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Design and Analysis of Piston by using Finite Element Analysis

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Abstract— **This paper describes the stress distribution of the piston four stroke engines by using FEM. The main objectives is to investigate and analyze the thermal stress and maximum or minimum principal stresses, Vanishes stresses distribution on engine piston at the real engine condition during combustion process. The paper describes the optimization techniques with using finite element analysis technique (FEM) to predict the higher stress and critical region on that component. The stress concentration on the piston head, piston skirt and sleeve are reduces by optimization with using computer aided design, Pro-ENGINEER/ CREO software the structural model of a piston will be developed. Furthermore, the FEM analysis is done using Computer Aided Simulation software.**

Keywords—— FEA, ANSYS, Piston crown, Piston skirt, Pro-E, stress concentration, Thermal analysis etc.

I. INTRODUCTION

A piston is a component of engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its transfer force from expanding gas in the cylinder to the crankshaft via a piston rod or connecting rod. As a main part in an engine, piston endures the cyclic gas pressure and the inertial forces at work, and this real working condition may cause the fatigue damage of piston, such as piston skirt wear, piston head or crown cracks and so on. The investigations denote that the greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure. On the other hand piston over heating-seizure can only occur when something burns or scrapes away the oil film that exists between the piston and the cylinder wall. Understanding this, it's not hard to visually why oils with exceptionally high film strengths are very desirable. Good quality oils will offer provide a film that stands up to the most intense heat and the pressure loads of a modern high output engine. Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. Finite element method (FEM) are commonly used for thermal Analysis. Due to the complicated working environment for the piston; on one hand, the finite element method (FEM) for the piston became more difficult, on the other hand, though there have many methods which are put forward to apply optimal design, the optimal parameters is not easy to determine. In this study, the piston is used in low idle and rated speed gas engine. In order to enhance the engine dynamic and economic, it is necessary for the piston to implement optimization. The mathematical model of optimization is established firstly, and the FEA is carried out by using the ANSYS software. Based on the analysis of optimal result, the stress concentrates on the Upper end of piston has evaluated, which provides a better reference for redesign of piston.

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

The paper presented by K.Jagdeesh [8] 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.

F.S. Silva [9] Fatigue on engine pistons – A compendium of case studies- provided valuable information on the first main conclusion that could be drawn from this work is that although fatigue is not the responsible for biggest slice of damaged pistons, it remains a problem on engine pistons and its solution remains a goal for piston manufacturers. And it will last a problem for long because efforts on fuel consumption reduction and power increase will push to the limit weight reduction that means thinner walls and higher stresses. To satisfy all the requirements with regard to successful application of pistons, in particular mechanical and high temperature mechanical fatigue and thermal/thermal–mechanical fatigue there are several concepts available that can be used to improve its use, such as design, materials, and processing technologies.

S N Kurbet's [10] 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 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.

II. RESEARCH OBJECT – PISTON

A piston is a component of reciprocating CI-engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its main purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod. Piston endures the cyclic gas pressure and the inside mechanical/thermal forces at work, and this operating condition may cause the fatigue damage of piston, like piston side wear, piston head cracks and so on.

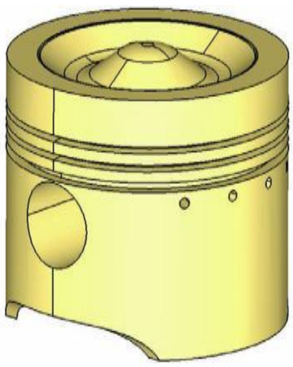

Fig.1 Piston in CI engine

Title Piston in CI engine must possess the following characteristics:

- Strength to resist gas pressure
- Must have minimum weight
- Must be able to reciprocate with minimum noise
- Must have sufficient bearing area to prevent wear
- Must seal the gas from top and oil from the bottom
- Must disperse the heat generated during combustion
- Must have good resistance to distortion under heavy forces and heavy temperature

In engine, always transfer of heat takes place due to difference in temperature. Thus, there's heat transfer to the gases during intakes stroke and the 1st of the compression stroke, however the throughout combustion and expansion processes the heat transfer happen from the gases to the walls. So the piston crown, piston ring and the piston skirt should have enough stiffness which can endure the pressure and the friction between contacting surfaces. Additionally, as an main part in engine, the operating condition of piston is directly associated with the reliability and durability of engine

III. CHARACTERISATION OF MATERIALS

Aluminum silicon alloys (predominantly cutectic) are widely employed to produce pistons due to their low density, high thermal conductivity, good cast ability and workability, good machinability and sound high temperature strength

In this study the piston material is AlSi12CuMgNi cast alloy with eutectic microstructure. As all the engine components around the combustion chamber experience significantly high temperatures and temperature gradients, temperature dependent material properties have to be used. Some temperature dependent properties of piston material are shown in Table 1.

According to thermal analysis results maximum piston temperature reaches 374 °C, therefore cyclic behavior of material is considered at 20, 150, 250 and 350 °C.

TABLE I
CHEMICAL COMPOSITION OF WORK MATERIAL

GROOVE INSERT MATERIAL		PISTON MATERIRL KS 1275	
C	2.2-3.0	Si	11-13.5
Si	1.5-2.5	Cu	0.8-1.5
Mn	0.8-1.5	Ni	0.7-1.3
Ni	13.5-17.0	Mg	0.7-1.2
Cr	0.8-1.6	Fe	0.7 Max
Cu	5.0-7.0	Mn	0.35 Max
P	0.1 Max	Al	Rest
S	< 0.1		
Fe	Rest		

(KS 1275). It is used extensively for making pistons and other different components. The chemical composition of this material is given in the table 1. Mechanical properties are:

Thermal conductivity = 100 W/mk.
Coefficient of thermal expansion at
3000C = 22.0 x 10-6 Kelvin,
Hardness = 60~70 HRB.

IV. Engine Specifications

The engine used for this work is a four cylinder four stroke air cooled type Bajaj Kawasaki diesel engine. The engine specifications are given in Table II.

TABLE III
ENGINE SPECIFICATIONS

PARAMETERS	VALUES
Engine Type	Four stroke, diesel engine
Induction	TCIC
Number of cylinders	4 cylinder
Bore	74 mm
Stroke	70 mm
Length of connecting rod	97.6 mm
Displacement volume	99.27 cm^3
Compression ratio	16
Maximum power	21.6 KW at 7000 rpm
Maximum Torque	86 Nm at 3500 rpm
Number of revolutions/cycle	2

V. CAE Procedure

In standard approach conception ideas are converted into sketches or engineering drawing. With the assistance of this drawings, the prototypes i.e. product which appearance as that of final product are created. It is launched in the market after testing of prototype which gives acceptable results. The thing is, product is launched after doing several practical testing and many trial and error procedures which consumes more time and cost too [1]. Figure 2 depicts the flow process adopted for typical design approach.

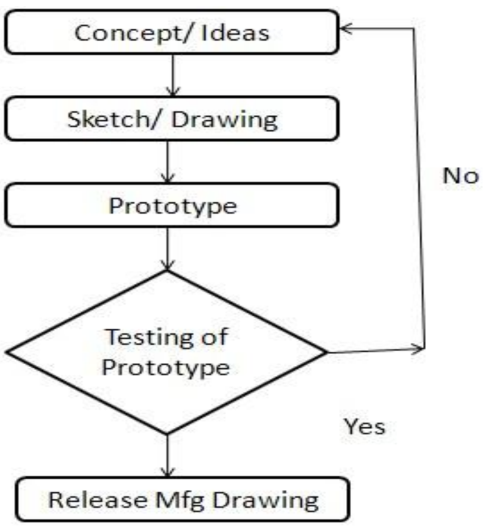

Fig.2 Conventional Approach

VI. CAE Approach

In CAE approach, some steps are same as that of conventional method. Here additionally conceptions, concepts are converted into engineering drawing, but it is then modeled on computer. Geometric model of product is made by the utilization of solid work software like CAD which enables better visualization of simple as well as complex models. These models then further utilizatised for computerized analysis by using different CAE tools (FEA/CFD software's) depending upon the application before the prototype is been made to check whether the components is going to work according to its intended function. After that once congruous results are obtained the final practical testing is carried out [1]. Figure 3 show the CAE approach for design a machine component.

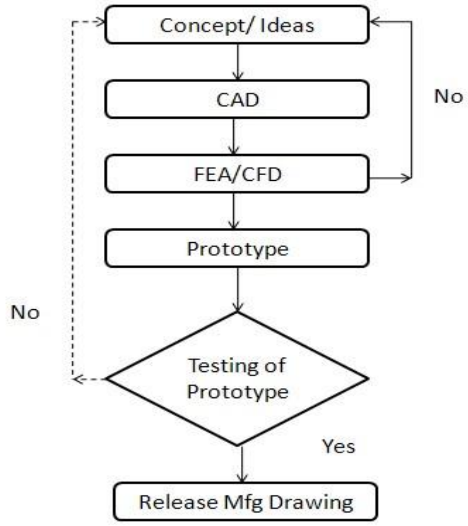

Fig.3 CAE Approach

A. *Finite element analysis*

FEA implement is the mathematical idealization of authentic system. It is a computer predicated method that breaks geometry into element and link a series of equation to every, which are then solved simultaneously to evaluate the demeanor of the complete system. It is utilizable for quandary with perplexed geometry, loading, and material properties where exact analytical solution are arduous to obtain. Most often utilized for structural, thermal, fluid analysis, however wide applicable for other type of analysis and simulation.

B. *Methodology of piston analysis*

The Piston during the working condition exposed to the high gas pressure and high temperature gas because of combustion. At the same time it is fortified by the minute terminus of the connecting rod with the avail of piston pin (Gudgeon pin). Therefore the methodology for analyzing the piston is considered as; the gas pressure given 180 bar is applied uniformly over top surface of piston (crown) and apprehended all degrees of liberation for nodes at upper a moiety of piston pin boss in that piston pin is going to fine-tune. Considering the type of fit between piston pin and piston is clearance fit. Only the upper a moiety of piston pin boss is considered to be fine-tuning during the analysis.

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C. Material properties of piston

Material of Piston: - Cast aluminum alloy 201.0
Young's Modulus [E] – 71 GPa
Poisson's ratio [µ] – 0.33
Tensile strength – 485 MPa
Yield strength – 435 MPa
Shear strength –290 MPa
Elongation – 7 % [4-5]

D. Geometry

The below image shows the geometry of piston foreign used for FEA.

A geometrical model of piston is prepared by modeling software's like CREO software or CATIA V5 which can also be modeled in the analysis software's like ANSYS. Figure 4 show the piston engendered by CAD software for further analysis.

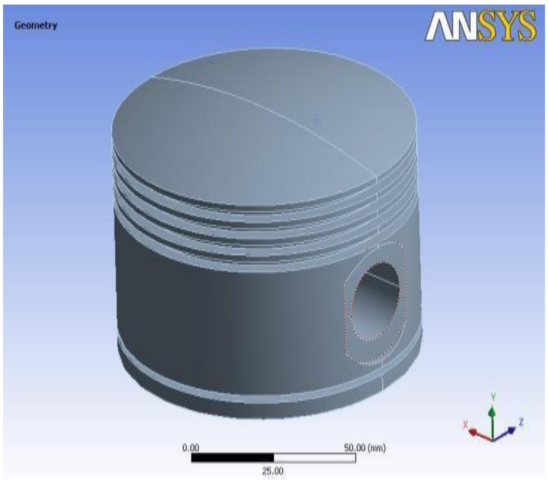

Fig. 4 Geometry of piston

E. Finite element model

The element type selected for meshing in the piston model is SOLID187 tetrahedron type of element which is higher order tetrahedral element. The mesh count for the model contain 71910 number of nodes and 41587 number of elements. Figure 4 shows the meshed model of piston.

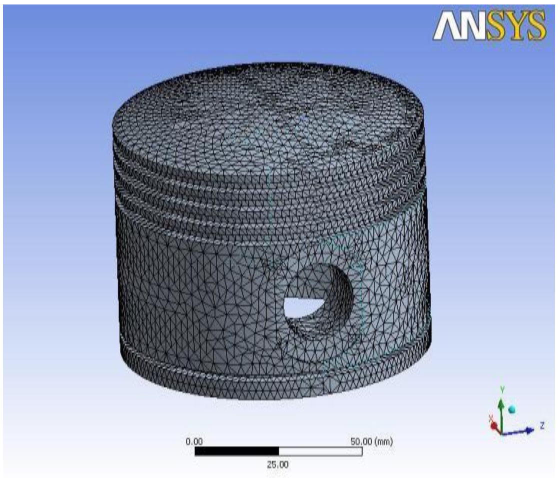

Fig.5 Meshed model of piston

F. Loading & boundary conditions

Figure 6 show the loading and boundary conditions considered for the analysis. The uniform pressure of 18 MPa is applied on crown of piston (red color) and the model is constrained on upper a moiety of piston pin aperture as shown by violet color.

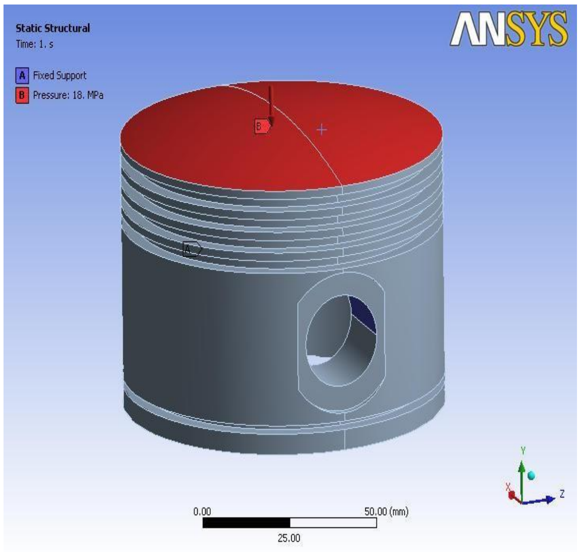

Fig.6 Loading and boundary conditions on piston

VII. Results and Discussion

A. Total deflection

Figure 7 show the maximum deflection in the piston geometry due to the application of gas pressure which is 0.29669 mm observed at the central portion of the piston crown.

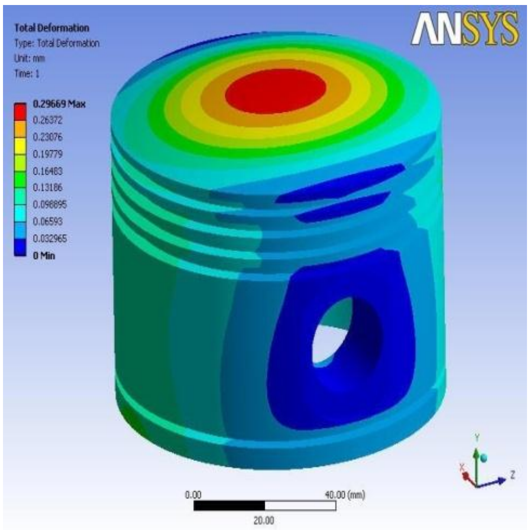

Fig.7 Total deflections on the piston head

B. Maximum principal stress

Figure 8 show the distribution of localized and observed at inner side of piston pin boss. The overall maximum stresses in the piston body are of value 231.25 N/mm^2 at the inner side of piston crown as well as piston boss.

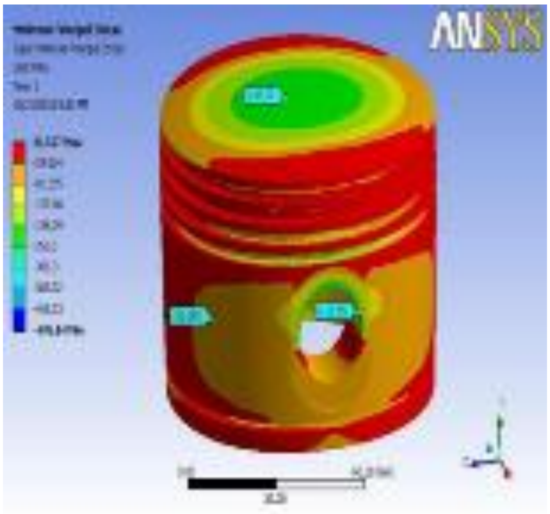

Fig.8 Maximum principal stress on piston

C. Minimum principal stress

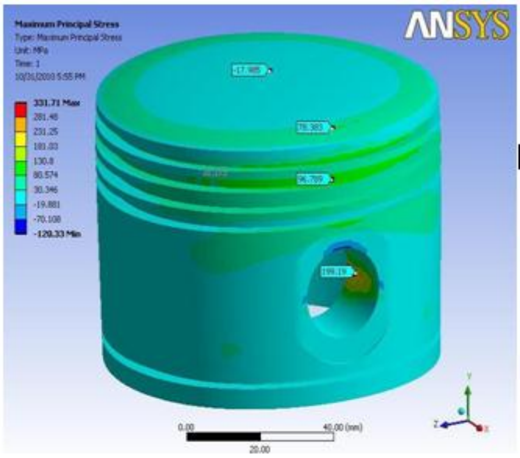

Fig.9 minimum principal stress on piston

Figure 9 show the distribution of the minimum principle stresses induced within the piston body. The most maximum values of equivalent stresses are goes up to - 376.74 N/mm^2, which are highly localized and observed at inner side of piston crown & skirt junction. The overall maximum stresses in the piston body is - 250.5 N/mm^2 at the top of piston crown.

D. Von mises stresses

Figure 10.1 and 10.2 show the distribution of Vonmises stresses induced within the piston body. The utmost maximum values of equivalent stresses are goes up to 200.97N/mm2.

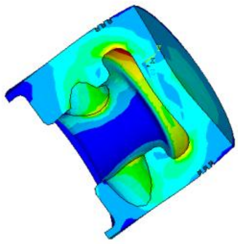

Fig. 10.1 Von mises stresses

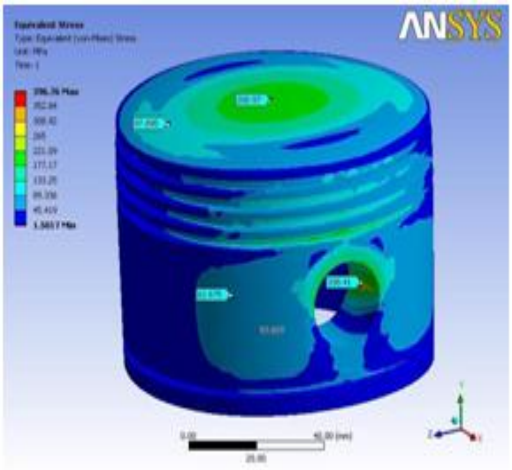

Fig. 10.2 Von mises stresses

E. Stress distribution on the piston body

The critical area is observed on the piston head and piston pin hole region. Figure 11 shows stress concentration at various point in piston.

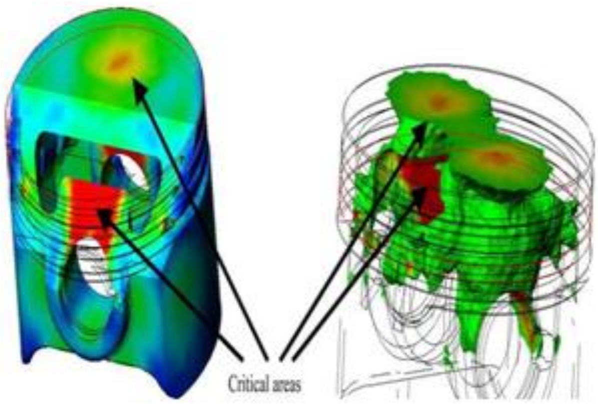

Fig.11 Typical stress distribution on an engine piston

VIII. CONCLUSION

Piston skirt may appear deformation at work, which usually causes crack on the upper end of piston head. Due to the deformation, the greatest stress concentration is caused on the upper end of piston, the situation becomes more serious when the stiffness of the piston is not enough, and the crack generally appeared at the point A which may gradually extend and even cause splitting along the piston vertical. The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough stiffness to reduce the deformation.

Also from analysis various results are obtained like The maximum deflection occurred about 0.29669mm due to the application of 180bar gas pressure on crown of piston, 231.25N/mm^2 of maximum principal stress is ascertained, -250.5 N/mm^2 of minimum principal stress is ascertained. Also von mises stress of 200.97N/mm^2 is observed.

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REFERENCES

[1] "CAD/ CAM/ CAE "by Coagula N. K. [SciTech Publication] pp1.6, 17.1, 17.2
[2] "Computer Aided Engineering in Compression Molding" (Antoine Rios, Bruce Davis and Paul Grumman, the Madison Group: Polymer Processing Research Corporation 505 S. Ronsard. Madison, WI 53719)
[3] C.H. Li., Piston thermal deformation and friction Considerations, SAE Paper 820086, 1982.
[4] Properties and Selection: Irons, Steels and High- performance Alloy, ASM Handbook, vol. 1, ASM International, 1990.
[5] Handbook of Internal Combustion Engines, SAE International.
[6] Martin, Gary G. Failure of stationary pump engine piston, J Failure Anal Prevention 2004;4(1):37–9.
[7] "Fatigue on engine pistons–A compendium of case Studies", F.S. Silva *, 31 March 2005
[8] FE Analysis of a Vibrating Rigid Circular Piston in Water" by K. Jagadeesh and M. S. Vijaya2SASTECH Vol. VI, NO.1, in the year April 2007
[9] F.S. Silva, Fatigue on engine pistons – A compendium of case studies, 13 (2006) 480–492
[10] "Finite Element And MBD Analysis Of Piston To Predict The Engine Noise" S N Kurbet1, Vinay V Kuppast1 and Vijaykumar N Chalwa2*Int. J. Mech. Eng. & Rob. Res. 2013