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THE EFFECT OF MATERIAL IN BRASS INSTRUMENTS; A REVIEW

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INTRODUCTION

Opinions on the matter of the contribution to musical quality made by the walls of wind instruments are diverse and certainly not lacking. They range from those of the staid scientist who refuses to consider that the walls could have any effect at all, to those of the misguided musician who proposes pseudo-scientific theories of sound production. The manufacturer would like to believe, for financial reasons, that materials have no effect at all, but to win players and customers for their product they need to concur with their views.

There are several critical reviews of the manufacturers literature {1,2} suggesting that brass manufacturers in particular make it clear that they believe that material imparts certain musical qualities to their instruments. It is not necessary to know whether this theory was initiated by the manufacturer or player, but we now have companies competing for business based on the acoustical properties of superior and exclusive materials. This in some way makes up for the unpredictable 'organic' element which string players and to some extent woodwind players enjoy and can claim some uniqueness for their own particular instrument. With improved production and testing techniques any variability or uniqueness is becoming lost.

Research

This paper reviews the research undertaken (some of it hitherto unpublished) to ascertain the influence of materials on the musical properties of brass instruments. Most work relates to the vibrational properties of trombone bells (chosen for their large free vibrational surface) and in several cases, the same set of experimental bells underwent a series of different tests.

There are several parameters which may be relevant to bell vibration studies, and they include:

a) Wall thickness
b) Material (chemical composition)
c) Clamping positions (stays)
d) Rim size
e) Coatings (e.g. plate or lacquer)
f) Method of fabrication (one-piece/single seam/hand hammered)

It is reasonable to assume that if the material is thick, the effect of most of the other parameters will be negligible. Hence recent work has tended to concentrate on the effect of the variation in wall thickness. Presenting bells of different thickness to players raises two other problems which are often overlooked by experimenters:

1. Weight and Balance. Players are surprisingly sensitive to the weight and balance variation caused by a small change in bell thickness. In the experiments performed by Smith {3}, each interchangeable bell of various thickness had its own counterbalance to give identical weight and centre of

gravity. Under such conditions the players were unable to detect differences due to weight or balance. Without this compensation the instruments were readily identified.

2. Identical Bore Shapes. Blaikley {4}, referring to his experiments with paper and metal bells {5}, states that "material has little influence as compared with form." Backus {6}, for example, was also well aware of the importance of using bells of identical bore profile when comparing materials. However, other reports of experiments do not give the reader confidence that the bores were identical. The experience of the author (and other designers) suggests that bells (and other drawn and spun parts) of different wall thickness do not retain the same internal dimensions when removed from the shape or mandrel. Measurements on trumpet bells, for example, indicate a .15 mm increase in diameter for thin bells (.3 mm wall) when compared with thick items (.6 mm wall). This variation can have a significant effect on the musical performance of the instrument, and is one explanation why manufacturers often fail in copying competitors instruments. Furthermore, materials of different constituents will compound this error.

Vibrational Properties of Brass Bells

There is no doubt that a player can feel his instrument vibrating through his hands in addition to the dynamic lip interaction, and so has good reason to suppose that the material is adding to the musical quality of his instrument.

The vibrating walls can interact with the standing wave in the air column, internally dissipate energy and radiate sound from their outer surfaces. If resonant at particular frequencies (e.g. harmonic frequencies of the air column) will the effect be constructive, detrimental or insignificant? The following review of recent experiments hopes to answer this.

Ando {7} reports on how the material affects tone quality through the results of Murakami and Kato. Fig.1 shows the various positions at which the vibration was measured along the length of a trombone bell. It appears that only one lateral measurement was made (along the top surface) and it shows zero vibration at the bell rim, as though it was clamped as a nodal point. Unlike the crossectional view measured at 20 cm from the rim (Fig.2), this does not correspond with the results of other workers. He concludes that material has no important effect as far as harmonic structure is concerned although a 1 dB s.p.l. was noted with a change to a more rigid bell.

Smith {3} constructed a set of six similar brass trombone bells using material of three different thicknesses. Each of the bells could be fitted in turn onto a trombone body which was coupled to an artificial acoustic driver. Time-averaged interferograms were produced for a large number of material resonances, and further analysis showed a mathematical relationship between the amplitude of the vibration of bells of different thickness {8}. The strongest resonances were found at about 240 Hz with a considerably reduced amplitude for the thicker bells (Fig.3). These results have been confirmed by other techniques (Kitchen, Watkinson and Richardson) using the same set of bells.

A finite element method was used by Watkinson {2} to predict the forms of vibration of the six bells. Although some of the input data is roughly estimated, he confirms a strongly excited mode at around 250 Hz for the medium bell and a weaker less consistent mode at a higher frequency (500 - 700 Hz). While Kitchen {9} agrees with the lower modes using a laser-doppler velocimeter technique, he finds a stronger resonance in the 450 Hz region. As expected, the modes of the thicker bells have higher frequencies than those of the thinnest.

A further holographic test by Richardson {10} shows that the structural modes by direct driving are very close in frequency to those measured by other techniques. When acoustically excited the thin bells showed a (2, 1½) structural mode close to the 4th harmonic of the air column. By changing the length of the slide tube the structural resonance was more easily excited when the air column mode coincides in frequency with this resonance, but there is no evidence of strong coupling which would otherwise cause mode splitting.

Acoustical Properties of Brass Bells

Knowing the frequencies of the structural modes indicates a region in which the acoustic spectrum might be influenced. The use of a human player source for acoustic and vibrational measurements was found unsatisfactory due to the poor repeatability of the results, hence the siren developed by Wogram {11} was used by Smith {12} to produce the steady state spectra for the six bells under investigation. The sound on the axis of the bell and at the players' ear position (via an artificial head) were recorded and later analysed. Of the three notes recorded (Bb,58 Hz,$Bb_2$116 Hz and F_4 349 Hz), only two harmonics were significantly affected:

a) the 4th harmonic of Bb_1 (i.e. at 232 Hz) and
b) the 2nd harmonic of Bb_2 (i.e. at 232 Hz)

In both cases, the harmonic frequency is close to the structural resonance. These two results and two others of harmonics not affected are shown in Fig.4.

Subjective Testing of Bells

The difference between ear and bell spectra amounts to about a 2 dB increase at a particular harmonic for the thinnest bells. Having taken precautions to equalise the weight and balance of the bells, ten of the best trombonists were put through an S.D.S. blindfold testing routine {13} to ascertain whether they could distinguish between the six bells. The statistical results showed that the difference between thin and thick bells was so small that it could not be detected by any of the players. At a later stage in the testing an electroformed pure copper bell (made on a similar - but not the same mandrel) was added into the playing sequence. Under test conditions this was not noticeably any different to the brass bells but when subsequently played in non-blind tests it gained magical properties!

These results indicate that the bell thickness does have a significant affect on the sound spectra measured at the players' ear position due to some sound radiation from the material itself. However, under controlled conditions players seem unable to distinguish between thick and thin materials.

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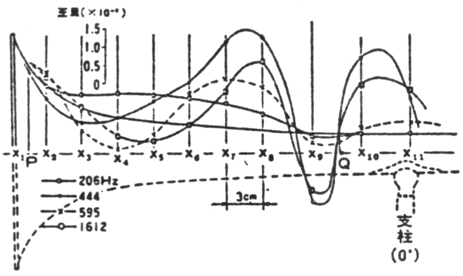

Fig 1 Lateral vibrations of a trombone bell (Ando 1971)

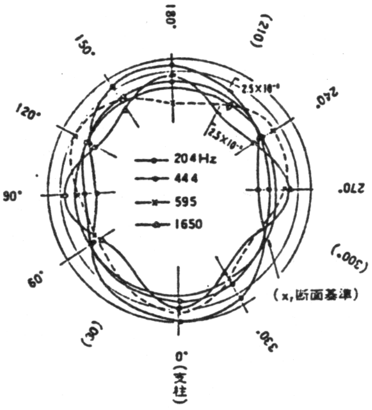

Fig 2 Cross-sectional vibration pattern at 20cm from the rim

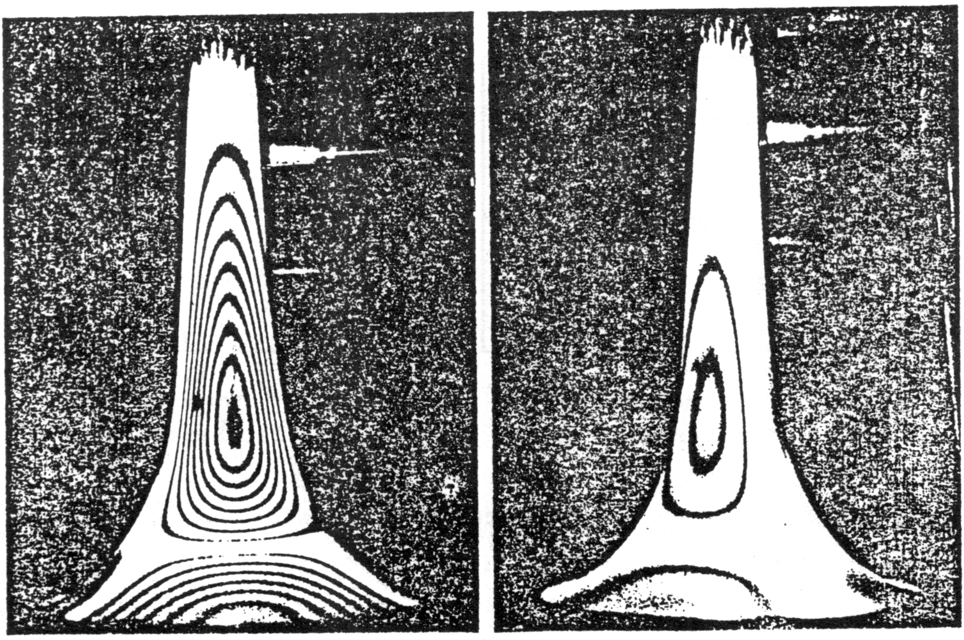

Fig 3 Holographic reconstruction of bell vibrations with air column excitation at approximately 240Hz. Left:0.3mm wall thickness,Right:0.4mm wall thickness (Smith 1978)

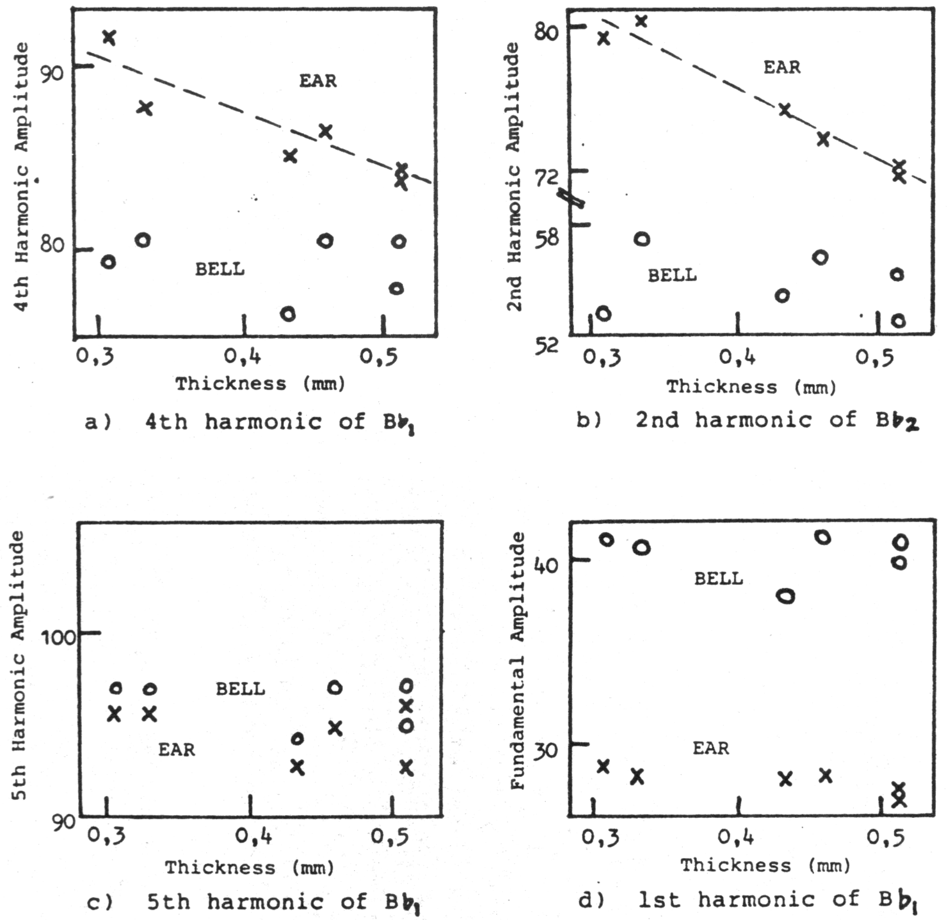

Fig 4 Comparison of particular harmonics at ear and bell positions