Numerical Assessment of Shape Optimization on One-chamber Mufflers with Reverse-flow Ducts Using a GA Method

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ABSTRACT

Shape optimization on mufflers within a limited space is essential for industry where the equipment layout is occasionally tight and the available space for a muffler is limited for maintenance and operation purposes. To proficiently enhance the acoustical performance within a constrained space, the selection of an appropriate acoustical mechanism and optimizer becomes crucial. A one-chamber muffler hybridized with reverse-flow ducts which can visibly increase the acoustical performance is rarely addressed; therefore, the main purpose of this paper is to numerically analyze and maximize the acoustical performance of this muffler within a limited space.

In this paper, the four-pole system matrix for evaluating the acoustic performance — sound transmission loss (STL) — is derived by using a decoupled numerical method. Moreover, a genetic algorithm (GA), a robust scheme used to search for the global optimum by imitating the genetic evolutionary process, has been used during the optimization process. Before dealing with a broadband noise, the STL’s maximization with respect to a one-tone noise is introduced for a reliability check on the GA method. Moreover, the accuracy check of the mathematical model is performed. The optimal result in eliminating broadband noise reveals that the one-chamber muffler with reverse-flow perforated ducts is excellent for noise reduction. Consequently, the approach used for the optimal design of the noise elimination proposed in this study is easy and effective.

Keywords: reverse-flow, decoupled numerical method, space constraints, genetic algorithm.

1. INTRODUCTION

To overcome the low frequency noise emitted from a venting system, a muffler has been continually used [1]. Research on mufflers was started by Davis et al. in 1954 [2]. To increase a muffler’s acoustical performance, the assessment of a new acoustical element — a reverse-flow mechanism with double internal perforated tubes — was proposed and investigated by Munjal et al. in 1987 [3]. On the basis of coupled differential equations, a series of theories and numerical techniques in decoupling the acoustical problems have been proposed [3, 4, 5, 6, 7]. Considering the flowing effect, Munjal [8] and Peat [9] publicized the generalized decoupling and numerical decoupling methods, which overcome the drawbacks seen in the previous studies.

Because of the necessity of operation and maintenance within an enclosed machine room, a space-constrained problem within a noise abatement facility will occur; therefore, there is a growing need to optimize the acoustical performance within a fixed space. Yet, the need to investigate the optimal muffler design under space constraints is rarely tackled. In previous papers, the shape optimizations of simple-expansion mufflers were discussed [10, 11, 12, 13]. To greatly enlarge the acoustical performance within a fixed space, a new acoustical mechanism of one-chamber mufflers hybridized with reverse-flow perforated tubes using the novel scheme of a genetic algorithm (GA) is presented. In this paper, the GA method patterned after the Darwinian notion of natural selection is applied in this work.

2. THEORETICAL BACKGROUND

In this paper, a one-chamber muffler with reverse-flow perforated mufflers was adopted for noise elimination in the air compressor room shown in Figure 1. The outlines of these mufflers are shown in Figure 2. Before the acoustical fields of mufflers are analyzed, the acoustical elements have to be distinguished. As shown in Figure 3, two kinds of muffler components, including two straight ducts and a reverse-flow perforated duct, are identified and symbolized as I and II. In addition, the acoustic pressure $\vec{p}$ and acoustic particle velocity $\vec{u}$ within the muffler are depicted in Figure 4 where the acoustical field is represented by four nodes.

The muffler system is composed of two kinds of acoustical elements. The individual transfer matrix derivations with respect to two kinds of acoustical mechanisms are described as below.

2.1 Transfer Matrix of a Straight Duct

For a one-dimensional wave propagating in a symmetric straight duct shown in Figure 5, the acoustic pressure and particle velocity are

$$p(x,t) = \left( c_1 e^{-j \omega (x-L)} + c_2 e^{-j \omega (x-L)} \right) e^{j \omega t} \quad (1)$$

$$u(x,t) = \left( \frac{c_1}{\rho c_0} e^{-j \omega (x-L)} - \frac{c_2}{\rho c_0} e^{-j \omega (x-L)} \right) e^{j \omega t} \quad (2)$$

Considering boundary conditions of pt 1 (x=0) and pt 2 (x=L), Eqs. (1) and (2) can be rearranged as