The motion of air-driven free reeds

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Summary. A number of measurements on individual free reeds have been made. Measurements of reed displacement as a function of time have been made with a variable impedance transducer, and measurements of reed velocity as a function of time have been made with a laser vibrometer system. The results show a nearly sinusoidal reed motion at normal pressure, which contrasts with the sound pressure waveform near the reed.

VARIABLE IMPEDANCE TRANSDUCER (VIT) MEASUREMENTS

There have been few studies of the vibration of individual free reeds. A paper by St. Hilaire, *et al*, concentrated on conditions for reed excitation.(1) In an earlier study with simple equipment, Koopman and Cottingham observed the amplitude of vibration as a function of blowing pressure for harmonium-type reed organ reeds of 100-200 Hz frequency.(2) It was observed that once the threshold pressure for vibration is reached (about 0.2 kPa), the vibration amplitude of the reed tip quickly rises to a large value of several millimeters. It then remains nearly constant with increasing pressure until it eventually begins to decrease at high blowing pressures. The equilibrium position of the reed shifts gradually about 1-2 mm in the direction of airflow.

A more detailed set of measurements of the motion of these reeds has been made using a variable impedance transducer (VIT) to measure reed displacement. Because of a range limitation of 2.5 mm, the VIT is used in the middle of the reed tongue, around 2 cm from the reed tip. (The reed tongue is about 4 cm long.) Figure 1 shows a diagram of the experimental arrangement. Observations with the VIT confirm the earlier results (Figure 2), and also provide information about the full cycle of reed vibration (Figures 3 and 4).

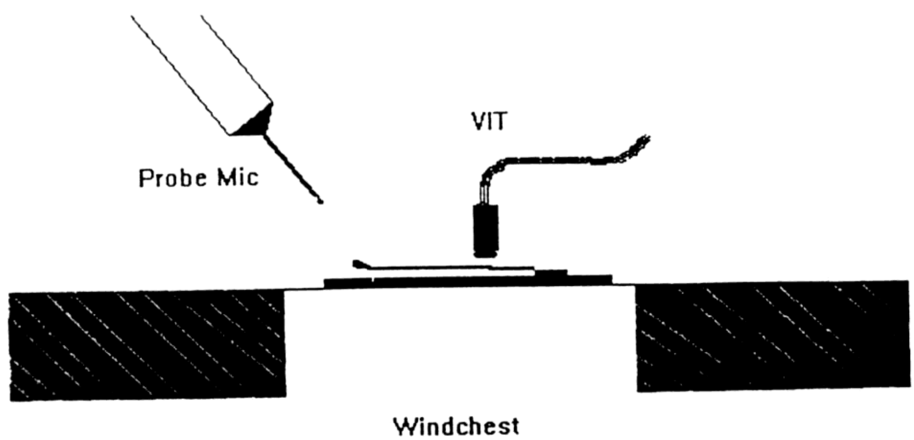

FIGURE 1. A sketch of the experimental arrangement. The VIT is positioned above the reed, which is mounted on the windchest. the windchest is evacuated by a blower so that the direction of air flow is downward.

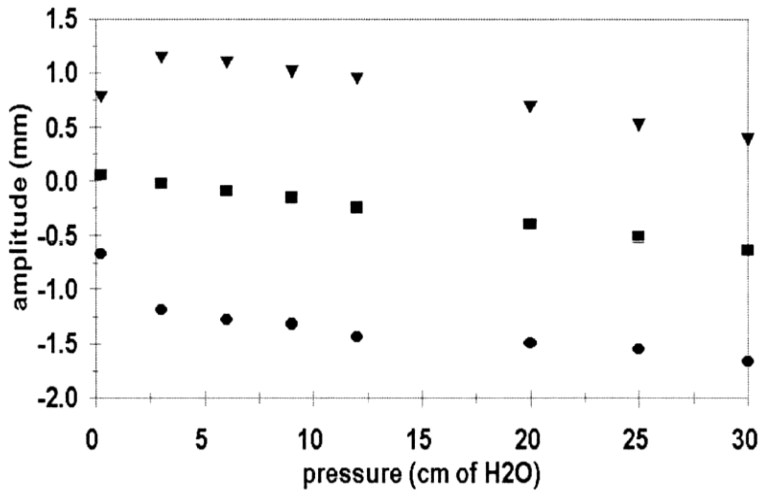

FIGURE 2. Graph of the amplitude of reed vibration vs. blowing pressure for an $A^{\#}$ organ reed. The top set of points represent maximum excursion above equilibrium, the bottom set diamonds the maximum excursion below equilibrium; the middle set the (shifted) equilibrium position at each value of the pressure.

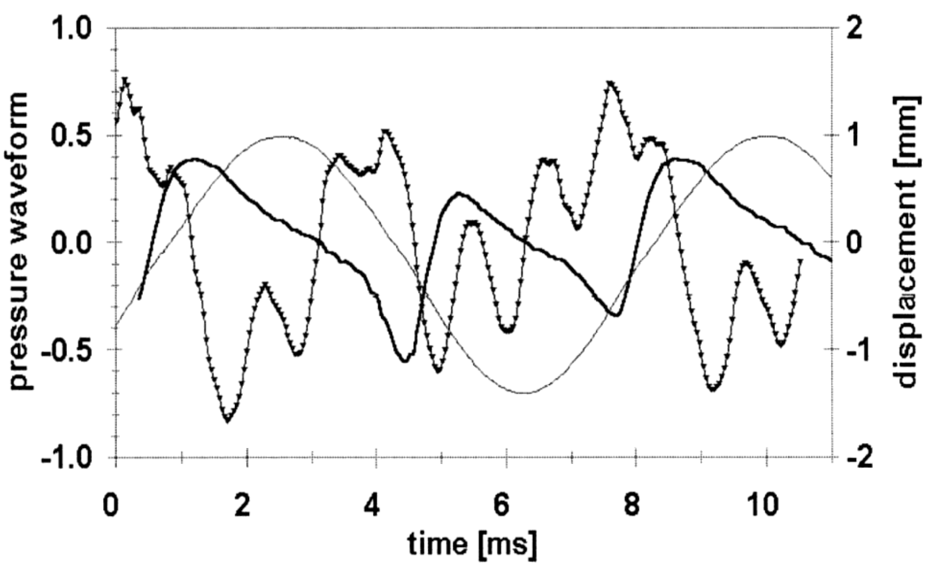

FIGURE 3. Reed displacement and sound pressure waveforms for a C_3 reed at p = 0.9 kPa. The thin solid line is the reed displacement [in mm], the heavy solid curve is the pressure waveform [arbitrary units] from a microphone just above the reed, the dotted curve is the pressure waveform inside the windchest just below the reed.

Figure 3 compares the motion of the reed with the sound pressure waveforms near the reed tip outside and inside the windchest. Although the reed motion appears to be approximately sinusoidal, the sound pressure waveform somewhat resembles a pulse wave, as the reed acts as a valve, alternately opening and closing the opening in the reed frame twice in each cycle of oscillation. At blowing pressures somewhat higher than normal playing pressure, some indications of the presence of the second beam mode ($f_2 = 6.27 f_1$) are observed in the spectrum of reed vibration as shown in Figure 4.

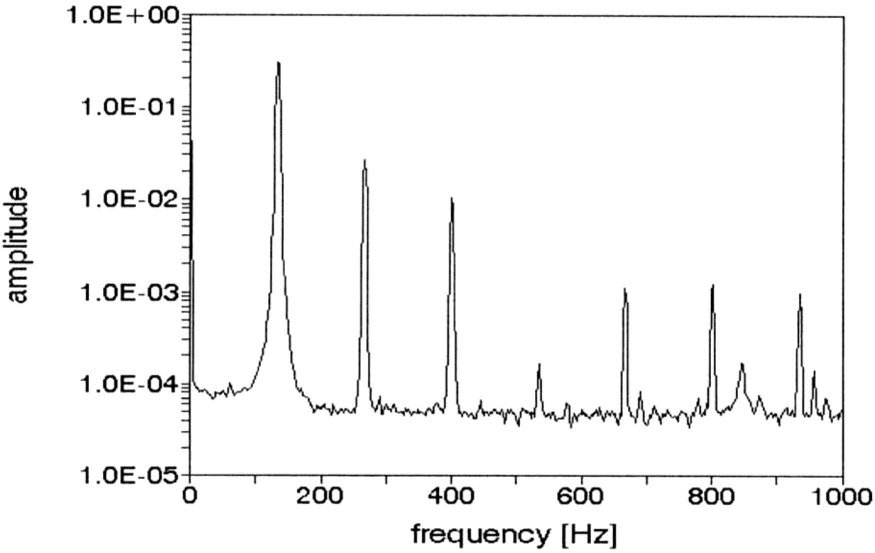

FIGURE 4. Spectrum of the reed displacement waveform from Figure 3.

LASER VIBROMETER MEASUREMENTS

The laser vibrometer system measurements complement those made with the VIT. The laser vibrometer measures reed velocity, rather than displacement, although the results can be integrated to give displacement curves which agree well with the results from the VIT. Unlike the VIT the laser vibrometer is not limited in range and can be used to explore the motion of the reed along its full length. Figure 5 shows the reed displacement profile at maximum amplitude as calculated from the laser vibrometer data, compared with a curve obtained by fitting Rayleigh's equation for the cantilever beam in mode 1 so that the two coincide at the tip of the reed. It can be seen that the fit is quite good.

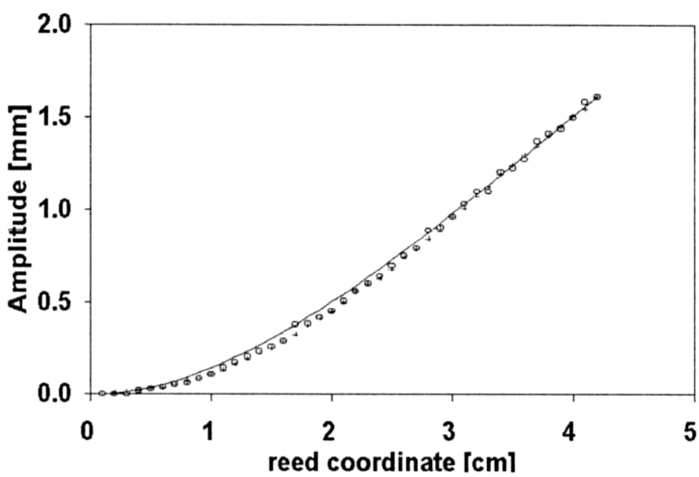

FIGURE 5. Reed profile at maximum amplitude calculated from laser vibrometer velocity data. The solid line is the theoretical curve from Rayleigh (3). Data points are from 4 cm H_2O [+] and 6 cm H_2O blowing pressure.

Figure 6 shows two velocity waveforms for the A# reed as observed with the laser vibrometer system. At a blowing pressure of 0.8 kPa (approximately normal playing pressure) the motion is still nearly sinusoidal. At 1.2 kPa the waveform becomes more irregular, and the amplitude is also slightly smaller.

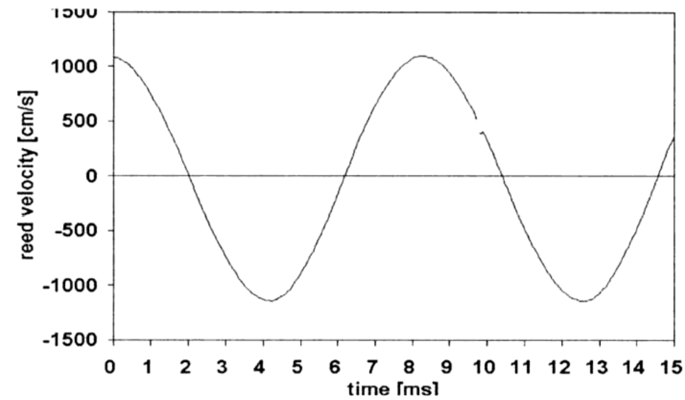

FIGURE 6a. The reed velocity waveform for the A# reed (frequency 118 Hz) at 0.8 kPa.

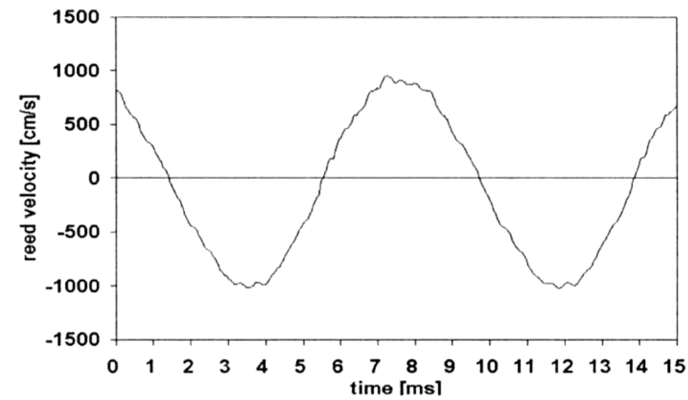

FIGURE 6b. The velocity waveform for the same reed at 0.8 kPa.

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