Wall vibrations in musical wind instruments

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When a musical wind instrument is blown, its air column begins to vibrate. The air particles within the instrument oscillate backwards and forwards and a note sounds. It is generally accepted that the pitch and timbre of the note produced are largely dependent on the relative strengths and frequencies of the air column resonances. However, blowing a wind instrument also causes the walls of the instrument to vibrate. Whether or not such wall vibrations perceptibly affect the tonal quality of the instrument remains a subject of debate.

This article describes experiments designed to study the wall vibrations of a simple brass instrument. This simplified experimental instrument consists of a Denis Wick trombone mouthpiece coupled to a 70cm long section of brass pipe, with a 14mm external diameter and 0.5mm wall thickness. To begin with, by using a mechanical source to excite the instrument through a range of frequencies and by measuring the velocities induced in the walls, the instrument's structural modes are identified. The instrument is then blown and the vibrational response measured and compared with the instrument's structural mode shapes and frequencies. Finally, the mechanism by which blowing the instrument excites wall vibrations is investigated.

Structural modes of a simple brass instrument

To determine its structural modes, the simple brass instrument was rigidly clamped at each end around its circumference and fixed horizontally on an anti-vibration table housed in an anechoic chamber. It was mechanically driven at a position close to the mouthpiece using a shaker with a needle attachment at discrete frequencies over a range of 10 Hz - 1 kHz. At each frequency, the velocity amplitudes at 3cm intervals along the instrument were measured using a laser doppler vibrometer *(Figure 1)*.

Figure 2 shows a two-dimensional contour plot of the variation in velocity amplitude with frequency along the length of the instrument. The first four structural modes of vibration, located at 90Hz, 255Hz, 520Hz and 835Hz, can be clearly distinguished.

Figure 1: Simple brass instrument being mechanically driven by the shaker

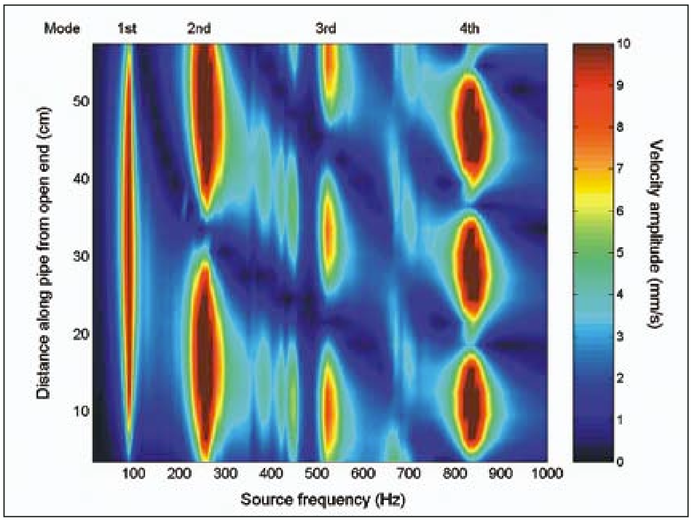

Figure 2: Velocity amplitude variation as function of frequency along the simple brass instrument when driven by a mechanical shaker

Measuring the wall vibrations induced by blowing the instrument

To measure the vibrations induced in the walls of the instrument when blown, the shaker was removed

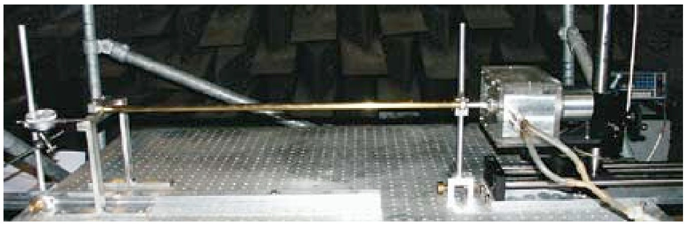

Figure 3: Simple brass instrument being blown by artificial mouth

and the simple brass instrument was attached to an artificial mouth *(Figure 3)*. This is a mechanical device that comprises a pair of water-filled latex rubber lips through which air is blown. It is designed to mimic the playing action of a human musician but has the advantage of being able to sustain notes for long periods.

When the air supply to the artificial mouth was activated, the instrument produced a stable note which spectral analysis revealed had a strong fundamental at 365Hz and a weak second harmonic at 730Hz. The laser doppler vibrometer was used to measure the velocity amplitudes at 3cm intervals along the instrument whilst it was being artificially blown. These measurements revealed that the walls also vibrated strongly at a frequency of 365Hz and weakly at a frequency of 730Hz. *Figure 4* shows the velocity amplitude variation along the length of the instrument induced by the artificial mouth at these two frequencies.

To check whether these velocities are comparable with those induced by a musician, a human player attempted to attain a note of similar frequency and loudness. Wall velocity measurements were then carried out as described previously. Again, the walls were found to vibrate strongly at a frequency of 365Hz and to a lesser extent at 730Hz. *Figure 5* shows the velocity amplitude variation along the instrument induced by a human player at these two frequencies.

Comparison of *Figures 4* and *5* reveals a good agreement in the shapes and amplitudes of the velocity variations, especially at 365Hz. This would appear to confirm the acceptability of using the artificial mouth when measuring the wall vibrations induced when an instrument is blown. The difficulty that the human player had in producing notes of similar loudness and quality is evident when the two graphs are compared. The constant output of the artificial mouth results in the much smoother variation in velocity amplitude along the instrument. The artificial mouth removes the problems encountered when using a human player, such as

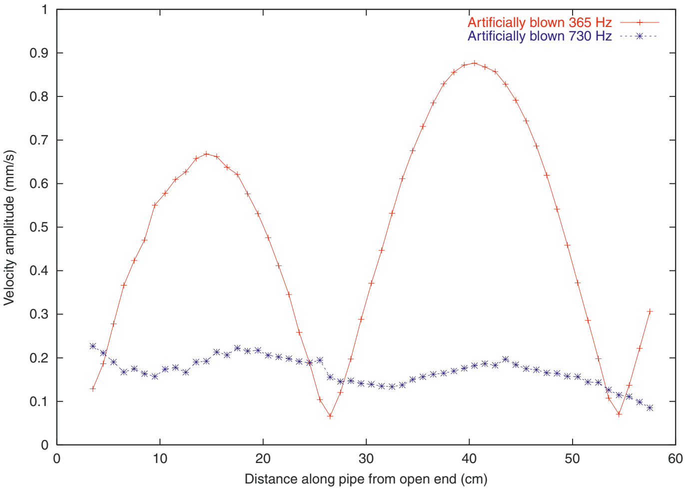

Figure 4: Velocity amplitude variation along the simple brass instrument when blown by artificial mouth. Measured at 365Hz and 730Hz

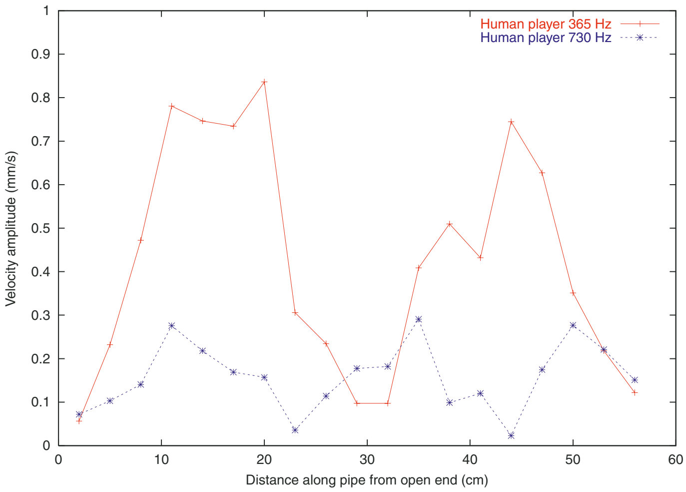

Figure 5: Velocity amplitude variation along the simple brass instrument when blown by a human player. Measured at 365Hz and 730Hz

the introduction of unavoidable movement into the system and the inability to repeat and sustain notes over long periods.

By comparing *Figures 4* and *5* with *Figure 2*, the velocity amplitude variation at 365Hz induced when

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the instrument is blown can be seen to match the shape of the structural response of the instrument at the same frequency. At 730Hz, the velocity amplitudes induced when the instrument is blown are smaller. This is mainly because the structural response at this frequency is quite weak.

Excitation mechanism for wall vibrations

The experimental results presented so far in this article show that when a wind instrument is blown, the walls are excited at frequencies that match those of the air column resonances. This excitation could be a result of direct coupling between the air column and the walls of the instrument. That is, air pressure changes within the instrument could be providing a driving force to excite the walls into vibration. However, the excitation could also be caused by the motion of the lips, which are in contact with the pipe through the mouthpiece. Certainly the strong coupling between the air column and the lips does mean that the lips end up oscillating at, or close to, the resonance frequencies of the air column.

In order to determine the dominant excitation mechanism, two experiments were carried out. The first was designed to decouple the air column from the walls of the instrument. The second was designed to decouple the lips from the walls of the instrument.

Decoupling the air column from the instrument's walls

To decouple the air column from the walls of the instrument, an aluminium pipe (again 70cm long but with an external diameter of 9.5mm) was inserted

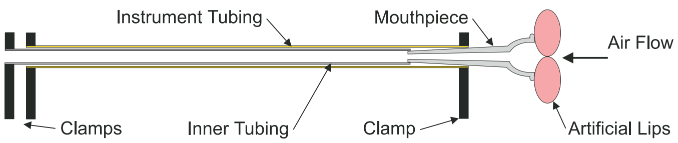

Figure 6: Schematic diagram of the simple brass instrument with an inner tube to decouple the air column from the instrument's walls

inside the brass pipe. This inner pipe was connected to the mouthpiece so that it behaved as the acoustic resonator *(Figure 6)*. This ensured that pressure changes within the air column were prevented from acting on the outer pipe. In this new configuration, the instrument was artificially blown and the velocity amplitude variation along the instrument was measured as before.

Figure 7 shows the velocity amplitude variations along the instrument induced by the artificial mouth at 365Hz and 730Hz. The plot shows velocity amplitudes similar to those measured when the brass pipe is normally coupled to the mouthpiece *(Figure 2)*, despite there being no interaction with the air column. This indicates that it is not pressure changes within the air column that excite the wall vibrations.

Decoupling the lips from the instrument's walls

To decouple the lips from the walls of the

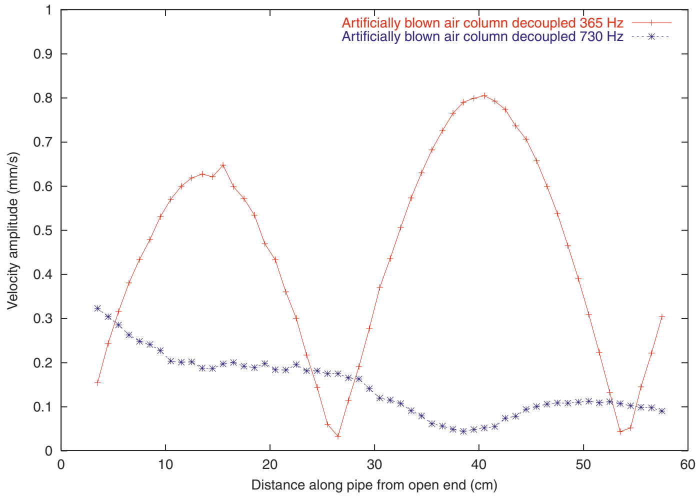

Figure 7: Velocity amplitude variation along the simple brass instrument when artificially blown with the air column decoupled. Measured at 365Hz and 730Hz

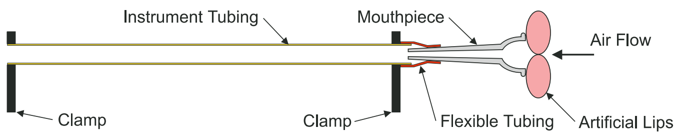

Figure 8: Schematic diagram of the simple brass instrument with flexible tubing to decouple the lips from the instrument's walls

instrument, a short length of flexible tubing was inserted between the brass pipe and the mouthpiece *(Figure 8)*. This reduced any vibration transmitted from the lips to the instrument walls without significantly altering the strengths and frequencies of the air column resonances. The instrument was again artificially blown and the velocity amplitude

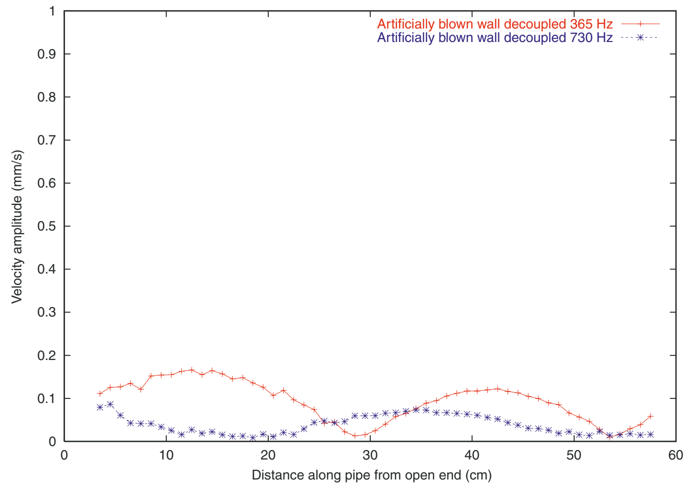

Figure 9: Velocity amplitude variation along the simple brass instrument when artificially blown with the lips decoupled. Measured at 365Hz and 730Hz

variation along the instrument was re-measured.

Figure 9 shows the velocity amplitude variations along the instrument induced by the artificial mouth at 365Hz and 730Hz. The plots show a reduction in the induced velocity amplitudes compared with those measured when the brass pipe is normally coupled to the mouthpiece *(Figure 2)*. The effect is most dramatic at 365Hz, indicating that at this frequency especially, the motion of the lips against the mouthpiece is the dominant mechanism by which wall vibrations are excited.

Concluding remarks

This line of research has so far provided useful insight into the size of the wall vibrations induced when musical wind instruments, in particular lip-reed (brass) instruments, are blown and the mechanisms by which these vibrations are excited. It is not yet clear whether the wall vibrations are of large enough magnitude significantly to affect the sound produced, either by direct radiation or by perturbation of the sound field within the instrument. If they are, this may go some way towards explaining why some musicians and instrument makers claim that particular materials give rise to particular timbres and playing qualities.

Work is currently being carried out to determine how the magnitude of the wall vibrations depends on the material from which the instrument is manufactured. Psychoacoustical tests are then planned to ascertain the extent, if any, to which listeners can discern differences between notes produced by instruments of different materials. It is hoped that by combining the results of these tests and the acoustical measurements described in this article, we will be in a position to unravel and dispel some of the problems and misconceptions that are quite often found surrounding musical instrument construction and performance.

Further reading

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