

## Piston Design and Analysis by CAE Tools

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**Abstract:** - Computer aided engineering (CAE) tools allow engineers to design product and to simulate these designs for residual stress, structural response, pre-processing and post processing fatigue and similar effects on the machine component. CAE allows engineers to load the component at its extreme conditions and simulate its response or otherwise it is not possible to do it because of safety limitations of cost consideration. Particularly for automobile components CAE helps to analyze them for crash simulation, creep and fatigue test on virtual component leading to reduction in time consuming trial and error procedure for design the prototype and it also helps to reduce the cost of manufacturing. The leading manufactures have accepted simulation as a part of early design process with prototyping and testing are done to ultimately verify the designs.

Piston design is carried out with the help of CAE tool and various stresses such as maximum principal stresses, minimum principal stresses, Von mises stresses, total deflection occurred during working condition are evaluated. The parameter used for the simulation are operating gas pressure and material properties of piston. The CAE results suggest that the total deflection(0.29669mm), maximum principal stresses ( $281.48 \text{ N/mm}^2$ - $331.71 \text{ N/mm}^2$ ), Minimum principal stresses ( $-376.24 \text{ N/mm}^2$ ) and Von mises stress ( $338.41 \text{ N/mm}^2$ ) for 180 bar cylinder pressure in case of SI engine. The simulation results suggest the stresses occurred in piston is within the permissible limit of the piston material and deflection is well with the

Tolerance limit as provided with IS standard.

### 1. Introduction

CAE analysis tools offer the tremendous advantage of enabling designers to consider virtually any molding option without incurring the expensive actual manufacturing of the machine component and machine time associated to make machine component. The ability to try new designs or concepts on the computer gives the opportunity to eliminate problems before beginning production. Additionally, designers can quickly and easily determine the sensitivity of specific molding parameters on the quality and production of the final part. The complex parts can be simulated easily by CAE tool. In this article case study is demonstrated with the help of piston design by CAE tool. Engine pistons are one of the most complex components among all automotive or other industry field components. There are significant research works proposing, for engine pistons designs, 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. The piston damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role.[2]

### 2. CAE Procedure

#### 2.1 Conventional Approach

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

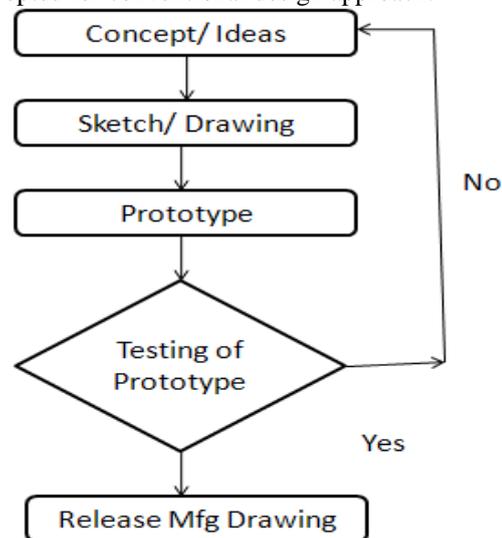


Fig 1 Conventional Approach

#### 2.2 CAE Approach

In CAE approach some steps are same as that of conventional method. Here also ideas, concepts are converted into engineering drawing, but it is then modeled on computer. Geometric model of product is made by the use of solid work software like CAD which enables better visualization of simple as well as complex models. These models then further used for computerized analysis by using different CAE tools (FEA/CFD software's) depending upon the application before the prototype is made to check whether the components is going to work according to its intended function. After that once appropriate results are obtained the final practical testing is carried out [1]. Figure 2 show the CAE approach for design a machine component.

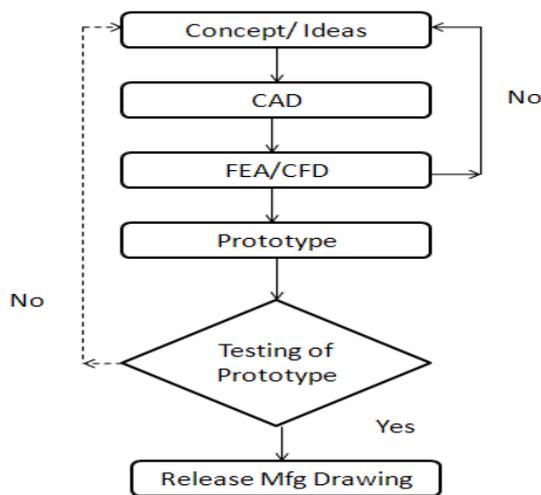


Fig 2 CAE Approach

**3. Finite Element Analysis (FEA)**

FEA tool is the mathematical idealization of real system. It is a computer based method that breaks geometry into element and link a series of equation to each, which are then solved simultaneously to evaluate the behavior of the entire system. It is useful for problem with complicated geometry, loading, and material properties where exact analytical solution are difficult to obtain. Most often used for structural, thermal, fluid analysis, but widely applicable for other type of analysis and simulation.

**4. 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 supported by the small end of the connecting rod with the help of piston pin (Gudgeon pin). So the methodology for analyzing the piston is considered as; the gas pressure given 180 bar (18 Mpa) is applied uniformly over top surface of piston (crown) and arrested all degrees of freedom for nodes at upper half of piston pin

boss in which piston pin is going to fix. Considering the type of fit between piston pin and piston is clearance fit, only the upper half of piston pin boss is considered to be fixing during the analysis.[7]

**4.1 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]

**4.2 Geometry:**

The below image shows the geometry of piston imported into the simulation software for Analysis.

Before going to import a geometrical model of piston which can be prepared by modeling software's like Pro –E or CATIA V5, the geometrical modeling can also done in the analysis software's like ANSYS. Figure 3 show the piston created by CAD software for further analysis.

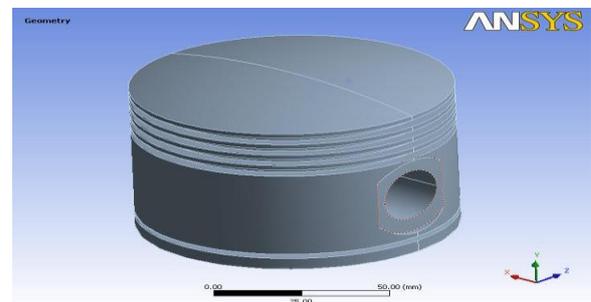


Fig.3. Geometry of piston

**4.3 Finite Element Model:**

The element selected for meshing 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.

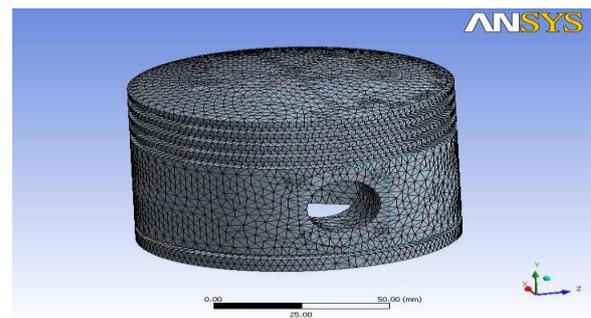
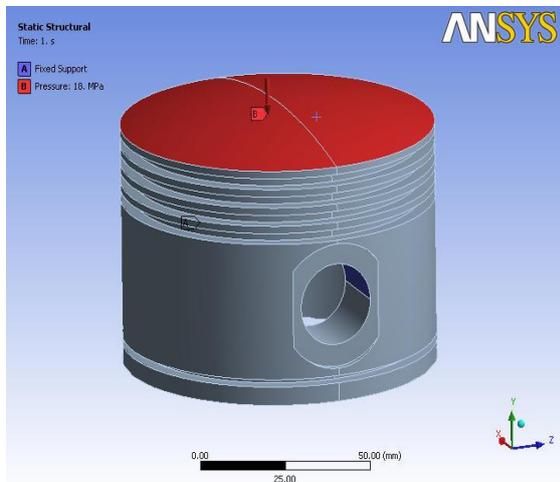


Fig.4. Meshed model of piston

**4.4 Loading & Boundary Conditions:** Figure 5 show the loading and boundary conditions considered for the analysis. The uniform pressure of **18 Mpa** is applied on crown of piston which is indicated by red color and the model is constrained on upper half of piston pin hole as shown by violet color.

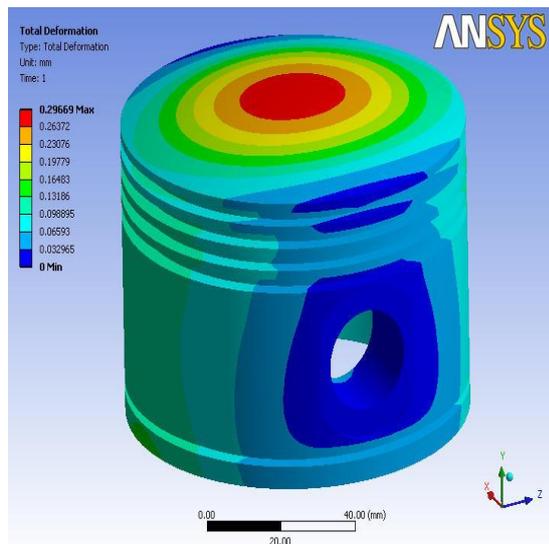


**Fig. 5. Loading and boundary conditions on piston**

**5. Results and Discussion:**

**5.1 Total Deflection:**

Figure 6 show the maximum deflection in the piston geometry due to the application of gas pressure is **0.29669 mm**, which is observed at the central portion of the piston crown.

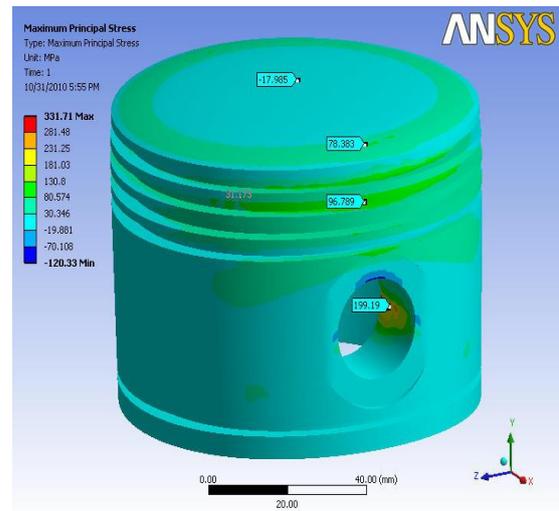


**Fig. 6. Total deflections on the piston head**

**5.2 Max Principal Stress:**

Fig 7 show the distribution of major principle stresses induced within the piston body. The maximum values of equivalent stresses are **281.48 – 331.71 N/mm<sup>2</sup>**, which are highly

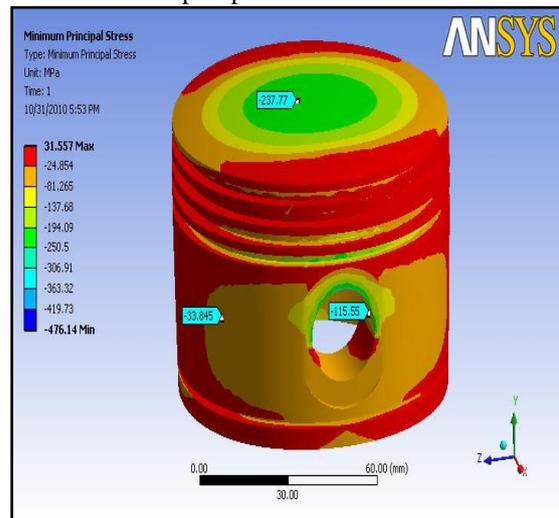
localized and observed at inner side of piston pin boss. The overall maximum stresses in the piston body are of value **231.25 N/mm<sup>2</sup>** at the inner side of piston crown as well as piston boss.



**Fig.7. Maximum principal stress on piston**

**5.3 Min Principal Stress:**

Figure 8 show the distribution of minor principle stresses induced within the piston body. The maximum values of equivalent stresses are goes up to **- 376.74 N/mm<sup>2</sup>**, which are highly localized and observed at inner side of piston crown & skirt junction. The overall maximum stresses in the piston body are of value **- 250.5 N/mm<sup>2</sup>** at the top of piston crown.



**Fig.8. Minimum principal stress on piston**

**5.4 Von mises Stresses:**

Figure 9 show the distribution of Von mises stresses induced within the piston body. The maximum values of equivalent stresses are goes up to **200.97N/mm<sup>2</sup>**

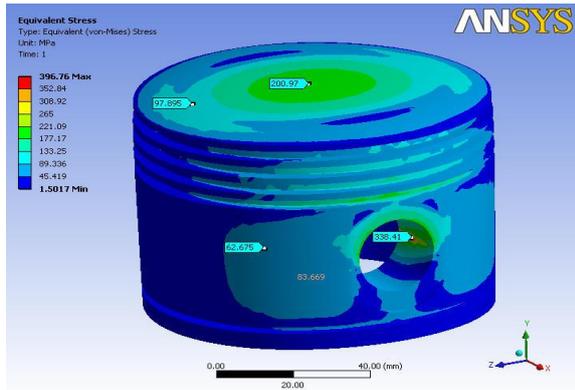


Fig.9. Von mises stresses

#### 5.4 Stress Distribution on the piston body:

The critical area is observed on the piston head and piston pin hole region. Figure 10 shows stress concentration at various point in piston.

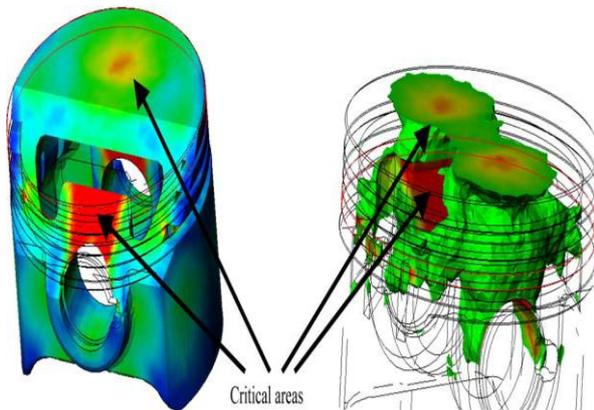


Fig. 10. Typical stress distribution on an engine piston

#### 6. Conclusion:

It is observed that although fatigue is not the responsible for biggest slice of damaged pistons, but the stresses induced are the major factor for piston failure. 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<sup>2</sup>** of maximum principal stress is observed., - **250.5 N/mm<sup>2</sup>** of minimum principal stress is observed. Also von mises stress of **200.97N/mm<sup>2</sup>** are observed.

#### References:

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