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4aMU7. Modes of reed vibration and transient phenomena in free reed instruments

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The motion of air-driven free reeds used in the harmonica, accordion, and reed organ is dominated by the fundamental transverse beam mode, but higher transverse modes and the first torsional mode are usually present during steady oscillation, even at low amplitude. In addition a lateral mode has sometimes been detected, in which the reed tongue oscillation is perpendicular to the transverse oscillation. Interaction of the reed with a resonance in the instrument can result in unusual effects. In the accordion, resonances of the reed cavity can interfere with the reed self-excitation mechanism. In the harmonica, when the reed is nearly closed, a strong aerodynamic instability can in some cases lead to torsional flutter. A characteristic of some free reed instruments is a slow attack, in which the sound builds gradually and often unevenly, with the effect being greater for the longer, lower-pitched reeds. There is evidence that the first torsional mode and the second transverse mode may be significant in initiating reed oscillation, so that reed design enhancing the torsional mode may be helpful in alleviating the problem of slow attack.

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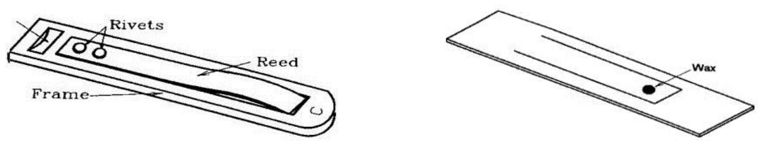
INTRODUCTION

The free reed instruments consist of two main families. One family includes instruments such as the harmonium, reed organ (shown in Figure 2), harmonica, and the accordion-concertina family that originated in Europe about 200 years ago. These instruments employ asymmetrically mounted reeds in which the tongue is mounted outside the reed plate in such a way that sounding is normally possible for only one direction of airflow. Under normal operating conditions these behave as "blown-closed" or (-,+) reeds in the classification of Fletcher.[1] This kind of reed, illustrated in Figure 1(a), sounds easily without the aid of a pipe resonator. The sounding frequency of the blown-closed free reed has been shown to be below the natural vibrating frequency of the reed tongue.[2] This paper deals with modes of vibration of the blown-closed reeds used in the Western free reed instruments, and their connections to attack transients and other transient phenomena.

The second principal family of free reed instruments consists of the Asian free reed mouth organs, including the *sheng* of China, the *sho* of Japan, and the Laotian *khaen*. They employ free reeds cut from a single sheet of material, resulting in approximate symmetry with respect to direction of airflow. With the reeds coupled to pipe resonators, these instruments often do operate on both directions of airflow, and in both cases the free reed normally functions as a "blown-open" or (+,-) reed. It has been shown that the sounding frequency of the reed-pipe combination is above both the natural frequency of the reed and the resonance frequency of the pipe.[3] Examples of both types of free reeds are shown in Figure 1.



(a) (b)

FIGURE 1. (a) A free reed from an American reed organ, showing the curve and slight twist at the free end of the reed tongue. (b) A *sheng* reed, cut from a single strip of material, with a drop of wax adding mass at the free end of the tongue. (Figures used by permission from Gellerman [4])

FIGURE 2. Some of the reeds used in these investigations came from this Williams reed organ.

MODES OF VIBRATION IN THE AIR-DRIVEN FREE REED

When a free reed instrument is played, the reed motion is smooth and appears approximately sinusoidal. The waveform of the resulting sound, resulting from pressure fluctuations in the airflow caused by the oscillating reed, is characterized by a very rich harmonic recipe. In addition, a number of previous investigations determined that modes of vibration other than the fundamental transverse mode are present in the vibration of the air-driven free reed, including higher transverse modes and some torsional modes.[5,6]

Identifying the modes requires a mechanical excitation of the reeds to determine the modes and mode frequencies. A reed mounted on a wind chamber is excited by a mechanical vibrator near the base of the reed, and a response curve is be obtained by driving the vibrator with a swept sine wave signal, producing an average spectrum of the reed vibration measured with a laser vibrometer or a variable impedance transducer (VIT) proximity sensor. An example of the kind of response curve is shown in Figure 3 for an accordion reed.[7]

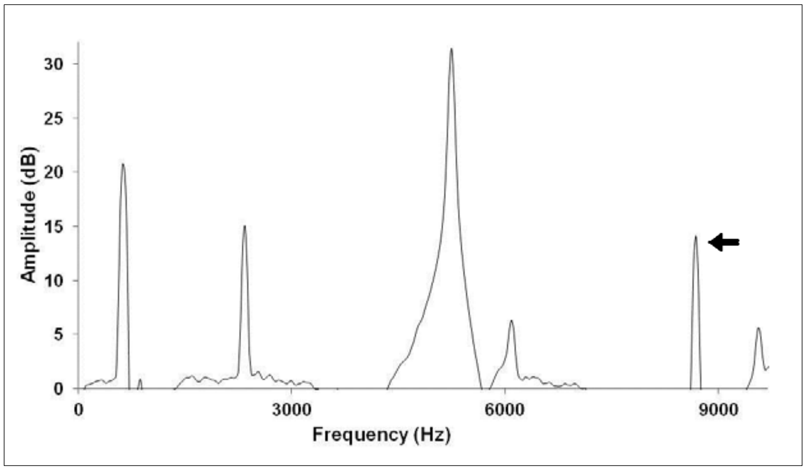


FIGURE 3. A vibrational response curve for a 634 Hz accordion reed showing several modes of vibration.

This response curve shows the fundamental mode at 634 Hz as well as the second, third, and fourth transverse modes at 2337 Hz, 5237 Hz, and 9564 Hz. The first torsional mode is represented by the peak at 8684 Hz (marked with arrow). In addition, it was discovered in this case that the relatively small peak at 6110 Hz represents a "lateral" mode, in which the reed tongue vibration is perpendicular to the vibration in the transverse modes: that is, the vibration is in the plane of the unexcited reed.

All of these modes have been observed in air-driven free reeds. The spectra shown in Figure 4 show the presence of the first torsional mode in a 113 Hz organ reed blown on a laboratory wind chamber. The figure shows vibrational velocity spectra obtained from the right and left edges of the vibrating reed tongue as well as the center. The spectral peak at 1850 Hz corresponding to the frequency of the first torsional mode disappears at the center of the reed, confirming the presence of that mode.

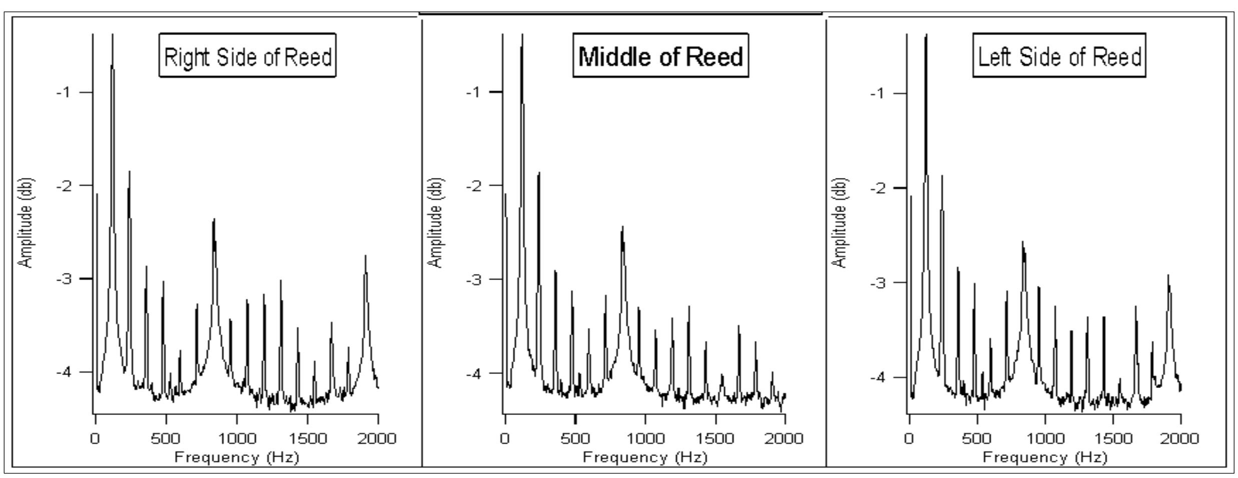


FIGURE 4. Reed velocity spectra for an air-blown A# organ reed. The fundamental frequency is 113 Hz, and a strong peak at 825 Hz is from the second transverse mode. The torsional mode is the peak at 1850 Hz.

ATTACK TRANSIENTS

The presence of higher modes of vibration in the air-driven free reed is of interest, but, given the dominant role of the fundamental transverse mode in steady-state oscillation, the effects of these modes on the sound produced in steady-state oscillation would likely be very small. It is possible that torsional modes, and perhaps the second transverse mode, may play a significant role as the reed is initially set into oscillation. For example, the organ reeds studied are typically designed with a slight twist in the tongue (shown in Figure 1(a)), and there is evidence discussed below that torsional modes are significant in the initial stages of oscillation.

Some work has been done in analyzing the attack transient of the reed motion in reeds from American reed organs using a reed mounted on a laboratory wind chamber fitted with a valve mechanism constructed to simulate the function of the pallet valve that opens the airflow to the reed in the complete instrument. Motion of the reed tongues was measured using a laser vibrometer system and variable impedance transducer (VIT) proximity sensors. The vibrational waveforms of the reed displacement and velocity during the attack transient were analyzed, with particular attention given to the degree to which the second transverse mode and first torsional mode were present in the reed vibration.

An attack transient of a typical reed organ reed is shown in Figure 5. When the pallet valve is opened there is a displacement of the reed equilibrium position of about 0.5 mm before oscillation is initiated. There is then a transition period of 20-40 ms during which the waveform seems irregular before steady oscillation at the fundamental frequency begins. In this transition period the first torsional mode and the second transverse mode of reed tongue oscillation may be significant, discussed further below.

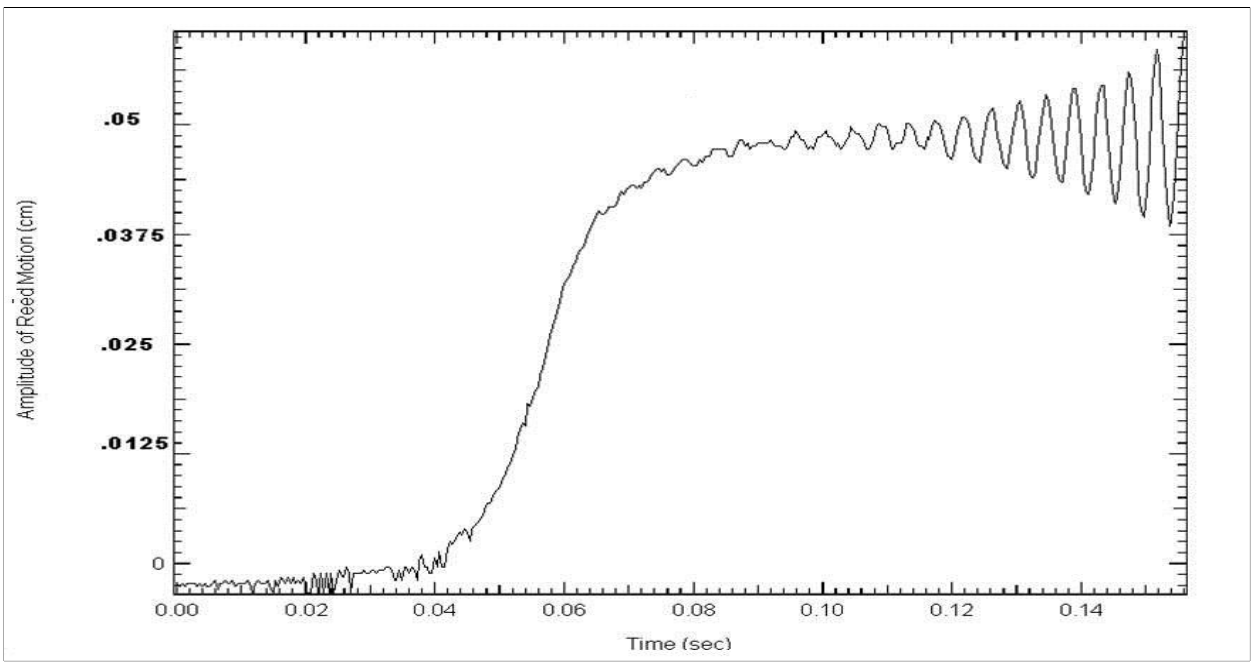
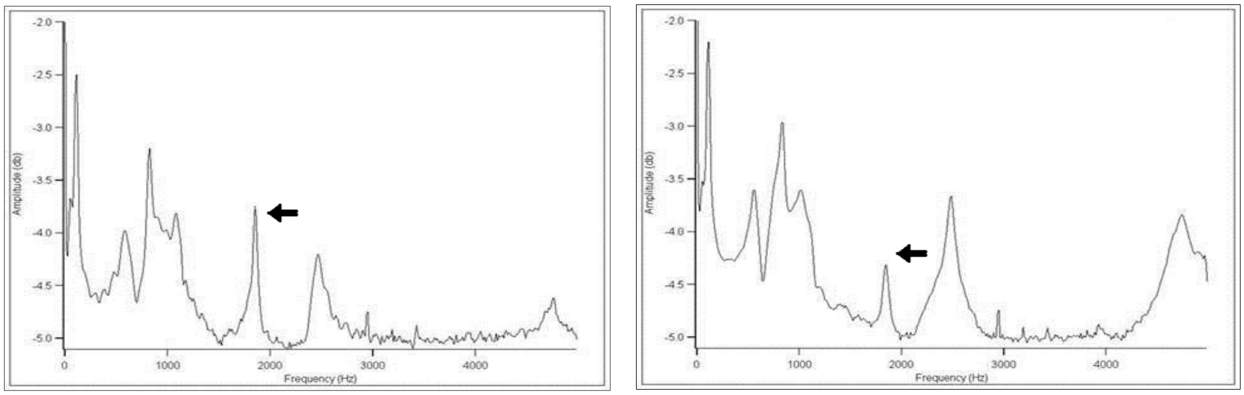


FIGURE 5. Attack transient of a free reed from a reed organ (115 Hz). Waveform shows displacement from an initial equilibrium position as measured with a VIT sensor.

As a preliminary step in studying reed vibration in attack transients, the mode frequencies of the reeds were determined as described in the previous section. Response curves are shown in Figure 6 for two American organ A# reeds (fundamental frequency 115 Hz), one with the characteristic curvature and twist illustrated in Figure 1 (A#3), and one flattened to remove these features (A#1). Of particular significance in the following discussion are the fundamental mode (≈115 Hz), the second transverse mode (≈830 Hz), and the first torsional mode (≈1850Hz). The amplitude of the first torsional mode in the flattened reed appears to be suppressed relative to the transverse modes.



(a) (b)

FIGURE 6. Response curves for two 115 Hz A# reeds. (a) Reed A#3 with the characteristic curvature and twist. (b) Reed A#1 with these features removed. The first torsional mode in both (marked with an arrow) is at approximately 1850 Hz.

Figure 7 shows some detail of the displacement waveform of the flat A#1 reed. At the beginning, the presence of the second transverse mode, with frequency about seven times that of the fundamental, is clear in the waveform. The relative prominence of the second mode decreases noticeably by the end of the excerpt. The torsional mode is not evident in this waveform sample. The spectrum of the initial transient is shown in Figure 8.

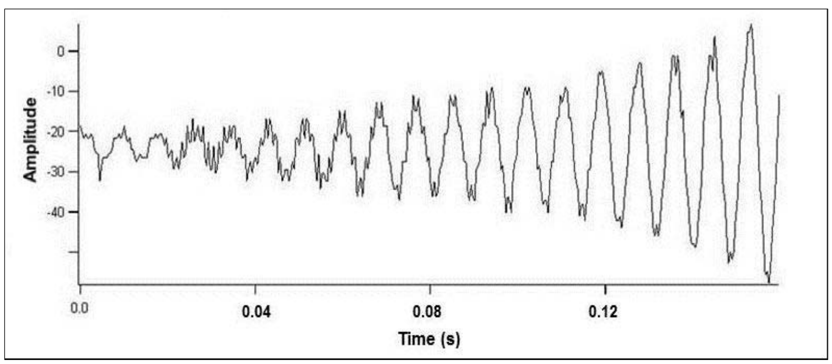


FIGURE 7. Detail of an attack transient of the “flattened” organ reed (A#1) measured with a laser vibrometer. The waveform shows reed tongue velocity in arbitrary units.

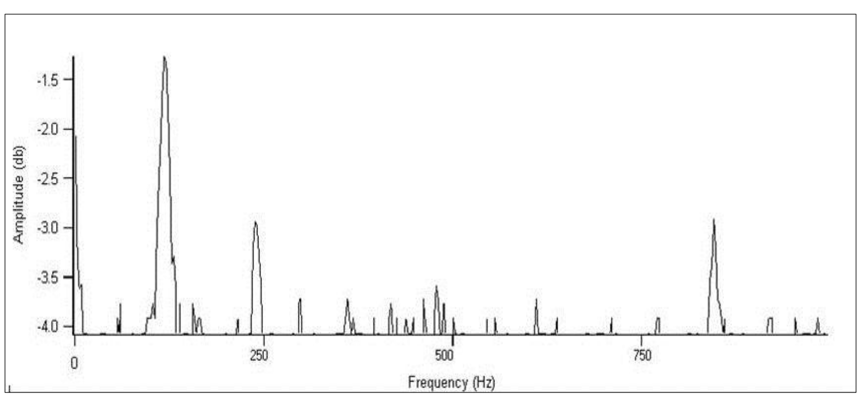


FIGURE 8. Reed tongue velocity spectrum of an attack transient of the “flattened” organ reed (A#1) measured with a laser vibrometer, with second transverse mode at 830 Hz. The amplitude is in arbitrary units.

In contrast the spectrum shown in Figure 9, of an attack transient of the reed with curve and twist (A#3), shows the torsional mode to much more significant, although the second transverse mode is still present to some extent. A waveform sample for this attack transient (Figure 10) illustrates this as well. Both the second transverse and the torsional modes contribute to the complexity of the waveform initially, but during the last few cycles the significance of the torsional mode seems to have diminished.

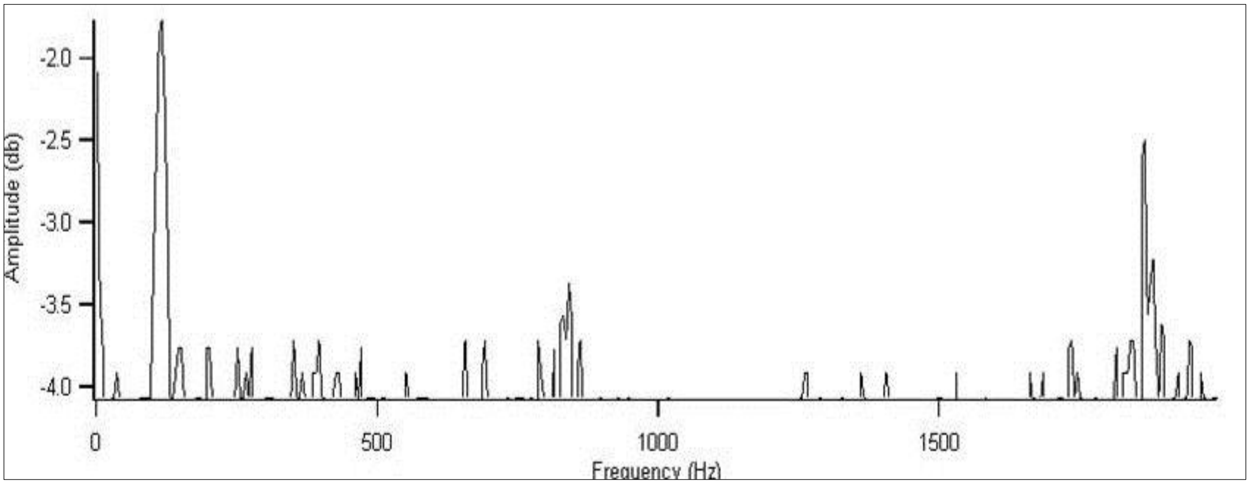


FIGURE 9. Reed tongue velocity spectrum of an attack transient of the curved organ reed (A#3) measured with a laser vibrometer. The amplitude is in arbitrary units.

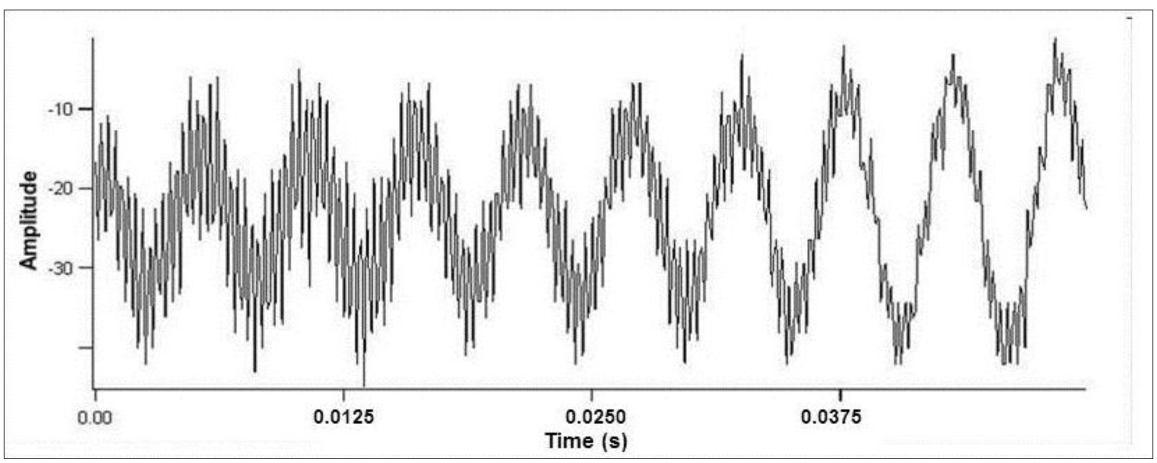


FIGURE 10. Detail of an attack transient of the curved organ reed (A#3) measured with a laser vibrometer. The waveform shows reed tongue velocity arbitrary units.

DISCUSSION

One motivation for this study is the well-known observation that free reeds, especially those with larger reed tongues used for lower-pitched notes, have slow attack, with the gradual building up after initiation of the sound sometimes causing problems. The makers of reed organs in the 19th and early 20th Centuries, who often provided a curve and slight twist in the free end of the reed, did so in the belief that it would both improve the tone and give a faster attack. Some makers even incorporated a “percussion” stop, in which a mechanism causes a small hammer to strike the reed when the key is pressed, giving the reed a jump start, and making possible more staccato playing.[4] There is some experimental evidence not shown here that the reed curvature does yield a faster attack. The results reported here suggest that excitation of the first torsional mode may be the mechanism for this improvement. Whether this reed shape “improves” the tone, remains a subject for a separate investigation. The results here also suggest that the role of the second transverse mode may be significant in the attack transient of free reeds, both flat and curved.

Others have reported results on attack transients in free reed instruments as well as the presence of torsional modes of reed vibration. Jonas Braasch and Christian Ahrens studied attack transients in free reed pipes in pipe organs, exploring variations in the attack transient, depending on the resonances of the pipe coupled to the reed.[8] Recently James Antaki and coworkers reported on the presence of torsional vibrations in harmonica reeds.[9] Their work, involving both experimental work and fluid dynamics simulations, concentrated particularly on factors responsible for torsional instability in the vibrating reed. Thomas Tonon has studied torsional instabilities in accordion reed vibration resulting from resonances between the reed and the reed cavity.[10,11] The study of torsional and other higher modes of reed vibration in free reed instruments continues to be an area of active interest.

ACKNOWLEDGMENTS

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