

Diagnostic Analysis and Optimization of the Acceleration Booming Noise Caused by the Intake System

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Date of publication (dd/mm/yyyy): 03/06/2023

Abstract – For fuel vehicles, the intake and exhaust noise are the main noise sources, which has a great impact on the vehicle NVH performance. This paper introduces the troubleshooting process of the acceleration booming noise of a light truck. Through the CAE transmission loss simulation and experimental adjustment of the intake system, the deficiencies of the intake system design are determined. Finally, the booming noise is significantly improved by optimizing the pipeline and designing the helmholtz silencer of the intake system.

Keywords – Vehicle, Intake System, Boom, NVH, Transmission Loss, Helmholtz Silencer.

I. INTRODUCTION

The intake and exhaust system noise of fuel powered vehicles are one of the main contributions to the interior noise, which has a significant impact on the NVH performance [1]. The inlet of intake system in the passenger car is generally at the forefront of the vehicle, far from the interior, so its impact on interior noise is relatively small; For light truck commercial vehicles, the intake system is mostly located near the driver's seat in the cab, very close to the interior, and has a significant impact on the noise inside the vehicle [2]. Therefore, it is necessary to focus on controlling the intake system NVH of light trucks to prevent significant NVH issues such as booming and high-speed airflow noise in the intake system.

The NVH problems that often occur in the intake system of commercial vehicles include booming noise, high-speed airflow noise, and turbocharger noise. Commonly used noise reduction schemes include resonant cavities, insertion tubes, and wavelength tubes. Yan Shi used transmission loss simulation method to optimize the intake system [3]. Yunfeng Xia conducted acoustic modal simulation on the intake system to solve the intake noise [4]. Xin Wang has done a lot of work on optimizing the noise of the intake system turbocharger [5]. In the later stages of automotive development, resonant cavities are mostly used to reduce intake noise. Just like the application in Jingjing Ma's paper [6].

This article focuses on the problem of acceleration booming in a certain light truck. By conducting CAE simulation analysis on the intake system and combining it with actual vehicle troubleshooting analysis and verification, the problem of acceleration booming caused by the intake system has been solved.

II. PROBLEM DESCRIPTION

During the evaluation of a light truck during the manual prototype stage, it was found that there was significant booming noise in the car at around 3000-4200rpm in each gear range. Subjectively and objectively, it was indicated that the booming noise at the intake system was very obvious, as shown in Figure 1. Through testing, it was found that the frequency of the car's interior noise is second-order 100-140Hz and fourth-order 270Hz, while the noise energy radiated by the inlet of intake is very high at 100-140Hz and fourth-order 270Hz, as shown in Figure 2. This indicates

that the intake system has a significant correlation with the car's interior noise in this frequency band and requires detailed diagnostic analysis.

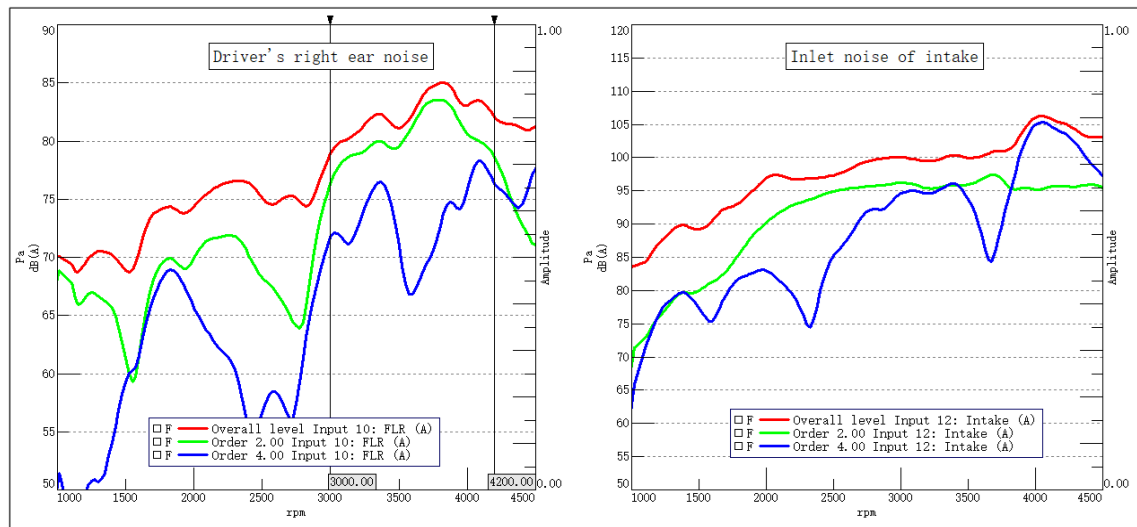


Fig. 1. Noise curve of the interior and air inlet of the gear 3 wot.

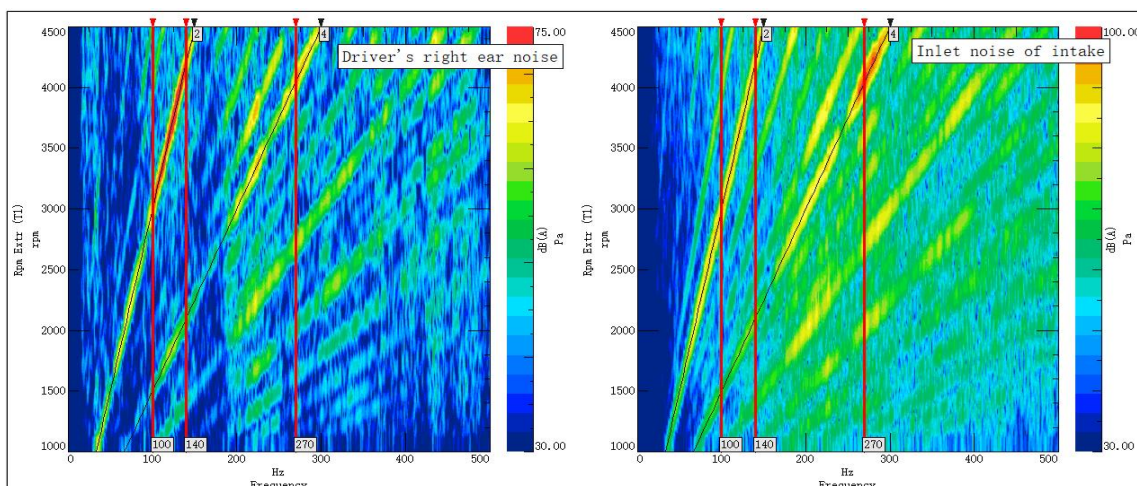


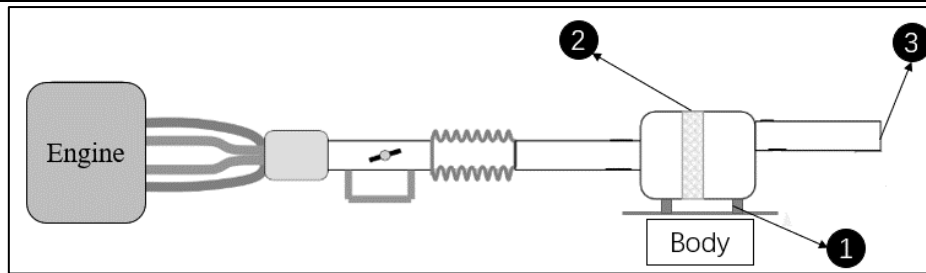
Fig. 2. Color map spectrum of the interior and air inlet of the gear 3 wot.

III. DIAGNOSTIC ANALYSIS

For NVH problems, it is necessary to use the source path response diagnostic approach for problem diagnosis and troubleshooting, identify the main factors that affect the problem, and optimize it to efficiently solve the NVH problem.

A. Analysis of the Contribution of the Intake System

According to the classification of noise transmission paths, the NVH problem of the intake system is divided into structure-borne sound and air-borne sound, as shown in Figure 3. Structure-borne sound refers to the noise generated by the intake system transmitted to the interior of the vehicle through the connection point between the intake system and the vehicle body in the form of structural vibration, as shown in path ① in the following figure 3; Airborne noise refers to the radiation noise of the air filter housing or the radiation noise of the air inlet transmitted to the vehicle through the air as the propagation medium, as shown in paths ② and ③ below.



Noise transmission path of the intake system		
1	structure-borne sound	Transmission of noise through air filter connection to the vehicle body
2	air-borne sound	Radiate noise in the form of airborne sound through the air filter housing
3		Radiate noise in the form of airborne sound through inlet

Fig. 3. Noise transmission path of the intake system.

To determine the main transmission path to the booming noise of the intake system, the contribution of each path is verified by disconnecting or shielding. Test the interior noise of the vehicle in three states: air filter disconnected (path ①), shell wrapped (path ②), and air intake system fully led out (path ③). The specific troubleshooting scheme is shown in Figure 4.

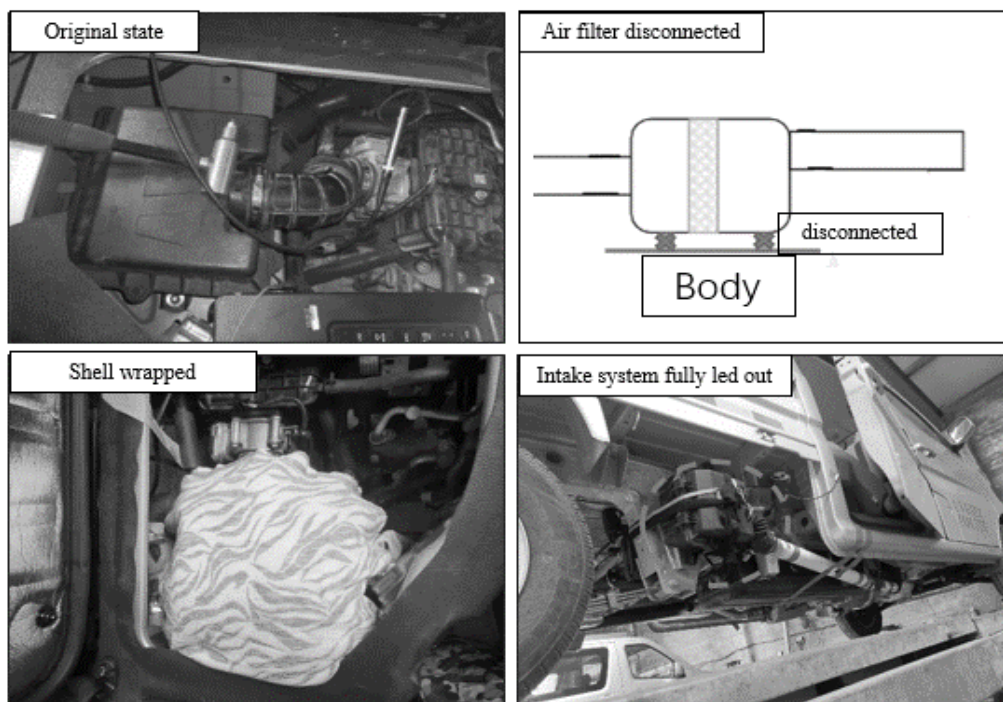


Fig. 4. Investigation scheme for contribution of air inlet system.

The investigation results are shown in Figure 5, and the test results show that only after all the intake air is led out (path ③), the noise inside the car decreases significantly (a decrease of 4-5dB at 3000-4200rpm). Subjectively, the noise inside the car decreases significantly, which is subjectively acceptable. Based on the results of the above verification scheme, it can be determined that the mechanism of the booming noise in the truck at around 3000-4200rpm is that the noise generated by the intake system radiates into the car in the form

of airborne sound through the inlet. The above verification indicates that the intake system equipped with this light truck has poor noise reduction ability, and it is necessary to optimize and improve the noise reduction performance of the intake system.

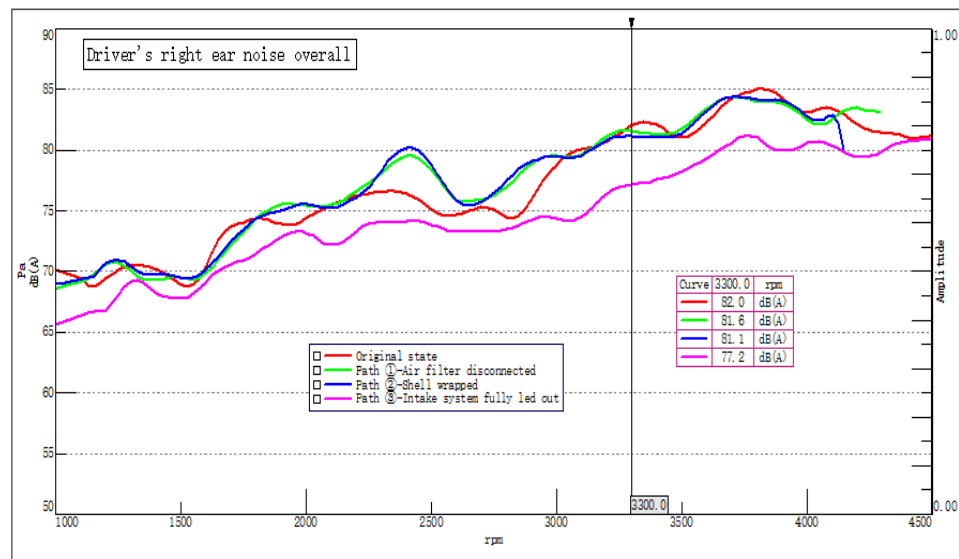


Fig. 5. Investigation scheme for contribution of air intake system.

B. Simulation Analysis of Intake System

One of the main functions of the intake system is to reduce the intake noise generated by the engine during the intake process. There are usually four indicators to evaluate the silencing ability of the intake system: insertion loss, sound pressure level difference, transmission loss, and intake sound pressure level [1]. Among them, transmission loss is the most commonly used method to evaluate the single body silencing performance of the intake system, which represents the attenuation ability of the silencing element to incident sound energy and is the difference between the incident sound power level Lw_i and the transmitted sound power level Lw_t . The transmission loss is represented by TL (Transmission Loss), and the calculation formula is as follows: $TL =$

$$Lw_i - Lw_t = 10 \lg \frac{W_i}{W_t} = 10 \lg \frac{s_i |p_i|^2}{s_o |p_t|^2}$$

In the equation:

-- Lw_i and Lw_t represent the incident sound power level and the transmitted sound power level;

-- W_i and W_t represent incident sound power and projected sound power;

-- s_i and s_o represent the areas of the inlet and outlet ends;

-- p_i and p_t represent incident and transmitted sound pressures [3].

Based on the acoustic theory of transmission loss calculation above, calculate the transmission loss of the intake system and calculate the acoustic cavity mode of the intake system to further determine the shortcomings of the intake system design. Establish an acoustic finite element analysis model based on the numerical simulation of the intake system, as shown in Figure 6. Boundary condition: 1W white noise sound source is applied at the inlet, there is no airflow, and the temperature is 293k; the exit adopts AML non reflective exit boundary, with a calculated bandwidth of 0-2000Hz and a step size of 10Hz.

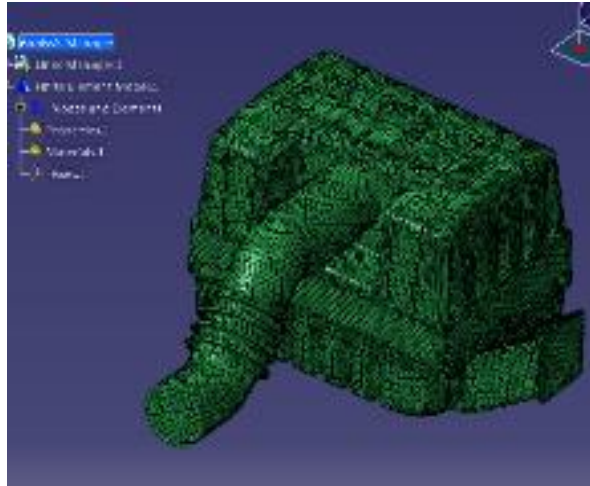


Fig. 6. CAE transmission loss and acoustic cavity modal calculation model of the intake system.

The transmission loss calculation curve and the acoustic cavity modal calculation results of the intake system are shown in Figure 7 and Figure 8: the transmission loss of the intake system at 100-140Hz is about 10dB, which does not meet the target requirement of 15dB; At 270Hz, the intake system has a third order cavity modal, with the inverse node located in the air filter outlet pipe. Through the above CAE simulation analysis of the intake system, it is shown that the intake system has poor noise reduction ability at low frequencies, and there is a cavity modal at 270Hz, which leads to very obvious booming noise during the acceleration process.

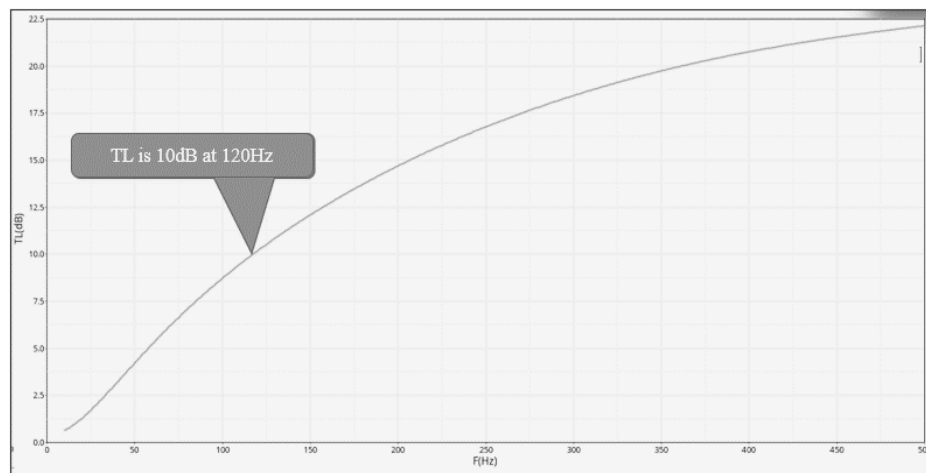


Fig. 7. CAE model and transmission loss calculation results of the intake system.

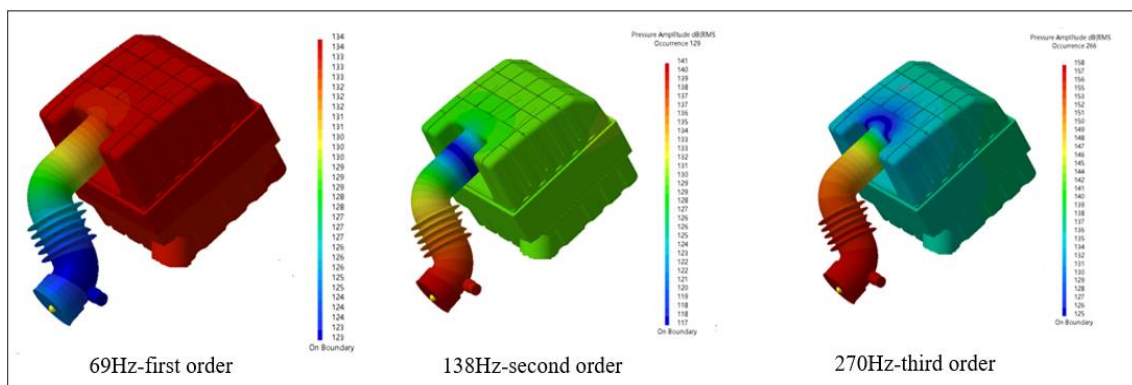


Fig. 8. Acoustic modal calculation results of the intake system.

C. Optimization Scheme for Intake System

In practical engineering applications, passive intake silencers are commonly used to improve the silencing ability of the intake system in response to the problem of insufficient silencing ability of the intake system. Passive mufflers are divided into reactive mufflers and resistive mufflers. Reactive silencers mainly include expansion silencers and side branch silencers, such as resonant cavities and quarter wavelength tubes. The principle of a reactive muffler is that when sound waves pass through the muffler, the acoustic impedance changes, and a portion of the sound energy is reflected back to the sound source, thereby achieving noise reduction [1].

For the low-frequency noise problem of 100-140Hz in this issue, engineering methods mainly include increasing the air filter volume, lengthening the intake pipeline, increasing the expansion ratio of the air filter, and increasing the number of internal tubes. Due to limited engine cabin space and the fact that increasing the expansion ratio of the air filter and increasing the insertion tube can affect other engine performance, this article proposes a solution to the 100-140Hz booming problem by increasing the length of the intake pipe. The design scheme is shown in Figure 9:

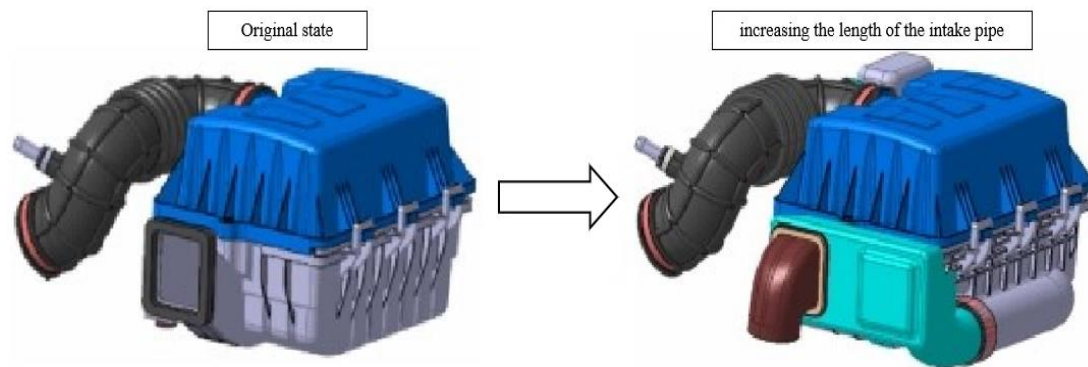


Fig. 9. Schematic diagram of increasing the length of the intake pipeline.

For the 270Hz intake acoustic cavity modal of this problem, it belongs to the medium frequency problem with a narrow frequency band, mainly by adding a resonant cavity to improve the noise reduction ability of the intake system. The resonant cavity needs to be arranged near the anti-node position of the intake sound modal in order to minimize the corresponding frequency noise to the greatest extent [4]. For the intake system of the truck, combined with the actual vehicle layout and the 270Hz acoustic cavity modal of the intake system, the anti-node at the outlet pipe position, the design parameters of the resonant cavity are as follows: the position is arranged at the air filter outlet pipe, the noise reduction frequency is 270Hz, the diameter of the connecting pipe is 3cm, the length of the connecting pipe is 5.1cm, and the volume of the resonant cavity is 0.5L, as shown in Figure 10.

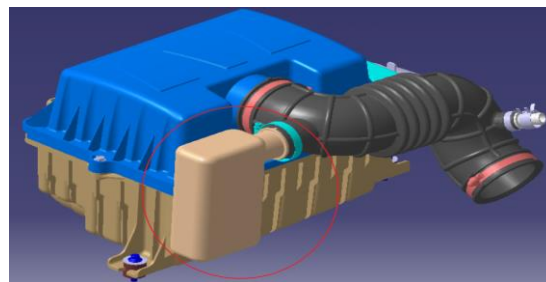


Fig. 10. Schematic diagram of resonant cavity.

Create a quick sample of the simulation optimized solution and validate the effectiveness of the solution using the real vehicle, as shown in Figure 11.



Fig. 11. Physical image of rapid sample solution.

After the implementation of the intake scheme, the overall noise inside the truck has significantly decreased with a maximum optimization of 7.6dB from 3000 to 4200rpm, as shown in Figure 12. The subjective driving evaluation feedback shows that the acceleration noise and booming noise are significantly reduced, which is subjectively acceptable, thus verifying the accuracy of problem diagnosis and simulation analysis.

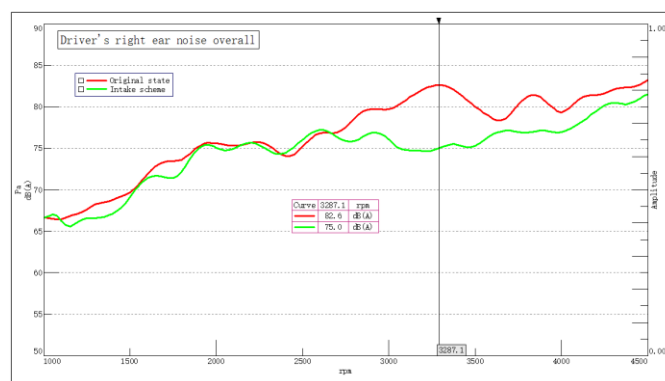


Fig. 12. Effect of intake system Scheme.

IV. CONCLUSION

- (1) Through diagnostic analysis and verification of the acceleration booming noise of a certain light truck, the contribution of each transmission path of the intake system to the acceleration booming noise was determined, and the reason for the insufficient noise reduction ability of the intake system was determined using CAE simulation analysis.
- (2) By increasing the length of the intake system pipeline and adding a resonant cavity in the outlet pipe, the noise reduction ability of the intake system has been improved. The actual vehicle verification shows that the effectiveness of the intake system is obvious. This scheme to improve the noise reduction performance of the intake system can provide a reference basis for the design of light truck intake systems.

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