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IMPULSE METHODS IN BRASS INSTRUMENT MEASUREMENT

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Introduction

The input impedance of a brass instrument has long been employed as a useful physical correlate of musical quality [1, 2, 3]. This quantity may be measured directly [4], or calculated from measurements of the bore shape [5, 6]. While this is useful in the assessment of steady-state playing characteristics, such as intonation, it has been shown that the steady-state is not sufficient to describe the perceived quality of a musical tone [7].

Preliminary investigations by the author and Dr. R. Shepherd (Psychology Dept., Surrey University) indicate that French Horn players are able to distinguish the presence of early reflections in the impulse response of an instrument [6]. The magnitude and location of such reflections cannot be accurately estimated from the inverse Fourier transform of input impedance data due to bandwidth limitations.

As an example, the impedance measuring device built at Surrey University [4] was not designed to measure above 2 kHz, as no peaks are present in the input impedance function above this frequency. An order of magnitude calculation shows that the smallest detail that may be resolved from the time-domain data (via the inverse F.T.) is approximately 9 cm. If detail smaller than 1 cm in size is to be resolved, the equivalent bandwidth must be greater than 17 kHz. This is not feasible with the impedance measuring device as it employs an 18" loudspeaker as the source, so an alternative approach is necessary.

Previous experiments by Frausson [8] on flutes and Krüger [9] on brass instruments, using an Ionophone as an impulse source, have given encouraging results, though due to differences in measuring conditions cannot be compared to results from the impedance measuring source.

Description of new device

A simple impulse source was constructed which eliminates the need for the stable EHT source required by the Ionophone, and produced considerably higher sound pressure levels (129 dB). A short pulse is desirable and a spark source meets this criterion, with pulse widths of 0.02 msec available. Control and repeatability are also important factors, and these were met by a TTL pulse triggered EHT generator, which did not have to be particularly stable as signal processing of the acoustic data compensated for varying amplitudes.

The EHT pulse is fed to a modified car spark plug placed in the mouthpiece of the instrument to be measured. The curved electrode is removed to increase the spark length and hence the acoustic output, and the cavity between the central

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electrode and outer body filled with insulating sealant to prevent pulse degradation from cavity reflections and compliance.

A ¼" microphone, whose response extended to 200 kHz, was positioned in the mouthpiece throat to receive the acoustic signal.

The measurement system was controlled by minicomputer (Fig.1) which synchronised the trigger pulse and data acquisition, as well as taking a running average of the signal to improve the signal to noise ratio.

Calibration of the measurement chain is simply effected by means of a pistonphone and a subroutine which calculates the true RMS voltage seen at the ADC.

Results

A typical measurement of the impulse response of a French Horn is shown in Fig.2. The principal reflection from the open end is not the same shape as the input pulse, due to the attenuation of higher frequencies within the bore and the characteristics of the horn shape which tend to radiate high frequencies better than low, and hence the overall effect is one of a lowpass filter. Additional reflections can be seen, and are easily related to features in the bore geometry such as the valves.

A French Horn was especially constructed by Paxmans Ltd., with the internal bore modified to remove as many sharp discontinuities as possible by chamfering the offending portions of bore. The difference between this and a standard instrument was measurable (and, as mentioned earlier, detectable by players).

It becomes progressively more difficult to identify reflections as the wave propagates into the instrument, for two reasons. One is the pulse degradation, which effectively reduces the pulse bandwidth, and hence the spatial resolution. The contribution from multiple reflections is more difficult to assess, though several standard techniques such as the Wiener filter could be applied to remove these from the impulse response.

If the sample rate and antialias filter are chosen properly, the impulse response may be Fourier Transformed to give a scaled version of the input impedance. A practical difficulty exists here if the phase of the input impedance is wanted, as the phase calibration of a microphone over the bandwidth employed is not trivial. This difficulty may be overcome by the Hilbert Transform which relates the real and imaginary parts of the Fourier Transform of real causal stable signals.

This property was exploited to give the result of Fig.3, which is a comparison of the input impedance evaluated by the measuring device and the Fourier and Hilbert transform processed impulse response. A direct comparison is not possible as the measurements were made at different temperatures, and the constant phase ramp on the measured input impedance due to the mouthpiece throat inertance was removed by the Hilbert transform of the corresponding impulse data, but it can be seen that a fair degree of agreement exists between corresponding impedance peak frequencies and peak widths.

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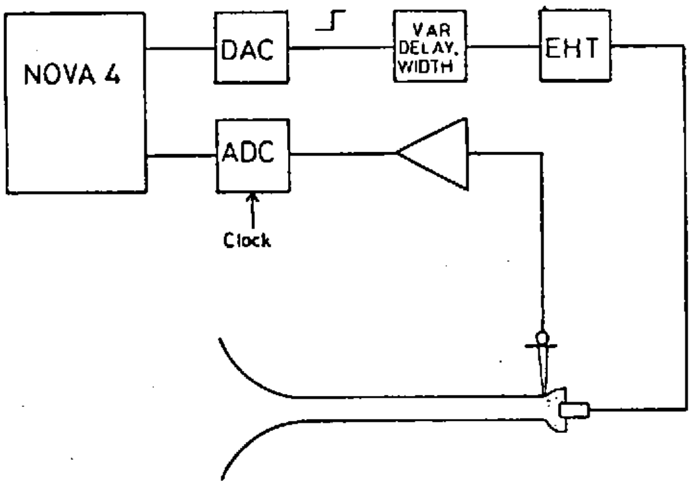

Schematic of impulse response measuring device

Fig.1.

Impulse response of a French Horn

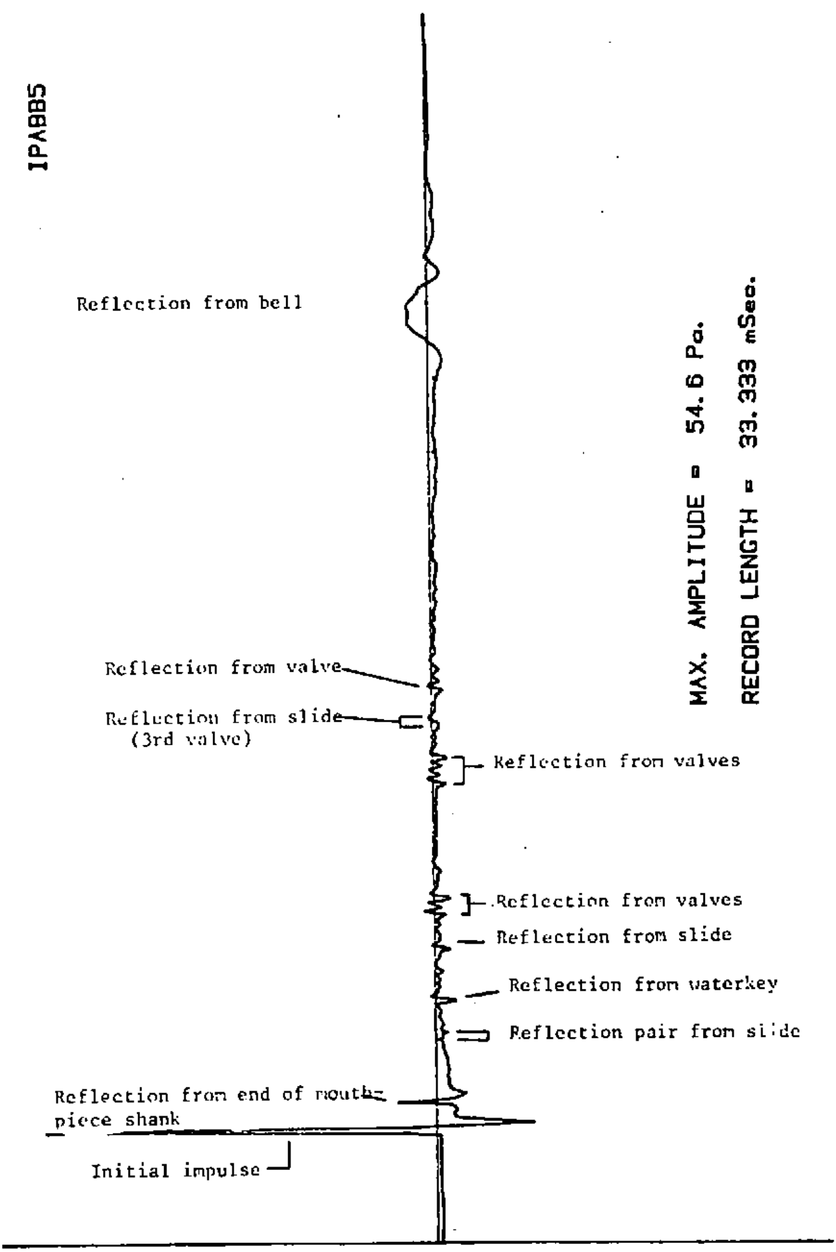

Fig.2

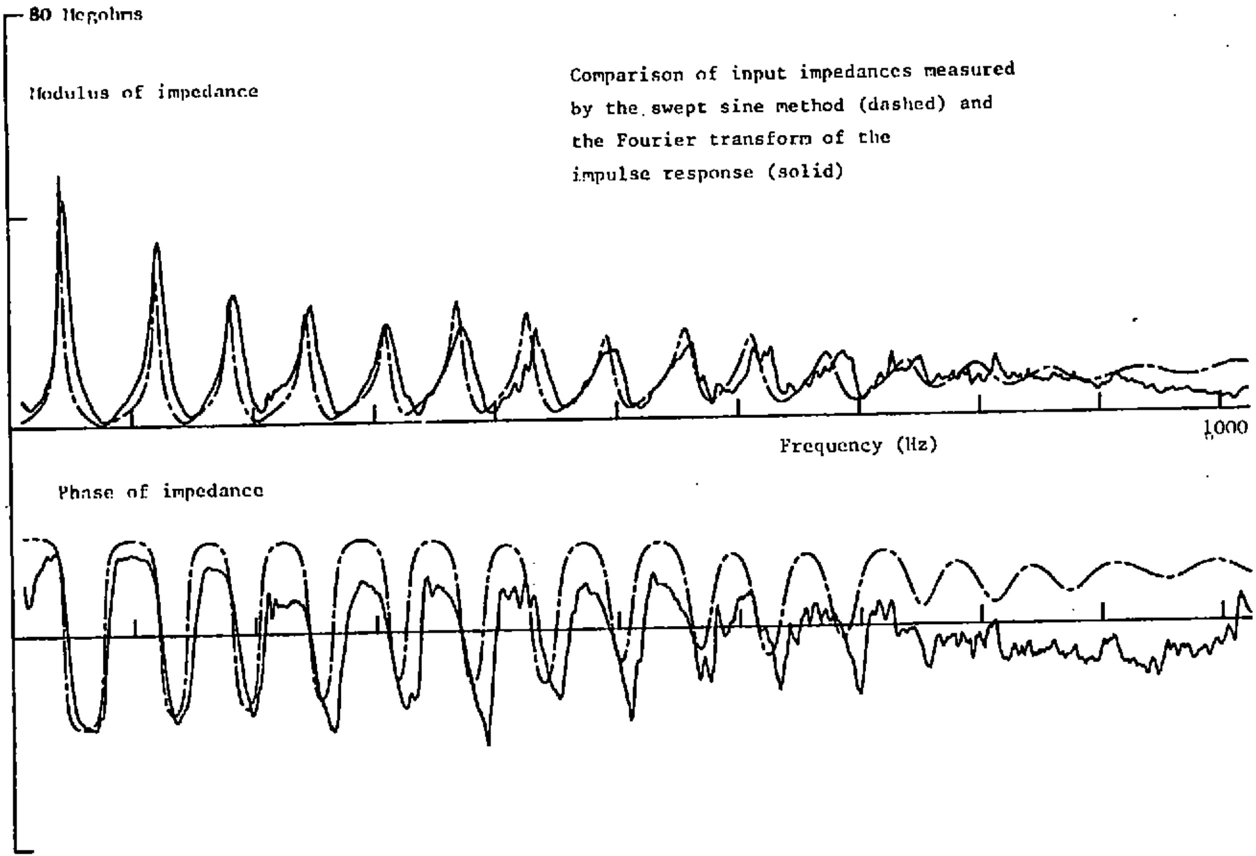

Fig.3.

Comparison of input impedances measured by the swept sine method (dashed) and the Fourier transform of the impulse response (solid)