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Design and Thermal analysis of Piston in Multi Cylinder Engine by Interring Gas Dynamics

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Abstract: The piston ring performs its function as a seal of high and low pressure sides in a cylinder and a medium of heat transfer from piston to cylinder walls. The operation of piston ring packs influences the performance, efficiency, durability, and emissions of engines in terms of friction, wear, oil consumption, and gas blow. In this Paper, the effect of changes in geometry of the grooves, lands, and bore on the interring gas dynamics, thermal deformation of the piston and bore. The piston and piston rings used in diesel engine will be designed and modeled in 3D modeling software Pro/Engineer. The mass flow rates between piston and bore at the piston top position will be calculated theoretically.. Thermal analysis will be performed to determine the temperature distribution and heat transfer rates by changing the materials of the piston and piston rings. thermal analysis will be done in Ansys

Key words: Piston, Piston Rings, Temperature, Heat Flux, Thermal Analysis etc.

I. INTRODUCTION

A. Introduction to Piston

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder wall.

II. DESIGN OF PISTON AND PISTON RINGS (SPECIFICATIONS OF TOYOTA ENGINE)

A. Engine type

4-Stroke multi cylinder petrol engine,

Cylinder bore	= 86mm
Stroke length	= 86mm
Speed	= 2000rpm
Fuel consumption	= 0.25kg/BP/hr
Higher calorific value of fuel	=47000kj/kg
Maximum gas pressure	=5N/mm ²

B. Thickness of piston head based on the strength of piston material (t_1)

$$t_1 = \sqrt{3pD^2/16\sigma_p} \text{ mm}$$

σ_p = 35 to 40 N/mm² for cast Iron

= 50 to 90 N/mm² for aluminum alloy

$$t_1 = 3 \cdot 5 \cdot (86)^2 / 16 \cdot 38 = 14 \text{ mm}$$

Where,

p = Maximum gas pressure, N/mm²

The average value of maximum gas pressure is taken as 4 to 5 MPa or N/mm²

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D= Diameter of piston (i.e. bore diameter of cylinder), mm

Stp= Allowable tensile stress of piston material, N/mm²

C. Thickness of piston head due to heat dissipation (t_1)

$$t_1 = 1000H / 12.56 \cdot k \cdot (T_c - T_e) \text{ mm}$$

$$H = 0.05 \cdot m \cdot C_v \cdot PB \text{ kW}$$

C_v = Higher calorific value of the fuel, kJ/kg

C_v =47000 kJ/kg for petrol fuel

PB= Brake power, kW

m= Mass of fuel used (i.e. fuel consumption) kg/kW/sec

$$m = 0.25 \text{ kg/BP/hr}$$

$$m = 0.25 / 60 \cdot 60 = 69.44 \cdot 10^{-6} \text{ kg/BP/sec}$$

$$PB = \text{pm} \cdot L \cdot A \cdot n / 60 \cdot 1000 \cdot 1000, \text{ kW}$$

Where,

pm= Brake mean effective pressure, N/mm²

L= Stroke length, mm

A= Area of the top side (facing cylinder head) of piston, mm²

Since the engine is a four stroke engine, the number of power strokes per minute,

$$n = N/2 = 2000/2 = 1000$$

$$A = \pi \cdot D^2 / 4 = \pi \cdot (86)^2 / 4 = 5808.80 \text{ mm}^2$$

$$P = 0.85 \cdot 86 \cdot 5808.80 \cdot 1000 / 60 \cdot 1000 \cdot 1000 = 7.07 \text{ kW}$$

k= Heat conductivity factor, kW/m/ °C

H= Heat flowing through the head, kW

T_c = Temperature at the centre of piston head, °C

T_e = Temperature at the edge of piston head, °C

$T_c - T_e = 220^\circ\text{C}$ for cast iron

$$H = 0.05 \cdot 69.44 \cdot 10^{-6} \cdot 47000 \cdot 7.07 = 1.153 \text{ kW}$$

$$t_1 = 1000 \cdot 1.153 / 12.56 \cdot (46.6 \cdot 10^{-3}) \cdot 220 = 8.954 \text{ mm}$$

Taking, the larger of the two values

We shall adopt, $t_1 = 14 \text{ mm}$

D. Thickness of rib (t_2)

$$t_2 = (0.3 \text{ to } 0.5) \cdot t_1 \text{ mm}$$

$$= (0.3 \text{ to } 0.5) \cdot 14 \text{ mm}$$

$$= 6 \text{ mm}$$

E. Radial thickness of piston (t_3)

$$t_3 = D \cdot \sqrt{3pc / S_{br}}$$

Where,

pc= Contact pressure by the piston rings = 0.035N/mm²

S_{br} = Allowable bending stress of ring material = 90N/mm²

$$t_3 = 86 \cdot \sqrt{3 \cdot 0.035 / 90} \text{ mm}$$

$$= 2.93 \text{ mm}$$

F. Axial thickness of piston rings (t_4)

$$t_4 = (0.7 \text{ to } 1) \cdot t_3 \text{ mm}$$

$$= (0.7 \text{ to } 1) \cdot 2.93 \text{ mm}$$

$$= 2.5 \text{ mm}$$

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G. Radial depth of ring-groove (b)

$$\begin{aligned} b &= t_3 + 0.4 \text{ mm} \\ &= 2.93 + 0.4 \text{ mm} \\ &= 3.33 \text{ mm} \end{aligned}$$

H. Thickness of barrel nearer to piston head (t_5)

$$\begin{aligned} t_5 &= 0.03 \cdot D + b + 4.5 \text{ mm} \\ &= (0.03 \cdot 86) + 3.33 + 4.5 \text{ mm} \\ &= 10.41 \text{ mm} \end{aligned}$$

I. Thickness of barrel at the open end of the piston (t_6)

$$\begin{aligned} t_6 &= (0.25 \text{ to } 0.35) \cdot t_5 \text{ mm} \\ &= (0.25 \text{ to } 0.35) \cdot 10.41 \text{ mm} \\ &= 3.2 \text{ mm} \end{aligned}$$

J. Length of the skirt (L_s)

$$L_s = \frac{\pi \cdot \mu \cdot D \cdot p}{4 \cdot (p_s)}$$

Where,

μ = Coefficient of friction between liner and skirt = 0.1

p = Maximum gas pressure, N/mm²

$$= 5 \text{ N/mm}^2$$

We also know that the side thrust to the bearing pressure on the piston barrel,

$$P_s = 0.45 \text{ N/mm}^2$$

$$L_s = \frac{\pi \cdot 0.1 \cdot 86 \cdot 5}{4 \cdot (0.45)} = 78 \text{ mm}$$

K. Length of the ring section (L_r)

$$L_r = t_4 \cdot (X_1 + 0.8 \cdot X_2) \text{ mm}$$

Where,

X_1 = Number of rings = 4

X_2 = Number of lands in between the rings = 3

$$L_r = 2.5 \cdot (4 + 0.8 \cdot 3) \text{ mm} = 17.5 \text{ mm}$$

L. Length of the piston (L_1)

$$L_p = L_s + L_r + L_t \text{ mm}$$

L_t = Length of the top land, mm

$$= t_1 \text{ to } 1.2 \cdot t_1 \text{ mm}$$

$$= 14 \text{ to } 1.2 \cdot 14 \text{ mm}$$

$$= 16 \text{ mm}$$

M. Diameter of the piston pin (d_1)

$$d_1 = \sqrt[3]{F_g / P_b \cdot l_1}$$

Where,

F_g = Maximum gas force, Newton

l_1 = Length of the piston pin, mm

P_b = Bearing pressure at the small end of the connecting rod bushing in N/mm²

It value for bronze busing is taken as 25 N/mm²

$$F_g = \frac{\pi \cdot D^2 \cdot p}{4} \text{ N}$$

$$= \frac{\pi \cdot (86)^2 \cdot 5}{4} \text{ N}$$

$$= 29044 \text{ N}$$

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$$\begin{aligned}l_1 &= 1.5 \cdot d_1 \text{ mm} \\d_1 &= 29044/25 \cdot (1.5 \cdot d_1) \text{ mm} \\&= 28 \text{ mm} \\d_2 &= 0.6 \cdot d_1 \text{ mm} \\&= 0.6 \cdot 28 \text{ mm} \\&= 17 \text{ mm}\end{aligned}$$

Where,

d_1 = Outer diameter of piston pin, mm

d_2 = Inner diameter of piston pin, mm

N. Mass flow rate calculations

For CO

M = mass flow rate

ρ = density (kg/m³)

V = velocity (m/s)

A = flow area (m²)

$$\begin{aligned}V &= \sqrt{\frac{3RT}{m}} \\&= \sqrt{\frac{3 \times 8.314 \times 1100.70}{28.01}} \\&= \sqrt{\frac{27453.6594}{28.01}} \\&= 31.30 \text{ m/s} \\m &= \delta VA \\ \delta &= 1.14 \text{ kg/m}^3 \\ \delta &= 1.14 \times 10^{-9} \text{ kg/m}^3 \\V &= 31.30 \times 1000 \\&= 31300 \text{ mm/s} \\A &= 5808.80 \\m &= 1.14 \times 10^{-9} \times 31300 \times 5808.80 \\m &= 0.2072 \text{ kg/s.}\end{aligned}$$

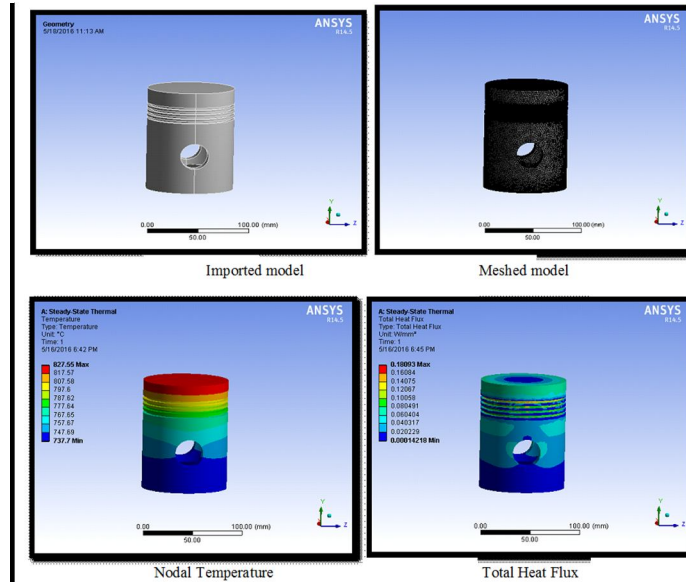
O. Calculation of NO

$$\begin{aligned}V &= \sqrt{\frac{3RT}{m}} \\&= \sqrt{\frac{3 \times 8.314 \times 1100.70}{30.01}} \\&= 30.24 \text{ m/s} \\&= 0.03024 \\V &= 30.24 \text{ m/s} \\&= 30240 \text{ mm/s.} \\m &= \delta VA \\&= 1.34 \text{ kg/m}^3 \times 30240 \times 5808.80 \\&= \frac{1.34}{1000^3} \times 30240 \times 5808.80 \\&= 1.34 \times 10^{-9} \times 30240 \times 5808.80 \\&= 0.2353\end{aligned}$$

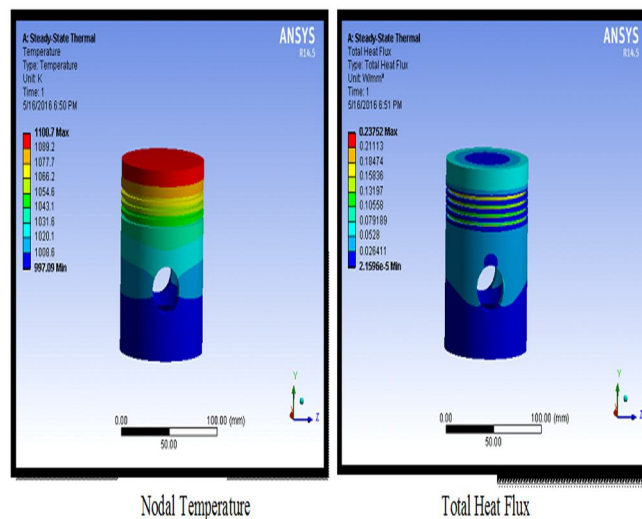
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III. THERMAL ANALYSIS OF PISTON

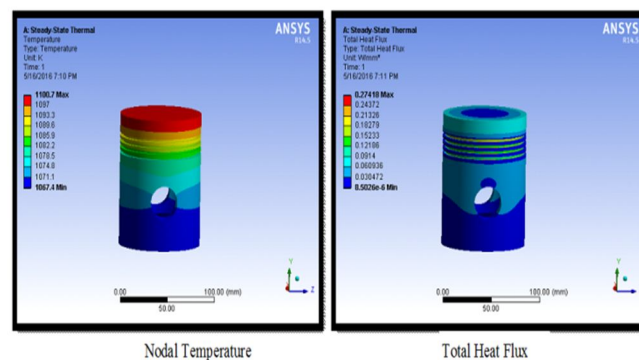
A. Thermal Analysis of Piston For Mild Steel



B. Thermal Analysis of Piston For Cast iron

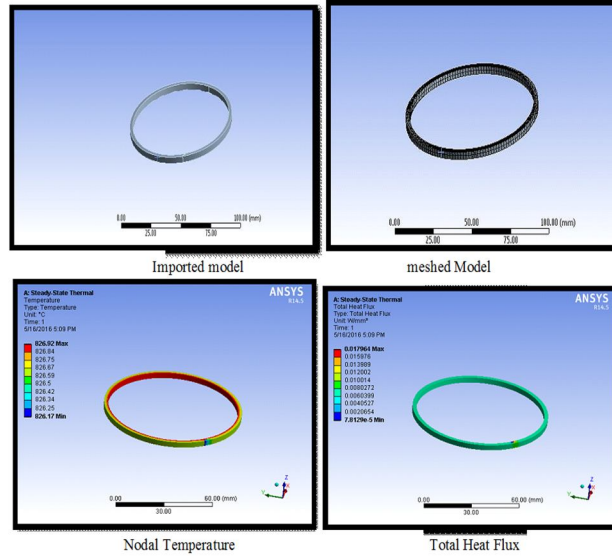


C. Thermal Analysis of Piston For Aluminum alloy

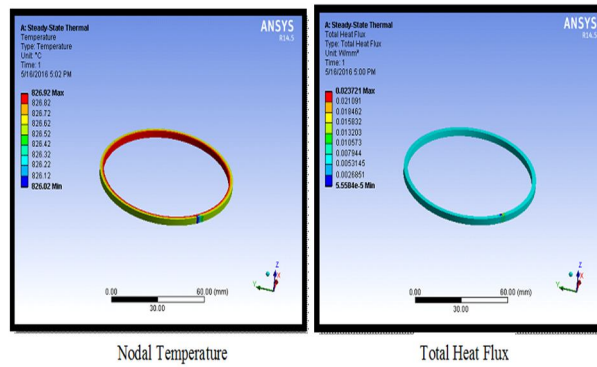


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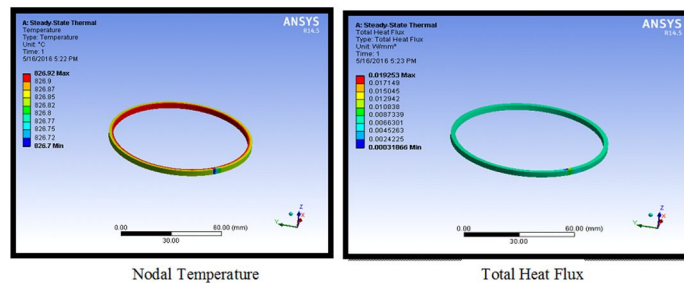
D. Thermal Analysis of Piston Rings For mild steel



E. Thermal Analysis of Piston Rings Cast Iron



F. Thermal Analysis of Piston Rings for Bronze

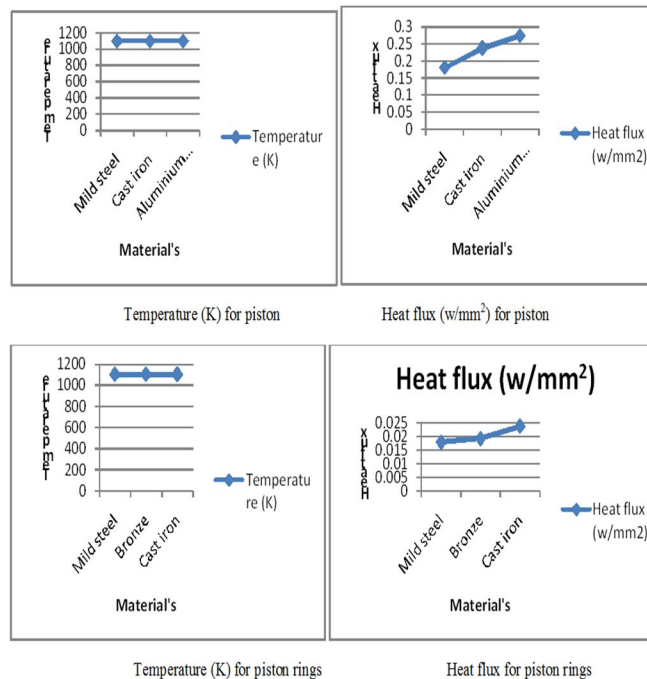


IV. RESULTS AND DISCUSSIONS

TABLE: THERMAL ANALYSIS RESULTS FOR PISTON AND PISTON RINGS

PISTON			PISTON RINGS		
	Temperature(k)	Heat flux(W/mm ²)		Temperature(k)	Heat flux(W/mm ²)
Mild steel	1100.70	0.18093	Mild steel	1100.70	0.017964
Cast iron	1100.70	0.23752	Bronze	1100.70	0.019253
Aluminum alloy	1100.70	0.27418	Cast iron	1100.70	0.023721

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V. CONCLUSION

Thermal analysis is performed to determine the temperature distribution and heat transfer rates by changing the materials of the piston and piston rings for fluid NO. By comparing the heat flux values for piston, it is more for Aluminum alloy (i.e) the heat transfer rate is more, the heat flux values for piston rings, it is more for Cast Iron (i.e) the heat transfer rate is more.

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