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Analysis of the Influence of Piston Cooling Cavity on Its Temperature Field

QijieLi[1], Changshui Wu[2]

Automotive engineering institute, Shanghai University of Engineering Science, Shanghai, China.

Abstract: Engine piston cooling design is an important work of engine design. This article based on the finite element analysis method, by studying two important structure parameters of the diesel engine piston, namely the cooling oil cavity area and cooling oil cavity location, the diesel engine piston cooling effect and structure parameters' influences on the piston temperature field were studied. The results showed that: appropriately increasing the cross-section of the cooling gallery is favorable for heat dissipation, but over-dimension will lead to small cooling liquid filling ratio and thus impede the cooling; The movements of cooling gallery of the piston will have great effect on the top of the piston, the combustion chamber, the fire shore, the first ring shore and the top of the inner chamber. The research of this paper provides a basis for engine piston cooling design.
Keywords: Diesel engine;piston cooling design;temperature field; the finite element analysis

I. 1.Introduction

Piston is the core moving part of internal combustion engine. Its working environment is extremely complex. In the process of developing toward the direct injection supercharged internal combustion engine, high power, low fuel consumption and low emissions, it will inevitably lead to increase in the pressure and temperature of in-cylinder gas which will result in the piston temperature rise accordingly. Studies show that: when the temperature exceeds 300 ℃ ~ 350 ℃, the aluminum piston material`s strength will drop about 50%.When the temperature reaches above 380 ℃ ~ 400 ℃, it will not guarantee continuous and reliable operation of internal combustion engines [1-2]. Thereby it seriously affects reliability and service life of the engine.

Therefore, it is important for engine parts design, especially the piston cooling design to make the internal combustion has good durability, reliability and economy. In general, there is three ways that are improved heat transfer, combustion and adiabatic cooling injection to reduce piston heat load [3]. Among them, the more current and mature technology is adiabatic cooling injection. This paper uses finite element analysis. The main study is that piston cooling cavity's cross-sectional area and position has impact on piston temperature field and it provides a reference for the design of future high-intensity combustion engine piston.

II. Establishment of Coupling Model

2.1. Pistons Parameters

In this study, the main technical parameters of the diesel engine as shown in Table 1:

Table 1 Parameters of the diesel

Projects	Value
Engine type	Line six-cylinder engine
Bore(mm)×Stroke(mm)	110×125
Intake type	supercharger
Compression ratio	17.5
Engine speed(rpm)	2300
Displacement(L)	7.127

2.2.FEM model and Mesh

According to project size, using three-dimensional modeling software UG establishes an accurate piston model. Using intelligent meshing technology meshes the model. As shown in Figure 1:

Fig.1Three-dimensional model of the piston and meshing

2.3.Temperature field boundary conditions of piston

In this paper, the third boundary condition is taken to simulate piston's temperature. Based on engine's test data [3], using empirical formula continuously corrects parameters. Finally, we obtain the boundary conditions of piston which we need in this study. As shown in Table 2:

Table 2 piston regional medium temperature and heat transfer coefficient

Location	Temperature(dec)	Heat transfer coefficient($W/(m^2·°C)$)
Piston top surface	1100	470
Combustoredge	1100	500
Combustor circumferential	1100	400
Combustor center top	1100	450
Piston junk	150	400
The first ring grooveupper	140	2100
The first ring groovebottom	140	2000
The first ring grooveLower part	140	2100
The first ring shore	140	500
The second ring grooveupper	140	2000
The second ring groovebottom	140	1900
The second ring grooveLower part	140	2000
The second ring shore	140	450
The third ring grooveupper	130	1900
The third ring groovebottom	130	1800
The third ring groovelower part	130	1900
Piston skirt	110	300
Piston pin hole	110	300
Inner cavityupper	95	500
Inner cavitybottom	95	400
Inner cavity lower part	95	300

2.4.Heat-transfer coefficient of piston cooling oil cavity

In this paper, the heat-transfer coefficient of piston's cooling oil cavity is obtained by the empirical formula

$$\left.\begin{aligned} N_{uf} &= 0.495 R_{ef}^{0.57} D^{*0.24} P_{rf}^{0.29} \\ D^* &= \frac{D}{b} \\ R_{ef} &= \frac{hD}{\lambda_f} \end{aligned}\right\} \qquad (1)$$

which is coming from the test data of pipe flow. Heat-transfer coefficient formula as shown in formula (1):

WhereN_{uf} is Nusselt number;$P_{rf}$is Prandtl number; D is equivalent diameter of piston cooling cavity; b is mean height of piston cooling cavity; λ_f is thermal conductivity of piston cooling cavity; h is mean heat-transfer coefficient.

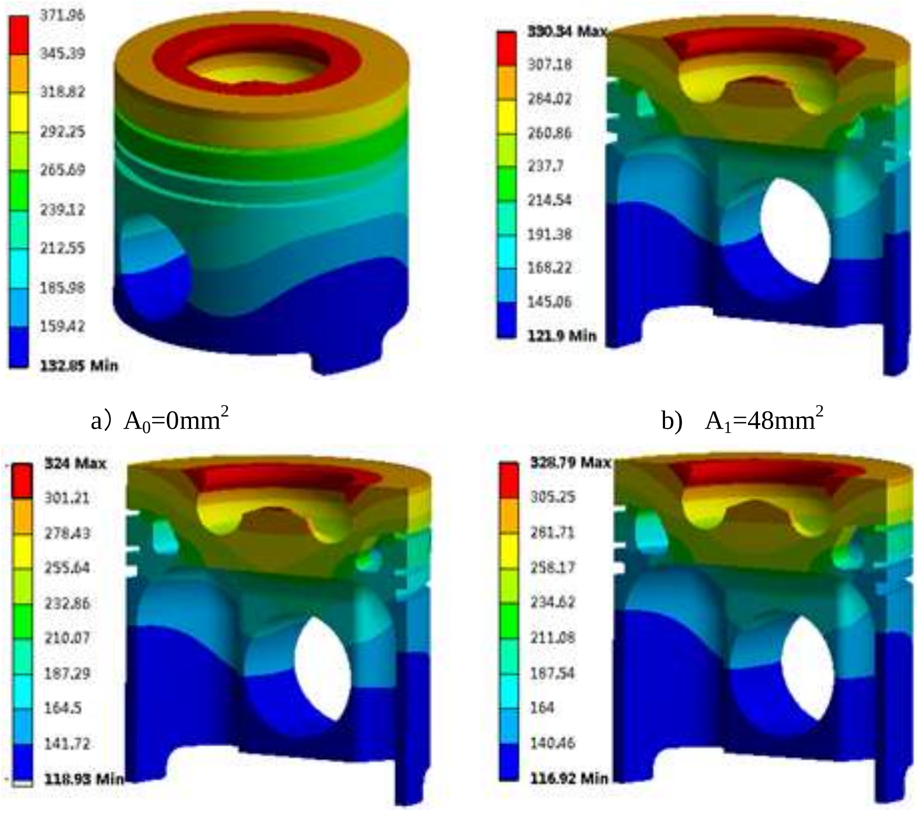
III. Simulation Results and Discussion

Temperature limit reference values of cast aluminum piston`s key parts as follows: The top surface of the piston ≤370 ℃, combustion ≤360 ℃, the first ring groove ≤260 ℃, cooling oil chamber ≤220 ℃, the top of the piston cavity ≤250 ℃, piston pin Block ≤180 ℃ [4].

Various models that have been built are imported ANSYS software. In ANSYS software, we exert appropriate boundary conditions and then solve equation to obtain the results of each piston temperature distribution model.

3.1.Effect of piston's cooling oil cavity cross-sectional area on temperature field

Cross-sectional area of the piston cooling oilcavity is set: piston (a) is A0=0mm2, piston (b) is A1=48mm2, piston (c) is A2=96mm2, piston (d) is A3=160mm2.plotting way of concentric zoom in and out is taken to guarantee cross-sectional area is unique variable. ANSYS calculation results shown in Figure 2:



a) A_0=0mm^2 b) A_1=48mm^2

c) A_3=96mm^2 d) A_4=160mm^2

Fig.2Different cooling oil cavity cross-sectional area of the piston temperature contours

Figure 2 shows:

(1) Compared figure (a) with figure (b), piston`s maximum temperature falls from 371.96 ℃ to 330.34 ℃.Piston's minimum falls from 132.85℃to21.9 ℃.Respective reduction is 41.62 ℃ and 10.95 ℃.Compared to the piston without the cooling oil cavity, we can see a small area of cooling oil chamber can effectively reduce the heat load and the cooling effect is good.

(2) Compared figure (b) with figure (c), we can see when we appropriately increase cooling oil chamber cross-sectional area, the piston maximum and minimum temperature dropped 6.34 ℃ and 2.97 ℃, respectively. The cooling effect is further improved. Analysis shows, an appropriate increase in the area of the oil chamber, can effectively reduce the cooling oil cavity coolant flow resistance and increase shock and turbulence effects in oil chamber. It's more conducive to heat.

(3)Compared figure (c) with figure (d), as shown in figure (d), however, the maximum temperature of the piston that ranges from 324 ℃ to 328.79 ℃from increased 4.79 ℃. Studies have shown that the piston cooling oil cavity coolant optimum filling ratio is 30% ~50%. If the cooling oil cavity cross-sectional area is too large, the coolant filling will be relatively small. Although there is a strong turbulent effect in the course of their work, it's limited by coolant medium flow which results heat less. In addition, the space which is vacuumed plays a part in thermal insulation. It is not conducive to heat.

3.2.Effect of piston cooling oil cavity's position on temperature field

As shown in figure 3, piston B's cooling oil cavity respectively moves up and down 2mm to obtain piston A and B.

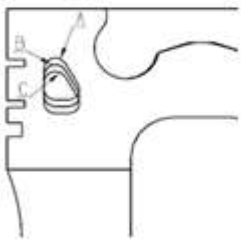
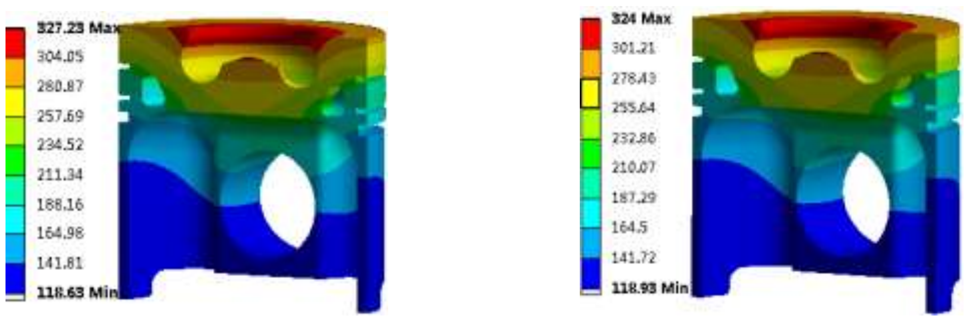
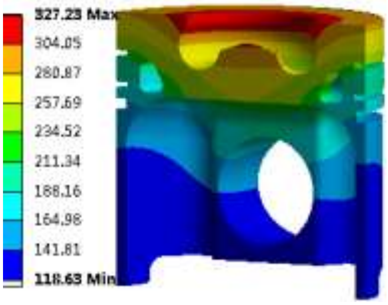


Fig.3 Diagram of cooling oil chamber

ANSYS software is used to solve the three piston temperature field, temperature field cloud shown in Figure 4:



a) Piston A b)Piston B



c) Piston C

Fig.4Different position of the piston cooling oil cavity's temperature field cloud

Figure 4 shows:

(1)Compared A with B, when cooling oil cavity shifts up 2mm, the inner maximum temperature of the top of the combustion chamber and the piston top surface will shift down 3.3 ℃.At the same time, the bottom of the combustion chamber, the top surface of the outer ring, piston junk and around top land shift down 1.74 ℃ ~ 2.91 ℃ and the piston the top chamber temperature drops 0.95 ℃ ~ 1.74 ℃. The rest of the temperature change is small and the lowest temperature of the piston is almost no change. It can be seen if the piston cooling oil chamber has a slight rise, there is great influence on the top of the piston, the combustion chamber, piston junk and top land. It will accelerate the cooling. Therefore, the temperature is lowered. Furthermore, the top of the piston inner cavity mainly passes the crankcase oil mist to cool and dissipate heat. When the cooling oil chamber moves up, the piston top and combustion temperature will be lowered. It indirectly results in the piston top and combustion temperature's reduction. The temperature decreased.

(2)Compared B with C, when cooling oil cavity shifts down 2mm, the inner maximum temperature of the top of the combustion chamber and the piston top surface will shift up 3.23 ℃.At the same time, the bottom of the combustion chamber, the top surface of the outer ring, piston junk and around top land shift up 1.66 ℃ ~ 2.84 ℃ and the piston the top chamber temperature rises 0.95 ℃ ~ 1.74 ℃. The rest of the temperature change is small and the lowest temperature of the piston is almost no change. It can be seen if the piston cooling oil cavity has a slight decline, there is great influence on the top of the piston, the combustion chamber, piston junk and top land. It will accelerate the cooling. Therefore, the temperature rises. It indirectly results in the piston top and combustion temperature's reduction. The temperature increased.

Thus, the piston head, combustion chamber, piston junk and temperature of top land are associated with down movement of the piston cooling oil cavity. Meanwhile, there is an indirect effect on the top of the piston cavity temperature and for the rest of the effect is less.

IV. Conclusions

(1)A cooling oil cavity was adopted on the piston cooling and it has a significant effect in reducing the temperature of piston. The effect of cooling oil cavity associated with its cross-sectional area. It is useful for radiating to appropriately increase sectional area which can reduce flow resistance and increase the effect of oscillation and turbulence of the cooling fluid in the cooling oil cavity. But research shows that the optimum filling ratio of cooling oil cavity is 30% ~ 50%. So if the cross-sectional area is too big, the cooling effect will be limited by cooling fluid medium flow while the part under vacuum will play the role of insulation.

(2) Moving up and down of the piston cooling oil cavity has a great influence on piston head, combustion chamber, piston junk and the first ring shore while there is an indirect relationship with top of the piston inner cavity`s temperature. Radiating of the piston inner cavity mainly passes through oil mist in crankcase. So the heat in piston inner cavity which is coming from piston head and combustion chamber is varying with the cooling oil cavity`s

position. And this is the reason why the position of cooling oil cavity has an indirect effect on the top of piston inner cavity`s temperature

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