Computer Aided Modeling and Simulation of IC Engine Speculative Piston

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Abstract: Piston is an essential part of an IC engine, the purpose of this work is to analyze the stress generated due to the gas pressure on an speculative IC engine piston head using the FEA software the IC engine piston is designed and analyzed using cast iron as piston material with a 4 node parabolic octree-tetrahedron meshing element and the variation in stresses as that of the numerically obtained result is analyzed. Finally the best possible solution is obtained at which the effect of load be minimum.

Keywords: FEA, IC engine Piston, pressure, stress, mesh size.

I. INTRODUCTION

IC Engine: Internal combustion engine is a device in which the chemical energy of fuel is released inside the engine and used directly for mechanical work. [1-ntel] in suction the fuel air mixture is first drawn into the crank case by the vacuum created during the upward stroke of the piston. During the downward stroke the poppet valve is forced closed by increased crank case pressure. The fuel mixture is then compressed in the crank case during the reminder of the stroke. Towards the end of the stroke the piston exposed the intake ort allowing the compressed fuel/air mixture in the crack case to escape around the piston end to the main cylinder this expels the exhaust gases out the exhaust port usually located on the opposite side of the cylinder, the piston then rises driven by the flywheel momentum and compress the fuel mixture, at the top of the stroke the spark plug ignites the fuel mixture the burning fuel expands driving the piston downward to complete the cycle.

a. Single cylinder engine:

It uses one power stroke per crank revolution (360 CA) for two strokes or every two revolution for four stroke engine. The torque pulses on the crank shaft are widely spaced and engine vibration and smoothness are significant problems.

b. Two stroke Single cylinder engine:

It needs a blower and usually use supercharger, its combustion process is not as complete (more pollution), two-stroke engine weigh less and have higher rpm operating speeds, used more for emergency, while four stroke used more for propulsion.

c. Principal parts

Cylinder and cylinder liner, piston, piston ring, gudgeon pin, Connecting rod, with mall and big end bearing, Crank crankshaft and crank pin and Valve gear arrangement

d. Piston:

The piston is a disc which reciprocates within a cylinder. It is either moved by the fluid or it moves the fluid which enters the cylinder. The main function of the piston of an internal combustion engine is to receive the impulse from the expanding gas and to transmit the energy to the crankshaft through the connecting rod. The piston must also disperse a large amount of heat from the combustion chamber to the cylinder walls [1]

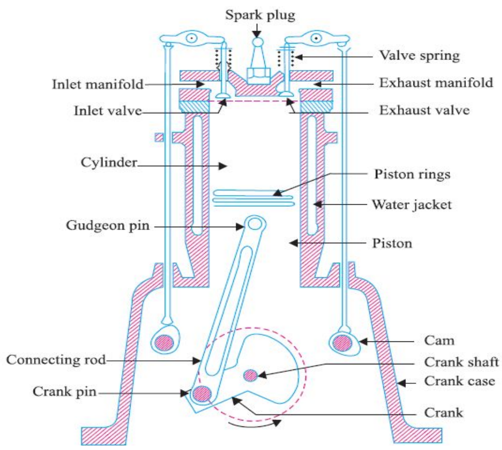

Figure 1: Internal Combustion engine parts

The piston of internal combustion engines are usually of trunk type as shown in Figure-2 such pistons are open at one end and consist of the following parts:

1. Head or crown-The piston head or crown may be flat, convex or concave depending upon the design of combustion chamber. It withstands the pressure of gas in the cylinder.
2. Piston rings-The piston rings are used to seal the cylinder in order to prevent leakage of the gas past the piston.
3. Skirt-The skirt acts as a bearing for the side thrust of the connecting rod on the walls of cylinder.
4. Piston pin-It is also called gudgeon pin or wrist pin. It is used to connect the piston to the connecting rod.

The piston should have enormous strength to withstand the high gas pressure and inertia forces, with minimum mass to minimize the inertia forces. The piston should be designed in such a way that it should disperse the heat of combustion quickly with minimum noise and sufficiently rigid construction to withstand thermal and mechanical distortion. The piston should form an effective gas and oil sealing of the cylinder and provide sufficient bearing area to prevent undue wear and mechanical distortion.

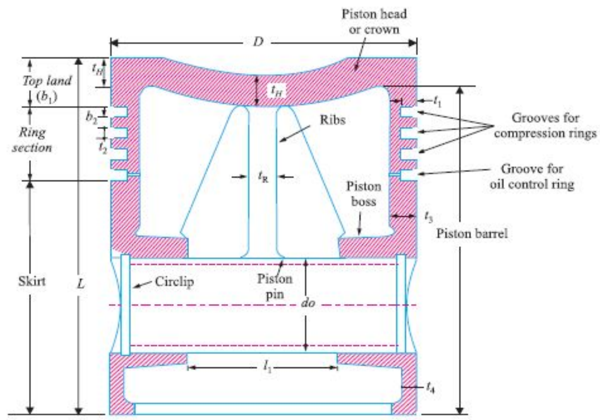

Figure 2: The Piston

II. LITERATURE REVIEW

A lot of research is been made in the IC engine piston Youngchul Ra presents A reduced chemical reaction mechanism for modeling the oxidation of multi-component fuels which is developed using a combination of chemical lumping, graphical reaction flow analysis and elimination methods[2]. S.S. Feng gives a combined experimental and numerical study on finned metal foam and metal foam heat sinks under impinging air jet cooling[3]. Ajay Raj Singh describes the stress distribution and thermal stresses of three different aluminum alloys piston by using finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature and material properties of piston[4]. Zbyszko Kazimierski gives the idea of using a double IC engine concept and its sealing has been presented. The engine should deliver nearly twice the amount of power when compared to its single components[5].

A Dynamic Analysis of single cylinder petrol engine was conducted using Finite element analysis to obtain the variation of the stress magnitude at critical locations of connecting rod and crankshaft by Dr. K.H. Jatkar[6].

A mathematical model of a free piston linear engine is established by Jin Xiao. The motion characteristics as well as the natural frequency map of the free piston are established. Then, its motion characteristics are successfully explained from the oscillation point. The full simulation model is built up in Matlab/Simulink for a better understanding of its motion features[7]. “Zhenpeng He” gives the numerical model which concludes lubrication part and dynamic motion is established, the lubrication is solved by the finite element method, and dynamic equation is solved by Runge–Kutta. The effect of piston skirt parameters on dynamic characteristics are compared based on a typical inline six-cylinder engine, such as: clearance, offset of piston pin, length of piston skirt, position of bump, curvature parameter and ellipticity of the piston, all the result mainly focus on the slap noise of the engine. All the analyses are very useful to design of piston-liner at the development of the engine, and it can provide the guidance for the design of the low noise engine.[8]

III. METHODOLOGY:

Piston Material:

The most commonly used materials for pistons of I.C. engines are cast iron, cast aluminium, forged aluminium, cast steel and forged steel. The cast iron pistons are used for moderately rated engines with piston speeds below 6 m/s and aluminum alloy pistons are used for highly rated engines running at higher piston speeds. In the present analysis the material used is cast iron for which the following design is made:-

The thickness of the piston head (t_h), according to Grashoff’s formula is given by

$$t_h = \left[\frac{3pD^2}{16\,\sigma_t}\right]^{(1/2)} \text{ mm}$$

Where

p = Maximum gas pressure in N/mm2,

D = Outside diameter of the piston in mm, and

σ_t = Permissible bending (tensile) stress

Radial thickness of piston rings:

$$t_1 = D\left[\frac{3P_w}{\sigma_t}\right]^{(1/2)}$$

Where

D = Cylinder bore in mm,

p_w = Pressure of gas on the cylinder wall in N/mm2.

σ_t = Allowable bending (tensile) stress in MPa.

Maximum axial thickness of piston rings:

$$t_2 = \frac{D}{10\,n_R}, \qquad n_R = \text{Number of rings}$$

The maximum thickness (t3) of the piston barrel may be obtained from the following empirical relation:

$$t_3 = 0.03\,D + b + 4.5 \text{ mm}$$

Where

b = Radial depth of piston ring groove which is taken as 0.4 mm larger than the radial thickness of the piston ring t_1

$$b = t_1 + 0.4 \text{ mm}$$

Length of piston skirt:

We know that maximum gas load on the piston,

$$P = p\frac{\pi D^2}{4}$$

Maximum side thrust on the cylinder,

$$R = P/10$$

Where

p = Maximum gas pressure in N/mm^2, and

D =Cylinder bore in mm.

The side thrust (R) is also given by

R =Bearing pressure × Projected bearing area of the piston skirt $= p_b \times D \times l$

Where l = Length of the piston skirt in mm.

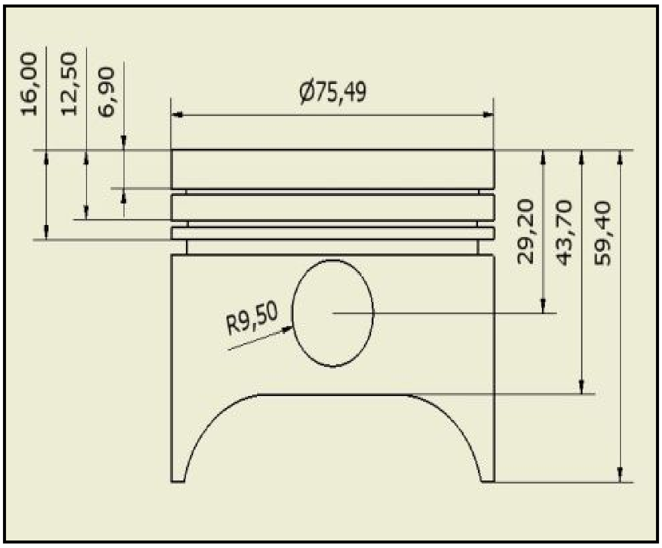

Figure 3: Geometry of Piston

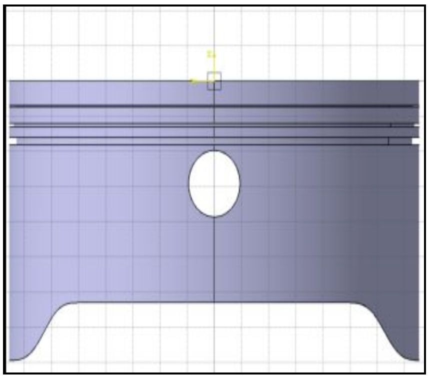

Figure 4: Model of IC engine piston

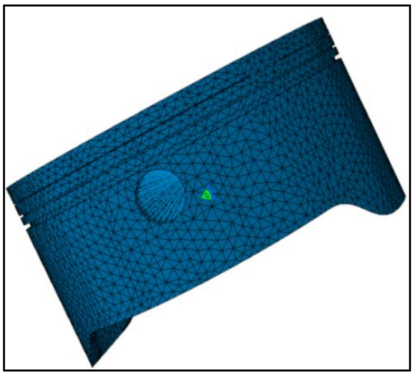

Figure 6: Meshing of piston

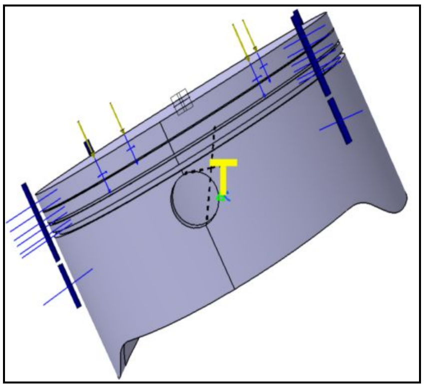

Figure 5: Boundary Conditions

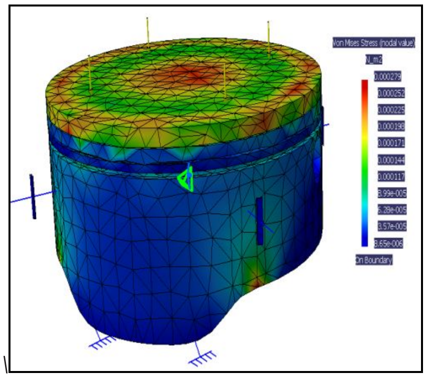

Figure 7: Von Mises Stress

IV. MATERIAL PROPERTIES

The following material properties have been taken for the present analysis:

1. Piston Material: Cast Iron
2. Young's modulus of elasticity: 100 KN/mm2
3. Poisson's Ratio: 0.27
4. Density: 7200 Kg/m3
5. Coefficient of thermal expansion: $0.1 \text{x} 10^{-6}$ m/°c
6. Shear modulus: 45 KN/mm^2

Above figure 3 to figure 7 shows the geometry, computer aided model, boundary conditions, meshing, and the von-mises stress of the piston, and figure 8 shows the flow process chart of the IC engine piston regarding the modeling procedure.

V. Modeling Procedure:

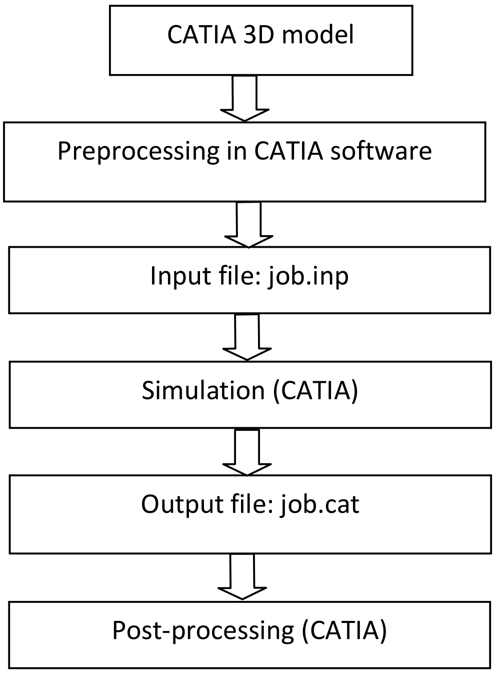

Fig.8:- Flowchart Process of IC engine piston

The geometric perimeters are taken with referral to the numeric and empirical formulae which are mentioned previously and the boundary conditions of the piston is taken in such a way that it can only moves in axial direction only, and a uniform gas pressure is applied to solve the problem by applying simulation. The meshing of the piston is done in the same software for which we had chosen a 4 node parabolic octree-tetrahedron element is selected with element size of 2. Finally the spring material property is defined and then the analysis is done in CATIA generative analysis workbench to obtain the best possible results. The flow chart shows the simulation procedure for the whole analysis.

VI. Result and Discussions

It has been found that the stress for a gas pressure of 50 M pa on the piston head is found to be 27.9 M pa by the simulation result while analytically it should be around 30 M pa which shows that the analysis is much closer to the complex numerical calculations and can be directly implemented.

VII. Conclusions

1. The CATIA solver provides much better results and is in the range of the complex numerical calculations. It saves much time and human effort.
2. Taking cast iron as the piston material is much effective in solving and analyzing IC engine piston problems.
3. A tetrahedron meshing element with least mesh size gives better results than simple three dimensional block type element and with bigger element size.

VIII. Future Scope

We may enhance the piston dimensions and material properties to analyze how it behaves in different loading conditions, moreover the simulation work can be made using some other software.

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