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Simulation Analysis and Research on Combustion Characteristics of Marine Natural Gas Engine

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***Abstract* – The effects of ignition energy, ignition advance Angle and injection time on engine combustion characteristics were studied by AVL-FIRE model. The results show that the injection time has a great influence on the combustion performance of the natural gas engine, and there is an optimal injection advance Angle for a given working condition. Improving ignition energy and ignition advance Angle can make up for the slow propagation of natural gas combustion to a certain extent, which can promote the combustion characteristics of the engine, but it should be controlled within a reasonable range.**

***Keywords* – AVL-FIRE, Combustion Characteristics, The Moment of the Jet, Ignition Energy, Ignition Advance Angle.**

I. Introduction

In today's society, with the shortage of petroleum energy and the increasingly strict emission requirements of maritime emission laws and regulations, it has become an irresistible trend to find a kind of fuel that can replace the traditional fuel as the power fuel of various modern high-power Marine engines[1][2]. As the main component of natural gas is methane, it has the advantage of abundant reserves and low price, so it is widely concerned by researchers all over the world. Although Marine natural gas engine and traditional fuel engine are very similar in structure and other aspects, due to the special physical properties of natural gas itself, the combustion characteristics are still very different from that of traditional fuel[3]. Therefore, it is of great significance to conduct simulation research on the combustion characteristics of Marine natural gas engine.

In this paper, the Z6170 Marine engine produced by Zichai Power Co., Ltd. is used as the prototype, and the in-cylinder combustion model of natural gas engine is established by using AVL-FIRE software. The accuracy of the model is verified by comparing the bench test data built by Zichai with the simulation data. According to the characteristics of the 3D model used in this paper, natural gas is assumed to exist in the combustion chamber in the form of premix and mixed evenly. This paper mainly studies the effects of four important operating parameters, including ignition energy, excess air coefficient, ignition advance Angle and jet time, on the combustion and emission process of the natural gas engine through simulation. The main contents include the following:

(1) Use PRO/E software to establish the geometric model of the combustion chamber, divide the grid and select appropriate combustion model, turbulence model, ignition model, emission model and other calculation sub-models.

(2) By adjusting different model parameters, the error of cylinder pressure curve obtained from bench test and cylinder pressure curve obtained from simulation model is controlled within 5% to ensure the feasibility of the calculation model.

(3) Taking the ignition energy of 30mj, the ignition advance Angle of 10 °CA, and the injection time as 310 °C

-A before the compression top dead center as references, the combustion and emission characteristics of the natural gas engine were numerically simulated by changing the above parameters, and the results were compared and analyzed. In addition, the optimization scheme was obtained by using the orthogonal experimental design method.

II. TEST DEVICE AND SCHEME

2.1. *Model Building*

The research content of this paper does not include the intake stroke and exhaust stroke, the calculation range is from the intake valve closed to the exhaust valve opened this period of the crankshaft Angle, namely 580 °CA to 835 °CA, to sum up, according to the geometric size of Z6170 diesel engine combustion chamber using modelling software Solid Works to draw a three-dimensional model[4]. As shown in Figure 2.1, it is divided into action grids as shown in Figure 2.2.

Fig. 2.1. 2D diagram of combustion chamber.

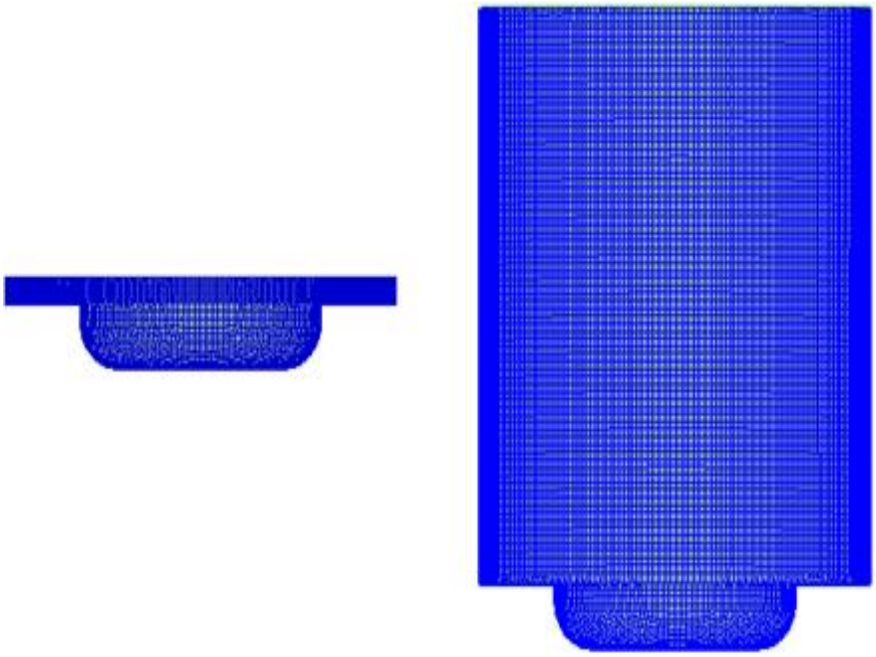

Fig. 2.2. 3D moving mesh model.

2.2. *Boundary Conditions*

The setting of initial conditions mainly includes two parts. First, the setting of relevant parameters such as pressure, temperature, turbulent kinetic energy, etc[5][6]. Secondly, the natural gas adopts the pre-mixed intake way[7]. This paper does not involve the study of the intake link, so it is assumed that natural gas as a component of air has been evenly mixed in the combustion chamber.

In this paper, the initial pressure is 0.2MPa and the temperature is 370.15K. Turbulent kinetic energy and turbulent length scale can be obtained by the following processes.

(1) Tubulence Energy (TKE)

$$TKE = \frac{3}{2} * u^2 \tag{1.1}$$

in, $u = 0.5 * C_m, C_m = 2 * h * \frac{n}{60}$

In the Green band *TKE*: tubulence energy (m^2/s^2), *u*: Turbulent pulsation velocity (m/s), C_m: average piston speed (m/s), *h*: piston stroke (m), *n*: engine speed (r/min).

The initial turbulent kinetic energy can be obtained by substituting the relevant parameters of the engine into the formula *TKE* = 37.5 m^2/s^2.

(2) Length Scale (TLS)

$$TLS = \frac{h_v}{2} \tag{1.2}$$

In, *TLS*: length scale (m), h_v: Maximum valve lift (m).

Base on computation, length scale TLS = 0.00631 m, In addition, the software can automatically calculate the turbulent dissipation rate based on the turbulent kinetic energy and turbulence length scale TDR[8][9].

III. Test Results and Analysis

3.1. *Effect of Ignition Energy on Combustion Performance*

As can be seen from Fig. 3.1, there is no heat release in the cylinder before combustion occurs. When the crankshaft Angle is around 713 °CA, the fuel in the cylinder starts to ignite. This is due to the high ignition energy, which is easier to ignite under the same conditions. After the spark plug ignites the natural gas, the natural gas rapidly burns and releases a lot of heat, and the heat released finally reaches its peak. It can be seen from the figure that with the increase of ignition energy, the duration of the heat released by the combustion in the cylinder gradually becomes shorter, which indicates that within a certain range, the higher the ignition energy, the better the ignition state of the natural gas, and the more concentrated the heat release of the fuel in the cylinder.

As can be seen from Figure 3.2, the maximum pressure in the cylinder increases with the increase of ignition energy, and the greater the value, the earlier the inflection point of the pressure in the cylinder. As can be seen from the figure, the law of the influence of different ignition energies on the pressure in the cylinder is that with the reduction of ignition energy, the pressure rise rate of the initial combustion slows down[10]. This is because the ignition energy is small, the instantaneous combustion is small, and the overall combustion is slow. However, when the ignition energy increases, the instantaneous ignition mixture increases, that is, the natural gas is ignited in large quantities. Fig. 3.3 shows the variation curve of the influence of different ignition energies on the temperature in the cylinder. In the figure, the variation trend of the temperature curves under different ignition energies is consistent, which increases first and then decreases.

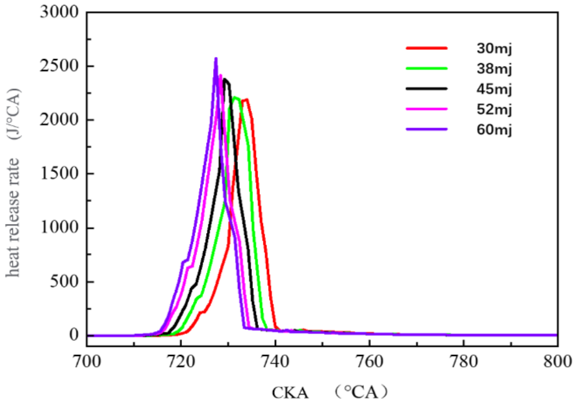

Fig. 3.1. Effect of ignition energy on heat release rate.

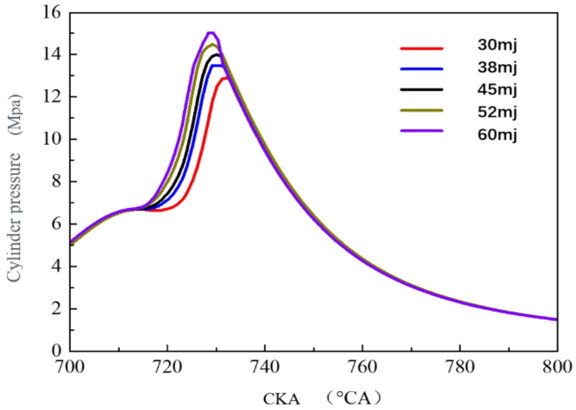

Fig. 3.2. Effect of ignition energy on cylinder pressure.

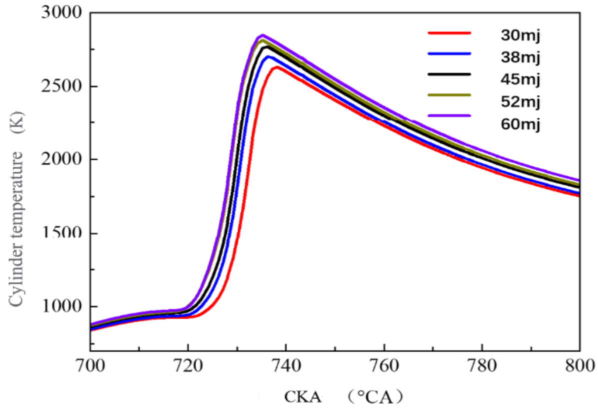

Fig. 3.3. Effect of ignition energy on temperature.

3.2. *Effect of Ignition Advance Angle on Combustion Performance*

Fig. 3.4 shows the variation curve of combustion heat release rate with ignition advance Angle. As can be seen from the figure, with the advance of ignition time, the inflection point of heat release in the cylinder is also advanced; the instantaneous heat release rate presents a trend of first increasing and then decreasing; the peak time of heat release rate also advances with the advance of ignition time[11]. This is because the spark plug ignits before the piston reaches the top dead center, and the earlier it ignits, The earlier the gas starts to burn, the earlier it spreads, and the earlier it reaches its peak heat release.

As can be seen from Fig 3.5, the pressure in the cylinder increases with the increase of ignition advance Angle, and the peak time also advances with the increase of variable value. However, if the value of the variable is too large, it will lead to too intense combustion, easy to produce rough work and other phenomena. Fig. 3.6 reflects the variation law of ignition advance Angle on the temperature in the cylinder. It can be seen from the figure that, with the increase of variable value, the peak value of the temperature curve in the cylinder is larger and the inflection point is earlier. The resulting heat leads to a relatively high pressure in the cylinder, which provides a good ignition condition for the fast burning period.

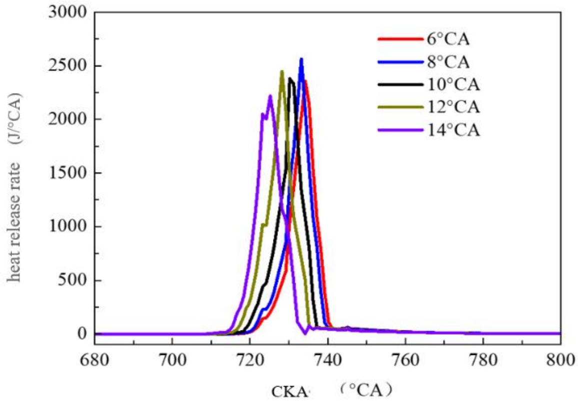

Fig. 3.4. Effect of ignition advance Angle on heat release rate.

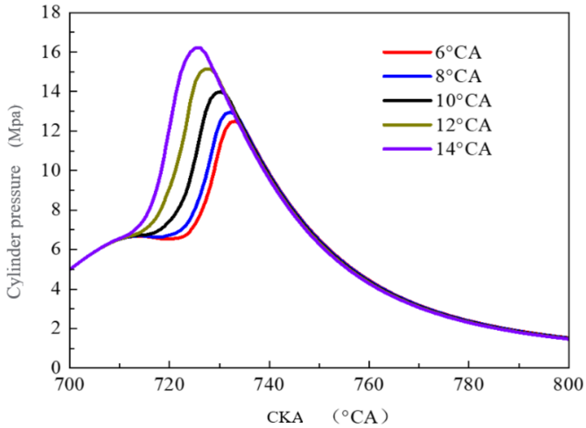

Fig. 3.5. Effect of ignition advance Angle on cylinder pressure.

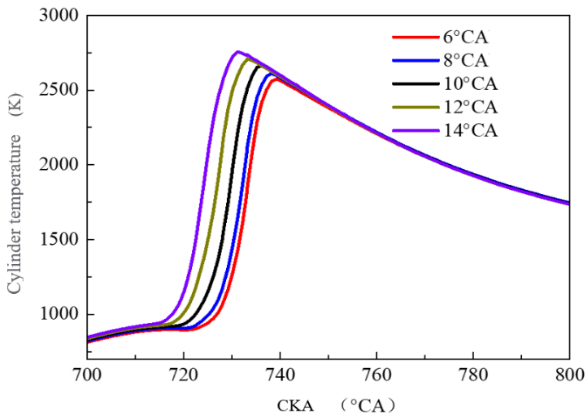

Fig. 3.6. Effect of ignition advance Angle on temperature.

3.3. *Effect of Injection Time on Combustion Performance*

Fig. 2.7 shows the influence of different injection times on the curve of combustion heat release rate. As can be seen from the figure, there are certain fluctuations in the heat rate curve at different injection moments, and it can be intuitively seen that, with the delay of the injection moment, the time point at which the heat release rate curve peaks is more delayed. The reason for this phenomenon is that the later the injection moment is, the more uneven the mixture of natural gas and oxygen injected into the cylinder, resulting in the hysteresis of combustion and diffusion[12]. Conversely, the earlier the injection, the more evenly the natural gas and oxygen mix, the earlier the peak heat release in the cylinder. Although the later injection time can make the combustion in the cylinder more concentrated, it is necessary to be vigilant that the concentrated heat release in a short time is easy to lead to a sudden increase in the pressure and temperature in the cylinder, resulting in rough work and other phenomena, which is not conducive to the work of the engine[12].

Fig. 2.8 shows the variation of the cylinder pressure with the crankshaft Angle at different injection moments. When the injection moment is 360°CA before the top dead center, the cylinder pressure reaches its maximum value. Fig. 2.9 shows the influence of air injection time on the temperature in the cylinder. It can be seen from the figure that, under the condition of the earliest air injection time, the peak value of the temperature curve in the cylinder is the largest, and the peak time is earlier. Under the condition of the same air injection time, the change of the temperature in the cylinder always increases first and then decreases.

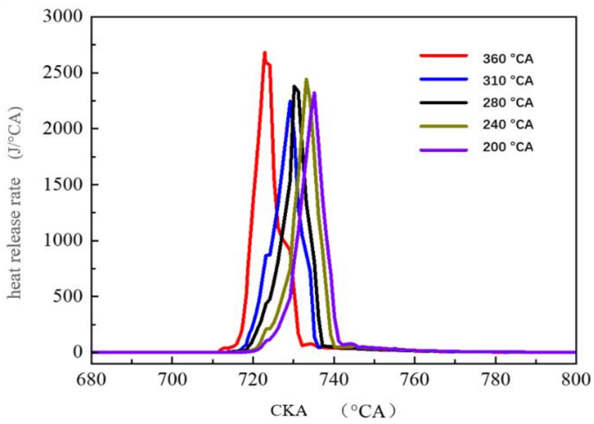

Fig. 3.7. Effect of the time of air injection on the rate of heat release.

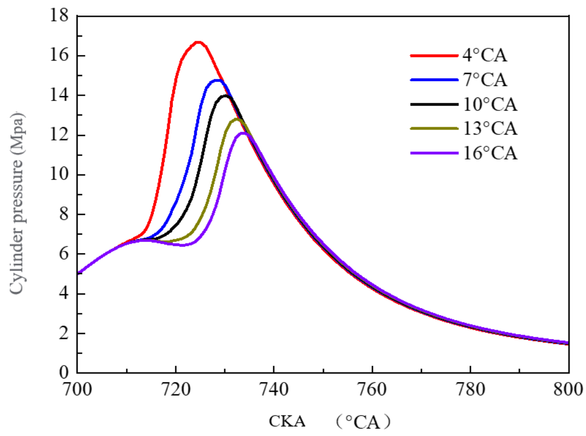

Fig. 3.8. Effect of air injection time on cylinder pressure.

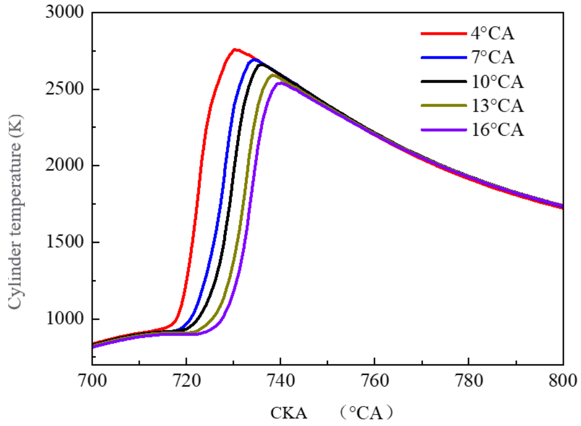

Fig. 3.9. Effect of air injection time on temperature.

IV. Conclusion

(1) The size of the ignition energy also determines the quality of the whole combustion process. In comparison, a larger ignition energy also represents a better combustion. Under the premise of ensuring the spark plug performance, the ignition energy can be appropriately improved.

(2) A larger ignition advance Angle will bring better combustion environment and heat release, but if the value is too large, the combustion will be too intense, easy to produce rough work and other phenomena, so the ignition advance Angle should be increased as far as possible within the range of meeting the requirements.

(3) The time of air injection is also an important factor that determines the quality of combustion. Earlier time of air injection creates more sufficient mixing time of fuel and oxygen, and only when the mixture is uniform will the combustion be better. Therefore, air injection should be carried out as early as possible.

(4) Through the comparison of various data obtained from the simulation test, the optimal solution obtained according to the three different parameters is to select a larger ignition energy, a larger ignition advance Angle and an earlier injection time. However, in practical application, it is necessary to analyze the specific situation and set up multiple sets of experiments to obtain the optimal solution.

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AUTHOR'S PROFILE

Mingxin Zhang, As a graduate student in Shandong University of Technology, majoring in vehicle engineering, I have learned the performance of Marine natural gas engines from Professor Liu Yongqi. I have participated in many academic forums on engines in the past three years, and have rich knowledge on engines. After graduation, I will continue to devote myself to engine research.