19th INTERNATIONAL CONGRESS ON ACOUSTICS
MADRID, 2-7 SEPTEMBER 2007

REED VIBRATION IN WESTERN FREE-REED INSTRUMENTS

PACS: 43.75.Lm

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ABSTRACT
Western free reed instruments, including the reed organ, harmonium, harmonica and accordion, use asymmetric free reeds that are able to maintain sustained oscillation in the absence of a pipe resonator. Studies of the motion of air-driven free reeds have been made using a laser vibrometer system. The reed vibration waveforms can be compared with corresponding sound pressure and airflow waveforms. For pressure and airflow waveforms among different types of reeds or for the same reed at different blowing pressures, differences can be understood in terms of the configuration of the reed and reed frame system as well as the amplitude of reed vibration. While free reed oscillation can be approximated as a sinusoidal oscillation of a cantilever beam in the fundamental transverse mode, measurements on free reeds from American reed organs have shown that higher transverse modes as well as the first torsional mode are present even at low amplitudes of oscillation.

INTRODUCTION

In recent years there has been a surge of interest in the acoustics of free reed instruments. Research has included not only the Western instruments – including the reed organ, harmonium, accordion and harmonica – but also the Asian free reed mouth organs, in which a free reed is coupled to a pipe. This paper focuses on measurements made on individual reeds from Western instruments. In these instruments pipe resonators are not necessary and are generally not used. The reed tongues are mounted on the reed frame asymmetrically so that sounding is only possible on one direction of airflow. This can be seen in the American organ reed shown in Figure 1.

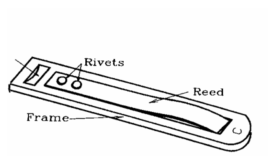

Figure 1.- A reed from an American reed organ, from Gellerman [1]

Measurements have been made relating the reed motion, airflow, and pressure waveforms associated with the vibration of free reeds. Reed displacement data is obtained by integrating a reed velocity waveform taken with a laser vibrometer system. The sound pressure waveform is measured with a probe microphone positioned close to the tip of the vibrating reed. The airflow waveform is determined by integrating the pressure waveform and calibrating it using the measured average airflow.

The free reed can be modelled as a cantilever beam, and the motion of the air-driven free reed is dominated by the fundamental transverse mode. Additional measurements have shown, however, that higher transverse modes as well as torsional modes are present as well.

Free reed instruments are characterized by a relatively high rate of volume airflow through the reed opening. Not only is this air flow responsible for driving the sustained oscillation of the reed, but the pressure fluctuations associated with the interruption of the airflow by the reed tongue constitute the principal sound production mechanism. These instruments are thus able to produce sound at high intensity levels without the aid of a pipe resonator.

THE REEDS

Measurements have been made on a number of reeds from American reed organs, accordions, and some Asian mouth organs. The measurements reported in the following section were made on a reed from an American reed organ similar to the one pictured in Figure 1 and on an accordion reed similar to those pictured in Figure 2. In both cases the reeds were mounted on a laboratory windchest and the measurements were made at a blowing pressure of 0.60 kPa. The reed dimensions are summarized in Table I below.

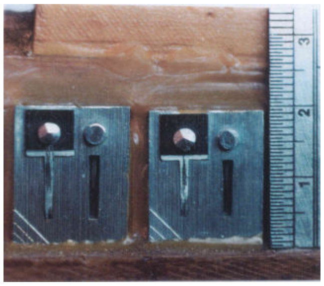

Figure 2.- Some accordion reeds

Table I.- Summary of reed dimensions

Reed	Length of tongue	Width at Fixed end	Width at free end	Average Thickness	Sounding Frequency
D# Organ Reed	19.3 mm	2.5 mm	2.5 mm	0.12 mm	642.5 Hz
D# Accordion Reed	32.2 mm	3.3 mm	2.0 mm	0.15 mm	627.5 Hz

REED DISPLACEMENT, PRESSURE, AND AIRFLOW MEASUREMENTS

Reed Displacement

The reed displacement measurements were taken using a laser vibrometer, which measured the velocity waveform at a specific point along the reed tongue. This waveform was then integrated to obtain the displacement waveform for that point on the reed. The points used for the two reeds were 7 mm from the tip for the D# organ reed and 11 mm from the tip for the D# accordion reed. The position of the top of the reed frame relative to the tongue was measured by using a micrometer screw to measure the difference between the top of the reed frame and the point of maximum displacement of the vibrating tongue.

Sound Pressure Waveform

The sound pressure waveform was obtained using a Bruel & Kjaer 4182 probe microphone and a dual trace digital oscilloscope. The tip of the microphone was placed 3 cm from the air-driven reed and while the reed velocity was simultaneously measured with the laser vibrometer. To get the pressure and displacement waveforms in the correct phase relationship, compensation was made for the delay caused by the distance of the microphone from the reed. (With the probe tip used, this was approximately 6 cm.)

Airflow

The flow rate was obtained by integrating the sound pressure waveform, using previously measured minimum and average flow rates to locate the zero value point. Because this graph is created by integrating the pressure waveform, these two are automatically in phase.

RESULTS FOR THE REED ORGAN AND ACCORDION REEDS

Organ Reed Displacement

Figure 3 depicts the movement of a specific point on an organ reed. The vertical dotted lines mark the points where the reed leaves or enters the area inside the frame. The reed motion is smooth and approximately sinusoidal.

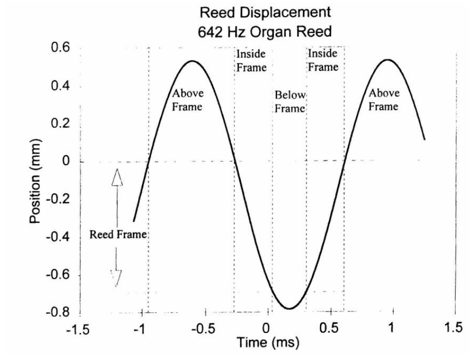

Figure 3

Organ Reed Sound Pressure Waveform

Figure 4 shows the pressure waveform as measured by a microphone near the reed. Again the dotted vertical lines are the points at which the reed enters of leaves its frame. There is an asymmetry in the waveform since the reed spends more time above the frame than below it.

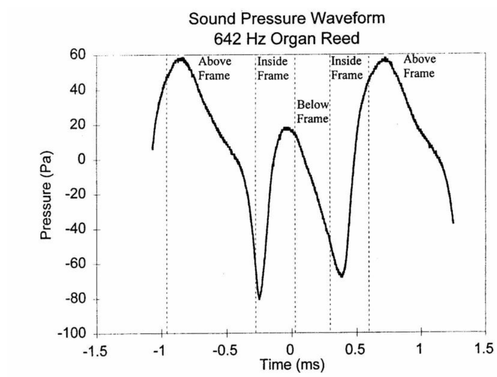

Figure 4

Organ Reed Airflow

Figure 5 shows the approximate volume airflow rate through the reed. Once again the dotted vertical lines represent the points where the reed either enters or leaves its frame.

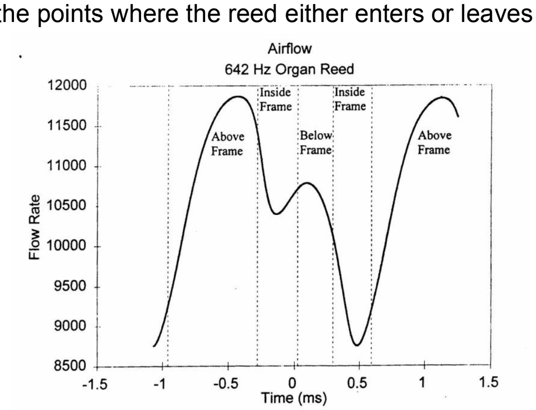

Figure 5

The Accordion Reed
Reed displacement, sound pressure, and airflow waveforms are shown in Figure 6 for the accordion reed. The major difference between this case and that of the organ reed is that the accordion reed never goes below the relatively thick reed frame. The secondary maximum in the airflow waveform that occurs for the reed organ is absent here.

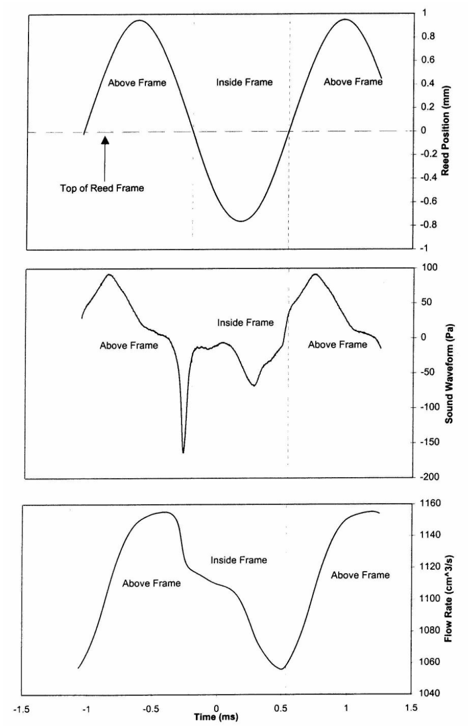

Figure 6

General Observations
The most noticeable relationships are those between the reed motion and the pressure and airflow graphs. When the reed enters the frame it is effectively closing the opening and consequently results in jump in pressure and a drop in airflow. Once inside the frame airflow continues to drop while the pressure tends to hold steady (especially in the case of the accordion reed) after the initial jump. Once the reed clears the frame (either above or below) the pressure declines and the airflow peaks to a local maximum as the reed continues to open, but begins to fall as the reed reverses its direction and moves towards the reed frame.

MODES OF VIBRATION OF THE AIR-DRIVEN FREE REED

Mode frequencies of the reeds
Additional investigations have been made to determine whether modes of vibration other than the fundamental transverse mode are present in the vibration of the air-driven free reed. The reeds used in this case were American organ reeds, mounted as in the previous cases on a laboratory windchest. Since these reeds have non-uniform cross section, the frequencies of the higher transverse modes and the torsional modes can not be calculated from the fundamental frequency of vibration of the reed tongue using the well-known results for a beam of uniform cross section. Thus a preliminary investigation was undertaken using mechanical excitation of the reeds to determine the mode frequencies.

The reeds were mounted on the windchest as usual, but in this case excited by a mechanical vibrator at the base of the reed near the rivets. A response curve can be obtained by driving the vibrator with a swept sine wave signal over an appropriate range of frequencies, and obtaining a long-time average spectrum of the reed vibration as measured with either a laser vibrometer or a variable impedance transducer (VIT) proximity sensor. The response curve shown in Figure 7 below is a typical result of this procedure.

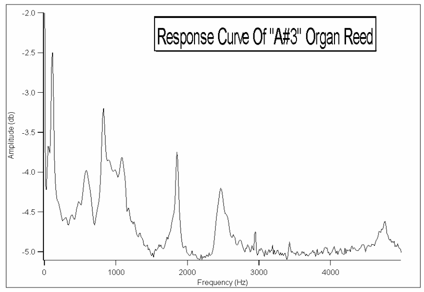

Figure 7.- A response curve for an organ reed showing several modes of vibration.

This response curve shows the fundamental mode at 113 Hz as well as the second, third, and fourth transverse mode at 825 Hz, 2460 Hz, and 4760 Hz, respectively. The first torsional mode is represented by the peak at 1850 Hz. Identification of the modes is done by scanning the reed for nodes and antinodes when the reed is excited at a frequency corresponding to one of the peaks in the response curve.

Modes of air-driven reeds

The search for higher modes of vibration in the air-driven free reed involves searching the spectra of reed displacement for peaks that correspond to the known frequencies of these modes. To verify that a given spectral feature is evidence of the presence of a particular mode, spectra taken at different points on the vibrating tongue can be compared to verify that nodes and antinodes appear at the expected points for the mode in question.

As an example of this procedure we can consider the evidence of the second transverse mode from the spectra in Figure 8. This shows the reed velocity spectra at two points along an organ reed mounted on the windchest: the upper one taken at 0.9 cm from the free end of the reed tongue and the lower one at 2.3 cm from the end. A quite noticeable feature is the peak at approximately 805 Hz, which is prominent at 2.3 cm but absent at 0.9 cm. The frequency of this peak corresponds to the previously measured frequency of the second transverse mode.

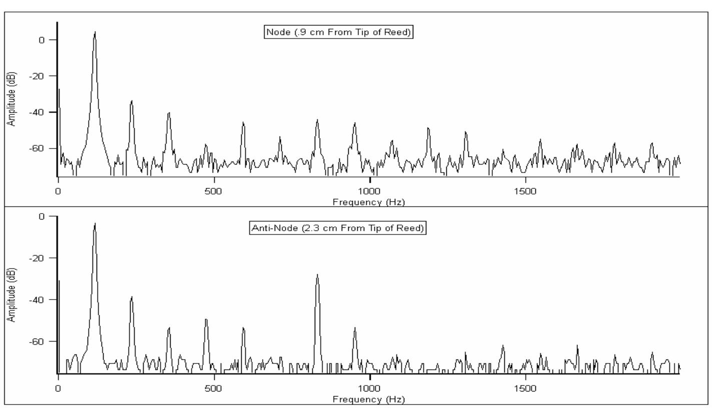

Figure 8.- Spectra of reed vibration taken at 0.9 and 2.3 cm from the free end of the tongue.

Figure 9 shows a plot of the amplitude of this peak – which is close to the frequency of the seventh harmonic of the fundamental – as a function of distance from the tip of the reed. The nodal pattern expected for the second transverse mode is evident, indicating that this mode is almost certainly present in the vibration recipe of this air-driven reed. The third and fourth transverse modes have also been detected in this way as well as the first torsional mode.

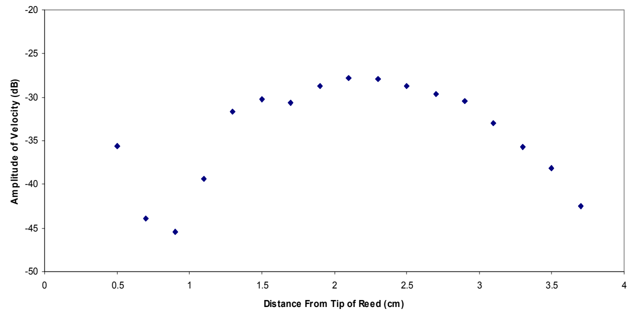

Figure 9.- Amplitude of the 805 Hz peak as a function of distance from the reed tip

Figure 10 shows spectra from the right and left edges of the 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.

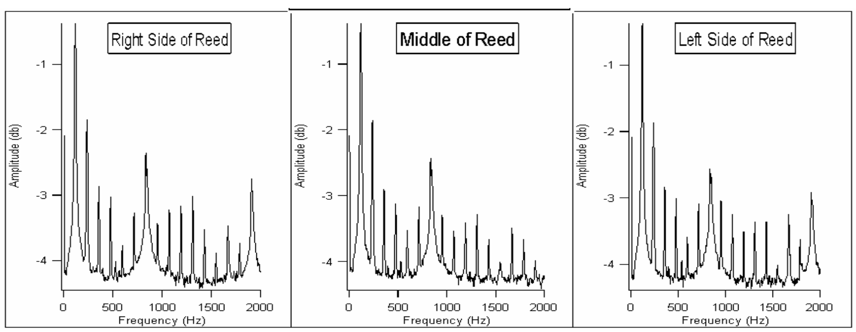

Figure 10.- Spectra showing the presence of the first torsional mode

CONCLUSIONS

It seems clear that, although the presence of higher modes of vibration in the air-driven free reed is interesting, the effect on the sound produced would be expected to be minimal, given the dominant role of the fundamental transverse mode in normal steady-state oscillation. More significant effects might occur transiently as the reed is initially set into oscillation. For example, the organ reeds studied are typically designed with a slight twist in the tongue, and there is some evidence (not shown here) that torsional modes may be significant in the initial stages of oscillation.[4] It is hoped that the results summarized in this short paper will be of use to those working at theoretical understanding and modelling of free reed oscillation

ACKNOWLEDGMENTS

The author is grateful to the undergraduate students who have made contributions to earlier investigations on these topics [2]-[4], especially Michael Busha and Ammon Paquette. This work was supported Coe College and by National Science Foundation REU Grant No. 0139096.

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