Acoustic impedance measurement of the clarinet players' airway

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Introduction

One of the most important ways whereby the musician's airway affects sound production in the clarinet is via its acoustical impedance spectrum. Impedance measurements have been previously attempted (Hoekje [1], Wilson[2]) but are not fully exploitable or applicable due to the fact that they either were not necessarily performed in playing conditions, lack phase information, or contain high levels of background noise. This study presents an experimental configuration for measuring the impedance for conditions closely approaching playing. The impedance spectrometer used, originally developed by Smith and Wolfe [3], has been modified to integrate the measurement head into a mouthpiece, so as not to disturb musicians. Both magnitude and phase are measured. A DC shunt is added to enable the musicians to blow normally. Although no oral pressure feedback is supplied, this seems not to be a problem as the musicians have adequate muscle memory. Consequently, embouchures are measured with high reproducibility. Impedance results for a number of professional musicians will be presented and discussed.

Experimental setup

The impedance spectrometer

The impedance spectrometer is described elsewhere [3]. The attenuator and head diameter (7.8 mm) was retained, because its cross section approximately equals the effective surface of the reed inside the mouth. Calibration is performed on an acoustically infinite waveguide of the same diameter.

Fitting of the measurement head in the clarinet mouthpiece

The attenuator The shape of the mouthpiece must be retained so that musicians feel comfortable so compromises must be made to place the measurement plane near the position of the reed tip, while allowing calibration. The impedance head enters the mouthpiece just beyond the position of the player's teeth, and at an angle slightly greater than that of the upper mouthpiece surface (Fig. 1). This gives a measurement plane whose shape is an ellipse of small eccentricity. Measurements on geometrically simple model vocal tracts, using both this and the standard impedance head, showed that the effects of the angle and the elliptical measurement plane were small.

The microphone The microphone used (Countryman CAI-B6 miniature B6) is 2 mm diameter . For several reasons, the attenuator output and the microphone are placed at a distance 9 mm from the end of the pipe. This

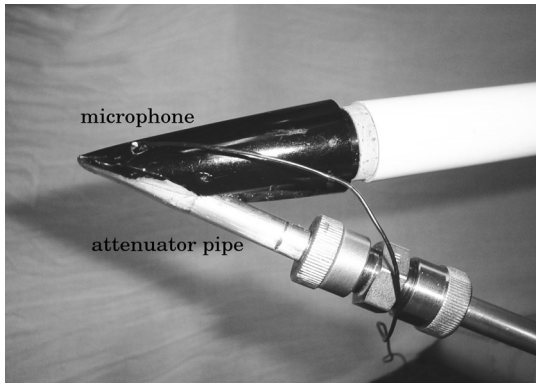

Figure 1: Insertion of the microphone

distance is much smaller than a quarter wavelength, so the impedance at the end of the pipe can be readily calculated from that measured at the microphone. The microphone is inserted from the side of the mouthpiece as shown in Fig. 2. The performance of this geometry and the calculation to remove the 9 mm stub were verified by tests on simple, cylindrical pipes.

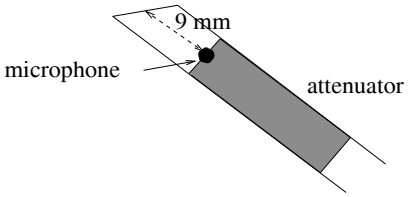

Figure 2: Position of the microphone on the median line

Introduction of a DC shunt While the player's muscle memory allows him to mime the mouth geometry of different playing techniques, it is essential that he can blow a typical airflow into the instrument so that the glottis, over which players have much less conscious control, takes a typical playing aperture. For that reason a small pipe (40 mm long and 3 mm diameter) was positioned to provide a shunt or leak from the mouth to the outside air. Its length ensured that resonances were outside the range of interest, its diameter ensures that its characteristic impedance is much larger than the vocal tract impedance in parallel with it, and it was filled with acoustic wool which makes the impedance largely resistive, reduces the turbulent noise due to flow and provides a DC resistance comparable to that of a real clarinet.

Heating To prevent water condensation in the measurement apparatus, a low voltage electrical circuit was used to raise the temperature of the apparatus to 40°C.

Results

Some twenty Australian players took part in the experiment and their musical level varied between advanced and professional. They first filled a survey about their musical background and their opinion about the influence of the vocal tract when playing. For measurements, they first played a note on their own clarinet, then mimed playing the same note on the modified clarinet. The notes were: (written) G3, G4, G5 and G6 to study the influence of the register and the length of the pipe; some peculiar configurations such as pitch bending, slurring a register change, miming different vowels; and embouchures of their own suggestion used for different playing conditions. Finally they were asked to play all these configurations on a laboratory clarinet, whose plastic-coated reed was maintained in a constant geometry during the two weeks of experiment, in order to be able to compare the recordings with impedance curves and with measurements made on the lab clarinet and mouthpiece.

Reproducibility

Reproducibility was tested by making several measurements of the embouchure for the same note (written G3) over the course of a session (typically 40 minutes). Players were able to repeat their embouchures rather reproducibly: the frequencies of resonance varied by 2 to 8 % and the impedance value by 2 dB.

Differences within and among players

Most of the subjects in our study reported that, for normal playing, they use an embouchure that varies little over most of the range, except for the highest register. However, the variation among players shows considerable range in impedance and resonant frequencies (Fig. 3). It should be noted that players also 'set up' their instruments rather differently: reeds of different hardness, different reed position on the lay, different tuning slide position.

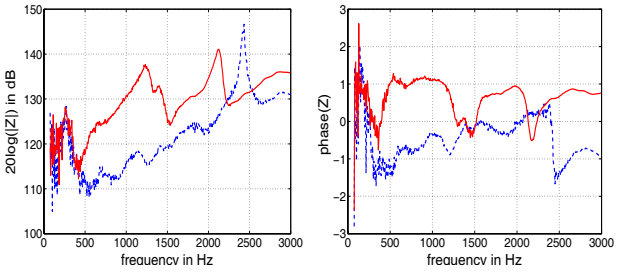

Figure 3: Impedance $Z(f)$ for the note G6 for two different players

Variations used by players

Players agree that they use different embouchures for different effects. One consequence is that the force, the damping and their position on the reed may vary. Another consequence is that mouth or vocal tract geometry changes can affect the impedance spectrum. The substantial changes shown in Fig. 4 suggest that this latter change may not be negligible.

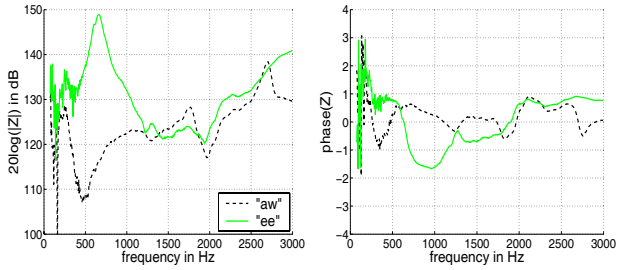

Figure 4: Two configurations, called "aw" and "ee" by the player, for the note C5

The sound for these two configurations was recorded. The sound spectra are quite different (Fig. 5). In particular, the third harmonic is stronger for "aw". The shift in pitch is about 25 cents or a quarter of a semitone. This of course will be due to the combination of acoustic effects of the vocal tract geometry and changes in the forces applied by the lips to the reed.

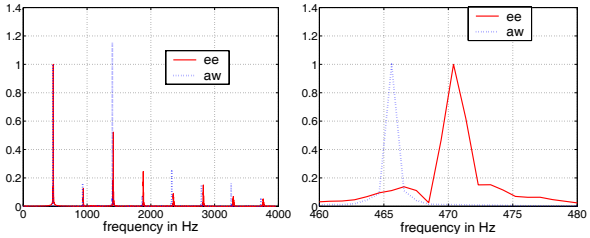

Figure 5: Sound spectra, normalised by the amplitude of the first peak, for the two configurations "aw" and "ee"

A more detailed theoretical study of the shift of the playing frequency was given in [4].

The change in the vocal tract configuration when playing has now been clearly measured. To correlate this change with sound recordings is complicated because changes in lip pressure, damping and position may also be involved. A way of avoiding this problem is to separate the effects by using an artificial blowing machine with vocal tract. This is presently under construction.

References

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