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Experimental Study on Relationship between NOx Emission and Fuel Consumption of a Diesel Engine

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Abstract. For YC6112 diesel engine assembled Delphi model single fuel pump electric controlled, in the premise of not changing its overall unit structure parameters of other systems, three different types of camshaft for single pumps, two kinds of fuel injectors, two types of superchargers and some phase shifting angle of different camshafts were chosen to match with the engine precisely, the experiments under thirteen kinds of working conditions for the engine with different matching were carried out, the change regulation between NOX emission and fuel consumption for the engine with different kinds of configurations was analyzed. The experiment results show the NOX emission and fuel consumption can be reduced greatly by configuring proper camshaft, fuel injectors and superchargers with YC6112 diesel engine.

1. Introduction

The emission of pollutants in internal combustion engines is one of the most serious challenge facing technical progress of internal combustion engines [1]. As the most important internal combustion engine, the emission and fuel consumption of diesel engines reveal a great influence to the economic and technical development of the whole society.

The emission of a diesel engine refers to the fuel products burned to diffuse to atmospheric environment. The type of a diesel engine emissions is extremely complex. According to its perniciousness to human being, it could be classified into two categories of noxious emissions and innocuous emissions. Innocuous emissions include nitrogen (N2), oxygen (O2), carbon dioxide (CO2), water vapour, and etc, although carbon dioxide among them is the largest contributor to the greenhouse effect on the earth, but it has no directly harm to human being, so in generally it is taken as a innocuous emissions. Noxious emissions, also known as contaminant, comprise carbon monoxide (CO), nitrogen oxide (NOx), hydrocarbon (HC), aldehydes (RCHO), multiring hydrocarbon (PAH), soot particle and sulfur dioxide (SO2), hepatic gas (H2S) exhausted from burned fuel including Sulphur and so on [2].

Aiming at the need for energy saving and emission reduction from a diesel engine, it is important to develop the measures reducing the fuel consumption and emissions from a diesel engine. But they are often contradictory and restricting each other, for example, despite improving combustion could improve the performance and decrease fuel consumption, but the promotion of the maximum burning
temperature would make the NO\textsubscript{X} emission higher at the same time. How to deal with this kind of contradiction well has become a technical problem facing today. In this paper, the performance matching tests of YC6112 diesel engine electronically controlled with different configuration were carried out, the relationship between NO\textsubscript{X} emission and fuel consumption was analyzed and the effect of relatively better matching plan is found.

2. Experimental plan
A YC6112 diesel engine has been approved by the market for its excellent performance plenarily, the quantity demanded for a YC6112 diesel engine of the market straight climb [3]. So this paper selected the diesel engine as the subject to be analyzed accurately.

2.1. Experiment circumstance
According to the requirement from appendix C of GB/T 17692 - 1999 “Measurement Methods of Net Power for Automotive Engines”, the experiment should be carried out under the standard atmosphere condition [4].
That is: Temperature (T\textsubscript{0}) = 298 K (25\degree C), Dry air pressure (PS\textsubscript{0}) = 99 KPa, Dry air pressure is obtained by calculation based on total air pressure is 100KPa, and water vapour partial pressure is 1KPa.
When there is a difference between the test atmosphere condition and the standard atmosphere condition, the measure power on site should be corrected.
According to GB/T 17692 - 1999 “Measurement Methods of Net Power for Automotive Engines”, Measurement methods of net power for automotive engines, to diesel engines, P\textsubscript{0} = \alpha\textsubscript{d} \times P.
In the formula, P\textsubscript{0} means corrected power, that is the power under standard air condition. \alpha\textsubscript{d} means a corrected coefficient, and P means an observed brake power.
To make the test valid, the correction coefficient \alpha\textsubscript{d} should satisfied: 0.9\leq \alpha\textsubscript{d} \leq 1.1.
The experiment should be carried out under following air condition:
Temperature (T): 283K \leq T \leq 313K; Air pressure (PS): 80KPa \leq PS \leq 110KPa.

2.2. Experiment circle
According to the testing regulations from appendix B of GB 17691 -- 2001 “Limits and measurement methods for exhaust Pollutants from compression ignition (C.I.) Engines of vehicles”, the experiment circle was used thirteen working conditions [5], it is shown as Table 1.

| No. | Working condition | Test speed of the engine | Load percent |
|-----|-------------------|--------------------------|--------------|
| 1   | Idling speed [700 rpm] | 0 | |
| 2, 3, 4, 5, 6 | Middle speed [1330rpm] | 10, 25, 50, 75, 100 | |
| 7   | Idling speed [700 rpm] | 0 | |
| 8, 9, 10, 11, 12 | Rated speed [2200 rpm] | 100, 75, 50, 25, 10 | |
| 13  | Idling speed [700 rpm] | 0 | |

2.3. The program of matching plan
The test matching plan was shown as Table 2.
When doing exhaust experiment, according to GB 17691 - 2001., the experiment order should be consistent with thirteen working conditions of a diesel engine as indicated in table 1. NO\textsubscript{X}, PM exhaust value and smoke intensity value should be measured in accordance with thirteen working condition too. The smoke intensity value would be measured especially at both point of rotation moment point (the Serial No. 6\textsuperscript{th} in table 2.) and rated point (the Serial No. 8\textsuperscript{th} in table 2.)
According to GB / T 17692 - 1999, as to a turbine supercharge diesel engine.
The calculation formula of intake coefficient $F$ in table 2 is:

$$F = \left( \frac{99}{P_s} \right)^{0.7} \times \left( \frac{T_a}{298} \right)^{1.5}$$

In the formula, $F$ means a intake coefficient, $T_a$ means a intake absolution temperature (K), $P_s$ means a dry air pressure (KPa).

After calculation, the intake coefficient $F$ values were listed in Table 2. According GB 17691-2001, $F$ values was in the range of $0.96 \leq F \leq 1.06$, so the test was effective.

**Table 2.** The test matching plan

| Serial No. | Cam shaft | supercharger | Fuel injector | Camshaft phase       | Intake coefficient $F$ |
|------------|-----------|--------------|---------------|----------------------|------------------------|
| 1          | S6        | LX GT3576    | Delphi P717   | No shifting          | 0.97                   |
| 2          | S6        | LX GT3576    | Delphi P717   | Fore shaft 4.5°      | 0.97                   |
| 3          | S6        | LX GT3576    | Oya P718      | Fore shaft 4.5°      | 0.98                   |
| 4          | S6        | LX GT3776    | Oya P718      | Fore shaft a tooth   | 0.97                   |
| 5          | S7        | LX GT3576    | Delphi P717   | Fore shaft 4.5°      | 1.01                   |
| 6          | S7        | LX GT3576    | Delphi P717   | Fore shaft a tooth   | 0.99                   |
| 7          | S7        | LX GT3576    | Oya P718      | Fore shaft a tooth   | 0.99                   |
| 8          | S7        | LX GT3576    | Oya P718      | No shifting          | 1.00                   |
| 9          | S8        | LX GT3576    | Oya P718      | No shifting          | 0.99                   |
| 10         | S8        | LX GT3576    | Oya P718      | No shifting          | 1.00                   |
| 11         | S8        | LX GT3576    | Delphi P717   | Fore shaft a tooth   | 1.00                   |

Note: All programs are matched with Delphi EUP single fuel pump system.

### 3. Test equipment

3.1. **The diesel engine for testing**

The diesel engine used for testing is YC6112, its main technical specifications are shown in Table 3.

**Table 3.** The main technical specifications of YC6112 engines

| Model/Cylinder number | YC6G240-30/6 |
|-----------------------|--------------|
| Type                  | Vertical, straight, water cooling, four strokes |
| Cylinder diameter×Stroke | 112[mm]×132[mm] |
| Compression ratio/Displacement | 7.8L/17.5: 1 |
| Rated power / Speed   | 177 [kw]±5%/2200 [r/min] |
| Max. Torsion / Speed  | 960 [N·m] ±5%/≤1500 [r/min] |
| Intake                | supercharged, inter-cooled |
| Mean speed of piston  | 9.68 [m/s] |
| Minimum BSFC at full load | ≤215 [g/kw·h] |
| Maximum idling speed  | 2400 ~ 2450 [r/min] |
| Idling                | 700 ~ 750 [r/min] |
| Exhaust smoke /Emission | ≤3.0FSN/EURO III |
| Exhaust temperature after supercharger | ≤ 600°C |

3.2. **The main instruments and devices used for testing**

The main instruments and devices are WE42 Hydraulic dynamometer, Hang Zhou, China; EIM604 Control system, Hang Zhou, China; FCM05 Oil consumption meter, Hang Zhou, China; Tocei L40N100314W Air flowmeter, Shang Hai, China; FID123 HC analysis meter, TEST Lit. Germany; NGA2000 NOX analysis meter, Rosemount Lit. Germany; NGA2000 CO Analysis meter, Rosemount.
Lit. Germany; PS2000 Full flow dilution particle measurement system, FEV. Germany; AVL 670 Combustion analysis meter, AVL Lit. Austria; AVL 415 Smoke opacimeter, AVL. Austria.

Note: The principle of CO Analysis meter is infrared ray absorbing form analysis method NDIR. HC measurement: Heating style hydrogen flame ion HFID testing method. NOX measurement: Heating style chemical lighting CLD testing method. PM measurement: Full flow dilution sampling method. Oil injection regulation measurement: BOSCH long pipe method.

3.3. The Main functions of the instruments and devices used for testing

The main functions of the instruments and devices are as follows:

The hydraulic dynamometer is used to measure various features parameters of the engine, and together with the engine to regulate the rotating speed and torque. The oil consumption meter is used to measure the transient oil consumption, mean oil consumption and ratio oil consumption.

The combustion analysis meter is an analysis instrument to measure and analyse the smoke composition quickly, at the same time, to gauge exhaust smoke temperature, oxygen (O2), carbon monoxide (CO) and other gases parameters from the smoke, and to calculate carbon dioxide (CO2), air excess coefficient (α), and when α = 1, to measure carbon monoxide value (CO) and the pressure of pump’s ends and the needle valve lift.

The discharge gases analysis meters are used to gauge the gas concentration of HC, CO, CO2 and NOX from engine’s exhaust gases, and to calculate ratio of Air and Fuel A/F automatically.

The smoke opacimeter is used to measure the smoke intensity from engine’s exhaust gases.

The full flow dilution particle measurement system is used to measure the particle content in engine’s exhaust gases.

4. Experimental data processing

When the experiment finished, recording the total sampling mass through the filter paper. Putting the filter paper back to weighing room and adjusting the paper at least two hours, but not exceeding thirty-six hours, then weighing, and recording the total weight of the filter paper [4].

To calculate the numerical reading of gaseous exhaust substance recorded on the recording paper, the final 60s of every working condition must be found, and to determine the average reading of NOx within this period. The NOx emission and fuel consumption data obtained in the test were processed according to the GB 17691-2001 China national standard, the ratio emission quantities of various gaseous emissions in thirteen working conditions were calculated, then according to the thirteen conditions points listed in table 1., thirteen figures to show the relationship between NOx emission and fuel consumption at different rotation speed and different working torsion are drawn.

Through comparison and analysis to thirteen NOx emission and fuel consumption figures, the typically significant NOx emission analysis figures are chosen in high, middle and low speed range of engine respectively, as shown as Fig. 1 to Fig. 4.
Figure 1. Relationship between NO\textsubscript{X} emission and fuel consumption at 1990rpm/224N.m status

Figure 2. Relationship between NO\textsubscript{X} emission and fuel consumption at 1660rpm/243N.m status

Figure 3. Relationship between NO\textsubscript{X} emission and fuel consumption at 1330rpm/724N.m status
5. Analysis on test results

It can be seen from Fig. 1 and Fig. 2, in the middle and high-speed region of the engine, it is gained the best effect for S6 camshaft matching with P718 fuel injector, among them, S6 camshaft matching with GT3776 supercharger appears an obvious advantage in middle and high-speed region.

It can be seen from Fig. 3, in the low speed region, it is gained the best effect for S6 camshaft matching with P718 fuel injector also, but S6 camshaft matching with GT3576 supercharger appears an obvious advantage in NO\textsubscript{X} emission and reducing fuel consumption.

Fig. 4 shows that in the high-speed region, it is gained the better effect for P717 fuel injector configuring GT3576 supercharger, but only with S6 camshaft shifting 4.5\degree, if no shifting, the effect then appears not so obvious.

It has more obvious dominant position for above mentioned two kinds of matching of the engine relative to another configuration. From the other experiments, the following conclusion are obtained: Once S7 camshaft matching P717 fuel injector no matter there is a phase shift for camshaft or not, and how it shafted, the effect would not be satisfactory and very poor. But once S7 camshaft matching P718 fuel injector, and matching with the same supercharger GT3576, the NO\textsubscript{X} emission and fuel consumption would be much better, this effect can be seen in Fig. 5. And as shown in Fig. 5 too, S6 camshaft matching P717, the effect appears much better than S7 matching P 717 fuel injector. When S8 camshaft matching P717 fuel injector, the power is shortage for testing at the rated point, so that testing result had not been compared with others, and when S8 camshaft matching P 718, the effect is not good enough too.

6. Conclusion

On the basis of analysis of test results mentioned above, to YC6112 diesel engine deployed Delphl model single fuel pump system electronic controlled, when the engine deployed with S6 model camshaft, GT3776 model supercharger, OyaP718 fuel injector, there is an obvious advantage than other systems for the fuel consumption rate and NO\textsubscript{X} emission, so the YC6112 diesel engine could improve accordance with the result of the tests.

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