Note

A System For Real Time Measurement of Acoustic Transfer Functions

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This system, the subject of a provisional patent application, was developed for measuring the acoustic impedance spectra and transfer functions of musical instruments and parts thereof [1]. Although it was initially developed as a research tool, we believe that it will benefit the manufacturers of musical instruments by providing a rapid, objective measurement of relevant acoustic properties during and after the construction of the instrument. These properties may be compared with those of a prototype instrument, or one judged to be good by competent players. Such comparison would be useful in quality control for complete instruments, and might be included in the feedback loop in the construction of parts of an instrument. In these situations, real time performance is desirable.

From the point of view of a musical instrument manufacturer, measuring the acoustic response of an instrument is in several ways preferable to measuring its sound. First, the sound of an instrument is dependent on the player - a good player may compensate for the defects of a poor instrument, and a poor player may produce defective sounds from a good instrument. Second, such measurements may be made without the assistance of a competent and patient player. Third, such measurements may be made on parts of instruments or incomplete instruments.

With the exceptions of reeds and lips in wind instruments, and the bow-string interaction in string instruments, most parts of most wind and string instruments behave linearly to a good approximation, so one would expect that most aspects of the acoustic performance of the instrument could be related to appropriate transfer functions, provided that these are known with sufficient detail and precision (see e.g. [2]). Many violin makers make simple measurements of acoustic properties during shaping of the belly and backs of these instruments. Tapping and listening is one test used by most makers, and suspending the components above loudspeakers driven with variable frequency sine waves is another. One manufacturer of brass instruments (Conn) has been making acoustic impedance measurements since 1945 using a swept frequency method [3]. We believe that such objective measurements would become much more widely used if the measurements could be made very quickly and easily, and in the workshop rather than in the laboratory. If a data file were established for the transfer functions of instruments with desirable qualities, instrument makers would be able to compare the measurements of the instruments or parts under construction with those of desirable instruments.

String instruments. In string instruments, the vibrating string drives the bridge, the bridge drives the belly, and the belly interacts with the rest of the body and the enclosed air to radiate sound. For an intact instrument, important transfer functions are the ratio of radiated sound to force applied at the bridge, and the mechanical impedance at the bridge. For the isolated belly of the instrument, the same functions are also important, though in this case we measure them at the position where the bass foot of the bridge would stand. For string instruments, we apply the input signal with an electro-mechanical transducer. Forces are measured with piezo-electric crystals.

Wind instruments. The input impedance is an important transfer function for a wind instrument. Most of the extrema in the magnitude of this spectrum occur at frequencies which

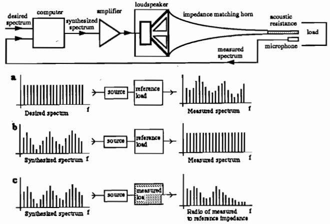

Figure 1 shows schematically the version of the device used for wind instruments, the vocal tract, and acoustic spaces. The frequency dependence of amplifier, horn, microphone etc are measured (a) and used to correct the input spectrum so as to produce a desired output spectrum - in this case flat - into a reference load (b). The same signal is applied to a different load and, providing the source output impedance is much higher than that of the load, the sound spectrum gives the impedance ratio (c). (In the version of the device used for string instruments, a purely mechanical signal is applied by an electro-mechanical driver, usually at the position of the bridge.)

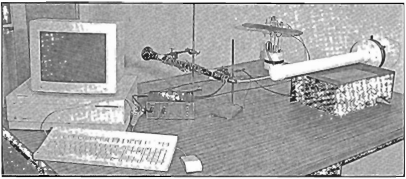

Figure 2. The hardware. At right, the long cylinder is a casing for the exponential horn which is an impedance matching transformer for the acoustic source (see Fig 1). In the background is one version of the electro-mechanical driver which is attached via a quick-release clamp to the belly of a violin.

lie approximately in a harmonic series. When the instrument is played, the reed or the players lips interact with the instrument's bore to produce a quasi-steady oscillation which occurs usually at a frequency which is close to an integral fraction of one or more of these impedance extrema [2,3,4].

Measuring transfer functions and impedance spectra. It is relatively easy to measure sound pressure, mechanical vibrations and forces. For a typical acoustic signal, however, the volume velocity of air is much more difficult to measure accurately. This makes it difficult to measure acoustic impedance directly as the ratio of pressure to volume velocity. This difficulty can however be avoided by supplying the acoustic signal from an ideal current source. When this source is input to two different impedances, the ratio of the measured sound pressure spectra is the ratio of their impedance spectra. A particularly simple case (see Fig 1) occurs when one of the impedances (the reference) is purely resistive and when the measured sound spectrum across the reference is flat. In this case, the measured sound spectrum in the test system is (proportional to) its impedance spectrum.

Broadband measurements. Any measurement of a spectrum takes a finite time and has a finite ratio of signal to noise and therefore yields a finite amount of information. A compromise must therefore be made among time of measurement, sensitivity, frequency range and frequency resolution. In our technique, the frequency range and frequency resolution are chosen first. A finite set of discrete frequencies is chosen and the input signal is synthesized digitally as the sum of a set of sine waves and output via a DAC and an amplifier. Usually several hundred frequencies over the range important to the instrument are chosen.

Correcting for frequency response of the signal source.

When a signal with a given, desired spectrum is synthesized, the frequency responses of the amplifier and the driving apparatus cause a different spectrum to be output. The measurement transducers also have non-flat frequency response. We correct for these responses iteratively. In one application, the reference load is resistive. We measure the output spectrum when the source drives this load and calculate the ratio of measured to input amplitude for all spectral components. We then divide the components of the input spectrum by this ratio, re-scale, and synthesize a corrected spectrum (see Fig 1). Because of non-linear response in some components, this procedure (b) needs to be repeated a few times.

Performance of the device.

The limit to fidelity of the spectrum is the digitization error of the ADC. Other performance parameters are determined by the compromise made among time of measurement, sensitivity, frequency range and frequency resolution. We are currently using the device to study flutes. Sampling the range 200 Hz to 4 kHz at 25 Hz intervals, a measurement time of 0.1 s, and using a 12 bit DAC, the sensitivity is rather better than 1 dB. This is adequate to detect quite subtle changes in the response function of the instrument [1].

Future developments.

We are continuing development of the versions of the device for wind and string instruments, and applying them as research tools to understand the acoustics of musical instruments. Application of the technique to the production of improved musical instruments will require the commercial manufacture of the device, and for this purpose we are seeking a corporate collaborator from the acoustic or electronic instrument industry who is interested in licensing the technique for production.

REFERENCES

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