Effect of Injection Parameters on Vibration of High Pressure Common Rail Diesel Engine for Light Vehicle at Idle Speed

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Abstract. With the progress of science and technology and the improvement of people's living standards, the comprehensive performance requirements of automobiles are also increasing. Reducing engine’s vibration and noise is one of the important research contents in the field of automobile research. An experimental study was performed to investigate the effect of injection parameters on engine’s vibration at idle speed by using a four-cylinder high pressure common rail diesel engine. On the premise of not changing the components, the influence of each parameter on the vibration is compared and analyzed by changing the parameters such as main injection timing, interval of pilot-main injection, pilot injection quantity and rail pressure. The test results show that the vibration of diesel engine can be reduced by delaying the main injection timing properly, and the optimal interval of pilot-main injection is related to the main injection moment and the quantity of fuel injection. The determination of the pilot injection quantity must be determined by the pilot-main injection moment and the cycle injection quantity together in order to achieve vibration reduction. The increase of rail pressure will increase the vibration of the whole machine. Thus, the proper injection strategy is conducive to improve engine vibration characteristics.

1. Introduction

Diesel engine is one of power sources that have been in common usage in the world. Because of its power and economy quality, it is widely used in passenger vehicle, especially in light passenger vehicle. The electronically controlled high pressure common rail system is pretty popular now, adopted by most diesel engines, and it can achieve the injection pressure, fuel injection timing and spray characteristics of flexible control [1-3]. While the power and economic performance become excellent, the vibration and noise also get large. With the continuous improvement in people's living standards and the increasingly stringent environmental standards, reducing vibration and noise has become an important aspect for major automakers and consumers to consider [4].

After doing a lot of work to explore the cyclic periodic variation of the pressure in the diesel engine cylinder, Panagiotis Kyrtatos found that the combustion rate and the maximum pressure in the cylinder become larger and the vibration is strengthened when the ignition delay was longer [5]. Blunddon and Dent used numerical simulation method to calculate the pressure distribution in the cylinder at different
locations at different times in the combustion chamber. The relevant parameters such as the position of injector, fuel injection time and injection quantity were changed. The results show that the change of these parameters has a great influence on the pressure change in the combustion chamber [5]. Wei W. et al. established the finite element calculation model of diesel engine body based on HyperMesh software. After the modal calculation results and experimental data were analyzed, the rationality of the body calculation model was verified. Meanwhile, burst pressure and piston knocking force were applied reasonably to calculate the vibration velocity. According to the results, suggestions for damping were proposed [7]. In addition, companies such as German FEV, American FORD and Belgian LMS have also made great contributions to the vibration and noise analysis of internal combustion engines [8-9].

Many research results show that when the structural parameters of the diesel engine are determined, the pressure change in the cylinder is mainly determined by the combustion law in the cylinder. The combustion law is closely related to the fuel injection parameters, so the fuel injection parameters of the diesel engine have an important impact on the vibration of the diesel engine. In order to investigate the influence of fuel injection parameters on diesel engine vibration, this paper takes a high pressure common rail diesel engine as the object, changes the injection parameters of idle speed conditions, and measures the vibration acceleration signal of vibration measuring points. The measurement results are analyzed, and the influences of main injection timing ($T_{in}$), interval of pilot-main injection ($T_{int}$), pilot injection quantity ($Q_{pre}$) and rail pressure ($p_{fin}$) on diesel engine vibration are summarized, so as to provide a basis for finding an optimal matching control for diesel engine operation.

2. Test device and scheme

2.1. Test object and installation requirements
The test was carried out in a standard engine noise semi-anechoic laboratory. The test prototype was a domestic SD4V25R-100 supercharged intercooled diesel engine equipped with Chengdu Witt's WFR-14 high pressure common rail system and 3601010-4JD1R-33ECU electronic control unit. The main equipments include CW350 eddy current dynamometer produced by Luoyang Kaimai, EMD0301-V1.0 control system and software of Hangzhou Crowd Company, FCM05 fuel consumption meter, KMK-02 medium cooling controller and KLQ7 intercooler produced by Hubei Dengfeng heat exchanger factory. KISTLER’s 8766A50M5 accelerometer is used as the sensor and LMS’s SCAdasSCM01/SCM-V4-II signal acquisition system and LMS TestLab 12 A-Signature Acquisition analysis software are used to collect and analyze the vibration signals. The accessories installed in the engine including an air cleaner, an intercooler controller, a transmission, a generator, a steering pump, and an air conditioner compressor. The base is elastically supported. The laboratory ambient pressure is 100.5 KPa, the temperature is 11℃, and the humidity is 50%. All experiment was carried out under warm start condition. The main technical specifications of the diesel engine are shown in Table 1.

| Parameters                        | Value                  |
|-----------------------------------|------------------------|
| Type                              | In-line water-cooled supercharged four-stroke diesel engine |
| Bore×Stroke/mm                    | 92×94                  |
| Number of cylinder                | 4                      |
| Type of combustion chamber        | direct injection       |
| Rated power/(kW)                  | 95                     |
| Rated torque/(r/min)              | 3600                   |
| Maximum torque/(N•m)              | 340                    |
| Maximum speed/(r/min)             | 1800～2400             |
| Size/(mm)                         | 710×630×765            |
| Idle speed/(r/min)                | 750±25                 |

Table 1. Main technical specifications of diesel engine
2.2. Measuring point arrangement

Usually, the natural frequency of the elastic vibration of the engine assembly and its suspension system does not exceed 30 Hz. In this range, the engine vibration only has a rigid body mode, so the engine can be simplified into a space rigid body. According to the GB/T 7184-2008 standard, the acceleration signal is measured at five points on the surface of the engine. The specific distribution and test site are shown in Table 2.

| Number | Position                                      |
|--------|----------------------------------------------|
| 1      | Cylinder head (boss beside high pressure rail in side of intake) |
| 2      | Body (boss above the oil sipstick)           |
| 3      | Gear chamber cover (boss above the center wheel) |
| 4      | Body (boss under the oil filter)             |
| 5      | Cylinder head (boss under the valve cam cover in side of flywheel) |

2.3. Test scheme

The vibration signals of diesel engine at idle speed conditions (750r/min, no load) under different fuel injection strategies were respectively measured. The pilot injection parameter setting of the engine itself is mainly -3°CA for the main injection timing (the top dead centre is 0°CA, the crank angle is positive before the top dead center), the interval of pilot-main injection is 8°CA, the pilot injection quantity is 1.5mg/str, the rail pressure is 40 MPa, and the cycle injection quantity is 4mg/str under this condition. In order to study the influence of injection parameters on the vibration of the whole machine, the above parameters were compared and tested by single factor analysis without changing the parts. Table 3 shows the ECU control schemes for different injection parameters set under different working conditions. Each group of schemes only changes one injection parameter based on the original setting of the engine. T represents the temperature of cooling water. All tests were carried out under the hot start condition of the testing machine [10].
Table 3. ECU control scheme of idle speed measurement condition

| Number | $T_{fin}$/°CA | $T_{int}$/°CA | $Q_{pre}$/mg | $p_{fin}$/MPa | T/°C |
|--------|---------------|---------------|--------------|--------------|------|
| 1      | -5            | 8             | 1.5          | 40           | 48   |
| 2      | -3            | 8             | 1.5          | 40           | 48   |
| 3      | -1            | 8             | 1.5          | 40           | 48   |
| 4      | 1             | 8             | 1.5          | 40           | 48   |
| 5      | -3            | 8             | 1.5          | 35           | 48   |
| 6      | -3            | 8             | 1.5          | 30           | 48   |
| 7      | -3            | 8             | 0            | 40           | 48   |
| 8      | -3            | 8             | 1            | 40           | 48   |
| 9      | -3            | 6             | 1.5          | 40           | 48   |
| 10     | -3            | 10            | 1.5          | 40           | 48   |

3. Test results

3.1. Influence of pilot injection quantity on vibration of the whole machine

The pilot injection quantity is set to 0 (no pilot injection), 1mg, 1.5mg under the idle speed condition (750r/min, no load). Figure 2 shows the vibration intensity of the whole machine under different pilot injection quantity.

![Figure 2. Vibration intensity of the whole machine under different pilot injection quantity](image)

The results show that with the increase of the pilot injection quantity, the vibration of the whole machine increases a lot, and vibration with pilot injection is higher than that with no pilot injection. The vibration intensity of no pilot injection under idle speed condition is 0.557 mm/s. When the pilot injection quantity is 1.5mg under idle speed condition, the vibration intensity is 0.726 mm/s, 30.3% higher than that without pilot injection. Taking the pilot injection quantity of 1mg at idle speed as an example, the pilot injection quantity is 1mg, accounts for 25% of the total circulating fuel injection and 33% of the main injection volume, so the pilot injection ratio is excessive. Excessive pilot injection ratio makes the pressure increase rate in the pilot injection phase increase rapidly, and the high-frequency pressure shock increases, eventually increasing the vibration of the whole machine. So the determination of the pilot injection quantity must be determined by the main injection timing and the cycle injection quantity, and can be adjusted in different working conditions.
3.2. Influence of pilot-main injection interval on vibration of the whole machine

The interval of pilot-main injection is set to 6°CA, 8°CA, 10°CA under the idle speed condition. Figure 3 shows the vibration intensity of the whole machine.

![Figure 3. Vibration intensity of the whole machine under different interval of pilot-main injection](image)

The test data shows that the interval of pilot-main injection has a certain influence on the vibration intensity. The vibration intensity of 6°CA interval of pilot-main injection under idle conditions is 6.5% lower than that of 8°CA. The interval of pilot-main injection determines the pilot injection time under certain conditions of the main injection timing. If the interval of pilot-main injection is small, the pilot injection time will be later, so that the pilot injection combustion is not enough, and its effect is greatly reduced. If the interval angle is too large, the pilot injection is too early, the pilot injection combustion ends prematurely, the purpose of the pilot injection is not be reached. The proper interval of pilot-main injection should be a little bit smaller than the pilot injection’s ignition delay period.

3.3. The effect of main injection timing on the vibration of the whole machine

Figure 4 shows the change trend of vibration intensity of the whole machine after changing the main injection timing under idle conditions.

![Figure 4. Vibration intensity of the whole machine under different main injection timing](image)

It can be seen from the figure that with the delay of the injection timing, the vibration intensity of the diesel engine is gradually reduced. The vibration intensity of 1°CA is 3.2% higher than that of -3°CA, and the vibration intensity of -5°CA is 1.2% lower than that of -3°CA. When the fuel is injected earlier,
the gas temperature and pressure are relatively low when the fuel enters the cylinder, and the slower reaction speed of the fuel causes the mixing time of the fuel and the air to be lengthened, resulting in prolonged ignition delay. Moreover, the increase of the fuel injection advance angle causes the ignition start point to move forward, and at this time, the quantity of combustibles accumulated in the cylinder is large, so that the maximum burst pressure and the maximum pressure increase rate are increased, and the vibration generated by the combustion is also large. On the basis of this, delaying the main injection timing properly can reduce diesel vibration.

3.4. Influence of rail pressure on vibration of the whole machine

The high pressure common rail is the mainstream trend of the current diesel engine. The high pressure oil pump, pressure sensor and ECU form a closed loop system, which separates the injection pressure generation and the injection process from each other. The high pressure oil pump delivers the high pressure fuel to the common fuel supply pipe. The oil pressure in the oil supply pipe is precisely controlled, so that the pressure of the high pressure oil pipe is independent of the engine speed, and the diesel fuel supply pressure can be greatly reduced as the engine speed changes, thereby reducing the defects of the conventional diesel engine. The magnitude of the rail pressure also has an effect on the vibration of the diesel engine. Under the idle speed condition of 750r/min, the rail pressure is adjusted to 30MPa, 35MPa, 40MPa, and the vibration intensity is shown in Figure 5.

![Figure 5](image)

Figure 5. Vibration intensity of the whole machine under different rail pressure

It can be seen from the figure that the vibration intensity of the whole machine increases with the increase of the rail pressure. The vibration intensity at 30 MPa and 35 MPa is reduced by 10.7% and 9.4% compared with that at 40 MPa. After the rail pressure is increased, the injection pressure is increased, and the amount of fuel injected into the cylinder per unit time is increased. At the same time, the increase of the injection pressure is beneficial to accelerate the fuel atomization, resulting in more combustible mixture during the deflagration period, and the combustion process is worsened, the pressure increase rate increases a lot, thus making the vibration of the whole machine larger. Appropriate reduction of rail pressure can reduce vibration.

4. Conclusion

1) The pilot injection quantity is determined by the pilot-main injection time and the cycle injection quantity. In order to reduce the whole machine vibration caused by pilot injection, accurate and continuous control of the pilot injection quantity is required according to the change of working conditions.

2) The interval of pilot-main injection has a certain effect on the vibration intensity. The proper interval of pilot-main injection should be a little bit smaller than the pilot injection’s ignition delay period.
3) With the delay of injection timing, the vibration intensity of the diesel engine is gradually reduced. Properly delaying the main injection timing can reduce the vibration of the diesel engine.

4) Increased rail pressure will lead to high pressure rise rate, which will aggravate the vibration of the whole machine.

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