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MEASUREMENT OF ACOUSTIC PROPERTIES OF POROUS DUCT FOR ENGINE INTAKE SYSTEMS

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ABSTRACT
The porous woven-hose is considered and practiced recently as an effective silencing element of many automotive intake systems. In order to predict the acoustic performance of an intake system with a porous duct, the information on the acoustic wall impedance is required. In this article, a measurement technique that is valid over the low frequency range and in the absence of mean flow is presented. The measurement is performed in a cylindrical chamber with a concentric layout of the sample and the resistance is estimated from measured reactance and transmission loss data. It is observed that the measured transmission loss for a tube with an arbitrary length agrees well with the predicted one that uses the estimated impedance for a small sample length.

1 - INTRODUCTION
Recently, the porous wire-reinforced circular tube of woven fabric comes into use as an effective element of intake systems of many internal combustion engines to reduce the intake noise. In order to predict the acoustic performance of an intake system with a porous woven hose, the information on the acoustic wall impedance is essential. However, the accurate measurement of wall impedance has not been easy because of its peculiar acoustical and structural characteristics that are involved with very high resistance, thickness, curvature, and inhomogeneity. In this study, an impedance measurement technique that is valid over the low frequency range, short length and without mean flow is developed. It is observed that the measured transmission loss for a porous woven hose with an arbitrary, but practical, length agrees reasonably well with the predicted one from using the estimated impedance.

2 - MEASUREMENTS

2.1 - Concentric measurement method
A cylindrical chamber as shown in Fig 1 was used for measuring the acoustic impedance of porous duct [1]. The acoustic impedance can be deduced from the measured transfer function between the microphone pair 1 and 2. At low frequencies below the first cross mode, one can only consider the wave propagation in the radial direction in the chamber. The acoustic pressure should be finite everywhere and the radial velocity at the outer rigid wall must be zero. Therefore, the acoustic pressures in regions I and II can be written as

$$P_I(r) = AJ_0(kr) \tag{1}$$

$$P_{II}(r) = B\left\{J_0(kr) - \frac{J_1(kR)}{Y_1(kR)}Y_0(kr)\right\} \tag{2}$$

where $J_n()$ and $Y_n()$ are Bessel functions of the first and the second kind of order n.

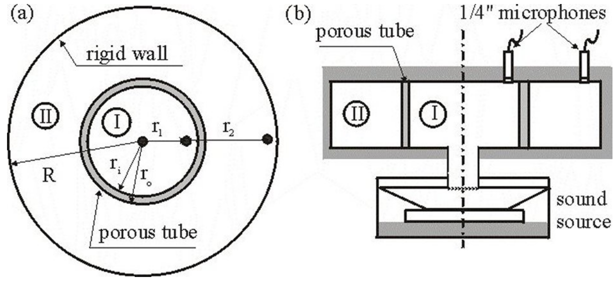


Figure 1: The experimental apparatus for initial impedance measurement: (a) top view, (b) side sectional view (R=50mm, r_i=27.5mm, r_o=30.5mm, r $_1$=20mm, 2: r_2=45mm, height=40mm).

The impedance of a porous duct is defined as

$$\frac{Z_p}{\rho_0 c_0} = \frac{\Delta P}{\rho_0 c_0 u_{avg}} = \frac{P_I(r_i) - P_{II}(r_o)}{\rho_0 c_0 u_{avg}} \tag{3}$$

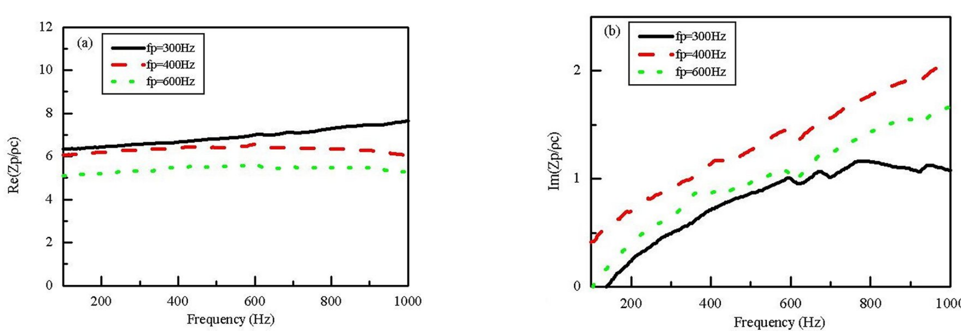
where Δp denotes the acoustic pressure difference across the wall partition and u_{avg} means the averages of the normal particle velocity at the duct wall. By substituting Eqs. (1) and (2) into Eq. (3) and using the continuity of volume velocity at the sample wall, one gets

$$\frac{Z_p}{\rho_0 c_0} = j\frac{2r_i}{r_i + r_o}\frac{(A/B)\,J_0(kr_i)\,Y_1(kR) - \{J_0(kr_o)\,Y_1(kR) - J_1(kR)\,Y_0(kr_o)\}}{J_1(kr_o)\,Y_1(kR) - J_1(kR)\,Y_1(kr_o)} \tag{4}$$

The amplitude ratio A/B can be expressed by the transfer function $H_{21} = P_{II}(r_2)/P_I(r_1)$ as

$$\frac{A}{B} = \frac{1}{H_{21}}\frac{J_0(kr_2)\,Y_1(kR) - J_1(kR)\,Y_0(kr_2)}{J_0(kr_1)\,Y_1(kR)} \tag{5}$$

Finally, substituting Eq. (5) into Eq. (4), one can obtain the acoustic impedance of the sample.
In Fig. 2, the measured impedances of several porous ducts are shown. The porous duct is identified by the so-called 'porous frequency' which is related to the flow resistance through the porous wall. The porous frequencies of test samples were 300, 400, 600 Hz. Fig. 3 displays a comparison of measured and predicted transmission loss (TL) of porous duct at an arbitrary length (L=480mm). The predicted TL was calculated from the measured impedance in Fig. 2. Large discrepancies between measured and predicted results can be observed and it is thought that this is mainly due to the errors in the measured resistance values.



(a): Resistance. **(b):** Reactance.

Figure 2: Acoustic impedance of several porous duct samples measured by using the concentric measurement apparatus in Fig. 1.

2.2 - Estimation of resistance from TL and reactance

Waves in a circular duct are governed by the conservation equations of mass, momentum, and energy. Assuming that the acoustic properties are constant along one azimuthal direction, equations of mass and momentum can be integrated term by term with respect to r from 0 to r_i [2]. Then, one can obtain

$$k = \pm\sqrt{k_0^2 - j\frac{2}{r_i}\frac{k_0}{Z_n/\rho_0 c_0}} \tag{7}$$

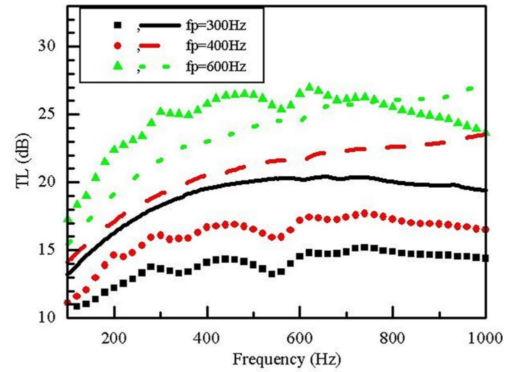


Figure 3: A comparison of predicted and measured TL (L=480mm); the impedance data in Fig. 2 was used in the calculation: symbols, measured; lines, predicted.

$$TL = 20\log_{10}\left[\sqrt{\frac{S_0}{S_L}}\left|\cos(kL) + j\frac{1}{2}\left(\frac{k_0}{k} + \frac{k}{k_0}\right)\sin(kL)\right|\right] \tag{8}$$

where k is the axial complex propagation constant, $k_0 = \omega/c_0$, S_0 and S_L are the areas at z=0 and z=L. One can find that TL can be expressed by the normal impedance Z_n. In these equations, if the reactance is given, then the resistance can be obtained by a direct solution.

If the radiation impedance can be ignored, which is approximately true for short length tubes, the normal impedance (Z_n) is approximately equal to the impedance of porous duct (Z_p) as follows [3]:

$$\frac{Z_n}{\rho_0 c_0} \approx \frac{r_i + r_o}{2r_o}\frac{Z_p}{\rho_0 c_0} \tag{9}$$

In Fig. 4, the resistance was estimated from Eqs. (7-9) that use the measured TL (L=480 mm) and the measured reactance by the concentric method. Fig. 5 shows a comparison of the measured TL with that calculated from the estimated impedance in Fig. 4 which was for L=393mm.

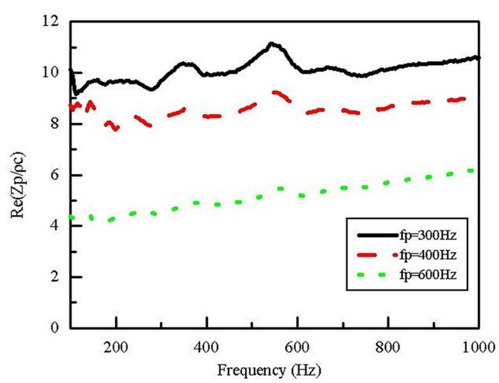


Figure 4: The resistance estimated from the measured TL (L=480mm) and the measured reactance by the concentric method.

3 - CONCLUSIONS

In order to measure the acoustic impedance of woven hoses for the prediction of TL, a concentric measurement apparatus was used and the resistance was estimated from the measured reactance and transmission loss. It is observed that the measured TL of an arbitrary sample length agrees reasonably well with the predicted one. The present measurement technique would be useful in the acoustic analysis of the automotive intake system including a porous woven hose.

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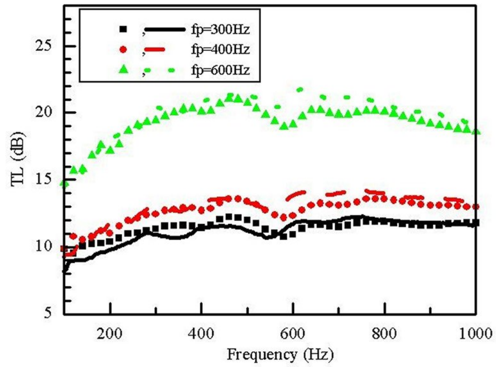

Figure 5: A comparison of predicted and measured TL (L=393mm); the resistance in Fig. 4 and the reactance in Fig. 2b were used in the calculation: symbols, measured; lines, predicted.

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