Study on the Influence of Inlet Drag at Front and Rear Sides of Compressor on the Performance of Supercharged Engine

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Abstract. In this paper, the influence of inlet drag at the front and rear sides of a compressor on the performance of a supercharged engine is tested. The test results show that the air flow into the engine, the combustion pressure and the engine output power decrease, the specific fuel consumption and the exhaust temperature behind the turbine increase with the increase of air intake drag. Especially when the engine at low speed operation, with the increase of inlet drag, engine performance will worsen sharply. Compared with the influence of the drag after compressor on the engine performance, the drag before compressor is more sensitive to the influence of the engine performance. When the engine speed is 1500r/min, 1900r/min and 2400r/min, the reduction in engine power caused by inlet drag in front of the compressor is 2.63 times, 4.1 times and 7.5 times that caused by the same inlet drag after the compressor. Also, the former results in an increase in specific fuel consumption 2.18 times, 3.1 times and 5.16 times of the latter. So optimizing the structure of the inlet system in front of the compressor can reduce the performance loss of the engine more effectively. The conclusions of this paper will provide guidance for the selection and matching of air filters, the spatial arrangement of multi-stage air filters in turbocharged engines, and the structural design of air intake system.

1. Introduction

The structural form and component composition of the intake system will affect the energy loss of the gas system of engine to a certain extent, thus leading to changes in engine performance[1]. Through the optimization of the intake system of engine, including the selection and matching and space arrangement of air filter, compressor, intercooler, as well as the optimization of the structure of the pipeline, joint and throttle device of intake system, to minimize the mechanical and thermal irreversible changes of the intake system as far as possible, so as to reduce the pneumatic power loss of the intake system.

For the intake system of special vehicles, heavy engineering vehicles and generator sets used in high altitude and windy and sandy environment, on the one hand, multistage air filters must be installed to filter dust and particles in the air to reduce the wear of particles on the compressor impeller and engine cylinder liner, so as to improve the service life of the power system[2], on the other hand, the drag of air filter constitutes a part of the drag of engine intake system, which directly determines the excess air coefficient of combustion in the cylinder and affects the combustion process of the engine, thus affecting the power output, specific fuel consumption and emission characteristics of the engine[3-5].
Multistage air filters are usually arranged in front and rear of the compressor. Compared with the rear air filter, the resistance characteristic of the front air filter affects the engine performance by directly affecting the working process of the compressor[6]. Therefore, the research on the influence of air intake drag on engine performance is of great significance to the arrangement and matching of air filter on the engine and the structural design of the engine intake system.

2. Test Method

2.1. Test engine

This test was carried out on a V-type, 16-cylinder, four-stroke, supercharged, intercooled, direct-injection diesel engine. The main technical parameters of engine are shown in table 1.

| Parameter                  | Index |
|----------------------------|-------|
| Cylinder diameter/ mm      | 132   |
| Stroke/ mm                 | 145   |
| Displacement/ L             | 31.73 |
| Compression ratio          | 17.5:1|
| Combustion chamber shape   | ω     |
| Rated power/ kW            | 1100  |
| Calibration speed /r.min⁻¹ | 2400  |

2.2. Introduction to test bench

Throttle throttle devices are arranged on the inlet pipes of the front and rear sides of the compressor respectively, and the inlet drag of the front and rear pipes of the compressor is simulated by adjusting the opening section of the throttling device.

The inlet drag before the compressor is defined as:

\[ \Delta P_{\text{front}} = P_0 - P_{\text{in-com}} \]  \hspace{1cm} (1)

Where, \( P_0 \) is environmental pressure, kPa, \( P_{\text{in-com}} \) is the inlet pressure of compressor, kPa.

Similarly, a restrictor plate is installed on the inlet pipe line behind the intercooler, and the pressure drop in the pipeline after the compressor is changed by adjusting the restrictor plate to the opening section of the inlet pipe line. The intake drag after the compressor includes the total pressure loss of the intercooler and the throttle plate, which is defined as:

\[ \Delta P_{\text{rear}} = P_{\text{out-com}} - P_{\text{out-cool}} \]  \hspace{1cm} (2)

Where, \( P_{\text{out-com}} \) is the outlet pressure of the compressor, kPa. \( P_{\text{out-cool}} \) is the outlet pressure of the intercooler, kPa.

The schematic diagram of test bench and measuring point layout is shown in figure 1.
The test equipment is shown in table 2. The opening of throttle valve is stepless regulated by servo motor. The engine is coaxially connected with the eddy current dynamometer. The control panel controls the throttle and dynamometer excitation to realize the change of engine working condition. Meanwhile, the turbocharger speed, fuel consumption, exhaust temperature behind the turbine and other parameters are tested and recorded.

### Table 2. Test equipment

| Name                          | Type                  | Measuring Range       | Precision  |
|-------------------------------|-----------------------|-----------------------|------------|
| Dynamometer                   | Hydraulic dynamometer | D2100 0-2100kW        | ±0.3%      |
| Fuel consumption instrument   | DF-2420               | 1-1440L/h             | ±0.1%      |
| Combustion analysis equipment | DEWETRON              | -- 2-100kPa           | ±0.5%      |
| SENEX pressure transmitter    | --                    | 2-100kPa              | 0.25%FS    |
| Temperature sensor            | T-type/K-type/PT100   | 0-200°C/0-1000°C/0-150°C | ILevel  |
| ABB mass flow sensor          | JYB (pressure)        | -10-0kPa              | 0.25%FS    |

### 3. Test results and analysis

#### 3.1. Influence of front drag of compressor

Figure 2~ figure 5 show the test results of the influence of the drag of the inlet pipe in front of the compressor on the performance of the engine under different working conditions. It can be seen from the figures that increasing the drag in front of the compressor will reduce the intake mass of the engine.
and reduce the maximum combustion pressure in the cylinder (figure 2). Meanwhile, the power and economy of the engine declines gradually, and the thermal load also increases continuously. At 1500r/min, 1900r/min and 2400r/min, the power output of the engine decreases by 7.1kW, 3.7kW, 3kW and the specific fuel consumption increases by 1.66g.(kW.h)^{-1}, 0.68g.(kW.h)^{-1}, 0.63g.(kW.h)^{-1} on average when the drag front of the compressor increases by 1kPa.

At the same time, when the engine is running at low speed, the performance of the engine deteriorates rapidly with the increase of inlet drag at the front side of the compressor compared with that at high speed. Figure 6 shows the variation trend of engine output power decline rate with the drag in front of the compressor. Therefore, it is particularly important to reduce the pressure loss in the front intake duct of the compressor for the turbocharged engine running at low speed for a long time.
Figure 6. Influence of the drag in front of the compressor on output power decline rate

The drag in front of the compressor affects the engine performance by directly affecting the working process of the compressor. As shown in figure 7, under the same pressure ratio, when the drag in front of the compressor is small, the influence of this resistance on the temperature behind the compressor is not obvious. However, when the drag in front of the compressor exceeds a certain value, the temperature behind the compressor will rise rapidly, and the turbocharger has the lowest speed at this time (figure 8). It can be inferred that the efficiency of the compressor is the highest.

Therefore, the speed of engine and the pressure loss of the inlet pipe in front of compressor should be considered at the same time in the process of designing of intake system for engine. In other words, under the condition of satisfying the air inlet pipe space arrangement and air filtration effect, the inlet pipe section shape and direction must be optimized to reduce the air inlet drag in front of the compressor, so as to ensure the air mass entering the engine and improve the working efficiency of the compressor and finally reduce the performance loss of the engine as far as possible.

3.2. Influence of rear drag of compressor

Figure 9~figure 11 show the test results of the influence of the drag of the inlet pipe behind the compressor on the performance of the engine. It can be seen that, similar to the variation trend of engine performance with the drag in front of the compressor, the mass of air entering the engine decreases, the combustion deteriorates, the engine output power decreases slightly, the specific fuel consumption and the exhaust temperature in front of the turbine increase gradually with the increase of drag behind the compressor at any speed. Moreover, with the increase of engine speed, the influence
trend of engine performance along with the drag behind the compressor weakens gradually. At 1500r/min, 1900r/min and 2400r/min, the power output of the engine decreases by 2.7kW, 0.9kW, 0.4kW and the specific fuel consumption increases by 0.76g.(kW.h)$^{-1}$, 0.22g.(kW.h)$^{-1}$, 0.122g.(kW.h)$^{-1}$ on average when the drag behind the compressor increases by 1kPa.

Figure 9. Influence of the drag at rear of the compressor on the output power

Figure 10. Influence of the drag at rear of the compressor on brake specific fuel consumption

Figure 11. Influence of the drag at rear of the compressor on the temperature behind the compressor

In addition, the change of the drag behind the compressor will also lead to a large fluctuation of the turbocharger speed (see figure 12), which will undoubtedly reduce the working efficiency of compressor. At the same time, at each running speed of the engine, when the drag behind the compressor is small, the temperature behind the compressor is hardly affected. However, when the drag behind the compressor increases to a certain value, the working efficiency of the compressor will suddenly decrease, resulting in a sharp rise in the gas temperature behind the compressor, especially when the engine is running at a low speed, the rise in the temperature will be more severe. (see figure 13).
3.3. Comparative analysis of the influence of drag at front and rear sides of compressor

Figure 14 and figure 15 show the influence of inlet drag on engine power and economy of the front and rear sides of the compressor respectively.

From figure 14 to figure 15, it can be seen that when the engine is running at 1500r/min, 1900r/min and 2400r/min, compared with the influence of drag at front of compressor on the performance of the engine, a small drag at rear of compressor can lead to the same power loss ($\Delta P_e$) and specific fuel consumption increase ($\Delta e_{fb}$).

Table 3 shows the engine performance test results for each 1kPa increase in front/rear intake drag of the compressor.

| $\Delta P_e$ /kW | n /min | 1500 | 1900 | 2400 |
|-----------------|--------|------|------|------|
| $\Delta P_e$ at $+1$/kPa | -7.1   | -3.7 | -3   |
| $\Delta e_{fb}$ at $+1$/kPa | -2.7   | -0.9 | -0.4 |
As can be seen from Table 3, when the engine runs at speeds of 1500r/min, 1900r/min and 2400r/min, the reduction in engine power caused by inlet drag in front of the compressor is 2.63 times, 4.1 times and 7.5 times than that caused by the same inlet drag after the compressor. Also, the former results in an increase in specific fuel consumption 2.18 times, 3.1 times and 5.16 times of the latter. Therefore, it shows that the pressure before pressure is more sensitive to the influence of power performance and economy of the engine. Therefore, it shows that the dynamic performance and economy of the engine are more sensitive to the front drag of compressor.

Therefore, under the condition of the total efficiency and total pressure loss of the multi-stage air filter, the turbocharged engine in the harsh environment should try to reduce the air filter resistance in front of the compressor as much as possible, and the influence of the common speed of engine on the compressor's working efficiency should be considered at the same time, in order to reduce the influence of the intake drag on the engine performance.

4. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The increase of the inlet drag at the front and rear ends of the compressor will reduce the intake mass of the engine, resulting in the deterioration of the performance of the engine. Especially at low speed, the performance of the engine is more sensitive to the change of the inlet drag.

(2) The design of the intake system of a supercharged engine should take into account the common engine speed of engine and optimize the drag of the inlet system before the compressor to reduce the loss of performance of engine effectively.

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