

Tuned Silencer Using Adaptive Variable Volume Resonator

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ABSTRACT

In this study, an adaptive control mechanism is proposed to design a silencer applying variable volume resonator concept. Transfer matrix method is used to calculate the transmission loss and evaluate acoustic performance of the proposed mechanism. Effects of damping factor, area ratio of expansion chambers are examined first for a fixed double chamber resonator. Then a two-dimensional search scheme is developed to find optimal piston position that achieves maximum transmission loss with minimal effort. This study shows that the proposed adaptive silencer can efficiently attenuate noise when comparing with a conventional fixed resonator.

INTRODUCTION

While significant improvement has been made in the area of automotive noise, vibration and

harshness, exhaust noise is still a severe issue, especially for the components of the firing orders of multi-cylinder engines. Conventional passive silencers are typically optimized for a specific or limited range of frequencies. Changes in operating conditions such as firing orders or engine speed will significantly degrade their effectiveness. For this reason, semi-active or active noise control has received a great deal of attention in the past [1-5].

Because of their structural simplicity and functional effectiveness, expansion chambers are widely employed to attenuate duct noise. Embleton have studied several types of reactive silencers [1]. Singh and Soedel applied the transfer matrix method to multi-cylinder air compressor discharge system and achieved great success [2]. Further, Lamancuse examined the transmission loss as well as insertion loss for an unequal sized double expansion chamber using simple wave equation method [3]. In this paper, transfer matrix method is employed for parametric study because more system parameters can be taken into account and

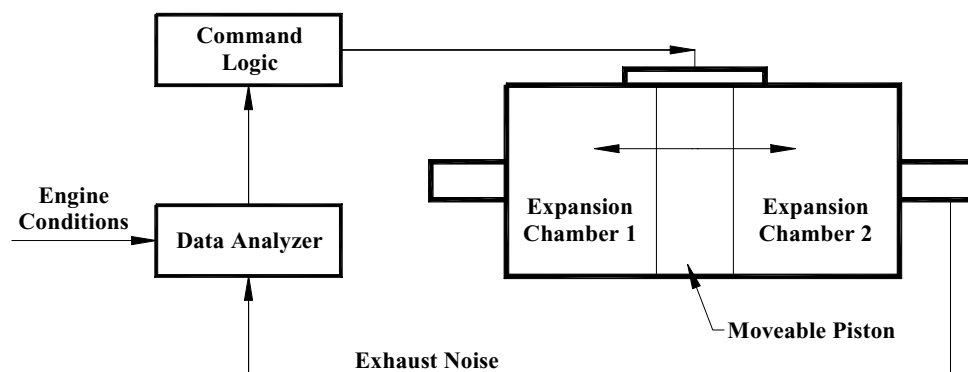


Figure 1 Schematic of an Adaptively Controlled Silencer.

it is more suited for large dimensional system than wave equation method. The schematic of the control mechanism is illustrated in Figure 1. The noise data is collected downstream of the silencer and the dominant frequency component of the noise is determined by a real time FFT analyzer. Through command logic, the system adaptively adjusts the movable piston position to achieve maximum noise reduction.

ASSUMPTION AND SCOPE

In this study, transmission loss (TL) is used to quantify the silencer's performance. Accordingly, anechoic termination, i.e. no reflection from the termination is assumed. Although reflection free termination is not strictly true for physical systems, TL can still be a good approximation of a silencer's performance. According to reference [1], the mean flow effect is insignificant when Mach number is less than 0.1. In this paper, mean flow effect is neglected. Plane wave with forward and backward traveling in the duct is assumed since the transverse system dimensions are smaller than one wavelength over the frequency range of interest (0~2500 Hz), i.e. $c/f > r_2$ and r_4 . Readers may refer the following section for prototype parameters. Abrupt discontinuity at all cross sections is assumed and thus no sound diffraction is considered.

TRANSFER MATRIX METHOD

The transfer matrix for simple expansion chamber can be described by equation (1), in which $\tilde{\gamma}$ is the propagation constant defined by $\tilde{\gamma}_q = \beta + j\omega/c$ and β is the damping factor.

$$\tilde{\Delta}_q = \begin{bmatrix} \tilde{\Delta}_{q11} & \tilde{\Delta}_{q12} \\ \tilde{\Delta}_{q21} & \tilde{\Delta}_{q22} \end{bmatrix} = \begin{bmatrix} \cosh \tilde{\gamma}_q l & \frac{\rho c}{S_q} \sinh \tilde{\gamma}_q l \\ \frac{S_q}{\rho c} \sinh \tilde{\gamma}_q l & \cosh \tilde{\gamma}_q l \end{bmatrix} \quad (1)$$

Here l is the effective length of the acoustic element:

$$l = l_{\text{geometric}} + \sigma \quad (2)$$

The end correction factors σ for unflanged and flanged end are defined as $\sigma = 0.32d$ and $\sigma = 0.425d$ respectively. For the outlet pipe, reflection free condition is applied. The anechoic termination transfer matrix is given by:

$$F_{\text{out}} = \begin{bmatrix} 1 & 0 \\ \frac{S_{\text{out}}}{\rho c} & 1 \end{bmatrix} \quad (3)$$

For the whole system, the governing equation can be written as:

$$\begin{bmatrix} P_{\text{ou}} \\ V_{\text{ou}} \end{bmatrix} = [\underline{\Delta}] \begin{bmatrix} P_{\text{in}} \\ V_{\text{in}} \end{bmatrix} \quad (4)$$

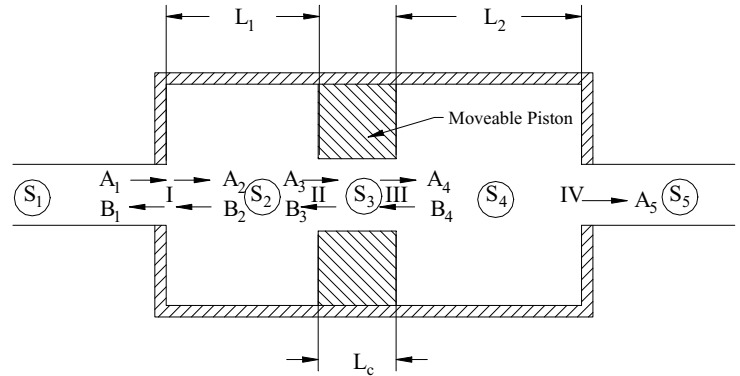


Figure 2 Double Chambers With $m = S_2 / S_1$ and $n = S_4 / S_3$.

Where P_{ou} and P_{in} are pressures at outlet and inlet respectively; V_{ou} and V_{in} are particle velocities at outlet and inlet. $[\underline{\Delta}]$ is the transfer matrix for the whole system and can be given by chain rule as:

$$[\underline{\Delta}] = \underline{\Delta}_1 \underline{\Delta}_2 \cdots F_{\text{out}} \quad (5)$$

The transmission loss of the system can be calculated as:

$$TL = 20 \log_{10} \left[\frac{1}{2} \left(\frac{S_{\text{in}}}{S_{\text{out}}} \right)^2 \left| \underline{\Delta}_{11} + \frac{S_{\text{out}}}{\rho c} \underline{\Delta}_{12} + \frac{\rho c}{S_{\text{in}}} \underline{\Delta}_{21} + \frac{S_{\text{out}}}{S_{\text{in}}} \underline{\Delta}_{22} \right| \right] \quad (6)$$

