PROCEEDINGS of ISMA 2019
International Symposium on Music Acoustics

13 - 17 September 2019 in Detmold, Germany

The khaen as a miniature pipe organ

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Abstract

The khaen is a Southeast Asian mouth organ consisting of a number of free-reed pipes (commonly sixteen) mounted in a wooden wind chamber. From one point of view, it is possible to think of this instrument as an extremely small pipe organ: one with one rank of sixteen free-reed pipes. There have been a number of studies of the khaen in recent decades, often focusing on the coupling between a single reed and the pipe in which it is mounted. Yet music for the khaen, both traditional music and new music by current composers and players, almost always involves multiple notes sounding simultaneously. This paper summarizes some investigations involving the instrument as a whole, sometimes observing similarities and differences between the khaen and the pipe organ. A significant difference is the wind supply, which in the khaen is continually reversing direction. This certainly affects the musical playing style of the instrument, but may have other acoustical complications. Another area recently explored experimentally involves possible musical consequences of mode locking between pipes.

Keywords: Free reed, mode locking

1 INTRODUCTION

Mouth-blown instruments using a free reed coupled to a pipe resonator have a long history in China, Japan, and throughout Southeast Asia. The khaen is an instrument of the Lao people in Northeastern Thailand and Laos. The most common type of khaen employs sixteen open pipes, each with an effective length determined by the placement of tuning slots cut in the pipe. For an effective length L, the reed is located at approximately L/4. Unlike the free reeds found in Western instruments such as the reed organ, accordion, and harmonica, the reeds of the khaen are not only coupled to pipe resonators, but are approximately symmetric, so that the same reed can operate on both vacuum and pressure (inhaling and exhaling). Figure 1 shows a khaen along with a typical reed. Details on the khaen and other Asian free reed instruments are found in the book and article by Miller [1, 2].

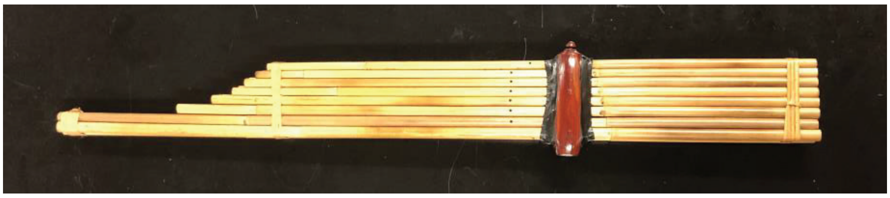

Figure 1. One of the khaen used in this study, along with a photo of a reed from a similar instrument.

The free reeds used in the khaen are cut from a single piece of thin metal, typically brass or a bronze alloy, and set into a bamboo pipe. In this single note per pipe instruments, a finger hole is drilled at a point that destroys the pipe resonance and prevents the reed from sounding unless the hole is closed. Wind is provided by blowing either in or out through the mouthpiece which forms the opening of the air chamber that surrounds the reeds. The instrument is held upright with the air chamber supported by the hands, with fingers and thumb of both hands are available to close the holes and sound notes. It is typical in playing the instruments that several notes are sounded simultaneously, some of them serving as drones.

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The frequency of reed vibration is determined by both the reed and the pipe. The tuning slots (usually two per pipe for the khaen) are cut into the back of the pipe, determining the effective acoustical length. The vibrating frequency of the blown reed can within certain limits be pulled to match the pipe resonance so that fine tuning of pitch is done by means of the position of the tuning slots. In the khaen, reed length only approximately corresponds to sounding frequency, with pipe length apparently used as the prime means for tuning. [3] A characteristic shared by the Asian free reed mouth organs with other free reed instruments is that the sounding frequency drops as blowing pressure is increased. Data on this has been reported elsewhere [3,4]. The pitch change encountered in practice does not generally seem to cause musical problems.

2 SUMMARY OF PREVIOUS RESULTS

2.1 Playing frequency

Figure 2 shows the general relationship between frequency and pipe length for a khaen pipe. The pipe length was gradually shortened by cutting lengths from the original pipe. As can be seen in the graph, the sounding frequencies follow closely the fundamental pipe frequency, always remaining slightly above it. At the shortest pipe length in this example, the reed did not sound at normal blowing pressure (0.8 kPa), but could be made to sound at +1.7 kPa. At this same length, underblowing (0.3 kPa) caused the reed-pipe to sound at a frequency very close to the reed frequency. The results presented in Figure 4 show that the sounding frequency of the reed-pipe combination is higher than the natural resonance frequencies of either the reed or the pipe taken alone.

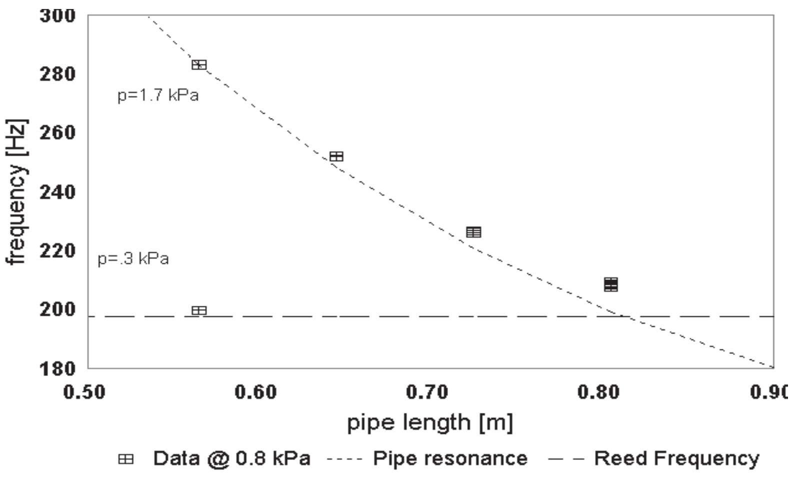

Figure 2. Sounding frequency of a khaen pipe as a function of fundamental pipe frequency at 0.8 kPa, with exceptions as noted for in the case of the shortest pipe.

2.2 Calculation of impedance curves and sounding frequencies

The sounding frequency measurements shown above suggest that the reeds in the khaen behave as “blown-open” reeds in which the playing frequency is above both the natural frequency of the reed and the first peak of the measured impedance curve. Detailed calculations of input impedance curves have been made for the khaen and other similar instruments using a method of transmission matrices [5]. These calculations take into account the position of the reed along the pipe, tuning slots, finger holes, and non-uniform cross sections. The details of these input impedance calculations are in good agreement with the measured impedances of the same instruments. Treating the reed as a damped, driven harmonic oscillator, the sounding frequencies of these reed-pipes can be predicted using a pipe-reed phase relation between the reed vibration and the phase of the complex impedance as formulated in the paper by Fletcher [6]. A sample result is illustrated below in Figure 3 and Figure 4.

The impedance curves calculated by the methods in this paper agree well with experimental results, even in smaller features and at higher frequencies. The agreement between calculated and experimental values is good, even for cases in which the sounding frequencies are not close to the pipe frequencies.

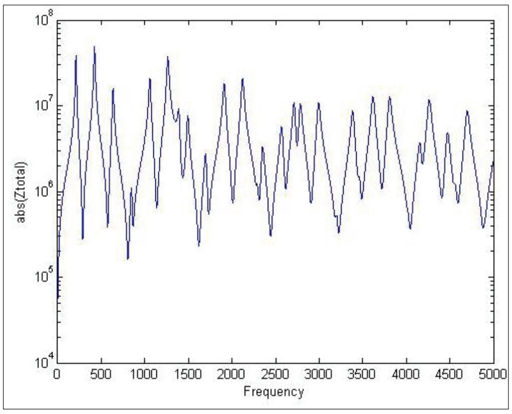

Figure 3. Magnitude of the calculated input impedance for a khaen pipe.

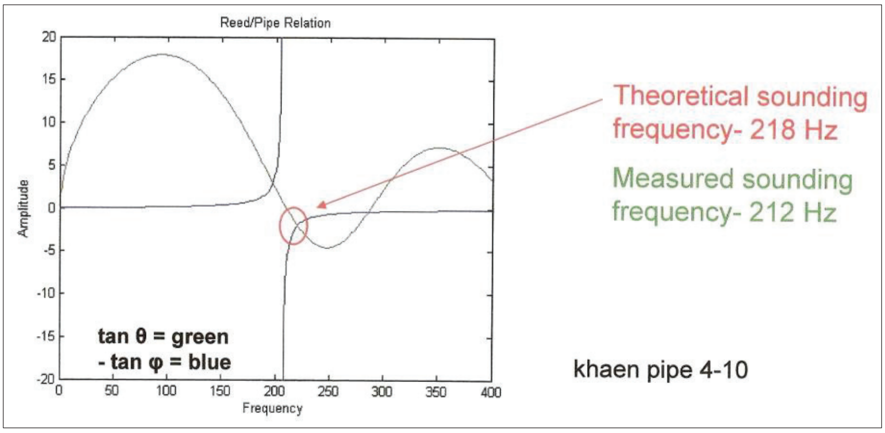

Figure 4. Determining the sounding frequency of the khaen pipe of Figure 3.

As shown in the above example, the methods used to obtain the sounding frequencies for the free-reed pipes of the khaen were quite successful. Similar calculations were also made for other Asian free reed instruments with pipes of more varied cross sections than the khaen pipes. There are some features of the khaen that have not been explored until recently. The acoustical effects of the end sections (the sections of the pipes extending beyond the tuning slots) have not been previously studied in any detail. The following section of this paper includes some results on this topic from simulations.

Another area of study is that of interactions between pipes. Music for the khaen almost always involves the sounding of several pipes simultaneously, yet most acoustical research thus far has been on the properties of a single pipe. One phenomenon that had been suggested for investigation is that of mode locking or synchronization, for which some preliminary results are presented in Section 4 of this paper.

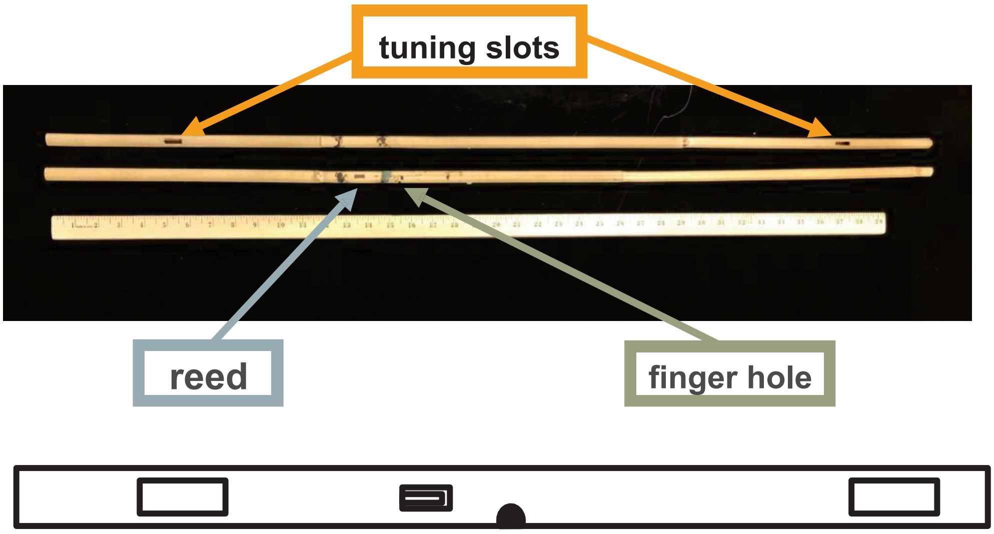

Figure 5. Above: Two views of the khaen pipe for which the calculated impedance is shown in Figure 6. Below: A diagram of a similar pipe showing the tuning slots, reed and finger hole.

3 KHAEN PIPE SIMULATIONS

A project has recently begun with the object of modeling the khaen using the finite element and multiphysics COMSOL® software. Some preliminary results are shown in the following figures. Figure 6 shows a calculated input impedance curve obtained by locating an oscillating pressure source at the reed position of the pipe. The impedance curve shows the expected maxima at the resonances of the open pipe with length determined by the tuning slots. The amplitude of the fourth harmonic is reduced, as expected, due to the location of the pressure source near a node of that mode.

In addition, there are a number of modes of the complete pipe indicated by the very narrow peaks that appear in the impedance curve. Some of these correspond to modes of one of the two end sections, while others involve both an end section along with the main pipe section.

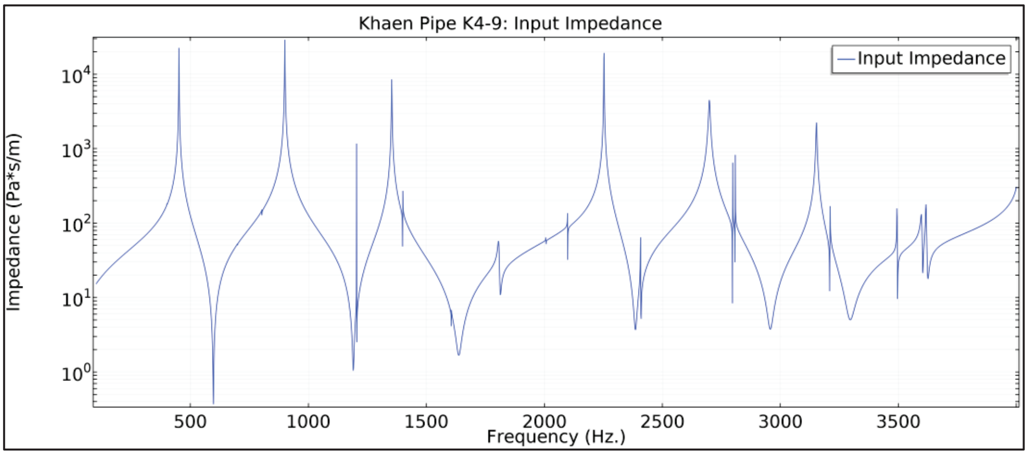

Figure 6. A COMSOL® generated impedance curve for khaen pipe K4-9.

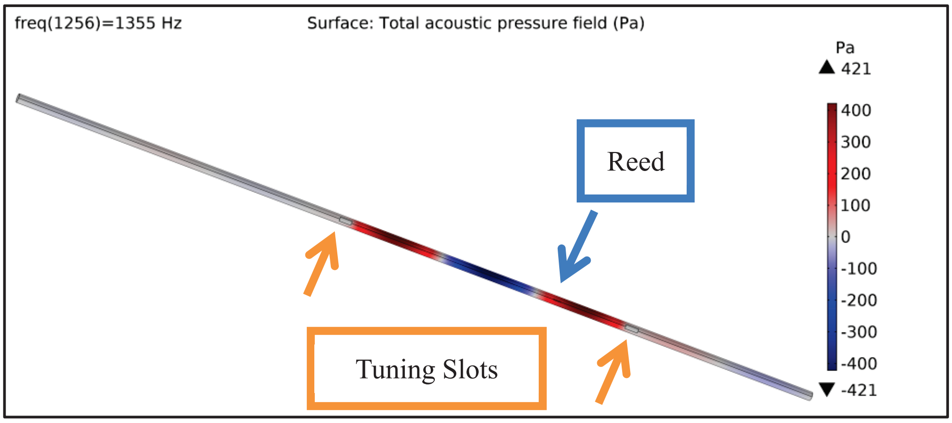

Figure 7. Mode 3 of the main pipe section (1355 Hz), locations of the reed and the tuning slots marked.

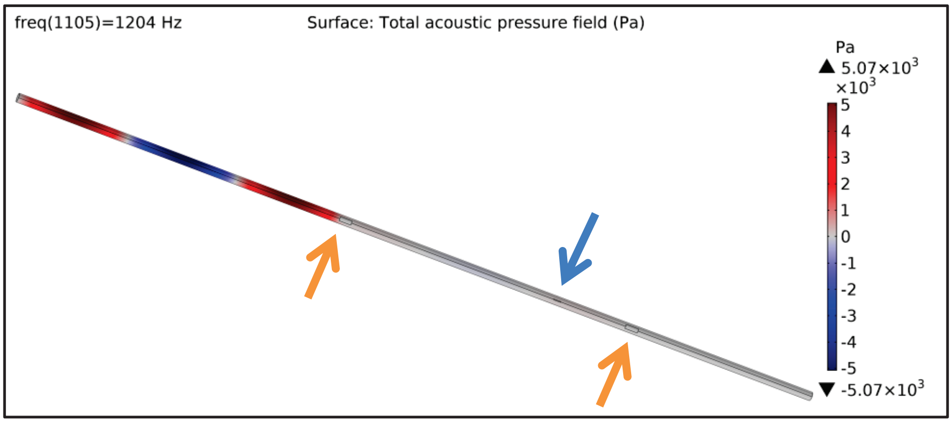

Figure 8. A mode of the upper end section (1205 Hz).

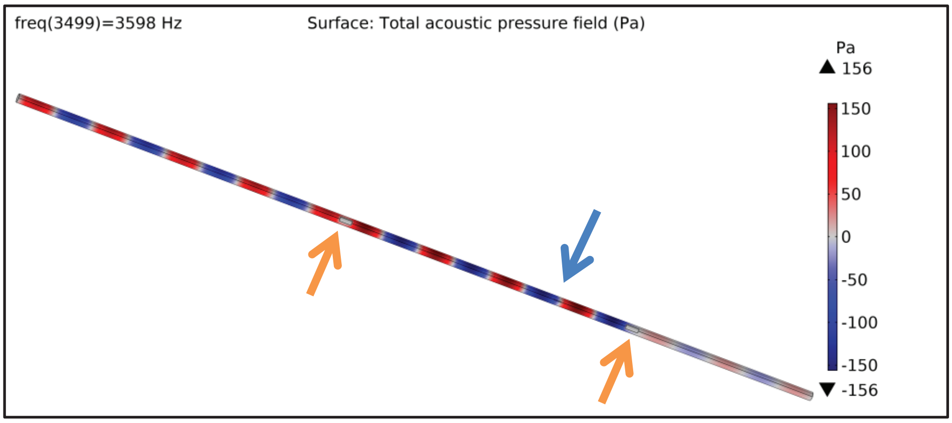

Figure 9. A mode (3598 Hz) involving both the main pipe section and the upper end section.

4 PIPE SYNCHRONIZATION

The phenomenon of frequency locking or synchronization in organ pipes has long been observed and has recently been the subject of acoustical investigations [6,7]. As part of an ongoing investigation, frequency synchronization has been studied in the khaen among pipes of the same nominal pitch and pipes with pitches in close harmonic relation (e.g., a perfect fifth). An example of this is illustrated below for the C_4 and C_5 pipes indicated in the diagram of Figure 10.

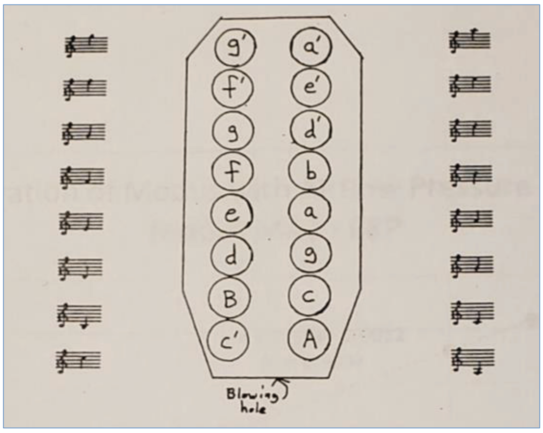

Figure 10. Pitch relationships for the sixteen-pipe khaen (from Miller [1]).

Two khaen pipes in a khaen, nominally at pitches C_4 and C_5, with sounding frequencies when played alone of 251.95 Hz and 503.91 Hz, are sounded simultaneously. At low pressure (0.4 kPa), observation of the frequency range around 500 Hz, which includes the second harmonic of the C_4 pipe and the fundamental of the C_5 pipe shows two frequencies (503.5 Hz and 505.9 Hz) with an average frequency and audible beats. As the pressure is gradually increased to 0.9 kPa, the two pipe modes synchronize into one frequency with no beats. This is illustrated in the four sections of Figure 11.

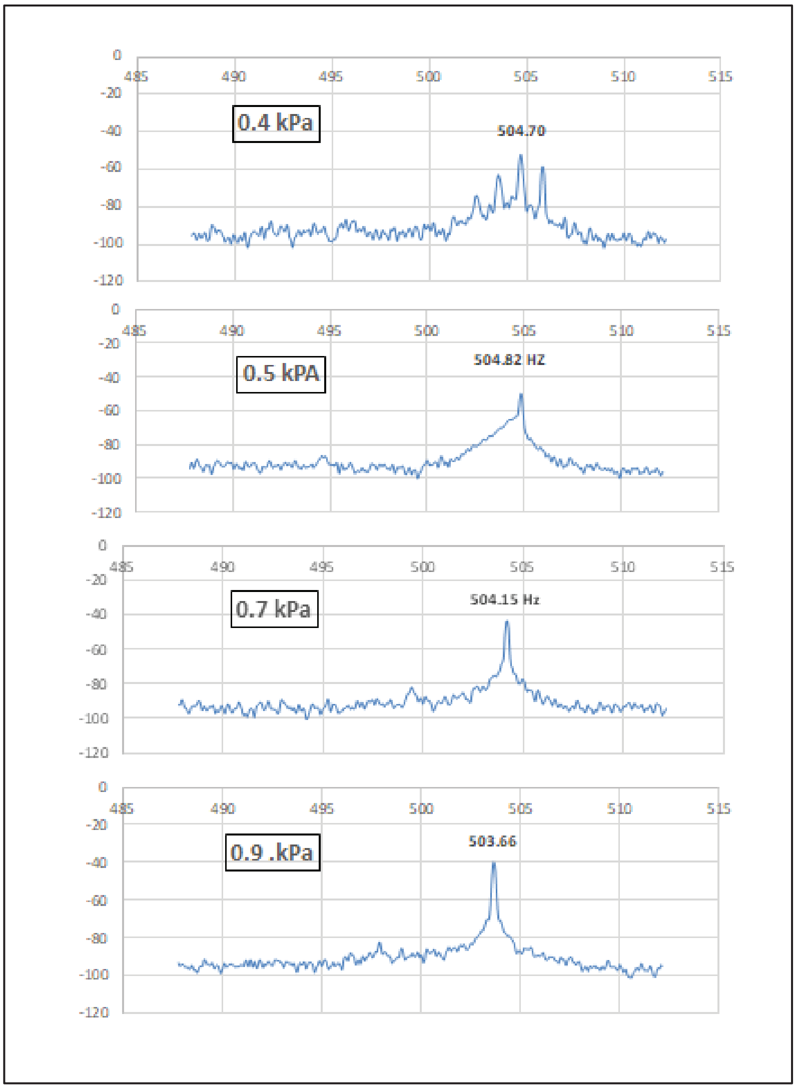

Figure 11. Two slightly mistuned octave khaen pipes sounding simultaneously synchronize as the blowing pressure is increased

5 SUMMARY

Both the simulations using COMSOL® and the experimental studies of pipe synchronization are ongoing investigations. It is anticipated that the modeling will eventually result in a more complex rendering of the complete instrument, including reed-pipe interaction and sound radiation. The frequency synchronization studies are being extended to cases involving multiple harmonically related notes.

ACKNOWLEDGEMENTS

Many of the results in Section 3 and Section 4 were obtained with the assistance of Will Martin and Kali Nash. Partial financial support for this research has been provided by United States National Science Foundation Grant NSF-REU1358968

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