Study on Flow Field Characteristics of Air Filter Intake System for Heavy Truck

Pidong Shi1, a, Renren Wang2, *, Fang Cao1, Chao Gao1, Hongliang Wang1, and Zhihao Liu1

1School of Mechanical and Automotive Engineering, Qilu University of Technology (Shandong Academy of Sciences), Ji’nan 250300, Shandong, P.R. China
2School of Electrical Engineering and Automation, Qilu University of Technology (Shandong Academy of Sciences), Ji’nan 250300, Shandong, P.R. China

*Corresponding author e-mail: wrr@qlu.edu.cn, a1410425716@qq.com

Abstract. A three-dimensional watershed model of the intake system of the air filter for heavy trucks is built. The influence of the structure parameters of the intake pipe and cyclone separator on the flow field characteristics of the intake system is studied by using computational fluid dynamics (CFD) method, the parameters of the forward gas system are optimized. The results show: The internal structure of the intake pipe and cyclone separator is complex, so that pressure loss of the whole flow field is larger, and it affects the performance of the intake system.

1. Introduction

As a protective barrier for air filters and engines, the intake system plays an extremely important role in removing large impurities and rainwater in the air. Intake system is also called air pre-filter. At present, the structure of air pre-filter can be roughly divided into centrifugal pre-filter, oil-bath pre-filter, electrostatic-cyclone pre-filter, and some new pre-filters [1]. In recent years, there is not much research on air filter and intake system. Shang Ming [2] has studied the structure design of the dry-wet composite air filter for heavy truck, and combined with the principles of fluid dynamics and aerodynamics, the internal flow field of the air filter is numerically simulated, which provides the theoretical basis for the optimization design of the air filter structure and the improvement of the filtration efficiency. Liu Qin [3] has studied the performance of the diesel engine dry-wet composite air filter, and obtained a method to solve the internal pressure loss with the flow situation. Cheng Jialei [4] has obtained the structure of reducing pressure loss with the influence of grid angle and rain shield on the forward air filter. Based on the current research situation and progress, it is found that there are still some deficiencies in the research of air filter and intake system. In this paper, the flow field of the gravity air filter intake system is studied and analyzed.

2. Calculation method and Model Establishment

2.1. Geometric Model

The model used in this simulation is a heavy truck air filter intake system. Because the shape of the internal structure is complex, as shown in figure 1, not easy to simulate directly. Therefore, the internal
fluid domain of the intake system is extracted by Geometry preprocessing software, and simplified processing is carried out to obtain the model needed for the simulation.

![Geometric model profile](image)

**Figure 1.** Geometric model profile

### 2.2. Computing method

The gas phase is regarded as a continuous phase, the flow process is assumed to be a three-dimensional incompressible steady-state flow.

#### 2.2.1. Control equation

**Continuous phase equation:**

Mass conservation equation:

\[
\frac{\partial \rho u_i}{\partial x_i} = 0
\]  

In the form: \(u_i\) is the velocity vector, \(x_i\) is a displacement vector.

**Momentum conservation equation:**

\[
\frac{\partial}{\partial x_j} \left( \rho \mathbf{u} \mathbf{u}_j \right) = \frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_i} \left( \mu_{\text{eff}} \frac{\partial u_i}{\partial x_j} - \rho u_i u_j \right) + S_i
\]

\[
-u_i u_j = \frac{\rho}{\mu} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{2}{3} \delta_{ij} k
\]

In the form: \(P\) is the pressure of air, \(\mu_{\text{eff}}\) is the viscosity of the air, \(S_i\) is the generalized source phase of momentum equation, \(\mu\) is a turbulent viscosity coefficient, \(\sigma_{ij}\) is the tensor component of the deformation rate of the fluid, \(k\) is turbulent kinetic energy.

### 3. Simulation results and analysis

In order to reduce the computational complexity, the intake system is studied in three steps. Firstly, the influence of the intake pipe on the flow field is studied. Secondly, the flow field characteristics of the cyclone separator are analyzed. Finally, the overall flow field is analyzed.

#### 3.1. Intake Pipe Flow Field Analysis

Through the simulation and analysis of the flow field of the intake pipe, the flow field before and after optimization is obtained. Fig. 2 shows the pressure cloud of the intake pipe, and Fig. 3 shows the velocity contour of the intake pipe.
From the pressure cloud, before optimization, the pressure loss of the structure is mainly concentrated in the upper right corner of the inlet arc and the double cone tube, and the pressure gradient is larger; From the velocity cloud, the velocity uniformity of the flow field is poor, and there is a large eddy current in the flow field, which results in a large loss of flow resistance. After simulation and optimization, when the arc radius is changed to 294.2 mm and the entrance radius of the double cone cylinder is changed to 63 mm, the total pressure loss of the optimized model is obviously reduced, the high pressure area on the upper right side is obviously reduced, and the velocity uniformity of the whole flow field is greatly improved.

3.2. Flow Field Analysis of Cyclone Separator
The cyclone separator plays a major role in filtering the intake system, and the most of dust particles can be filtered out by centrifugal force. Figure 4 shows the velocity contour diagram before and after optimization, and Table 1 shows the pressure comparison before and after optimization.
After simulation and analysis, the conclusion is drawn. When the radius of the exhaust port is 54 mm, the height of the inner wall of the exhaust port is 147 mm, the inclination angle of the exhaust port is 24 degrees and the inclination angle of the bottom of the dust collecting chamber is 6 degrees, the maximum velocity of the optimized cyclone separator in the exhaust port decreases, and the uniformity of the velocity distribution increases, which reduces the impact of the fluid on the exhaust port, it can be seen from the velocity contour map before and after optimization in Figure 4. From the pressure comparison chart in Table 5, it can be seen that the pressure drop at the inlet and outlet of the optimized cyclone separator decreases, which means that the internal flow resistance of the optimized cyclone separator decreases.

3.3. Analysis of Overall Flow Field
On the basis of sub-area optimization, the whole flow field of heavy truck intake system is studied and analyzed, and the whole flow field after optimization is studied.

3.3.1. Overall Flow Cloud Map. Figure 5 shows the overall flow field cloud of the optimized structure. Figure 5 (a) shows a pressure cloud. Figure 5 (b) shows the velocity cloud.

|                  | Before optimization | After optimization |
|------------------|---------------------|--------------------|
| Intake pressure/Pa | -61.87              | -61.34             |
| Exhaust pressure/Pa | -738.35            | -648.47            |
| Pressure drop/Pa | 676.48              | 587.13             |

Figure 4. Velocity contours before and after optimization
As can be seen clearly from the static pressure cloud map in Figure 5 (a), at the inlet grille, the incoming flow moves to the grille baffle, and the airflow is blocked. A part of kinetic energy is rapidly converted into pressure energy, which results in the pressure behind the grille being less than that in front. At the same time, behind the intake grille, due to the obstruction of the spoiler, the local pressure is relatively high. The air passing through the blade flows downward in a rotating state, which is conducive to the separation of dust particles in the air. From the velocity cloud map of Figure 5 (b), it can be seen that the airflow velocity at the grid position, the blade position and the exhaust pipe position is relatively high, the velocity of the blade is high in the middle, low in the edge and symmetrically distributed, which is conducive to the filtration of dust particles.

3.3.2. Overall Pressure Gradient. In order to further study the change of internal pressure in the intake system of heavy truck, a benchmark line based on impeller axis is established in CFD-Post, as shown in Figure 6. The pressure at each point on the datum line is analyzed to get the pressure gradient, as shown in Figure 7.
Figure 7. Pressure curve on datum line

From the above pressure curves, it can be clearly seen that the two pressure curves have similar trends, where the pressure gradient varies greatly, it concentrates between 0.2 and 0.5 m, which indicates that the resistance of impeller part between 0.2 and 0.5 m is larger; between -0.2 m and 0 m, the pressure also shows a downward trend. The reason is that the entrance area of the double cone tube decreases, resulting in greater resistance.

4. Conclusion

1) Through the flow field analysis of the intake pipe and the cyclone separator, the influencing factors of intake system of heavy truck are obtained, and the optimization design is carried out.

2) The complex three-dimensional flow field in the optimized intake system of heavy truck is studied by numerical simulation. Through velocity cloud picture, pressure cloud picture and pressure gradient curve, the variation of internal flow field parameters is analyzed in detail. After optimization, the pressure drop of the structure is reduced, and the speed of the blade is obviously increased, which is conducive to improving the filtration efficiency.

3) The velocity uniformity and pressure drop of the whole flow field of the intake system of heavy truck need to be further improved.

Acknowledgments
This work was financially supported by Key R&D Program Projects in Shandong Province (2015GGH303001).

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