Analysis and Optimization of Aerodynamic Noise in the Rearview Mirror Region

Xiaowei Rao *, Zhaobo Zhuang

Shandong University of Science and Technology, Qingdao 266590, China

College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao, 266590, China.

* Correspondence: 579 Qianwangang Road, Huangdao District, Qingdao, Shandong Province, 266590. Tel: 17806256300.

Abstract

The noise problem of car has risen to a new height as people demand more and more noise in driving car. In this paper, the ANSYS Fluent is used to analyze the aerodynamic characteristics of the back of the rearview mirror, and the Isight (a multidisciplinary collaborative simulation optimization software) is applied to optimize its shape and compare the aerodynamic noise characteristics of the back of the rearview mirror before and after optimization. It can be concluded from the results that the aerodynamic noise characteristics of the optimized rearview mirror model are reduced, which the maximum noise reduction amplitude of the same receiving point at the back of the rearview mirror can be up to 3dB.

Keywords

Rearview mirror; aerodynamic noise; Fluent; Isight.

1. Introduction

With the increase of the automobile driving speed, the aerodynamic noise of the automobile increase gradually, When the automobile speed reach 100km/h, which has a direct impact on the automobile driving performance[1]. As the automobile has a very complex surface profile, which surface each part will produce vortex and noise when the air flow through the automobile surface. As the rearview mirror protrudes from the outside of the automobile, a strong turbulent structure is generated in the wake region of the rearview mirror by the flow around a blunt body.

Wang Yi-Ping et al has used the modeling software to increase the bottom arc transition of the rearview mirror, making it more streamlined, and then the Large Eddy Simulation is used to simulate and analyze the aerodynamic noise characteristics, their results showed that the aerodynamic noise after the modification of the rearview mirror has declined[2].

The researchers have made a more comprehensive study of aerodynamic noise in the rearview mirror region, however, in the study of the influence of different shapes of rearview mirrors on aerodynamic noise, the shape of the rearview mirror is modified all through manually, the amount of time consumed in the establishment of the model and the division of the grid.

2. Analysis process of aerodynamic noise

2.1 Analysis theory of aerodynamic noise

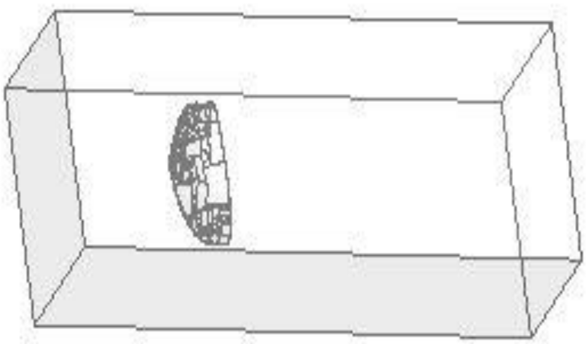
According to the previously mentioned, the main reason for the aerodynamic noise of the automobile is that the rearview mirror protrudes from the outside of the automobile, in the process of automobile running, around the rearview mirror will produce airflow instability and pressure pulsation[3]. Therefore the computational fluid dynamics (CFD) theory[4] is applied to solve the fluctuating pressure around the flow field of the rearview mirror in time domain, the aerodynamic acoustics (CAA) theory[5] is applied to solve the noise spectrum and the sound pressure level around the rearview mirror in the frequency domain. Figure 1 is the three-dimensional geometric model of the rearview mirror

Figure 1. Three-dimensional geometric model of the rearview mirror

2.2 Analysis procedure of aerodynamic noise

2.2.1. Computational domain model selection and mesh generation

Before the fluid analysis is performed, it is necessary to determine the computing domain of the rearview mirror in the flow field, in order to ensure that the airflow in the computing domain is fully developed, the length of the computational domain model, the width of the computational domain model and the height of the computational domain model are 10L * 5L * 5L (L is the length of the rearview mirror), respectively, figure 2 shows the computational domain model. The ICEM is used to mesh the rearview mirror, structure grid and unstructured grid are adopted in the process of mesh generation, that is the core computing domain is divided into non-structural grids by using tetrahedral element; the non-core computing domain is divided into the structure grid by using hexahedron element[6]; the grid model of computing domain is shown in figure 3.



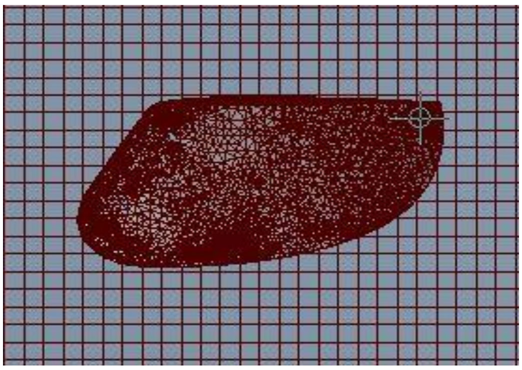


Figure 2. Geometry model of computational domain Figure 3. Grid model of computational domain

2.2.2. The scheme of numerical simulation

The rearview mirror is directly installed in the cuboid computing domain, the Reynolds-Averaged Navier Stokes (RANS) method is used to solve the steady flow field, the LES method is used to solve the transient based on the steady-state flow field, after the transient flow field is calculated, the

Ffowcs-Williams and Hawkings acoustic model is transferred into the simulation, in which the noise source and the receiving point is defined, the noise source is disposed on the surface of the rearview mirror, the position of the receiving point is evenly distributed near the back of the rearview mirror, finally, the noise spectrum and the sound pressure level is obtained by Fast Fourier Transform (FFT).

2.3 Analysis of simulation result

2.3.1. Analysis of outflow field

Figure 4 shows the streamline diagram at the back of rearview mirror, as can be seen from the graph, the streamline produce disorder when it through the back of the rearview mirror, in which the above of the streamline is less disorder, but the below of the streamline is more, so the vortex that is generated in below is larger than the vortex that is generated in above.

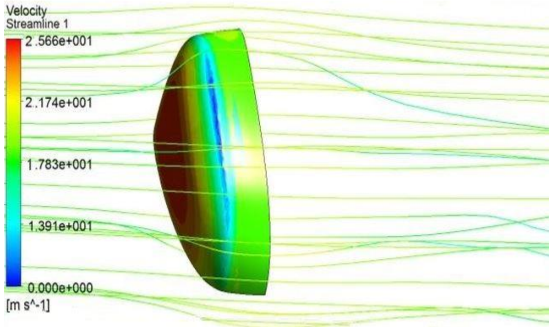


Figure 4. Streamline diagram at the back of rearview mirror

2.3.2. Analysis of aerodynamic noise

Figure 5 shows the noise spectrum curve behind the rearview mirror on the basis of the flow field, the noise spectrum curve of the receiving point near the window side is selected for analysis, which frequency range is 0-50000Hz, as can be seen from the sound pressure spectrum curve, in low frequency region, the sound pressure level is higher and the energy is larger, in high frequency region, the sound pressure level is low and the energy is smaller. Human hearing is the most sensitive to noise of 2000-6400Hz, the result shows that the sound pressure level is larger in this region, therefore the noise around the rearview mirror is mainly concentrated in the low frequency region which can be heard by the human. As can also be seen from the sound pressure spectrum curve, the sound pressure level around the receiving point has periodic fluctuation, and the greater the fluctuation, the greater the noise, so it is important to optimize the shape of the rearview mirror for reducing the noise of the back of rearview mirror.

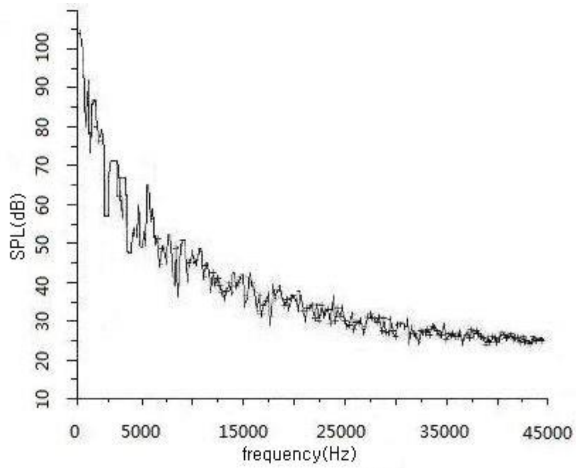


Figure 5. Noise spectrum of receiving point at the back of rearview mirror

3. Optimization method

The multidisciplinary collaborative simulation optimization platform Isight is used to optimize the external shape of the rearview mirror, the objective of optimization is flow field resistance coefficient, which is a single-objective optimization problem, all things considered, the approximate model of Isight ——response surface model (RSM) and optimization Algorithm ——multi-island genetic algorithm (MIGA) is used to optimize the flow field resistance coefficient.

3.1 Response surface model（RSM）

Response surface model is the most widely used model in multidisciplinary optimization, which uses polynomial functions to fit the design space[7], which characteristics are: it can make use of simple algebraic expression to approximate the objective function relation more accurately and make calculation simpler and more convenient; the regression model can be selected to fit the complex response surface model, which has better robustness; the theory is practical and widely applicable.

The relationship between the input variables and the output response of the response surface model method is shown as follows:

$$y(x) = y(x)' + \varepsilon \tag{1}$$

Where $y(x)$ is the actual value of the response, which is unknown function; $y(x)'$ is the approximate value of the response, which is a known polynomial; ε is a random error, which is subject to a standard normal distribution usually.

The expression of the response surface model is shown as follows:

$$y(x)' = f(x) = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} x_i x_j + \cdots \tag{2}$$

Where n is the number of samples, $x_1 \cdots x_n$ is the component of the independent variable x , β_0 、 β_i 、 β_{ij} is the unknown coefficient and is arranged in a certain order to form β ：

$$Min:[y_k - f(x_k)]^2 \tag{3}$$

Where y_k and $f(x_k)$ is the response values and predictive values of the samples, respectively.

3.2 Multi - island genetic algorithm (MIGA)

The multi-island genetic algorithm simulates population migration and genetic inheritance in random global optimization, which is developed on the basis of traditional genetic algorithm, the whole evolution of the population is divided into multiple sub-genetic population and called it the "island", individuals on each island perform traditional genetic manipulations such as selection, crossover, inheritance, and variation independently, and the individuals surviving on different islands are migrated periodically so that the diversity of the population is maintained. Simultaneously, multi-island genetic algorithm can perform global optimization automatically in these populations, which is no fixed optimization path, so it can avoid the disturbance of the local optimal solution effectively.

The multi-island genetic algorithm in Isight can define various optimization variables easily, such as the number of islands, the number of sub-populations, migration rate and mutation rate. In the design optimization, these settings can be defined according to the optimization objectives, and the optimization is carried out on the basis of the established response surface model.

3.3 Optimization technical process of rearview mirror

First of all, the width of the side and the top surface height of the rearview mirror are parameterized by the grid deformation software Sculptor, and the drag coefficient function is obtained by simulation calculation in ANSYS Fluent, secondly, applying the optimized Latin hypercube in Isight to create the experimental sample point and establish the response surface approximation model, at last, the response surface approximation model is optimized by multi-island genetic algorithm.

3.3.1. Parameterized control of the Sculptor

The previously mentioned CFD model of the rearview mirror is imported into the Sculptor, the arbitrary deformation scheme of control body is established, the control variable of the rearview mirror is defined and the deformation scheme is determined, which deformation control body is shown in figure 6, and side and top surfaces are also shown as 1 and 2 in figure6, respectively.

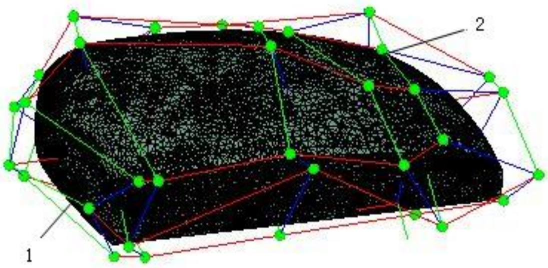


Figure 6. The deformation control body of rearview mirror

3.3.2. Extracting object function and writing files

The parameterized CFD model is calculated in ANSYS Fluent, and the objective function (drag coefficient) is extracted, since Isight integrate each software in a way that reads its call file, it is necessary to write its corresponding integration calling file in Sculptor, ICEM and ANSYS Fluent.

3.4 Design optimization

3.4.1. Description of the optimization problem

Design variable: side width w, top surface height h; constraint condition: -10mm<w<25mm; 0mm<h<30mm; objective function: the smallest of resistance coefficient C_d .

3.4.2. Design of the experiment

Design of the experiment can replace complex simulation calculation, which is an effective design method, considering various experimental design methods, the optimized Latin hypercube is used for sampling and selecting points. The optimized Latin hypercube is developed on the process of randomly selecting sample points using Latin hypercube, which can ensure that the sample points can be distributed uniformly throughout the design space, therefore it has better space filling and balance than Latin hypercube.

The experimental design model is established as shown in figure 7. 60 groups of experiments are selected to calculate randomly, and the corresponding relationship between design variables and target response is obtained by post-processing, the corresponding Pareto diagram is shown in figure 8.

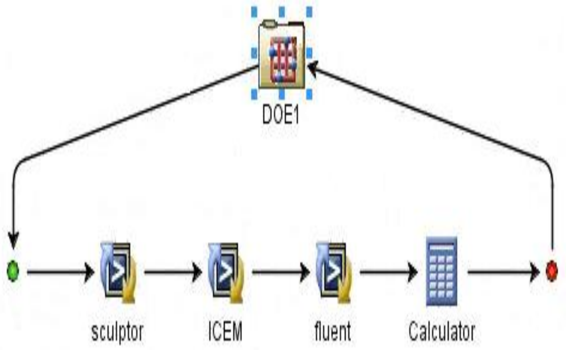


Figure 7. The experimental design model

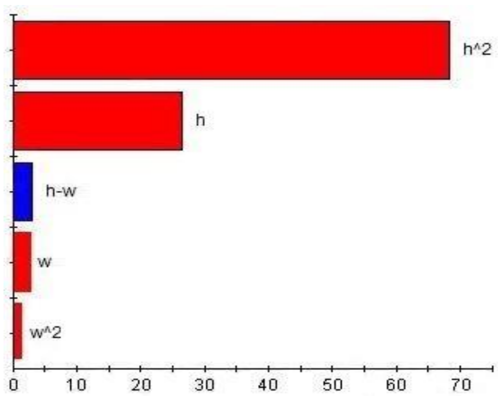


Figure 8. Pareto diagram

As can be seen from the graph, the height of the top surface of the rearview mirror is highly sensitive to the drag coefficient, the width of side also has an impact on the drag coefficient, but the height of the top surface and the width of side are inversely proportional to the drag coefficient.

3.4.3. The establishment of approximate model and optimization

The response surface approximation model is established in Isight as shown in figure 9, the relationship table between the 60 groups of design variables and response values is imported into the response surface approximation model, which is optimized by using MIGA in Isight.

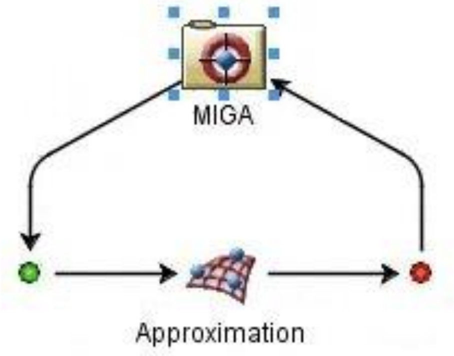


Figure 9. The optimization model

4. Results

Through the fitting of the response surface approximation model and the optimization of the multi-island genetic algorithm, the geometry model of the optimized rearview mirror is derived by Sculptor, which is shown in figure 10, and the aerodynamic noise of the optimized rearview mirror is calculated in ANSYS Fluent, figure 11 shows the comparison diagram of the noise spectrum curve of the receiving point before and after the optimization behind the rearview mirror, as can be seen from the graph, in the frequency range of 2000-6400Hz, the noise pressure level of the noise have decreased, in this range, the maximum reduction amplitude of noise can be up to 3dB.

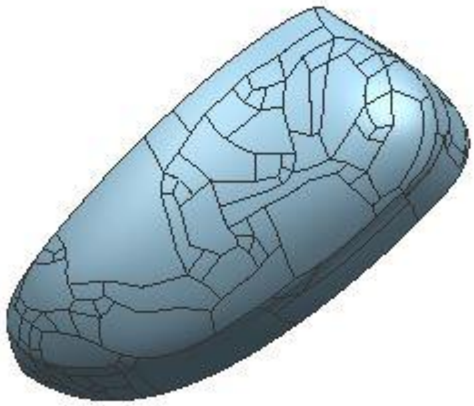


Figure 10. Geometry model of optimized rearview mirror

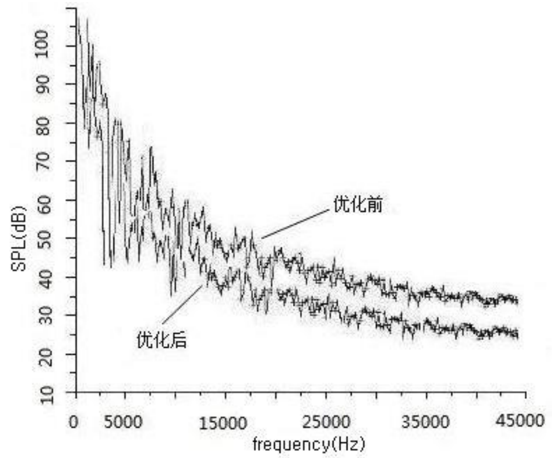


Figure 11. The comparison diagram of the noise spectrum before and after optimization

5. Conclusion

In the present paper, a specific rearview mirror is taken as the object of research, the aerodynamic noise characteristics behind the rearview mirror are analyzed by using Fluent based on the reverse modeling technology, the analysis results can provide a reference for predicting the aerodynamic noise behind the rearview mirror. Due to rearview mirror plays an important role in automobile aerodynamic noise, it is concluded that the optimized aerodynamic noise characteristics in the rear of the rearview mirror have a significantly reduced by optimizing the external shape of the rearview mirror, which maximum noise reduction amplitude of the same receiving point at the back of rearview mirror can be up to 3dB in the range of 2000-6400Hz. During the analysis process, the external shape of the rearview mirror is optimized by an integrated and optimized method, the simulation time is reduced effectively, the cost is saved, and the work is improved.

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