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Effect of the Structure Parameters of High Pressure Common Rail System on Engine Performance

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Abstract: The structure parameters of high pressure common rail system have a direct effect on high pressure common rail system performance, thus affecting the whole engine performance. In order to make a good match of the high pressure common rail system and engine, GT-SUITE engine performance analysis software is used to establish the high pressure common rail system and the coupling model of engine, analysis the effect of the injector control volume, the mass of the needle valve and the number and the diameter of nozzle hole on the engine performance (dynamics, fuel economy and emissions).We can see from the result that when the control volume is not under the minimum limit, we should reduce the control volume; on the condition of keeping the needle valve working smoothly, we should reduce its mass; according to the common rail pressure and biggest injection quantity requirements and combined with the combustion chamber shape to choose the diameter and the number of the injection hole. Only in these ways, can we get a better engine performance.
Key words: Diesel engine; high pressure common rail system; numerical simulation

I. Introduction

Diesel engine electric control high pressure common rail inject technology is a type of technology that can improve the oil economy characteristic and emission characteristic. Because its good performance in economy and emission, add the good motivation performance of diesel engine, make it get a lot of research in Europe, Japan and America, and be used in automobile system widely. But its research in China is in early stage, and there is a big gap with the first level, so it is necessary to research it. The research abroad mainly focus on improve the engine performance, decrease the emission and noise. Like: the research in system pressure waving [1-2]; the research in oil spraying and burning process [3];the effect of control strategy on engine performance and emission [4]. There are some researchers do some research in high pressure common rail system in China. Like: the effect of high pressure common rail system key structure parameters on the law of injection [5-6]; the effect of high pressure common rail system structure parameters on response characteristic [7]; the effect of high pressure common rail system structure parameters on system performance and its improvement [8]. However, the most researches focus on the high pressure common rail system itself, don't consider the influence between the common rail system and the engine. So we build the model with GT-SUITE software, and combine with the test, analysis the effect of injector control volume, needle valve mass, nozzle hole number and diameter on diesel engine performance, provide the basis for the high pressure common rail system optimization.

II. Model build and validate

2.1 Model build

The model we build in the message include two parts: the diesel engine model and high pressure common rail system model.

The engine we used to build the model is 4HK1-TC, its style is in-line arrangement, water -cooling, four stroke, and fuel injection form is electric control high pressure common rail injection. Its main technical parameters is shown on the table 1.

Tab.1the main technical parameters of diesel engine

Parameter name	Cylinder number N_1	Cylinder diameter D/mm	Cylinder stroke l/mm	Compression ratio$r$
Numerical value	4	115	125	17.5：1
Parameter name	Engine displacement VL/L	Rating power P/kW	Rating speed n/(r•min^{-1})	Maximum torque T/(N•m)
Numerical value	5.193	147	2100	686

The high pressure common rail system we used to build the model is BOSCH CRSN2-16, its main technical parameters is shown on the table 2.

Tab.2 the main parameters of high pressure common rail

Parameter name	Common rail diameter d_1/mm	Common rail volume V_1/ml	Outhole diameter d_2/mm	In hole diameter d_3/mm	Control chamber volume V_2/ml
Numerical value	10	15	0.30	0.21	15

Parameter name	Oil spray hole number N_2	Oil spray hole diameter d_4/mm	Needle valve mass m/g
Numerical valve	6	0.18	3

The diesel engine model include three parts: induction system, cylinder and exhaust system. when we build the model, the boundary condition of inlet is the temperature is 350k and the pressure is 0.26Mpa; the boundary condition of outlet is the temperature is 700k and the pressure is 0.15Mpa. The flow model we used in cylinder is EngCylFlow model and EngCyPistCup model, they are used to compute the flow velocity of gas and the turbulent intensity, the compute result can be used in the heat transfer model and the combustion model. The combustion process simulation in the cylinder is the core part in the simulation of the engine working process, it can influent the reliability and computational accuracy of the entire simulation directly. The combustion model we used is DIJET model, because DIJET model is compliant in direct injection diesel engine, and it can be used to forecast the combustion rate and the NO_X emission, also can forecast the Soot emission, but because the limit of the model, the forecast of the Soot emission is not very accurate, only can be used to forecast the trend [9].The heat transfer computation is use EngCylHeatTr part and EngCylTWall part. When compute the heat transfer coefficient, we use the woschni model. And we used the InjProfileCoon part to simulate the diesel injection.

The high pressure common rail system include three parts: high pressure oil pump, common rail and injector. We build the common rail model and injector modelon the basis of the structure and working principle of high pressure common, treat the high pressure oil pump as boundary condition like a stable high pressure oil source.

The model we build is as fig.1 shows.

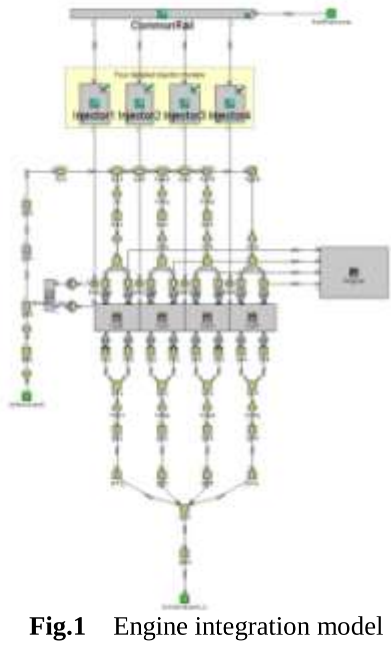


Fig.1 Engine integration model

III. Model validate

In order to make sure the correct of the model, we use the experiment datathat be gotten from the high pressure common rail system test bench. The engine rotate speed we choose is 1000-3500r/min, and we compare the simulation results and the experiment data on the power, torque and NO_X emission, the results we get is shown under.

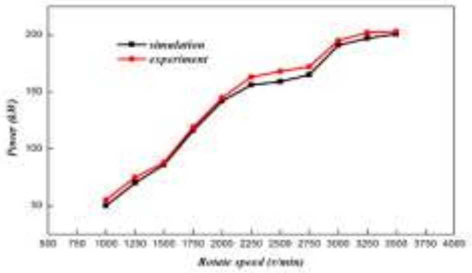


Fig.2 the comparison of power from experiment and simulation under different rotate speed

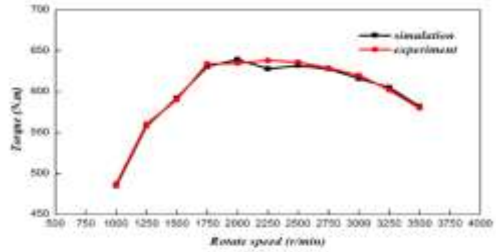


Fig.3 the comparison of torque from experiment and simulation under different rotate speed

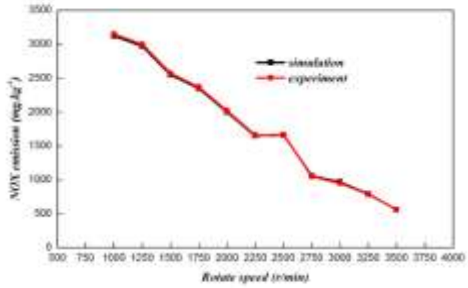


Fig.4 the comparison of NO_X emission from experiment and simulation under different rotate speed

From the figures above we can see that the deviation between simulation data and experiment data is under 5%, so we consider the simulate model has enough accuracy, can be used to simulate.

IV. Simulation results and analysis

Because the engine performance mainly includes dynamic performance, economic performance and emissions performance. So we use the indexes like the torque, the fuel consumption, the NO_x and soot emissions to measure the effect of the key structure parameters of the high pressure common rail system on the engine performance inthis text. The rotate speed we use is 2100r/min, the common rail pressure is 150Mpa, the fuel injection advance angle is$-17°$CA, the fuel injection law is rectangular jet.

4.1 The effect of control volume

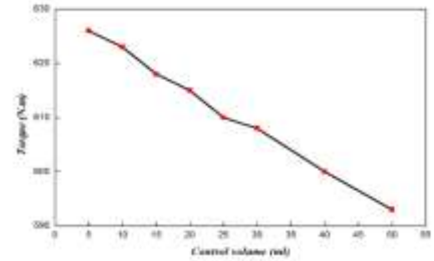
In the condition of the other factors is unchanged, the control volume is collected between 5-50mm^3, and use it to simulate.

The fig.5 is the simulation results of the effect of the control volume on the engine performance, and the fig.5 (a) is the effect of different control volume on engine torque. We can see from the figure that with the increase of the control volume, the engine torque is to linearly decrease as a whole. The reason is that the size of the control volume make a big different on the pressure establishment in the control room. When the control volume is small, the pressure establishment in the control room quickly, when the electromagnetic valve opens, the pressure in the control room decreases quickly, the needle valve lifts quickly; when the electromagnetic valve closes, the pressure in the control room increases quickly, the needle valve seats quickly. When the control volume is big, the needle valve cannot lift and seat quickly, makes the poor fuel atomization, the fuel in the cylinder cannot combust timely and completely, and the engine torque declines.

The fig.5 (b) is the effect of different control volume on engine fuel consumption. We can see from the figure that with the increase of the control volume, the engine fuel consumption is increase at first and decrease after volatility, and the size is little, it's under $1\text{g} \cdot (kW \cdot h)^{-1}$, so we can consider that there is no effect of control volume on the size of fuel consumption, the effect mainly focuses on the violate feature. The reason is that the decreases of the control volume make the lift of needle valve decreases, the injection resistance increases, and the fuel pressure fluctuation frequency and range in the control room and sheng oil chamber increase, it makes the needle valve lifts, maintains and seats instability, makes the injection abnormal, so the fuel consumption put up the characteristics of volatility. We also can find that with the decreases of the control volume, the vitality feature is stronger.

The fig.5 (c) is the effect of the different control volume on engine emission. We can see from the figure that there is nearly no difference of the NO_x and soot emission with the different control volume. So we can consider that there is no effect of the control volume on engine emission.

From the analysis above we can see that the small control volume can improve the engine power, but if the control volume is too small, it will cause the needle valve lifts, maintains and seats instability, makes the injection abnormal, worsens the economic performance.Besides this, because the maximum lift makes sure, so the height of the control room is limited, it is appropriate to choose the control volume between 20mm^3 and 30mm^3.



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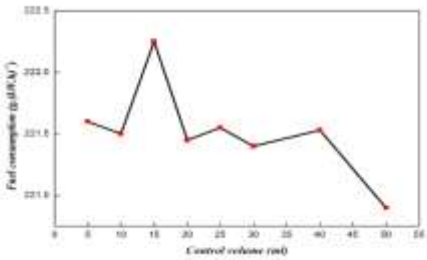

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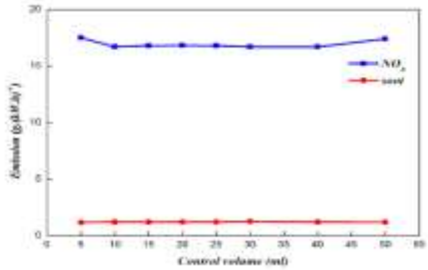


(c)

Fig.5the effect of control volume on the engine performance

4.2 The effect of needle valve mass

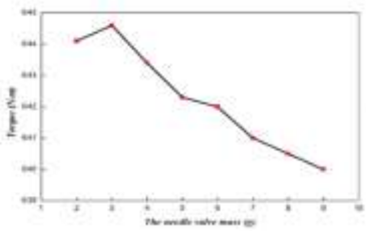
The needle valve mass we set is range from 2g to 9g, and we simulate to different needle valve mass.

The fig.6 is the effect of needle valve mass on engine performance. And the fig.6 (a) is the effect on engine torque, we can see from the figure that when the needle valve mass is 3g, the engine torque reaches the maximum. When the needle valve mass is bigger than 3g, with the increases of the needle valve mass, the engine torque decreases. The reason is that the smaller the needle valve mass, the response speed more quickly, however, the stability is worse, so when the needle valve mass is less than 3g, because the effect of the stability is bigger than the effect of the response, the engine torque decreases.

The fig.6 (b) is the effect on engine fuel consumption, we can see from the figure that with the increase ofthe needle valve mass, the volatility of fuel consumption decreases, the reason is that the increase of mass cause the increase of the stability. We also can find that to the engine fuel consumption, the effect of the stability is bigger than the effect of the response characteristics.

The fig.6 (c) is the effect on engine emission, we can see from the figure that there is nearly no effect on NO_x and soot emission.

We can see from the analysis that when we choose the needle valve mass, we should make sure the needle valve working stability, and then we decrease the needle valve mass.



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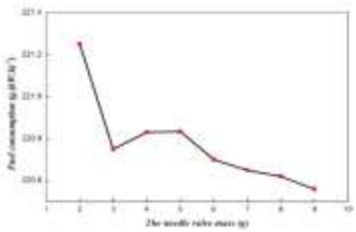

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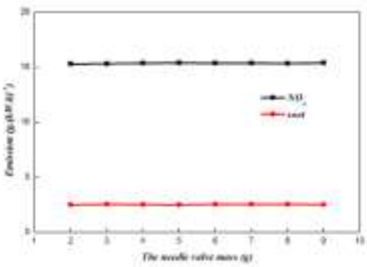


(c)

Fig.6 the effect of needle valve mass on the engine performance

4.3 The effect of nozzle holes number and nozzle hole diameter

We set up 11 groups of different nozzle number and diameter in the simulation. The 1-5th groups is set up different nozzle hole number and diameter on the condition of the total circulation area is 0.1570mm^2, and the 6-10th groups is set up different nozzle hole number and diameter on the condition of the total circulation area is 0.1884mm^2, and the 11th group is used to compare. The detail is shown in the tab.3.

Tab.3 the nozzle holes number and diameter

number	1	2	3	4	5	6
Nozzle hole number	4	5	6	7	8	4
Nozzle holediameter d_5/mm	0.2236	0.2	0.1826	0.1690	0.1581	0.2449
Total circulation area m/mm^2	0.1570	0.1570	0.1570	0.1569	0.1570	0.1883

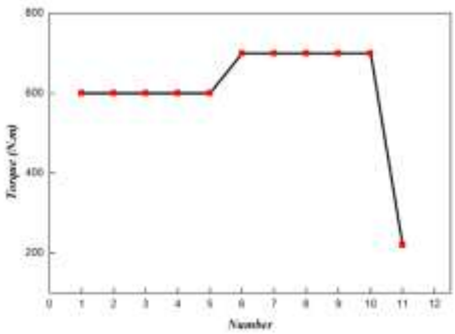
number	7	8	9	10	11
Nozzle hole number	5	6	7	8	6
Nozzle hole diameter d_5/mm	0.2191	0.2	0.1852	0.1732	0.16
Total circulation area m/mm^2	0.1884	0.1884	0.1884	0.1884	0.1206

The fig.5 is the simulation results of the effect of the nozzle holes number and diameter on the engine performance. And the fig.7 (a) is the effect of the nozzle holes number and diameter on the engine torque. We can see from the figure that, there is nearly no change of torque in the 1-5th groups, there is nearly no change of torque in the 6-10th groups too, but there is a big increase compare to the 1-5th groups, and there is a decrease in the 11th group. We can see that the engine dynamic performance is mainly affected by the total circulation area. The reason is that the increase of the total circulation area causes the increase of the fuel-injection quantity, and then the burning fuel increases in the same time, so the torque increases. The torque decrease in the 11th group is because the total circulation area is so little that the combustion in the cylinder is abnormal.

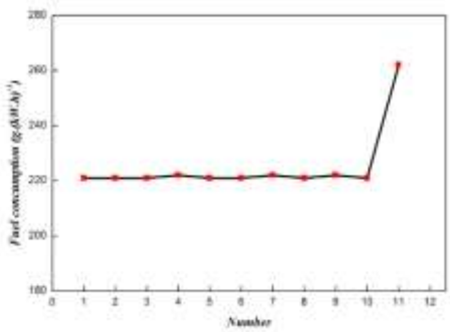
The fig.7 (b) is the effect of nozzle holes number and diameter on the engine fuel consumption. We can see from the figure that there is nearly no effect on the engine fuel consumption, and because of the combustion abnormal in the cylinder, the engine fuel consumption increases in the 11th group.

The fig.7 (c) is the effect of nozzle holes number and diameter on the engine emission, we can see from the figure that when the total circulation area is the same, the NO_x emission increases when the nozzle holes number increases, the reason is that when the nozzle hole number increases, although the decrease of the nozzle holes diameter can improve the fuel atomization, but if we want to form the homogeneous mixture, there has something matter with the combustion chamber shape. Because the combustion chamber shape is unsuitable, the NO_x emission increases. The increase of total circulation area causes the decrease of the NO_X, it maybe be caused by the factors like common rail pressure and the combustion chamber shape. The soot emission increases when the total circulation area increases, the reason is the increase of the fuel-injection quantity causes the combustion incompletely.

We can see from the analysis above that the choice of the nozzle holes number and diameter should consider the common rail pressure, the combustion chamber shape and the fuel-injection quantity.



(a)



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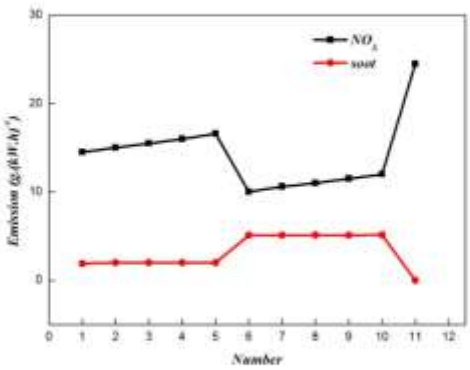

(c)

Fig.7 the effect of nozzle number and nozzle number on the engine performance

V. Conclusion

(1) The size of control volume affects the pressure building in the control room, and then influents the engine performance. If the control volume is little enough, the pressure volatility increases, the fuel economy deteriorates. But with the control volume increases, the engine dynamic performance decreases. So on the condition of injection normal, we should reduce the control volume.

(2) The lighter of the needle valve mass is, the more rapidly the response speed, and the better the engine dynamic performance, but the stability decreases, worsen the engine economic performance. So on the condition of working steadily, we should reduce the needle valve mass.

(3) The smaller the nozzle holes diameter is, the better the atomization, the better the combustion performance. But if we want to get a good engine performance, we should consider the effect of the combustion chamber shape, the injection pressure and the fuel-injection quantity.

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