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Active Control of Diesel Engine Exhaust Noise Incorporating Widrow-hoff LMS Algorithm

Amar Velmurugan[*]

Myanmar Institute of Information Technology, Myanmar

[*]*corresponding author*

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Abstract: Diesel engine(DE) is the most thermally efficient and least polluting thermal machinery at present, and it has greater advantages in economy and environmental protection. However, the DE is too noisy in the process of use, which brings great harm to human health and the surrounding environment. With the progress of human society, people are not only limited to meet the requirements of practicality, but also have higher and higher requirements for comfort and noise control, so the reduction of DE noise has become a key concern of various countries. In this paper, we develop the study of DE exhaust noise(EN), design the DE exhaust system and active muffler device, use the muffler to reduce the EN of oil recovery engine, then use Widrow-Hoff LMS algorithm to train GT-Power simulation software and conduct the simulation experiment of exhaust system with muffler to find the feasible noise reduction by comparing the size of aerodynamic noise under the improved scheme and the original scheme. The simulation results of this paper show that From the simulation results of this paper, it is obtained that Option 2 is the best noise reduction solution, i.e., adding muffler cotton at the rear end of the exhaust system and enlarging the tail pipe diameter.

1. Introduction

Under the current severe situation of fuel tension and emission restriction, DEs are receiving more and more attention because of the advantages of economic performance and good emission performance, and are recognized as a powerful tool for energy saving and emission reduction. However, its excessive noise has become a prominent problem, this paper addresses the problem of excessive noise, research from EN, reduce the DE pneumatic noise, for manufacturers to solve the problem of reducing the difficulty of pneumatic noise, has a very important economic and practical significance.

Foreign research on DE noise started relatively early. Researchers at home and abroad through the analysis of the noise source and the propagation path, seeking the noise control methods. For example, some scholars proposed a new method to analyze the static model of DE, that is, the finite element method, as a way to optimize the vibration characteristics of the DE, so as to control the noise generated. After that, a large number of noise predictions of DEs were made by the finite element method, and the shape and structure of DEs were optimally designed in order to reduce the noise, and finally the noise of DEs was reduced [1]. In recent years, in order to occupy the market and seize profits, DE manufacturers in developed countries have invested a lot of money in DE noise control research, and use lower costs to develop and produce low-noise DEs, so that developed countries are still ahead of China in the field of DE noise control [2]. Many domestic research scholars have also conducted a lot of research on DE noise reduction, but compared with foreign countries, there is still a big gap between China's DE noise technology research and foreign developed countries. Some scholars have used sound intensity test systems in the identification of DE noise sources [3]. Some scholars use FLUENT for simulation and calculation when studying the hydrodynamic properties and pressure loss of perforated and non-perforated mufflers [4]. With the improvement of the level of DE noise control in China, more and more domestic studies on DE noise have been conducted, and the gap between China and developed countries is being further reduced.

In this paper, we first analyzed the Widrow-Hoff LMS algorithm model, which is used to solve the noise interference problem; then proposed the optimal design objectives of the muffling according to the different mechanisms of EN components; then designed the schematic diagram of the exhaust system and the active muffling device; finally simulated the diesel EN after Widrow-Hoff LMS algorithm training on the simulation software, and finally, the performance of the DE before and after the installation of the active muffler was compared.

2. Widrow-Hoff LMS Algorithm

Although the Widrow-Hoff LMS algorithm has improved the system recognition performance to a certain extent when dealing with sparse systems compared to the LMS algorithm. However, one thing must be clear that the Widrow-Hoff LMS algorithm is an improvement on the traditional LMS algorithm and still has the same problem faced by the traditional LMS algorithm, i.e., how to have both fast convergence and small steady-state error [5]. In addition to this, the performance metric of the Widrow-Hoff LMS algorithm is the mean squared deviation, which imposes too much weight on the small coefficients near the zero point when the algorithm converges, thus again making the steady-state misalignment of the algorithm increase [6].

$$Y(W(n)) = \left|e(n)\right|^2 + r\left\|W(n)\right\|_0 \tag{1}$$

where e(n) represents the error signal, W(n) represents the estimated weight coefficient, $\|\ \|_0$ represents the norm, and r is a positive number that is used to balance the estimation error and the penalty term.

The core of this algorithm is to solve the problem of random gradient noise interference by using the connection between e(n) and the degree of convergence to establish the use of e(n) to control the variation of μ [7]. The specific expressions are as follows.

$$\mu(n+1)=\begin{cases}\mu_{\max},\mu_{\max}>\mu_{\max}\\ \mu_{\min},\mu^{'}(n+1)<\mu_{\min}\\ \mu^{'}(n+1),other\end{cases} \tag{2}$$

$$\mu^{'}(n+1)=\alpha\mu(n)+\beta e^{2}(n) \tag{3}$$

Where, α and β represent the step adjustment factors.

3. DE EN Reduction System

3.1. Muffler Optimization Design Target

EN contains a variety of complex components, and the mechanisms of various components are different and the spectral characteristics are also different, therefore, the control of EN is a difficult task. At present, the most effective way to reduce EN is to design exhaust mufflers with superior performance [8].

For the EN, its size is related to the DE noise source, the whole exhaust system assembly arrangement, the exhaust pipe diameter and the internal structure of the exhaust muffler, etc. However, since the DE technology has been mature for a long time, it is difficult to continue to reduce the noise from the consideration of the noise source, and the space limitation of the DE makes it difficult to change the whole exhaust assembly arrangement [9]. Therefore, the current method of improving the design of the internal structure of exhaust muffler and the diameter of exhaust connection pipe to reduce EN is widely used.

The design of exhaust muffler must consider its acoustic performance, pressure loss performance and structural performance at the same time. In actual engineering applications, specific analysis can be made according to the specific situation, and the performance of a certain aspect can be focused on. In the study of this paper, the main purpose is to reduce EN, so the focus should be on improving the acoustic performance of the muffler, considering its pressure loss on this basis, and trying to ensure that the engine power after installing the optimized new muffler is not less than that when the original muffler is installed; at the same time, ensure that the muffler is coordinated with the whole engine, easy to install and simple in structure [10-11].

3.2. Exhaust System Design

As shown in Figure 1, the schematic sketch of the exhaust system including the middle and rear mufflers is shown, and its structure includes the front pipe, catalytic converter, middle muffler, middle connection pipe, rear muffler and tail pipe. For the exhaust system studied in this paper, two improvement schemes are adopted to reduce the EN.

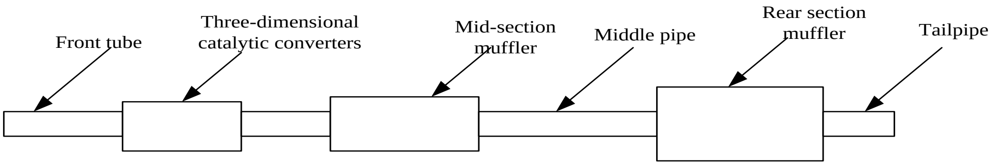

Figure 1. Exhaust system diagram

On the one hand, through the study of DE EN generation mechanism, it is known that EN contains all the noise from low frequency, medium frequency to high frequency, in addition, through the study and analysis of muffler, it is known that impedance composite muffler can well reduce the pneumatic noise with a wide frequency range [12-13]. Therefore, this paper adopts adding muffling cotton inside the rear section muffler to achieve the purpose of reducing the aerodynamic noise. This muffling cotton is composed of fine glass fibers, thus countless small gaps are formed inside the glass fibers. When the sound waves enter these gaps, they are attenuated by vibration and friction with the air in the gaps, thus reducing the aerodynamic noise of the exhaust system [14].

On the other hand, the airflow regenerative noise needs to be minimized. In order to reduce the generation of airflow regenerative noise, usually let the internal pipe and tail pipe of the muffler be straight, the wall of the pipe should be as smooth as possible, and try to expand the diameter of the tail pipe to reduce the airflow speed so as to achieve the purpose of reducing airflow regenerative noise [15-16].

3.3. Active Anechoic Device Design

In view of the deficiencies of the existing technology for the control of the fundamental frequency EN, as well as the non-stationary noise of the transition conditions, this paper provides a new active muffling device, as shown in Figure 2. The device mainly consists of a valve-based active control bypass muffler and a passive muffler, and the bypass muffler includes a main line, a bypass piping system, a piping control valve and a controller [17]. The bypass muffler for a certain determined frequency of gas noise in the pipeline, only two pipelines are connected, while the others are closed, and the difference in length of the two connected pipelines should meet certain requirements, so as to achieve the purpose of muffling; the passive muffler can reduce the noise at other frequencies not covered by the bypass muffler, so as to ensure that the whole device can achieve the required noise reduction effect [18].

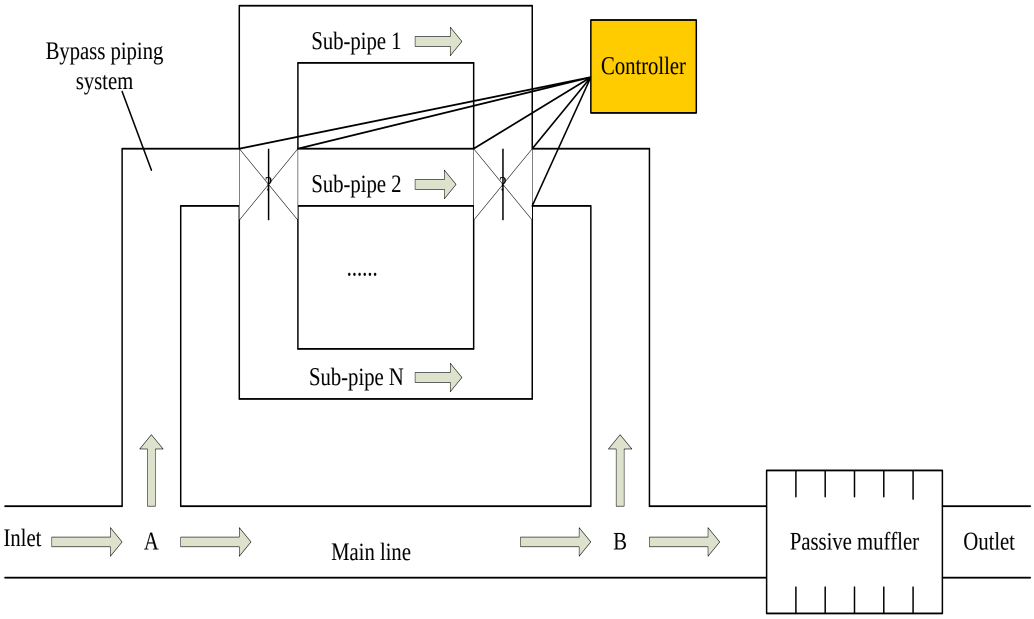

Figure 2. Schematic diagram of the active sound elimination device

4. Experimental Simulation of Active Control of Diesel EN Based on Widrow-Hoff LMS Algorithm

4.1. Simulation Results of Exhaust System

In this paper, GT-Power simulation software is used to simulate the exhaust system with different mufflers, calculate the sound pressure level of tail pipe noise at different speeds, analyze the results and find measures to reduce the aerodynamic noise in the exhaust system. Taking a certain type of DE exhaust system as the research object, the Widrow-Hoff LMS algorithm was first trained in the GT-Power simulation software, and the Widrow-Hoff LMS algorithm was used to improve the accuracy of the target value of noise sound pressure level calculated by the GT-Power simulation software. The sound pressure level of the tailpipe noise of the original scheme as shown in Figure 3. According to the analysis of the tailpipe noise, it is known that the total sound pressure level of tailpipe noise consists of order noise and aerodynamic noise, and the difference between the total order noise and the total sound pressure level is the aerodynamic noise. From the simulation results, it can be seen that the total sound pressure level exceeds the target limit above 3000rpm, and the order noise accounts for the main component before 2000rpm, and as the speed increases, the aerodynamic noise becomes larger and accounts for the main component.

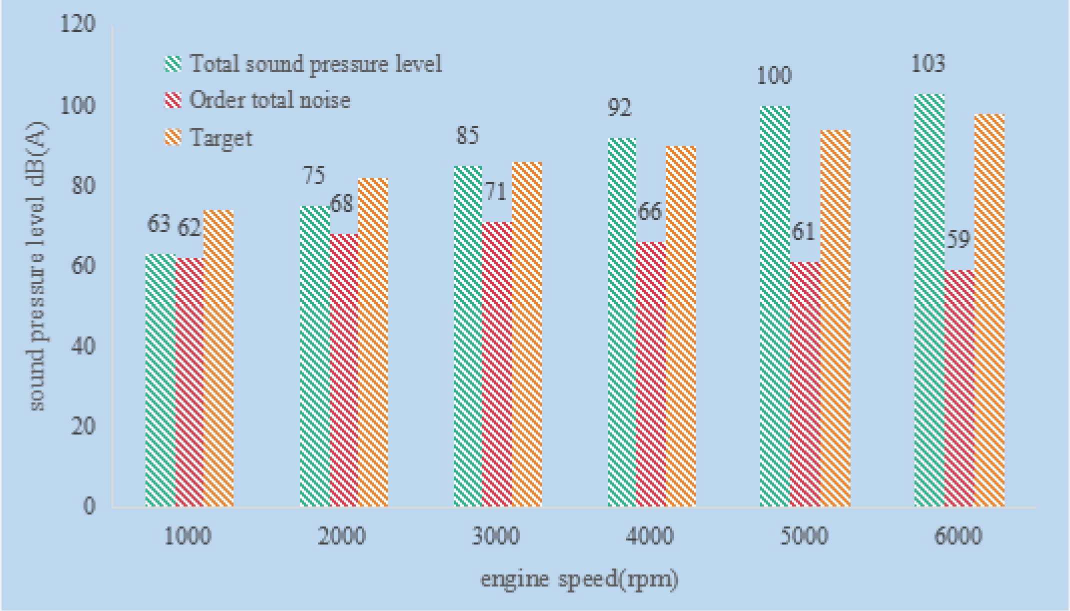

Figure 3. The sound pressure level of tail pipe noise of the original scheme

From the simulation results, it can be seen that the aerodynamic noise of the original scheme is obviously too large. On the basis of the original scheme, two schemes are designed to improve the rear muffler model. Option 1: add muffling cotton in the rear section muffler; Option 2: expand the tail pipe diameter by 5mm based on Option 1.

The results of the simulation analysis of the three options are shown in Table 1. From the simulation results, we know that compared with the original option, option 1 has a certain degree of improvement in reducing the aerodynamic noise by adding muffler cotton, and option 2 further reduces the aerodynamic noise by expanding the tail pipe diameter based on adding muffler cotton, and the improved tail pipe noise of option 2 meets the target requirements.

Table 1. Simulation analysis results of three options

	1000	2000	3000	4000	5000	6000
Original program	63	75	85	92	100	103
Program 1	62	73	80	84	89	96
Program 2	57	61	66	73	78	81
Target	74	82	86	90	94	98

4.2. Impact of Active Muffler on DE Performance

The installation of a muffler on a DE increases the exhaust airflow resistance of the DE and raises the exhaust back pressure, thus reducing the output power of the DE and increasing the fuel consumption rate. In order to study the effect of the addition of the bypass muffler, three-way perforated pipe muffler and active muffler combination device on the engine, a coupling model of the DE and muffler was established. Since some parameters need to be adjusted when GT-POWER software calculates the engine performance with noise prediction, the coupling model is based on the calculation of the external characteristics model of the DE, and a Muffler Subassembly module is added to insert the muffler as a substructure into the model of the DE, and after the cyclic calculation, it is possible to extract in the GT-POST post-processing program The calculation results such as power, torque and fuel consumption rate of the DE can be extracted in the GT-POST post-processing program.

Table 2. Comparison of power, torque and fuel consumption rate of DE before and after installation of active muffler

		1400	1500	1600	1700	1800	1900
Power(kW)	Before installation	36	39	43	45	46.5	49
	After installation	34	38	42.5	46	47	49
Torque(N*m)	Before installation	241	253	247	238	226	221
	After installation	242	256	251	232	218	210
Fuel consumption rate(g/kW*m)	Before installation	217	208	212	229	241	246
	After installation	217	207	210	224	248	257

The performance changes of the DE after adding the active muffler and before connecting any device are shown in Table 2. From the comparison data, it can be calculated that the maximum loss ratio of power, torque and fuel consumption rate does not exceed 6%, which means that the device can meet the design requirements of low impact on DE performance. Also considering the low exhaust gas flow velocity at low speed, the problem of the pipe length having a large impact on the along-range resistance loss of the exhaust system, and the error existing in the simulation software itself. The actual effect of the active muffler on the DE performance needs to be further verified by tests in the future.

5. Conclusion

This paper combines the EN generation mechanism and the study of muffler structure, analyzes two optimized solutions to reduce the pneumatic noise of the exhaust system, and then uses GT-Power software to establish a simulation, and compares the simulation results to conclude that all three solutions can meet the back pressure required by the enterprise, but the tail pipe noise value of solution 2, which fills the muffler in the rear section and expands the tail pipe, is the lowest. The best solution is Option 2. Since the simulation analysis used in this paper does not consider the temperature factor, the simulation study is only a qualitative study, so in the future the noise reduction of the exhaust system needs to take tests to further verify the desirability of the improvement scheme.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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