Muffler Optimization

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14-05-2015

Introduction

- Maximization of muffler performance is important, but there is always space volume constraints
- Shape optimization of multi-segments Muffler coupled with the GA searching technique

Outline

- Problem Statement
- Derivation of Four Pole Matrices and an expression for STL
- Introduction to GA and it's Implementation
- A numerical case of noise elimination on pure tone
- Results and Discussion

Problem Statement

- The available space for muffler is 0.3 m (Length) ,0.3 m (Width) and 1 m (Height)
- To reduce the pure tone noise effectively, four kinds of multi-segments mufflers (2–5 segments) are proposed

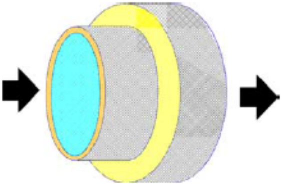

Figure 1: Three-dimensional cross-section for two-segments muffler

Multi-segment Mufflers

- Four kinds of multi-segments mufflers are graphically depicted

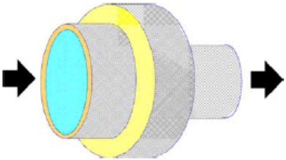

Figure 2: Three-dimensional cross-section for three-segments muffler

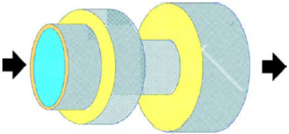

Figure 3: Three-dimensional cross-section for Four-segments muffler

Space Constraints

- The related boundary constraints for the mufflers are specified.

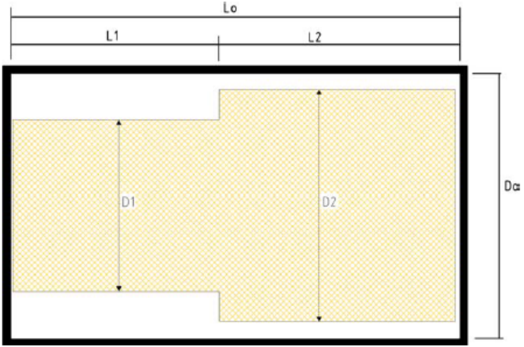

Figure 4: Space constraints for two-segments muffler [$L_0 = 0.3m$, $D_0 = 0.3m$]

Derivation of Four Pole Matrices and an expression for STL

- For the ease of theoretical derivation on muffler, two kinds of muffler elements, are identified,
- On the basis of plane wave theorem, a transfer matrix between inlet and outlet can then be deduced in each muffler element

$$\begin{pmatrix} p_1 \\ \rho_0 c_0 u_1 \end{pmatrix} = \exp\left\{-\mathrm{j}\frac{M_1 kL}{1-M_1^2}\right\} \begin{bmatrix} \cos\left(\frac{kL_1}{1-M_1^2}\right) & \mathrm{j}\sin\left(\frac{kL_1}{1-M_1^2}\right) \\ \mathrm{j}\sin\left(\frac{kL_1}{1-M_1^2}\right) & \cos\left(\frac{kL_1}{1-M_1^2}\right) \end{bmatrix} \begin{pmatrix} p_2 \\ \rho_0 c_0 u_2 \end{pmatrix}$$

$$= \exp\left\{-\mathrm{j}\frac{M_1 kL}{1-M_1^2}\right\} \begin{bmatrix} b_{11}^* & b_{12}^* \\ b_{21}^* & b_{22}^* \end{bmatrix} \begin{pmatrix} p_2 \\ \rho_0 c_0 u_2 \end{pmatrix},$$

where

$$b_{11}^* = \cos\left(\frac{kL_1}{1-M_1^2}\right); \quad b_{12}^* = \mathrm{j}\sin\left(\frac{kL_1}{1-M_1^2}\right);$$

$$b_{21}^* = \mathrm{j}\sin\left(\frac{kL_1}{1-M_1^2}\right); \quad b_{22}^* = \cos\left(\frac{kL_1}{1-M_1^2}\right).$$

Figure 5: Four poles matrix between point 1 and point 2 with mean flow

Derivation of Four Pole Matrices....2

Four poles matrix between point 2 and point 3 with mean flow is:

$$\begin{pmatrix} p_2 \\ \rho_0 c_0 u_2 \end{pmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & \frac{S_2}{S_1} \end{bmatrix} \begin{pmatrix} p_3 \\ \rho_0 c_0 u_3 \end{pmatrix}.$$

Figure 6: Four poles matrix between point 2 and point 3 with mean flow

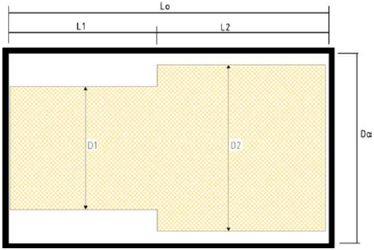

Figure 7: Space constraints for two-segments muffler

After multiplying all the above matrices, we will obtain the final transfer matrix

$$\begin{bmatrix} p_1 \\ \rho_0 c_0 u_1 \end{bmatrix} = \begin{bmatrix} T_{11}^* & T_{12}^* \\ T_{21}^* & T_{22}^* \end{bmatrix} \times \begin{bmatrix} p_4 \\ \rho_0 c_0 u_4 \end{bmatrix}$$

The sound transmission loss (STL) of muffler is defined as

$$\mathrm{STL} = 20 \log \left(\frac{|T_{11}^* + T_{12}^* + T_{21}^* + T_{22}^*|}{2} \right) + 10 \log \left(\frac{S_1}{S_{10}} \right).$$

Figure 8: Final expression for STL

Genetic Algorithm

- Search algorithms based on the mechanics of natural selection and natural genetics
- Based on "survival of fittest" concept
- Simulates the process of evolution
- KEY IDEA: "Evolution is an optimizing process"

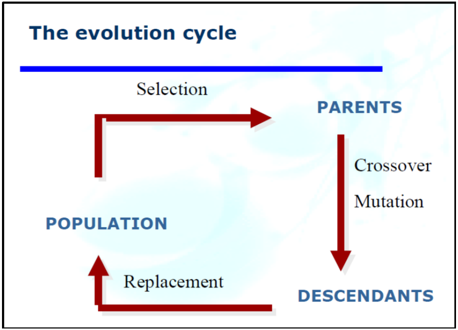

Figure 9: The Evolution cycle

Genetic Algorithm : Initialization

- Population, whose individuals represent solution to problems
- (d_1,d_2)=(5.4064,3.8005) is a member in our population!
- A member/Design vector (d_1,d_2)=(5.4064,3.8005) may be represented using binary numbers like this

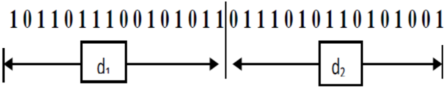

Figure 10: Design vector coded to string structure

Genetic Algorithm : Ranking the Genomes

- Each individual/ String is evaluated to find the fitness value
- Roulette Wheel Selection is implemented

Point	*Fitness*
1	25.0
2	5.0
3	40.0
4	10.0
5	20.0

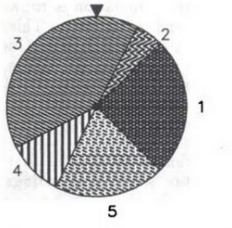

Figure 11: A roulette wheel marked for five individuals according to their fitness [Figure Courtesy: Optimization for Engineering Design: Algorithms and Examples, Kalyanmoy Deb]

Genetic Algorithm : Reproduction Operators

Single Point Crossover

- Each chromosome of parent is divided into two parts and then joined stochastically

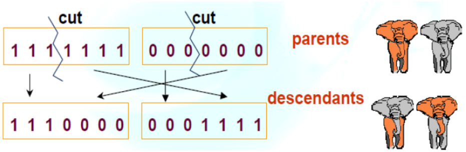

Figure 12: Single point Crossover

Mutation

- To make sure that sufficient variety of strings are there to assure that GA will go through the entire problem space
- Prevents premature convergence

Genetic Algorithm : Reproduction Operators...2

Elitism

- The elitism scheme to keep best gene in the parent generations
- To prevent the best gene from the disappearing and improve the accuracy of optimization during reproduction

A numerical case of noise elimination

- With the spectrum analysis in sound, it is found that the sound energy at 500 Hz is highly remarkable.
- The minimal diameters at each segment are specified to be no less than 0.0762 m
- The design volume flow rate is confined to 0.8 CMS.
- For optimization of a Two segments muffler, 3 parameters were selected
  - Diameter, D_1
  - Diameter, D_2
  - Length, L_1

- The maximal value of STL is 38.5 dB

Table 1
Results comparison for two-segments muffler

	Common parameters			Control parameters			Results				Elapsed time, t (min)
	PopuSize	Gen_no	Bit_no	pc	pm	Elt_no	D_1 (m)	D_2 (m)	L_1(m)	STL	
Case 1	60	500	40	0.8	0.05	1	0.3000	0.0762	0.1424	38.5	0.70
Case 2	60	500	40	0.8	0.05	0	0.2982	0.0764	0.8395	38.4	0.69
Case 3	60	500	40	0.8	0	1	0.2478	0.0801	0.1500	35.5	0.70
Case 4	60	500	40	0	0.05	1	0.2992	0.0790	0.1566	37.5	0.65

Figure 13: Tabulation of finally obtained results

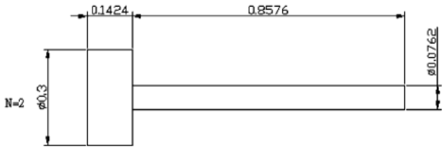

Figure 14: Optimal shape in a two segment muffler

Results and Discussion...2

- The performance curves for different GA control parameter are plotted.

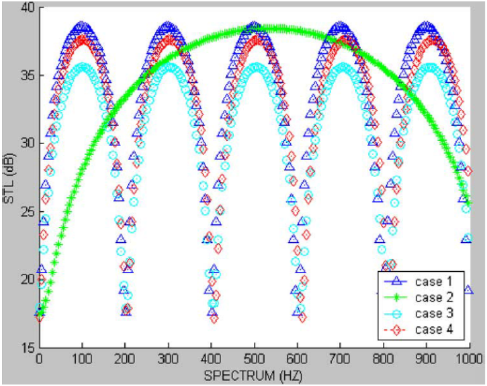

Figure 15: STL of two-segments muffler at four sets of GA parameters.

Conclusion

- Because of no first derivative and starting design data of objective function as required in traditional gradient method, GA becomes easier.
- The case study reveals that by increasing the segments in muffler, the performance in STL can be improved efficiently.
- Results are sensitive to the GA control parameters like, probability of crossover p_c and probability of mutation p_m

Thanks