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Research Paper

THERMAL ANALYSIS OF SINGLE CYLINDER DIESEL ENGINE PISTON

Ashish P Jadhao[1]* and Ajitabh Pateriya[1]

*Corresponding Author: Ashish P Jadhao, ✉ ashishjadhao111@gmail.com

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This paper describes the stress distribution of the single cylinder diesel engine piston by using FEA. ProE wildfire 4.0 Computer Aided Design (CAD) software was used to design the existing piston. The main objectives is to investigate and analyze the temperature distribution and heat flux of piston at the real engine condition during combustion process. The paper describes the use of finite element analysis technique to predict the higher stress and critical region on the component. The original diesel engine piston is coated by using different materials for specific thickness. The optimization is carried out to reduce the stress concentration on the upper end of the piston, i.e. (piston head/crown and piston skirt and sleeve). The coating analysis is tested using ANSYS workbench 11.0 thermal analysis.

Keywords: Diesel engine piston, Piston skirt, ProE, ANSYS workbench, Temperature concentration, Thermal analysis

INTRODUCTION

A piston is a cylindrical piece of metal that moves up and down inside the cylinder which exerts a force on a fluid inside the cylinder. Pistons have rings which serve to keep the oil out of the combustion chamber and the fuel and air out of the oil. Most pistons fitted in a cylinder have piston rings. Usually there are two spring compression rings that act as a seal between the piston and the cylinder wall, and one or more oil control ring s below the compression rings. The head of the piston can be flat, bulged or otherwise shaped. Pistons can be forged or cast. The shape of the piston is normally rounded but can be different. Figure below shows the part of piston engine. A special type of cast piston is the hypereutectic piston. The piston is an important component of a piston engine and of hydraulic pneumatic systems (Smart, 2006). Piston heads form one wall of an expansion chamber inside the cylinder. The opposite wall, called the cylinder head, contains inlet and exhaust valves for gases.

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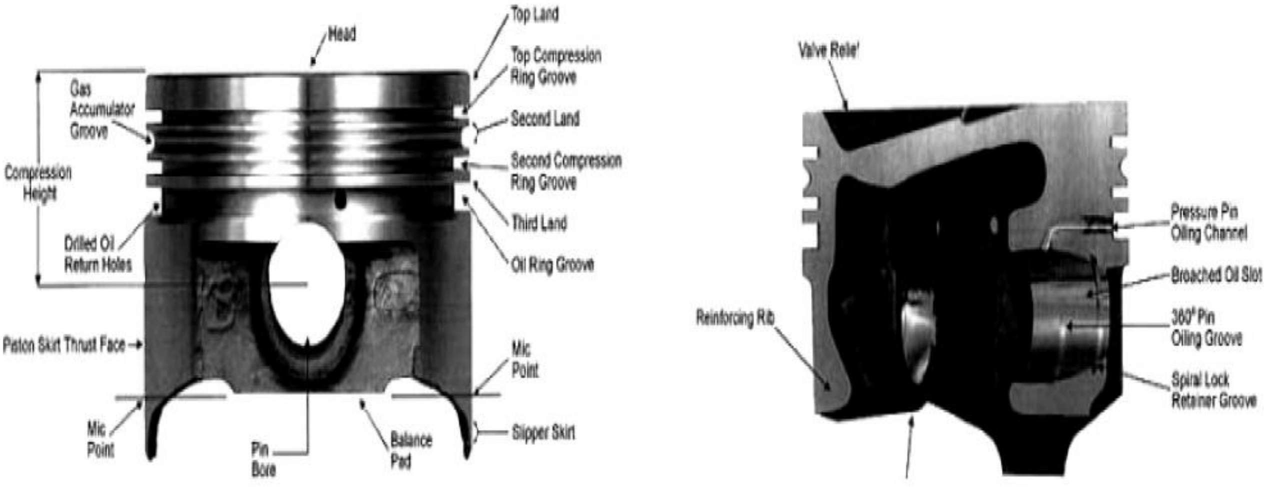
[1] PDAM., Dr. V.B Kolte College of Engineering, Malkapur, M.S., India.

Figure 1: The Part of the Piston Consisting of Many Parts that be Assemble



Source: NASIOC (2008)

As the piston moves inside the cylinder, it transforms the energy from the expansion of a burning gas usually a mixture of petrol or diesel and air into mechanical power in the form of a reciprocating linear motion. From there the power is conveyed through a connecting rod to a crankshaft, which transforms it into a rotary motion, which usually drives a gearbox through a clutch (Auto Zentro, 1990).

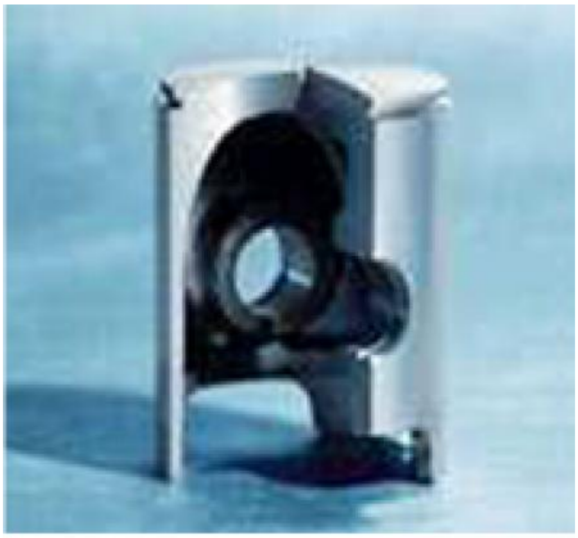
TYPES OF PISTON

On this new modern century, many type of piston that have been design or already in the market. Every type of piston has their capability and also has limitation. Some of these types will now be considered (Stratman, 2010).

Two-Stroke Piston

Figure shows two stroke piston that be made by casting process. These pistons are mainly used in gasoline and diesel engines for passenger cars under heavy load conditions. They have cast-in steel strips but are not slotted. As a result, they form a uniform body with extreme strength.

Figure 2: Two Stroke Piston



Cast Solid Skirt Piston

Cast solid skirt pistons have a long service life. Furthermore this piston more useable that can be used in gasoline and diesel engines. Besides that, their range of applications extends from model engines to large power units as shown in Figure below. Piston top, ring belt and skirt form a robust unit.

Figure 3: Piston Cast Solid Skirt Piston

Forged Solid Skirt Piston

For this piston as shown in Figure below, there are made by forged process that gives the piston more strength. This type of piston can mainly be found in high performance series production and racing engines. Besides that, due to the manufacturing process, they are stronger and therefore allow reduced wall cross-sections and lower piston weight. Also, due to relative manufacturing procedures, forged pistons tend to be more expensive than other process.

Figure 4: Forged Solid Skirt Piston

LITERATURE REVIEW

Kong *et al.* (1995) classified diesel combustion model into two groups; thermodynamic and multidimensional. In our study we focus on thermodynamic-type model. The thermodynamic type models emphasize the thermodynamics aspects of an engine system with the major concern of energy conservation. The typical application of these types of models in diesel engine Numerical Modeling is to calculate the heat release rate according to a given pressure history. These models intend to describe the real engine processes by considering temporal and spatial variations of the temperature, pressure and turbulence within the combustion chamber. Lu Xiaoming *et al.* (2005) carried out combustion analysis that mainly includes heat release analysis, cylinder pressure and fuel injection pressure trace interpretation. Heat release analysis, including rate of heat release and its integral curve was based on cylinder pressure data recorded. Bicheng Gui *et al.* (2004) define about the combustion model and characteristic of light-duty DI diesel engine fueled with dimethyl ether (DME). In this paper they gives the detailed chemical kinetics of DME which is chemical kinetic of DME which is useful to study combustion model of DME as fuel.

Ganesan (2000) defines and gives idea about different models that occur in combustion modeling, i.e., heat release and heat transfer model, adiabatic flame temperature model which is essential to calculate it in combustion modeling further he had given different equations for Numerical Modeling for C.I. Engine processes.

Su *et al.* (1996), University of Wisconsin-Madison characterization of high pressure diesel sprays has been performed both experimentally and numerically. The experimental study was conducted using a fuel injection system which has a capability of producing multiple injection sprays. The Numerical study can be conduct using the KIVS-II code for the operating conditions used in the spray experiments. The KIVA calculations show reasonable agreement with the experimental results, and indicate that the present spray breakup model characterizes the physical phenomena well at pressures and injection velocities currently seen in diesel engines.

Haworth (2005) focused on the device-scale Computational Fluid Dynamics (CFD)-based in-cylinder turbulent combustion modeling for reciprocating-piston Internal-Combustion (IC) engines. In this paper he define that the combustion process in IC engines is characterized by complex turbulence-chemistry interaction that span multiple combustion regimes: premised flame propagation, mixing-controlled burning, and chemical-kinetics-controlled processes may occur simultaneously within a single device.

Rutland *et al.* (1995) apply a individual model for each part of combustion process, i.e., 1) Spray model, 2) turbulence model, 3) ignition model, 4) combustion model. An ignition model is used whenever and wherever the temperature is lower than 10000 K and if the temperature is higher than 10000 K then combustion model is activated describing high temp chemistry. Ayoub and Rolf Reitz (1995) define the ignition modeling in which the ignition characteristics of a diesel fuel are assumed to be given by the local Cetane Number (CN) of that fuel at each point in the combustion chamber. The higher the CN, the more readily the fuel ignites, and vice versa they gives the eight reactions involved in kinetic model from which they conclude that for higher values of CN, the activation energy decreases resulting in shorter ignition delays and vice versa.

Colin Ferguson and Allan Kirkpatrick (2000) defines that the combustion process can be classified into three phases which are ignition delay, premixed combustion and mixing controlled combustion and explain about all phases and changes occur in it. Senator *et al.* (2000) define that a detailed experimental description of combustion evolution in diesel engines is extremely complex because of the simultaneous formation and oxidation of air/fuel mixture. Therefore they simplified the heat release rate equation by considering various assumptions

Suryavanshi *et al.* (2005). The mathematical models described in the various literatures developed by number of investigators provide a flexible tool for the analysis of transient hydraulic and mechanical phenomena that occur in an operating fuel injection system. Mathematical simulation is very powerful tool for studying fuel injection system response to changes in design and operating parameters. The results of calculations obtained from the computer program shows that the results obtained are quite similar to those obtained by other investigators and also they are according to expectation. Gowd *et al.* (1995). The four-stroke DI diesel engine with hemi-spherical bowl in piston was considered for analysis. The global parameters, such as, pressure, turbulent kinetic energy and emissions were predicted using KIVA CFD code with two turbulence models, namely, standard k – ∈ and RNG k – ∈ turbulence models. The parameters were compared with the experimental values. The predicted in-cylinder peak pressures were 6.7 MPa and 6.3 MPa with the standard k – ∈ and RNG k – ∈ turbulence models, respectively. The experimental peak pressure was only 6.1 MPa Between the two turbulence models used in the computations,the RN k – ∈ turbulence model predictions were very close to the measured values.

PRESSURE CALCULATIONS

So the piston crown/head, piston ring and the piston skirt should have enough stiffness which can endure the pressure and the friction between contacting surfaces. In addition, as an important part in engine, the working condition of piston is directly related to the reliability and durability of engine. So it is important for the piston skirt and the piston ring to carry out structural and optimal analysis which can provide reference for design of piston. The formula can be expressed as,

$$IHP = \frac{Pm \times L \times A \times N/2}{60 \times 10^3} \quad \text{...(1)}$$

where,

Pm – Mean effective pressure (bar);

L – Stroke length (mm);

A – Area (mm^2);

N – Speed (rpm);

IHP – Indicated Horse Power (watt)

Remember that the system is in equilibrium so the gas is supporting not only the piston but the atmosphere as well. The gas is isolated from the atmosphere.

P = F/A

F = 23 kg * 9.81 = 226 N

Area = pi r^2

r = d/2 = 28/2 = 14 cm = 0.14 m

Area = 3.141592 * 0.14^2 = 0.0616 m^2

P = 226/0.0616

= 3670 N/m^2 = 3670 pascals

1 atmosphere = 101325 pascals

Therefore the pressure inside the cylinder must be 101325 pascals + 3670 pascals = 104995 Pascals.

Table 1: Data Used for Analysis

	Existing Material AlSi	Coat of NiCrAl	Coat of 3YSZ	Coat of Mullite	Coat of La2Zr2O6
Youngs Modulus (GPa)	90	90	200	30	175
Poissons Ratio	0.3	0.27	0.22	0.25	0.2
Density (Kg/m3)	2700	7870	6080	2800	5740
Thermal Expansion (x 10^{-6} 1/°C)	21	12	10.7	5.3	9.1
Thermal Conductivity (W/mK)	155	16.1	2.12	3.3	1.56
Specific Heat (J/kgK)	960	764	640	950	490
Weight Of Piston (Kg)	2.931	5.0659	4.9245	4.665	4.897
Weight of coat for 0.15 mm thickness (Kg)	0	2.1349	1.9935	1.734	1.966

Table 2: Results

	Existing Material AlSi No Coat	**Coat of NiCrAl**	**Coat of 3YSZ**	**Coat of Mullite**	**Coat of La2Zr2O6**	**Remark**
Maximum Temperature Attend	651.46 °C	651.19 °C	650.2 °C	650.07 °C	650.37 °C	Mullite is better in thermal distribution
Equivalent Stress	2.2827e+007 Pa	7.9121e+006 Pa	1.1267e+007 Pa	4.0451e+006 Pa	1.0824e+007 Pa	Mullite is better
Shear Stress	7.9094e+006 Pa	2.4048e+006 Pa	3.5692e+006 Pa	1.0263e+006 Pa	3.4139e+006 Pa	Mullite is better
Max Principal Stress	1.5217e+007 Pa	4.7623e+006 Pa	6.7375e+006 Pa	2.1777e+006 Pa	6.3244e+006 Pa	Mullite is better

Now we can use PV = nRT to solve for n. (the number of moles of the gas).

P = 104995 Pa

V = Area * h

V = 0.0616 m^2 * 0.77 m (how did I get that? See the radius calculation above).

V = 0.0474 m^3

MULLITE MATERIAL PROPERTY

Mullite or porcelainite is a rare silicate mineral of post-clay genesis. It can form two stoichiometric forms $3Al_2O_32SiO_2$ or $2Al_2O_3$ SiO_2. Unusually, mullite has no charge balancing cations present. As a result, there are three different Al sites: two distorted tetrahedral Al sites and one Al other site which adopts a higher co-ordinate octahedral state.

Mullite is a good, low cost refractory ceramic with a nominal composition of $3Al_2O_3 \bullet 2SiO_2$. The raw materials for mullite are easily obtainable and are reasonably priced. It has excellent high temperature properties with improved thermal shock and thermal stress resistance owing to the low thermal expansion, good strength and interlocking grain structure.

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