Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2013, 5(9):388-393

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Thermal analysis of diesel engine piston

Hongyuan Zhang, Jian Xing and Chang Guo

School of Automobile and Traffic, Shenyang Ligong University, Shenyang, Liaoning, China

---

ABSTRACT

Piston as one of the most important components in a diesel engine, its thermal load always causes fatigue failure. We may design the structure of a piston on purpose and reduce its thermal load with the temperature field. This paper describes the fundamental of thermal analysis for the diesel engine piston. A calculation model of the transient gas temperature and the transient heat exchange coefficient is built based on AVL-boost software, through calculation gets the top of the piston and the piston with cooling water heat exchange coefficient and temperature distribution, calculates the temperature field of the piston with the finite element method and modifies the calculation model by repeatedly comparing the result with the measured temperature. It is found out that the temperatures of the piston top and the first circular groove are proper after calculating the temperature field.

Key words: engine, piston, thermal analysis, temperature field, heat exchange coefficient

---

INTRODUCTION

Piston as one of the most important parts of the diesel engine, the working conditions are harsh, because it exposed to the influence of the thermal load in the work process. As the most critical part of the engine, the working conditions of the piston, it is possible to greatly affect the life and performance of the engine, so it is particularly important to carry out the thermal analysis to the engine piston.

Nowadays, the temperature field analysis work for the piston includes: study the thermal boundary conditions and calculates the coefficient of heat transfer to an engine piston [1-4], to prediction of the steady state temperature distribution of piston in diesel engines [5-7]. Calculate the temperature and thermal stress fields for the piston of a diesel engine [8].

In this paper, we introduces the basic theory of thermal analysis, by thermal analysis to diesel engine piston, calculated the temperature field of the piston with the finite element analysis software. We have compared the measured temperature of the piston at several key points with the calculated results and repeatedly modified the boundary condition for the temperature and the heat exchange coefficient. From the analysis results, we have found out that the temperatures of the piston top and the first circular groove zone are good.

FINITE ELEMENT MODEL

Establish reasonable and accurate finite element model is the most important part of the piston finite element analysis, thus carrying out analysis by marking element grids to obtain the accurate results finally. According to the structural symmetry of the piston, in order to be convenient for calculation and decrease workload, cut the established piston model to maintain 1/4 and then import the model to the finite element software for the finite element analysis to the piston according to the fine interface between the modeling software and the finite element analysis software. During the importing process, some details have been omitted, such as the chamfer and the snap ring of the piston pin etc. The geometrical model for the piston is as shown in Figure 1. Physical Properties of the Material is as shown in table1. During the mesh generation for the piston model, based on experiences and with several trials, the eight-node hexahedron cell SOLID70 is selected in this paper.

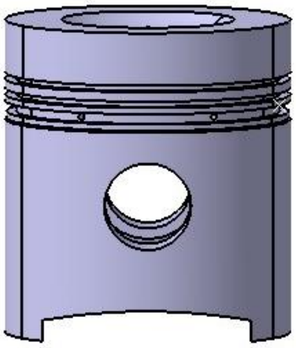

Fig.1: Geometrical model for the piston

Table 1: Parameters of the piston material

Parameters	Values of the parameters
Piston material	Aluminum alloy
Poisson ratio	0.32
Elastic modulus of the piston	$70\,\boldsymbol{GPa}$
Material density	$2700\,\boldsymbol{kg/m^3}$
Conductivity factor	$160\,\boldsymbol{w/(m^2 \cdot K)}$
Coefficient of thermal expansion	$21\times10^{-6}\,m/K$

FINITE ELEMENT ANALYSIS

Fundamental of Thermal Analysis

The stable thermal load means that the temperature field of the piston remains unchanged during the working process of the piston and that the heat flowing from the gas to through the piston top equals that discharged from the ring zone, the skirt and the cooling chamber of the piston etc. The heat of the gas and the piston top mostly come from heat convection of the gas and the piston top, the heat transfer within the piston abides by Fourier Law and no heat can occur within the piston itself, so the thermal analysis to the piston is a stable thermal analysis to the problem without any internal heat source.

Fourier Law is the basis for the heat conduction theory, and the vector expression for the Fourier Law is:

$$q = -k \times gradT \qquad (1)$$

Where,*q*—heat flux, which is a the vector in w/m^2; *k*—the heat conduction coefficient of the material treated as the constant, in $w/(m \cdot K)$; $gradT$ — the temperature gradient, also a vector, in $°C/m$.

Where, the negative sign means that the direction of q is always opposite to that of $gradT$. In the mathematical field theory, it is very convenient for Equation (1) to utilize vector expressions for the gradient and divergence to deduce the differential equation for heat conduction and the component expressions are:

$$\left.\begin{aligned} q_x &= -k \times \frac{\partial T}{\partial x} \\ q_y &= -k \times \frac{\partial T}{\partial y} \\ q_z &= -k \times \frac{\partial T}{\partial z} \\ q_n &= -k \times \frac{\partial T}{\partial n} \end{aligned}\right\} \qquad (2)$$

Where, *n*—the exterior normal direction vector of the object at any boundary.

From Equation (2) we can get that when the direction of the gradient component $\frac{\partial T}{\partial x}$ is opposite to x-axial and $\frac{\partial T}{\partial x}$

is negative, q_x is positive, indicating that q_x is in the same direction with x-axial; or else, when $\frac{\partial T}{\partial x}$ is in the same direction with x-axial, q_x is negative indicating that the heat flow is in the opposite direction to x-axial.

Based on the fundamental of heat transfer and abiding by the law of conservation of energy, we can get that the differential equation for solid heat conduction is as follows:

$$\frac{\partial T}{\partial t} = \alpha\left[\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2} + \frac{\partial T^2}{\partial z^2}\right] + \frac{\omega}{c\rho} \quad (3)$$

Where, α —the heat conduction coefficient, $\alpha = \frac{k}{c\rho}$, in m^2/s ; c— the specific heat at constant pressure of the material, treated as a constant in $J/kg\cdot°C$; ω — the internal heat source intensity of the material, in W/m^3.

If the solid is in the adiabatic condition:

$$\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2} + \frac{\partial T^2}{\partial z^2} = 0$$

The temperature rise of the solid in this condition is called the adiabatic temperature rise, written as θ, and from Equation (3) we can get:

$$\frac{\partial \theta}{\partial t} = \frac{\omega}{\rho c} \quad (4)$$

With Equation (4), the heat conduction equation can be expressed as:

$$\alpha\left[\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2} + \frac{\partial T^2}{\partial z^2}\right] + \frac{\partial \theta}{\partial t} - \frac{\partial T}{\partial t} = 0 \quad (5)$$

If no change occurs to the temperature in z direction, which means that $\frac{\partial T}{\partial z}$, the temperature field is a plane problem and the heat conduction equation can be simplified as:

$$\alpha\left[\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2}\right] + \frac{\partial \theta}{\partial t} - \frac{\partial T}{\partial t} = 0 \quad (6)$$

After long-term heat exchange, the temperature will no longer change with the time, thus getting:

$$\frac{\partial \theta}{\partial t} = \frac{\partial T}{\partial t} = 0$$

This kind of temperature field which does not change with the time is the stable temperature field.

With Equation (6), the heat conduction equation can be simplified as:

$$\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2} + \frac{\partial T^2}{\partial z^2} = 0 \quad (7)$$

The heat conduction equation establishes the relationship of the temperature with the time and space, but there are indefinite solutions for the heat conduction equation; in order to determine the unique solution for the differential equation of the solid, the boundary condition and the initial condition must considered when understanding the actual temperature distribution with the solid. In the general description, we collectively call the boundary condition and the initial condition as the definite condition and simultaneously solve the differential equation for heat conduction, thus obtaining the temperature distribution within the solid.

Determination of the boundary condition

When calculating as a stable temperature field, it is necessary to calculate the average temperature and the average heat exchange coefficient of the comprehensive gas within a working cycle. It is necessary to obtain the transient heat exchange coefficient and the transient gas temperature first, respectively.

A calculation model is established by AVL-BOOST software; calculate transient heat transfer coefficient h_g and the transient gas temperature T_g respectively after set parameters. The AVL-BOOST model is as shown in Figure 2. The transient gas temperature T_g and transient heat transfer coefficient h_g calculated by AVL-BOOST software, is as shown in Figure 3 and Figure 4.

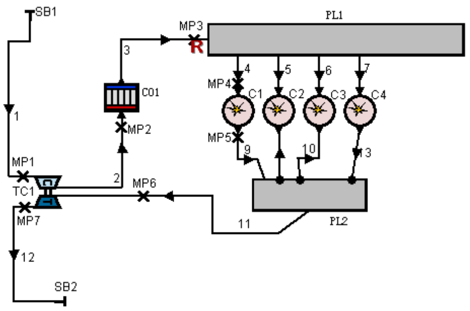

Fig.2: AVL-BOOST model of the piston

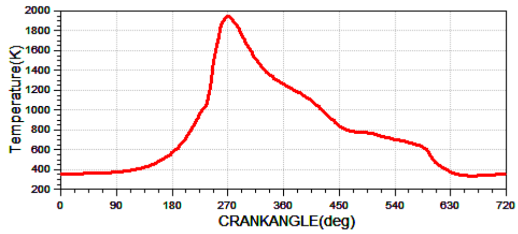

Fig.3: The transient gas temperature

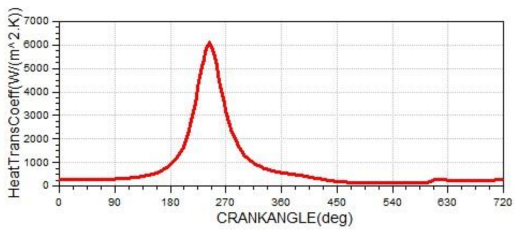

Fig.4: The transient heat transfer coefficient

As for the initial boundary condition of the piston ring zone, please refer to Table 2

From the heat exchange coefficient calculation for each part of the aforesaid piston, we can get that the boundary condition for the heat exchange coefficient calculation for each part, thus getting the piston temperature field calculation. In some parts, the original computational domain is subdivided according to the computation results, increased or decreased based on the different positions, thus meeting the actual condition better.

When determining the boundary condition, in order to get the analyzed results more close to the actual operation condition of the piston. Based on the structure features and key parts, the piston surface can be divided into 18 boundary zones with the position of each part.

Table 2: The boundary condition of the piston ring zone

Location	Symbol	Heat exchange coefficient
Piston junk	h_1	88
Top edge of the first circular groove	h_2	384
Inner edge of the first circular groove	h_3	246
Bottom edge of the first circular groove	h_4	2162
Top edge of the second circular groove	h_5	390
Inner edge of the second circular groove	h_6	182
Bottom edge of the second circular groove	h_7	390
Top edge of the third circular groove	h_8	277
Inner edge of the third circular groove	h_9	40
Bottom edge of the third circular groove	h_{10}	277
Bottom ring land of the first ring	h_{11}	88
Bottom ring land of the second ring	h_{12}	88
The piston skirt	h_{13}	341

With the comparison to the experimental results and repeated computation adjustment of the experimental results, the heat exchange coefficient and the temperature of the piston boundary are as shown in Table 3.

Table 3: Heat exchange coefficient and temperature of the piston

Location	Ambient temperature	Heat exchange coefficient
piston crown	741	460
combustion chamber	741	400
fire bank	180	88
Top edge of the first circular groove	180	384
Inner edge of the first circular groove	180	246
Bottom edge of the first circular groove	180	2162
Top edge of the second circular groove	160	390
Inner edge of the second circular groove	160	182
Bottom edge of the second circular groove	160	390
Bottom ring land of the first ring	180	88
Bottom ring land of the second ring	160	88
Top edge of the third circular groove	140	277
Inner edge of the third circular groove	140	40
Bottom edge of the third circular groove	140	277
The piston skirt	120	341
Top of the intracavity	100	2000
Middle of the intracavity	95	1800
Lower of the intracavity	90	1500

Computation and Result Analysis of the Thermal Analysis

Based on the established geometrical model and finite element model as well as the established boundary condition and with the stable thermal analysis module of the finite element analysis software, we can calculate and get results as shown in Figures 5.

From Figures 5, we can get: the piston temperature changes between 97.601 and 255.684℃ with the maximum temperature at the piston top and the minimum temperature at the lower part of the piston skirt. At the piston ring land, temperatures are distributed uniformly along the piston in the radial direction. We can see clearly that the temperature of the piston skirt is along the piston pin hole is higher than that perpendicular to the pin hole, thus causing the thermal deformation of the piston in the direction of the piston pin is greater. The piston temperature changes uniformly from the piston top to the bottom, without any sharp change phenomenon. The piston maximum temperature is at the piston top surface with the temperature of about 255℃ and the temperature of the upper surface of the first circular groove being about 202℃. However, the allowable average temperature of the first circular groove of the aluminum piston is 180℃ to 220℃ and the temperature of the first circular groove is proper.

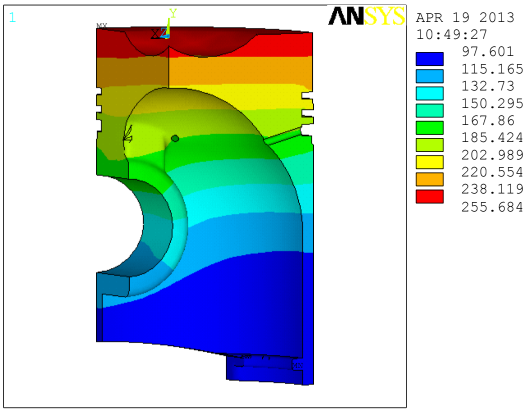

Fig.5: Temperature field of the inner chamber of the piston

CONCLUSION

Result of the finite element analysis of the piston shows that, the maximum temperature of the piston is 255℃ which occurs at the piston top, the temperature of the first circular groove is about 202℃, The isothermal line of the circular groove zone is thicker than that of the skirt, indicating that the temperature of the circular groove zone of the piston changes greatly, so the thermal stress is relatively concentrated, causing it easy to be damaged. To assess the thermal condition of the piston, we should first pay attention to the maximum temperature of the piston top and the temperature of the first circular groove, the allowable average temperature of the aluminum piston top is 250℃ to 350℃ and the allowable average temperature of the first circular groove is 180℃ to 220℃. This standard indicates that the overall temperature of this piston is within the allowable average temperature.

REFERENCES

[1] V. Esfahanian, A. Javaheri, M. Ghaffarpour, **2006**. *Applied Thermal Engineering*, 26: 277–287.
[2] H.W. Wu, C.P. Chiu, **1989**. *Computers & Structures*, 32: 997–1004.
[3] Yuh-Yih Wu,Bo-Chiuan Chen, Feng-Chi Hsieh, **2006**. *International Journal of Heat and Mass Transfer*, 49: 3895–3905.
[4] Avinash Kumar Agarwal, **2011**. *International Communications in Heat and Mass Transfer*, 38: 1080－1085.
[5] Hidehiko Kajiwara, Yukihiro Fujioka, Tatsuya Suzuki, Hideo Negishi, **2002**. *JSAE Review*, 23: 429–434.
[6] J.H, Ong, **1990**. *Computers in Industry*, 15: 255–258.
[7] Ravindra Prasad, **1989**. *International Journal of Mechanical Sciences*, 31: 765–777.
[8] Shu Yao Long, Xing Cheng Kuai, Jun Chen, **1993**. *Engineering Analysis with Boundary Elements*, 12: 293–303.
[9] R. Tichanek, M. Spaniel, M. Divis, **2003**. *International Journal of Széchenyi István University of Applied Sciences*, 20: 74–75.
[10] M. Spaniel, J. Macek, M. Divis, R. Tichanek, **2003**. *International Journal of Middle European Construction and Design of Cars*, 2: 34–41.