Shape Optimisation on Constrained Single-Chamber Muffler by Using GA Method and Mathematical Gradient Method

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Shape optimisation to maximise a muffler's performance is essential when the space volume of the muffler is constrained for the necessity of maintenance and operation in practical design work. This paper presents numerical optimal studies on single chamber mufflers. Additionally, two numerical approaches, the genetic algorithm (GA) method and mathematical gradient searches, are applied to muffler design work. In this paper, the exterior penalty function method (EPFM), interior penalty function method (IPFM), and feasible direction method (FDM) all belong to mathematical optimal searches. The four-pole transfer matrix was used in evaluating the sound transmission loss (STL) in conjunction with the numerical techniques. Furthermore, a numerical case of noise elimination of pure tone noise was studied. Before optimisation, a simple example was tested and compared with the experimental data in order to check the accuracy of the mathematical model. Results reveal that multiple local optimal solutions exist with respect to the GA and gradient methods. The optimal values of STL in the GA and the gradient method are found to be the same. Consequently, we investigated GA parameters and optimal muffler shapes that produced various pure tones. From an economics point of view, GA is indeed a good tool that provides a quick and effective approach in optimising the shape of single-chamber mufflers.

Nomenclature

ACC	− accuracy desired in EPFM, IPFM, and FDM
bit_n	− bit length
c_0	− sound speed (m/s)
D	− diameter (m)
$elite$	− selection of elite (1 for yes and 0 for no)
$F(\bar{X})$	− unmodified objective function
f	− cyclic frequency
f_c	− cut-off frequency
gen_no	− maximum number of generation
$g_i(\bar{X})$	− the i-th inequality constraints
j	− imaginary unit ($\sqrt{-1}$)
k	− wave number (w/c_0)
L_i	− length of the i-th segment of straight duct (m)
M_i	− mean flow Mach number at the i-th segment of straight duct
pc	− crossover ratio
P_i	− pressure; acoustic pressure at i (Pa)
pm	− mutation ratio
$popuSize$	− number of population
Q	− volume flow rate of venting gas (m³/s)
r_p	− penalty parameter in EPFM
r_p'	− penalty parameter in IPFM
$rt1$	− GA's design parameter (L_1/L_2)
S_i	− section area at i (m²)
STL	− sound transmission loss (dB)
TT	− initial step size in EPFM, IPFM, and FDM
T_{max}	− maximum step size in EPFM, IPFM, and FDM
U_i	− acoustic particle velocity at i (m/s)
ww	− push-off factor in FDM
$\bar{X}$	− initial starting point in EPFM, IPFM, and FDM
Y	− characteristic impedance
ρ_0	− air density (kg/m³)
Φ	− modified objective function

1. INTRODUCTION

As was studied by the Occupational Safety and Health Act (OSHA) in 1970,[1] the high noise levels are harmful to workers, in both psychologically and physiologically. Therefore, attention has been focussed more and more on noise control of equipment. According to America Petroleum Institute (API),[2] a reactive silencer is suitable for a noise source whose sound energy is especially strong at either low frequency or in a limited frequency band. While most electric machines produce this type of noise,[3] muffler systems are normally used in gas venting systems.

The shape of a muffler is often limited by the necessity of operation and maintenance for engineering work. However, discussion of optimal design under space constraints is rarely emphasised. Bernhard has studied the shape optimisation of simple expansion mufflers by using design sensitivity matrices.[4] The space volume of the reactive silencer is still non-constrained, and the calculation of design sensitivity matrices is difficult especially for complicated mufflers.

To solve for the optimal design of a constrained single-chamber muffler, two kinds of numerical assessments are introduced. One of them is classical gradient searching[5-7] by using the derivatives in STL, including the 1) the exterior penalty function (EPFM), 2) the interior penalty function method (IPFM), and 3) the feasible direction method (FDM). The other is the use of genetic algorithms,[8] these have been applied successfully in many fields of optimal problems.

In this paper, the above numerical techniques are coupled with the transfer matrix method[9,10] to optimise the value of STL by adjusting the shape of a single-chamber muffler whose space volume is constrained.