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Determination of the Coupled Field Stresses on Piston by Using Finite Element Analysis in Four Stroke Engine: A Review

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Abstract

Piston is to be one of the most important parts in a reciprocating engine in which it helps to convert the chemical energy obtained by the combustion of fuel into useful mechanical power. The purpose of the piston is to provide a means of conveying the expansion of the gasses to the crankshaft, via the connecting rod, without loss of gas from above or oil from below. Generally the piston made of Al Alloy, which is acting as heart of the I.C. engine and is a crucial part of internal combustion engines. When the combustion of fuel takes place inside engine cylinder; high temperature and pressure are developed due to combustion of the fuel. Because of high speed and at high loads, the piston is subjected to high thermal and structural stresses. If these stresses exceed the designed values, failure of piston may take place. The stresses due to combustion are considered to avoid the failure of the piston. Intensity of thermal and structural stresses should be reduced to have safe allowable limits. This review introduces an analytical study of the thermal effects and structural stresses on engine piston in the four stroke engine and analytical method to find out the stresses acting on the piston.

Keywords: *Engine piston, thermal analysis, structural analysis, FE analysis*

1. Introduction

The objective of the review is to carry out a number of Finite Element (FE) analyses to predict thermal and mechanical stresses in the piston and optimize its shape. The original design of the piston was fully analyzed under full load and maximum torque conditions. A parametric study of various design features was conducted to strengthen the design and improve its safety. The I.C. engines working on liquid fuels need to be optimum temperature efficient so that the temperature resisting and the various stresses such as structural stresses resisting capacity must be quite high enough to maintain constant optimum performance while running at high speeds and high load conditions. Piston is essentially cylindrical component that moves up and down in the cylinder. Although the piston appears to be a simple part, it actually quite complex from the design point of view. The efficiency and economy of the engine primarily depends on the working of piston. It must operate in the cylinder with minimum of friction and should be able to with stand the high explosive force and stresses developed in the cylinder and also the very high temperature ranging from 2000 °C to over 2800 °C during operation. The piston should be as strong as possible, however its weight should be minimized as for as possible in order to reduce the inertia due to its reciprocating mass while working piston is also equipped with piston rings to provide a good seal between the cylindrical wall and piston, so that the gases which are released after the power stroke should not pass through into the crankcase past the piston so the need for study of high thermal and structural stresses have been raised

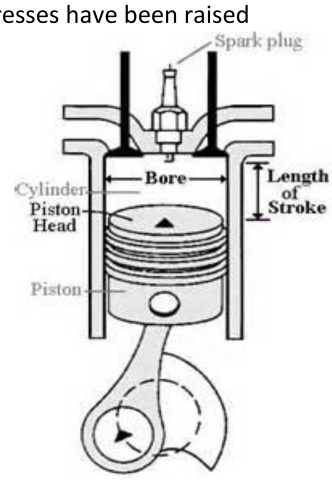

Fig. 1 Representation of engine piston

1.1. Functions of piston

• To receive the thrust force generated by explosion of the gas in the cylinder and transmits it to the connecting rod and also to withstand the various stresses acting on the piston.
• To reciprocate in the cylinder as a gas tight plug causing suction, compression, expansion and exhaust stroke.
• To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to the obliquity of the rod. The top of the piston is called crown of the piston. Portion below the ring grooves is called skirt. The portion of the piston that separates the grooves is called the lands. Some pistons have a groove in the top land called a heat dam which reduces heat transferred to the rings. The piston bosses are those reinforced section of the piston designed to hold the piston pin.

2. Literature survey on piston materials

The properties of the material used for the piston manufacturing plays the important role in withstanding this various stresses and the and also to resist the temperature while working at higher speeds and higher loads, the study of the material properties is also very important. The material used for pistons is mainly aluminum alloy Aluminum pistons can be either cast or forged. Cast iron is also used for pistons. In early years cast iron was almost universal material for pistons because it possesses excellent wearing qualities, coefficient of expansion and general suitability in manufacture. But due to the reduction of weight in reciprocating parts, the use of aluminum for piston was essential.

The result of various authors who studied the various material properties of the piston showed that the various types' material used for manufacturing of the piston such as steel, cast iron and aluminum alloy. The material such as steel is excellent to heat resistance and corrosion resistance and the cast iron is a highly brittle material with good machining ability also the weight of cast iron piston is higher which increases the overall weight of the engine unnecessarily, so the study was carried out by Piotr Szurgott [6] on the composite materials to find out the behavior of different piston material with the use of finite element analysis so the need has been raised to find out the best suitable material for the piston which can handle higher temperature and structural stresses which could not affect the working of piston. The material for the piston should have low hysteresis, the difference of coefficient of thermal expansion which allows the piston resistance to fatigue damage and thermal shock. So it was found that the aluminum with 11% silicon is the best material which can be used for handling higher temperature and structural stresses. To obtain equal strength a greater thickness of metal is necessary. But some of the advantage of the light metal is lost. Aluminum is inferior to cast iron in strength and wearing qualities, and its greater coefficient of expansion necessitates greater clearance in the cylinder to avoid the risk of seizure or engine jamming. The thermal conductivity of aluminum is about thrice that of cast iron and this combined with various ingredients for strength, mechanical properties and allows aluminum alloy piston to run at much lower temperature than a cast iron this cool running property of aluminum is now recognized as being quite as valuable as its lightness. Indeed; pistons are sometimes made thicker than necessary for strength in order to give improved cooling and less weight.

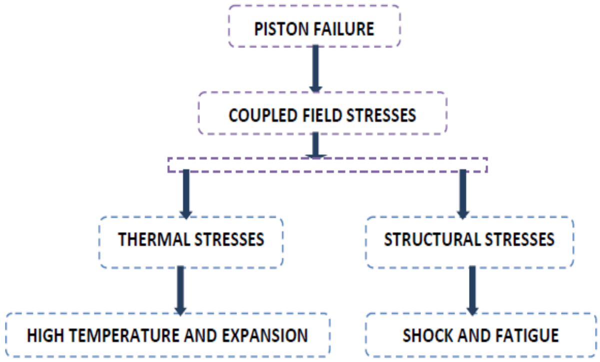

Fig. 2 Schematic representation of piston failure

3. Literature survey on thermal and structural stresses

The study of the various authors found out that the stress is nothing but force per unit area the stress develop on the mechanical parts of the engine need to be considered for the safe working of the piston it is possible to find out the various stresses acting on the mechanical parts by analytical and experimentation method but this method are more time consuming and are expensive so modern software like CAD CAM and CATIA V5 were used by the researcher L. N. Wankhade [7] and found out that the model created using CATIA V5 tool can be imported in HyperMesh which is used for finding out the structural stresses. The stress distribution on the piston of an IC Engine can be found out by using FEA. The FEA is performed by using CAD and CAE software which analyzed the stress distribution of the piston at real engine condition during combustion process. Several specific features of the original design may be modified depending upon results to reduce stresses in the critical areas of the piston. As a result of this work, the overall design of the piston will be optimized and its structural integrity and safety factor are improved. The finite element analysis performed using CAD software to investigate and analyze thermal stress distribution at the real engine condition during combustion process. Piston skirt may appear like cracked surface on the upper end of the piston head. Therefore piston crown should have enough stiffness to reduce the deformation, the preliminary analyses presented in the paper was to compare the behavior of the combustion engine piston made of different type of materials under thermal load

Finite element analysis is used to analyze stresses in a piston of an internal combustion engine. The stresses due to combustion gas load only are considered so as to reduce the weight and hence to increase the power output of engine, the use of software's such as CatiaV-5 for drawing 3D model of piston ,the hypermesh is used for the meshing of the piston and finite element analysis can be used for the analysis of the piston and to study the various properties of the piston, the use of this software's is important to calculate the boundary conditions at various design speed, pressure and temperatures in the cylinder is required. Measurement of these values by experimentation is very costly process hence the simulation of the engine is used to calculate these values at design speed. ENGINE ANALYZER PRO is the simulation software used.

The paper presented by K.Jagdeesh [1] helped to study the various parameters of the piston mainly dealing with the finite element analysis of the vibrating piston who studied the effect of the water waves on the vibrating piston. The acoustic pressure values along the axis of the piston as a junction of distance from the piston and frequency are evaluated. The radiation impedance of the vibrating piston is also evaluated. The results of FE analysis are compared with the theoretical values.

Finally he concluded that finite element analysis can be successfully used for simulation of the vibrating piston in the water. Which helped in the design of the solar projection which were important in the naval application also calculations helped to find out useful parameters such as axial pressure, far field pressure, radiation impedance.

Jian Chen [2] studied the commonly observed defects which the piston is subjected such as piston slap and the bearing knock; he studied that the detection of these faults at the initial stage would lead to prevention of IC engine while working and it is also economical to prevent the engine before failure. For finding out the different mechanical faults in engine piston slap is first determined and then the bearing knock is determined with the experiments. Use of angular acceleration was done to separate out mechanical faults from the low frequency combustion. The impulsiveness of the signal is indicated by the "kurtogram" which was applied to precursor for analysis. After adjusting frequency, the common frequency was selected for finding the piston slap and bearing knock and also showed that piston slap and bearing knock can be illustrated in the phases of the 2nd and 3rd harmonics, the severity of the piston slap and bearing knock can be related with the amplitude changes the inputs are in the terms of signal processing can be used in detection system for example using Artificial Neural Networks (ANN), to automatically monitor the operation of IC engines.

The study of the M.M. Rahman[3] who studied the details regarding the various structural and mechanical stresses acting on the piston which is of oscillating type; the random vibration theory was introduced three decades back which deals with all kinds of random vibration behavior. The failure of the component due to repetitive load shocks or impact is called as fatigue. Since fatigue is one of the primary causes of component failure, fatigue life prediction has become a most important issue in almost any random vibration problem. Nearly all structures or components have been designed using the time based structural and fatigue analysis methods, the accurate composition of random stress can be determined by optimum fatigue design process. The main purpose of paper was to predict fatigue life when the component is subjected to statistically-defined random stresses these are the best performed in the frequency domain using the power spectral density functions of input loading and stress response. It is often easier to obtain a PSD of stress rather than a time history in the study, his dynamic analysis of complicated finite element models is considered and finally he presented with the concept of vibration fatigue analysis where random loading and frequency can be separated by using PSD (power spectral density) functions. A state of art of the vibration fatigue techniques has been presented Frequency response fatigue analysis has been applied to a typical cylinder block for a free-piston engine. From the results, it can be concluded that the Goodman mean stress correction method gives the most conservative prediction for all loading conditions and materials. The results clearly showed that AA2024-HV-T6 is a superior material for all the mean stress correction methods.

Marek flekiewicz et al [4] Piston slap is one of the most important characteristic sources of engine body vibrations. Intensity of excitation and its variations for different engine cycles depends mainly on in-cylinder pressure alterations. Changing of piston slap force value, changing the piston horizontal movement's result also from the following factors:

- Piston and piston pin mass, connecting rod mass,
- Dimensions and the geometry of crank-connecting rod mechanism,
- Engine crankshaft angle,
- Engine speed and its load,
- Piston skirt clearance.

Vibrations in the Engine block results from sum of many excitations mainly connected with engine speed, and their intensity increases with the appearance of a fault or in case of higher engine elements wearing. The various methods which are used to determine to faults and are currently use are based on spectrum density analysis both in time and frequency domains, FFT, as well as on wavelet transform and Wigner-Ville transform. The author of the paper used acceleration signals to estimate the effect of piston skirt clearance on cylinder block and the dynamic models of the piston-connecting rod mechanism and in-cylinder pressure variations in the function of engine crank angle were used to find piston slap force, responsible for piston movement. The object of preliminary analysis was to determine the Engine body vibration signal, registered for three simulated cases representing piston skirt Clearance variations.

S N Kurbet's [5] study related to the working of the engine parts, the piston is considered as main source of the vibration and noise the emphasis is on the piston vibration and to find out the various methods to predict mechanical noise produced by the primary and secondary motion of the engine part. As the primary motion of the piston is due to the combustion of fuel inside the combustion chamber which makes it to move from TDC to BDC which is linear motion and the secondary motion is due to explosion of the fuel which creates the impact on the head of the piston which is of transverse nature. Mostly the petrol engines are replaced by the diesel engines due to cost factor The diesel engine are mostly being used as commercial engines due to high break power and high fuel economy, but it produces bad noise. The piston slap which is the result of piston side thrust on the cylinder liner as it moves TDC to BDC The objectives of the his work was, to develop 3-Dimentional Finite Element (FE) model of piston for the piston motion considering regions; piston, piston before TDC, at TDC and after TDC, and to study stress distribution and deformation of piston in different regions. The system is modeled using CATIA5 software to create needed geometry and finite element software to implement physics and carry out simulations. The next would be a force analysis of the piston slap followed by the simulation aspects of the Finite element Method. Using commercial software ANSYS 10and then meshed with software Hypermesh-9. Finally the results were illustrated as noise and vibration in the IC engine is emphasis on the combustion and mechanical movement of engine part. The Combustion noise is primarily due to rapid pressure fluctuations in the combustion chamber. The structural analysis of the piston for the various pressure on the piston for different position of the piston in the cylinder moving between TDC to BDC have been studied and the following conclusions are made. The piston experiences maximum stress in the region where the combustion of the fuel takes place, i.e., at the piston head and skirt. This high stress region in the piston deforms more than the other region of the piston. The maximum displacement of the piston for structural analysis resembles the maximum displacement of the piston in MBD analysis. Hence the piston experiences maximum displacement in this region. The deformation in the piston causes it to displace more in this region and this cycle repeats even for the reduction in combustion pressure. The MBD analysis confirms the relative motion between the parts and reveals that the engine noise is associated with the stress developed in the engine parts.

4. Discussion

This paper discusses the significance of thermal and structural stresses and its severity, if they remain undetected. The technique will help to create the awareness in the community to technicians, engineers and researchers to motivate them for further study in the area of piston optimization. A stress in a structural member introduces local flexibility that would affect engine performance. Piston optimization may be used to optimize the weight of piston so that it would work efficiently. The main aim of this review is to study the various stresses acting improve quality of piston to withstand high thermal and structural stresses and at the same time reduce stress concentration the upper end of the piston. The FEA is proposed to be carried out for standard four stroke engine piston and the result of analysis are compared for maximum stress. Different alloys of aluminium are tested for maximum stiffness at operating thermal and structural stress using FEA.

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