A Numerical Assessment of Shape Optimization on Multi-chamber and Plug-Inlet Mufflers Using Simulated Annealing

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Abstract
Research on new techniques of single-chamber mufflers conjugated with extended inlet tubes has been well addressed and developed; however, the research work of multi-chamber mufflers hybridized with perforated plug-inlet tubes which may dramatically increase the acoustical performance is rare. Moreover, the application of high performance mufflers with compact volume becomes a prerequisite for the precious space in modern industry. Therefore, the main purpose of this paper is to not only analyze the sound transmission loss (STL) of a multi-chamber muffler hybridized with perforated plug-inlet tubes but also to optimize the design shape under space-constrained conditions. In this paper, both the numerical decoupling technique and plane wave theory for solving the coupled acoustical problem of perforated plug-inlet tubes are used. The four-pole system matrix in evaluating the acoustic performance is also deduced and optimized by a simulated algorithm (SA). Noise reductions in broadband and pure tones noise are also introduced. To achieve a better optimization in the SA, several parameter values were used. But before the SA operation can be carried out, the accuracy of the mathematical model has to be checked by experimental data. Results reveal that the maximal STL is precisely located at the desired target tone. Moreover, the more chambers the mufflers have the higher acoustical performance they reach. Consequently, the approach used for the optimal shape design of the plug-inlet muffler proposed in this study is indeed easy and quite effective.

Keywords: Multi-chamber Muffler, Numerical Decoupling Technique, Space Constraints, Simulated Annealing

1. Introduction
In dealing with industrial flowing noise which is emitted from a venting system, a reactive muffler is customarily used [1]. As the space-constrained problem is mostly concerned with the necessity of operation and maintenance in practical engineering work, there is a growing need to optimize the acoustical performance under a limited space. To increase the acoustical performance, the assessment of a new acoustical element — an internal perforated tube — was introduced and discussed by Sullivan and Crocker in 1978 [3]. Based on the coupled equations derived by Sullivan and Crocker in 1978 [3], a series of theory and numerical techniques in decoupling the acoustical problems have been proposed [4, 5, 6, 7, 8]. Concerning the flowing effect, Munjal [9] and Peat [10] put forth the generalized decoupling and numerical decoupling methods in 1987 and 1988. However, the application of multi-chamber perforated plug-inlet tube mufflers within a space-constrained situation is rarely tackled.

In previous work, the shape optimization of one-chamber mufflers conjugated with extended tubes has been discussed by Chang et al. [2]. In order to appreciate the space-constrained multi-chamber perforated and plug-inlet tube mufflers used in eliminating industrial venting noise, two kinds of plug-inlet mufflers — a one-chamber and a two-chamber muffler conjugated with extended inlet tubes — are proposed and investigated individually. Additionally, to distinguish the acoustical efficiency of a perforated and plug-inlet duct, the acoustical performance of a multi-chamber muffler hybridized with non-perforated and extended inlet tubes under the same space-constrained condition has also been discussed. By adjusting the muffler’s shape and using the simulated annealing (SA) method, the optimal acoustical performances of mufflers can be achieved. Here, to achieve the optimal shape of mufflers, the SA method, a stochastic relaxation technique oriented by Metropolis et al. [11] and developed by Kirkpatrick et al. [12] that imitates the physical process of annealing metal to reach the minimum energy state, is applied in this work.

2. Mathematical Models
In this paper, two kinds of mufflers hybridized with plug inlet tubes in 1–2 chambers were adopted for the noise elimination in the constrained blower room shown in Figure 1. The outlines of these mufflers selected as the noise-reduction device are shown in Figures 2–3. In addition, the recognitions of acoustical elements with respect to various mufflers are shown in Figures 4–5. As indicated in Figures 4 and 5, three kinds of muffler components, including straight duct, perforated plug-inlet duct, and simple contracted/expansion duct are recognized and symbolized as I, II, and III. In Figure 4, the one-chamber muffler system hybridized with a perforated plug-inlet tube has six acoustical