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Research On Thermal Load Characteristics Of Piston Based On Fluid-Structure Coupled Heat Transfer

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Abstract: In order to study the thermal load characteristics of piston, the temperature field of piston is predicted based on fluid solid coupling heat transfer numerical simulation. A numerical model for the coupled heat transfer of a piston is established. The top surface of the piston, the bottom of the combustion chamber, is used as the coupling surface of the fluid and the solid, and the fluid mechanics software FLUENT is used to simulate the heat transfer. By comparing the calculated cylinder pressure with the experimental data, the correctness of the spray combustion simulation is verified. Comparing the temperature distribution of piston at different time, the results show that the transient temperature field of piston can be obtained directly by the fluid solid coupling method, which reflects the transient change of the temperature field of the piston. For the whole piston, the temperature fluctuation of the coupling surface defined in this paper is larger, the temperature fluctuation in other places is smaller. The flow field in the combustion chamber has a certain effect on the temperature field of the piston, where the direct contact with the gas has a greater impact, and the place where it does not directly contact with the gas has less influence.

1.Introduction

As one of the core of the internal combustion engine parts, piston in the cycle of work, the long-term impact of high temperature gas and the effect of cyclic heat load, making the piston head high temperature, and uneven distribution, the larger temperature gradient produces thermal stress and thermal deformation, which affects the service life and performance of the piston. Therefore, the correct prediction of piston thermal load is beneficial to prolong the service life of the piston and optimize the piston performance [1-3]. The most intuitive and effective way to evaluate piston thermal load is to obtain the piston temperature field [4].

At present, the fluid-solid coupling method is mainly used for the study of the overall coupling of the engine. Among them, Lu Xiaofei and Zhong Lei [5] of the North China Engine Research Institute have calculated the flow and solid coupling of the piston and its cooling oil cavity by using the average gas temperature and the average heat transfer coefficient calculated by the combustion calculation as the wall surface heat boundary conditions. Finally, the simulation results of the piston temperature field are obtained. Ling Youlin and Pan Zhigang[6] used the finite element software and fluid dynamics software to carry out the joint simulation, and obtain the piston coupling face flow heat transfer coefficient and temperature field distribution. The fluid-solid coupling method is relatively rare in the study of piston-combustion chamber, and the bottom of the piston top is the weak part of the piston and the most intense area of the piston[7-8]. In the above research,the convective heat transfer coefficient given by the empirical and semi-empirical formula is used as the thermal boundary

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condition. The steady temperature field of the piston is obtained, to some extent, it is inconsistent with the actual working environment of the piston, which is not conducive to the comprehensive analysis of the piston thermal load characteristics and the optimization of piston design. Therefore, by studying the fluid solid coupling heat transfer mode of the gas and piston in the diesel engine, the numerical model of the piston flow and solid coupling heat transfer is established, which is of great significance for the study of the heat load of the piston.

In this paper, a type of diesel engine is taken as the research object. The piston top, that is, the bottom of the combustion chamber is used as the coupling surface, is simulated by the fluid mechanics software FLUENT, and the In-cylinder module in FLUENT dynamic grid is used to simulate the cylinder movement. The combustion chamber fluid domain and piston solid domain are solved together, the cylinder pressure and temperature field distribution are obtained to analyze the influence of combustion chamber flow field on piston temperature field by comparing with experimental results and simulation results.

2.Numerical Simulation

In this paper, a model of the piston - combustion chamber fluid-solid coupling model is drawn by using the 3d modeling software CATIA, and the grid model is drawn by ICEM CFD. In this paper, the diesel engine is simulated numerically from BTDC(Before Top Dead Center) 60°CA(crank angle) to ATDC(After Top Dead Center) 60°CA. The specific parameters are shown in table 1 below.

Table 1. The specific parameters of diesel engine

Project	Parameter
Speed	1800r/min
Cylinder Bore	170mm
Stroke	195mm
Connecting Rod Length	350mm
Number Of Nozzle	5
Injection Starting Angle	337°
Injection Termination Angle	362°

2.1.Fluid-Solid Coupling geometry model and grid model

In order to study the heat load of piston, a model of piston - combustion chamber fluid-solid coupling was established. The geometry and grid graphics of the model are shown in figure 1 and figure 2. In this model, the combustion chamber formed by the top of the piston and the bottom of the cylinder head is used as the piston fluid field,the piston matrix is used as the piston solid field, as shown in figure 1. Because there is a large number of chamfering and reversing areas on the surface of the piston, the mesh size will be greatly changed when the mesh is divided. The meshed mesh is difficult to reflect the shape of the chamfering and inverted circle. While retaining the chamfering and inverted circle of the piston does not necessarily improve the calculation accuracy, this paper ignores the partial chamfering and reciprocal circle of the piston.When meshing, the cylinder part is structured grid, and the omega type combustion chamber and piston are unstructured grid. The total number of meshes is 474289 nodes. The physical property parameters of the piston material are shown in table 2

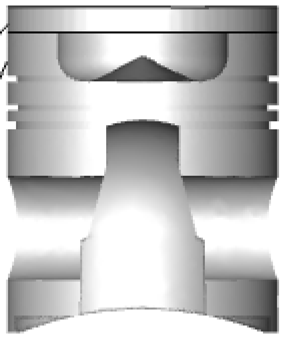

Figure 1. Geometric model of fluid solid coupling piston

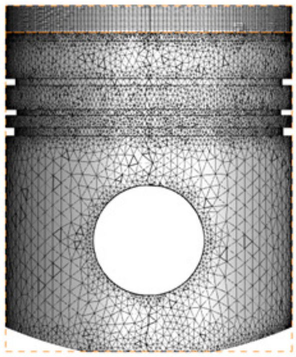

Figure 2. Mesh model of fluid solid coupling piston

Table 2. Material properties of piston material

Material	Density （kgm^{-3}）	Specific heat capacity ($Jkg^{-1}K^{-1}$)	Thermal conductivity ($Wm^{-2}K^{-1}$）
Aluminum	2719	871	2024

3.Boundary conditions

The boundary conditions of the piston fluid-solid coupling model are divided into two parts: the fluid domain and the solid domain.

3.1 Boundary conditions of fluid domain

According to the Ref.[9], the pressure and temperature at the initial state were 1.1MPa and 685K. Regardless of the intake and exhaust process, the initial moment is considered as a static flow field. The piston pits and cylinder walls are set as adiabatic boundary conditions. In the numerical simulation of spray combustion in the flow field, the RNG k-ε model is chosen for the turbulence model, the EBU model is adopted for the combustion model, and the WAVE crushing model is adopted for the droplet breakup model. In order to simulate the piston working stroke, the layer method in the dynamic mesh is used to simulate the cylinder motion. Part of the dynamic mesh in the fluid domain is shown in figure 3. Solid domain parts are rigid bodies.

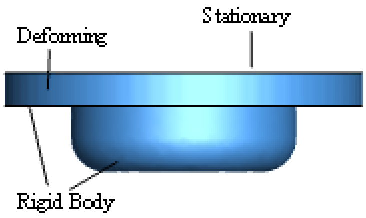

Figure 3. Dynamic mesh setting of fluid domain

3.2 Solid boundary conditions

Based on the empirical formula and the technical parameters of the piston, the surface convection heat transfer coefficient and ambient temperature are given, taking their average value for unsteady state calculation, see Ref.[10] for details. In the analysis of the transient temperature field of the piston, it is necessary to set the initial temperature as the initial condition of the simulation analysis. If the initial temperature is taken as the initial condition, it will calculate thousands of diesel engine cycles to reach the stable condition, which requires a high calculation time cost. In this paper, an approximate method is used to determine the initial condition. The steady temperature field of the piston is taken as the initial condition of the transient analysis, and the transient temperature field of the piston is analyzed on the basis of the steady temperature field.

4.Analysis of calculation results

4.1 Analysis of combustion chamber results

Figure 4 shows the comparison of the pressure in the cylinder with the experimental data obtained by the fluid solid coupling simulation under 75% working conditions. The two results are in good agreement, and the correctness of the calculation results in this paper is verified, which lays the foundation for the analysis of the effect of flow field combustion on the piston temperature.

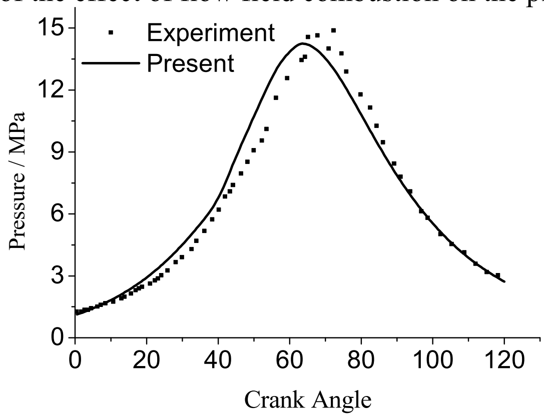

Figure 4. Comparison of pressure curves in cylinder

4.2 Analysis of piston results

Take the 30° BTDC, 20 ° BTDC and 10° ATDC moments of the piston coupling surface and cross section temperature field cloud chart as shown in figure 5-10 below.

At this time, the piston is in a pure compression state. As shown in figure 5, the piston temperature field is not affected by the combustion chamber flow field, and the coupling surface temperature distribution is relatively uniform. Among them, the piston throat and the temperature of combustion chamber pit center is the highest, 490K. It can be seen from figure 6 that the temperature field of the piston section is centered in the combustion chamber, and the temperature shows a symmetrical distribution, which shows a gradual downward trend along the radial direction and along the axial direction. Among them, the temperature of the piston throat and the center of the combustion chamber pit is the highest, 490K, the fire bank temperature is second, and the temperature gradient is large, the range of temperature changes is 454-478k. Because of the cooling effect of the cooling oil channel, the lower side temperature of the cooling oil channel is lower than that of the upper side. The bottom side of the piston skirt has the lowest temperature.

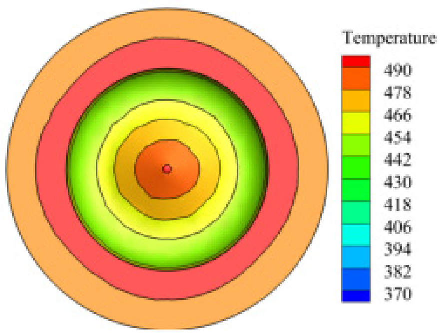

Figure 5. The temperature field cloud picture of 30 ° BTDC piston coupling surface

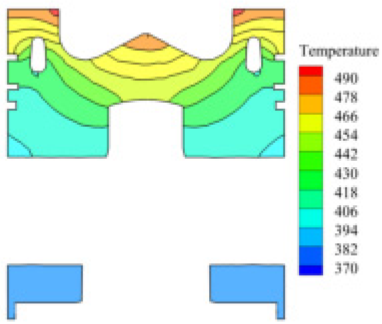

Figure 6. The temperature field cloud picture of 30 ° BTDC piston section

At this time, the piston is in the initial stage of fuel injection. As shown in figure7, the temperature distribution of the piston coupling surface is more uneven than that before the injection. Among them, the temperature at the throat of the piston rises by 10K, because it is the most serious impact on the piston during the movement of the piston. Similarly, in figure 8, the temperature in the section of the piston with the highest temperature rises by 10K. The temperature of piston skirt remained basically unchanged at about 400K.

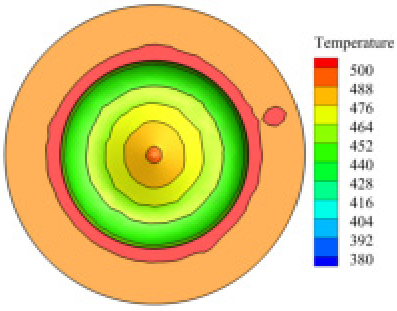

Figure 7. The temperature field cloud picture of 20 ° BTDC piston coupling surface

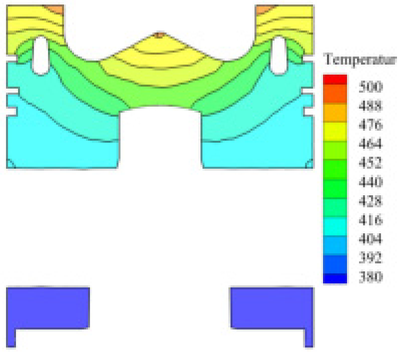

Figure 8. The temperature field cloud picture of 20 ° BTDC piston section

At this time, the running state of the piston is 8 degrees after the injection. From figure 9, it can be seen that the temperature distribution of the piston coupling surface fluctuates greatly at this time. Under the influence of the jet gas, a uniform distribution of 5 high temperature zones is formed on the coupling surface, the temperature is as high as 620K, while the temperature of the combustion chamber bit is changed with the rotation angle of the crankshaft, compared with the temperature before the injection. It dropped nearly 14K. As can be seen from figure10, the temperature change of the piston section is relatively small, and the location of the high temperature zone has not changed. The temperature of piston skirt remained basically unchanged at about 400K. It shows that the flow field of the combustor has a great influence on the temperature field of the piston which has direct contact with the gas, but has less influence on the temperature field of the piston which is not directly contact with the gas.

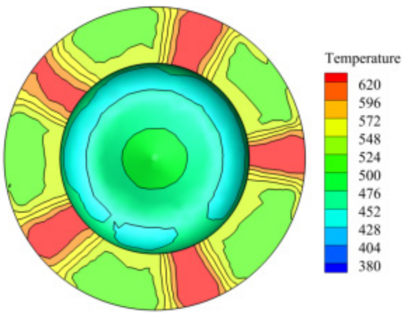

Figure 9.The temperature field cloud picture of 10 ° ATDC piston coupling surface

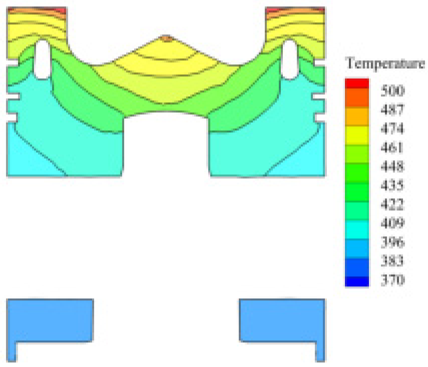

Figure 10.The temperature field cloud picture of 10 °ATDC piston section

In order to reflect the influence of flow field on the piston temperature field successfully, taking the fire bank ,which is the nearer fireside of the combustor as the monitoring surface, and obtain the curve of temperature distribution of fire bank,wich is change over time, as shown in figure 11. It can be seen that, with the change of the crankshaft angle, the temperature amplitude of the fire bank varies greatly. Before the injection, the temperature of the fire bank is basically around 485K. After the injection of oil, the temperature of the fire bank rises gradually. The temperature reaches the highest value at about 8 degrees after the end of injection, which is 712K. It is shown that the flow field in the combustion chamber has a great influence on the piston temperature near the combustion chamber.

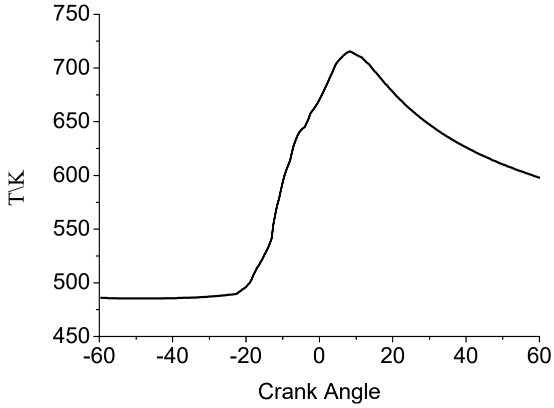

Figure 11.The temperature distribution of fire bank at each crankshaft angle

5.Conclusions

In this paper, the heat load characteristics of piston are studied by fluid solid coupling heat transfer method. By comparing the distribution of piston temperature field at different times, the influence of combustion chamber flow field on piston temperature field is analyzed. By comparing the simulation results at different times, the transient temperature field of the piston can be obtained directly by the fluid solid coupling method, which reflects the transient change of the piston temperature field. The temperature of the piston throat, the fire bank and the concave pit of the combustion chamber is the highest, and it is the most prone to deformation. It is also the place where the stress is most concentrated. That is necessary to focus on research,when study the thermal stress of the piston and the thermal deformation of the piston.Meanwhile ,the emphasis should be given to the piston design.It is considered that the flow field of the combustor has a certain influence on the temperature field of the piston near the combustion chamber and the direct contact with the combustion chamber, and the degree of influence varies with the change of the crankshaft angle. The combustion chamber flow field has the greatest influence on the piston temperature field at about 8 degrees after the injection.

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