Heat Transfer Analysis In The Cylinder Head Of A Four-Stroke Si Engine

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ABSTRACT

The importance of heat transfer in design of four stroke engine is important to make sure the engine will perform to expectation during actual working conditions. For this a prediction is done on the various heat distributions that might occur during a normal operation of the engine. The finite element model was evolved with many boundary conditions that are predicted from theoretical studies. This is to see the general heat transfer of the engine and whether or not the engine will withstand the thermal loads occurring during the theoretical operation. Assumptions are made by approximating temperature to the actual operating condition of the engine. Heat transfer was modeled with conduction and convection as the main source of heat transfer and neglecting radiation. The values are to be verified when the actual engine is operating with correct boundary conditions. It is hoped that the engine will not come to the boundary applied as it is assumed very high compared to actual condition. The study is a transient study with assumption that the engine is running at 6000 rpm for 60 seconds and generating the boundary heat from theoretical calculations.

First thermal analysis was done and analyzed the temperature distribution over the fin area. In the second stage structural analysis was carried out using the thermal loads obtained in the first stage. Three different types of materials were taken for analysis.

Keywords: Four stroke engine, transient heat, thermal analysis, structural analysis

1. INTRODUCTION:

Internal combustion engine, the descendent of steam engine, which was discovered a century ago, has still retained its basic anatomy as a piston-in-cylinder mechanism to convert reciprocating motion to rotary motion. The kinematics requiring numerous moving parts are still posing dynamic problems of vibration, friction losses and mechanical noise. Empiricism has been the secret of its evolution in its yester years. As the knowledge of engine processes has increased, these engines have continued to develop on scientific basis. The present day engines have to satisfy the strict environmental constraints and fuel economy standards in addition to meet the competitiveness of world market. Today the IC engines have synthesized the basic knowledge of many disciplines like thermodynamics, fluid flow, combustion, chemical kinetics and heat transfer as applied to a system with both spatial and temporal variations in state of non-equilibrium. With the availability of sophisticated computers multidimensional mathematical modeling the electronic instrumentation have added new refinements to the engine design.

Heat transfer is a very wide field used in analysis of internal combustion engines. Heat transfer affects the parameters such as performance, emissions and also efficiency. It is said that for a given mass of fuel the higher the heat transfer to the combustion wall will reduce the average combustion pressure and temperature. This indirectly reduces the work done by the piston per cycle and these effects the specific power. Heat transfer in spark ignition engines is needed to determine thermal stress on material components. This will provide confidence to proceed the project and make sure that the design will not fail due to thermal stresses. Mainly the engine is not fully developed and not tested for any data. So the values of the parameters that are taken for the thermal modeling are based on theoretical values. This will be validated using experiments once the full engine is completed and further help to modify the engine in future works. The shape of isothermal lines and high temperature regions becomes more important in these studies. The experimental way will find these regions but are costly and time consuming. Analytical methods are almost equally good for fast conformation of these regions by using finite elements. With the information the amount of experiments can be reduced to save cost on a project. To represent the problem of heat transfer the model of the engine was analyzed. The temperature at the beginning of induction is that of clearance gases. Temperature in the cylinder falls rapidly as the cool charge is inducted. The temperature then rises during compression and is increased to a maximum by combustion process. The expansion process later decreases the temperature and the exhaust process then rapidly drops the gases temperature.

During the process of converting thermal energy to mechanical energy, high temperatures are produced in the cylinders of the engine as a result of combustion process. Large portion of heat is transferred to the piston, cylinder head and walls. Unless this excess heat is carried away and these parts are adequately cooled, the engine will be damaged. A cooling system must be provided not only to prevent damage to the vital parts of the engine, but the temperature of these components must be maintained within certain limits in order to obtain maximum performance from the engine. Adequate cooling is then a fundamental requirement associated with reciprocating internal combustion engines. Hence a cooling system is needed to keep, from not getting so hot as to cause problems and yet to permit it to run hot enough to increase maximum efficiency operation. The duty of the cooling system in other words, is to keep the engine from getting not too hot and at the same time not to keep it cool. Some of the fundamental cooling problems and the cooling systems in general use were discussed in [1] & [2].

The material used for cylinder head at one time was cast iron, because of good wearing qualities. As the technology developed, aluminum alloy replaced cast iron as cylinder head material due to its light weight, high thermal conductivity, easier to machine during production and attractive in appearance. The major draw back of the aluminum cylinder head is its softness and is costly. Air-cooled cylinder heads with cooling fins are made of aluminum alloy on account of high heat transfer coefficient of aluminum. This gives a cooler combustion chamber and allows higher compression ratios without danger of detonation, and some of the important information regarding cylinder head was mentioned in [3]. Effective cylinder cooling is crucial to prevent engine failure in improving its thermal efficiency and service life. A higher temperature of charge in the combustion chamber may be preferred for higher engine efficiency. However this high temperature may adversely affect engine elements and cause considerable thermal-tribological problems discussed in [4].

The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surroundings or environment to maintain the system in a steady state condition. Heat transfer by convection between a surface and the fluid surrounding it can be increased by attaching to the surface thin strips of metals called ‘fins’, also referred as ‘extended surfaces’. Heat transfer through extending surfaces was studied extensively in the literature [5-6]. The mathematical analysis of convective fins was first provided by Gardner [7], based on the assumption of constant conductivity and a uniform coefficient of convective heat transfer along the fin surface. The heat flow due to conduction depends on the temperature gradient and the cross-sectional area. On the other hand, the convective heat transfer depends on the local temperature excess and the surface area. The rate of heat transfer from the fin of a given volume can be maximized by a proper selection of the cross-sectional area and the surface area of the fin from its base to tip. In other words, the designer has to find the profile geometry for a given fin volume that will maximize the rate of heat transfer. This aspect of fin design was first appreciated by Schmidt [8], who proposed a heuristic reasoning to show that the heat conduction in optimum thin fins has to be one dimensional and every section of the fin will be equally effective in dissipating the thermal energy. Duffin [9] established the proposition of Schmidt [8] on firm ground through a rigorous mathematical analysis using calculus of variation.

Fins have always been used as a passive method of enhancing the convection heat transfer from cylinders [10-13]. The presence of the solid fins has an effect on both the aerodynamic as well as the thermal characteristics of the flow. The fins tend to obstruct the airflow near the cylinder surface, thus reducing the heat transfer from the cylinder to the surrounding fluid. On the other hand, the fins increase the heat transfer area resulting in an increase in the heat transfer from the cylinder to the surrounding fluid. The net result of these two opposing effects depends on the combination of the number of fins, fin height, and Reynolds number. A.R.A. Khaled [14], modeled and analyzed analytically heat transfer through joint fins systems that are exposed to two different convective media from its both ends and concluded that heat transfer through joint fins is maximized at certain critical length of each portion. Bassam A/K Abu-Hijleh [15-16] investigated numerically the problem of laminar natural and forced convection from a horizontal cylinder with multiple equally spaced high conductivity permeable fins on its outer surface. The heat transfer characteristics of a cylinder with permeable versus solids fins were studied for several combinations of number of fins and fin height over the range of Reynolds number in case of forced convection and Rayleigh number in case of natural convection. Permeable fins provided much higher heat transfer rates compared to more traditional solid fins for a similar cylinder configuration.

In the present work, thermal and structural analysis of a four stroke petrol engine cylinder head has performed numerically by varying thermal load conditions, i.e., convections and heat fluxes for temperature and thermal stress values. The geometry of the model is unchanged throughout the analysis and the results so obtained are consistent with expectations, in the sense that the temperature and thermal stresses increase with applied heat flux and decrease with applied heat transfer coefficients.

2. FINITE ELEMENT MODELLING

The heat transfer model was created based on a fabricated engine that is going to be used for research purpose. Boundary condition to the problem was modeled based on standard heat transfer that would occur normally in a two-stroke engine at steady state. This model was done with temperature distribution (conduction) at the spark plug location and convection is applied over the fin surface.

Boundary Conditions

Since the cooling system of the engine uses air, convection boundary is defined on all the outer surfaces (at fins) of the engine assembly. The value is taken as 13.3 W/mK from running engine calculation. The engine speed used is the maximum theoretical speed which is 6000 rpm and a transient analysis is done for 60 second the time the engine is running. This is to see the amount of heat that is transferred during the time and does it cause a lot of displacement to the engine components.

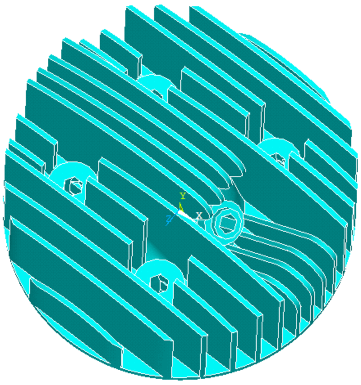

Fig 1. 3D Pro E Model of Cylinder head

To capture the physics of the problem and to estimate the stresses correctly, the model is finely meshed using solid 187\solid 87 elements.

Total number of elements in the model 43341

Total number of nodes in the model 45267

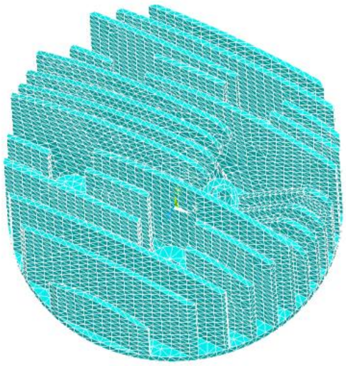

Fig 2. Mesh Model of Cylinder head

Engine Specifications

Item	Specifications
Engine Type	Four Stroke
Number of Cylinders	One
Displacement	150 CC
Expected Speed r.p.m	6000
Cylinder bore : mm	60
Stroke :	53 mm
Compression rato :	9
Clearence Volume cm^3	18.75
Piston area cm^2	28.2743
Inlet Port area cm^2	8.4823
Outlet Port area cm^2	7.0686
Delivery ratio, RCC	1.5
Scavenging Efficiency	77.6%

The cylinder head is subjected to convection on the fins and conduction on the spark plug area at the centre of the cylinder head. The mathematical formulation, the variation of temperature in the cylinder head and the rate of heat loss for steady one-dimensional heat transfer.

3. RESULTS AND DISCUSSIONS

To perform the couple field (Thermal & Structural) analysis of the Cylinder head, and optimize the material properties to reduce stresses and deflections due to thermal loads with Film coefficient of 1330 W/m2K.

The original model is modeled in Pro-e. After the generation of geometric model a parasolid model of the cylinder head is generated in Pro-e which is imported into Ansys using the parasolid translator. Couple field analysis is carried out in Ansys using structural solid 187 and thermal solid 87 elements. The main objective of the paper is to observe the stress distribution and deflections at the fins area in both radial and axial directions. Also the heat dissipation in the cylinder head can be increased by changing the material properties.

A coupled-field analysis is a combination of analyses from different engineering disciplines (physics fields) that interact to solve a global engineering problem; hence, we often refer to a coupled-field analysis as a multiphysics analysis. When the input of one field analysis depends on the results from another analysis, the analyses are coupled.

Some analyses can have one-way coupling. For example, in a thermal stress problem, the temperature field introduces thermal strains in the structural field, but the structural strains generally do not affect the temperature distribution.

Some of the applications in which coupled-field analysis may be required are pressure vessels (thermal-stress analysis), fluid flow constructions (fluid-structure analysis), induction heating (magnetic-thermal analysis), ultrasonic transducers (piezoelectric analysis), magnetic forming (magneto-structural analysis), and micro-electromechanical systems (MEMS).

3.1Temperature Distribution in the cylinder head for the Material (A413.0)

Due to the thermal loading given in temperatures is 600^{o}C (873K), the following contours are obtained looking at the cylinder head view of the engine

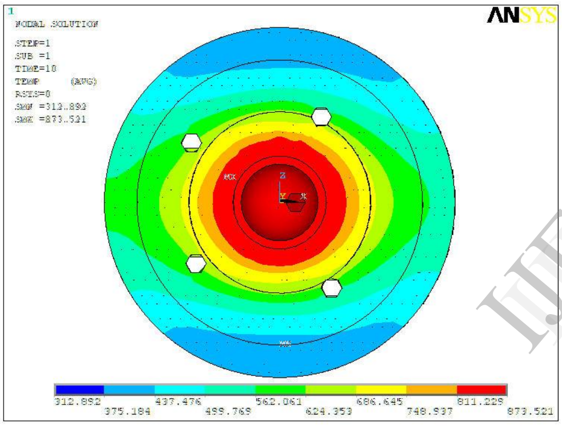

Fig 3.Temperature distribution contour of cylinder head shown in bottom view for time at 10S.for A413

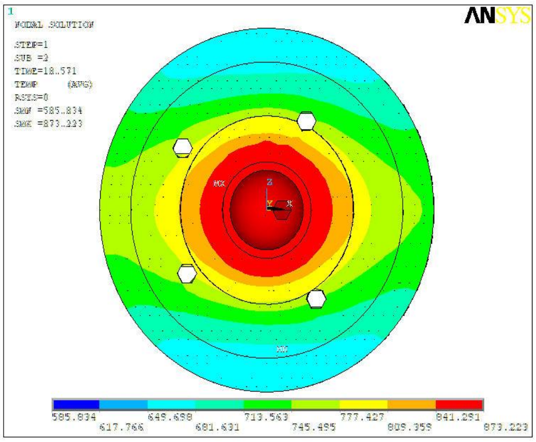

Fig 4.Temperature distribution contour of cylinder head shown in bottom view for time at 20S.for A413

3.2Thermal Stress (Von Mises) Distribution in the cylinder head for the Material(A413.0)

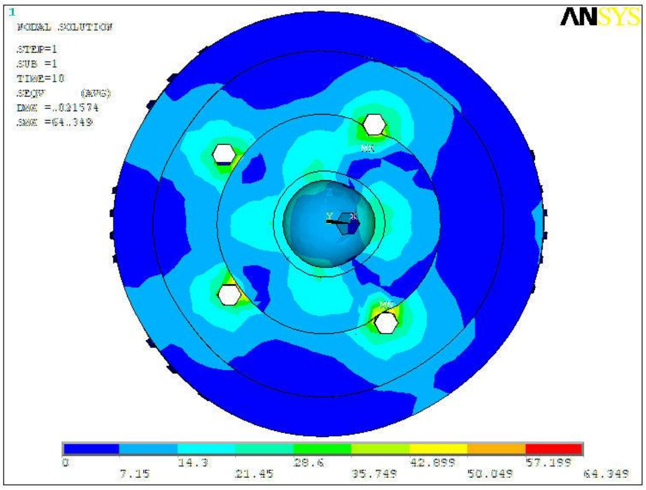

Fig5. Thermal stress (Von Mises) distribution contour of the cylinder head has shown in bottom view for time at 10 seconds at 873K for (A413.0).

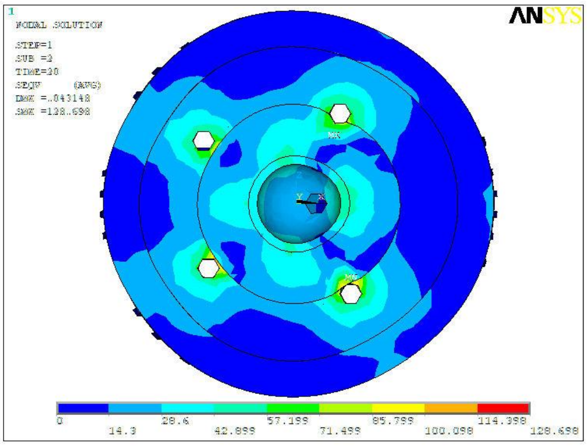

Fig6. Thermal stress (Von Mises) distribution contour of the cylinder head has shown in bottom view for time at 20 seconds at 873K for (A413.0).

3.3Temperature Distribution in the cylinder head for the material (C443.0)

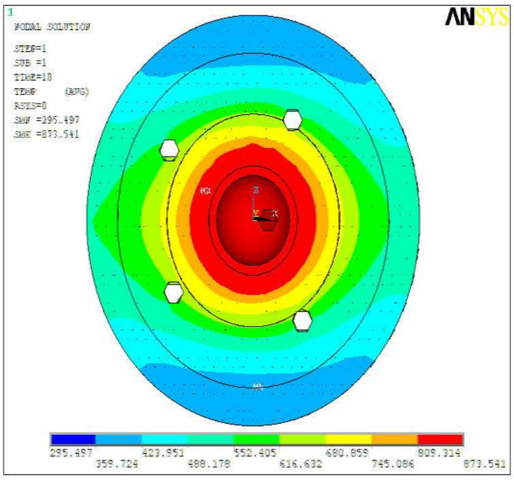

Fig7. Temperature distribution contour of cylinder head shown in bottom view for time at 10S.for (C443.0)

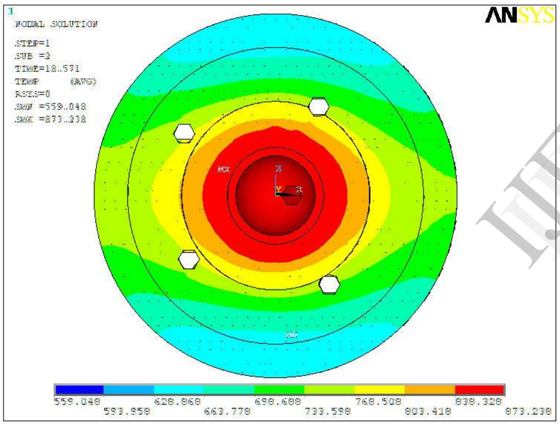

Fig8. Temperature distribution contour of cylinder head shown in bottom view for time at 20S.for(C443)

3.4 Thermal Stress (Von Mises) Distribution in the cylinder head for the material (C443.0)

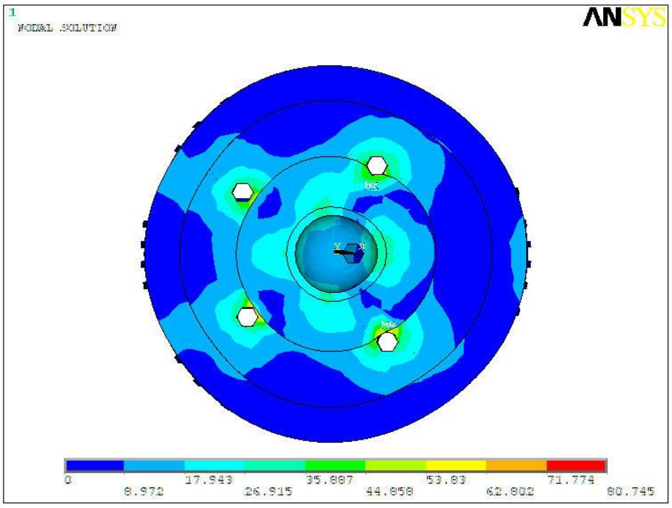

Fig9. Thermal stress (Von Mises) distribution contour of the cylinder head has shown in bottom view for time at 10 seconds at 873K for (C443.0).

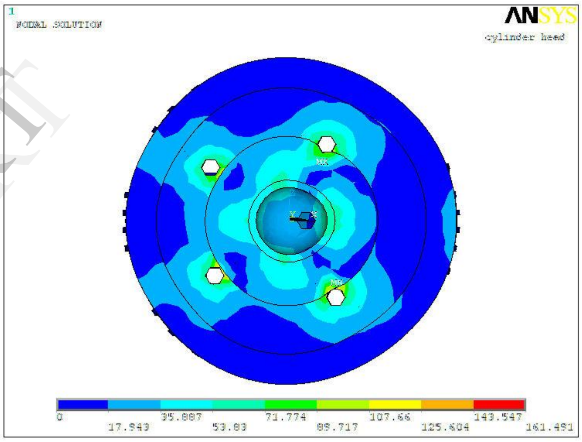

Fig10. Thermal stress (Von Mises) distribution contour of the cylinder head has shown in bottom view for time at 20 seconds at 873K for (C443.0).

3.5Temperature Distribution in the cylinder head for the material (B390.0)

Fig11.Temperature distribution for (B390)

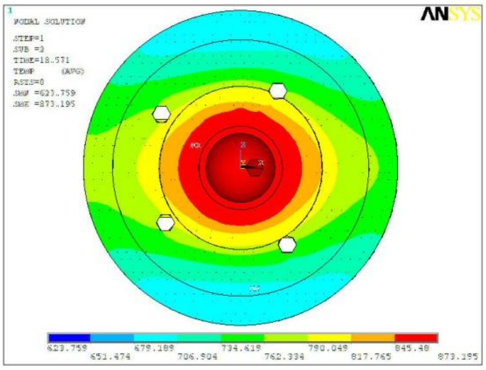

Fig11. Temperature distribution contour of cylinder head shown in bottom view for time at 20S.for(B390

3.6 Thermal Stress (Von Mises) in MPa Vs Time in seconds for material A413.0

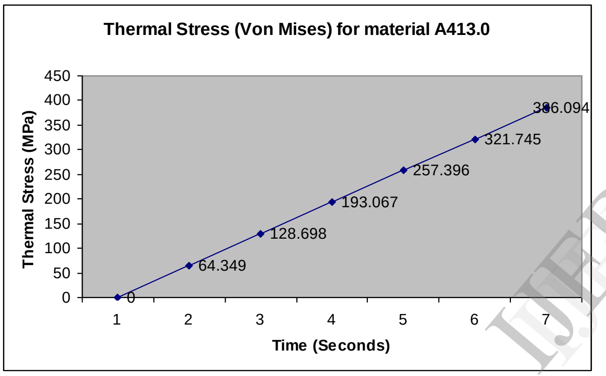

Fig12. **Thermal Stress (Von Mises) in MPa Vs Time in seconds for material A413.0**

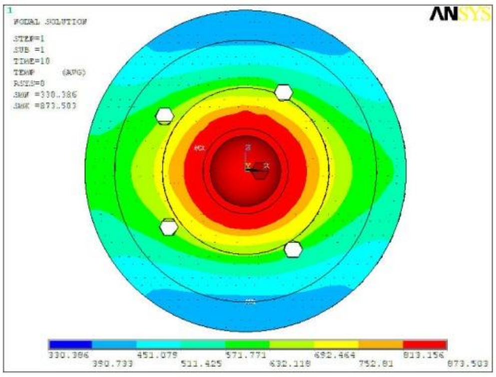

Fig13. Thermal Stress (Von Mises) in MPa Vs Time in seconds for material C443.0

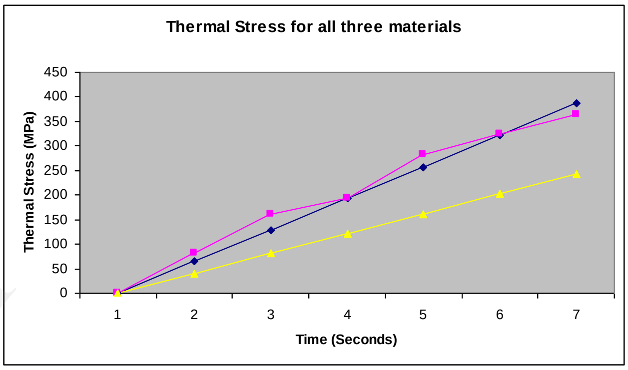

Fig14. Comparison Graph between all three materials

4. CONCLUSIONS

After doing the three different coupled (thermal & structural) analysis with three different materials, we found that the maximum stresses for those three materials. For material A413.0, the maximum stress was 386.094 MPa. For material C443.0, the maximum stress was 363.354 Mpa. For material B390.0, the maximum stress was 242.236 MPa.

Finally we calculated the factor of safety for all three materials. The factor of safety of all three materials was 0.3367 for A413.0, 0.266 for C443.0 and 1.032 for B390.

Finally we concluded that the B390.0 was the best material among all because it is more Factor of Safety than other two and the FOS should always more than one.

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