INSERTION LOSS MEASUREMENT OF SILENCERS BY DOUBLE PAIR MICROPHONE TECHNIQUE

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ABSTRACT The insertion loss is the measured change in power flux at a specified receiver, when the acoustic transmission path between it and the source is modified by the insertion of silencer element. Such measurements have clear and valid physical meaning particularly if the source impedance remains while the transmission path is altered. When the invarient condition is satisfied, the insertion loss is given by the ratio of the acoustic pressure in upstream to that in downstream of the silencer, and that of the particle velocity. The measurement is consisted of using an adaptation of the two microphone method to obtain the complex amplitude of the sound in upstream tube as well as in downstream tube of the silencer. Examples of the data, reduced and presented in terms of the pressure ratio and particle speed ratio, are compared with the theoretical calculations.

1. INTRODUCTION

The design of mufflers has been a topic of great interest for many years, and hence a great deal of understanding has been gained. Among the various descriptions devised for the acoustic performance of the muffler system such as transmission loss, noise reduction, and insertion loss, it is evident that insertion loss is the most practicle and depicts the effectiveness of a muffler system. In the analysis of the acoustical characteristics of mufflers, Davis et al [1] used the one dimensional plane wave acoustic theory based on the concept that the acoustic pressure P and volume velocity U are continuous at change in cross sectional area, while Igarashi [2] introduced the two-port network theory with use of four-pole parameters. Prasad and Crocker [3] developed a prediction scheme for the insertion loss for a multi-cylinder engine exhaust muffler system with measured source impedance.

This paper describes double pair microphone technique for measurements of insertion loss of silencers. A model silencer system comprised a loud speaker acoustic driver and expansion chamber with upstream and downstream pipes. For the theoretical evaluation of the insertion loss, we need to know the overall four-pole parameters, source impedance, and radiation impedance. The source impedance was measured by using the two microphone method [4, 5]. The theoretical radiation impedance for the case of an unflanged open end pipe has been calculated by Levine and Schwinger [6]. The overall four-pole parameter matrix for the model silencer system is obtainded by sequential multiplication of the elemental four-pole matrices for a straight lead pipe, and expansion discontinuity, and for a straight tail pipe. Experimental results are compared well with the theoretical calculations.

2. SYSTEM DESCRIPTIONS AND BASIC EQUATIONS

Following Prasad and Crocker [3], the insertion loss can be determined by considering two system models with and without silencer shown in Figure 1.

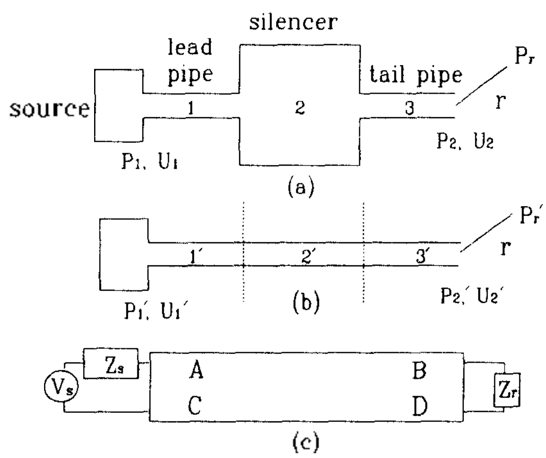


Figure 1. Representation of system models with and without silencer. (a) model with silencer, (b) model without silencer, (c) volume velocity analogous circuit.

The silencer system is composed of three componental parts, i.e., the source, the silencer with lead and tail pipes, and the unflanged open end radiation. The source is characterized by impedance Z_s and volume velocity V_s. The silencer is represented by the overall four-pole parameters A, B, C, D. The acoustic radiation property of the tail pipe exit is characterized by radiation impedance Z_r. The acoustic pressure at the tail pipe exit is given by [3]

$$P_2 = [Z_s Z_r V_s]/[(AZ_r+B)+Z_s(CZ_r+D)], \tag{1}$$

$$P_2' = [Z_s Z_r V_s]/[(A' Z_r+B')+Z_s(C' Z_r+D')]. \tag{2}$$

where primes denote quantities for the case without silencer. If the radiated acoustic pressures with and without silencer in the system, i.e., P_r and P_r', respectively, are measured at a reference point in free space outside the tail pipe, then one can show the equality $|P_2'|/|P_2| = |P_r'|/|P_r|$. Hence the insertion loss can be determined from the measurements of sound pressure made either just inside or at some distance outside the tail pipe [3],

$$IL = 20 \log|P_2'/P_2| = 20 \log|P_r'/P_r| \text{ (dB)}, \tag{3}$$

$$IL = 20 \log \left| \frac{(AZ_r+B)+Z_s(CZ_r+D)}{(A'Z_r+B')+Z_s(C'Z_r+D')} \right| \text{ (dB)}. \tag{4}$$

Equation (3) is for the experimental determination, and equation (4) is for theoretical prediction of insertion loss. On the other hand, the acoustic pressure P can be decomposed into the incident wave P^+ and the reflected wave P^-, and then the volume velocity U (or particle velocity V) can be expressed as

$$P = P^+ + P^- , \quad U = VS = S(P^+ - P^-)/(\rho c), \tag{5}$$

where S, ρ, c are acorss sectional area, density, speed of sound respectively.

The sound pressure P_1 and velocity U_1, at the entrance of lead pipe (as shown in Figure 1), are related to P_2 and U_2 at the exit of tail pipe through the overall four-pole parameter matrix as

$$\begin{vmatrix} P_1 \\ U_1 \end{vmatrix} = \begin{vmatrix} A & B \\ C & D \end{vmatrix} \begin{vmatrix} P_2 \\ U_2 \end{vmatrix}. \tag{6}$$

Using the radiation impedance $Z_r = P_2/U_2$, equation (6) can be written as

$$(AZ_r+B) = Z_r(P_1/P_2) = Z_r(P_1^+ + P_1^-)/(P_2^+ + P_2^-), \tag{7}$$

$$(CZ_r+D) = U_1/U_2 = (S_1/S_2)(P_1^+ - P_1^-)/(P_2^+ - P_2^-). \tag{8}$$

Hence the insertion loss expression equation (4) can be written as

$$\mathrm{IL} = 20 \log \left| \frac{Z_r \left(\dfrac{P_1^{+} + P_1^{-}}{P_2^{+} + P_2^{-}} \right) + Z_s \dfrac{S_1}{S_2} \left(\dfrac{P_1^{+} - P_1^{-}}{P_2^{+} - P_2^{-}} \right)}{Z_r \left(\dfrac{P_1'^{+} + P_1'^{-}}{P_2'^{+} + P_2'^{-}} \right) + Z_s \dfrac{S_1'}{S_2'} \left(\dfrac{P_1'^{+} - P_1'^{-}}{P_2'^{+} - P_2'^{-}} \right)} \right| \ \text{(dB)}. \qquad (9)$$

A computer program was written which evaluates insertion loss from the complex sound pressure profiles measured at the front and tail side of the silencer system.

3. EXPERIMENTAL

Through the response test on phase and sensitivity over a wide range of audio frequency sound signals, four nearly identical microphones, with response error less than 2 percent, are selected from commercial products. These microphones are used to form the double pair microphone system (as shown in Figure 2). Each pair of microphones detect the sound profile in upstream side or in downstream side of the silencer accordingly as indicated in Figure 2. One pair of microphones used for the measurement of the source impedance of the loud speaker.

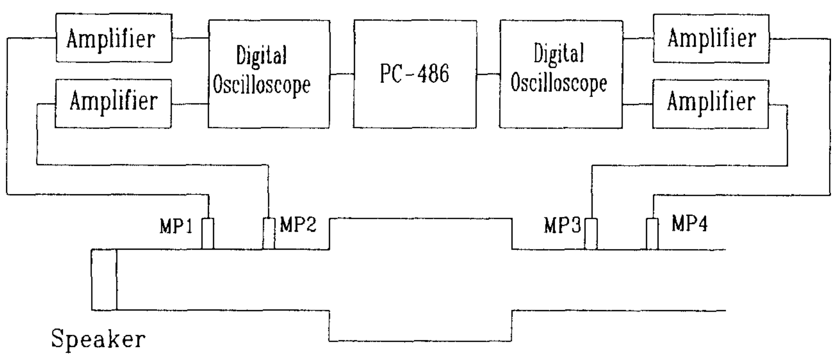


Figure 2. Experimental arrangement.

Two of expansion type model silencers are made of PVC pipe of inside diameter 10.8 cm and of different length 25 cm and 15 cm. PVC pipes of length 25 cm and diameter 5.1 cm are used as lead and tail pipes. Proper length of PVC pipes of diameter 5.1 cm are used as the reference model system without silencer. Sound signals detected by each pair of microphones both in upstream and downstream sides are analyzed in corresponding Fourier's components of P^{+} and P^{-}.

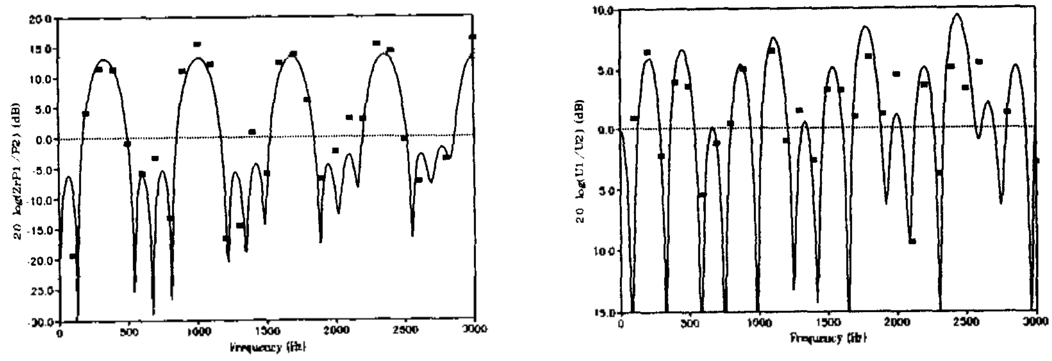
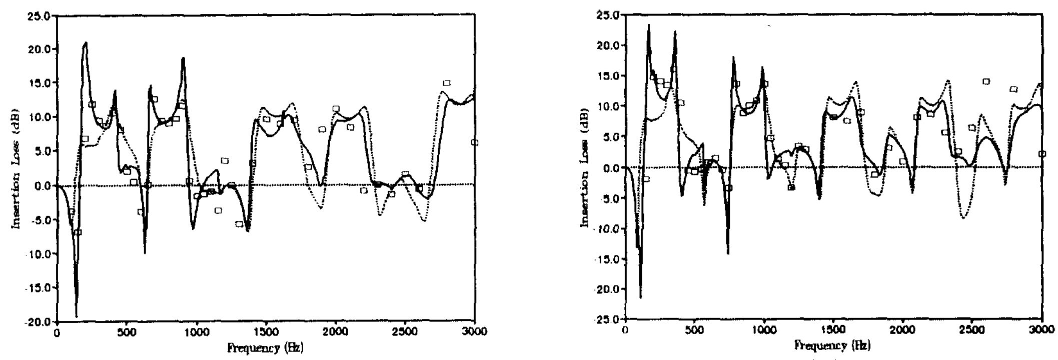
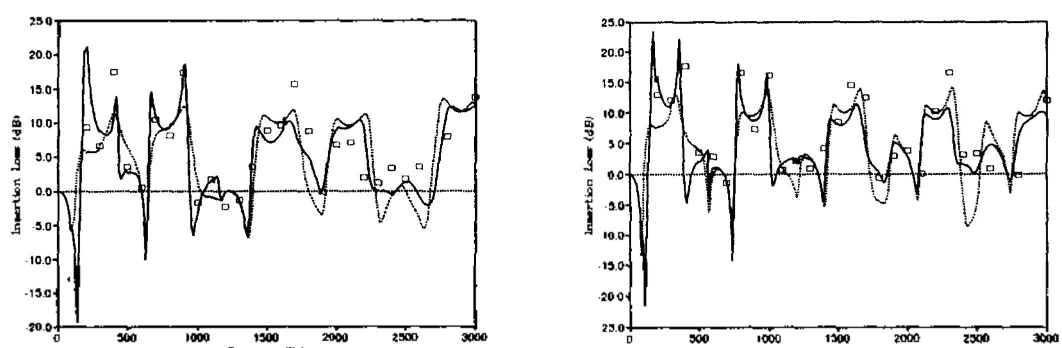


Figure 3. Transmission ratio of pressure (eq. 7) and that of volume velocity (eq. 8) for the silencer of length 25 cm. ■, measurement; ——, theory.



(a) (b)

Figure 4. The insertion loss of model silencers of length (a) 15 cm and (b) 25 cm. □, external measurement with and without silencer; ——, theoretical prediction with source impedance; ·······, theoretical prediction assuming characteristic impedance.



(a) (b)

Figure 5. The insertion loss of model silencers of length (a) 15 cm and (b) 25 cm. □, internal measurement with source impedance; ——, ·······, theoretical prediction in Figure 4.

4. RESULTS

Experimental and theoretical values of transmission ratio of pressure (equation 7) and that of volume velocity (equation 8), for the silencer of length 25 cm, are compared in Figure 3. As seen in Figure 3, experimental values follow the theoretical predictions within the experimental error. In Figure 4 and Figure 5, solid curve is the theoretical prediction with experimental values of source impedance, while the dotted curve represents the theoretical prediction assuming characteristic impedance for the source. In Figure4, the empty squares represent insertion loss determined from the measurements of sound pressure made at a distance of 10 cm outside the tail pipe. In Figure 5, empty squares represent the loss evaluated using double pair microphone measurements and source impedance. As seen in Figure 4 and Figure 5, each experimental results follow the theoretical pattern. Deviation appeared in loss data determined by measurements outside the tail pipe are mainly due to the mon-anechoic environment for measurements. Loss evaluated using the characteric impedance of gas seems resonable, though the loss evaluated using the source impedance gives better agreement with the theoretical predictions.

REFERENCES

1. D. D. Davis, Jr, G. M. Stokes, D. Moore and G. L. Stevens, Jr, "Theoretical and experimental investigation of mufflers with comments on engine exhaust muffler design," NACA 1192 (1954).

2. J. Igarashi and M. Toyama, "Fundamentals of acoustical silencers (I), "Aeronautical Research Institute, Unversity of Tokyo, Report No. 339, 223-241 (1958).

3. M. G. Prasad and M. J. Crocker, "Studies of acoustical performance of a multi-cylinder engine exhaust muffler system," J. Sound Vib. 90(4), 491-508 (1983).

4. A. F. Seybert and D. F. Ross, "Experimental determination of acoustic properties using two microphone random excitation technique," J. Acoust. Soc. Am. 61(5) 1362-1370 (1977).

5. J. Y. Chung and D. A. Blaser, "Tranfer function method of measuring in duct acoustic properties. I. theory," J. Acoust. Soc. Am. 63(3), 907-913 (1980).

6. H. Levin and J. Schwinger, "On the radiation of sound from an unflanged circular pipe," Phys. Rev. 73(4), 383-406 (1948).