

The Effect of Phase Difference between Inputs on Insertion Loss for a Two-Inlet Muffler

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ABSTRACT

A recently developed superposition approach for determining the insertion loss of a two-inlet muffler is reviewed. To validate the approach, calculated and measured insertion losses are compared for a small engine muffler with two inlets and one outlet. After which, the phasing between the two inputs is varied and the insertion loss is evaluated. Results show that the insertion loss is strongly affected by the phasing between sources at low frequencies while phasing between sources has a lesser impact at high frequencies. At the conclusion of the paper, the theory for applying the superposition approach to transmission loss is reviewed.

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INTRODUCTION

The extant literature on mufflers and silencers is primarily dedicated to the single inlet and outlet case [1, 2, 3, 4]. Recently, some efforts have been aimed at two-inlet or even multi-inlet mufflers.

Selamet and Ji [5] investigated the transmission loss of circular expansion chambers for the multiple outlet case using a mode-matching approach. Later, they investigated expansion chambers with two inlets and one outlet using a one-dimensional analytical approach and the boundary element method [6]. Denia et al. [7] extended this work to elliptical mufflers with two outlets. In each of these studies, equations were developed for a specific muffler configuration. The equations developed, though convenient for certain configurations, were not easily extended to the general multiple inlet case and complicated geometries.

Jiang et al. [8] developed an impedance matrix approach to calculate transmission loss for general multi-inlet mufflers. The impedance matrix was determined using the boundary element method. Mimani and Munjal [9] proposed a similar approach by determining the impedance matrix using plane wave analysis. Mimani and Munjal [9] also developed expressions for insertion loss and noise reduction. Hua et al. [10] extended Jiang's impedance matrix approach to calculate insertion loss and then proposed a superposition approach for determining two-inlet muffler insertion and transmission loss. In Ref. [8, 9, 10], it was noted that the transmission and insertion loss depend on the amplitude and phase relationship between the sources. This can be expressed as either a ratio of the complex wave amplitudes of the incident sound pressure waves or as a ratio of sound pressure source strengths.

In the authors' opinion, the superposition approach is more straightforward than the impedance matrix approaches and is more easily extended to multi-inlet mufflers. Accordingly, this paper focuses solely on the superposition approach and its use to determine insertion loss for two-inlet single outlet intake and exhaust systems. To validate the approach, calculated and measured insertion losses are compared for a small engine muffler with two inlets and one outlet. After which, the phasing between the two inputs is varied and the insertion loss is evaluated.

At the conclusion of the paper, the theory is applied to the case of transmission loss. Though probably not as useful for design work, analysts may have some use for it.

REVIEW OF SUPERPOSITION APPROACH TO DETERMINE INSERTION LOSS OF TWO-INLET MUFFLERS

A more detailed description of the theory and the validation of the method can be found in Ref. [10]. The work in the next two sections is a condensation of that paper.

Insertion loss is defined as the difference in outlet sound pressure (or power) with and without the muffler or silencer in place. It is the metric used to assess muffler performance in the field. A two-inlet muffler with two sources and a termination is shown in Figure 1, assuming the two sources have source strengths p_{s1} and p_{s2} , and source impedances z_{s1} and z_{s2} . The insertion loss of the muffler is defined as the difference between SPI_1 and SPI_2 . The source strengths can be defined as

$$\beta = \frac{P_{s2}}{P_{s1}} \quad (1)$$

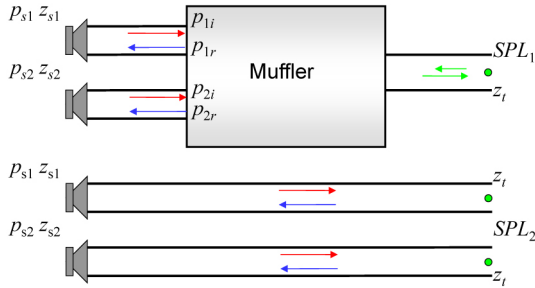


Figure 1. Schematic illustrating the variables for determining the insertion loss for two-inlet and one-outlet muffler.

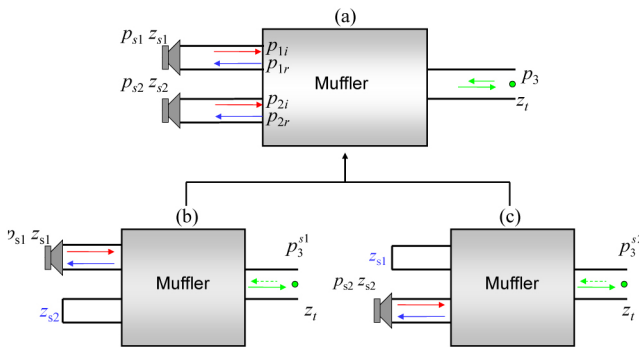


Figure 2. Schematic illustrating superposition approach for determination of the insertion loss of a two-inlet muffler.

The insertion loss can be determined by superimposing the contributions from each inlet or source as shown in Figure 2. The first source contribution can be determined by assuming the second source is passive. Thus, the source pressure of the second source is zero but the source impedance remains as indicated in Figure 2(b). The system can then be considered as a one-inlet one-outlet muffler and the transfer matrix of the reduced system can be deduced using either numerical simulation or plane wave theory. The sound pressure at the termination contributed by the first source can be obtained using

$$P_3^{s1} = \frac{P_{s1} z_t}{A_{13}^p z_t + B_{13}^p + C_{13}^p z_{s1} z_t + D_{13}^p z_{s1}} \quad (2)$$

where A_{13}^p , B_{13}^p , C_{13}^p , and D_{13}^p are the four-pole parameters relating source 1 to the outlet assuming that source 2 is passive. Similarly, the sound pressure at the termination contributed by the second source can be calculated as

$$P_3^{s2} = \frac{P_{s2} z_t}{A_{23}^p z_t + B_{23}^p + C_{23}^p z_{s2} z_t + D_{23}^p z_{s2}} \quad (3)$$

where A_{23}^p , B_{23}^p , C_{23}^p , and D_{23}^p are the four-pole parameters of source 2 to the outlet as shown in Figure 2(c). The total sound pressure at the termination is the summation of these two contributions and can be expressed as

$$P_3 = P_3^{s1} + P_3^{s2} \quad (4)$$

The sound pressure at the termination (p_{d1} and p_{d2}) of each straight duct without muffler installed can be calculated using

$$p_{d1} = \frac{P_{s1} z_t}{A z_t + B + C z_{s1} z_t + D z_{s1}} \quad (5)$$

$$p_{d2} = \frac{P_{s2} z_t}{A z_t + B + C z_{s2} z_t + D z_{s2}} \quad (6)$$

where A , B , C and D are the four-pole parameters of each straight duct. Then, the insertion loss can be calculated using

$$IL = 10 \log_{10} \frac{|p_{d1}|^2 S_1 + |p_{d2}|^2 S_2}{|P_3|^2 S_3} \quad (7)$$

This method can conveniently be expanded to the n -inlet and one-outlet muffler. The total pressure at the outlet can be expressed as

$$P_o = \sum_{n=1}^N P_o^{sn} \quad (8)$$

Where P_o^{sn} denotes the sound pressure contributed by the n th source with other sources turned off. The contribution from each source (P_o^{sn}) can be obtained by

$$P_o^{sn} = \frac{P_{sn} z_t}{A_{no}^p z_t + B_{no}^p + C_{no}^p z_{sn} z_t + D_{no}^p z_{sn}} \quad (9)$$

where z_{sn} is the source impedance of the n th source. A_{no}^p , B_{no}^p , C_{no}^p , and D_{no}^p are the four-pole parameters from the n th source to the outlet with other sources inactive.

EXPERIMENTAL VALIDATION OF SOUND PRESSURE SUPERPOSITION

In order to verify the superposition approach, an experiment was carried out as shown in the photograph in Figure 3. Two impedance tubes were connected to the two inlets of the muffler respectively. The loudspeakers at the entry to both impedance tubes are the sources and random excitation was used for each loudspeaker. First, the source impedance and source strength of each speaker was measured. A two-load wave decomposition method [11] was applied to determine the source impedance and the source strength. The source impedance was measured a second time after reducing the excitation by 24 dB and was unaffected by the difference in source amplitude as shown in Figure 4.