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THE EFFECT OF WALL MATERIAL ON THE STRUCTURAL VIBRATIONS EXCITED WHEN LIP-REED INSTRUMENTS ARE BLOWN

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1 INTRODUCTION

The shape of the air column is the dominant factor in determining the playing characteristics of a lip-reed instrument. The material from which the instrument is manufactured is generally considered by acousticians to be of minor importance. However, this view is not universally held. Instrument makers have claimed that they are able to distinguish between the musical qualities of instruments manufactured from different materials [1]. Meanwhile, some players are of the opinion that they produce different timbres when playing instruments made from different materials. For example, they claim to generate a “dark” sound when playing a silver trumpet and a “bright” sound when playing one made from brass [2, 3].

The most likely way that the wall material might affect the sound produced is through its influence on the structural vibrations of the instrument [4]. Recent experiments by Whitehouse [5] analysed the wall vibrations excited when a simple lip-reed instrument is blown. These experiments involved blowing the instrument (which comprised a cylindrical pipe coupled to a trombone mouthpiece) using an artificial mouth and measuring the velocities induced at different positions along the walls of the instrument using a laser Doppler vibrometer (LDV). The investigation revealed that the wall vibrations are primarily excited by the motion of the oscillating lips against the mouthpiece. It also showed that the amplitude of the wall vibrations depends on the type of metal from which the cylindrical pipe is manufactured.

The simple lip-reed instrument that was used in the study by Whitehouse has a relatively small surface area. As a result, the wall vibrations excited when the instrument is blown create little disturbance in the surrounding air and the sound radiated directly from the walls is minimal. Therefore, if the wall vibrations have any effect on the overall sound produced by this simple lip-reed instrument, it is only a tiny one. In general, however, lip-reed instruments are terminated with a flaring bell section. This has a much larger surface area and so, when set into vibration, will create a greater disturbance in the surrounding air and will radiate more sound. Whether the sound radiated directly from the walls will have a significant effect on the overall sound produced by the instrument is unclear. Several studies [6-8] have been carried out in the past to investigate whether the construction, material and finish of the bell section affects the sound produced by a lip-reed instrument. Although there is still much speculation as to whether there really is a genuine variation, results have been presented that do indicate small differences between bells. For instance, if played at a high dynamic level, an unlacquered bell will radiate more energy at all frequencies compared with a bell with a lacquered finish [9].

The post horn is one of the most basic lip-reed instruments in common use. Historically, post horns were used by guards of mail coaches in the 18th and 19th centuries [10]. They can be crescent-shaped, coiled, or straight but are all terminated with a bell section. In this paper, experiments are presented which have been designed to study the wall vibrations of five straight post horns manufactured from different copper alloys, but with the same surface finish and geometry.

2 POST HORN SPECIFICATIONS

The five post horns used in this study were manufactured by Michael Rath Brass Musical Instruments Ltd. of West Yorkshire. The post horns have identical geometry and surface finish but are made from different copper alloys. The material designation for the copper alloys is shown in Table 1.

The Michael Rath post horn is straight and comprises two sections; a cylindrical pipe that connects to a flare/bell. The length of the cylindrical section is 750 mm, with an outside diameter of 13.14 mm and relatively thin walls of thickness 0.40 mm. Fitted into the input end of the cylindrical section is a 75 mm long receiver, with a number 1 Morse taper, that is designed to centrally locate a trumpet mouthpiece. The bell section is 380 mm in length, with a spout gauge of 0.50 mm, and flare gauge of 0.70 mm. The bell, pipe and mouthpiece receiver slot together to give an overall instrument length of 1080 mm.

Material	Material Designation	Composition % Range			
		Cu	Ni	Ag	Zn
Red Brass	CuZn10	90 ± 1			10 ± 1
Gold Brass	CuZn15	85 ± 1			15 ± 1
Yellow Brass	CuZn20	80 ± 1			20 ± 1
Copper	C101	≥99.95		≤0.05	
Nickel Silver	CuNi10Zn27	63 ± 1	10 ± 1		27 ± 1

Table 1: Copper alloys used in the manufacture of the post horns

3 STRUCTURAL RESPONSES OF POST HORNS

3.1 Experimental method

Figure 1 shows a schematic diagram of the experimental apparatus used to measure the structural responses of the five post horns. The post horn under test was clamped horizontally to an anti-vibration table housed within a semi-anechoic chamber. The clamps were applied at each end of the cylindrical section of the post horn to prevent movement perpendicular to the axis of the instrument at these positions. The mouthpiece receiver of the post horn was coupled to a Denis Wick trumpet mouthpiece embedded in the faceplate of an artificial mouth (a mechanical blowing device comprising a pair of water-filled latex lips housed within a hermetically sealed box).

A Ling Dynamic Systems V201 mechanical shaker with a knife edge attachment was used to drive the post horn from above at discrete frequencies from 50 Hz to 2 kHz in 5 Hz steps. The shaker was located approximately 80 mm from the clamp at the mouthpiece end of the instrument.

A Polytec OFV-303/OFV-3001 laser Doppler vibrometer was used to measure the wall vibrations excited at each of the driven frequencies. The vibrometer laser beam was focussed on to the top of the post horn and vibration measurements were carried out at 32 predetermined locations (at 10 mm intervals) along the flaring bell section and 14 locations (at 40 mm intervals) along the cylindrical section of the post horn. The angle of incidence of the laser beam was such that, for both the cylindrical and bell sections of the post horn, the vibrometer measured the velocity component perpendicular to the axis of the instrument.

A National Instruments DaqPad 6052E data acquisition board connected to a PC generated the frequency sweep signal sent to the shaker and acquired the velocity amplitude information output by the vibrometer. The data acquisition board was controlled by in-house software written under the Matlab programming environment.

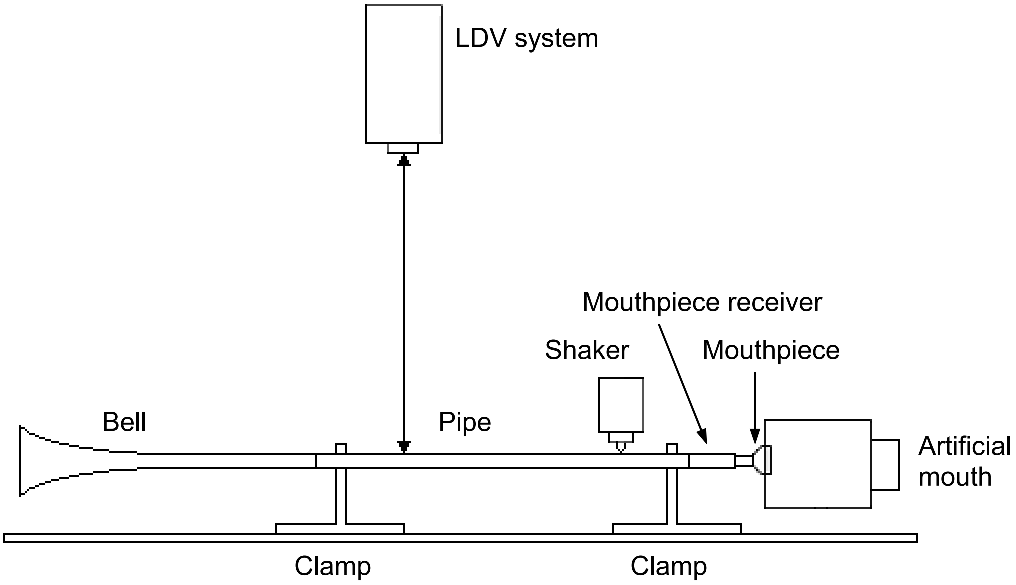


Figure 1: Schematic diagram of the experimental apparatus

3.2 Structural response results

Figure 2 shows 2D contour plots of the variation in velocity amplitude with frequency along (a) the cylindrical section and (b) the bell section of the yellow brass post horn.

Examination of Figure 2(a) reveals that the cylindrical section of the post horn exhibits similar behaviour to that of a cylindrical pipe rigidly clamped at both ends. The shapes and frequencies (approximately 120 Hz, 370 Hz, 990 Hz and 1415 Hz) of four bending modes are all clearly distinguishable.

Figure 2(b) displays slightly more complex behaviour. There appear to be three structural modes between 100 Hz and 400 Hz. The modes at 120 Hz and 370 Hz are simply the first two modes that were seen in Figure 2(a) and are bending modes of the whole post horn. The mode at 270 Hz, on the other hand, only appears weakly on Figure 2(a). This is the first bell mode. The second bell mode can be seen at 905 Hz.

Similar plots were generated for the gold brass, red brass, nickel silver and copper post horns. Table 2 summarises the mode frequencies and amplitudes for the five post horns deduced from the 2D contour plots of (a) the cylindrical section and (b) the bell section of the instruments.

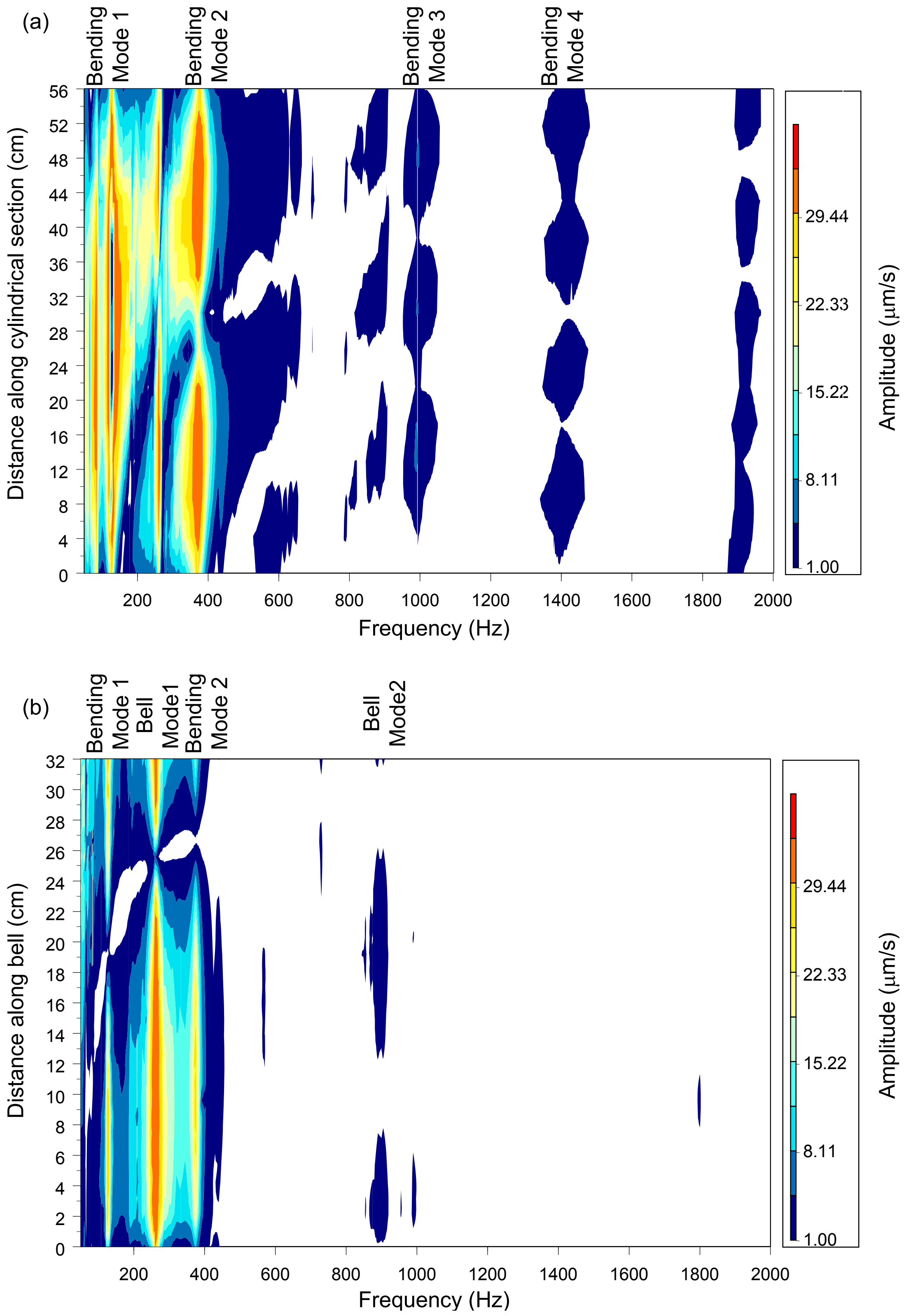


Figure 2: 2D contour plots of the variation in velocity amplitude with frequency along (a) the cylindrical section and (b) the bell section of the yellow brass post horn

	Copper		Red Brass		Gold Brass		Yellow Brass		Nickel-Silver	
	Freq.	Ampli.	Freq.	Ampli.	Freq.	Ampli.	Freq.	Ampli.	Freq.	Ampli.
	(Hz)	(μm/s)	(Hz)	(μm/s)	(Hz)	(μm/s)	(Hz)	(μm/s)	(Hz)	(μm/s)
Bending Mode 1	130	31.61	130	31.61	125	31.5	120	31.3	135	31.47
Bending Mode 2	400	31.28	370	31.56	385	31.07	370	31.41	400	30.23
Bending Mode 3	1040	6.19	910	4.3	1040	2.72	990	4.89	865	11.93
Bending Mode4	1515	4.78	1405	4.67	1470	4.54	1415	4.03	1570	8.96

Table 2(a): Structural mode frequencies and amplitudes for the five post horns, derived from measurements on the cylindrical section of the instrument

	Copper		Red Brass		Gold Brass		Yellow Brass		Nickel-Silver	
	Freq.	Ampli.	Freq.	Ampli.	Freq.	Ampli.	Freq.	Ampli.	Freq.	Ampli.
	(Hz)	(μm/s)	(Hz)	(μm/s)	(Hz)	(μm/s)	(Hz)	(μm/s)	(Hz)	(μm/s)
Bending Mode 1	135	31.52	125	31.4	130	31.41	125	29.28	135	28.4
Bell Mode 1	275	31.69	265	31.68	265	31.65	260	31.69	280	31
Bending Mode 2	400	21.92	370	28.46	385	26.92	375	28.16	400	13.92
Bell Mode 2	920	4.82	910	4.70	900	3.64	905	2.73	940	4.75

Table 2(b): Structural mode frequencies and amplitudes for the five post horns, derived from measurements on the bell section of the instrument

4 WALL VIBRATIONS INDUCED WHEN POST HORNS ARE BLOWN

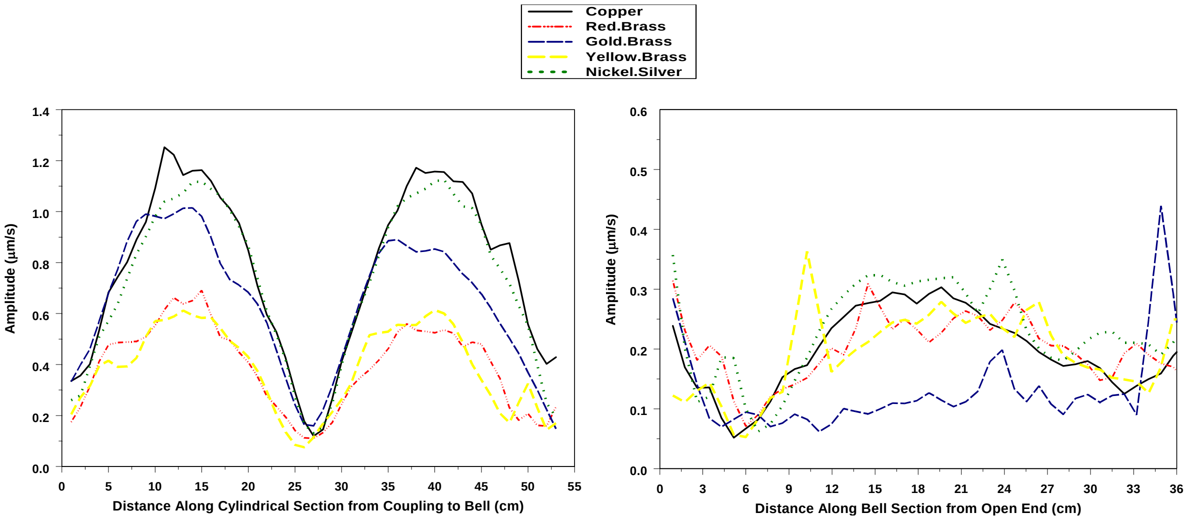
4.1 Experimental method

To measure the wall vibrations excited when the post horn under test was blown, the shaker was removed from the set-up described in Section 3 and the air supply to the artificial mouth was activated. The lips were adjusted until a discernible stable note was produced. This note was recorded and frequency analysis revealed a fundamental frequency of 419 Hz and a second harmonic at 838 Hz, corresponding to a note of pitch G#4 (sounding slightly sharp). The velocity amplitudes induced in the walls of the post horn at these two frequencies were measured using the LDV. Measurements were taken at intervals of 10mm over the cylindrical pipe section and at intervals of approximately 9mm over the bell section.

4.2 Induced wall vibration results and discussion

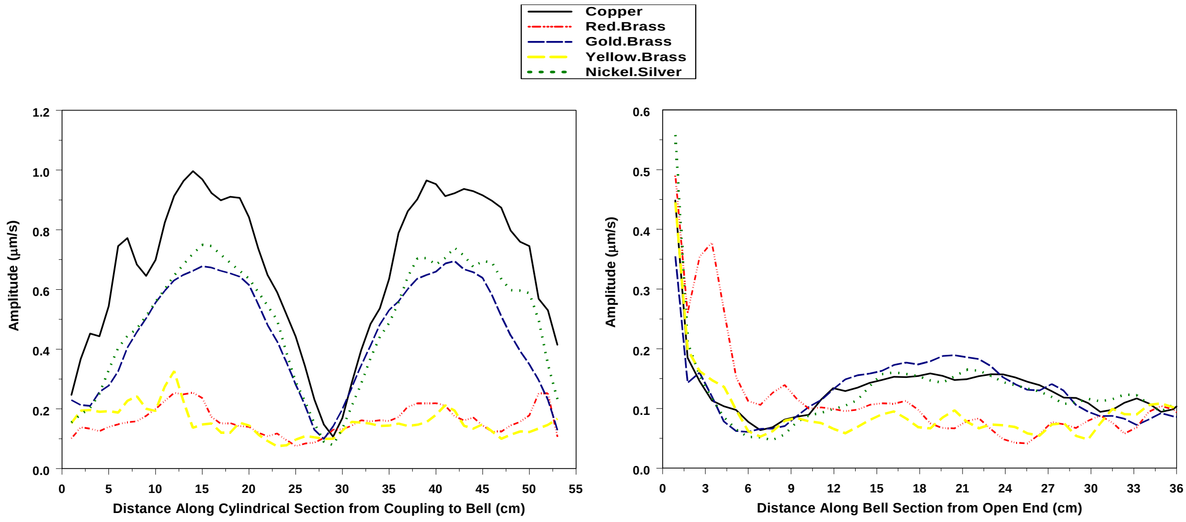
4.2.1 Measurements at fundamental frequency of played note (419 Hz)

Figure 3 shows the velocity amplitude variation at 419 Hz along (a) the cylindrical section and (b) the bell section of the five post horns, excited when the instruments are blown by the artificial mouth. Figure 4 shows the structural responses of the post horns at 419 Hz plotted for (a) the



(a) (b)

Figure 3: Velocity amplitude variation at 419 Hz over (a) the cylindrical section and (b) the bell section of the five post horns when artificially blown.



(a) (b)

Figure 4: Structural response at 419 Hz over (a) the cylindrical section and (b) the bell section of the five post horns

cylindrical section and (b) the bell section of the instrument. (These structural response curves are extracted from the data acquired in Section 3.)

Examination of Figure 3(a) reveals that, over the cylindrical part of the post horn, the wall vibrations induced when the instruments are artificially blown are strongest in the copper post horn (with peak velocity amplitudes of approximately 1.2 µm/s). Only slightly weaker are the wall vibrations induced in the cylindrical section of the nickel silver post horn, followed by those seen in the gold brass instrument. The wall vibrations induced in the red and yellow brass post horns are almost identical

in strength but are the weakest observed in the instruments tested (with peak velocity amplitudes of approximately 0.6 μm/s).
Figure 4(a) shows that, over the cylindrical section of the instrument, the copper post horn has the strongest structural response. The next strongest responses are those of the nickel silver and the gold brass instruments. The red and yellow brass post horns both have very weak structural responses over the cylindrical part of the instrument.

By comparing Figure 3(a) and Figure 4(a), it is clear that, over the cylindrical section of the instruments, there is a good correlation between the magnitudes of the wall vibrations induced when the post horns are artificially blown and the strengths of the structural responses at 419 Hz.

Turning to the bell section of the instrument, Figure 3(b) shows that when the post horns are blown, the wall vibrations induced are all very weak. The copper, nickel silver, red brass and yellow brass instruments all show a very similar variation in velocity amplitude along the bell section (with the largest velocity amplitudes observed not much greater than 0.35 μm/s). The wall vibrations induced in the bell section of the gold brass instrument are the weakest (with a peak velocity amplitude of approximately 0.20 μm/s).

Figure 4(b) confirms that, over the bell section, the structural responses of the five post horns at 419 Hz are all very weak. Indeed, the responses of the yellow and red brass post horns in this region of the instrument are so weak that the measurements become dominated by noise.

4.2.2 Measurements at second harmonic of played note (838 Hz)

Figure 5 shows the velocity amplitude variation at 838 Hz along (a) the cylindrical section and (b) the bell section of the five post horns, excited when the instruments are blown by the artificial mouth. Figure 6 shows the structural responses of the post horns at 838 Hz plotted for (a) the cylindrical section and (b) the bell section of the instrument. (These structural response curves are extracted from the data acquired in Section 3.)

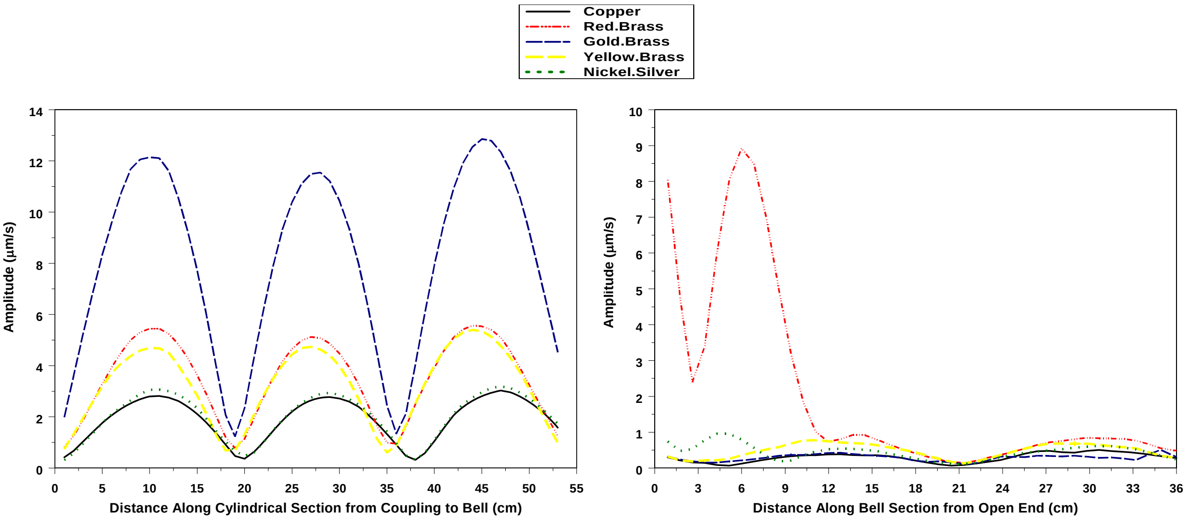
Figure 5(a) shows that, over the cylindrical section of the instrument, the induced wall vibrations are very much strongest when the gold brass instrument is blown (with peak velocity amplitudes of approximately 12 μm/s). The wall vibrations excited when the red and yellow brass post horns are blown are somewhat weaker. However, at 838 Hz, the weakest wall vibrations are observed when the copper and nickel silver instruments are blown (with peak velocity amplitudes of around 3 μm/s).

It is worth noting that, over the cylindrical section, the velocity amplitudes excited at 838 Hz when the post horns are blown are an order of magnitude greater than those excited at 419 Hz. The reason for this becomes clearer from an examination of Figure 6(a). This shows that the structural responses of the five post horns at 838 Hz are all quite strong in comparison with the responses at 419 Hz (see Figure 4(a)).

Figure 6(a) also reveals that, just as was noted at 419 Hz, there is a good correlation between the magnitudes of the wall vibrations induced when the post horns are artificially blown and the strengths of the structural responses of the post horns at 838 Hz.

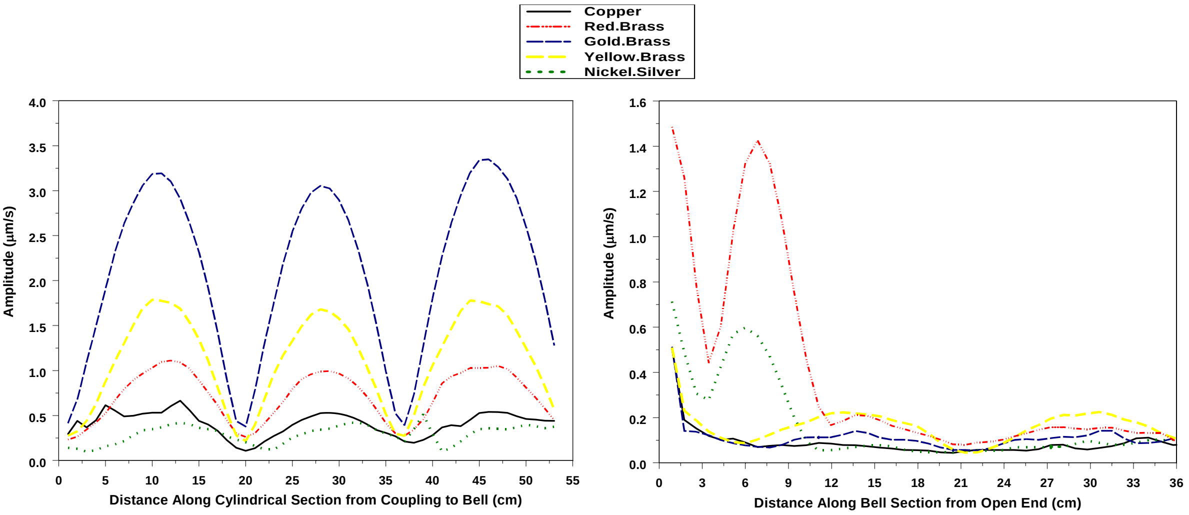
Turning once more to the bell section, Figure 5(b) shows that when the instruments are blown, the wall vibrations induced are all quite similar in amplitude except for the red brass post horn. For this instrument, velocity amplitudes as large as 9 μm/s are excited in the bell.

Figure 6(b) shows that, as might be expected, the structural response over the bell section of the red brass post horn is significantly stronger than the structural responses of the other instruments over this region.



(a) (b)

Figure 5: Velocity amplitude variation at 838 Hz over (a) the cylindrical section and (b) the bell section of the five post horns when artificially blown



(a) (b)

Figure 6: Structural response at 838 Hz over (a) the cylindrical section and (b) the bell section of the five post horns

5 CONCLUSION

The experiments presented in this paper have shown that when a lip-reed instrument is blown, vibrations are excited in the walls of the instrument. The amplitude of these wall vibrations correlates strongly with the structural response of the instrument at the frequencies present in the played note. Therefore, as the structural response of an instrument depends on the material from which it is manufactured, the strength of the wall vibrations also depends to a certain extent on the construction material.

Compared with the cylindrical section of the instrument, the bell of a post horn has a relatively large surface area. In this region, therefore, any structural vibrations will be more efficiently radiated as sound. Whether or not this directly radiated sound from the walls has a significant effect on the overall sound produced by the instrument is unclear. A series of psychoacoustical tests are planned to investigate whether listeners can discern differences between notes produced by the five post horns. An attempt will be made to correlate the data acquired with the differences in wall vibration amplitude observed between the instruments.

Further wall vibration measurements will also be carried out on the bell section of the instruments. In particular, the circumferential variation in the velocity amplitudes induced in the bell walls will be measured.

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