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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/mm²

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

$t_1=\sqrt{3pD^2/16S_{tp}}$ mm

Stp= 35 to 40 N/mm² for cast Iron

= 50 to 90 N/mm² for aluminum alloy

$t_1= 3*5*(86)^2/16*38 = 14$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

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*k*(Tc-Te) mm
H=0.05*m*Cv*PB kW
Cv= Higher calorific value of the fuel, kJ/kg
Cv=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 kg/BP/hr
m=0.25/60*60 = 69.44*10^{-6} kg/BP/sec
PB = pmLAn/60*1000*1000, 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= ∏*D²/4 = ∏*(86)²/4 = 5808.80 mm²
P= 0.85*86*5808.80*1000/60*1000*1000 = 7.07 kW
k= Heat conductivity factor, kW/m/ ℃
H= Heat flowing through the head, kW
Tc= Temperature at the centre of piston head, ℃
Te= Temperature at the edge of piston head, ℃
Tc-Te = 220℃ for cast iron
H= 0.05*69.44*10^{-6}*47000*7.07 = 1.153 kW
t1= 1000*1.153/12.56*(46.6*10^{-3})*220 = 8.954 mm
Taking, the larger of the two values
We shall adopt, t_1= 14mm

D. Thickness of rib (t_2)

t_2 = (0.3 to 0.5)*t_1 mm
= (0.3 to 0.5)*14 mm
= 6 mm

E. Radial thickness of piston (t_3)

t_3= D*√3pc/Sbr
Where,
pc= Contact pressure by the piston rings = 0.035N/mm²
Sbr= Allowable bending stress of ring material = 90N/mm²
t_3= 86*√3*0.035/90 mm
= 2.93mm

F. Axial thickness of piston rings (t_4)

t_4= (0.7 to 1)*t3 mm
= (0.7 to 1)*2.93 mm
= 2.5mm

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G. Radial depth of ring-groove (b)

b= t3+0.4mm
=2.93+0.4 mm
=3.33mm

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

t_5 = 0.03*D+b+4.5 mm
= (0.03*86) +3.33+4.5 mm
= 10.41mm

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

t_6 = (0.25 to 0.35)*t5 mm
= (0.25 to 0.35)*10.41 mm
= 3.2mm

J. Length of the skirt (Ls)

Ls = ∏*μ*D*p/4*(ps)
Where,
μ= Coefficient of friction between liner and skirt = 0.1
p= Maximum gas pressure, N/mm²
= 5 N/mm²
We also know that the side thrust to the bearing pressure on the piston barrel,
Ps = 0.45N/mm²
Ls = ∏*0.1*86*5/4*(0.45) = 78mm

K. Length of the ring section (Lr)

Lr= t_4*(X_1+0.8*X_2) mm
Where,
X_1= Number of rings = 4
X_2 = Number of lands in between the rings = 3
Lr = 2.5*(4+0.8*3) mm = 17.5 mm

L. Length of the piston (L_1)

Lp = Ls+Lr+Lt mm
Lt = Length of the top land, mm
= t_1 to 1.2*t_1 mm
= 14 to 1.2*14 mm
= 16mm

M. Diameter of the piston pin (d_1)

d_1 = Fg/Pb *l_1
Where,
Fg = Maximum gas force, Newton
l_1 = Length of the piston pin, mm
Pb = 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
Fg = ∏*D²*p/4 N
= ∏*(86)²*5/4 N
= 29044 N

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$l_1 = 1.5*d_1$ mm
$d_1 = 29044/25*(1.5*d_1)$ mm
= 28 mm
$d_2 = 0.6*d_1$ mm
= 0.6*28 mm
= 17 mm
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
$\rho = desity$(kg/m^3)
V = velocity (m/s)
A = flow area(m^2)

$V = \sqrt{\frac{3RT}{m}}$
$= \sqrt{\frac{3\times 8.314\times 1100.70}{28.01}}$
$= \sqrt{\frac{27453.6594}{28.01}}$
=31.30 m/s
m = δVA
δ = 1.14kg/m^3
$\delta = 1.14 \times 10^{-9}$kg/m^3
V = 31.30×1000
= 31300mm/s
A = 5808.80
m $= 1.14 \times 10^{-9} \times 31300 \times 5808.80$
m = 0.2072 kg/s.

O. Calculation of NO

$V = \sqrt{\frac{3RT}{m}}$
$= \sqrt{\frac{3\times 8.314\times 1100.70}{30.01}}$
= 30.24 m/s
= 0.03024
V = 30.24 m/s
= 30240mm/s.
m = δVA
= 1.34$kg/m3 \times 30240 \times 5808.80$
$= \frac{1.34}{1000^3} \times 30240 \times 5808.80$
$= 1.34\times 10^{-9} \times 30240 \times 5808.80$
= 0.2353

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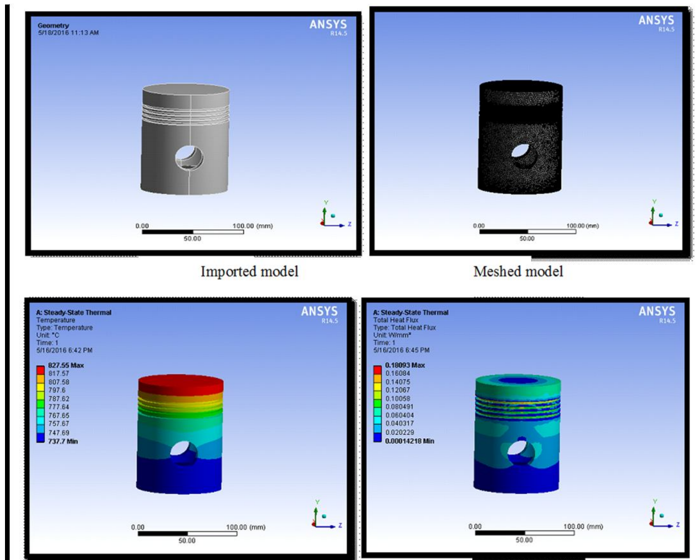
III. THERMAL ANALYSIS OF PISTON

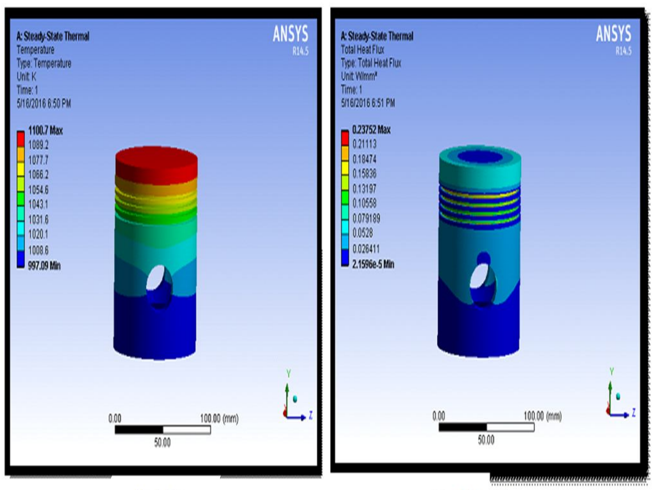
A. Thermal Analysis of Piston For Mild Steel



Imported model | Meshed model

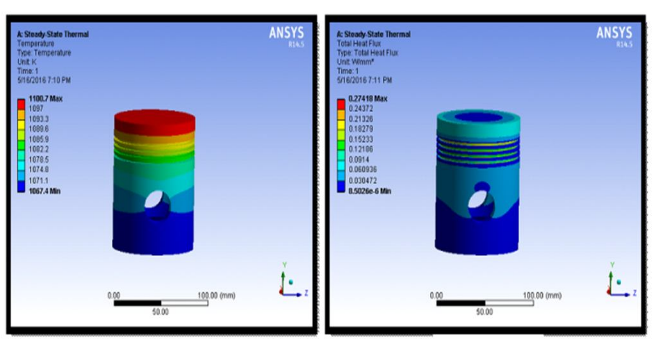
Nodal Temperature | Total Heat Flux

B. Thermal Analysis of Piston For Cast iron



Nodal Temperature | Total Heat Flux

C. Thermal Analysis of Piston For Aluminum alloy



Nodal Temperature | Total Heat Flux

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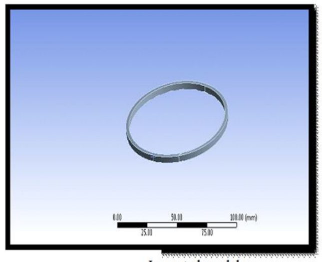
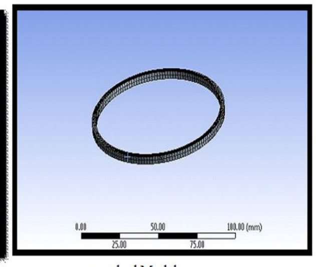
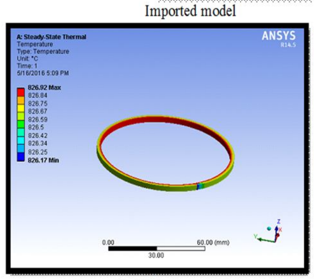
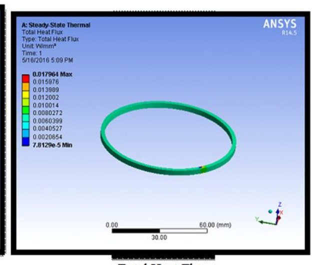
D. Thermal Analysis of Piston Rings For mild steel

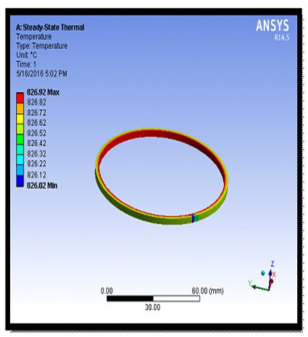

Imported model

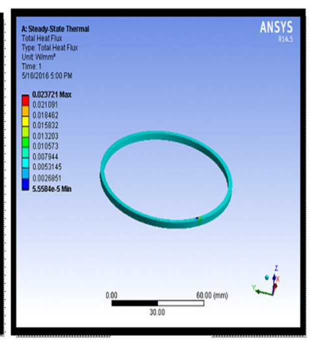

meshed Model


Nodal Temperature

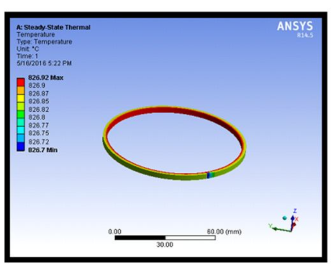

Total Heat Flux

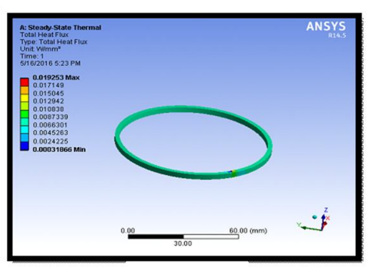
E. Thermal Analysis of Piston Rings Cast Iron


Nodal Temperature


Total Heat Flux

F. Thermal Analysis of Piston Rings for Bronze

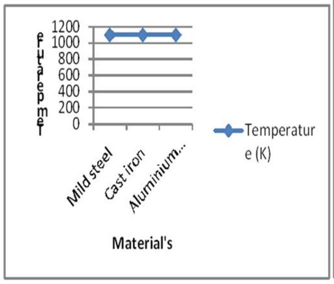

Nodal Temperature

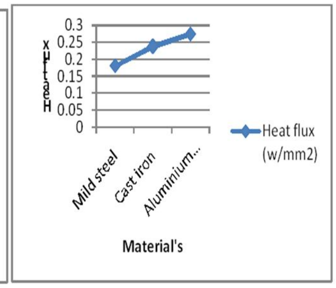

Total Heat Flux

IV. RESULTS AND DISCUSSIONS

TABLE: THERMAL ANALYSIS RESULTS FOR PISTON AND PISTON RINGS

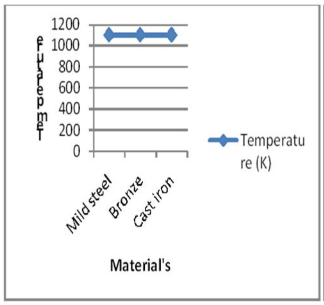
PISTON			PISTON RINGS		
	Temperature(k)	Heat flux(W/mm^2)		Temperature(k)	Heat flux(W/mm^2)
Mild steel	1100.70	0.18093	Mild steel	1100.70	0.017964
Cast iron	1100.70	0.23752	Bronze	1100.70	0.019253
Aluminum alloy	1100.70	0.27418	Cast iron	1100.70	0.023721

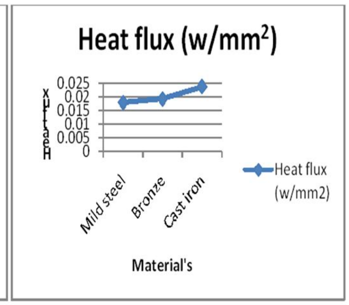




Temperature (K) for piston

Heat flux (w/mm^2) for piston





Temperature (K) for piston rings

Heat flux for piston rings

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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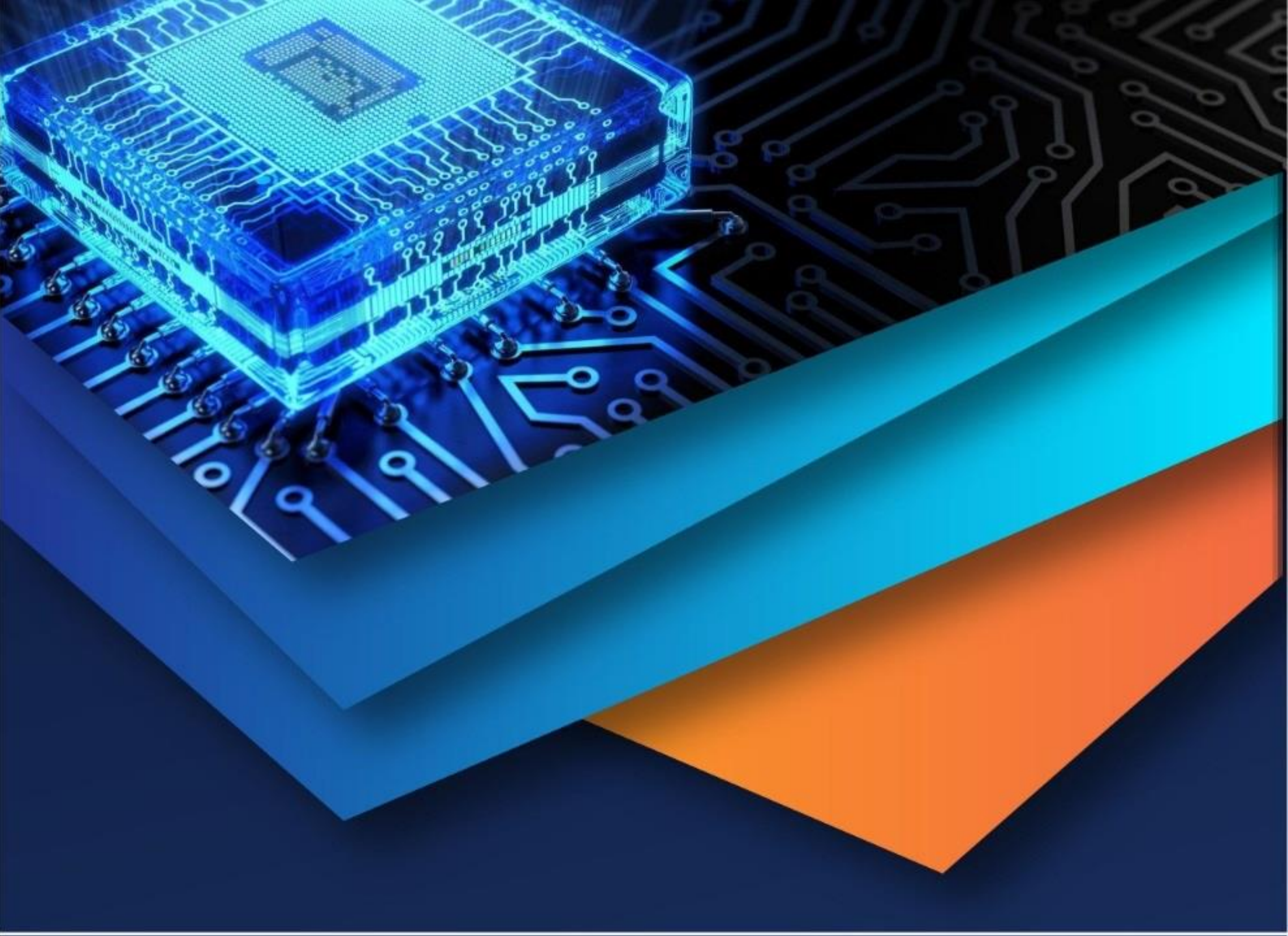

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