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A Review Paper on Steady State Thermal Analysis of Piston Using Composite Material

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ABSTRACT

A piston is a component of reciprocating engines, reciprocating pumps, compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. The piston transforms the energy of the expanding gasses into mechanical energy. The piston rides in the cylinder liner or sleeve. Pistons are commonly made of aluminum or cast iron alloys. The present work is to study the design a piston petrol engine of bike. Computer aided engineering tools allow engineers to design product and to simulate these designs for residual stress, structural response, thermal effects, pre-processing and post processing fatigue on the automotive component. By observing the analysis results, we can decide whether our designed piston is safe or not under applied load conditions. The thermal flux, thermal temperature distribution studied by reviewing various authors in the field of thermal analysis. This study will be helpful for persons working in field of steady state thermal analysis of piston.

Keywords : Internal Combustion (IC) Engines, Performance, Heat Transfer, Temperature Field Of The Piston.

I. INTRODUCTION

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the six-stroke piston engine and the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described. Firearms are also a form of internal combustion engine.

II. METHODS AND MATERIAL

General Working of Petrol Engine

In the most general form, an internal combustion engine is a device that converts chemical energy in fuels into useful mechanical energy, through a combustion process. Combustion is the process of converting chemical energy into thermal energy, using fuel and an oxidizer Internal refers to the combustion process taking place inside the engine, in a combustion chamber. There are many internal combustion engine concepts, but the most common is the reciprocating engine. The reciprocating engine concept uses pistons that move up and down, driven by the thermal energy from the combustion process.

The combustion process is a set of reactions which release energy or heat through oxidization.

A typical combustion reaction is the methane-oxygen reaction:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + energy \quad (1)$$

All combustion reaction are exothermic reactions, meaning that they release energy to the environment. This energy is what can be converted into useful mechanical energy in a reciprocating engine. The modern reciprocating engine is a four stroke engine. It is called a four stroke engine because the engine does four piston movements before it completes the combustion process. The four strokes make it possible to complete a thermodynamic cycle.

A four-stroke engine (also known as four cycle) is an internal combustion (IC) engine in which the piston completes four separate strokes while turning a crankshaft. A stroke refers to the full travel of the piston along the cylinder, in either direction. The four separate strokes are termed:

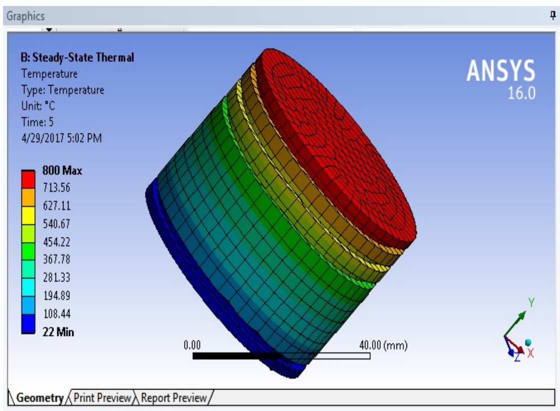
a) **Intake:** also known as induction or suction, this stroke of the piston begins at top dead center (T.D.C.) and ends at bottom dead center (B.D.C.). In this stroke the intake valve must be in the open position while the piston pulls an air-fuel mixture into the cylinder by producing vacuum pressure into the cylinder through its downward motion.

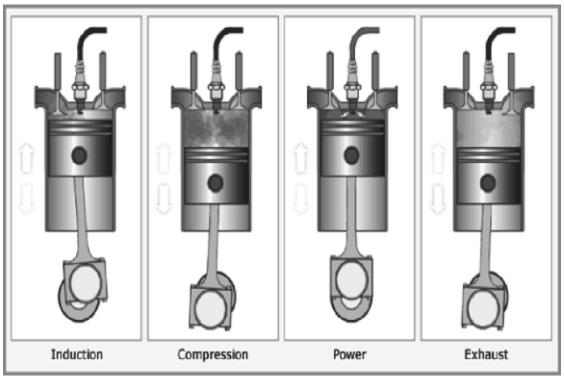
b) **Compression:** This stroke begins at B.D.C, or just at the end of the suction stroke, and ends at T.D.C.

In this stroke the piston compresses the air-fuel mixture in preparation for ignition during the power stroke (below). Both the intake and exhaust valves are closed during this stage.

c) **Combustion:** also known as power or ignition. This is the start of the second revolution of the four stroke cycle. At this point the crankshaft has completed a full 360 degree revolution. While the piston is at T.D.C. (the end of the compression stroke) the compressed air-fuel mixture is ignited by a spark plug (in a gasoline engine) or by heat generated by high compression (diesel engines), forcefully returning the piston to B.D.C. This stroke produces mechanical work from the engine to turn the crankshaft.

d) **Exhaust:** also known as outlet. During the exhaust stroke, the piston once again returns from B.D.C. to T.D.C. while the exhaust valve is open. This action expels the spent air-fuel mixture through the exhaust valve





An internal combustion engine is defined as an engine in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work, as opposed to an external combustion engine in which a separate combustor is used to burn the fuel.

The internal combustion engine was conceived and developed in the late 1800s. It has had a significant impact on society, and is considered one of the most significant inventions of the last century. The internal combustion engine has been the foundation for the successful development of many commercial technologies. For example, consider how this type of engine has transformed the transportation industry, allowing the invention and improvement of automobiles, trucks, airplanes and trains.

Thermal analysis of Petrol Engine

The thermodynamic analysis of the actual four-stroke or two-stroke cycles is not a simple task. However, the analysis can be simplified significantly if air standard assumptions are utilized. The resulting cycle, which closely resembles the actual operating conditions, is the Otto cycle.

During the normal operation of the engine as the fuel mixture is being compressed an electric arc is created to ignite the fuel. At low rpm this occurs close to TDC (Top Dead Centre). As engine rpm raises the spark point is moved earlier in the cycle so that the fuel charge can be ignited while it is still being compressed. We can see this advantage reflected in the various Otto engines designs. The atmospheric (non-compression) engine operated at 14% efficiency. The compressed charge engine had an operating efficiency of 32%.

The heat flow through the piston ring to the cylinder liner is complex to model analytically due to a large number of circumstances that occurs under a four-stroke cycle which all can affect the heat flow.

A number of these circumstances are presented below.

- Varying oil film thickness affect the thermal conductivity of the oil and causes surface-to-surface contact between the piston rings and the cylinder liner.
- The rings may twist during a stroke and change the contact geometry.
- Piston ring manufacture tolerances can vary and affect the clearance between the ring and the liner.
- Surface-to-surface or hydrodynamic friction may arise in the ring-liner interaction and raise the oil and surface temperatures.
- Tilting of the piston varies the amount of contact between the piston rings circumferentially.
- Combustion gases may penetrate the top land crevice and locally increase the heat flux input to the piston top land.
- Thermal expansion of the piston and the piston rings changes the piston- and the piston ring geometry.
- Combustion gas blow-by will affect the heat transfer by adding convective heat transfer to both the piston and the cylinder liner.

Finite Element Method

- **Definition**

The finite element method is a numerical technique which is commercially used for the finding of an approximate solution of partial differential equation as well as integral equation. In some solving partial differential equations the first problem is to create an equation that approximate the equation which is to be studied. It means that during calculations the error should not accumulate, thereby causing the output as to be meaningless.

- **Heat transfer analysis using the Finite Element Method**

In order to perform a multidimensional heat transfer analysis the Finite Element Method can be utilized. This type of solution method is based on the use of elements which represents the body of the object. Each element expresses the physical, geometrical and material properties of the structure. The elements consist of nodes in which a shape function describes the node value changes along the elements. The number of nodes of an element can vary, but generally three- or four node elements are used in a 2D-analysis, while for 3D-analysis four- or eight node elements are commonly used. Depending on the type of analysis that is conducted, each node has a certain number of degrees of freedom.

The finite element analysis consists of a computer model of a material or designs that are stressed and analyzed for specific results. It is often used either for the refinement of existing product or for any new design. The modification of existing design or product or a structure is utilized to qualify the product for a new service condition. Sometimes in structural failure, FEA may help for the determination of design modification to meet the new conditions. Generally two types of analysis are used in manufacturing industry: 2D modeling and 3D modeling. In case of 2D modeling the analysis runs on a normal computer, it leads to lesser accurate results. On the other hand 3D modeling gives more accurate results by sacrificing the ability to run on all but the fastest computers effectively. The complex nature of linear systems is less as comparing with the non linear systems. Non linear systems accounts for plastic deformation and many are also capable of testing a material all the way to fracture of a material.

- **Advantages of finite element method**

a. Solving of non linear problems can be easily performed.
b. Formulation is easy in FEM, allows solving of different problems.
c. Domains having more than one material are easily analyzed.
d. Selecting approximation of higher degree polynomial can improve the accuracy of results.
e. Method can be used for any irregular shaped domain.
f. It can be used in all types of boundary conditions.
g. Generation of algebraic equations can be easily done and solved.

h. A generalized code can be developed for analysis if required for a large class of problems.

III. LITERATURE REVIEW

Shubham Shrivastava[1], Shikar Upadhyay[2], [2016] – In this present work, cylinder block was made in 3D software Solidworks in which perpendicular fins are mounted. After that modifications is done in engine cylinder block fins, thickness is reduced from 3 mm to 2 mm. so that weight will reduced, second thing to choose material which has to replace the existing materials, in this analysis aluminium alloy 1050 is chosen for thermal analysis to evaluate the better heat transfer rate. In first case due to modification weight of block reduced to **13.2 %,** in second case due to material change weight reduced to **2.1 %** without compromising with strength.

K. Venkatareddy, V. Chandrashekar Goud – In the project we design a piston by using solid works 2016 design software and we did the structural load analysis and thermal analysis by applying various materials such as composites on piston in ansys workbench software. Modeling and analysis of piston is done. Modeling of piston is done in solid works 2016 design software by using various commands. The solid works part file is converted into IGS file and imported to Ansys workbench. First Static structural analysis is carried out on piston at 1.5MPa pressure with four different materials, such as grey cast iron, aluminum alloy and al-sic graphite and aluminum oxide in ansys workbench. Maximum stress, deformation, maximum strain and maximum shear stress are noted and tabulated Then steady state thermal analysis is carried out at maximum temperature 400deg and minimum temperature 30deg for the above four various materials. Temperature distribution and heat flux are noted for four different materials and tabulated. From the tables it is concluded that the aluminum silicon carbide graphite (Al-SiC Graphite) is showing efficient results Hence Al-SiC-Graphite is preferable among the four applied materials.

K. Sundaram, N. Palanikumar – In this work, material composition test, hardness test, of such composite coatings are carried out. The effect of particle size and number of particles suspended is reported. SiC Composites have been deposited on Aluminium by casting process. The resulting castings are studied using scanning electron microscopy and hardness tests. The piston is modeling using Pro-E modeling and analyzing using ANSYS simulation software for Aluminium (Pure) and Aluminium-SiC and the results were discussed. In this project, 3D Model is prepared in CREO and then CAE analysis is performed by Ansys 14.5 and three different materials (Al with 10% SiC, AL with 20% SiC and AL With 30% SiC) for piston are taken into thermal analysis. From the result obtained from Ansys, It Seems that the Aluminium with 10% SiC material having better temperature distribution in both steady state thermal analysis as well as transient state thermal analysis hence aluminium with 10% SiC Material is better than Aluminium alloy Material therefore Aluminium with 10% SiC Material is most suitable for piston.

Abino John[1], Jenson T Mathew[2], [2015] - A piston made of composite material (aluminium silicon carbide) is designed and analyzed successfully. Composite piston made of metal matrix offers high strength retention on ageing even at severe environments. Compared to aluminium, the aluminium silicon carbide is found to have lesser deformation, lesser stress and good temperature distribution. Some of the limitations faced by aluminium piston are overcame by the aluminium silicon carbide piston. From this project we get the clear knowledge about the composite material AlSiC and its features.

S. Bhattacharya[1], A. Basu[2], S. Chowdhury[3], Y.S. Upadhyaya[4], [2014] — has presented a thermo-mechanical analysis of a natural gas, internal combustion engine cylinder head are presented in this paper. The results are pertinent to the evaluation of overheating damage in critical areas. The three-dimensional geometries of the cylinder head and the water jacket were modeled by means of a computer-aided engineering tool. Commercial finite element and computational fluid dynamics codes were used to compute details of mechanical stress in the head and flow details in the cylinder and cooling jacket, respectively. A six-cylinder, four-stroke diesel engine and a spark-ignition natural gas engine were modeled over a range of speeds at full load. Computed results, such as maximum allowable cylinder pressure, output power, BMEP and BSFC, were validated by experimented data in the diesel engine model. The results were in good agreement with experimental data.

The results show high stresses at the valve bridge. Cylinder head temperatures and comparison of output power with high stress measurements, often exceeding the elastic limit, were found at the valve bridge.

J. Barriga, U. Ruiz-de-Gopegui, J. Goikoetxeaa, B. Coto, H. Cachafeiro, **—** has presented the CSP technology based on parabolic trough solar collector for large electricity generation purposes is currently the most mature of all CSP designs in terms of previous operation experience and scientific and technical research and development. The current parabolic trough design deals with a maximum operating temperature around 400ºC in the absorber collector tube but some recent designs are planned to increase the working temperature to 600ºC increasing the performance by 5-10% to attain the improved productivity that the market demands .These systems are expected to be working during 20-25 years. One of the key points of the receiver is the stack of layers forming the selective absorber coating. With this new design the coating has to fulfill new requirements as the collector will be working at600ºC and in a low vacuum of 10-2 m bar.

Li Wanyou, Guo Yibin – The present work features detailed interring gas dynamics of piston ring pack behavior in internal combustion engines. The model is developed for a ring pack with four rings. The dynamics of ring pack are simulated. Due to the fact that small changes in geometry of the grooves and lands would have a significant impact on the interring gas dynamics, the thermal deformation of piston and bore has been considered during the ring packmotion analysis in this study. In order to get the temperature distribution of piston head more quickly and accurately, an efficient method utilizing the concept of inverse heat conduction is presented. The result of the temperature analyzed using the optimum HTC is compared with the measured temperature, and reasonable agreement is obtained. A sensitive analysis based on the analysis of partial regression coefficients is presented to investigate the effect of groove parameters on blow by. And the result shows that $\Delta h_1(1)$ and $\Delta h_2(1)$ have significant influence on blow-by gas flow, while other parameters have no obvious impact on it. As the thermal effect on $\Delta h_1(1)$ and $\Delta h_2(1)$, the interring gas dynamic analysis should consider the thermal effect.

Isam Jasim Jaber and Ajeet Kumar Rai – Using CATIAV5R20 software design and modeling become easier. Only few steps are needed to make drawing in three dimensions. Same can be imported to ANSYS for analysis. Piston made of three different materials Al alloy 4032, AISI 4340 Alloy steel and Titanium Ti-6Al-4V (Grade 5) are analyzed. Their structural analysis shows that the maximum stress intensity is on the bottom surface of the piston crown in all the materials, but stress intensity is close to the yield strength of Al alloy piston. Maximum temperature is found at the centre of the top surface of the piston crown. This is equal for all materials. Depending on the thermal conductivity of the materials, heat transfer rate is found maximum in Al alloy piston and minimum in Ti alloy piston. For the given loading conditions, Al alloy piston is found most suitable. But when the loading pattern changes, other materials may be considered. With the advancement in material science, very light weight materials with good thermal and mechanical properties can be used for fail safe design of the I. C. engine. This will reduce the fuel consumption and protect the environment.

A. J. Helmisyah, M. J. Ghazali — has presented the high temperature and pressure produced in an engine that uses compressed natural gas with direct injection system (CNGDI) may lead to high thermal stresses. The piston crown fails to operate effectively with insufficient heat transfer. In this study, partially stabilized zirconia (PSZ) ceramic thermal barrier coatings were plasma sprayed on CNGDI piston crowns (AC8A aluminium alloys) to reduce thermal stresses. Several samples were deposited with NiCrAl bonding layers prior to the coating of PSZ for comparison purposes. Detailed analyses of microstructure, hardness, surface roughness, and interface bonding on the deposited coating were conducted to ensure its quality. High stresses were mainly concentrated above the pinhole and edge areas of the piston. In short, the PSZ/ NiCrAl coated alloys demonstrated lesser thermal stresses than the uncoated piston crowns despite a rough surface. Extra protection is thus given during combustion operation.

Petkovic et al. (2011) carried out experimental verification of developed mathematical model of the heat transfer in exhaust system. They developed 1-D mathematical model of unsteady heating up of the exhaust system parts. Experimental investigations carried out to measure temperature at various locations on the exhaust pipe for different gas flow rates. The gas was air supplied by a compressor. They reported that comparison between modeling and experimental results showed good agreement.

A.Triwiyanto, E. Haruman, M. Bin Sudin. S. Mridha and P.Hussain, — has presented low temperature thermo chemical treatments in fluidized bed furnace involving nitriding, carburizing and hybrid treating, sequential carburizing-nitriding, have been conducted with the aim to improve surface properties of AISI 316L. The resulting layer is expanded austenite which is responsible to the higher hardness and better wears properties. Characterization of this expanded austenite layer were performed including XRD analysis, SEM and SPM and micro hardness indentation were used to reveal the characters of the produced thin layers.

SONG Ming, M A Yue, GONG Sheng-kai — has presented the Royal Automotive Club of Victoria (RACV) Energy Breakthrough annual event is to provide an opportunity to school students to design and develop human powered vehicles (HPVs) and race a nonstop 24 hours event that requires energy conservation, endurance and reliability. The event involves primary and secondary school students, teachers, parents and local industry to work together on the design and use of energy efficient vehicles. The key areas with interest of HPVs are the significance of aerodynamic design and ways to improve overall aerodynamics as most HPVs are designed with minimal or no aerodynamic consideration.

A. Moridi, M. Azadi and G.H. Farrahi — has presented Cast aluminium-silicon alloy, A356.0, is widely used in automotive components such as diesel engine cylinder heads and also in aerospace industries because of its outstanding mechanical, physical, and casting properties. Thermal barrier coatings are applied to combustion chamber in order to reduce fuel consumption and pollutions and also improve fatigue life of components. However, studies on behaviour of A356.0 with thermal barrier coating are still rare. The purpose of the present work is to simulate stress distribution of A356.0 under thermo-mechanical cyclic loadings, using a two-layer elastic-viscoplastic model of ABAQUS software. The results of stress strain hysteresis loop are validated by an out of phase thermo-mechanical fatigue test. Ceramic coating thickness effect on stress distribution of test specimens is investigated. Different thicknesses from 300 to 800 microns of top coat and also roughness of the interfaces are simulated to get best stress gradient which can cause an improvement of fatigue life.

B.M. Krishna and J.M. Mallikarjuna, has investigations of the in-cylinder flow pattern around the intake valve of a single-cylinder internal combustion engine using Particle Image Velocimetry (PIV) at different intake air flow rates. The intake air flow rates are corresponding to the three engine speeds of 1000, 2000 and 3000 rev/min., at all the static intake valve opening conditions. In-cylinder flow structure is characterized by the tumble ratio and maximum turbulent kinetic energy of the flow fields. Two specified lines of the combustion chamber, the radial and axial velocity profiles have been plotted. It is found that the overall airflow direction at the exit of the intake valve does not change significantly with the air flow rate and intake valve opening conditions.

F. S. Silva, — has presented engine pistons are one of the most complex components among all automotive or other industry field components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wearing, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role.

IV. CONCLUSION

After going through literature review of various authors it can be concluded that, Al–Si based alloys have been widely used in automotive piston and other thermal applications because of good mechanical and thermal properties, lightweight structures, environmental and other attractive properties. But to manufacturing the automotive piston the basic Al-Si alloys are unbeneficial and may not fulfill the basic requirements of piston. And produced various unwanted stresses in components during the manufacturing. By controlling the exhaust gas temperature, catalytic converter life span can be improved. The heat transfer in exhaust system directly affects the performance and the emission characteristics of the internal combustion engine. For improvement in the performance of an engine, it is necessary to control the temperature in automotive exhaust system. Mechanical and thermal properties of aluminum based piston alloys (eutectic, hypereutectic alloys) chiefly depend on the heat treatment. Two-step solution treatment of the Al Si alloy resulted in the good mechanical properties then the single step solution treatment. The desire to reach higher efficiencies, lower specific fuel consumptions and reduce emissions in modern internal combustion (IC) engines has become the focus of engine researchers and manufacturers for the past three decades. The global concern over the decreasing supply of fossil fuels and the more stringent emissions regulations has placed the onus on the engine industry to produce practical, economical and environmentally conscious solutions to power our vehicles. To calculate the temperature effect and heat transfer to the engine piston crown it was concluded that spatial and time averaged combustion side boundary condition is a most favorable and suitable treatment method within engineering approximations.

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