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NOVEL FLOW RESISTANCE MEASUREMENT DEVICE USING CHOKED MICRO-ORIFICES

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ABSTRACT

A novel flow resistance device that uses choked micro-orifices to induce flow through the sample is presented. It has no moving parts, requires no critical adjustments, and uses any readily available low capacity vacuum source. In this device the metering valve is replaced with a micro-orifice which is aerodynamically choked by the suction produced by the vacuum source. The device can accommodate standard 3 cm and 10 cm diameter samples and has a parallel array of eight micro-orifices which can be individually selected to induce mean flows through the sample to simulate sound pressure levels between 90 and 155 dB. The micro-orifices used at UTRC range in size from 0.089 mm diameter to 2.05 mm diameter. The accuracy of this device has been verified through independent measurements of selected test samples at the K. U. Leuven Laboratories on ASTM standard certified test equipment.

1 - INTRODUCTION

Sound propagation in a lined duct is governed by the complex acoustic impedance of the lined side walls. For dissipative liners at low frequencies the real part of the impedance, the acoustic resistance, is of primary importance to duct designers. Two methods, acoustical and aerodynamic, have been devised to measure the acoustic resistance of porous materials. There are two acoustical methods. The first, rarely used today, uses an impedance tube that is terminated at one end by a sound source and at the other end by a porous sample with a rigid backing. By traversing a microphone probe to measure pressure maxima and minima along the axis of the tube, the complex acoustic impedance of the sample can be determined. At low frequencies long tubes are required in which sound wave damping by the side walls becomes significant making accurate impedance measurements difficult. The second acoustical method, the two-microphone method [1], becomes inaccurate at very low frequencies because of minimal phase difference between the microphones.

In the aerodynamic method, a mean flow is used to simulate the acoustic particle velocity at low frequencies [2]. The pressure drop induced across the sample by the mean flow is measured to determine the flow resistance, θ, of the sample

$$\theta = \frac{\Delta P}{\rho c u} \quad (1)$$

The flow resistance equals the acoustic resistance only when the mean flow, U, equals the rms particle velocity at the sound pressure level to which the liner is to be exposed.

For moderate sound pressure levels extremely low flow speeds are required. The rms particle velocity is 0.49 cm/sec at 100 dB and it increases (decreases) by an order of magnitude for each 20 dB increase (decrease) in the sound pressure level. Sometimes because of the difficulty of producing such low speed flows accurately, flow resistance measurements are taken at higher flow speeds where the flow resistance might be dependent on V^2 and the results are extrapolated back to the linear range. This method is not accurate for perforated plates and non-fully reticulated acoustical foams which induce turbulent flow at low flow speeds.

In the ASTM standard flow resistance measurement device [2], low speed flow is induced through the sample by the positive displacement of water drained from a holding tank through a precision metering valve. Although this device measures flow resistance quite accurately, it is frequently not available in aerodynamic and acoustic test facilities. A much less complicated flow resistance device, which has no moving parts, requires no critical adjustments, and uses any readily available low capacity vacuum source, is described in this paper.

2 - DESCRIPTION OF APPARATUS

In this "choked orifice" flow resistance measurement device the metering valve is replaced with a micro-orifice which is aerodynamically choked by the suction produced by a vacuum pump. The device is shown schematically in Fig. 1. A photograph of the rig is shown in Fig. 2. The device consists of a cylindrical inlet section, a measurement section, that can accommodate standard 3 cm or 10 cm diameter samples, a downstream cylindrical section, and a manifold which is connected to a parallel array of eight micro-orifices. The micro-orifices can be individually selected by toggle valves to induce means flows through the sample that can simulate sound pressure levels between 90 and 155 dB. The static pressure across the specimen is measured with a differential pressure transducer.

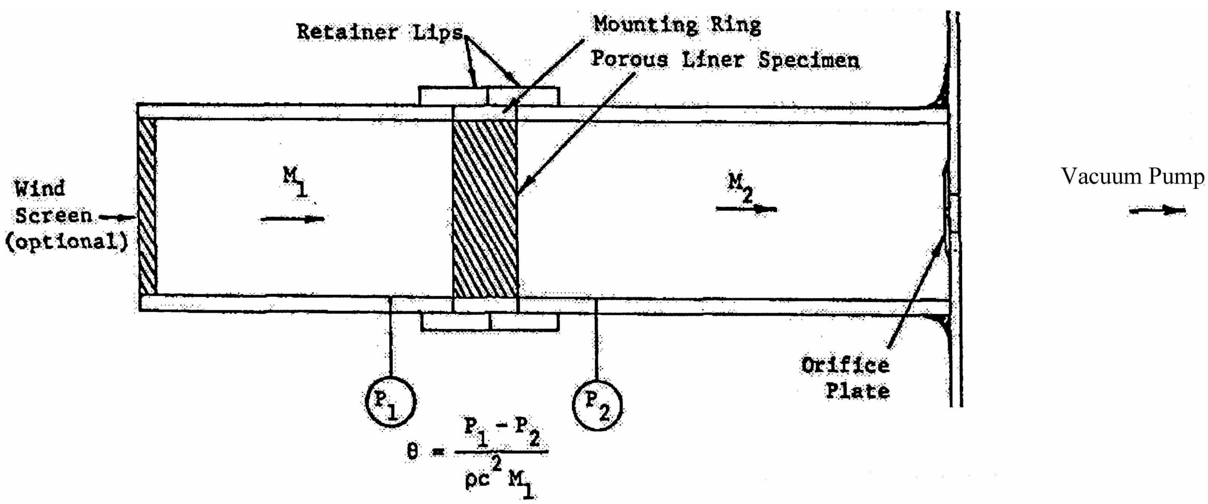

Figure 1: Schematic of choked-orifice flow resistance rig.

The magnitude of the flow induced by the interchangeable sonic orifice is set by the orifice-to-tube area ratio according to the compressible flow relation

$$M_2 \left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}\mathrm{M}_2^2\right)\right]^{\frac{-(\gamma-1)}{2(\gamma-1)}} = \frac{\mathrm{A}^*}{\mathrm{A}_2} \tag{2}$$

Where A_2 is the flow area of the tube and A^* is the effective choking area of the sonic orifice. A^* is related to A_H, the geometric area of the orifice, by the discharge coefficient C_D, which is determined through calibration.

$$A^* = \mathrm{A_H C_D} \tag{3}$$

3 - LIMITATIONS OF APPARATUS

M_2 will differ from M_1, the Mach number at the face of the sample, because of the throttling effect of the resistive sample on the flow. Although the difference $M_2 - M_1$ was expected to be insignificant except for highly resistive liners at high simulated sound pressure levels, an analysis was conducted to determine the change in Mach number through the sample due to the viscous losses in the sample. An equation relating M_1 to M_2 has been derived and is plotted Fig. 3 with θ as a parameter. For simulated pressure levels below 140 dB ($U_1 = 49$ cm/sec) there is no discernible difference between M_1 and M_2. At 150 dB ($U_1 = 156$ cm/sec), M_1 differs from M_2 by less than 4% for $\theta \leq 5$. Above 150 dB the throttling effect of the liner becomes increasingly important as M_2 diverges from M_1 with increasing flow speed.

4 - RESULTS

In an earlier embodiment of this device the author measured the flow resistance of eight samples of acoustical foam and one sample of fiberglass at each simulated dB level [3]. For the fiberglass sample

Figure 2: UTRC choked orifice flow resistance tester.

and the foam samples that were fully reticulated, the flow resistance was independent of the flow speed indicating laminar flow through the sample. These samples were acoustically linear across the dB range tested. However, the measured flow resistance of non-fully reticulated foam samples, had nonlinear flow resistance starting at 115 dB simulated sound pressure level due to turbulent flow that was induced within the sample due to the pore structure. A few sample results from the UTRC tester for typical acoustical liner components are show in Fig. 4. Sample 1A, which is comprised of a fiberglass facing sheet over a 4.5% open perforated plate exhibits non-linear flow resistance above 110 dB. Sample 2A, which is a fully reticulated foam, is linear to 135 dB above which it shows slight non-linearity. Sample 3A, a partially reticulated foam, becomes non-linear above 120 dB. The linearity of the flow resistance of each sample can be obtained in a few minutes simply by toggling the valves in the parallel orifice array. This device has proven to be extremely useful at UTRC for designing and testing linear and non-linear acoustical liners. The accuracy of the UTRC choked-orifice flow resistance tester was verified on additional test samples which were independently tested at both UTRC and at the K. U. Leuven Laboratories on ASTM standard certified test equipment.

REFERENCES

1. *ASTM E10050-1986, Test Method for Impedance and Absorption of Acoustical Material using a Tube, Two Microphones, and d Digital Frequency Analysis System*, 1986

2. *ASTM C522-87, Standard Method of Test for Airflow Resistance of Acoustical Materials*, 1993

3. **W. P. Patrick**, *Sound Transmission through Lined Ducts in Parallel*, 1979

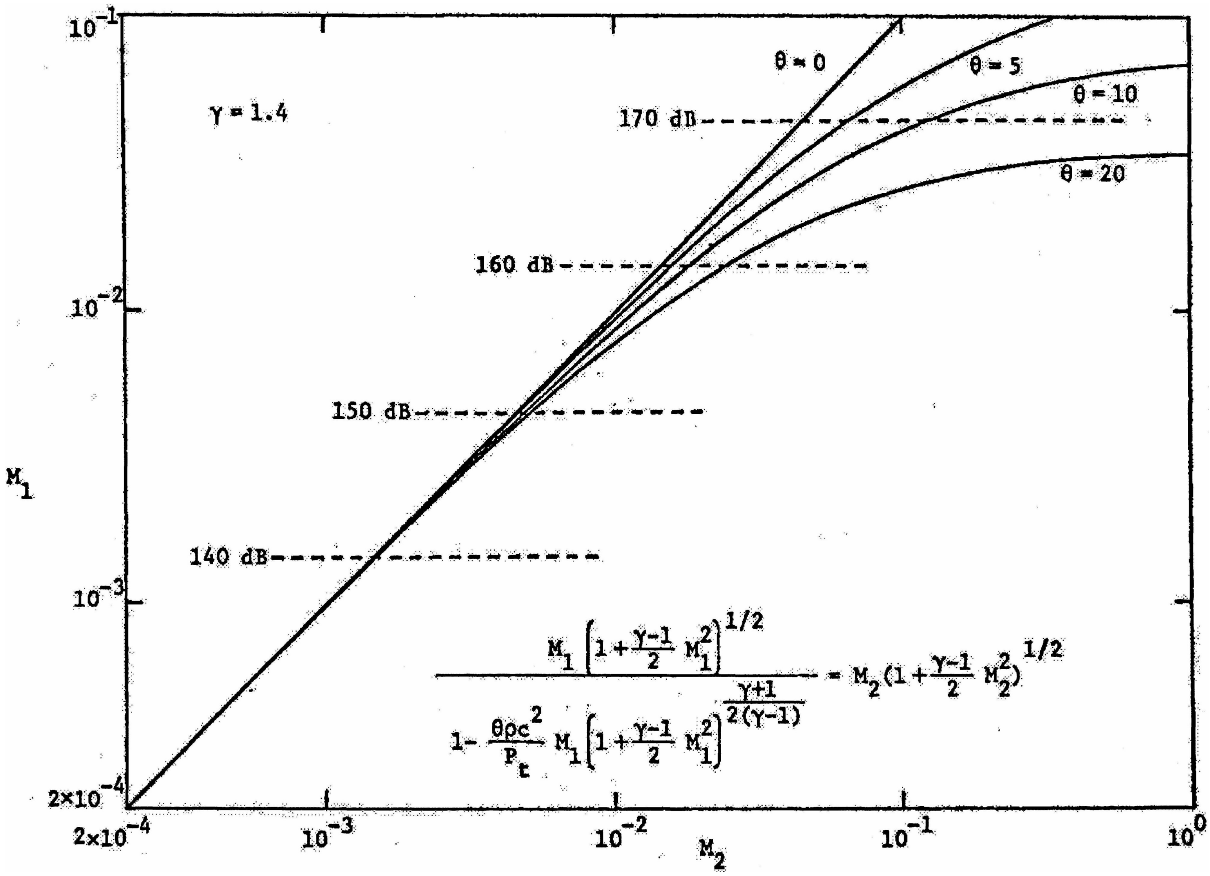

Figure 3: Limits of linear operation of flow resistance tester (i.e. $M_1 = M_2$) due to viscous losses in the test sample.

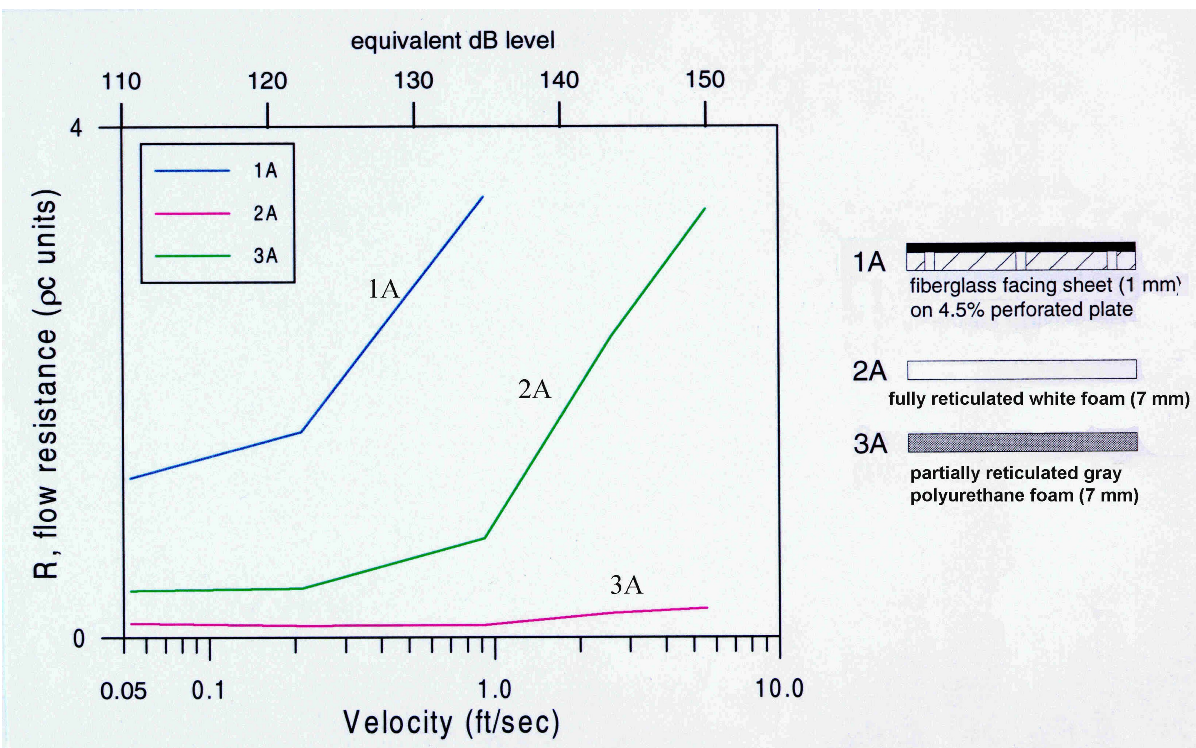

Figure 4: Flow resistance of acoustic liner components.