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Design Analysis and Optimization of Internal Combustion Engine Piston using CAE tool ANSYS

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Abstract
In the internal combustion engine there are many reciprocating parts which are responsible for giving the motion to the engine. from them the piston is very important part of the internal combustion engine.. The working condition of the piston is so worst in comparison of other parts of the internal combustion engine. There is very high probability to failure of the piston due to high wear and tear. So there is necessary to inspection the working condition of piston. In before there is no availability of software packages. So there is difficult to check out the failure of the piston, it is also very time taken process. In now days the software packages are used to consume less time and give quality assurance.

In this study work there are two steps of analysis of the piston they are Designing and Analysis. Firstly design the model of the piston in giving design specification on the modelling software like INVENTOR . Then giving it the constraints which are act on the working condition of the piston after import the model of the piston into the analysis software ANSYS in IGES format. Then the analysis become completed on the different parameters(temperature, stress, deformation) and easily analysis the result. In this work the piston become optimized after the reducing the material of the piston. the mass and volume of the piston become reduced. The deformation also increased after the optimization which is responsible for the stress distribution on the piston head or piston crown.

Keywords: Piston , INVENTOR, ANSYS

I. Introduction

Piston is a most important component of an internal combustion engine. Its working condition is so worst. It is very important to calculate the piston temperature distribution in order to control the thermal stresses and deformation. In the working condition piston produce the stress and deformation due to periodic load effect which produce from high gas pressure, high speed reciprocating motion of the inertia force and lateral pressure. By the chemical reaction of burning the gas the high temperature generates which make the piston expand which creates thermal stress and thermal deformation. The thermal deformation and mechanical deformation causes piston cracks, tortuosity etc. Therefore it is very essential to check out or analyze the stress distribution, temperature distribution, heat transfer, thermal load, mechanical load in order to minimize the stress, minimize the thermal stress and different loads on working condition of the piston. Most of the internal combustion engine piston is made of Al alloy which have thermal coefficient is 80% higher than the cylinder bore material made of cast iron. This creates difference between the running and design clearances. Therefore it is very necessary to examine the crucial thermal behaviour of the piston. In this study firstly make the virtual piston on real working environment by the modelling software INVENTOR and finally analysis the piston giving boundary constraints by ANSYS. The present work has been based on the following objectives-

1. To design an IC engine piston using INVENTOR.

2. To perform the structural and thermal analysis of piston using ANSYS 13.0.

II. Piston

Piston is considered as a very important part of a reciprocating engine in which it helps to convert the chemical energy after the burning of fuel into mechanical energy. The purpose of the piston is to help in conveying the gasses to crankshaft via connecting rod without loss of gas. The piston ring is used to provide seal between the cylinder and piston. It must able to work with low friction, high explosive forces and high temperature around 2000℃ to 2800℃.The piston is to be strong but its weight should be less to prevent inertia forces due to reciprocating motion.

III. Functions of Piston

- To receive the thrust force generated by the chemical reaction of fuel in the cylinder and transmits to connecting rod.
- To reciprocate in the cylinder provide seal in suction, compression, expansion and exhaust stroke.

IV. Piston Materials

Generally pistons are made of Al alloy and cast iron. But the Al alloy is more preferable in comparison of cast iron because of its light weight which suitable for the reciprocating part. There are some drawbacks of Al alloys in comparison to cast iron that are the Al alloys are less in strength and in wearing qualities. The heat conductivity of Al is about of thrice of the cast iron. Al pistons are made thicker which is necessary for strength in order to give proper cooling.

V. Design consideration for a Piston

In designing a piston, the following points should be taken into consideration:

1. It should have enormous strength to withstand the high gas pressure and inertia forces.
2. It should have minimum mass to minimise the inertia forces.
3. It should form an effective gas and oil sealing of the cylinder.
4. It should provide sufficient bearing area to prevent undue wear.
5. It should disperse the heat of combustion quickly to the cylinder walls.
6. It should have high speed reciprocation without noise.
7. It should be of sufficient rigid construction to withstand thermal and mechanical distortion.
8. It should have sufficient support for the piston pin.

Procedure for design of Piston

The procedures of the piston design are

1. The thickness of the piston head (t_H)
2. Heat flow through the piston head(H)
3. Radial thickness of the ring(t_1)
4. Axial thickness of the ring(t_2)
5. Width of the top land(b_1)
6. Width of the other land(b_2)

The explanations of the above steps are

Thickness of the Piston (t_H)

$$t_H = \sqrt{\frac{3pD^2}{16\sigma_t}}$$

Where p= maximum gas pressure(2MPa)
D= Bore diameter (mm)
σ_t= Permissible stress(90MPa)

Heat flow through the piston head (H)

$$H= 12.56\times t_H\times K\times(T_c-T_e)$$

Where K=thermal conductivity
T_c=Temperature at the centre of the piston head in℃
T_e=Temperature at edges of piston in℃

Radial thickness of Ring (t_1)

$$t_1=D\sqrt{\frac{3p_w}{\sigma_t}}$$

Where p_w= Pressure of fuel on cylinder wall(0.025N/mm^2-0.042N/mm^2)

Axial thickness of Ring (t_2)

$t_2 = 0.7t_1$ to t_1
or

$$t_2= \frac{D}{10\times n_r}$$

Where n_r= number of rings

Width of the top land (b_1)

$b_1= t_H$ to $1.2\ t_H$

Width of the other land (b_2)

$b_2= 0.7t_2$ to t_2

Maximum thickness of barrel (t_3)

$t_3=0.03\times D+t_1+4.9$

Designing specification for Piston:

S. No.	Parameters	Values
1	Length (L)	158mm
2	Bore Diameter(D)	120mm
3	Pressure(p)	2MPa
4	Permissible stress(σ_t)	90MPa
5	Gas pressure(p_w)	0.25MPa

Material properties of Piston

Material of Piston	Young's Modulus (M Pa)	Poission's Ratio	Bulk Modulus (M Pa)	Shear Modulus (M Pa)	Density ($Kgmm^{-3}$)	Coefficient of thermal expansion ($°C^{-1}$)
Al alloy	71000	0.33	69608	26692	2.77×10^{-6}	2.3×10^{-5}

Designing of Piston

The piston is designed by giving the dimensions into the modelling software INVENTOR. The geometry of the piston is designed in INVENTOR is imported to the analysis software in the IGES format. The figure of the designed piston is below-

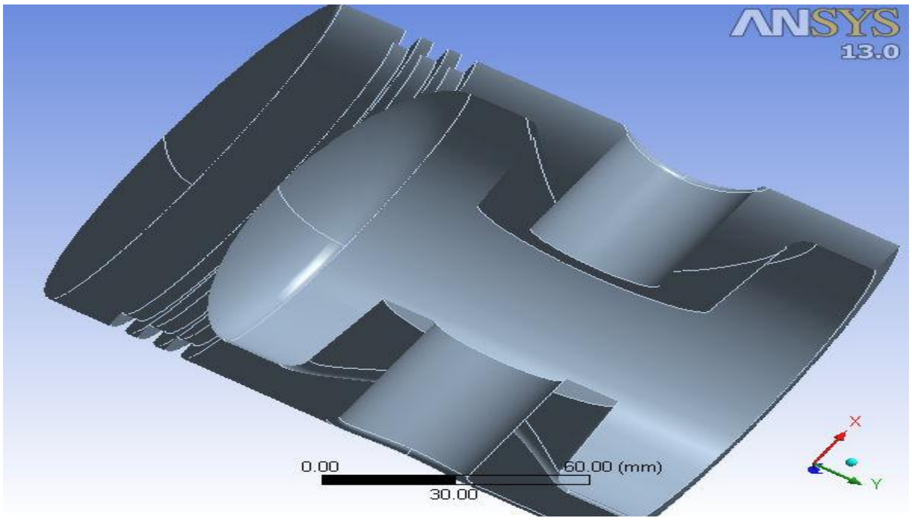

Fig.1. Design of Piston

Analysis of Piston

The piston is analyzed by giving the constraints they are

1. Pressure
2. Select the material properties,
3. Fine meshing,
4. Initial Temperature
5. Convection Temperature

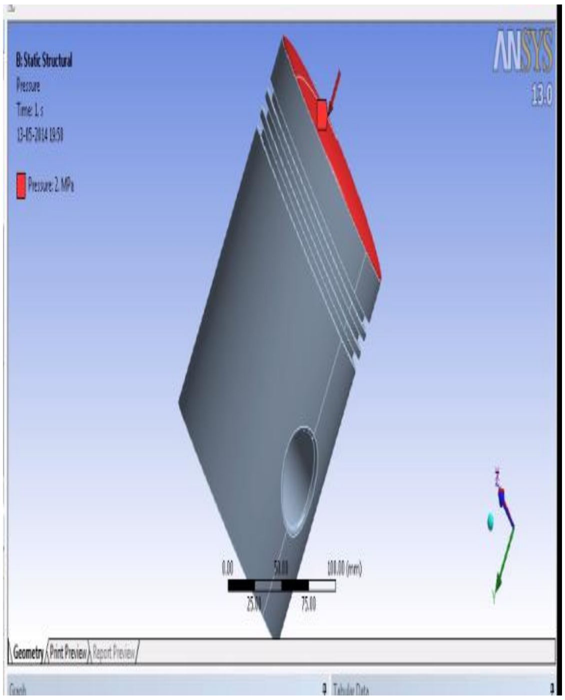

Fig.2. Applied Pressure

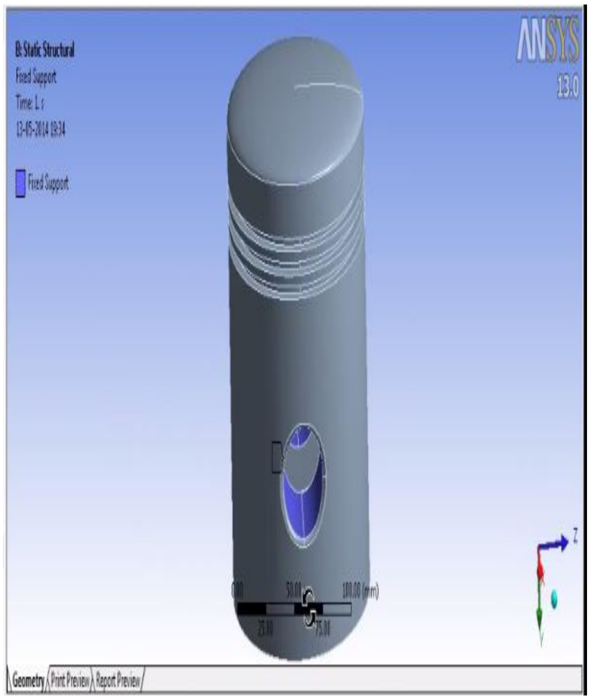

Fig.3. Fixed supports

5. Fixed the piston pin,
6. Film coefficient:-9.56×10^{-3}W/mm^2K

After giving the constraints the analysis become goes on into the mechanical APDL in ANSYS software.

VI. Result and Discussion

1.Before optimization

When the constraints are given to the design of the piston and analysis is done then the result are come out by which we analysis the piston working condition. The some results are given below

1.1 Temperature distribution

The temperature distribution of piston is very important to check the effect of temperature is maximum on which part of piston. After the analysis of temperature distribution the result comes out that the maximum temperature is on the piston head and the minimum temperature is on the piston skirt. The temperature distribution of the piston is given below.

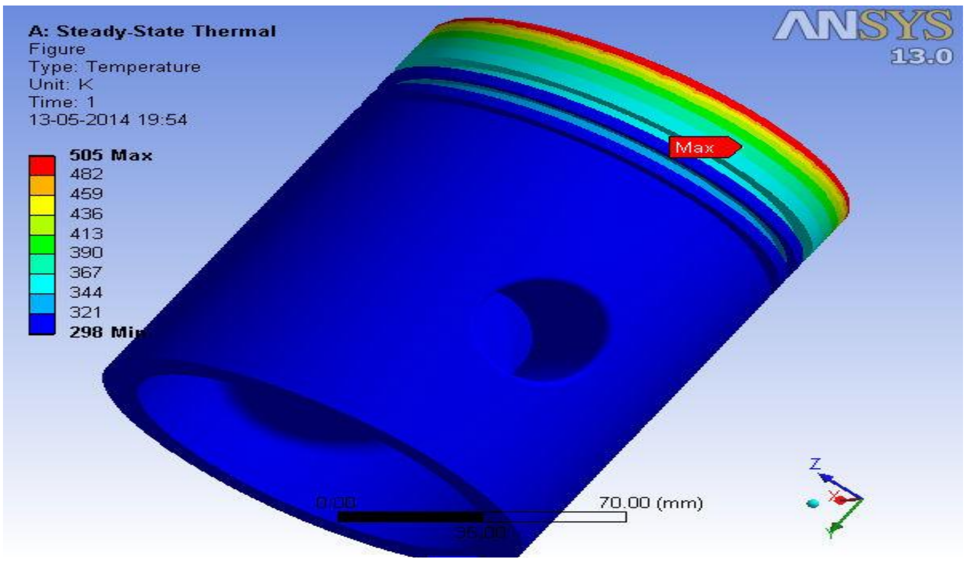

Fig.4. Temperature distribution

1.2 Total Deflection

The deformation of the piston is essential to know the resistance of the piston material on working condition. The deformation occurred into piston is **0.25483mm**.The deformation in the piston is given below

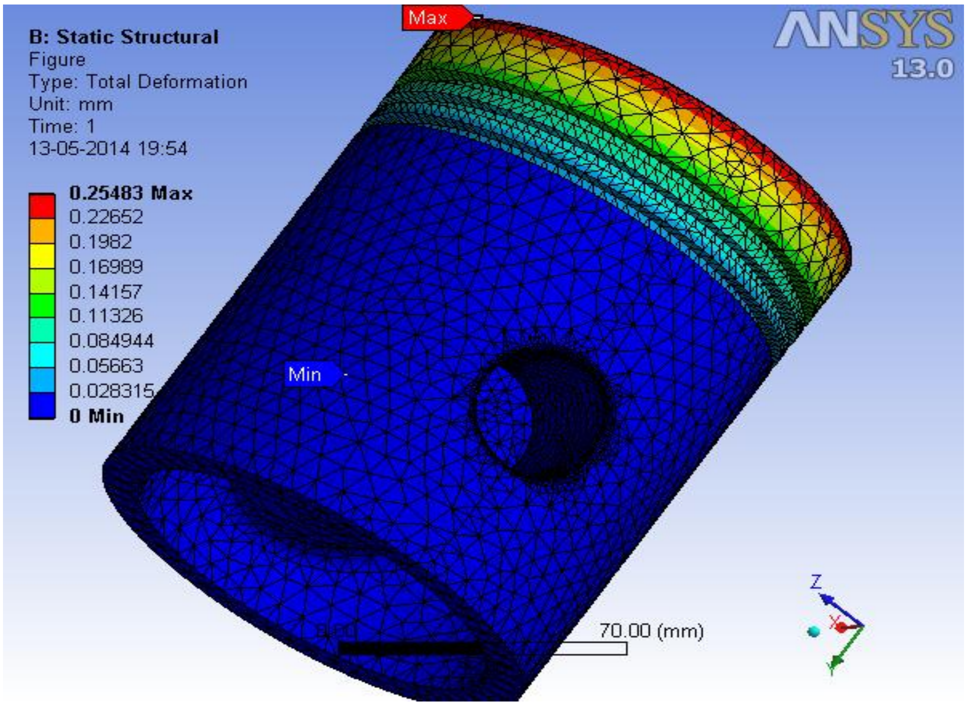

Fig.5. Total Deformation

1.3 Equivalent stress (Von- Mises)

Von mises stress is important to calculate the factor of safety by which we decide that design is safe. The maximum Von-mises stress is **81.636MPa**. The Von-Mises stress is become less than the permissible stress. In this permissible stress is **90MPa** for the Al alloy. By this the design is safe because factor of safety is greater than 1. It is very important to calculate to design the piston that the design is safe or not.

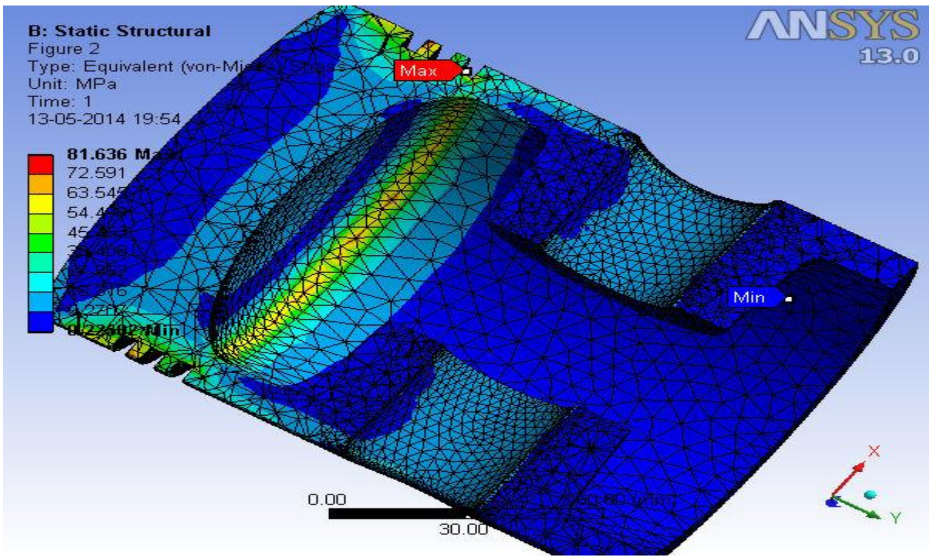

Fig.6. Von -Mises stress

Optimization

Optimization is technique to improve the design specifications. There are some constraints which are consider for optimization of piston they are

1. Maximum Von mises stress<Allowable stress

2. Factor of safety>1
3. Deflection

2. After Optimization

The changes after optimization are discussed by the following results

2.1 Deflection after optimization

After the optimization the deflection becomes **0.2687mm** from **0.25483mm**.By this the resistance from pressure applied to piston become increase. The chances of failure decrease by the optimization process.

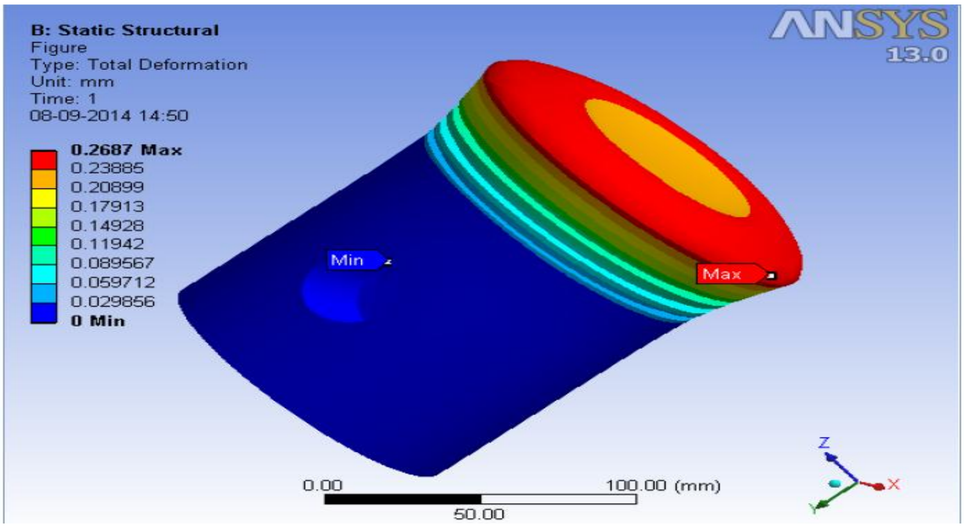

Fig.7.Deflection after optimization

2.2 Von-Mises stress after optimization

The Von-mises stress becomes **87.875MPa** from **81.636MPa** after optimization.

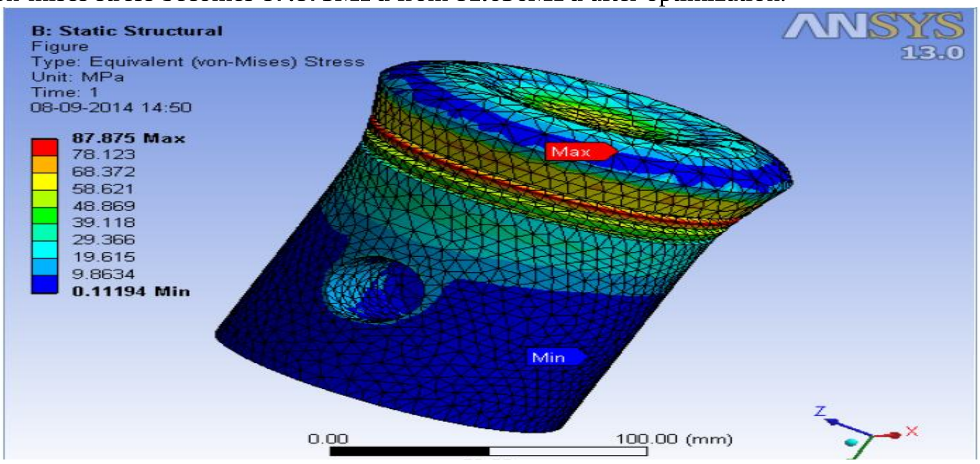

Fig.8.Von-Mises stress after optimization

Design values after optimization

Parameter after the analysis of piston after optimization on working environment the results are

S. No.	Parameter	Before Optimization	After Optimization	Design Consideration
1	Volume	904370mm^3	863980mm^3	863980mm^3
2	Mass	2.5051 kg	2.3932 kg	2.3932 kg
3	Length	158mm	158mm	158mm
4	Bore Diameter	120mm	120mm	120mm
5	Deflection	0.25483mm	0.2687mm	0.2687mm
6	Von-Mises Stress	81.636MPa	87.875MPa	87.875MPa
7	Factor of Safety	1.102	1.02	1.02

VII. Conclusion

Concluded from above study and analysis by using INVENTOR and ANSYS software the deflection due to pressure applied to the piston become increased after optimization. This is taken for the design consideration for the design of piston. The stress induced in the piston is mainly formed due to the deformation of piston. Therefore the stress reduction is very important factor which is responsible for the designing of pistol crown or piston head. In this work the main consideration is to optimize the piston with reduction of piston weight. The material of the piston becomes reduced. Then the optimized result of the piston obtained. The design become consider as safe when Von-Mises stress is less than the permissible stress.

The factor of safety becomes greater than one then the design become safe. The factor of safety after optimization is **1.02** obtained. The permissible stress induced in the piston is about **81.636Mpa** to **87.875MPa**.

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