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RECENT PROGRESS IN TIME DOMAIN WORK ON BRASS INSTRUMENTS

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Introduction

At the Spring '84 meeting of the Institute of Acoustics, Anne Duffield [1] spoke about the problems she encountered while making impulse measurements with a spark-source. These included the inconsistency of the pulses in both amplitude and timing and their effect on signal averaging, and temperature variations. Much software was written to take account of these problems but the problems of deconvolution of the pulse and subsequent bore-reconstruction procedures remained unsolved. After undertaking a re-examination of the transient measuring apparatus at Surrey we have changed to using a loudspeaker source and many of the problems mentioned above have been eliminated. Further work has been done on deconvolution and we now have an FFT-based frequency domain method which is allowing accurate determinations of the impulse response of brass instruments. This is confirmed by the work we are doing on bore reconstruction where the deconvolved impulse response is used in an algorithm to calculate the cross-sectional area of a tube or instrument as a function of distance along its axis.

Transient measuring apparatus

The apparatus is basically as described previously [1,2] and shown in Fig. 1. The source is directly coupled to a tube about 4m long and the instrument under test is attached to the other end. A microphone is situated about half way along the tube and penetrates through a hole into the tube. The length of the tube and the microphone position are chosen so as to separate the reflection sequence of the instrument from reflections off the source. Normally, the source tube fits into the instrument in the same way that a mouthpiece does via a slight taper. The microphone is a B&K 1/8th inch for reasons of size and low-frequency response. The source is one of the new generation of metal-dome tweeters which has a fast response combined with low ringing of the surround to the dome. When driven by a short electrical pulse this provides a sharp acoustical pulse of short duration and surprising low-frequency extension. The microphone signal is fed via an (optional-see later) anti-aliasing filter to an ADC controlled by a BBC microcomputer. The computer synchronizes the pulse being fed to the source to the sampling of the ADC and stores and averages the data at high speed so that 250 pulse responses can be obtained and averaged in under 30 seconds. A separate measurement of the pulse itself is obtained by removing the instrument and closing the end of the source tube and measuring the pulse reflected from this closed end. This is the shape of the pulse as it enters the instrument. Fig. 2 shows the pulse as measured in this way. This method of measuring the pulse was suggested by Sondhi & Resnick [3], the idea being to account for losses present in the propagation of the pulse over twice the distance between the microphone and the instrument.

Deconvolution

Much work has been done on obtaining an accurate prediction of the impulse reflectance from the basic pulse measurement. After carrying out comparative tests of various methods, we chose to deconvolve by performing a frequency-domain division of the spectra of the instrument reflection response and the pulse which caused that response. Time signals are Fourier transformed to the frequency domain. Noise in the signals at the bandwidth extremes produces even more noise in the result obtained by división. If this noise is not removed by windowing then when the quotient is inverse transformed to the time-domain to form the impulse response severe distortion will occur. Windowing the data in the frequency domain to suppress the noisy parts of the spectrum produces a much cleaner looking impulse response but the window affects the signal as well, thus causing a different kind of distortion to appear in the impulse response. This distortion may well be small but for our purposes it is unacceptable. We therefore investigated ways of deconvolving without using windows at all. Consider first the low-frequencies where any distortion will show up in the impulse response as spurious low-frequency components throughout the response. It was mentioned above that if the source is securely coupled to the source tube then the low-frequency output of the source is quite considerable. In fact with sufficient signal averaging useful signal can be obtained down to our lowest frequency sample point of about 30 Hz. Taking care to choose a microphone which has an extended low-frequency response such as the B&K 1/8th inch then accuracy is maintained in the impulse response without having to window or extrapolate in the frequency domain. If we window the frequency-domain division at high-frequencies then much 'fuzziness' will be removed from the impulse response but again the real signal will be affected; particularly with respect to the height and sharpness of the reflections. This 'fuzziness' is a visual problem more than anything and tends to be integrated out in procedures such as Bore-Reconstruction. However one can vary the the sampling-rate of the data acquisition apparatus so the upper limit of the signal bandwidth occurs much closer to the Nyquist frequency and thus any noise occurring in the frequency domain division is restricted to a much smaller region. It is also possible to dispense with the anti-aliasing filter in the data acquisition stage so long as one knows exactly how this affects the end result and whether it is significant. Figs. 3 to 6 illustrate the deconvolution procedure for a trumpet.

Bore-Reconstruction

Once an accurate calculation of the impulse reflectance has been obtained then several signal processing algorithms can be implemented to illustrate specific aspects of the acoustical and structural properties of the instrument. One of these is that of bore reconstruction: to determine the cross-sectional area of the instrument as a function of distance along its axis. We have implemented the lossless algorithm of Sondhi [3] and applied it to simple tube geometries and to brass instruments with promising results.

Results

Fig. 7 shows the deconvolved reflectance and Fig. 10 the bore-reconstruction of a tube constriction from 6.3mm to 3.85mm radius. Figs. 8 and 11 show the same for an expansion from 6.3mm to 15.25mm. Figs. 9 and 12 are for a trombone and Figs. 6 and 13 are for a trumpet. Bore reconstruction is not so good for a cone because the model is based on plane-wave propagation and we should have spherical-waves in the cone. The same applies to the bells of brass instruments (not shown). Further work is in hand to consider non-planar wave propagation and loss of energy.

Application to the manufacturing environment

It is important that instruments leave the facory in perfect working order and that those based on a prototype are all consistent and up to standard. This helps reduce the frequency at which instruments are returned from retailers and players with faults, or simply through being badly set-up. The transient response of a prototype can be stored on a computer and compared with that of every instrument coming off the production-line. Either a straight arithmetic subtraction or a cross-correlation for instance can be used to detect differences in transient responses. This could form the basis of a diagnostics routine to tell the manufacturer where the faults, if any, are located.

Discussion

A transient measuring apparatus with software support has been developed which eliminates many of the problems encountered previously with spark-source based systems. The system has the advantage of low-cost while still maintaining efficiency in data capture and analysis. Accurate deconvolutions of pulse measurements allow for good results in a bore reconstruction procedure to determine the cross-sectional area of a tube or brass instrument as a function of distance along its axis. The accuracy of the technique is not yet sufficient for precision work, largely for the reasons already given that only plane, lossless propagation has been implemented in the reconstruction algorithms.

Acknowledgements

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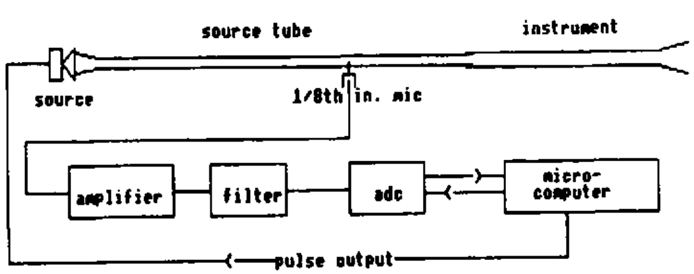
References

[1] A.Duffield, 'Problems encountered when making simple impulse measurements.' Proc. IOA. Spring meeting 1984, Swansea.

[2] A.P.Watson & J.M.Bowsher, 'Impulse measurement of brass musical instruments.' Submitted for publication 1986.

[3] M.M.Sondhi & J.R.Resnick, 'The inverse problem for the vocal tract: Numerical methods, Acoustical experiments and Speech Synthesis.' J.Acoust.Soc.Am. 73, 985-1002, 1983.

Fig. 1, schematic diagram of measurement system



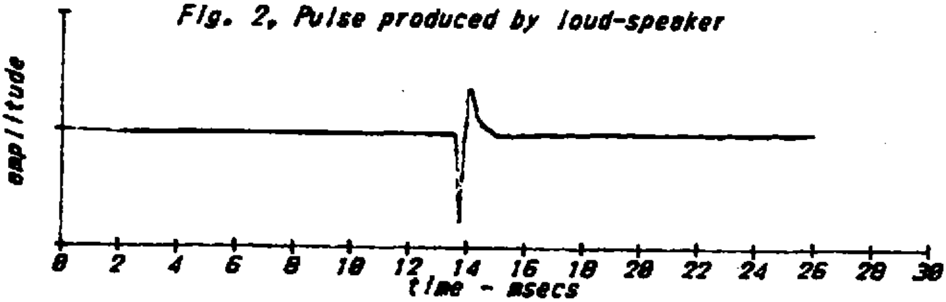


Fig. 2, Pulse produced by loud-speaker

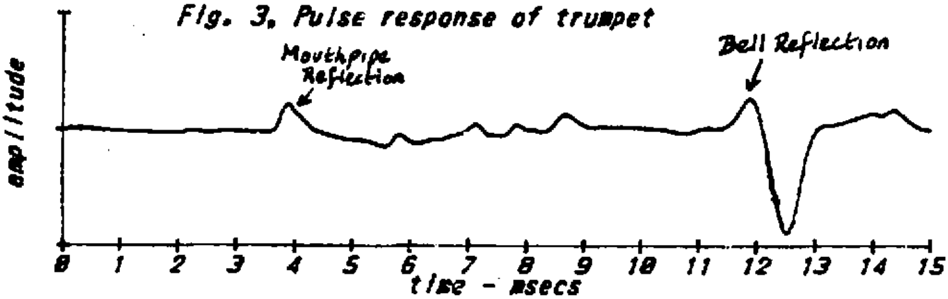


Fig. 3, Pulse response of trumpet

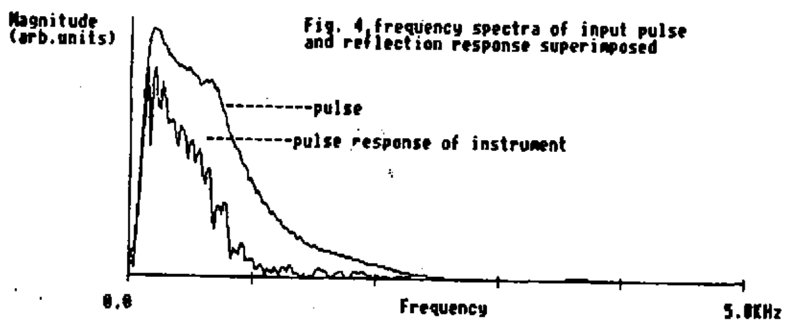


Fig. 4, frequency spectra of input pulse and reflection response superimposed

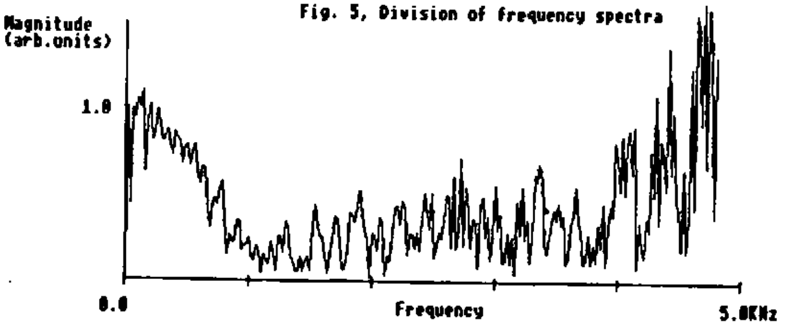


Fig. 5, Division of frequency spectra

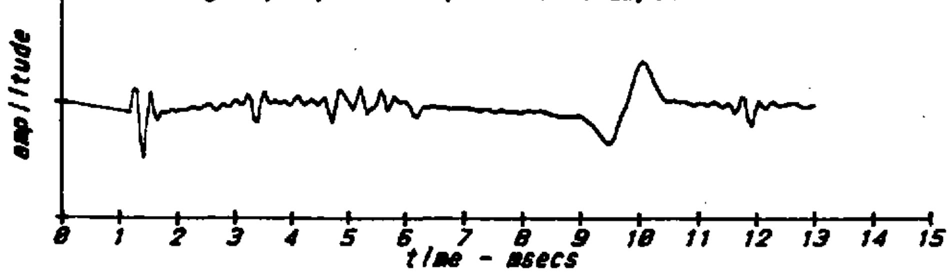


Fig. 6, Impulse response of trumpet

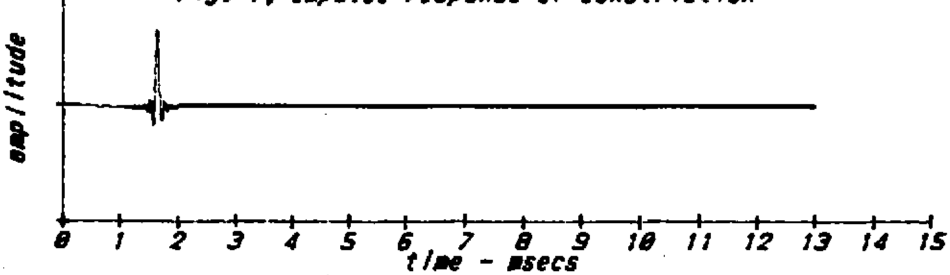


Fig. 7, Impulse response of constriction

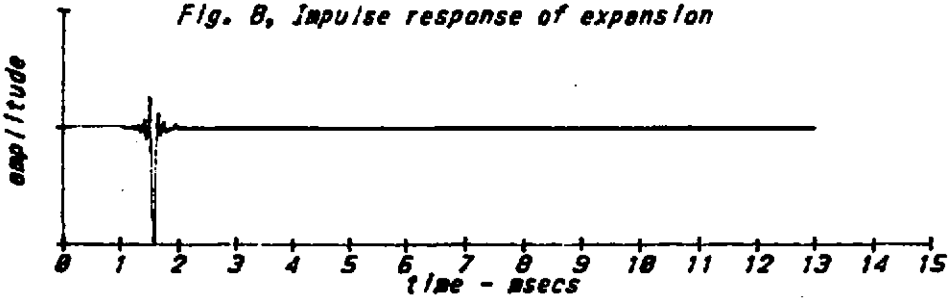


Fig. 8, Impulse response of expansion

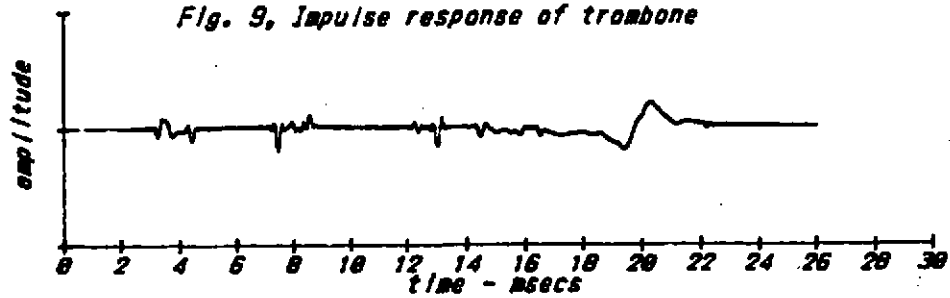


Fig. 9, Impulse response of trombone

Fig. 10, Bore-reconstruction of constriction

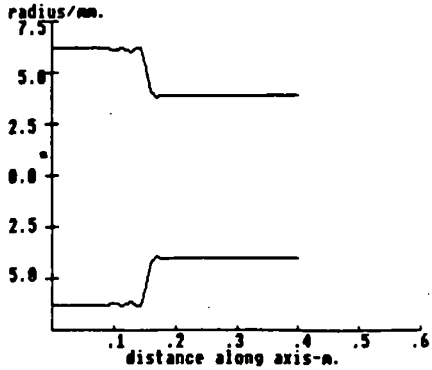


Fig. 11, Bore-reconstruction of expansion

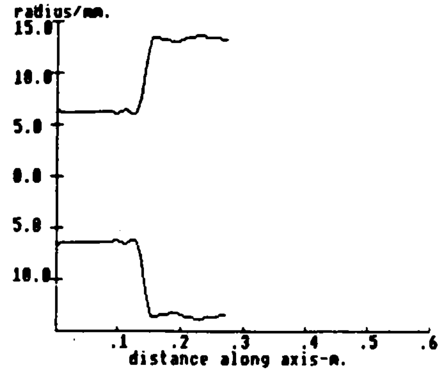


Fig. 12, Bore-reconstruction of a trombone

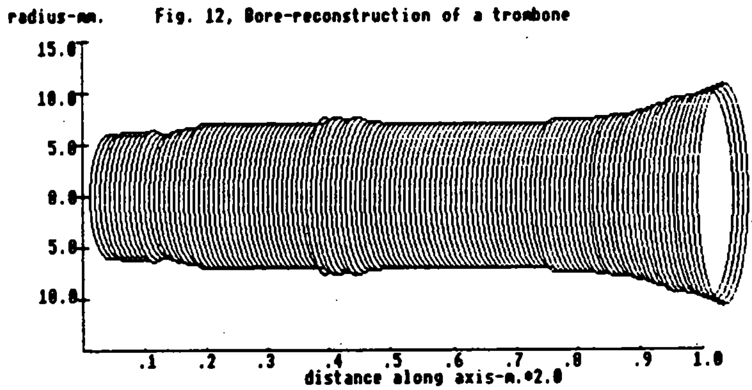


Fig. 13, Bore-reconstruction of a trumpet