International Journal of Advance Research in Science and Engineering
Vol. No.5, Special Issue No. (01), February 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

CFD THERMAL ANALYSIS FOR THE OPTIMAL DESIGN OF A MARINE DIESEL ENGINE PISTON HEAD

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ABSTRACT

This article aims to study the numerical thermal analysis of a modified geometry of a marine diesel engine piston head.The numerical thermal analysis determinesthepiston head temperature distribution which isthe basis for identifying the thermal stresses and deformations.Three piston head designs are introduced in this paper which are: bowl, domed and flat piston head. These three types are investigated in order to specify the optimal temperature distribution of piston head. The piston model is developed in CATIA V5R19 and exported to ANSYS for finite element analysis. The input parameters are gas temperature, cooling water temperature and oil temperature, whereas the boundary conditions given in the analysis are coefficients of heat transfer (CoHTs) and heat flux. COHTs vary radially on the piston head and these values are calculated using Seal's formula. The piston top surface is divided into five sub-regions of equal intervals and the thermal analysis results show thatflat top piston is less affected by the combustion with maximum temperature range of 736.59 K-703.34 K. On the other hand, the results show that domed top piston is exposed to the highest level of temperature ranging from 749.49 K to 714.88 K.

Keywords: Marine Diesel Engine, Piston Head Design, Thermal Analysis and Temperature Distribution.

I. INTRODUCTION

The piston is considered one of the most important parts of an IC diesel engine since it is subjected to lots of thermal and mechanical loads [1]. These loadings increased dramatically in last recent years due to diesel engine power boost leading to higher thermal stresses and deformations [2]. Accordingly different design variables can be studied in order to investigate their effects on stresses reduction by controlling temperature variation along the piston head.

In this work we investigate the effect of combustion chamber design on piston head temperature distribution and specify the optimal design that achieves the minimum temperature variation.It plays a significant role in fuel-air mixing process resulting in an important effect on power and combustion efficiency [3]. The piston considered in the analysis has a radius of 150 mm and a height of 250 mm. Threepiston top surface designsare considered which are: bowl, domed and flat and it is divided into five sub-regions of equal intervals of 30 mm. The temperatures of cooling water and oil are respectively 400 K and 450 K.

The effect of combustion chamber geometry on different thermal aspects has been studied in previous works. One of these aspects is Heat Release Rate (HRR) investigated by Christensen et. al. [4].The research results showed that HRR decreased by about 50% and the combustion duration doubled by the use of a bowl compared to a disc shaped combustion chamber during similar operating conditions. This means that the load can be increased by the use of bowl geometries with acceptable pressure rise rates. The penalty was lower efficiency for late combustion phasing in the bowl case.

II. FINITE ELEMENT ANALYSIS

The idea behind finite element analysis is to divide the model into a fixed finite number of elements where each element expresses the physical and geometrical properties of the body [5]. The piston is modelled using 3D CAD software (CATIA V5R19) and exported to FEA software for processing (ANSYS). To obtain accurate calculation results, a reasonable mesh size must be determined. The smaller the cell, the higher the accuracy and the longer the calculation time.The thermal analysis of the piston is conducted based on the assumption of steady working state of engine. Based on this assumption, both piston top surface temperature and the instant CoHT of gas are considered time averaged to fit the need of steady thermal analysis in this paper and can be calculated by the following equations:

$$h_m = \frac{1}{720}\int_0^{720} h_g \, d_\varphi \qquad (1)$$

$$T_{res} = \frac{1}{720.h_m}\int_0^{720} h_g T_g d_\varphi \qquad (2)$$

Where h_g , T_g are respectively the instant CoHT of gas at piston top surface and instant gas temperature. H_m was defined as the average CoHT of gas at the top surface of piston head and the average piston surface temperature is denoted as T_{res} [6].

For more precise and detailed thermal analysis, the spatial effect of CoHTs on the top surface of piston should be considered. For this reason Seal's formula was used which assumes that the CoHTs change along the radial direction. The equations are as below followed:

$$If\ r<N, \quad h_r = \frac{2h_m}{1+e^{0.1N^{1.5}}} e^{0.1r^{1.5}} \qquad (3)$$

$$If\ r>N, \quad h_r = \frac{2h_m}{1+e^{0.1N^{1.5}}} e^{0.1(2N-r)^{1.5}} \qquad (4)$$

Where r is the distance from local point to the center axis of piston head, N is the distance from the point where maximum temperature occurs to the center axis of piston.

III. NUMERICAL RESULTS OF THE EFFECT OF PISTON HEAD DESIGN MODIFICATION

Piston head has many different designs but there are three basic types viz., bowl piston head, domed piston head and flat piston head. In this work, we analysed all the three types of piston heads and the reference is taken for bowl piston head. The second and third cases were taken for domed piston top and flat piston top. The results were compared to investigate the optimum values regarding piston head temperature distribution.

IV. RESULTS AND DISCUSSION

Three different geometries of piston head are investigated to obtain their optimum temperature distribution results. The cases are studied as the following:

4.1 Case 1: Bowl Piston Head

Figure 1 shows a sketch of a bowl top piston modelled in CATIA V5R19 which is considered the reference piston design in this work. A 3D geometric model is drawn as depicted in figure 2 and the model is exported to FEA software (ANSYS).To obtain accurate results, reasonable mesh size must be determined which is well known that the smaller its cell size, the higher is the accuracy and the longer is the calculation time. The model element type selected is “triangular” with 149901 nodes and 97590 elements as shown in figure 3. The numerical thermal analysis results show that piston head is exposed to the highest temperature with range of 739.97 K-706.41 K as depicted in red in figure 4.

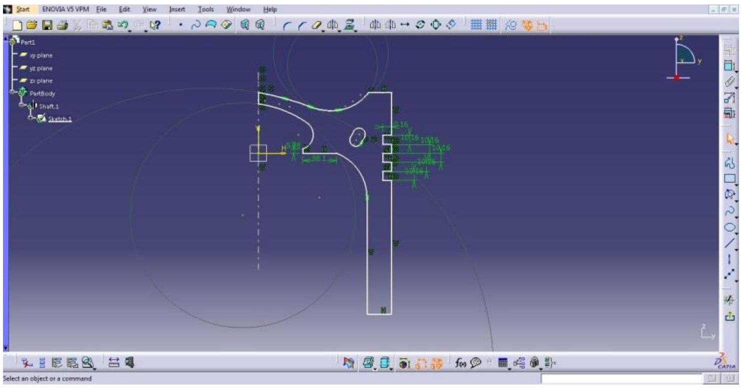

Fig.1: Bowl top piston sketch in CATIA V5R19

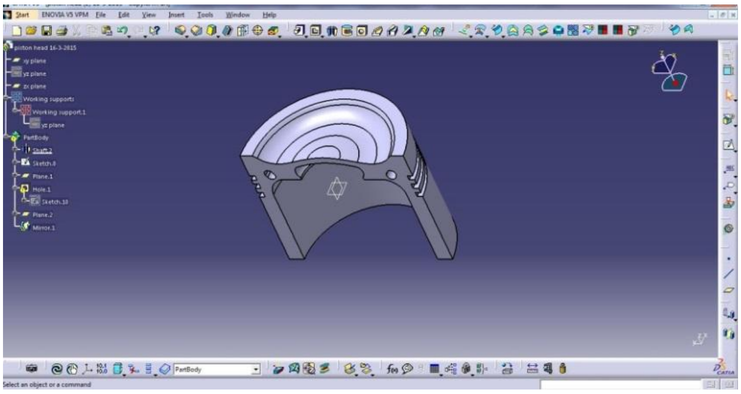

Fig. 2: Geometric model of bowl top piston half part created in CATIA V5R19

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ISSN 2319 - 8354

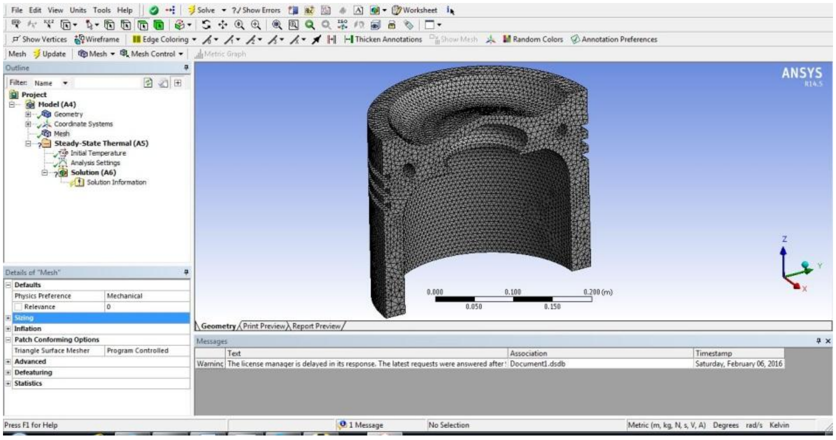

Fig. 3: Finite element model of bowl top piston half part

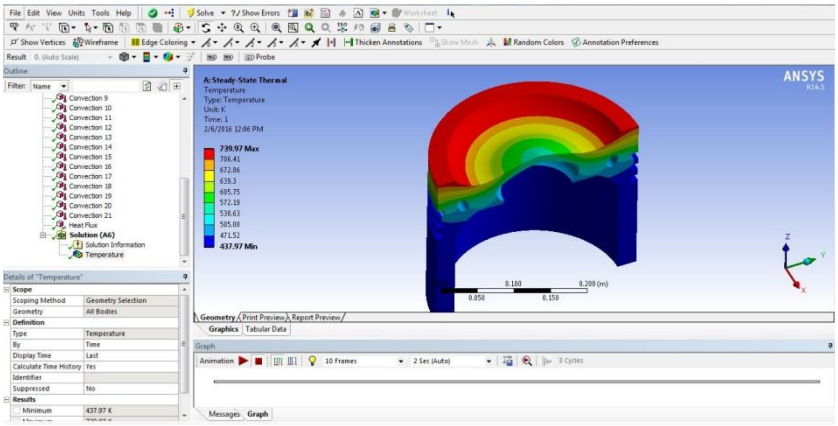

Fig 4: Numerical thermal analysis results of bowl top piston head

4.2 Case 2: Domed Piston Head

Figure 5 shows a sketch of domed top piston modeled in CATIA V5R19 and a 3D geometric model is shown in figure 6. The model is exported to FEA software (ANSYS). Figure 7 presents the meshing of domed top piston half part with 140732 nodes and 91934 elements. The numerical thermal analysis results show that the highest temperature affecting the piston is with range of 749.49 K- 714.88 K as depicted in red in figure 8.

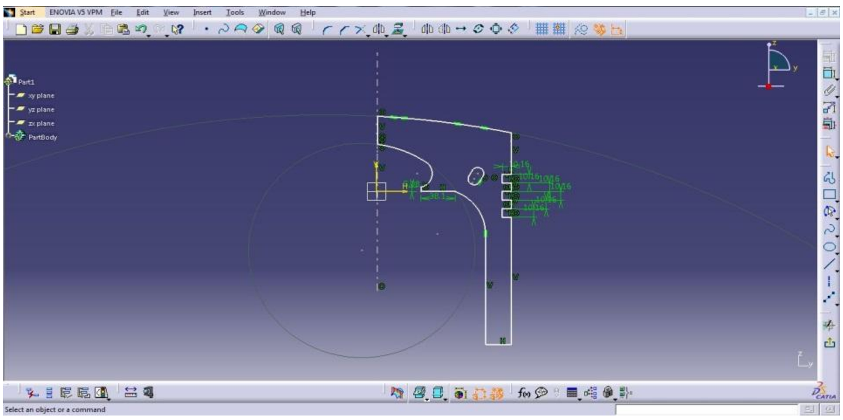

Fig. 5: Domed top piston sketch in CATIA V5R19

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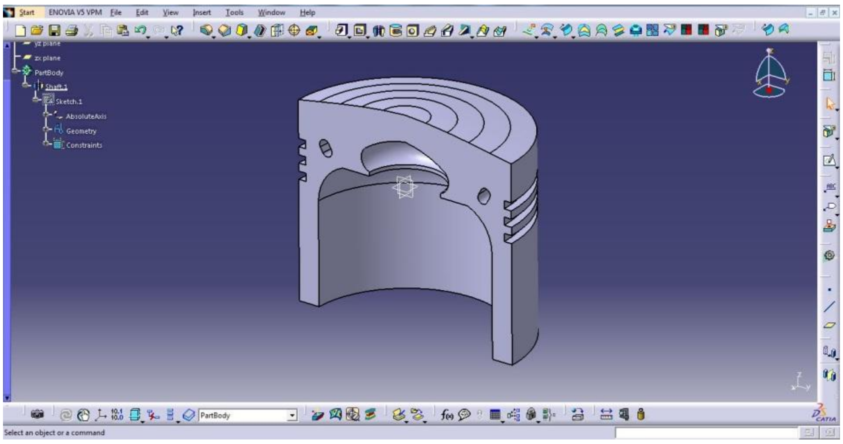

Fig. 6: Geometric model of domed top piston half part created in CATIA V5R19

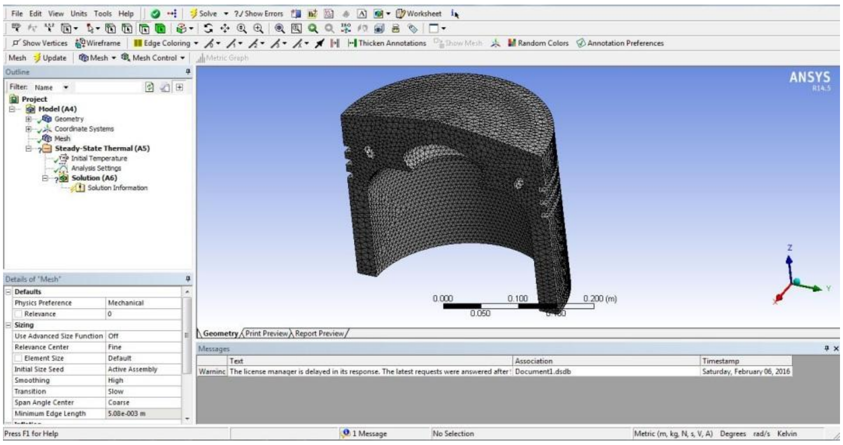

Fig. 7: Finite element model of domed top piston half part

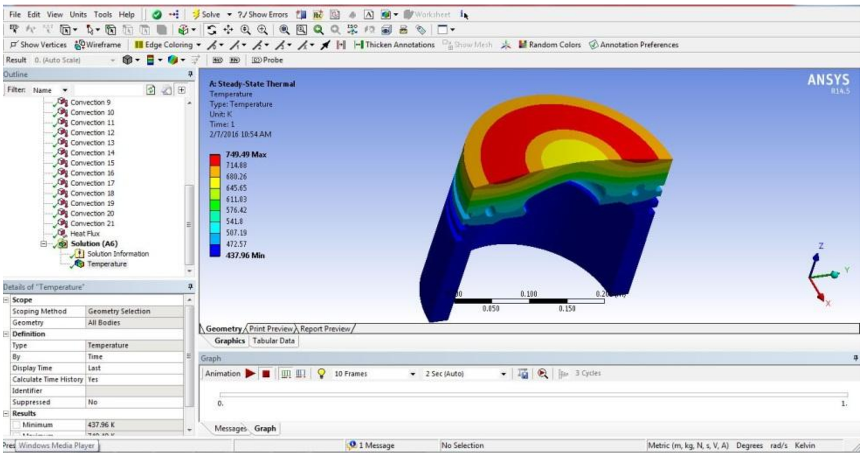

Fig. 8: Numerical thermal analysis results of domed top piston head

4.3 Case 3: Flat Piston Head

Figure 9 shows a sketch of flat top piston modeled in CATIA V5R19. The model is exported to FEA software (ANSYS) and a 3D geometric model is shown in figure 10. Figure 11 presents the meshing of flat top piston half part with 149836 nodes and 97839 elements. The numerical thermal analysis results show that the highest temperature affecting the piston is with range of 736.59K- 703.34 K as depicted in red in figure 12.

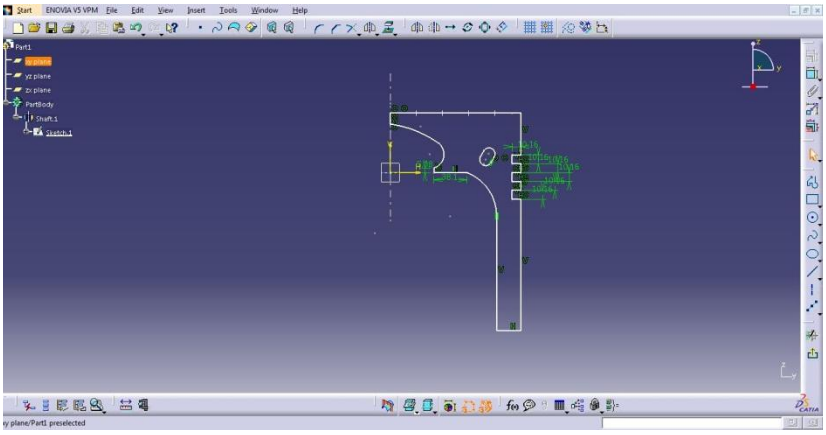

Figure 9: Flat top piston sketch in CATIA V5R19

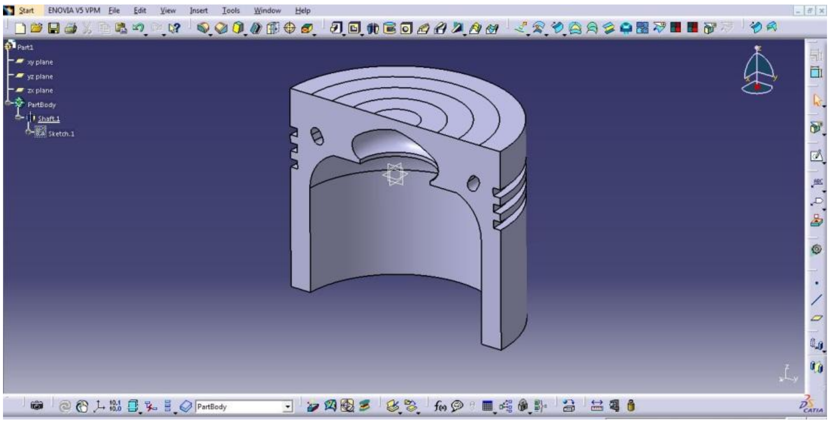

Figure 10: Geometric model of flat top piston half part created in CATIA V5R19

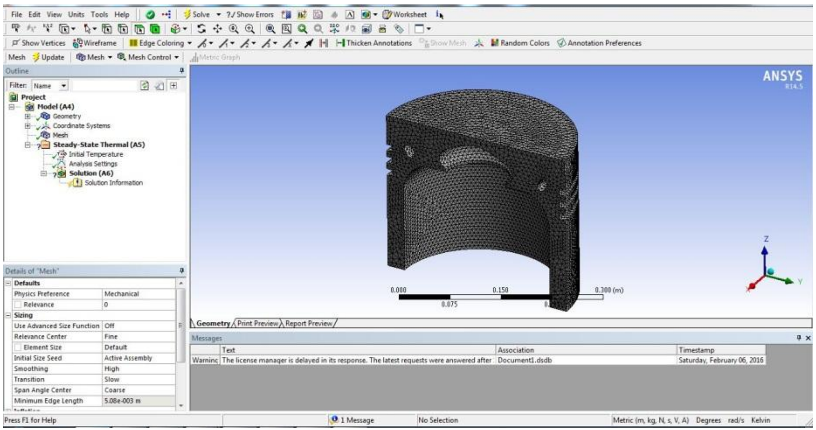

Figure 11: Finite element model of flat top piston half part

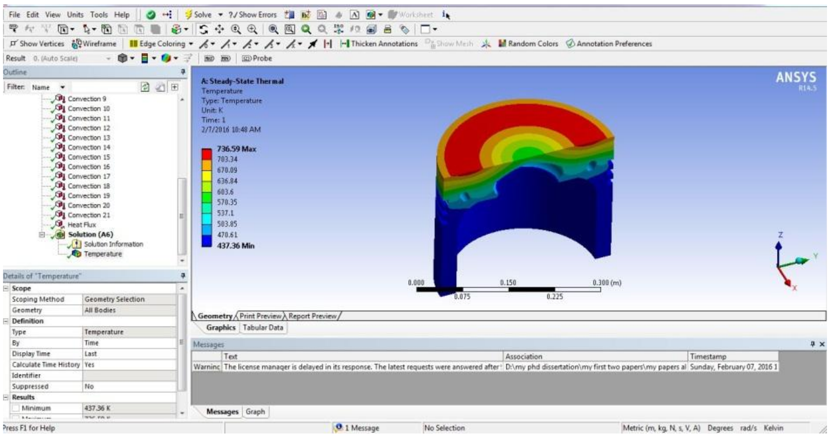

Figure 12: Numerical thermal analysis results of flat top piston head

V. CONCLUSIONS

In this work, a numerical thermal analysis of three different geometries of a marine diesel engine piston head is presented to investigate its effect on temperature distribution fields. Accordingly thermal stresses and deformations can be controlled by minimizing the temperature distribution variation of piston head. Three piston head designs are studied and the first case taken is bowl top piston and it is considered at the same time the reference case. Domed and flat top pistons are taken as second and third cases. The model is drawn in CATIA V5R19 and exported to ANSYS for thermal analysis. The results show that domed piston head will be exposed to the highest temperature level during gas combustion which has a range of 749.49 K- 714.88 K due to the large piston surface area exposed to combustion whereas the least temperature range is achieved in case of flat top piston with value of 736.59 K-703.34 K. For the bowl piston head the highest temperature level is ranged between 739.97 K-706.41 K.Another design variable such as cooling gallery position can be studied in the future to investigate its effect on temperature distribution.

VI. ACKNOWLEDGEMENTS

The present work has been funded by Research Fund- Tishreen University for the doctoral program of higher education of Syria. The first Author would like to highly express her appreciation.

REFERENCES

[1] F.S. Silva, Fatigue on engine pistons – A compendium of case studies, Engineering Failure Analysis 13 (2006) 480–492.

[2] M.Shimotsu, T. Shimonaka, T. suma and S. Hirata, A Study of the Effects of the Chamber Walls on the Diesel Combustion Phenomena (Test Results of Highly Supercharged 4-Cycle Medium-Speed Diesel Engine),Journal of the MEJS, Vol. 20 (1985) No. 5 P 339.

[3] Hoffman, M. and Filipi, Z., Influence of Directly Injected Gasoline and Porosity Fraction on the Thermal Properties of HCCI Combustion Chamber Deposits,SAE Technical Paper 2015-24-2449, 2015, doi: 10.4271/2015-24-2449.

[4] Christensen, M., Johansson, B., and Hultqvist, A., The Effect of Combustion Chamber Geometry on HCCI Operation,SAE Technical Paper 2002-01-0425, 2002, doi: 10.4271/2002-01-0425.

[5] Introduction to Finite Element Analysis(FEA) or Finite Element Method (FEM).

[6] M Tahar Abbes, P Maspeyrot, A Bounif, and J Frene, A thermomechanical model of a direct injection diesel engine piston, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering- 2004 218: 395.