

The Influence of Temperature on Motor Engine Efficiency

Aqeel hameed basher al-hussein

- **Abstract**

This paper deals with a theoretical and analytical study of three real pistons of internal combustion engines (work with gasoline). These pistons are different from each other in shape, speed , and power. Three dimension (3 D) models for the real pistons were build using . Ansys software. The boundary conditions were set in order to carry out the thermal analysis.

The thermal analysis covered also cases of different changes in the shape of each piston in order to carry out comparisons with the real shapes of the pistons.

The analysis offers for the designer the ability to understand the behavior of thermal stresses, their locations and the way they spread in order to reach to the optimum design.

Introduction:

Today, internal combustion machines are considered a miracle of technology, but the amazing thing about this is that after a century they work with the same principle, and the piston is the most important and most complex part of internal combustion engines, as it is subjected to both mechanical and thermal loads that may sometimes lead to its failure and thus it was necessary to Studies tend to be designed, analyzed and studied.

This research represents a modern method in terms of drawing and analysis without neglecting any part of the compressor parts. Ansys program was used, which uses the finite element method to find the temperature distribution and thermal and mechanical stresses after determining the boundary conditions of pressure, temperature and heat transfer coefficient for all parts Piston In order for the search to be more comprehensive, three real pistons, different in shape, power and speed, were used, and were drawn in real dimensions. These pistons are for gasoline engines, the first is for a Mercedes engine, the second is for a Volkswagen and Akun (Brazilian) and the third is for a Peugeot car engine.

Where models of these pistons were built in the form of a quarter of a piston (to match the rest of the quarters / in 3D and with the same dimensions of the real piston for each of them), after which the research included finding the temperature distribution on all parts of the piston and the distribution of thermal stresses, as well as different states of each piston, the effect of the crown shape The piston (PistonCrown) on the temperature and the effect of the piston rings and their number, as well as the effect of the presence of a cave in the crown of the piston and the effect of the thickness of the prop on the temperature.

- **Research Objective:**

- 1- Analyzing the pistons thermally.
- 2- Study the distribution of temperature and heat stress on pistons and compare them with each other.
- 3- Making changes in the shape of the pistons in terms of changing the shape of the crown, the number of pressure rings, the increase in the thickness of the piston support, adding a cooling channel in the crown, and comparing it with the real pistons in terms of temperature distribution and thermal stresses resulting from these changes.
- 4- The pistons are designed with some of the features that result in specific functions during the operation of the engine, so the piston head or crown receives the largest part of the initial pressure and force resulting from the combustion process. The piston crown or the piston body is also subjected to a thermal expansion greater than the rest of the piston parts, and this is one of the characteristics of the thermal expansion of the aluminum alloy and the mass in the piston nail area.
- 5- Heat transfer in the pistons that the heat transfer in the piston is the addition of heat from the hot gases in the combustion chamber, and the piston expels this heat to the outside through the rings and spaces between the rings and through the piston skirt and from the bottom surface of the piston that the overall heat transfer rate From the gas (combustion chamber) to the outside is represented by the following relationship.

$$Q/A = h (T_g - T_a)$$

- **Calculate the heat transfer coefficient:**

The severity of the complexity of the heat exchange process between the piston and its surroundings makes it difficult to make accurate calculations of the heat transfer coefficient on the piston surfaces and cannot be accessed without knowing the temperature distribution under known working conditions. In this paper, the temperature and its distribution were obtained depending on the calculation of the heat transfer coefficients, where the heat transfer coefficient for all surfaces was calculated as follows.

The heat transfer coefficient in the gases and the surface of the piston crown , It is difficult to find the heat transfer coefficient for this area accurately because the situation is complex in the combustion chamber, but in general the surface of the piston can be considered in the form of a plate over which a turbulent forced current passes, where it is possible to use the Reynolds and Neselt equations (1).

$$V_{Re} = U_d /$$

$$Nu = hD / k$$

The speed of the gas is the speed of the piston for that

$$U = V_P = \frac{2RP, M \text{ stro}}{60}$$

The average heat transfer coefficient h_g for the piston crown area can be calculated from the following equation:

$$H_g = C_1 V_c^{-0.06} P_m^{0.8} T_g^{-0.4} (V_p + C_2)^{0.8}$$

(1)

Volume of cylinder V_c (m³)

Average effective pressure P_m (bar)

The temperature of the combustion gases (K)

The average linear speed of the piston V_P (m/ sec)

Constants $C_2 = 1.4$, $C_1 = 130$

That about 50 - 70% of the total heat of the piston is dissipated through the rings, as the heat transfer is from the piston to the rings and then to the cylinder wall, and the heat transfer will be considered by conduction and the thermal resistance is considered as follows (2)

$$R_1 = \frac{1}{D\pi} \left[\frac{\delta/2}{2 \cdot a \cdot S_r \cdot K_{oil}} \right] + \left[\frac{1}{K_{ring}} \right] + \left[\frac{\delta_w}{K_{oil} \cdot b} \right]$$

(2)

$$A = \frac{1}{\left[\frac{25}{\delta_1} \right] \cdot \left[\frac{K_{oil}}{K_{ring}} \right] + 1}$$

Heat transfer can be represented by the load in the ring region for the same amount of heat transferred, given that the state is stable (Steady State) And that the amount of heat transferred through each ring is a constant amount that is the heat transfer coefficient of the load (h_{ring})

For the inner groove surfaces of the pressure ring is:

$$R_r = 1 / h_{ring} A \quad (3)$$

$$h_{ring} = 1 / R_r A \quad (3 a)$$

$$\delta_r = 0.03 \text{ (mm)}$$

$$\delta W = 2.54 \cdot 10^{-3} \text{ (mm)}$$

$$S_r = 4 \text{ (mm)}$$

$$D = 2 \text{ (mm)}$$

$$K_r = 52.5 \text{ (W/m.k)}$$

$$K = 1758 \text{ (W/ m.k)}$$

For aluminum

Calculate the heat transfer coefficient on the spaces between the grooves of the rings and the skirt of the piston

The heat transfer is by the load of the spaces between the grooves of the rings and the skirt of the piston, that the oil is in the clearance area between the surface of the piston, and that the oil in the clearance area between the piston surface and the cylinder walls is very small, and thus the heat transfer will be considered by conduction and through a very light oil layer (3).

$$Q = h_{av} A (T_1 - T_2)$$

$$Q = \frac{K_{oil}}{\delta} A (T_1 - T_2)$$

The heat transfer coefficient to be used along the height of the piston skirt is

$$h_{skirt} = K_{oil} / \delta \dots\dots\dots(4)$$

That's valuable (h_{av}) Which represents (h_{skirt}) It will depend on the amount of lateral clearance of the compressor area.

Calculate the heat transfer coefficient on the inner surface of the piston:

The heat transfer between the oil and the internal surfaces of the piston is carried by the method of convection, and to calculate the heat transfer coefficient for this region it will be difficult to find due to the presence of the stiffening ribs of the piston unit and the oil spray ejected from the movement of the connecting arm and the air vortices resulting from the reciprocating piston, thus simplifying the calculation of the heat transfer coefficient. By considering the piston in the form of a tube through which oil passes at a certain velocity equivalent to the linear velocity of the piston, the heat transfer is carried out by carrying a forced turbulence flow, depending on the Reynolds number.

$$Nu = \frac{hD}{K} \dots\dots\dots(5)$$

$$Nu = 0.023 Re^{0.8} Pr^{0.3} \dots\dots(6)$$

$$Re = P. U. D. / \mu$$

$$Pr = \frac{\mu C_p}{K}$$

$$h_{oil} = Nu * K / D \dots\dots\dots(7)$$

Thus, the average heat transfer coefficient of the inner surface of the piston is found, where

$$Pr = 0.77$$

$$Pr = 276$$

$$E = 3.6 \text{ Kg} / \text{m}^3$$

$$\mu = 0.06924 \text{ Kg} / \text{m.s}$$

$$e = 840 \text{ Kg} / \text{m}^3$$

Calculate the maximum pressure of the cylinder gas That the maximum pressure is about (7) times the value of the average effective pressure and is calculated from the following equation: (2)

$$P_{me} = \frac{\text{power} * 60}{L * A * Z * N * \eta} \dots\dots\dots (8)$$

Design and analysis method:

When designing and analyzing piston, one of the numerical methods must be used in the analysis, and in this research the finite element method was used (Finite Element Method) Through a program Ansys.

It is an advanced program in the analysis of specific elements and is used in solving various engineering problems. It is capable of performing static and dynamic analyzes, heat transfer, fluid flow and electromagnetism.

Formatting

Real models of different pistons were used in the following car engines:

Piston engine for a 1985 German-made Mercedes, with engine size of 1997 c.c, capacity of 66KW and speed of 5000r. P. m, number of cylinders (4) and the type of fuel is gasoline.

Piston for a Brazilian-made Volkswagon Passat, the engine size is 1000C.c, the capacity is 65KW and the speed is 5800r. P.m, number of cylinders 4 and the fuel type is petrol.

Piston for a French Peugeot 1998 Peugeot, engine size 2165C.c, capacity 79KW, speed 4500 r.P.m, number of cylinders 4, and fuel type.

Building forms:

Work has been done on a program Ansys The same without using specialized drawing software such as a program (Auto Cad) And since the piston is not axially symmetric, the pistons had to be represented in a standard representation by which we can shorten the number of nodal points Which is followed by the shortening of the calculation time. Therefore, the models were built in the form of a quarter-piston containing the main thrust side (Major Thrust Side) With the piston pin ribs (Pin Bosses) The reason, in addition to shortening the calculation time by reducing the nodal points, is that one-fourth of the piston is similar to its remaining quarters in terms of loads and surrounding conditions, as well as the possibility of observing what is happening inside the piston depth. As for how to build the piston model, this takes a lot of time and effort because the piston is considered from The designs are very difficult and have different heights.

Therefore, it will be drawn in two dimensions and then rotated at an angle of 90, as it rotates around two points, the first is above the crown of the piston and the other is under the crown

of the piston, to transform the design from two-dimensional 2D to 3D as it requires great practice and effort, and then the support is added, punching and opening the incision in the lubrication groove And reduce the length of the plunger skirt(Piston Skirt) This is all in the original piston, but when making changes to the piston crown, pressure rings, support thickness, and adding a cave in the crown of the piston then requires great skill to work because it will only be in 3D level.

Boundary conditions

By it we mean the conditions surrounding the piston, which make it as if it is actually running inside the engine and not be free under the influence of the forces controlling it, and the boundary conditions are divided into two parts

The first section: the boundary conditions for fixing the piston:

These conditions are very important for the purpose of finding a solution to the equations in the manner of specified elements, which make the piston as if it is actually moving inside the cylinder, and from these conditions

- 1- Connecting the piston quadrant form with the remaining quadrants.
- 2- The piston shall be free to move in the vertical direction with the Y axis and restricted in movement in the X axis i.e. the vertical axis on the plane of the thrust axis and the plane Z axis on the plane of the axis of the piston pin.
- 3- The pivot and attachment of the piston to the piston pin, which is represented by the nodal points confined between the two sides of an angle of approximately 45, starting from the top of the middle of the piston pin.

Section Two: Limit Conditions for Analysis:

They are the boundary conditions for thermal analysis, i.e. the conditions surrounding the piston, which make it work as if it were real inside the engine and are as follows

Boundary conditions by thermal analysis:

The heat is transferred from the hot gases in the combustion chamber, which is at a temperature of [6] $T_g = 900^\circ\text{C}$ and the surface of the piston crown by the method of convection. Therefore, all points must be temperature h_g and the average temperature of the gas T_g extracted from equation (1) and as in Table No. (1)

- 2- The heat transfer by the load between the area of the grooves of the rings and the wall of the cylinder, which is the average temperature of the cylinder [1] 115°C . The heat transfer

coefficient is set for the hring area, which was calculated from the treatment (3a) with a temperature of 115c, so it is placed on all the nodal points of the grooves region With a heat transfer coefficient of hring and a degree of 115c, as shown in Table (1)

- 3- As for the area between the grooves of the rings, the heat transfer coefficient for them is used from equation (3), which represents h_1 , h_2 , h_3 as shown in Table (1) and it is noticed that there is no value for h_3 for the Mercedes engine for the shortening of the piston skirt than it is It at rest
- 4- The piston is subjected to the transfer of heat by the load between the inner surface of the piston and the oil and the amount of heat transfer depends on the speed of the piston, which was calculated for all pistons from equation (6) and as in Table (1)

Piston thermal analysis

The thermal analysis of compressors means studying the effect of temperature, thermal stress and the resulting deformations.

First: Study the effect of the shape of the piston crown on temperatures as follows:

A-The crown of the piston is flat

B-Piston crown with a spherical combustion chamber

C - the crown of the piston is concave.

Second: To study the effect of raising the initial loop by making the hring equal to zero

Study the effect of adding another pressure ring.

Study the effect of adding a cooling channel to the piston crown. .

Third: the change of thickness of the support pillar of the presses and the study of the effect of temperature

As for the stress calculation of the piston models, the thermal expansion coefficient of aluminum alloy (HG. 416) (Table 2) was used because it is very suitable for the metal of the pistons and is close in terms of the chemical components obtained from the analysis of the pistons in practice.

Results and discussion:

The pistons were studied in their real form and shown in Figure (1) and compared with each other first, then studied after changing the shape of the piston crown, the number of pressure

rings, the thickness of the support, adding a cooling channel in the crown area, and comparing it with the real piston state to reach the design. The thermal differences will also be discussed, which includes the temperature distribution and the thermal stresses of the compressors.

Temperature distribution:

Figure (2) represents the temperature distribution of the three pistons Mercedes, Volkswagen and Peugeot, as it is generally observed that the temperatures rise in the upper regions of the pistons close to the thermal source and gradually decrease whenever we go to the bottom of the pistons, that is, the areas far from the source where the lowest temperature of the pistons is. They are in the lower areas of the piston skirt (Piston Skirt).

For the purpose of discussion, the main Mercedes engine piston was chosen for comparison with the rest of the pistons, as it was noted in the results that it is the lowest temperature pistons and the values of thermal stresses and the easiest pistons to draw and design.

Temperature distribution / piston for a Mercedes (Figure 3)

By observing the temperature distribution of the Mercedes engine piston, it is noticed that the highest temperature is about (527 K) (245°C) and that it spreads over the upper surface of the piston crown area and takes a larger area in the area of (Top land) From the point of payment (Thrust) Than it is from the side of the bundle (Pin Bosses) And it decreases to reach (238°C) (511 K) and this degree continues to the beginning of the first ring of the piston from the thrust side. It follows from this that the temperatures on the thrust side (Thrust) (Side) And starting from the crown of the piston and up to the third ring is higher than that on the side of the navel of the piston and when descending from the half of the third ring from the pushing side to the bottom of the piston skirt (Piston Skirt) The opposite is noticed, as the temperatures of this region are lower in the area of the navel side and the reason for this phenomenon is due to the presence of the support that acts as a thermal path for the flow of heat, which leads to a good thermal transfer, i.e. the upper areas of the piston are lower than the temperature of this side from the side thrust. The presence of the bundle attached to the piston pin, as it acts as an obstacle to the flow of heat, meaning that the temperatures start from half of the third ring of the piston to the bottom of the piston skirt higher than those on the push side.

Temperature distribution of a Volkswagen / Passat Volkswagen (Figure 4)

In the case of the Volkswagen / Passat piston, which is similar to the piston in a Mercedes engine in that there are circular holes distributed in the groove of the third ring of the piston and differs from it in terms of the concavity of the crown of the piston and the increase in the

speed and power of the engine and thus there is an increase in the piston temperature compared to the piston of a Mercedes engine. The temperature is significantly higher than in the piston in a Mercedes engine, as the highest temperature a piston in a Volkswagen Vahn engine is (285 C) (558 K) which is at the crown of the piston and the lowest temperature is at the end of the piston skirt area with a value of (115 C) (388 K) The temperature in the thrust area, pressure rings and the lubrication ring at the top of the piston crown to the end of the third ring, as it is in the piston in a Mercedes engine, but at higher temperatures. Also in the thrust area due to the presence of the piston support, this increase in temperature and in the whole piston of a Volkswagen engine was due to an increase in the value of the heat transfer coefficient between the surface of the piston crown and the gases hg, which is a value of (721E- 6 W / mm K) while in the piston of a motor The Mercedes (71E- 6 W / mmK) and this increase is due to the increase in the piston speed of the Volkswagen Vahn engine and the small size of its cylinder relative to the size of the Mercedes' piston cylinder, as the coefficient of heat transfer is directly proportional to the speed and inversely with the volume according to the usual (6(

Temperature distribution / piston for Peugeot

The highest temperature that the Peugeot engine piston reaches is the value (296C) (5681 K) and it is concentrated in the center of the crown of the piston and spread to the end of the crown from the thrust side more than it is from the hub side, and the temperatures from the push side gradually decrease until it reaches the beginning of the third ring To the value of (256C) (5271K) and at the end of the third ring to the value of (136C) (405K), then it decreases to the value of (116C) (385K), which is the lowest temperature that the compressor reaches due to its distance from the heat source and in the Top Land area at the push side The temperature value was (279 C) (552 K) and the temperature value in the first and second grooves in the pressure rings from the thrust side was the value of (259 C) (532 K) and the first and second grooves from the hub side were (239 C) (512 K). Then it decreases to a value of (219 C) (492 K). It is also noticed that the temperature drop on the hub side is faster than it is on the push side, and this is due to the presence of the pillar, which is considered a good thermal path.

Peugeot engine piston cases

Figure (5) represents the distribution of the thermal stresses of the Peugeot engine piston, and in all cases it is noticed that the thermal stresses spread in the third ring and around the slot and are concentrated in a small area at the end of the slit as well as at the end of the third ring from the side of the navel, in the case of a crown with a spherical chamber and a case

Concave crown and the presence of a cooling channel there is an increase in the area of spreading stresses in the area under the crown of the piston.

Conclusions

Through the results obtained, the following conclusions can be reached:

- The Mercedes engine piston is considered the best in terms of temperature distribution and thermal stress, its flat crown shape, the lubrication ring devoid of cracks and the shortness of the piston skirt.

- Pistons with slit-free lubrication rings are similar in terms of temperature distribution and stresses and their locations, but different in terms of their value due to the difference in piston speed, engine capacity, pistons diameters, and crown shape.

- The Peugeot engine piston is the fastest heat loss due to the presence of the slit, i.e. the absence of this region of metal, but it has a thermal piezo center, especially at the end of the slit, and this means that the designer should note the type of alloy used in the manufacture of the piston and its tolerance to bypass the weak points of the slit.

- The presence of a combustion chamber in the piston means increasing the surface area exposed to the heat source, i.e. increasing the temperatures of the piston, so there must be ways and passages to get rid of this heat, such as increasing the number of rings or increasing the thickness of the support or placing a crack in the lubrication ring.

- It is necessary to have a slit in the lubrication ring in the piston with a flat crown, but rather to have holes for lubrication due to the lack of very high temperatures, as well as to be satisfied with a suitable support size in order not to increase the weight of the piston.

- Placing a cooling channel in the piston crown is necessary for pistons where the maximum pressure on the piston is large in order to reduce temperatures.

The real design of the pistons is the best design, as although the cooling channel reduces the temperatures of the piston, this decrease was not significant in addition to the difficulty of fabricating the channel in the crown, and although the increase in the thickness of the support will reduce the piston temperatures and thermal stresses, but not that big difference from The real design is better to avoid the increase in the thickness of the pillar, especially as it increases the weight of the piston.

The results we obtained facilitate the process of finding the appropriate design by changing the shape of the piston, determining the areas of stress concentration, obtaining the results and comparing them without resorting to long and expensive practical tests for each case and

comparing them with other cases in knowing the concentration of stresses, that is, this study is characterized by low cost and shortness. Time and accuracy of results.

This study, which used modern computer techniques to complete it through the use of the Ansys stress analysis program, and this study cannot be completed by conventional arithmetic methods due to the large number of complex equations and the difficulty of solving them, especially when the stress analysis is in a three-dimensional model.

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Table no 1

Peugeot engine piston	Mercedes engine piston	Volkswagen / Passat engine piston	Units	
7.3	6.2	7.5	(N / mm) ²	Maximum gas pressure
677	544	721	HG (w/m.K)	The heat transfer coefficient of the piston crown area
2788	2811	2328.5	Hring (W/m ² .K)	The heat transfer coefficient of the ring area
438	438	438	H1 (W/m ² .K)	Heat transfer coefficient for an area between the second and third piston rings
850	1528	850	H2(W/m ² .K)	Heat transfer coefficient for an area between the second and third piston rings
1528	-	1528	H3(W/m ² .K)	Heat transfer coefficient for the area between the

				third ring and the piston skirt
1367	1382	1434	Hoil (w/m2.K)	The heat transfer coefficient of the ring area

Table no 2

Young's modulus E N/ mm2	Expansion coefficient α E- 6(1/c*)	Delivery factor K (W/m.K)	LDensity Kg/m3	Tensile stress N/mm2	The name of the alloy
71.7	23	175.8	2740	371	Aluminum HG.416