Multi-objective Optimization of a Multi-chamber Perforated Muffler Using an Approximate Model and Genetic Algorithm

Shuguang Zuo, Kaijun Wei and Xudong Wu

Clean Energy Automotive Engineering Center, School of Automotive Studies, Tongji University, Shanghai 201804, P.R. China

(Received 19 November 2013; accepted 11 December 2014)

Perforated mufflers are widely used in automotive intake and exhaust systems and need to be properly designed. However, multi-objective optimization in practical perforated muffler designs usually involves finite element or boundary element models, which demand a higher computation time for evolutionary algorithms. In this paper, an approximate model for transmission loss (TL) predictions is established by correcting the thickness correction coefficient in the transfer matrix using the data calculated by the finite element model (FEM). The approximate model is computationally cheap and applicable for TL predictions above the plane wave cut-off frequency. A popular evolutionary algorithm, NSGA-, amalgamated with the approximate model, has been adopted to carry out the multi-objective optimization of a multi-chamber perforated muffler. The goals of optimization are to maximize TL at the target frequency range, as well as to minimize the valleys of TL and the size of the muffler. Both transmission loss and insertion loss of the optimized muffler are measured. Numerical and experimental results are in good agreement and show significant improvements of acoustic performance precisely at the target frequency range. Consequently, the combination of the approximate model and the NSGA- algorithm provides a fast, effective, and robust approach to co-axial perforated muffler optimization problems.

NOMENCLATURE

a	Radius of perforated holes (m)
b	Distance between two perforated holes (m)
c	Sound speed (ms^{-1})
d	Inner tube diameter (m)
D	Outer tube diameter (m)
d_h	Diameter of perforated holes (m)
f	Frequency (Hz)
ω	Angular frequency ($\omega = 2\pi f$)
k	Wave number ($k = \omega/c$)
j	Imaginary unit
l	Total length of the chamber (m)
l_c	Length of the perforated segment (m)
l_a	Length of the non-perforated segment near inlet (m)
l_b	Length of the non-perforated segment near outlet (m)
p	Acoustic pressure (Pa)
R_e	Expansion ratio ($R_e = D/d$)
R_l	Perforated length ratio ($R_l = l_c/l$)
t	Thickness of inner tube (m)
t_e	Equivalent acoustic thickness (m)
u	Acoustic particle velocity (ms^{-1})
ρ	Air density ($\mathrm{kg{\cdot}m}^{-1}$)
μ	Dynamic viscosity of air (Pa·s)
ζ_p	Specific acoustic impedance of the perforated tube
A_p	Acoustic admittance of the perforated tube
R_h	Specific resistance of acoustic impedance
α	thickness correction coefficient
η	Porosity of the perforated tube

1. INTRODUCTION

Perforated mufflers have been widely used for reducing noise in automobiles, compressors, venting systems, etc. Various methods have been developed to predict the acoustic performance of perforated mufflers. The transfer matrix method based on the plane wave theory is the earliest and fastest method. Sullivan and Crocker[1] first analysed the acoustic wave propagation in a co-axial perforated muffler and presented the coupled differential equations. Jayaraman and Yam[2] then presented a decoupling solution for Sullivan and Crocker's[1] equations and provided the transfer matrix of co-axial perforated mufflers. Further, Munjal[3] improved the transfer matrix by considering the effects of mean flow, and developed a cascading method using the transfer matrices of basic acoustic elements for relatively simple mufflers. To analyse the complex mufflers with multiply-connected parts, Vijayasree and Munjal[4] developed an integrated transfer matrix method. However, these methods are only appropriate below the plane wave cut-off frequency. Numerical techniques such as finite element methods (FEM) and boundary element methods (BEM) have been proven to be more accurate at higher frequencies. Barbieri, *et al.*[5] applied the Galerkin-FEM to obtain the four-pole parameters to predict the acoustic performance. Kirby[6] developed a fast and accurate hybrid finite element method for modelling automotive dissipative mufflers with perforated ducts and absorbing material. Wu, *et al.*[7] developed a direct mixed-body BEM to derive the four-pole parameters and predict the transmission loss of perforated mufflers. Ji, *et al.*[8] proposed a multi-domain BEM to analyse three-pass perforated duct mufflers.