Effect of Air Filter on Performance of S1110 Diesel Engine

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Abstract. Single-cylinder diesel engine are manufactured in large numbers and widely used in China. Both industry and academia are spending efforts to improve its performance by reducing the exhaust emission level, vibration, noise and energy consumption. This article studies the effects of different air filters on the performance of a S1110 single-cylinder diesel engine. Through the load characteristic and speed characteristic bench tests, output power, torque, smoke and other parameters under different working conditions were measured. The results show that the new designed air filter (type-B) has significantly improved the power and economy of the diesel engine, and the exhaust smoke is significantly reduced.

1. Introduction
China is the country with the largest production and highest social ownership capacity of single-cylinder diesel engines in the world. China is also the largest exporter of such engines with more than 2 million units each year, accounting for about 65% of the total global use [1-2]. The single-cylinder diesel engine mainly provides power for various types of small tractors, low-speed trucks, three-wheeled vehicles, small transport vessels, irrigation and drainage machinery, generator sets, agricultural engineering machinery, garden plant protection machinery, etc. The single-cylinder diesel engine is popular among users because of its low price, simple structure and convenient use. Diesel engine products belong to the national production license management products, yet the relative technical supervision departments have not paid enough attentions on the exhaust emission from a single-cylinder diesel engine. Moreover, improvements are needed for the reduction of vibration, noise and energy consumption [3-4]. Air filter is one of the important accessories for diesel engine, whose performance not only determines the reliability of the engine and the engine's service life, but also affects the engine's power, economy, and even affects the exhaust emissions [5-6]. Particularly, air filter is located at the intake system, which can filter out hard particles to provide cleaner air to the engine. Depending on the design structure, air filters are in different types including tangential inlet oil immersed air filter, composite oil bath air filter and dry paper filter. The type-B air filter with a new structure is designed based on multi-faceted considerations. The load characteristic test and the speed characteristic test are carried out under different working conditions for a S1110 single-cylinder diesel engine at three different setting: without air filter, with type-A air filter and type-B air filter. The
output power, torque, fuel consumption, exhaust smoke, oil temperature, exhaust temperature and other parameters were tested and analysed [7]. Then the impact of air filter on the power, economy and smoke emissions of the S1110 engine was comprehensively analysed.

2. Equipment

2.1. Test engine

The test engine is the model S1110 diesel engine. The technical parameters of the diesel engine are shown as table 1.

| Serial number | Name                                  | Specification     | Measurement accuracy |
|---------------|---------------------------------------|-------------------|----------------------|
| 1             | Automatic measurement and control system | ET2000            | speed: ±1(r·min⁻¹)   |
| 2             | Eddy current dynamometer              | DWD63             | torque: ±0.4%(F.S)   |
| 3             | Intelligent fuel consumption meter     | ET2500            | ±0.4%(F.S)           |
| 4             | Smoke meter                           | YDJ-2000          | ±3%                  |
| 5             | Opacity smoke meter                   | SV-5Y             | 0.1%                 |

2.2. The main equipment of testing

The main equipment of testing is shown as table 2.

The structure of air filter type-A and type-B for testing is different. Type-A air filter (figure 1) is the traditional one. Type-B air filter (figure 2) is a newly designed oil bath type composite filter. Its upper strainer has a blade ring and a tangential inlet, lower filter is provided with a pancake-like metal filter, and the bottom of the filter has an oil pool. Most of the air containing impurities first enters the coarse filter cap through the blade ring to form a swirling airflow, and a small portion of the air accelerates the rotational velocity of the swirling airflow through the tangential inlet, so that large particles of impurities are thrown onto the strainer casing. After passing through the central pipe into the oil pan, the air passing through the coarse filter reaches the lower part of the main filter through the central pipe, and under the action of the suction in the engine cylinder, the direction of the air flow is changed, the air is moved upward through the pancake-like metal filter, then passed through the elbow to the intake manifold of the engine. Compared with the original air filter, the filter effect is good, which increases the size of the filter and reduces the air resistance. The Structure parameter of air filters is shown as table 3.
Table 3. The main structure parameter of air filters

| The Structure parameter                        | Type   | Type-B          |
|-----------------------------------------------|--------|-----------------|
| Outer diameter of filter cap (mm)             | —      | 160             |
| Blade ring of filter cap                      | —      | The number of blades, n=24; Blade angle, $\alpha=32^\circ$ |
| Outside diameter of oil bath filter (mm)      | 130    | 190             |
| Center tube diameter of outside diameter (mm) | 46     | 60              |
| Precision filter height (mm)                  | 125    | 220             |
| Iron wire filter core total height (mm)        | 65     | 80              |

3. Test method
All the tests were carried out using a S1110 engine. The influence of the air filter on the engine power, economy and smoke emission level was analyzed. Three experiment settings were used by (1) without air filter, (2) type-A air filter (old design) and (3) type-B air filter (new design).

4. Results and Discussion

4.1 The load-characteristic test results
Figure 3 shows all the load-characteristic curves including the tests without air filter, with type-A air filter (old design) and with type-B air filter (new design). Performance test results summarize as follows:

4.1.1. Maximum power of engine
At calibrated rotation speed, the maximum power of engine can be 16.54 KW without air filter, 16.45 KW with type-B air filter, and only 16.27 KW with type-A air filter. The maximum power increases by 1.1% when our newly designed type-B air filter is used compared with the type-A air filter.

4.1.2. Fuel consumption rates
The fuel consumption rates of all three settings are relatively close within the entire power range. Compared with the original air filter, the new air filter is 5 grams per kilowatt hour. At calibrated load condition, the modified fuel consumption rate using type-B air filter is 214.1 g/(kW·h), while the modified fuel consumption rate using type-A air filter is 216 g/(kW·h). 0.9% decrease is achieved using type-B air filter. At 75% load condition (9.93KW/2200rpm), the modified fuel consumption rates using type-B and type-A air filter are 218.6g/(kW·h) and 220.1g/(kW·h), which are very close.
4.1.3. Exhaust temperature
In the whole power range, the exhaust gas temperature of using type-A air filter are 20°C higher than using type-B air filter, and both of them show an increase in the exhaust temperature as the load increases.

![Figure 3. Load-characteristic curve of different air filter](image)

4.1.4. Smoke emission
In the whole power range, the smoke emission without using air filter is obviously on the low side, the one using the type-A air filter is apparently high degree, the one using type-B air filter is in the middle. Again, the exhaust smoke obviously increases with the increasing of load. The smoke value without using air filter is 1.7FSU, and the smoke value using type-B and type-A is 1.8FSU and 2.0FSU. A decrease of 11% is achieved when replacing type-A with type-B air filter.

4.2. The speed-characteristic test results
Figure 4 shows all the speed-characteristic curves including the tests without air filter, with type-A air filter (old design) and with type-B air filter (new design). Performance test results summarize as follows:
4.2.1. Fuel consumption rates
At determined throttle, the fuel consumptions of all three setting are almost the same under different speed; while for fuel consumption rate, no air cleaner is the lowest, type-B air filter is in the middle and type-A air filter is the highest. When using type-A air filter, the fuel consumption rate is 234.2g/(kW·h) under the maximum torque (72.45 N-m/1500rpm). When using type-B air filter, the fuel consumption rate is 230.8g/(kW·h) under the maximum torque (73.58 N-m/1500rpm), which is 1.5% lower than the one using type-A.

![Figure 4. Speed characteristic curve of different air cleaner](image)

4.2.2. Torque
The torque at all three settings increases with the increasing loading and decreasing rotation speed, while the maximum torque appears at the range of 1500rpm. They are relatively flat between 1300 rpm and 2000 rpm. When using the type-B air filter, the maximum torque is 73.58N-m/1500rpm, and the torque reserve rate is 28%. When using Type-A air filter, the maximum real torque is 72.45 N-m/1500 rpm, and the torque reserve rate is 26%. When using no air filter, the maximum torque is 75.32 N-m/1500 rpm, and the torque reserve rate is 31%.
4.2.3. Rotation speed rate at maximum torque
The rotation speed rate at maximum torque of all three settings is 68.2%.

4.2.4. Smoke emission
The smoking level at all three settings showed an upward trend with the increasing loading and decreasing rotation speed. At the maximum torque, the smoking level at no air filter, type-A and type-B setting is 3.9, 4.5 and 4.2 FSU; and the maximum opacity value (optical absorption coefficient) at no air filter, type-A and type-B air filter is 1.7, 2.36 and 2.0/m$^3$.

4.2.5 Heat emission
At all the power range, the heat emission at no air filter is the lowest, type-A is the highest, while the type-B is in the middle.

5. Conclusions
The prototype test results show that compared with the old air filter (type-A air filter), the using of the new designed oil bath composite air filter (type-B) on the single cylinder S110mm diesel engine can significantly improve the power and economy efficiency, and lower the emission smoke level. The maximum torque point Bosch smoke value decreased by 0.3FSU, and the maximum opacity smoke value decreased by 0.5 m$^{-1}$. The maximum power increased by 5.5%, the fuel consumption rate of the calibration condition decreased by 1.4%, the fuel consumption rate of the maximum torque condition decreased by 2.1%, the torque reserve rate increased by 2.7%, and the exhaust gas temperature was low in the entire power range.

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References
[1] He, Q. (2014) Environmental regulations promote the transformation and upgrading of single-cylinder machines. Agricultural Machinery Market, 1: 30-32.
[2] Xu, F., He Y. (2016) Analysis and suggestions on the development difficulties of single cylinder diesel engines in China. Farm Machinery, 11: 97-101, 104.
[3] Fan, J. (2011) Status of China's agricultural diesel engine products and energy saving and Emission Reduction. Farm Machinery, 9: 13-15.
[4] Yang, A., Yang, J. (2018) Study on the Performance of the Model ZH1125 Single Cylinder Diesel Engine by Changing the Air Cleaner. In: Proceedings of the 2018 3rd Joint International Information Technology , Mechanical and Electronic Engineering Conference, Chong Qing. pp.138-141.
[5] Tan, Y. (2010) Simulation analysis and experimental study of air filter. https://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CMFD&dbname=CMFD2012&filename=1011052115.nh&ui d.
[6] Thomas, J., West, B., Huff, S. (2013) Effect of Air Filter Condition on Diesel Vehicle Fuel Economy. SAE Technical Paper, Doi: 10.4271/2013-01-0311.
[7] Huang, J., Li L., Huang, Y., Qin, J. (2012 )Experimental research on reducing the emission of small diesel engine. Small Internal Combustion Engine and Motorcycle, 4:55-61.