Research on Structure Size of Muffler to the Influence of Acoustic Properties

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Abstract. The dimention for muffler has great impact on the car engine. Based on software GAMBIT, GT-POWER,SYSNOISE,through comprehensively using finite element and boundary element method,simulating and analyzing the acoustic performance for the basic noise reduction unit,establishing the finite element model, comparing the frequency and noise reduction of different volume ratio of cavity and throat tube.Simulation analysis and experimental results show that the resonant structure parameters have a direct effect on its resonant frequency and noise reduction amount. the relationship characteristic between them is that the ratio more bigger,the requency and noise reduction amount more bigger , too.And draw the two relation formulas through calculation.

Introduction

In many cases,engine intake noise ,which influencing the main noise source inside and outside the car[1],decides the total noise level of engine, The muffler performance evaluation mainly adopts three indexes,namely,acoustic performance, aerodynamic performance and the structure performance [2].

To measure the stand or fall of acoustic performance for muffler mainly consists of two aspects,the silencing amount of size and silencing frequency range , the desired silencing frequency range required has a high enough silencing quantity.

Air intake noise spectrum for internal combustion engine is the main characteristics of low frequency. Resistance muffler not olny does, but also can work under the conditions of high temperature, high speed, pulsating flow.Using the grid division software GAMBIT, another software SYSNOISE as tools of the muffler transmission loss calculation and analysis, guiding the optimization design of the silencer.

Solution for Helmholtz Muffler Finite Element Model

Mathematical Model Inner Muffler Cavity

As Fig. 1, The inlet end and outlet end of the muffler for *S1*, *S2*.

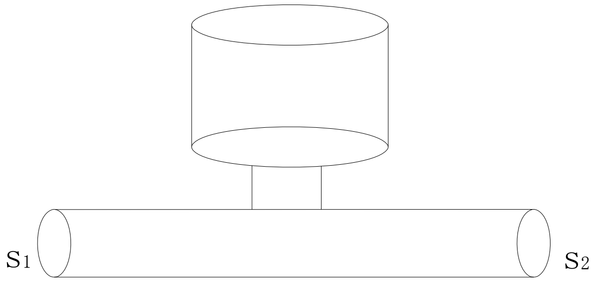


Fig. 1 Helmholtz resonant muffler structure

Especialy, *S1, S2* is much smaller than the size of the muffler cavity. According to the acoustics principle, Helmholtz resonant muffler cavity[1] acoustic equation refers with: Eq. 1.

$$\frac{\partial^2 p}{\partial t^2} = c^2\left(\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2}\right) \quad (1)$$

Applied boundary conditions for:

(1) the inlet boundary conditions: applied unit speed incentive at entrance.

(2) the outlet boundary conditions: applied full acoustic conditions at export, namely,the absorption coefficient α = 1.

(3) wall boundary conditions: a wall for rigid, i.e. not considering wall absorption, and the absorption coefficient $\alpha = 0$.

(4) damping boundary conditions: applied damping boundary conditions for the perforated pipe.

Calculation scheme research

In order to reveal the law of resonator structure shape on the influence to the muffler resonance frequency, compare different structure silencing the quantity change, according to the conventional engine air intake system structure, determine the inlet pipe (main tube) diameter and connection tube (throat tube) size,using four terminal parameter method for three dimensional acoustic analysis.

Relevant parameters of the three aspects should be considered.

(1) According to the car air intake system arrangement [3], the main tube diameter analysis range will be determined between 0.03 ~ 0.10 *m*, the calculation length within 0.30 *m*.

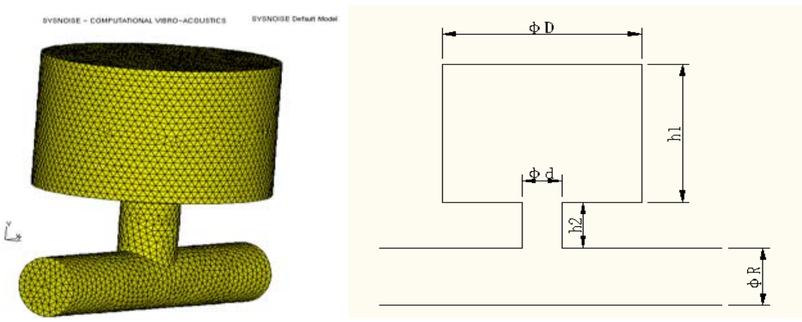
(2) Inside the existing engine space, intake silencer installation space narrow, for the study of all kinds of cavities, by changing the dimention of cavity, throat pipe and the size of the main tube, analyzing the resonator silencing frequency and noise elimination quantity.

(3) the model is ***CA20*** type gasoline engine, take the single muffler frequency less than 2 000 *hz*.

Single Cylindrical Helmholtz Resonator Acoustic Performance Study

Figure 2 for a three-dimensional grid map of single cylindrical Helmholtz resonator cavity.Among them, the main tube diameter for *R*, cavity of the bottom diameter for *D*, height for *h1*, the cavity and inlet pipe connection throat length is *h2*, throat diameter is *d,* throat and cavity for coaxial cylinder.

The muffler transmission loss only with the body structure, is the most commonly used in the study of the muffler performance [4]. Under the plane wave conditions of import and export of muffler, the transmission loss expression for Eq.2 [5,6,7].



(1) Three-dimensional grid pattern for cavity (2) Two dimensional diagram

Fig. 2 2 d/3 d diagram for single Helmholtz resonator cavity

$$20\lg\left|\frac{P_1+\rho cv}{2P_2}\right| = TL = 10\lg\frac{W_i}{W_t} = 20\lg\left|\frac{P_i}{P_t}\right| \quad (2)$$

Where,P_1, P_2 for the entrance pressure and transmission pressure, ρ for air density, *c* for the speed of sound.

During the calculation, selecting $D = 0.1668\ m$,$h1= 0.1460\ m$, $h2 = 0.0630\ m$, $d = 0.0404\ m$, $R =$

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0.0512 *m*, resonant cavity velocity for 343.0 *m/s*.

Acoustic Performance Analysis for the Volume Ratio of Cavity and Throat Pipe

Table 1 lists the volume ratio for cavity and tube,but the length and diameter of main tube is changeless.

Table 1 Data for volume ratio unit: [m]

Number	D	d	h_1	h_2	R	V_1/V_2
N14	0.12	0.03	0.05	0.16	0.10	5:1
N15	0.15	0.05	0.111	0.10	0.10	10:1
N16	0.18	0.06	0.133	0.08	0.10	15:1
N17	0.20	0.08	0.16	0.05	0.10	20:1
N18	0.09	0.06	0.03	0.135	0.10	1:2
N19	0.10	0.05	0.04	0.160	0.10	1:1

Through the acoustic finite element analysis , as shown in Fig.3.

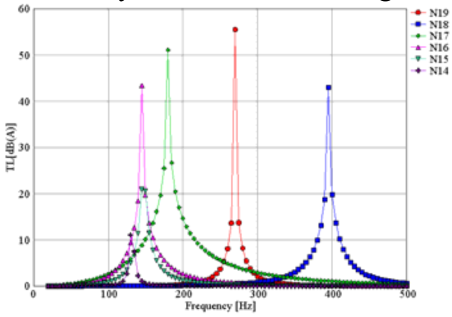

Fig.3 Relationship for noise reduction amount and resonant frequency among different volume ratio with the resonant cavity and throat tube

Fig.3 can be found,from N14 to N17,their volume increases gradually, and then,the largest amount of noise elimination and its corresponding resonance frequency increases,either.when the volume ratio for 1:1, the noise elimination quantity is the biggest of all, while silencing frequency under the low frequency range.

For the further research the relationship among the volume ratio and the resonance frequency and the amount of noise elimination, establishing Table2, the relationship diagram as Fig.4and Fig.5.

Table 2 Relationship for volume rate with frequency and noise reduction

Number	*V1/V2*	*f(Hz)*	Noise *Q(dB)*
N14	5:1	130	11.0897
N15	10:1	145	20.8999
N16	15:1	145	43.4252
N17	20:1	180	51.1036

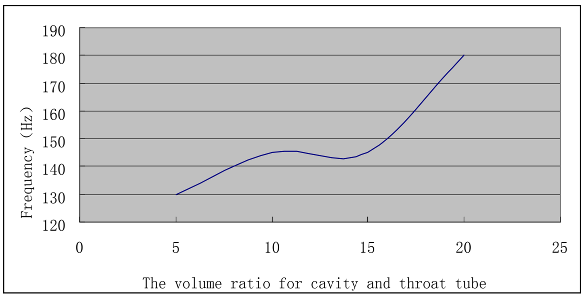

Fig.4 Relationship for volume rate with frequency

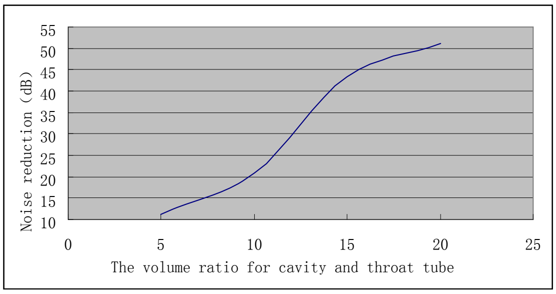

Fig.5 Relationship for volume rate with noise reduction

The relationship for Cavity and pipe volume ratio with the resonance frequency ,shown as regression analysis index function Eq.3.

$$y = 0.2x^2 - 2x + 137.5(R^2 = 0.9074) \qquad (3)$$

Where, R =0.953. Expressed as ordinary equation form as shown Eq.4.

$$y = ax^2 + bx + c \qquad (4)$$

Where, a , b ,the regression coefficient, c for constant.

In the same way,the relationship for volume ratio and silence amount shown as Eq.5.

$$y = 1.657x^{1.1575}(R^2 = 0.975) \qquad (5)$$

The general form, see Eq.6.

$$y = ax^n\varepsilon \qquad (6)$$

Where, a , the regression coefficient, n for power index.

For Eq.6, the variable may be transformation into Eq.7.

$$y' = a' + bx' + \varepsilon', \varepsilon' \sim N(0, \sigma^2) \qquad (7)$$

Where, $a' = \ln a$, $b = n$, $y' = \ln y$, $x' = x$, $\varepsilon' = \ln\varepsilon$. The data may be transformation into the follow table,shown as Table 3.

Table 3 Relationship between independent variable and dependent variable after the transformation

$x' = x$	5:1:	10:1	15:1	20:1
$y' = \ln y$	2.4060	3.0397	3.7710	3.9339

Through calculation, $\hat{a} = 0.3264$, $\hat{b} = 0.2369$.So, $\hat{y}' = 0.3264 + 0.2369x$

At the same time,if $\alpha = 0.05$,the confidence level of y for 0.95.

$$|t| = \frac{\hat{b}}{\hat{\sigma}}\sqrt{S_{xx}} = 0.2369\times\sqrt{750}/\sqrt{(44.7246 - 0.2369\times177.6700)/2} = 7.4460 > t_{0.05/2}(4) = 2.7764$$

The type shows that the formula is right.

Summary

In summary conclusion, the volume ratio for different cavity and throat tube increases, the resonance frequency and noise elimination amount increases,too, the equation presents the relationship respectively the quadratic function and power function, and when the two volumes the same, the noise reduction amount largest.

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