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Numerical Investigation and Fatigue Life estimation of Conventional Diesel Engine Piston

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Abstract: *Nowadays engine components are subjected to higher load at elevated temperature than before, due to the increase requirement regarding weight, performance and exhaust gas emission. Thus, Fatigue due to simultaneous thermal and cyclic loading become determinant among the damage forms.*
At the same time, there is the need to reduce development time and cost to handle the growing number of model variant. Therefore, the development of suitable simulation tools, which reduces the number of necessary component tests, seems to be very rewarding.
By using special material (aluminum alloy) we can reduce the fatigue load (Thermal and cyclic) on the piston by using finite element analysis, ANSYS work bench 14.5 version.

I. Introduction

Mechanical systems are frequently subjected to cyclic or random loading, inducing damages and fatigue failure of many structural components. One of these structures, namely pressure vessels, is widely used in many important branches of industry, such as power engineering, chemical engineering, and the petrochemical industry.

IC engine, in general, are loaded by cyclic pulses and as a result stress concentration zones with plastic strains may appear which induce initiation and propagation of fatigue cracks, leading to fatigue failure. Thus, it is obligatory to estimate the fatigue limit and the fatigue life of pressure vessels to ensure safe service time for these important expensive structures having far-reaching effects after their failure.

IC engine Piston are subjected to operating loading conditions which includes pressure, nozzle loads and thermal loads, resulting in the occurrence of stress concentration zones, initiation and propagation of fatigue cracks. Approaches to fatigue life prediction are based on intensity stresses and strains. In the present calculation, fatigue evaluation is carried out using stress based approach.

Approach and Assumptions:

- ANSYS Meshing is used for meshing the component.
- ANSYS 14.5 is used for solving and post-processing.
- Material is assumed to be linear and isotropic.
- Stress based approach is used for fatigue evaluation.
- Fatigue life prediction is done as per ASME VIII DIV 2.

II. Methodology

Geometries can be created top-down or bottom-up. Top-down refers to an approach where the computational domain is created by performing logical operations on primitive shapes such as Piston crown, Skirt of the Piston and Piston bowl. Bottom-up refers to an approach where one first creates vertices (points), connects those to form edges (lines), connects the edges to create faces, and combines the faces to create volumes. Geometries can be created using the same pre-processor software that is used to create the grid, or created using other programs (e.g. CAD, UNI-GRAPHICS). Geometry files are imported into HM to create computational domain.

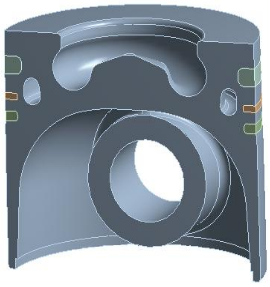

Fig 1: Sectional view of Conventional Piston.

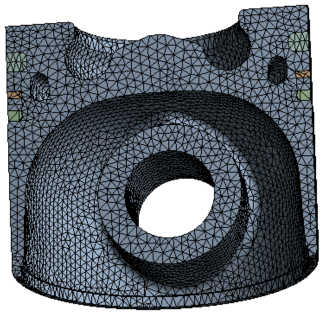

Fig 2: Meshed Sectional view of Modified Piston.

A. FE (mesh) details:

Thermal Element = SOLID 70
Structural Element = SOLID 45
Total No. of Elements = 90223
Total No. of Nodes = 138661

B. Material Properties:

Material Type	Young's Modulus (GPa)	Poisson's Ratio	Density (Kg/m3)	Thermal Exp. cm/cm °C	Thermal Conductivity (W/mK)	Yield Stress (MPa)
Aluminum Alloy	70	0.3	2770	23.4×10^{-6}	155	240

C. Boundary Condition:

The connecting rod support of IC is constrained in all translational DOF as given in Fig.3

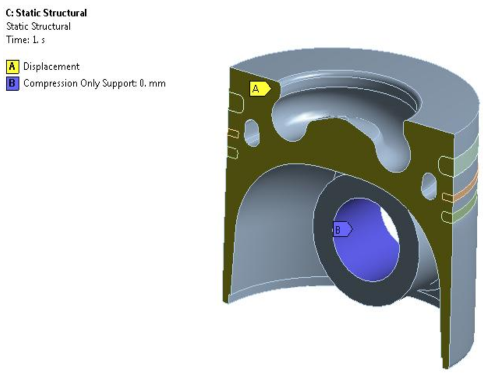

Fig 3: Boundary Conditions (Conventional Piston)

D. Loading Conditions:

1. Temperature Load:

- Piston exposed to min temperature = 25^0C
- Vessel exposed maximum temperature = 650^0C

2. Pressure Load:

- Vessel exposed maximum Pressure = 60Bar
- Vessel Exposed minimum pressure = 1 bar

III. Results And Discussion

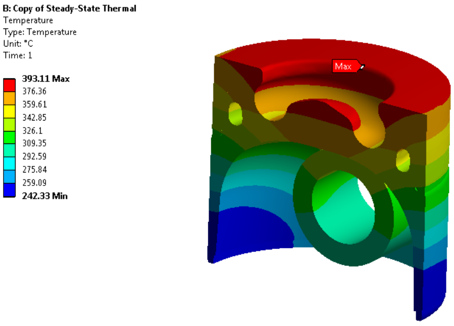

Fig4: Temperature contour.

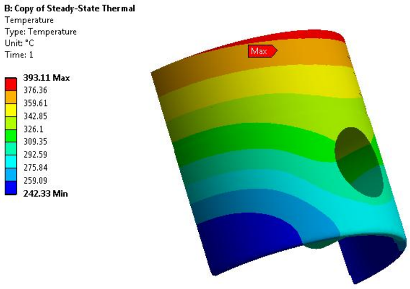

Fig5: Temperature contour.

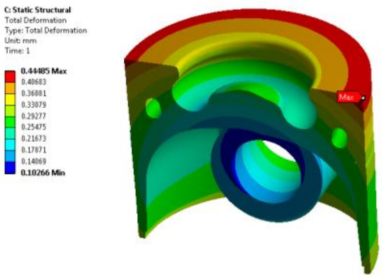

Fig6: Displacement plot

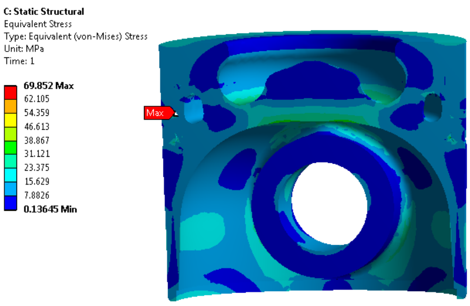

Fig 7: Von-misses plot.

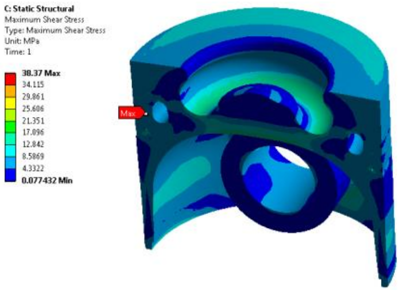

Fig8: Shear stress plot.

IV. Damage Analysis:

The damage analysis was performed with FEM (Finite element analysis) using transient temperature stress and strain and time information from this analysis the concept of TMF analysis with FEM is displayed on the fig: 8. The creep damage is not relevant for this component because it governed by thermal loading shows in fig: 7.

V. Conclusion:

In this paper, it is shown how to evaluate the life of thermal and cyclic loaded components using FEM. The method covers most of the effects and influences that operate under variable thermal and cyclic loading in engine components. The life cycle calculation method includes the calculation of constants X,Y,Sa & N by using following formulae.

$$S_{alt} = \frac{K_{f\times} K_e \times \Delta S_{p,k}}{2} = 277.54 \text{ Mpa}$$

K_f= Fatigue Strength Reduction Factor = 2 for piston
K_e=Fatigue Penalty Factor = 1
$\Delta S_{p,k}$= 68.2Mpa

$$N = 10^X$$

$$X = \frac{C_1 + C_3Y + C_5Y^2 + C_7Y^3 + C_9Y^4 + C_{11}Y^5}{1 + C_2Y + C_4Y^2 + C_6Y^3 + C_8Y^4 + C_{10}Y^5}$$

$$Y = \left(\frac{S_a}{C_{us}}\right) \cdot \left(\frac{E_{FC}}{E_T}\right)$$

C_{us} = conversion factor.
C_{us} = 6.894757 for unit of stress in Mpa.
C_{usm} = conversion factor =14.148299 for units of stress in Mpa.
E_{ACS} = modulus of elasticity of carbon steel at ambient temperature.
E_{FC} = modulus of elasticity used to establish the design fatigue curve.
E_T = modulus of elasticity of material under evaluation at the average temperature of the cycle being evaluated.

Y=10.13
X=5.92
N= 868587

Thermal stress analysis results shows 69.8 MPa stress at pressure vessel. Considering fatigue reduction strength factor 2 art this stress range, the fatigue life of this vessel approximately 868587 Cycles.

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