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Study on Effect of the High Pressure Common Rail System on the HPD Diesel Engine Combustion

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Study on Effect of the High Pressure Common Rail System on the HPD Diesel Engine Combustion

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Abstract. The CFD simulation model of the spray and combustion in the cylinder of the diesel engine was built by mean of the FIRE software and was checked through the test; the influence of the common rail pressure and the injection period on the velocity field, fuel-air equivalent ratio distribution and the temperature field were studied when the injection mass was constant; the influence of injection timing on the velocity field, fuel-air equivalent ratio distribution and the temperature field was studied when the common rail pressure and the injection period were constant. The study provided the foundation to match the high pressure common rail system parameters.

1. Introduction

The HPD diesel engine had a high speed and a short time combustion process [1]. It was the key to improve the performance of the diesel engine by properly organizing the mixing of fuel and air near the top dead center(TDC) [2-4]. The fuel injection and combustion process in the diesel engine cylinder were very complicated, and it was difficult to obtain the microscopic information such as velocity field, fuel-air equivalence ratio distribution and temperature field in the combustion chamber using the traditional test method. This paper used FIRE software to establish CFD model for the spray and combustion in-cylinder of the diesel engine. The simulation model was used to analyse the influence of the injection characteristics of the high pressure common rail system under different control parameters on the combustion process of HPD diesel engine. From the microscopic characteristics, the influence law of control parameters was studied.

2. Mathematical model of fuel evaporation process in cylinder

According to the Dukowicz model [5], the fuel evaporation process injected into the cylinder was simulated. The model made certain assumptions about the oil droplets. The equation was finally described as:

$$m_d c_{pd} \frac{dT_d}{dt} = \dot{Q}\left(1 + L\frac{\dot{f}_{vs}}{\dot{q}_s}\right)$$

In formula： m_d —Droplets quality; c_{pd} —Specific heat capacity of droplets; L —Latent heat of fuel gasification; $\dot{Q}$ —Heat transfer from the surrounding medium to the droplet; $\dot{q}_s$ —Partial surface heat flow; $\dot{f}_{vs}$ —Steam mass flow.

3. Meshing and verification of the calculation results

3.1Computational area meshing

Any simulation calculation had certain conditions. In order to take into account the practical effect of calculation and the reasonable application of computing resources in the actual calculation, the corresponding system was simplified, and some combustion chambers were calculated. Under the same conditions, the calculation after simplifying the model could shorten the calculation time. The piston geometry model and the combustion chamber geometry model were shown in Figures 1 and 2.

Figure 1. Piston geometry model

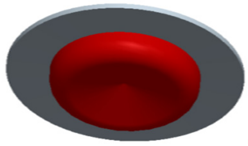

Figure 2. combustion chamber geometry model

Meshing was performed using the ESE function module of the FIRE software. The mesh model was shown in Figures 3 to 5.

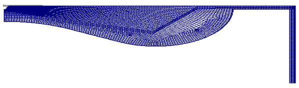

Figure 3. 0° Grid

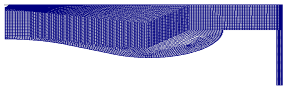

Figure 4. 30° Grid

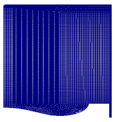

Figure 5. 180° Grid

3.2Comparative analysis of calculated cylinder pressure curves

The simulation calculation conditions were as follows: the rated speed of the diesel engine was 3600r/min, the single-cylinder circulating fuel injection amount was 141.2mg, the common rail pressure was 150MPa, the calculation starting angle was the intake valve closing angle, and the ending angle was the exhaust valve opening angle, according to the diesel engine. The phase of the valve was calculated from 621° to 829°.

The Eddy Dissipation Model was used to calculate the fuel mixing, atomization and combustion process in the diesel engine cylinder. The simulation of the simulated cylinder pressure curve and the test cylinder pressure curve was shown in Fig. 6.

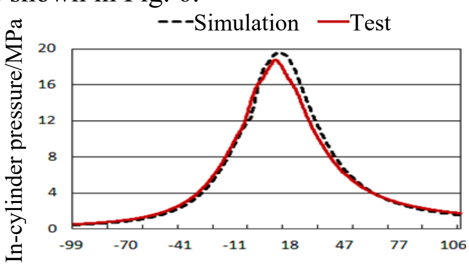

Figure 6. Comparison of simulation result and test result

It could be seen from Fig. 6 that the maximum error between the simulation result and the test result was less than 7.3%, and the accuracy of the model meet the requirements, the simulation calculation and analysis of the in-cylinder spray and combustion of the diesel engine could be performed.

4. Influence of Common Rail Pressure and Energization Time on Combustion in the Cylinder

On the one hand, the common rail pressure affects the fuel injection pressure. On the other hand, when the fuel injection amount was constant, the energization time, that was, the fuel injection duration was changed. Reasonable determination of the fuel injection end point and the corresponding fuel injection duration was a complex problem, which involved the length of the retarding period, the fuel injection law and the proportion of the fuel injection amount during the deflagration period and the amount of fuel injected into the cylinder after the fire. In addition, the fuel injection end point and fuel injection duration were also related to the presence or absence of airflow movement in the combustion chamber and its strength and formation. Therefore, analysing the influence of common rail pressure and energization time change on the velocity field, fuel-air equivalence ratio and temperature field in the diesel engine cylinder was of great significance for the matching and optimization of diesel engine control parameters.

4.1Influence of common rail pressure and energization time on the velocity field in the cylinder

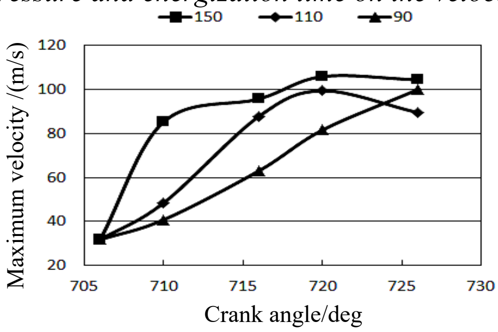

Figure 7. Comparison of the maximum velocity in different common rail pressure

From the calculation results in Fig. 7, it could be seen that the fuel injection amount was constant, the maximum velocity of the velocity field at the TDC was 106 m/s when the common rail pressure was 150 MPa, the maximum flow velocity at the TDC was 99.474m/s when it was 110 MPa and the maximum velocity at the TDC was only 81.65m/s when it was 90MPa.During the whole fuel injection process near the TDC, the highest velocity in the cylinder increased when the common rail pressure increased. This was mainly because: when the fuel injection amount was constant, as the common rail pressure increased, the fuel injection duration was shortened, the injection rate and the kinetic energy carried were increased, and the disturbance to the air was enhanced, so that the overall speed of the field was increased, and the oil droplets were broken and atomized. At the same time, it could be seen from Fig. 7 that when the common rail pressure was 90 MPa, the fuel injection amount was constant, the fuel injection duration became longer, and the amount of oil injected into the cylinder before the TDC was small, and the amount of oil injected into the cylinder after the TDC was large, so that the average flow velocity in the cylinder after the TDC was higher, and the maximum flow rate continued to increase.

Increasing the common rail pressure could promote the atomization of the fuel. However, if the geometry of the combustion chamber was improperly matched, the amount of fuel injected to the wall would increase and the fuel consumption rate of the diesel engine would increase. The common rail pressure was too small, the injection pressure was reduced, the fuel atomization was deteriorated, and on the other hand, the fuel injection duration was prolonged, and the airflow velocity of the bottom of the cylinder inner combustion chamber along the wall surface was higher during the expansion process, and the afterburning was severe, and the exhaust energy loss was increased. Therefore, for HPD diesel engines, increasing the common rail pressure to improve the fuel atomization in the cylinder, not only had to match the geometry of the combustion chamber to reduce the amount of fuel wall adhesion, reduce the fuel consumption rate, but also the oil quantity and the fuel injection duration were matched to reduce the exhaust loss and increase the power of the diesel engine.

4.2Influence of common rail pressure and energization time on the fuel-air equivalent ratio in the cylinder

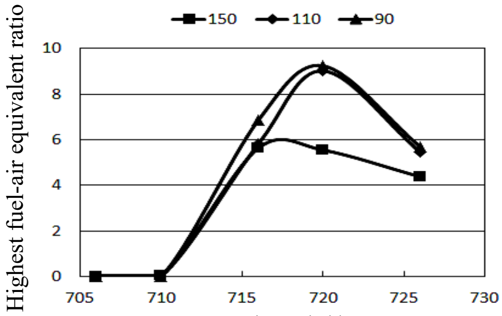

Figure 8. Comparison of the highest fuel-air equivalence ratio in different common rail pressure

It could be seen from the calculation results in Fig. 8 that when the common rail pressure was 150 MPa, the highest fuel-air equivalent ratio near the TDC was 5.5473, when it was 110 MPa, the highest fuel-air equivalent ratio near the TDC was 9.0198, When it was 90 MPa, the highest fuel-air equivalent ratio near the TDC was 9.2451. When the common rail pressure was large, the maximum fuel-air equivalent ratio in the cylinder was relatively small, and the area where the fuel-air equivalent ratio was close to 1 was large; when the common rail pressure was small, the maximum fuel-air equivalent ratio in the cylinder was relatively large, and the area where the fuel-air equivalent ratio was close to 1 was smaller.

As the common rail pressure increased, the relative motion of the fuel and air injected into the cylinder was more severe, and the more combustible mixture was formed in the combustion chamber, the closer the fuel-air equivalent ratio was to 1. At the same time, as the common rail pressure increased, the penetration distance of the injection in the combustion chamber was large, and the amount of fuel on the wall increased.

As the common rail pressure decreased, the formation of combustible mixture in the cylinder was relatively delayed, so that the amount of rich mixture in the cylinder at the later stage of combustion was still large, resulting in a decrease in the heat release rate of the combustible mixture and a decrease in thermal efficiency. It could be seen from Fig. 8 that when the crank angle was 726° and the common rail pressure was 90 MPa, the maximum fuel-air equivalent ratio in the cylinder was 5.6912, and it was 110 MPa, the maximum fuel-air equivalent ratio in the cylinder was 5.4549, and it was 150 MPa, the maximum fuel-air equivalent ratio in the cylinder was 4.3779.

4.3Influence of common rail pressure and energization time on temperature field in the cylinder

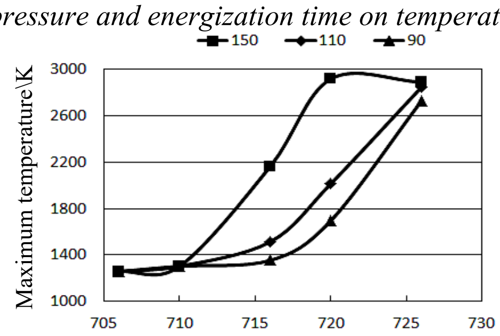

Figure 9. Comparison of the maximum temperature in different common rail pressure

It could be seen from the calculation results in Fig. 9 that with the increase of the common rail pressure, the maximum temperature of the temperature field in the cylinder during the whole fuel injection process near the TDC increased, when the common rail pressure was 150 MPa, the highest temperature in the cylinder at the TDC reached 2919.5K, when it was 110MPa, the maximum temperature in the cylinder at the TDC was 2015.2K, when it was 90MPa, the maximum temperature in the cylinder at the TDC was only 1696.1K; when it was 150MPa, the maximum temperature in the cylinder gradually decreased after the TDC, when the it were 110 MPa and 90 MPa, the maximum temperature of the mixed gas in the cylinder continued to rise after the TDC.

From the analysis of the common rail pressure change to the velocity field and the fuel-air equivalence ratio distribution of the in-cylinder mixed gas, it could be known that when the common rail pressure was large, the fuel injection pressure was large, the average velocity in the cylinder was high, and the fuel-air equivalent ratio was relatively small, there was more combustible mixtures formed during the compression process, and the fire was earlier, and the temperature inside the cylinder was higher; when the common rail pressure was small, the injection pressure became smaller on the one hand, and the injection duration became longer on the other hand, the amount of oil in the cylinder was more after the TDC, and the temperature continued to rise after the TDC, the combustion mainly occurred during the expansion period, the heat release rate decreased, and the thermal efficiency decreased.

5. Effect of fuel injection timing on combustion process in diesel engine cylinder

The common rail pressure and energization time was kept constant, and the effects of different injection timing on the velocity field, fuel-air equivalence ratio and temperature field of the cylinder were studied.

5.1Influence of fuel injection timing on velocity field in the cylinder

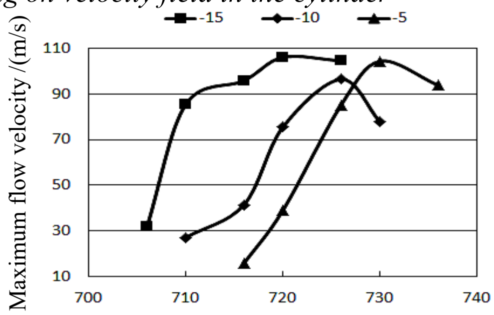

Figure 10. Comparison of the maximum velocity in different injection timing

It could be seen from the calculation results in Fig. 10 that when the injection timing was -5°, the maximum velocity of the velocity field in the cylinder at the injection start point was 15.882 m/s, when it was -10°, the maximum velocity was 27.161m/s, when it was -15°, the maximum velocity was 31.755m/s; when it was -5°, the maximum velocity of the velocity field in the cylinder at the TDC was 39.046m/s, when it was -10°, The maximum velocity in the cylinder at the TDC was 75.476 m/s, when it was -15°, the maximum velocity in the cylinder at the TDC was 116.08 m/s.

With the advance of injection timing, the velocity field in the cylinder at the beginning of injection had a higher flow velocity, and the relative movement of the fuel after injection into the cylinder was more severe, which was conducive to fuel cracking and atomization at the initial stage of fuel injection. At the same time, with the advance of injection timing, the maximum flow velocity in the combustion chamber near the TDC increased, and the average flow velocity in the combustion chamber before the TDC was higher, which was conducive to fuel fragmentation and atomization, the atomization fuel increased during the stagnation period which lead to an earlier start of combustion, and the highest burst pressure and maximum pressure rise rate in the tank rise. Therefore, the timing of the injection was advanced, although the mixing and atomization of the fuel could be promoted, but the combustion in the cylinder became severe, and the mechanical and thermal load on the cylinder block, the cylinder head and the piston increased.

5.2Influence of injection timing on the fuel-air equivalent ratio of internal combustion in cylinder

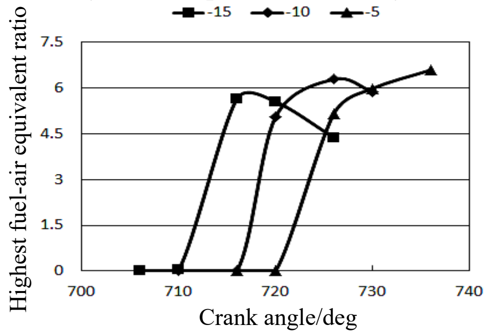

Figure 11. Comparison of the highest fuel-air equivalent ratio in different injection timing

It could be seen from the calculation results in Fig. 11 that when the injection timing was -5°, the highest fuel- air equivalent ratio in the cylinder at the TDC was relatively small, only 0.005, and when the injection timing was -10°, the highest fuel- air equivalent ratio in the cylinder at the TDC was 5.051, and the maximum fuel-air equivalent ratio in the cylinder at the TDC was 5.5473 when the injection timing was -15°. With the delay of injection timing, the highest fuel-air equivalence ratio in the cylinder at the TDC became smaller, mainly because the amount of oil injected into the cylinder before the TDC was less, and the air was more, the amount of fuel involved in the mixing was small, and the fuel-air equivalent ratio in the cylinder was relatively low.

The injection timing was changed from -5° to -15°. At the TDC, the area where the fuel-air equivalent ratio was close to 1 became larger, the oil and gas mixture was more sufficient, and the fuel quantity during the anti-storage period increased. At the same time, the possibility of forming an oil film on the wall in the combustion chamber was increased, and the combustion temperature and the maximum burst pressure in cylinder were increased.

When the injection timing was -10° and -15°, the fuel-air equivalent ratio in cylinder gradually decreased after the TDC, and when the injection timing was -5°, the fuel-air equivalent ratio in the cylinder continued to rise after the TDC. As shown in Fig. 11, when the injection timing was -5° and the crank angle was 726°, the maximum fuel-air equivalent ratio in the cylinder was 5.1529, and when the crank angle was 730°, it was 5.9799. This was mainly because that as the injection timing was pushed back, the fuel injection was too late. When the piston descended after the TDC, a large amount of fuel was injected into the cylinder, so that the fuel-air equivalent ratio in the cylinder was increased.

In summary, the fuel injection was earlier, the fuel-air equivalent ratio in the cylinder was relatively small, which was conducive to the mixing of fuel and air, but would increase the burst pressure and pressure increase rate in the cylinder; the fuel injection was late, which was beneficial to reduce the burst pressure and pressure rise rate, but would increase the afterburning.

5.3Influence of injection timing on temperature field in diesel engine cylinder

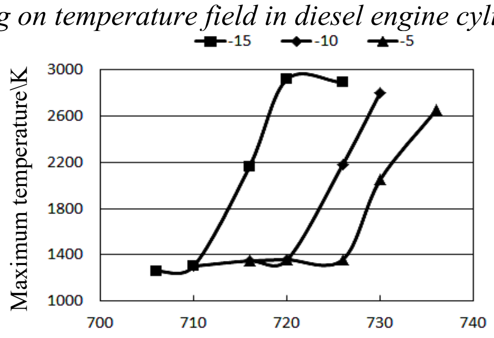

Figure 12. Comparison of the maximum temperature in the cylinder in different injection timing

From the calculation results in Figure 12, it could be seen that when the injection timing was -5°, the maximum temperature in the cylinder at the fuel injection starting point was 1349.1K, and the

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maximum temperature at the TDC was 1358.1K; when it was -15°, the maximum temperature in the cylinder at the fuel injection starting point was 1257.7K, the maximum temperature at the TDC reached 2850.1K;when it was -15°, the maximum temperature in the cylinder after the TDC was lowered, when the injection timing was -10° and -5°, the maximum temperature continued to rise after the TDC.

The advanced injection timing lead to low the maximum temperature in the cylinder at the fuel injection starting point, advance the combustion starting point and increase the maximum temperature and maximum burst pressure of the cylinder gas; the injection timing was postponed so that the combustion process mainly occurred during the expansion period, and the heat release rate decreased, the thermal efficiency was reduced.

6. Conclusion

In this paper, a CFD simulation model for in-cylinder spray and combustion of a certain type of HPD diesel engine was established, the influence of the control parameters of the injector on the combustion process of the diesel engine cylinder was analysed, and the influence law of the control parameters was clarified. It could be seen from the calculation results that when the fuel injection amount was constant, as the rail pressure increased and the energization time was shortened, the average velocity of the velocity field in the cylinder increased, which was beneficial to fuel atomization, but would cause the combustible mixture increased in the pre-combustion period, the maximum burst pressure and temperature increased and the combustion process became severe. At the same time, when the rail pressure was further increased, the fuel which was injected on the wall was increased. Therefore, when the diesel power density was further increased, not only the injection pressure should be increased, but also the shape of the combustion chamber must be matched to achieve the desired effect; as the injection timing was advanced, the velocity field in the cylinder was higher at the initial stage of injection, which was beneficial to fuel atomization. In the initial stage of fuel injection, the temperature in the cylinder was lower; the retardation period became longer, the combustible mixture during the deflagration period increased, and the highest burst pressure and maximum temperature in the cylinder raised.

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