ACOUSTIC IMPEDANCE MEASUREMENT METHODS

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Abstract. Acoustic impedance measurements pose a fundamental measurement problem because, of the of the two primary variables -- acoustic pressure and particle/volume velocity -- only pressure can be measured reliably and accurately in the plane wave regime. Conversely, particle/volume velocity cannot generally be measured at any arbitrary point. Investigators have thus been forced to devise indirect means for measuring acoustic impedances and other characteristics. The most commonly used method is the standing wave tube method [ASTM C384-58, 1972]. But its limitations have forced investigators to search for alternate experimental methods; some of these use digital instrumentation. This paper is a critical review and comparative assessment of these measurement methods.

Acoustic systems and materials can be characterized by acoustic impedance Z(f), which is defined as Z(f) = p(f)/Q(f); p is the acoustic pressure, Q is the acoustic volume velocity, and f is the frequency. A tilde over a symbol indicates that it is a complex quantity and has both magnitude and phase. Other inherent acoustic characteristics such as absorption and reflection coefficients, transmission loss, and four-pole coefficients are related to acoustic impedance [15, 24, 27, 32]. One advantage of using the impedance approach is that excitation sources and loads/terminations can also be described with impedances.

Acoustical theory is somewhat similar to the subjects of electrical transmission lines and structural vibrations. But, unlike these disciplines, acoustics poses a unique and fundamental measurement problem: out of the two primary variables p and Q, only p can be measured reliably and accurately in the plane wave regime. Conversely, Q generally cannot be measured at any arbitrary point. This problem has forced many investigators over the years to devise indirect means for measuring acoustic impedances and other characteristics.

PREVIOUS LITERATURE REVIEWS

In 1949 Beranek [15] provided an authoratative review of the state of the art of measurement attempts; he recommended the standing wave impedance tube method. Gatley and Cohen [30] in 1969 reviewed the literature critically; they investigated several methods for evaluating small acoustic filters and recommended the standing wave tube method. Singh [66] in 1978 published a brief review of the acoustic impedance measurement literature. No other review or assessment of all available measurement methods has been found in the literature. Of course, techniques applicable to some special applications have been reviewed periodically; e.g., by Dean in 1974 for in-situ wall impedance measurement in flow ducts [46].

STANDING WAVE TUBE METHOD

Perhaps the most commonly used technique is the standing wave impedance tube method [15, 20, 21]. This method was first proposed by Taylor [1] in 1913 and has since been refined. In this method a traversing microphone is used to determine the magnitude and location of successive maxima and minima of standing wave patterns in a tube terminated by an unknown acoustic system. The input impedance, reflection, and absorption coefficients can be calculated from the data obtained. The standing wave method can be extended to transmission loss measurement with an anechoic termination after the muffler/resonator [32, 43].

The standing wave is simple to use but has many shortcomings. Some of these are listed in the table.

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COMPARISON OF METHODS

Over the years many researchers have found the standing wave tube method unsuitable for their applications and have developed other measurement techniques. The table lists and compares these methods. Space limitations prevent a detailed discussion of these methods. However, the following considerations have been taken into account.

- conceptual considerations
- type of measured acoustic characteristics
- physical setup and inclusion of flow and heat
- frequency limitations
- excitation type and sources
- transducers
- signal processing techniques
- ease of measurement, sources of error, reliability, and validation procedures
- applications

Table. Comparison of Acoustic Impedance Measurement Methods

	METHOD	REFERENCE	STRENGTH	WEAKNESS
1	Standing wave tube method (Standard)	15, 20, 21, 30 32, 37, 48, 80	Absolute measurement not required Only one variable (pressure) measured	Limited at lower frequencies Single frequency measurement Time consuming Some measurement reliability problems
2	Modified standing wave tubes	51, 53, 58, 59	Improvements over the standard tube	Adapted toward particular applications
3	"Tone-burst" pulse method	30, 42	Quasi-steady state method	Long tubes required for the separation of waves Single frequency measurement
4	Single pulse method	33	Short measurement time Continuous frequency measurement	Poor dynamic range Tedious instrumentation and data processing
5	Impulse method	66, 67, 76, 78	Short measurement time Continuous frequency measurement Automation possible	Moderate dynamic range Complicated and sophisticated instrumentation and data processing
6	Hot-wire anemometer	26, 61	Direct measurement of both pressure and volume velocity	Hot-wire anemometer calibration problems Unsuitable for general measurement of volume velocity
7	Constant volume velocity method	15, 29, 44, 77	Single measurement (pressure)	Only magnitude is measured Constant excitation difficult to maintain
8	Electroacoustic bridge method	15	Acoustical measurements conducted through analogous electrical measurements	Difficult to construct exact analogs
9	Surface method	10, 14, 15	Volume velocity known	Horn driver dynamics can affect results

Table. (continued)

	METHOD	REFERENCE	STRENGTH	WEAKNESS
10	Shaker-piston method	65, 68, 82	Input volume velocity determined by measuring piston motion Excellent dynamic range obtained	Difficult to adapt to a large acoustic system as only low sound levels can be produced
11	Convertible driver method	68	Only two pressure measurements required Excellent dynamic range obtained	Requires proper calibration procedures Driver loading effects can affect measurements
12	Three pressure method	30, 58, 59	Absolute measurements not required	Phase measurements very critical Curve fitting a problem
13	Two-microphone (front & back locations) method	39, 43, 48	Absolute measurements not required	Phase measurements very critical
14	Two-microphone (adjacent-cross correlation) method	52, 70	Standing waves decomposed into incident and reflected waves using cross-correlation technique	Single frequency measurement Mostly used for magnitude determination
15	Two-microphone (adjacent-cross spectral density) method	60, 69, 74, 75, 79, 80	Determination of cross spectral density of two adjacent pressures yields acoustic intensity Reliable and efficient	Elaborate post-data processing Digital two-channel FFT analyser required Microphone spacing critical at high frequencies Moderate dynamic range
16	Four-pole coefficients measurement method	22, 71-73	Transfer function/building block type measurement; easily combined with theory	Several setups and measurements required Phase measurement critical Exact terminations required
17	Two sources-two microphones method	50	Pressure measurements at only two locations required	Phase measurements very critical Single frequency measurement

DIGITAL INSTRUMENTATION METHODS

The advent of such digital instrumentation as the two-channel FFT analyzer and minicomputer-based data acquisition and data processing systems has made several methods possible [53, 60, 65, 66, 69, 74-76, 78, 79]. Some of the promising techniques are as follows.

- Two-microphone cross-spectral density method [60, 69, 74, 75, 79]
- Shaker-piston method [65, 68, 82]
- Impulse method [66, 67, 76, 78]

The above mentioned methods have the following advantages over such conventional methods as the standing wave impedance tube method.

1. They should measure both magnitude and phase of complex acoustic characteristics.
2. They should provide a continuous frequency measurement over a wide frequency range.

3. Digital methods should be capable of providing a large dynamic range.
4. These methods should allow the measurements to be conducted in the presence of mean fluid flow and heat sources.
5. These methods should be capable of determining source impedances, especially of fluid machines.
6. Automation using a microprocessor/minicomputer should be possible.

CONCLUDING REMARKS

The latest acoustic impedance measurement methods based on digital instrumentation are accurate, efficient, repeatable, and reliable. These methods are thus recommended and should be considered as standard alternatives to the standing wave tube method [20].

Experimental modal analysis techniques in acoustics have not yet been developed even though they are now widely used in structural dynamics. A technique based on a digital method for measuring acoustic impedance that will extract and display acoustic mode shapes is currently being developed [82]. Another area of active research is the acoustic intensity technique, especially intensity measurements in the presence of fluid flow and interferring sound sources [74, 75]. The above mentioned topics will be the focus of further investigations.

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