipes. When looking into Fig. 4, it can be seen that the velocity signal corresponds to a distorted sine wave. One period of the reed vibration can be divided into two parts by the red vertical dash lines. Period t1 represents the movement of the reed outside the foot of pipe, while period t2 represents the movement inside the foot. In blowing condition t1 is longer than t2. On the contrary, t1 is shorter than t2 in sucking condition. As for the reed acceleration, its amplitude is higher in period t2 than in period t1 when blowing, and it reverses again when sucking.

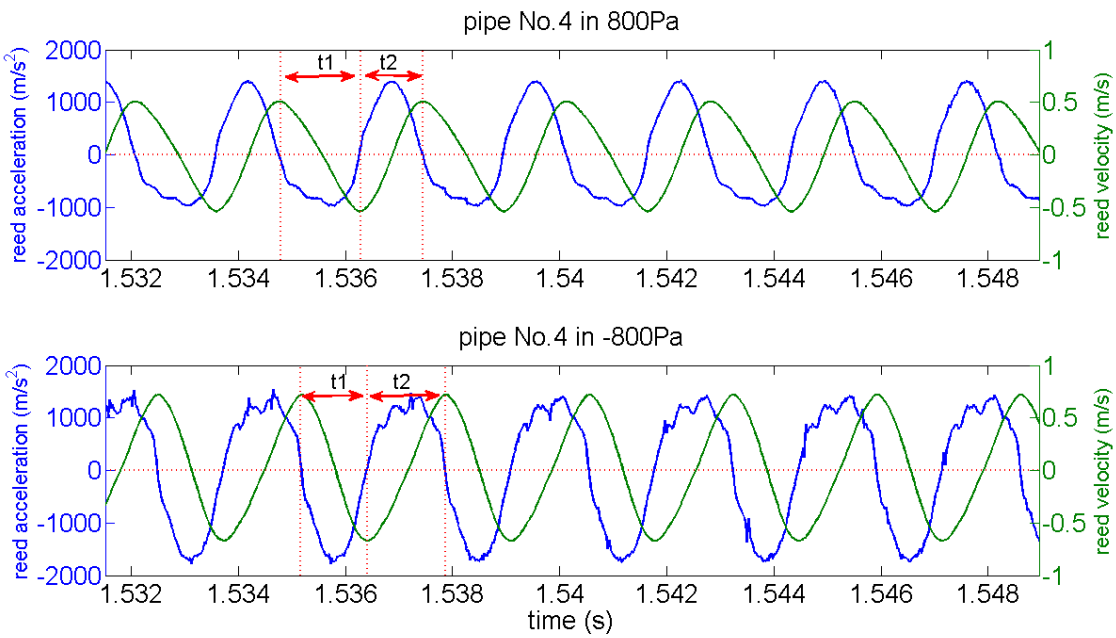
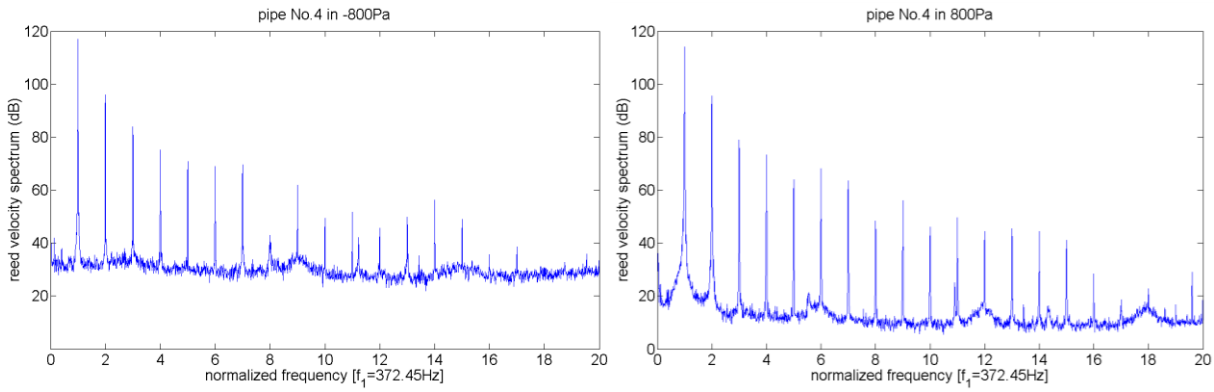


Figure 4. The reed velocity and acceleration in blowing and drawing conditions

Reed velocity spectra of pipe no.4 are presented in Fig. 5. As expected from the sine-like waveform, the spectra are dominated by the fundamental; the levels of the other partials are much lower. No significant difference can be observed between spectra measured in blowing and sucking condition; the levels of the corresponding harmonic partials are close to each other. Similar behaviour was found by the velocity spectra of the other two investigated sheng pipes, too.



(a) (b)

Figure 5. Reed velocity spectra of pipe No.4 in blowing and drawing conditions

3.2 Sound spectra and sound pressure level

Spectra of the stationary sound were calculated from the recorded signals by a special software Sound Analysis. The shapes of the spectra of the investigated three pipes are similar to the spectrum presented in Fig. 6. The 2nd and 4th harmonic partials are always stronger than the fundamental, 3rd and 5th partials. The amplitude decreases with frequency in the first ten to fourteen harmonic partials. The sounding frequency remains constant among various wind pressure.

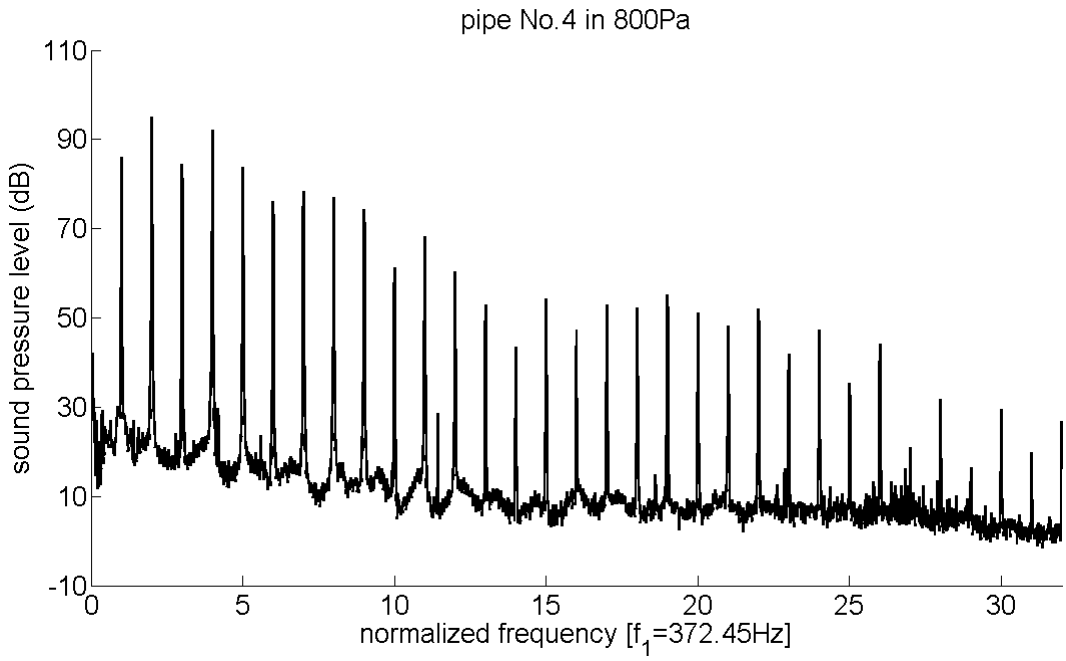


Figure 6. An example of the measured stationary sound spectra

The relationship between sound pressure level and wind pressure can be observed in Fig. 7. For comparison, we only display the envelopes of the measured spectra. As can be seen by different pipes, the sound spectral envelopes at different pressures are similar. While increasing the wind pressure, the amplitudes of higher harmonics grow faster than lower harmonics. The 4th harmonic partial of pipe No.19 is very interesting; it grows fast as well and even becomes the strongest one. For sucking condition, the case is similar; the tendency remains unchanged while the amplitude relation between adjacent harmonics varies more or less. These changes in spectra have an effect on the loudness as well as on the timbre. We present the calculated loudness in different representations as well as the linear sound pressure level in Table 1. The loudness calculation is based on a Loudness Toolbox downloaded from GENESIS S.A. Strictly speaking, this is not the real loudness of the investigated pipes, because the sound pressure was recorded near the source. However, the calculated values can be used as references for the dynamic range of different pipes in the investigated pressure range. Quite large differences were found among the pipes: we can see, for example that pipe No.19 is much louder than the other two pipes under the same wind pressure.

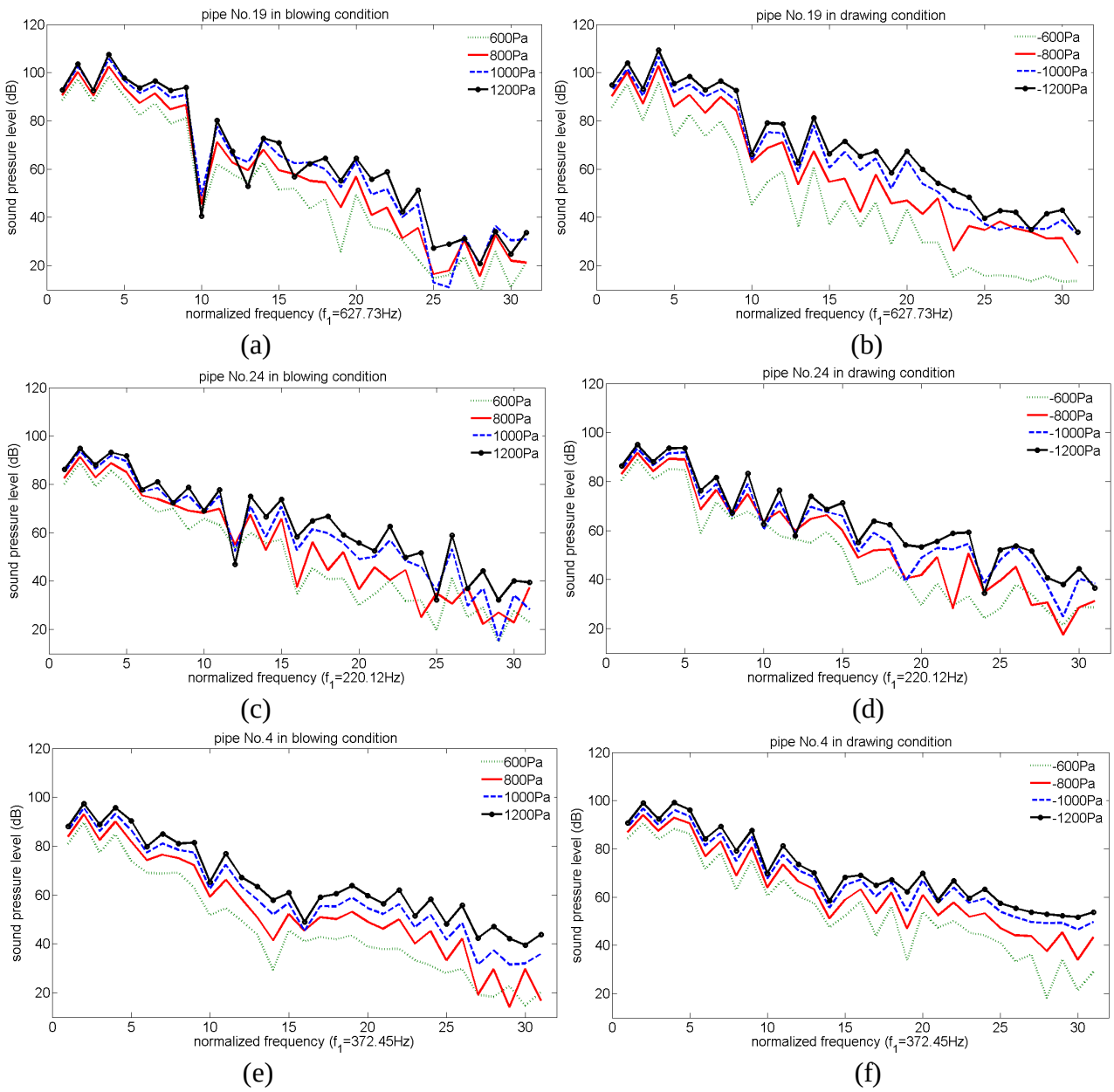


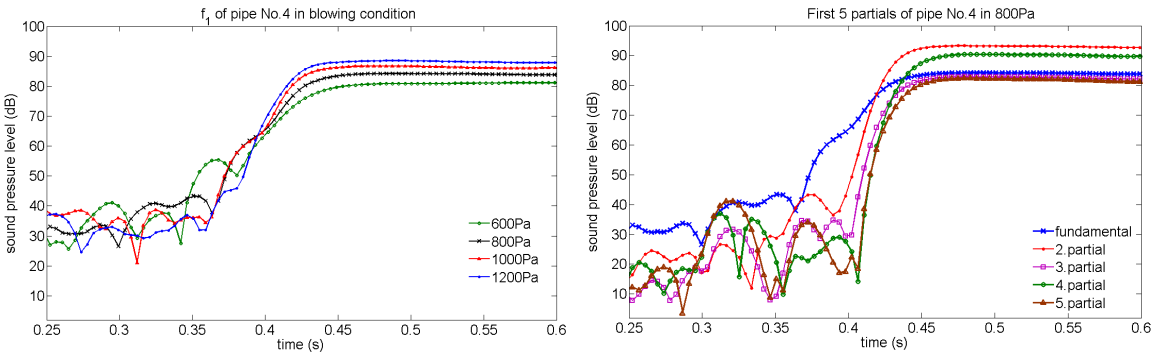
Figure 7. Pressure dependence of sound spectrum envelope

Table 1. loudness in different wind pressure

wind condition		blowing				drawing			
wind pressure(Pa)		600	800	1000	1200	-600	-800	-1000	-1200
total loudness (sone)	No.19	115.6	146.2	175.0	186.6	91.6	128.2	164.1	190.2
	No.4	55.1	71.2	87.7	102.3	69.2	88.1	105.3	118.8
	No.24	51.3	63.4	78.9	87.4	51.0	65.4	76.8	86.4
total loudness level(phon)	No.19	106.2	109.3	111.5	112.3	103.2	107.5	110.8	112.5
	No.4	96.5	100.1	102.6	104.9	99.7	102.7	105.2	106.6
	No.24	95.7	98.4	101.3	102.6	95.6	98.9	101.0	102.4
linear sound pressure level (dB)	No.19	109.6	113.3	116.4	118.0	105.5	112.6	116.2	119.1
	No.4	98.5	103.3	106.7	109.4	103.0	107.2	110.3	113.0
	No.24	99.5	102.9	106.2	108.0	99.9	103.8	106.3	108.4

3.3 Attack transients of harmonics

To know how the harmonics grow with time in various pressures, we analysed the attack of first five harmonics. Figure 8 gives a typical example. In Fig. 8(a) can be seen that the sound pressure level of the fundamental is getting higher with pressure, its attack slope is getting steeper, too. We should notice that the small peak at the beginning of the attack by 600Pa is a special and common feature for all the pipes by this pressure. For comparing the attacks of the first five partials, the attack of pipe No.4 by 800Pa is shown in Fig. 8(b). The fundamental component starts rising 30-50ms earlier yet much slower than the other partials. They rise very fast and simultaneously. Finally they achieve stable state nearly at the same time. The behavior of the attack of other pipes is similar to the presented one. Attacks by blowing and sucking conditions were also very similar.



(a) (b)

Figure 8. (a): pressure dependence of the attack of the fundamental frequency, (b): attacks of the first five partials at 800 Pa wind pressure

4. Discussion and conclusion

The sheng pipes we have chosen to investigate differ in geometric structure of resonator, yet their waveforms and spectra shown similar characteristics. In spectral domain, the 2nd and 4th partials of the sound pressure are always stronger than others. The 2nd partial can be observed clearly in time domain as two positive peaks in a period in Fig. 3.

When looking into the reed vibration, these peaks correspond to the almost symmetric outside and inside movements of reed relative to the frame. This is a feature of Asian free reed instruments while the reed tongue is riveted to the top of the frame in Western free reed instruments. However, the movement of the reed of sheng pipe isn't symmetric strictly, at least in those we measured in this paper. The reed velocity achieves its maximum while going through the frame. In blowing condition, this value is slightly lower when the reed moves outwards than inwards; while the opposite can be observed in sucking condition. Similar phenomena can be observed in reed acceleration, which reaches maximum and minimum at the reed extreme positions. In blowing condition, the highest value occurs when the reed moves to the inside extreme position. On the contrary, the highest value is at the outside extreme position, when sucking. Besides, the time duration when the reed stays outside and inside the frame differs, too (see Fig. 4). These relations hold for all investigated pipes and pressures.

Reed velocity and sound pressure spectra are completely different; the velocity spectrum is dominated by a strong fundamental, while the 2nd and 4th harmonic partials are the strongest components of the sound spectra. This behaviour can be explained by the fact that air is blown in (or sucked from) the foot of the pipe two times within one period of reed oscillation (see Fig. 3).

In spite of the different geometry of the investigated pipes the sound spectra are remarkably similar. It may be assumed that the acoustic properties of the pipes play only a secondary role in the sound generation of the investigated sheng pipes.

The effect of increasing wind pressure in both conditions boosts the amplitude of higher partials with the main spectral structure nearly unchanged. While the amplitude of the fundamental component increases several dB in sound pressure level, the amplitudes of high frequency components increase tens of dB. This change has effect on the timbre of sound as the spectral centroid increases mainly. According to our informal subjective test, sound is getting brighter and sharper when increasing the pressure. This is consistent with the timbre perception result of which spectral centroid can be account for the brightness of sound.

In addition to, the attack of sound pressure is accelerated with increasing wind pressure. This behaviour is common among partials (see Fig. 8). The attack of fundamental frequency is always slower than other harmonics which burst more rapidly.

In summary, this paper presents the experiment and several common results among three geometric different pipes. The different behaviour of reed vibration and sound pressure spectrum in blowing and sucking conditions are worth noticing. To explore the physical mechanism of reed and resonator, further experiments will be carried out in the near future.

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