Enhancement of Heat Transfer Rate Using Transient Thermal Analysis For Actual And Proposed Design of The Single Cylinder Air Cooled Four Stroke Spark Ignition Engine

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Abstract: Heat transfer from the IC engine take place in all modes like conduction, convection & radiation. About 25 % of the fuel energy is converted into useful work and the remaining 75% to be transferred from the engine to the environment. The calculation of engine heat transfer is very difficult because the engine geometry is complex and there are periodic air and fuel flow during the entire cycle. The main object of present work is to increase heat transfer rate from cylinder head & block of single cylinder SI engine and also provide best solution to increase heat transfer rate with optimum design of the IC engine. For that Three CAD models have been created with the help of CATIA & further Thermal analysis are performed in ANSYS 16.0. Transient thermal analyses were performed for actual as well as proposed design of IC engine one by one to optimize geometrical parameters and enhanced heat transfer rate from the same. Investigated result revel that the proposed design -2 of single cylinder four stroke IC engine has better performance and heat transfer rate from the heating zone in the IC engine.

Key words: Heat Transfer, IC engine, Transient Thermal analysis, engine geometry etc.

I. INTRODUCTION

Combustion temperature in the IC engines cylinders can be reached the values of 2700 K and more without sufficient cooling. The higher temperatures of this magnitude would destroy engine components quickly and lubricants used for cooling. Heat removed from engine cylinder is finally dissipated in the surroundings.

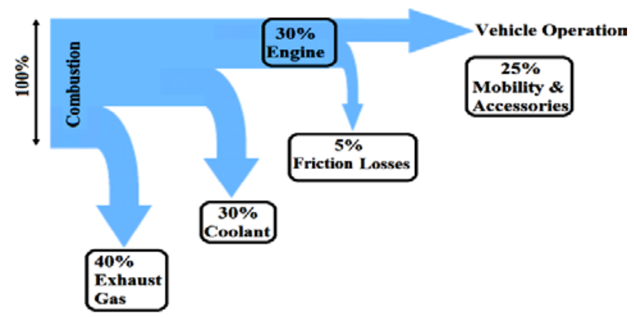

Figure 1: Energy transfer in internal combustion engine vehicle

Heat removed from overheated engine to the atmosphere transfer large percent of the generated heat from the engine due to transfer of Heat from the engines the brake thermal efficiency lie between 30-40%. [1]

1.1 Working principle of SI engine:

Working principle of SI engine was invented by a German engineer Nikolaus Otto who built the first Spark Ignition engine in 1876. Figure 2 & 3 shows PV & TS diagram of this cycle which explains that how the pressure varies during compression and expansion stroke. Otto cycle is a four stroke six event cycles and generally it is used in SI engine that mean combustion of fuel is taking place with the help of spark. Fuel used in this cycle engine is gasoline. The six events are suction stroke, compression stroke, combustion, expansion stroke, blow by or heat rejection and exhaust stroke. In the above events, combustion & heat rejection is an instantaneous event and rest of all is stokes [2]. The air standard Otto cycle uses the following process assumptions:

1-2 Compression which is reversible and adiabatic

2-3 Heat addition from fuel

3-4 Expansion which is reversible and adiabatic

4-1 Heat rejection to cylinder walls

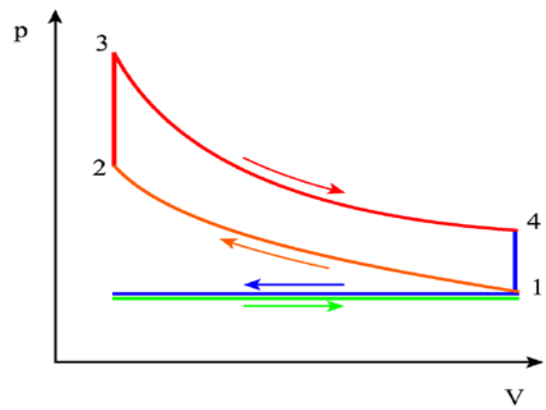

Figure 2: PV diagram of Otto cycle

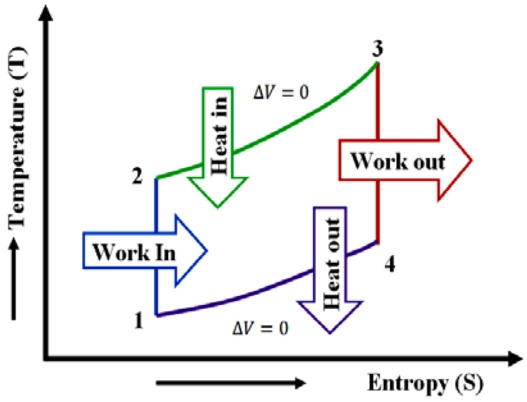

Figure 3: TS diagram of Otto cycle

1.2 Modes of Heat Transfer IC engine:

Conduction:

Heat is transferred by the molecular momentum or motion through solids and through fluids at rest due to a temperature gradient. The Fourier relation explains that the heat transfer per unit area $\left(\frac{Q}{A}\right)$ in $\frac{W}{m^2}$ is proportional to the temperature gradient$\frac{dT}{dX}$.

Fourier's equation:

$$\frac{Q}{A} = -k\frac{dT}{dX} \ or \ \frac{k(T_2 - T_1)}{\Delta x} \quad W/m^2$$

Convection:

Heat transfer in the convection process is through fluid/gases motion and between a fluid/gases and solid surface in relative motion.

$$\frac{Q}{A} = h(T_s - T_f) \quad W/m^2$$

Radiation:

The heat transfer by radiation is directly proportional to the fourth power of the absolute temperature of material. The proportionality constant ϵ is Stefan Boltzman constant & equal to 5.67 x 10^{-8} W/m^2K^4.

$$\frac{Q}{A} = \in \sigma T^4 \quad W/m^2$$

1.3 Heat Transfer in Intake System:

The intake manifold wall is hotter than the other nearest components of engine the manifold is hot either by design or by its location close to other hotter components in the IC engine. The heat transfer is calculated through convection process.

Heat transfer by convection:

$$Q = hA(T_{wall} - T_{gas}) \text{ Watt}$$

1.4 Heating the Manifolds:

Intake manifold is the part of an IC engine that supplies the air/fuel mixture to the engine cylinder. In some systems comprise special restricted hot surfaces which are also called *hot spot* as shown in figure 4 and the temperature of intake valve rise upto 200º-300ºC. *[Engine Heat Transfer by PMV Subbarao Professor IIT Delhi]*

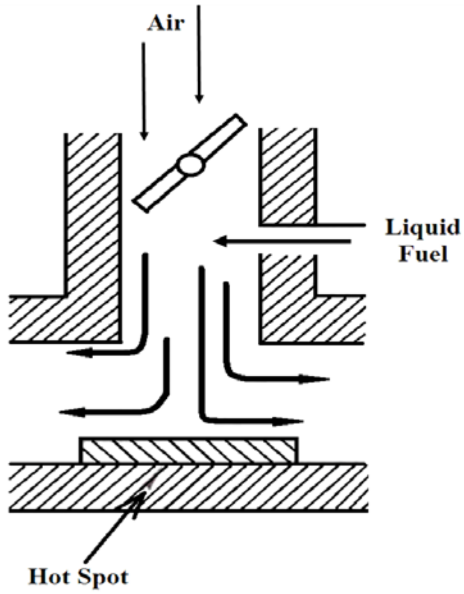

Figure 4: Air fuel intake system

1.5 Heat Transfer in Combustion Chambers:

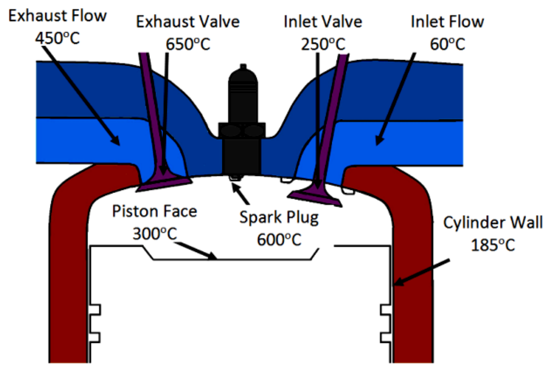

Figure 5: Distribution of Temperatures in combustion chambers.

During combustion process highest gas temperatures occur around the spark plug as shown in figure 5 in this figure three hottest points identified the first one is exhaust valve, second is exhaust flow pipe and third is face of the piston which creates a critical heat transfer problem. The exhaust valve is very hot about 650 ºC as shown in above because it is opening for hot exhaust gases, these hot gases passes from exhaust manifold and liberated to atmosphere.

1.6 Heat Transfer in Exhaust System:

Exhaust temperature of an IC engine are lesser or lower due to greater expansion ratio of burnt gases and generally it ranging from 200ºC-500ºC. The working principle of exhaust system is showing in figure No. 6.

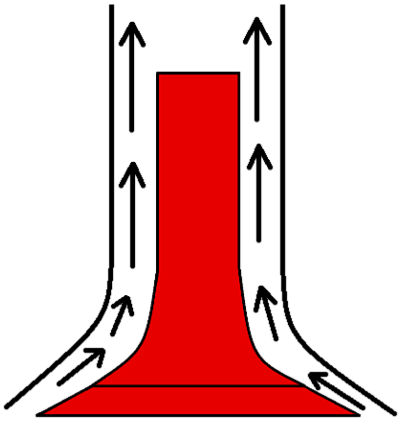

Figure 6: Heat Transfer in Exhaust System

II. LITERATURE REVIEW

Xueying Li at el [3] They investigated experimentally A typical end-wall configuration with matched non-dimensional parameters to the engine condition in this study. They use four different coolants to mainstream mass flow ratios were tested in a linear cascade. The temperature sensitive paint and pressure sensitive paint were used to get these parameters. One dimensional and two dimensional methods for overall effectiveness prediction based on experimental data for separate parameters and correlations were also studied.

Ravindra D. Jilte, Jayant K. Nayak & Shireesh B. Kedare [4] In this work an experimental testing have been done to analyze the heat losses from the cylindrical solar cavity. Tests are carried out under the temperature range from 225°C to 425°C at cavity inclination from 0° to 90° in steps of 30°. They observed that for off-flux investigation of solar cavity receiver with the differential heating arrangement. The total loss is found at sideways (θ = 0°). It decreases by 43-51% when the inclination was 90°. The conduction loss is found to accounts up to 32-34 % of the total heat loss whereas cavity radiative losses is estimated 13%, 16% and 20% of total heat loss respectively for cavity wall temperature 225°C, 325 °C and 425°C. The convective loss is found to accounts up to 46- 54 % of total heat loss when the cavity aperture is facing sideways (θ = 0°), whereas its value reduces to up to 4 % of total heat loss when the inclination was 90°.

Brajesh Kumar & Sanjay Kumbhare[5] they proposed three design of IC engine. Mathematical and analytical studies were performed in order to optimize geometrical parameters for natural convective heat transfer from Actual cylinder block and proposed cylinder block. The transient thermal analysis in ANSYS v16.0 was performed on two different ambient temperatures; the first one is on 25 ^{o}C & another one is on 45 ^{o}C. They found that lower temperature is much below in proposed design-2 hence the proposed design -2 of cylinder block has better performance and heat dissipation from the heating zone in the IC engine.

Vijayakumar P, Sathyamoorthy G & Velavan R [6] The present paper is aiming to enhancing the performance of I.C engine, in order to change the fin materials and geometry. It is an attempt to study and analyze the internal combustion engine fins for maximizing the performance by considering different geometrical profile, fin material, and variable fin length for weight reduction. Fins are analyzed with different fin profiles, fin materials, variable fin profile and with minimal cooling conditions for an air cooled diesel engine of 5 H P. From the investigation they observed Trapezoidal profile or Stepped rectangular profile adoption will result in material saving and increases in performance.

Ashkan Alimoradi [7] In this work the effect of operational and geometrical parameters on the thermal effectiveness of shell and helically coiled tube heat exchangers was investigated. Analysis was performed for the steady state. The working fluid of both sides is water. They found for same values of NTU and Cr, the effectiveness is averagely 12.6% less than the effectiveness of parallel flow heat exchangers and this difference is approximately constant.

Adnan M. Hussein, H.K. Dawood, R.A. Bakara & K. Kadirgamaa [8] In this paper the friction factor and forced convection heat transfer of TiO_2 nano particles dispersed in water in a car radiator. Four different nano fluid volume concentrations (1%, 2%, 3% and 4%) were used The Reynolds number and inlet temperature ranged from 10000 to 100000 and from 60 to 90 °C, respectively. It has been concluded that the used nanofluid at low concentration can improve the heat transfer efficiency upto 20% as compared with pure water.

Pooya Arbabi, Abbas Abbassi, Zohreh Mansoori, Mohammad Seyfi [9] This work is devoted to provide a numerical model to estimate the amount of generated power and recovered heat, based on the engine performance features. Grey Systems Theory is proposed as a multi decision making strategy to determine the optimal engine. Applying the numerical model on engines provides the efficiency,power and heat production characteristics of the engine.

Teresa Castiglione, Sergio Bova & Mario Belli [10] This paper presents results of the Model Predictive Controller methodology applied to the cooling system of an Internal Combustion Engine. The proposed controller is evaluated during the city driving part of the NEDC homologation cycle, and replaced at the engine test rig. The results show that the proposed controller is robust in terms of disturbance rejection and is effective in reducing warm up time.

V.A. Romanov & N.A. Khozeniuk [11] The cooling system of the designed diesel engine was investigated using specially prepared models. they found that the uniformity of the cylinder cooling and the intensity of cooling of the cylinder heads can be controlled by choice of the place of coolant penetration into the jacket for the considered design of a crankcase and cylinder heads.

Andrew Roberts, Richard Brooks, Philip Shipway [12] They found that the thermal efficiency of the internal combustion engine is significantly lower at cold-start than when the vehicle reaches steady state temperatures. The approaches have a common theme of attempting to reduce energy losses so that systems and components reach their intended operating temperature range as soon as possible after engine start. they observed at the target operating temperature. The approaches used to tackle the problem include the use of phase change materials and the use of thermal barrier coatings in an attempt to insulate the cylinder bore and prevent heat loss. a critical review of the research into vehicle thermal management during the cold-start phase which has been driven by a desire to improve both engine and overall vehicle engine efficiency.

III. OBJECTIVE

There are following objective are to be expected from the present work

1. The main object of present work is to increase heat transfer rate from cylinder head & block of single cylinder SI engine.
2. To study the heat transfer behavior from an IC engine.
3. To perform transient thermal analysis for Actual design of single cylinder IC engine.
4. To perform transient thermal analysis for proposed designs of single cylinder IC engine.
5. To compare the results of heat transfer rate for actual and proposed design of single cylinder IC engine.
6. To present best solution to increase heat transfer rate with optimum design of the IC engine.

IV. METHODOLOGY

4.1 Mathematical Analysis:

The purpose of fins in IC engine is to enhance convective heat transfer from engine. The primary purpose behind the operation of fins is to raise the effective heat transfer area from the surface.

Heat in to the left face = Heat out from the right face + Heat loss by convection

This yield

$$Q_x = Q_{x+\Delta x} + Q_{con}$$

After solving the above equation we got the general solution

$$\theta = C_1 e^{-mx} + C_2 e^{mx}$$

C_1 and C_2 are constant and can be determined from the boundary conditions.

Case I: The fin of infinite length:

Conductive heat transfer at the base of fin, according to Fourier's law

$$Q_{Fin} = -kA\left(\frac{dT}{dx}\right)_{x=0}$$

Case II: Fin Insulated at the tip:

$$Q_{Fin} = \sqrt{hPkA}(T_0 - T_\infty)\tanh(ml)$$

Case III: The finite length of the fin:

$$Q_{Fin} = \sqrt{hPkA}\,(T_0 - T_\infty)\left[\frac{\tanh\ (ml) + \frac{h}{km}}{1 + \frac{h}{km}\tanh\ (ml)}\right]$$

4.2 Heat Flux Calculation:

The total heat flux on the wall surface can be calculated by solving the unsteady heat conduction equation with the boundary condition given by the surface temperature measurement. In the measurement heat flux it is assumed that the heat flow is one dimensional and the hottest junction temperature gives the surface temperature.

Since the unsteady component on the inner wall temperature field exist only within a very small distance from the wall surface the unsteady component of the temperature gradient perpendicular to the surface is usually much larger than that of parallel to the surface. Therefore one dimensionality is safely assumed for the unsteady component of the surface heat flux. This assumption is rarely true for the time average component. [13]

The well known one dimensional unsteady heat conduction equation is given by

$$\frac{\partial T}{\partial t} = \frac{1}{\rho C} \times \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)$$

Where ρc is a constant heat capacity and k is thermal conductivity of the material

The steady periodic surface temperatureT_w, changing with angular velocity of ω rad/sec can be expanded into the Fourier series.

$$T_w = T_m + \sum_{n=1}^{N}[A_n\cos(n\omega t) + B_n\sin(n\omega t)]$$

Where T_m is a time averaged component of T_w, A_n and B_n. Are Fourier coefficients and n is a harmonic number.

The boundary conditions are

$T = T_w(t)\ at\ x = 0$

$T = T_l = constant\ at\ x = l$

$$T(x,t) = T_m - (T_m - T_l)\frac{x}{l} + \sum_{n=1}^{N} exp(-\emptyset_n x) F_n(x,t)$$

$$F_n = A_n \cos(n\omega t - \emptyset_n x) + B_n \sin(n\omega t - \emptyset_n x)$$

$$\emptyset_n = \sqrt{n\omega/2\alpha}$$

α is the thermal diffusivity of the wall material, k/ ρC.

$$q_w = \frac{k}{l}(T_m - T_l) + k\sum_{n=1}^{N} \emptyset_n [(A_n + B_n)\cos n\omega t - (A_n - B_n)\sin n\omega t]$$

It has been usually observe that the measured surface temperature fluctuate significantly and almost arbitrarily from cycle to cycle under steady state operation of engines.

4.3 Finite Element Analysis:

Finite element analysis is a method which evaluate that how a product behave in real world during forces, heat & fluid flow, vibration and other physical effects. It helps to confirm whether a product will fail or work the way it was designed. FEM used for design and development of various product on which various analysis can be performed like thermal, structural, electromagnetic, fluid working environment. It is a powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications.[14] The benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue.

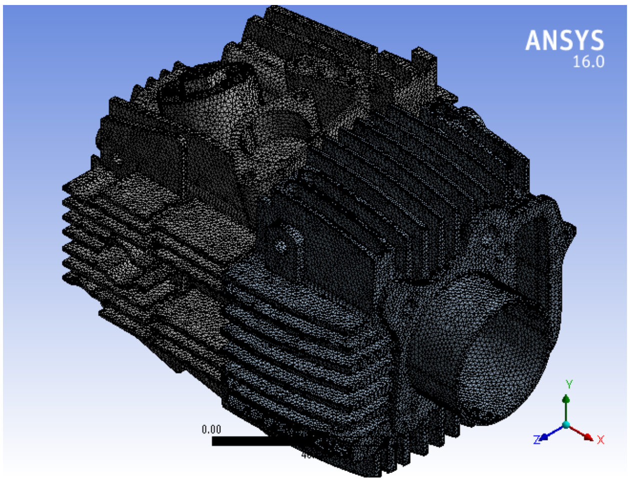

Figure 8: Meshing of actual design of IC engine

4.4 Transient Thermal analysis:

Transient thermal analysis is used to determine temperature distribution and other thermal parameters that may vary over the time. Thermal analysis is a technique in which a property of the work is monitored against the time and in a definite atmospheric condition. The thermal analysis allows to learn that how chemical processes which are associated with heating or cooling.

4.4.1 CAD Modeling:

In the present work a three dimensional CAD model of actual design of IC engine cylinder block with Head is created with the help of CATIA software then imported in ANSYS workbench for further analysis. A three dimensional view of actual design of IC engine is shown in figure No.7.

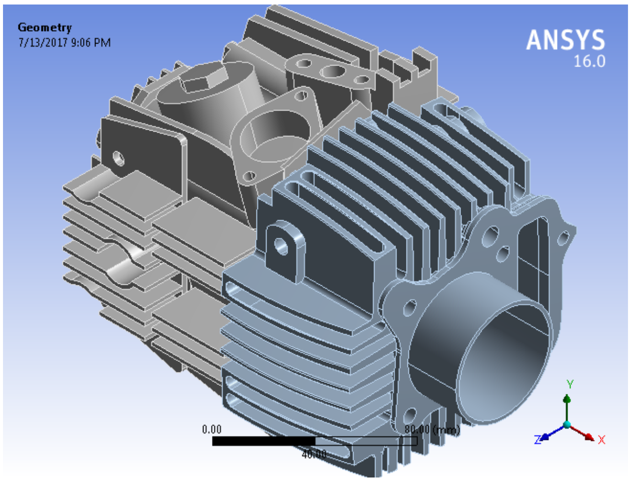

Figure 7: CAD geometry of actual design of IC engine

4.4.2 Meshing:

After completing the CAD geometry of cylinder block is imported in ANSYS workbench for further thermal analysis.

The mesh created for actual design of IC engine cylinder block & Head in this work is shown in figure No. 8. The total Node is generated 1799644 & Total No. of Elements is 1043403 in which total contact elements are 508280 and solid elements are 1689169. it is clear from the mesh geometry the node numbers and element numbers are almost seven in digit which show that the mesh is very fine because the result accuracy depends on the mesh quality.

4.4.3 Defining Material Properties:

In the present work Gray cast iron is used for cylinder block and aluminium alloy is used for cylinder head as a material of IC engine. The material properties of cylinder head are as: Density: 2700 kg/m3, Isotropic thermal conductivity: 167 w/m ^{o}C, Specific Heat: 896 J/kg ^{o}C. and material properties of cylinder block are as: Density: 7200 kg/m3, Isotropic thermal conductivity: 52 w/m ^{o}C, Specific Heat: 447 J/kg ^{o}C. [*http://www.matweb.com*]

4.4.4 Boundary condition:

1. The maximum temperature generated on inside the cylinder block is taken as 650°C (John B.LHeywood "*Engine Heat transfer*").
2. The increment of temperature magnitude factor is in X- direction.
3. For the meshing SOLID87 & SURF152 element is used.
4. Since an IC engine traveled in open space that is why normal air available and it forced in opposite direction of moving vehicle hence force convection is applied and the value of convective coefficient for the present work is taken as 100 W/m^2.
5. The Quasi Linear Thermal Transient Solution solver is used for transient thermal analysis.

4.4.5 Temperature Distribution of Actual design of IC Engine:

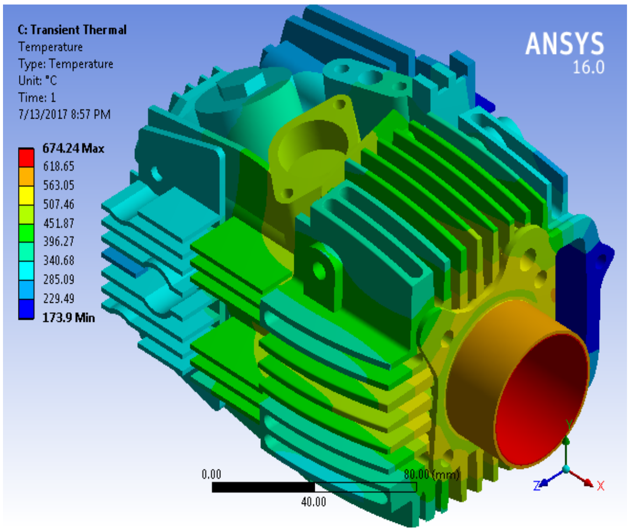

Figure 9: Temperature distribution on actual design of IC engine

Transient thermal analysis where performed on actual design of IC engine at 25 °C atmospheric temperature. The maximum temperature is 674.24 °C and minimum temperature is 173.9 °C as shown in Figure No. 9.

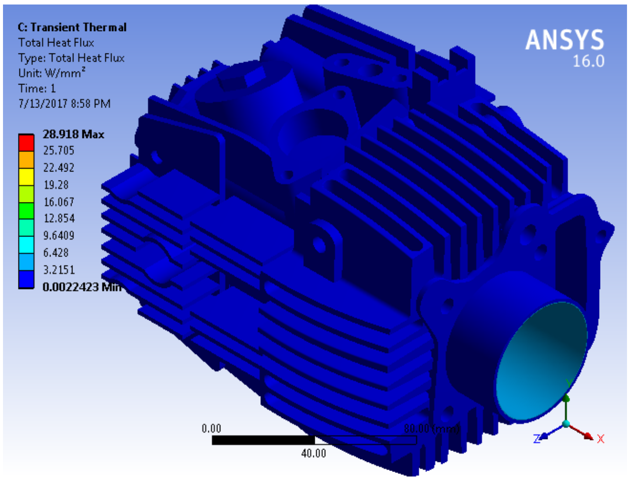

Figure 10: Total Heat Flux of Actual design of IC engine

4.4.6Total heat flux:

The total heat flux generated in the actual design of engine cylinder is 28.918 W/mm^2 as shown in Figure No. 10.

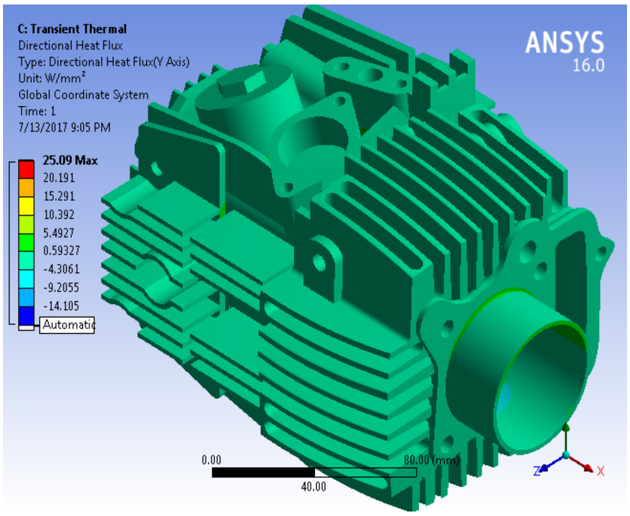

Figure 11: Directional Heat Flux of Actual design of IC engine in Y direction

4.4.7 Directional heat flux in Y- direction:

The directional heat flux in the Y- direction generated on the actual engine cylinder, Maximum Directional heat flux generated is 25.09 W/mm^2 and minimum Directional heat flux generated is -5.8731 W/mm^2. Figure No. 11

4.5 Transient Thermal analysis of proposed Design-1:

4.5.1 CAD geometry:

A three dimensional CAD model of proposed design-1 of IC engine is also created with the help of CATIA then its stp format is imported in ANSYS workbench for further analysis. A three dimensional view of engine cylinder is shown in figure No.12.

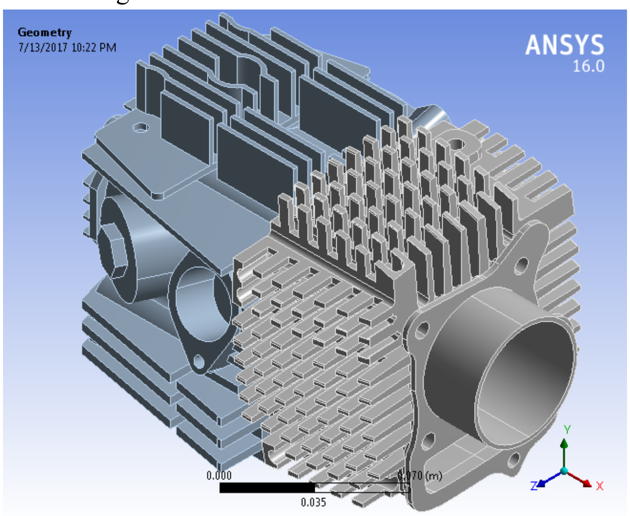

Figure 12: CAD Model for proposed design-1of IC engine

4.5.2 MESHING:

The mesh created in this work is shown in figure No.13 where total generated nodes are 1769666 & Total No. of elements are 1037358.

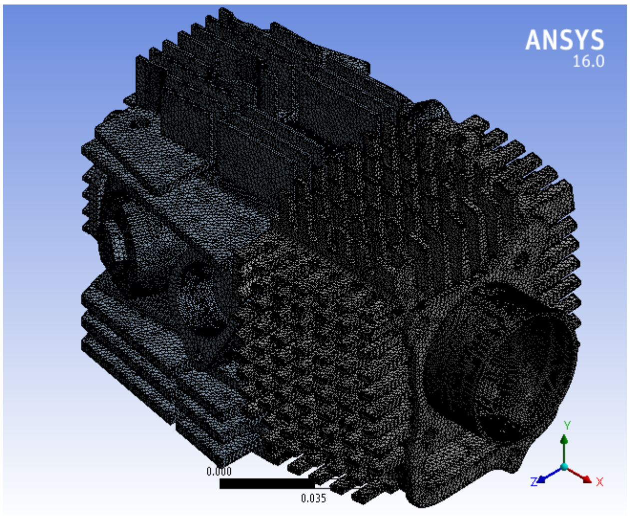

Figure 13: Meshing for proposed design-1of IC engine

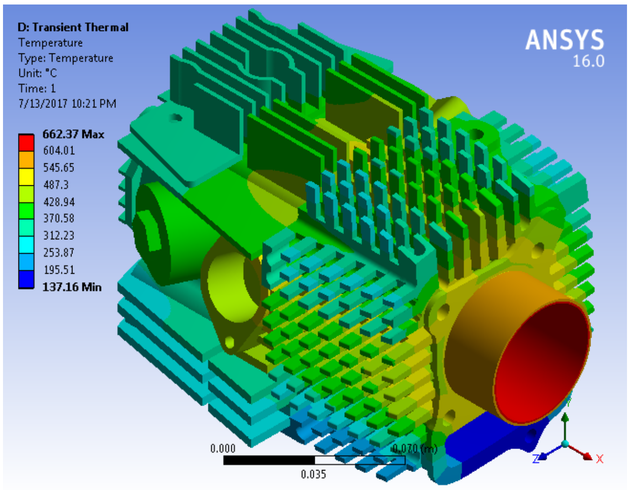

Figure 14: Temperature Distribution over entire surface of proposed design-1 of IC engine

4.5.3 Temperature Distribution For Proposed Design-1:

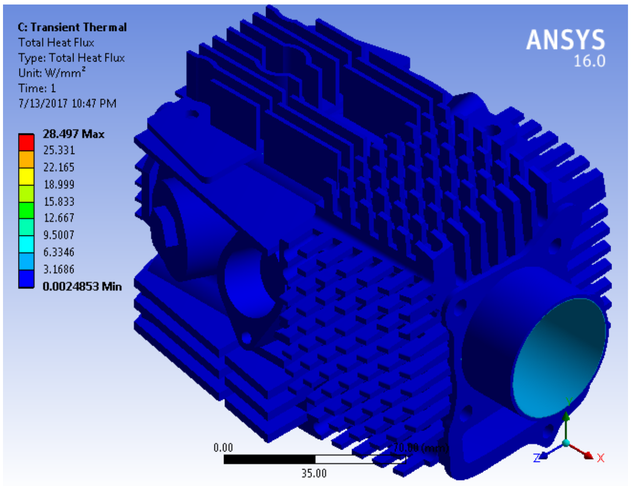

Figure 15: Total Heat Flux of Proposed design-1 of IC engine

Transient thermal analysis where performed for proposed design-1 of engine cylinder at the same atmospheric temperature as accrual engine cylinder and the result indicates the temperature distribution for proposed design-1 of actual engine cylinder the maximum temperature is 650 ^{o}C and minimum temperature is 137.16 ^{o}C. Figure No. 14.

4.5.4 Total Heat Flux for proposed design-1:

The result indicates for Total Heat Flux of proposed design-1 the maximum Total Heat Flux is 28.497 W/mm^2 and minimum Total Heat Flux is 0.0024853 W/mm^2. Figure No. 15.

4.5.5 Directional Heat Flux in the Y- direction for proposed design-1:

Transient thermal analysis where performed for proposed design-1 of engine cylinder at the same atmospheric temperature as actual engine cylinder and the result indicates the directional heat flux in the Y- direction generated for proposed design-1 of actual engine cylinder the maximum Directional Heat Flux is 19.16 W/mm^2 and minimum Directional Heat Flux is -16.719 W/mm^2. Figure No. 16

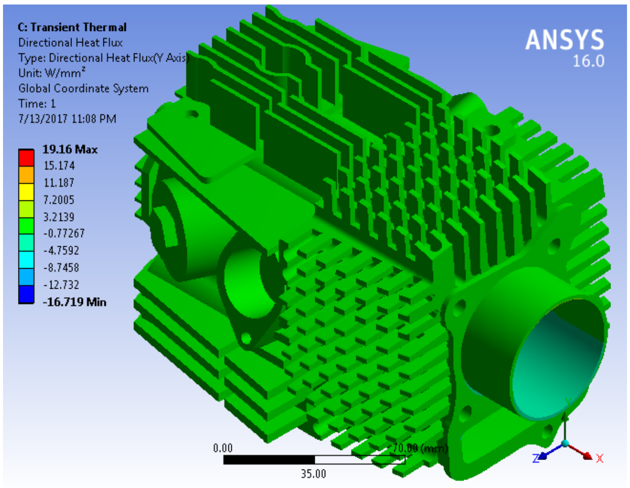

Figure 16: Directional Heat Flux of Proposed design-1 of IC engine in Y direction

4.6 Transient Thermal analysis of proposed Design-2:

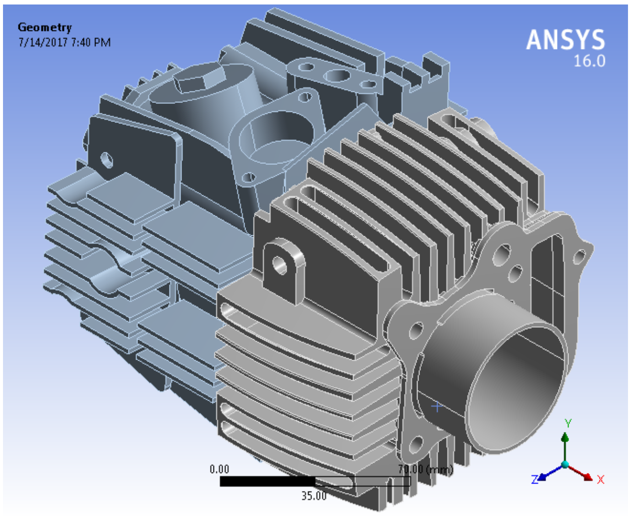

Figure 17: CAD Model for proposed design-2of IC engine

4.6.1 CAD geometry:

A three dimensional CAD model of proposed design-1 of IC engine is also created with the help of CATIA then its stp format is imported in ANSYS workbench for further analysis. A three dimensional view of engine cylinder is shown in figure No.17.

4.6.2 MESHING:

After completing the CAD geometry of proposed design-2 of engine cylinder is imported to ANSYS workbench for further transient thermal analysis and the next step is meshing. The mesh created in this work is shown in figure No.18. The total Node is generated 1897017 & Total No. of Elements is 1496498. Types of element used in the present work is solid87 and surf152, in which total contact elements are 383926 and solid elements are 1112572. It is clear from the present mesh geometry the total node numbers and total element numbers are six in digit which show that the mesh is very fine because the result accuracy depends on the mesh quality.

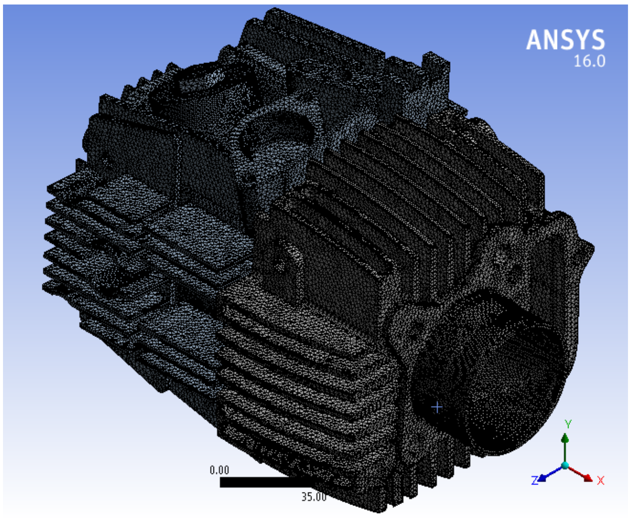

Figure 18: Meshing for proposed design-2 of IC engine

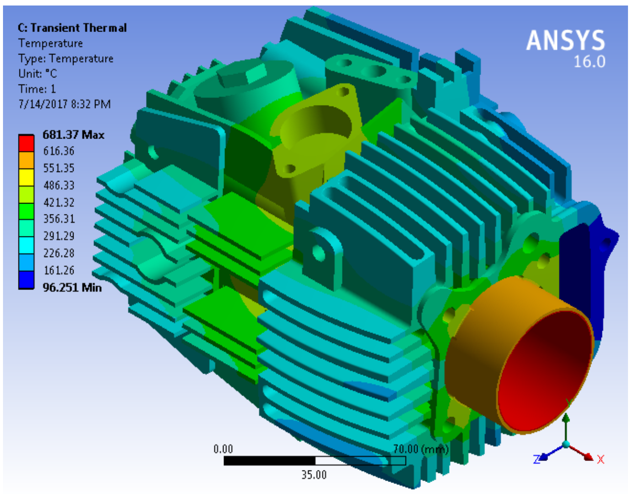

Figure 19: Temperature Distribution over entire surface of Proposed design-2 of IC engine

4.6.3 Temperature Distribution For Proposed Design-2:

Transient thermal analysis where performed for proposed design-2 of engine cylinder at the same atmospheric temperature as accrual engine cylinder and the result indicates the temperature distribution for proposed design-1 of actual engine cylinder the maximum temperature is 681.37 ^{o}C and minimum temperature is 96.251 ^{o}C. Figure No. 19.

4.6.4 Total Heat Flux for proposed design-1:

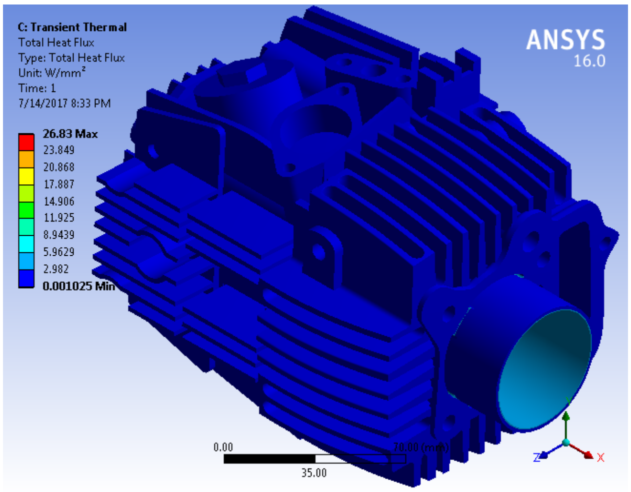

Figure 20: Total Heat Flux of Proposed design-2 of IC engine

Transient thermal analysis where performed for proposed design-2 of IC engine cylinder at the same atmospheric temperature as actual engine cylinder and the result indicates the maximum and minimum value of total heat flux for proposed design-1 are 26.83 W/mm^2 and minimum Total Heat Flux is 0.001025 W/mm^2 as shown in figure No. 20.

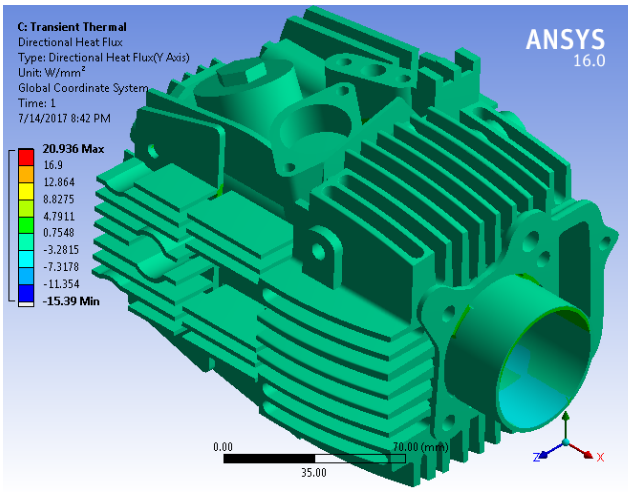

Figure 21: Directional Heat Flux of Proposed design-2 of IC engine in Y direction

4.6.5 Directional Heat Flux in the Y- direction for proposed design-2:

Transient thermal analysis where performed for proposed design-2 of IC engine cylinder at the same atmospheric temperature as actual engine cylinder and the result indicates the maximum and minimum value of directional heat flux in the Y- direction generated for proposed design-2 are 20.936 W/mm^2 and -15.39 W/mm^2. A multicolor couture diagram is shown in figure No. 21.

V. RESULT AND DISCUSSION

The transient thermal analysis ware performed using an analytical software ANSYS workbench based on finite volume analysis for the Hero Honda Splendor 4-Stroke, 97.2 CC single cylinder OHC Air Cooled engine. The effects of different important geometrical parameters for the transient natural convective heat transfer rate from both actual and proposed design of engine.

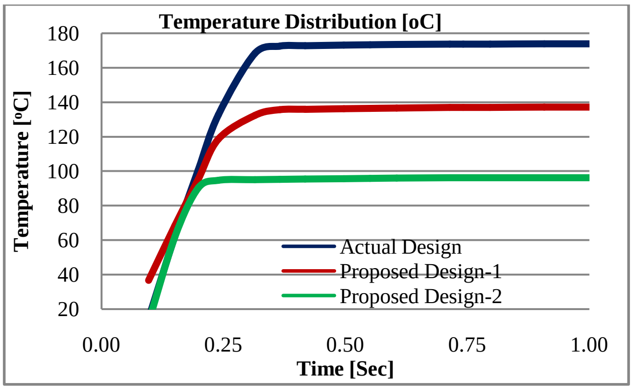

Figure 21: Comparative result temperature distribution

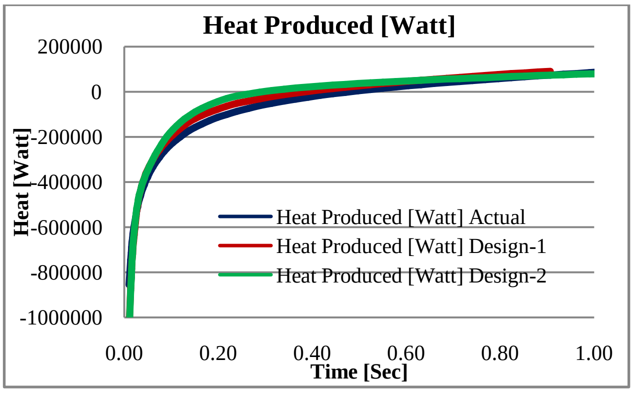

Figure 22: Comparative result of Heat produce

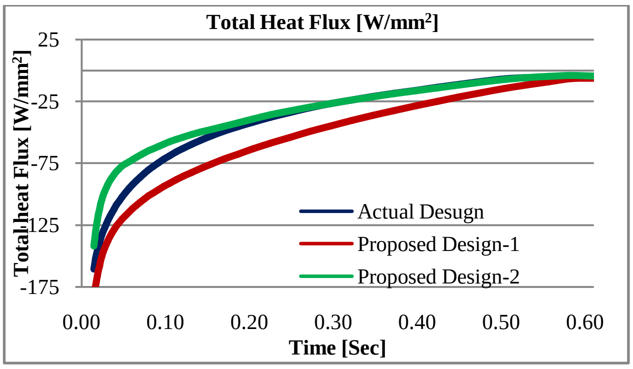

Figure 23: Comparative result of Total Heat Flux

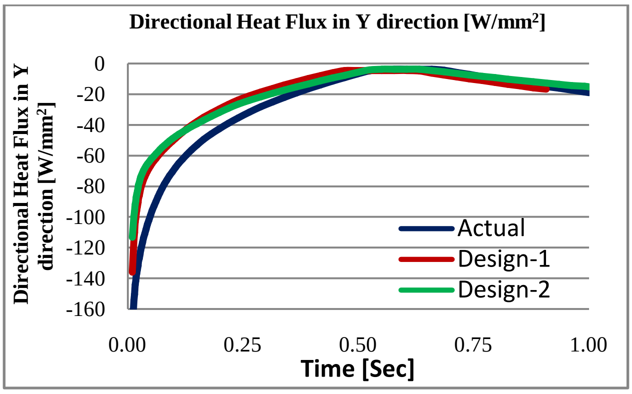

Figure 24: Comparative result of Directional Heat Flux in Y direction

VI. CONCLUSION

In the present work it has been tried to increase heat transfer rate from the Hero Honda Splendor 4-Stroke, 97.2 CC single cylinder OHC Air Cooled engine. Transient thermal analyses were performed for actual as well as proposed design of IC engine one by one to optimize geometrical parameters and enhanced heat transfer from the same. For that Three CAD models have been created with the help of CATIA & further Thermal analysis are performed in ANSYS 16.0. at 25 C^o ambient temperature.

The following points have been acknowledged in the form of conclusive statements which are as follows.

1. As per the transient thermal analysis done on ANSYS for actual design of IC engine at ambient temperature 25^o C. The total Node is generated 1799644 & Total No. of Elements is 1043403 in which total contact elements are 508280 and solid elements are 1689169. The maximum and minimum temperatures are 674.24^o C and 173.9^o C, The total heat flux generated is 28.918 W/mm^2 and The maximum directional heat flux in Y-direction generated is 25.09 W/mm^2.
2. The results for proposed design-1of IC engine at ambient temperature 25^o C. The total generated nodes are 1769666 and total No. of elements are 1037358. The maximum and minimum temperatures are 662.37^o C and 137.16 ^{o} C, The total heat flux generated is 28.497 W/mm^2 and The maximum directional heat flux in Y-direction generated is 19.16 W/mm^2.
3. As per the transient thermal analysis done on ANSYS for actual design of IC engine at ambient temperature 25^o C the maximum and minimum temperatures are 650^o C and 92.091 ^{o} C, The total heat flux generated is 16.2 W/mm^2 and The maximum directional heat flux in Y-direction generated is 12.35 W/mm^2.

To summarize this conclusion, the proposed design -2 of single cylinder four stroke IC engine has better performance and heat transfer rate from the heating zone in the IC engine that is why the result of present work is more concentrate on it and also recommended for replacement of new design.

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