Amended Analysis of Fins - (Heat Transfer Analysis)

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Abstract— In order to increase the less amount heat transfer due to the air contact area, here in this project the arrangement of circular fin can be modified into the circular fins along with the slots in the vertical direction and the heat transfer rate, material for the fin extrusion, and the reduction in the material, the air contact area could be gradually increased will increase the heat transfer rate can be identified and analyzed with the three types of slots & they are semicircle, triangle, rectangle profiles.

Key words: Heat Transfer of the Fin, Heat Transfer Analysis

I. Objective

The main objective of this analysis is to find out the heat transfer of the fin with various geometrical profiles and shapes along with this analysis, the transfer rate can increased by varying the air contact area and by introducing the slots in the fins we can reduce the fins materials for manufacturing.

II. Introduction

Most of the engineering problems require high performance heat transfer components with progressively less weights, volumes, and costs. Extended surfaces (fins) are one of the heat exchanging devices that are employed extensively to increase heat transfer rate. The rate of heat transfer depends on the surface area of the fin. Radial or annular fins are one of the most popular choices for exchanging the heat transfer rate from the primary surface of cylindrical shape. In this project we are going to analyze the heat transfer rate and efficiency for circular fins along with the vertical slots for increasing the air contact area to improve the heat transfer rate by using a vital tool – ANSYS11 software.

A. Structural Analysis

- Static Structural Analysis
- Dynamic Analysis
- Modal Analysis
- Harmonic Analysis
- Transient Analysis
- Nonlinear Analysis

B. Thermal Analysis

- Steady State Thermal Analysis
- Transient Thermal Analysis

III. Problems in the Present Fin Arrangement

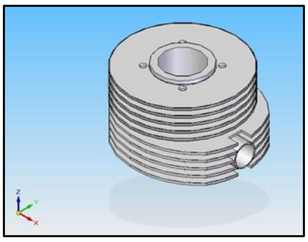

Fig. 1: Arrangement of the fin

In this type of the two stroke petrol engines due to the arrangement of the circular fins behind the roof of the cylinder head the air contact area is reduced so the heat transfer is also reduced, due to this reason the life time of the material is reduced and the efficiency of the engine is also reduced. Here there is no aware of the space restriction but due to simplification of the fins the air contact area is reduced.

IV. Methodology

Import the beam file from Solid Works as described in last lecture

A. Define the analysis as a thermal analysis

Main Menu - Preference - check “Thermal” - ok

B. Select the element type as Solid 87

Main Menu - Preprocessor - Element Type - Add/Edit/Delete - Click “Add” in the element dialog box - Choose “Solid” under “Thermal” in the left scroll box of the library of element types- Choose in the right scroll box - Click “ok” to close the library - Click “close” to close the element dialog box

C. Input the material properties

Main Menu - Preprocessor - Material Props - Material Models - In the “Define Material Model Behavior” dialog box, double click “Thermal” on the right box -double click “Conductivity” - double click “Isotropic” - Input in the box for KXX- Click “ok” to add the properties - double click “Specific Heat” - Input in the box for C - Click “ok” to add the property - double click “Density” - Input in the box for DENS – Click “ok” to add the property - Close the “Define Material Model Behavior” dialog box

Main Menu - Preprocessor - Material Props - Temperature Units - Change the unit to Celsius in the pop up window - ok

D. Mesh the structure

Main Menu - Preprocessor - Meshing - Mesh Tool -

In the “Mesh Tool” dialog box, check “Smart Size” and move the size down to fine “1” - Click on "Mesh" - In the dialog box of pick, click "Pick All" - After meshing, click on "Refine" in the "Mesh Tool" dialog box - Click "Pick All" - Change the level of refinement to "2" - Click ok - Click "Close" to close the Mesh Tool dialog box.

E. Apply the load

Main Menu - Solution - Define Loads - Apply - Thermal - Temperature - On Areas -Pick the left end area by mouse click (You can go to File Menu – Plot Controls - Pan Zoom Rotate, to find the area, check "Dynamic Mode" to rotate the model by mouse) - Click "ok" - Choose "Temp" and put "25" as the value

Main Menu - Solution - Define Loads - Apply - Thermal - Heat Flux - On Areas - Pick the right end area by mouse click - Click "ok" - Input 1000 into the value

F. Solve the problem

Main Menu - Solution - Current

G. Review the results

Main Menu - General Postprocessor - Plot Results -Contour Plot - Nodal Solution - Choose the results review, for example, DOF Solution - Nodal Temperature - Click "ok

V. DESIGN AND CALCULATION

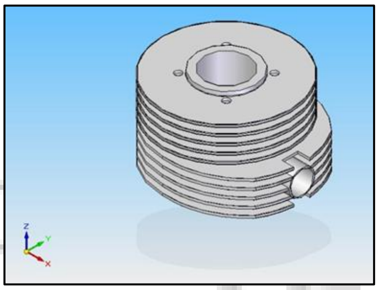

Fig. 2: Arrangement of the fin

1) Inner diameter of the cylinder bore – 55mm
2) Outer diameter of the cylinder bore – 72mm
3) Length of the fin from the base of the cylinder – 43.50mm
4) Total outer radius of the circular fin arrangement – 139mm
5) Thickness of the fin – 03mm
6) Distance between the fins – 07mm
7) Inner diameter of the exhaust port – 29mm
8) Inner diameter of the exhaust port – 32mm
9) Diameter of the holes for mounting the fin – 09mm
10) Distance between the holes and the center of the cylinder – 65mm
11) Total number of fins – 10 no's (circular 5 & non circular 5)
12) Length (vertical) of the fin arrangement – 103mm (approximately)

VI. PROPOSED MODELLING AND DESIGN

Fin arrangement with the semicircular slot along the vertical direction.

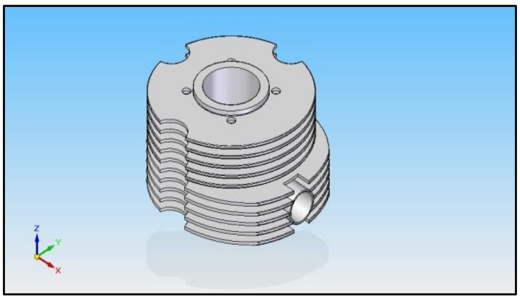

Fig. 3: Semicircular slots

– Triangular slots along the vertical direction.

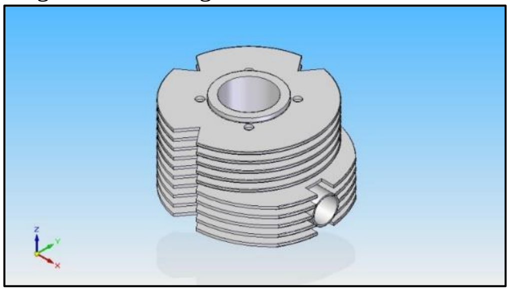

Fig. 4: Triangular slots

– Rectangular slots along the vertical direction.

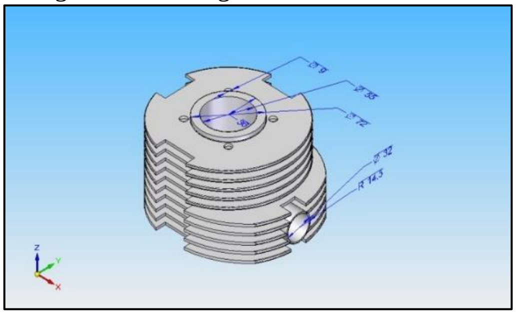

Fig. 5: Rectangular slots

VII. DIMENSIONS OF THE PROPOSED MODIFICATION

1) With slots having the 3 slot with the semicircle of diameter is 35 mm (radius – 17.5 mm) (3 no's)
2) With the rectangular slot of dimension is 40 mm *15 mm (length * breadth) (3 no's)
3) With the triangle of dimension
– Base 30 mm
– Height 20 mm
– Slant height 35 mm

VIII. MANUAL CALCULATION

A. Formulas Used

1) Actual heat transfer rate

$$Q_{fin} = h\, A_c\, \Delta T$$
$$*\Delta T = (T_{avg} - T_\infty)$$

2) Maximum amount of heat transfer

$$Q_{max} = h\, A_c\, \Delta T$$
$$*\Delta T = (T_o - T_\infty)$$

3) Efficiency

$$\eta_{fin} = Qfin / Qmax$$

4) Area of the circle = πr^2
5) Area of the semicircle = $\frac{1}{2} \pi r^2$
6) Area of the hollow cylinder = $\pi/4\ (D^2 - d^2)$
*7) Area of the triangle = ½ b*h (b- base, h-height)*
*8) Area of the rectangle= l*b (length * breadth)*

B. Constant Values &Data's

– Convective heat transfer co-efficient for aluminum = 25.0 W/m^2K
– Ignition temperature inside the cylinder = 880 K
– Fin base temperature at the base of the fin = 628.57 K (T_b)
– Room or ambient temperature = 308 K (T_∞)
– Average temperature value from analysis = 848.22 (T_{avg})

C. For Hollow Cylinder

- Outer diameter = 0.16 m
- Inner diameter = 0.072 m

D. For Circle

- Diameter of small circular holes = 0.009 m*(radius = 0.0045 m)

E. For Semicircle

Diameter of the semicircle = 0.035 m*(radius = 0.0175 m)

F. For Triangle

- Base of the triangle = 0.03 m
- Height of the triangle = 0.02 m
- Slant height of the triangle = 0.035 m

G. For Rectangle

- Length of the rectangle = 0.04 m
- Height of the rectangle = 0.015 m

H. Calculation of Areas

S. No	Areas	Data's (m)	Formula 's	Value's (m^2)
1.	Hollow cylinder	D =0.16 d = 0.072	$\pi/4$ (D^2 - d^2)	0.01603
2.	Circle	r = 0.0045	πr^2	6.3617 × 10^{-05}
3.	Semicircle	r = 0.0175	½ πr^2	4.8105 × 10^{-04}
4.	Triangle	b = 0.03 h = 0.02 l = 0.035	½ b*h	3 × 10^{-04}
5.	Rectangle	l = 0.04 b = 0.015	l*b	6 × 10^{-04}

Table 1: Calculation of Areas

Fin base temperature = 5/7 × ignition temperature inside the cylinder = 5/7 × 880 = 628.57K

I. Efficiency for the Fin without Slots

1) Area of the total fin

$= \pi/4\ (D^2 - d^2) = \pi/4\ (0.16^2 – 0.072^2) = \pi/4\ (0.020416) = 0.01603\ m^2$

2) Area of the holes (for mounting the bolts)

$= 4 \times \pi r^2 = 4 \times \pi\ (0.0045^2) = 4 \times 6.3617 \times 10^{-05} = 2.5 \times 10^{-4}\ m^2$

Main area of the fin = (Area of the total fin – Area four holes for mounting the Bolts)

$= 0.01603 – 2.5 \times 10^{-4} = 0.01577\ m^2$

To find the maximum heat transfer

$Q_{max} = h\ A_c\ \Delta T = h\ A_c\ (T_o – T_\infty) = 25.0 \times 0.01577 \times (628.57 – 308)$

$Q_{max} = 126.38$ W

To find the Actual heat transfer

$Q_{fin} = h\ A_c\ \Delta T = h\ A_c\ (T_{avg} – T_\infty) = 25.0 \times 0.01577 \times (848.22 – 308)$

$Q_{fin} = 212.98$ W

Efficiency η_{fin} = Qfin / Qmax = 212.98 / 126.38 = 1.6852 = 0.5933 = 59.33 %

J. Efficiency for the Fin with Semicircular Slots

Area of the semicircular slot $= ½\ \pi r^2 = ½\ \pi \times 0.0175^2 = 4.8105 \times 10^{-04}\ m^2$

Area of the holes (for mounting the bolts) $= 4 \times \pi r^2 = 4 \times \pi\ (0.0045^2) = 4 \times 6.3617 \times 10^{-05} = 2.5 \times 10^{-4}\ m^2$

Main area of the fin = (Area of the total fin – Area of the semicircular slot -Area four holes for mounting the Bolts)

$= 0.01603 – 4.8105 \times 10^{-04} - 2.5 \times 10^{-4} = 0.01529\ m^2$

To find the maximum heat transfer

$Q_{max} = h\ A_c\ \Delta T = h\ A_c\ (T_o – T_\infty)$

$= 25.0 \times 0.01577 \times (628.57 – 308)$

$Q_{max} = 126.38$ W

To find the Actual heat transfer

$Q_{fin} = h\ A_{semicircle}\ \Delta T = h\ A_{semicircle}\ (T_{avg} – T_\infty) = 25.0 \times 0.01529 \times (848.22 – 308)$

$Q_{fin} = 206.49$ W

Efficiency η_{fin} = Qfin / Qmax = 206.49 / 126.38 = 1.6339 = 0.6120

Efficiency of semicircular slotted fins = 61.20 %

K. Efficiency for the Fin with Triangular Slots

Area of the triangular slot = ½ b * h = ½ 0.03 * 0.02 = 0.0003 m^2

Area of the holes (for mounting the bolts)

$= 4 \times \pi r^2 = 4 \times \pi\ (0.0045^2) = 4 \times 6.3617 \times 10^{-05} = 2.5 \times 10^{-4}\ m^2$

Main area of the fin = (Area of the total fin – Area of the triangular slot -Area four holes for mounting the Bolts)

$= 0.01603 – 3 \times 10^{-04} - 2.5 \times 10^{-4} = 0.01548\ m^2$

To find the maximum heat transfer

$Q_{max} = h\ A_c\ \Delta T = h\ A_c\ (T_o – T_\infty) = 25.0 \times 0.01577 \times (628.57 – 308)$

$Q_{max} = 126.38$ W

To find the Actual heat transfer

$Q_{fin} = h\ A_{triangular}\ \Delta T = h\ A_{triangular}\ (T_{avg} – T_\infty) = 25.0 \times 0.01548 \times (848.22 – 308)$

$Q_{fin} = 209.065$ W

Efficiency η_{fin} = Qfin / Qmax = 209.065 / 126.38 = 1.6542 = 0.6045

Efficiency of triangular slotted fins = 60.45 %

L. Efficiency for the Fin with Rectangular Slots

Area of the rectangular slot

$= l * h = 0.04 * 0.015 = 6 \times 10^{-4}\ m^2$

Area of the holes (for mounting the bolts)

$= 4 \times \pi r^2 = 4 \times \pi\ (0.0045^2) = 4 \times 6.3617 \times 10^{-05} = 2.5 \times 10^{-4}\ m^2$

Main area of the fin = (Area of the total fin – Area of the triangular slot -Area four holes for mounting the Bolts)

$= 0.01603 – 6 \times 10^{-04} - 2.5 \times 10^{-4} = 0.01518\ m^2$

To find the maximum heat transfer $Q_{max} = h\ A_c\ \Delta T = h\ A_c\ (T_o – T_\infty) = 25.0 \times 0.01577 \times (628.57 – 308)$

$Q_{max} = 126.38$ W

To find the Actual heat transfer

$Q_{fin} = h\ A_{rectangular}\ \Delta T = h\ A_{rectangular}\ (T_{avg} – T_\infty)$

$= 25.0 \times 0.01518 \times (848.22 – 308)$

Q_{fin}= 205.013 W

Efficiency η_{fin} = Qfin / Qmax = 205.013 / 126.38 = 1.6221 = 0.6164

Efficiency of rectangular slotted fins= 61.64 %

M. Theoretical Result

Material / Area	Without slots (%)	With semicircle slot (%)	With triangle slot(%)	With rectangle slot (%)
Aluminium	59.3	61.2	60.4	61.6

Table 2: Theoretical result

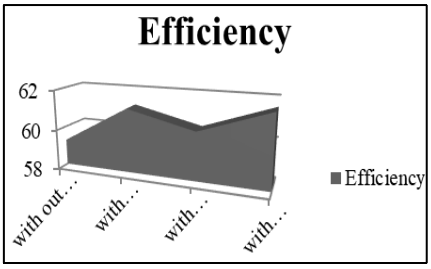

Fig. 6: Area chart for efficiency

N. *Heat Transfer and Distribution Analysis Procedure*

Step by step procedure for analyzing

1) *Preference → thermal*
2) *Preprocessor → element type → ADD → solid → brick node 70*
3) *Material property → material model → thermal → isotropic →*
   - Thermal conductivity
   - Specific heat
   - Density
   - Emissivity
4) *Meshing → mesh tool → free → pick all → ok*
5) *Load → define load →apply → thermal → temperature → on areas*
6) *Solution → solve → current LS*
7) *General postprocessor → plot result → contour plot →nodal solution*
   - Nodal temperature
   - Thermal gradient
   - Thermal flux

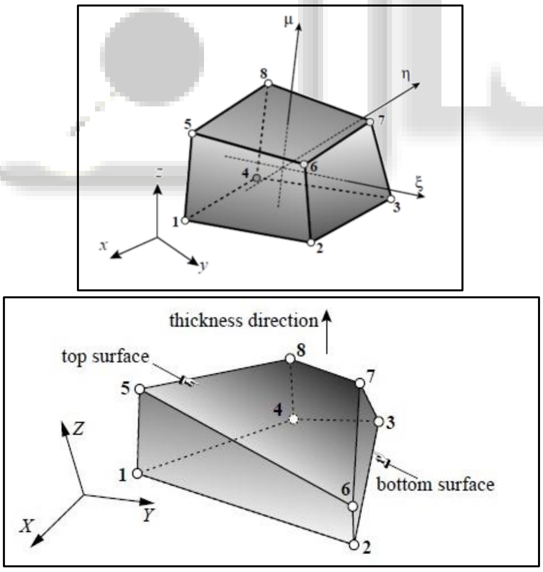

Fig. 7: Heat Transfer and Distribution Analysis Procedure

O. *Material properties*

An eight-node "brick" finite element for three dimensional analysis has three isoparametric natural coordinates called ξ, η and μ. These coordinates vary from -1 at one face to $+1$ at the opposite face, Construct the (trilinear) shape function for node 1 (follow the node numbering of the figure). The equations of the brick faces are:

$1485: \xi = -1$	$2376: \xi = +1$
$1265: \eta = -1$	$4378: \eta = +1$
$1234: \mu = -1$	$5678: \mu = +1$

IX. ANALYZED RESULTS

A. *Nodal Temperature Distribution*

1) *Without the slots*

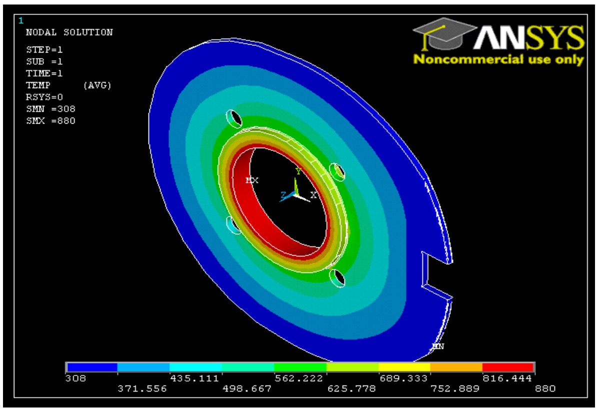

Fig. 8: Lower fin

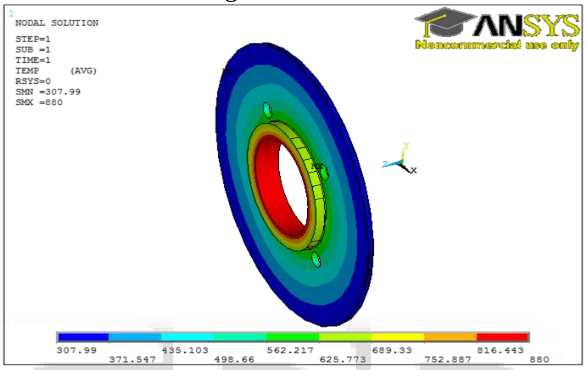

Fig. 9: Upper fin

2) *With the semicircular slot*

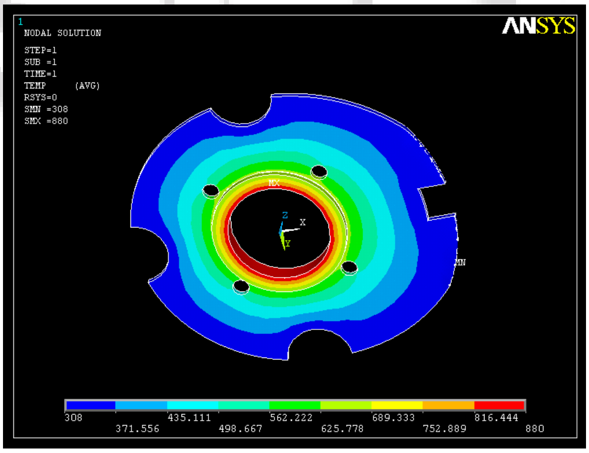

Fig. 10: Lower fin

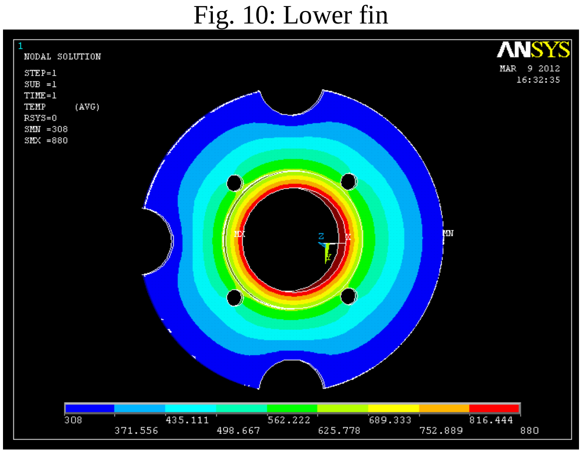

Fig. 11: Upper fin

3) With triangular slot

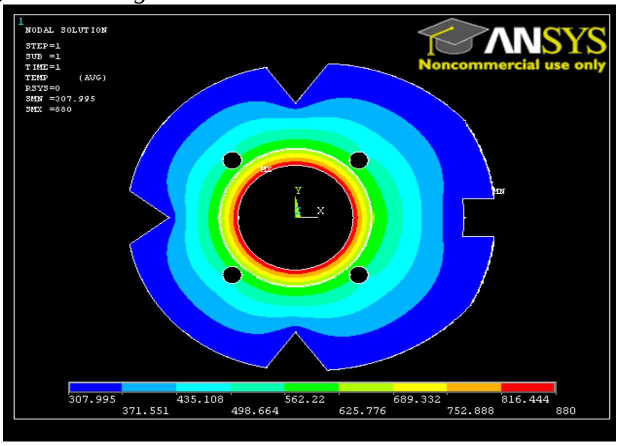

Fig. 12: Lower fin

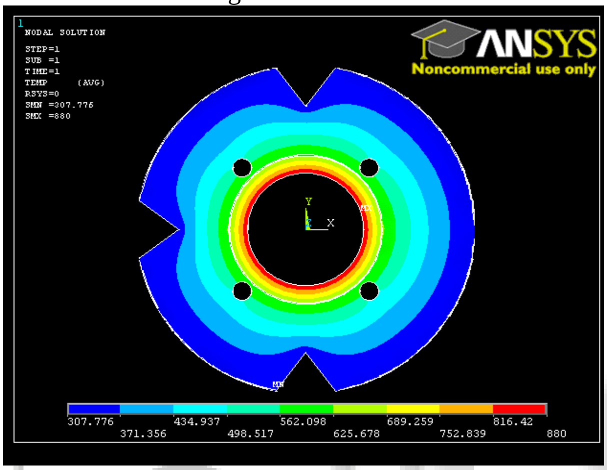

Fig. 13: Upper fin

4) With the rectangular slot

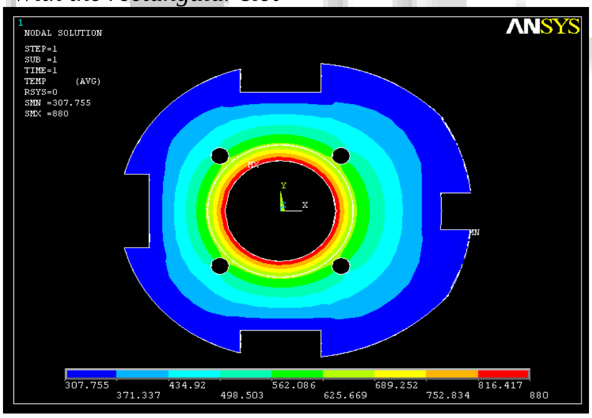

Fig. 14: Lower fin

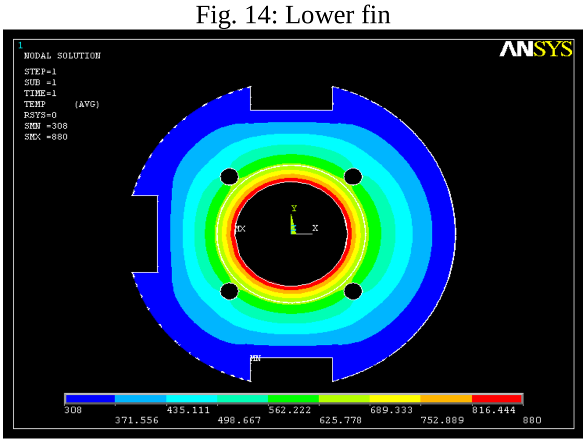

Fig. 15: Upper fin

B. Temperature Gradient Results

1) Without the slots

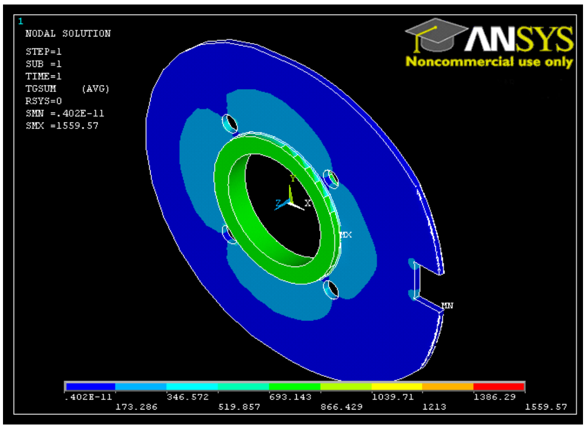

Fig. 16: Lower fin

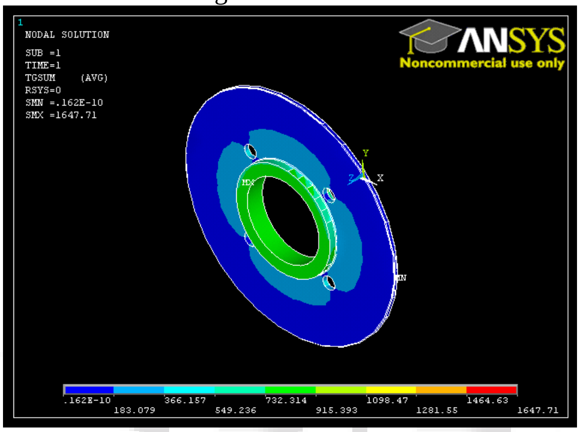

Fig. 17: Upper fin

2) With the semicircular slot

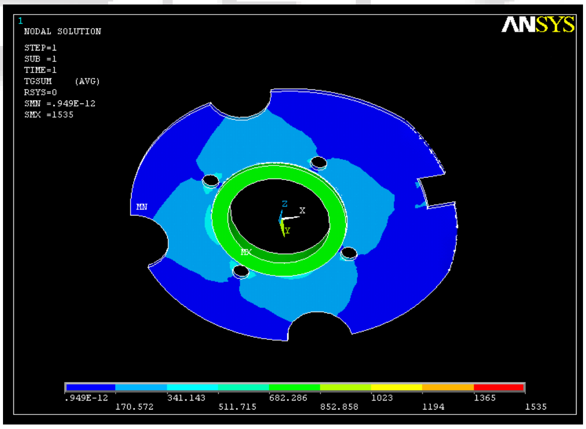

Fig. 18: Lower fin

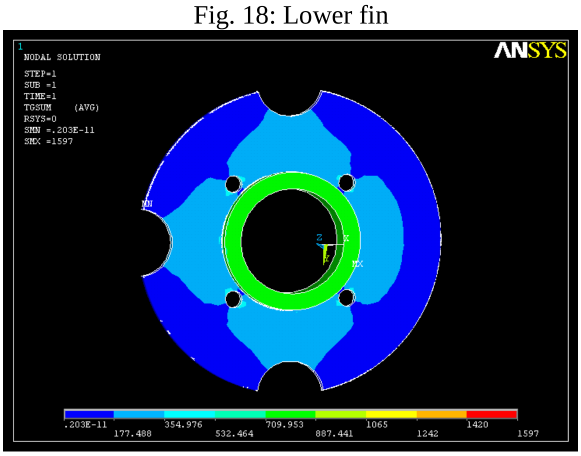

Fig. 19: Upper fin

3) With the triangular slot

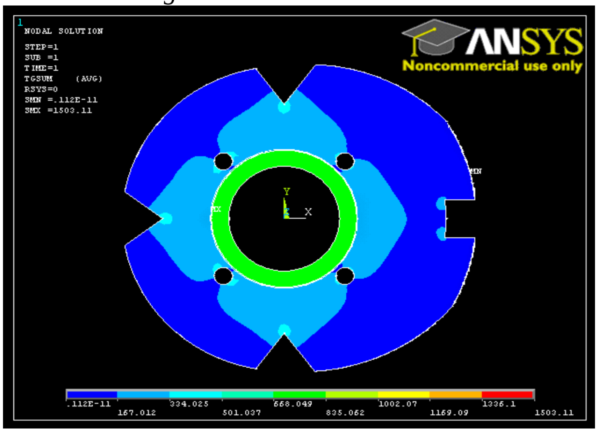

Fig. 20: Lower fin

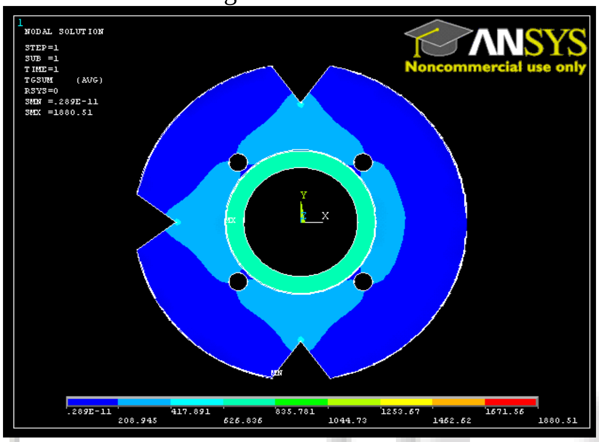

Fig. 21: Upper fin

4) With the rectangular slot

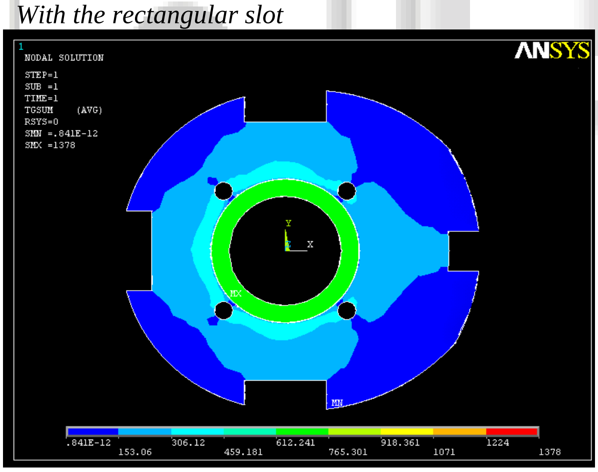

Fig. 22: Lower fin

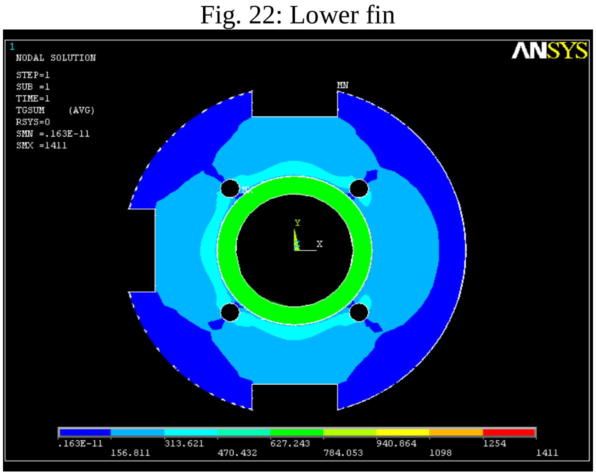

Fig. 23: Upper fin

C. Thermal Flux Distribution Results

1) Without the slots

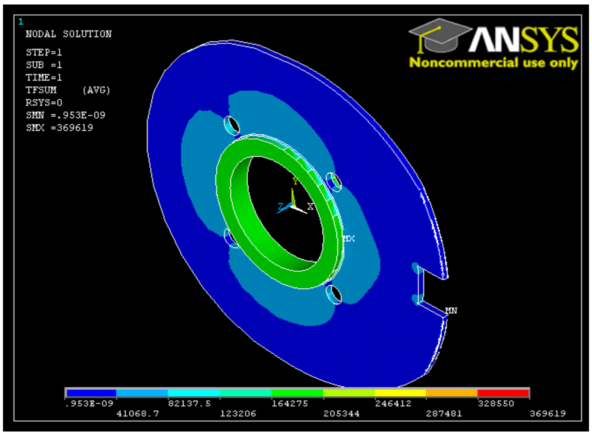

Fig. 24: Lower fin

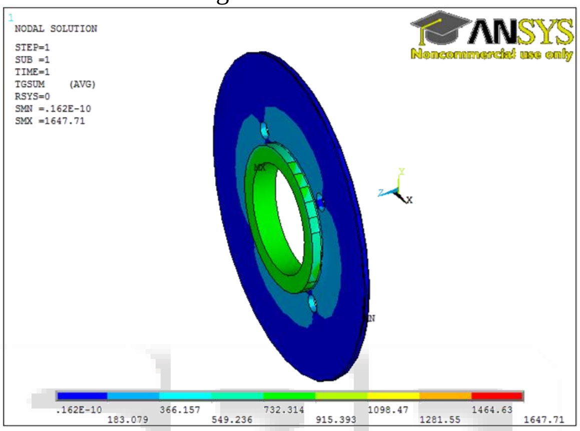

Fig. 25: Upper fin

2) With the semicircular slot

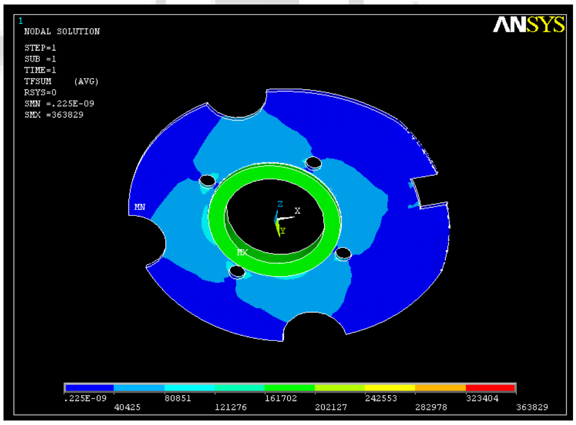

Fig. 26: Lower fin

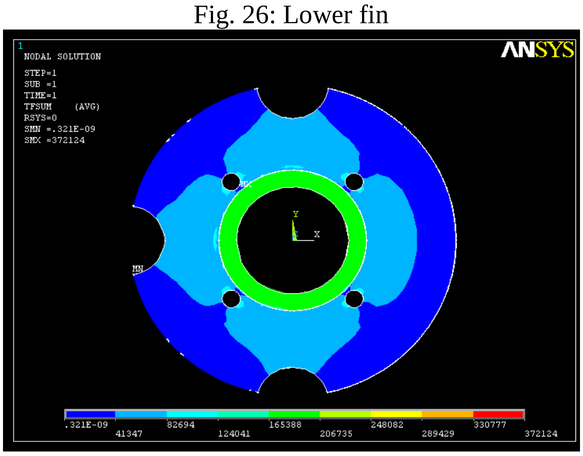

Fig. 27: Upper fin

3) *With the triangular slots*

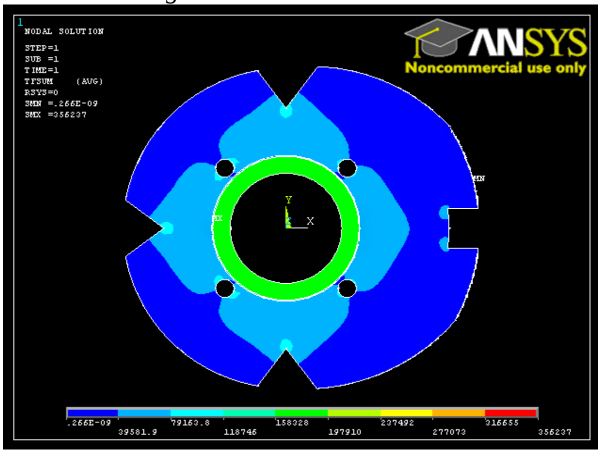

Fig. 28: Lower fin

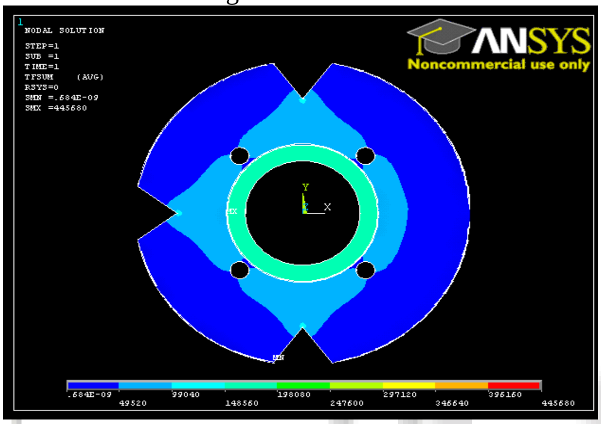

Fig. 29: Upper fin

4) *With rectangular slot*

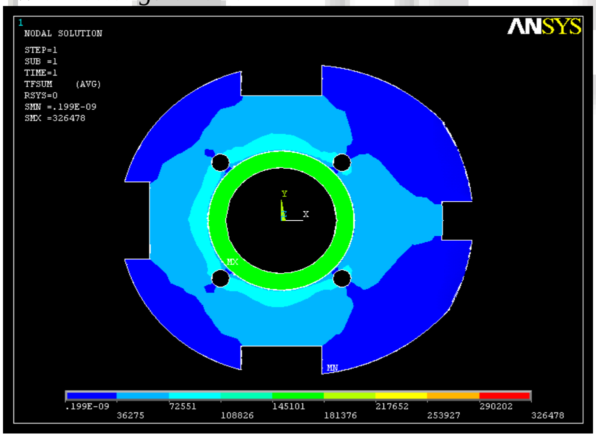

Fig. 30: Lower fin

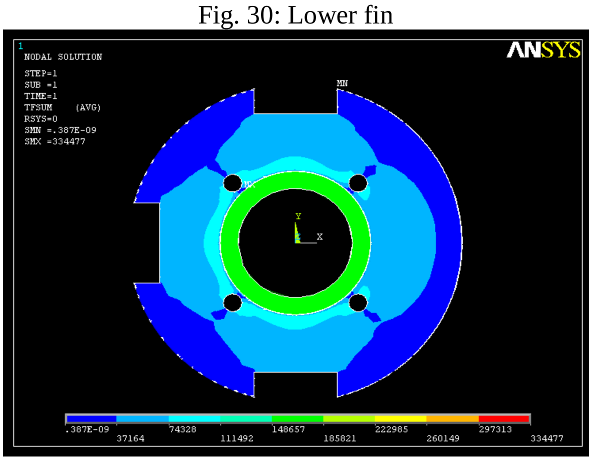

Fig. 31: Upper fin

Without Slots			
Lower Fin			
Temperature Gradient Values			
Load Step = 1 Sub Step = 1			
Time= 1.0000 Load Case= 0			
Nodal Results Are For Material 1			
Minimum Values			
Node 390 3823	291	3982	
Value -793.20 -793.39	-900.56	3.37e-12	
Maximum Values			
Node 3836 398	513	249	
Value 796.74 790.75	887.1	994.76	
Thermal Flux Values			
Load Step= 1 Substep= 1			
Time= 1.0000 Load	Cas	E= 0	
Nodal results are for mate	Rial	1	
Minimum Values			
Node 3836 398	513	3982	
Value -0.18883e 0.18741e0.21	024e	7.98e-10	
Maximum Values			
Node 390 3823	291	249	
Value 0.18799e 0.18803e 0	0.213	43e 0.23576e	
Upper Fin			
Temperature Gradient Values			
Minimum Values			
Node 1355 1302	1360	1446	
Value -791.73 -802.68	-1128.8	1.62e-11	
Maximum Values			
Node 623 1324	303	1360	
Value 808.30 756.77	829.38	1170.8	
Thermal Flux Values			
Minimum Values			
Node 623 1324	303	1446	
Value -0.19157e+06- 0.17935e	+06-	1.97e+05	3.84e-09
Maximum Values			
Node 1355 1302	1360	1360	
Value 0.18764e+06 0.19024	E+06	2.68e+05	2.77e +05
With Semicircular Slots			
Lower Fin			
Temperature Gradient Values			
Minimum Values			
Node 7290 886	3566	49	
Value -1010.9 -1053.0	-876.25	6.76e-13	
Maximum Values			
Node 7289 290	4215	1824	
Value 915.56 996.30	928.8	1331.1	
Thermal Flux Values			
Minimum Values			
Node 7289 290	4215	49	
Value -0.21699e+06- 0.23612e	+06-	2.20e+05	1.60e-10
Maximum Values			
Node 7290 886	3566	1824	
Value 0.23958e+06 0.24957	E+06	2.08e+05	3.15e +05

Upper Fin			
Temperature Gradient Values			
Minimum Values			
Node 22913 7928	7615	6462	
Value -899.93 -833.92	-960.14	3.05e-12	
Maximum Values			
Node 1332 22811	22507	252	
Value 881.57 842.52	855.77	1283.8	
Thermal Flux Values			
Minimum Values			
Node 431 457	224	763	
Value - 0.18682e0.18484e0.19	270e	9.19e-10	
Maximum Values			
Node 470 3649	349	349	
Value 0.18797e 0.19002e 0	0.263	29e 0.31670e	
With Triangular Slots			
Lower Fin			
Temperature Gradient Values			
Load Step = 1 Substep =		1	
Time= 1.0000 Load	Cas	E= 0	
Nodal results are for mate	Rial	1	
Minimum Values			
Node 408 5794	5858	6078	
Value -791.18 -791.64	-1026.7	1.79e-12	
Maximum Values			
Node 372 398	513	5858	
Value 788.76 782.32	964.46	1171.5	
Thermal Flux Values			
Load Step= 1 Substep =	1		
Time= 1.0000 Load	Cas	E= 0	
Nodal results are for mate	Rial	1	
Minimum Values			
Node 372 398	513	6078	
Value - 0.18694e0.18541e0.22	858e	4.24e-10	
Maximum Values			
Node 408 5794	5858	5858	
Value 0.18751e 0.18762e 0	0.243	33e 0.27764e	
Upper Fin			
Temperature Gradient Values			
Minimum Values			
Node 470 3649	349	763	
Value -793.14 -801.77	-1110.9	3.88e-12	
Maximum Values			
Node 431 457	224	349	
Value 788.25 779.92	813.08	1336.3	
Thermal Flux Values			
Minimum Values			
Node 431 457	224	763	
Value - 0.18682e0.18484e0.19	270e	9.19e-10	
Maximum Values			
Node 470 3649	349	349	
Value 0.18797e 0.19002e 0	0.263	29e 0.31670e	

With Rectangular Slots			
Lower Fin			
Temperature Gradient Values			
Minimum Values			
Node 7358 899	3566	2501	
Value -932.33 -1005.8	-819.73	9.06e-13	
Maximum Values			
Node 7357 290	4223	360	
Value 940.84 951.81	936.4	1203.2	
Thermal Flux Values			
Minimum Values			
Node 7357 290	4223	2501	
Value - 0.22298e0.22558e0.22	193e	2.15e-10	
Maximum Values			
Node 7358 899	3566	360	
Value 0.22096e 0.23838e 0	0.194	28e 0.28516e	
Upper Fin			
Temperature Gradient Values			
Load Step= 1 Substep=	1		
Time= 1.0000 Load	Cas	E= 0	
Nodal results are for mate	Rial	1	
Minimum Values			
Node 21197 6987	7460	6039	
Value -921.87 -878.81	-918.45	2.21e-12	
Maximum Values			
Node 1324 20203	7170	1868	
Value 862.40 876.75	804.52	1157.6	
Thermal Flux Values			
Load Step = 1 Substep =	1		
Time= 1.0000 Load	Cas	E= 0	
Nodal results are for mate	Rial	1	
Minimum Values			
Node 1324 20203	7170	6039	
Value - 0.20439e0.20779e0.19	067e	5.23e-10	
Maximum Values			
Node 21197 6987	7460	1868	
Value 0.21848e 0.20828e 0	0.217	67e 0.27434e	

Table 3: Plot Results

X. Conclusion

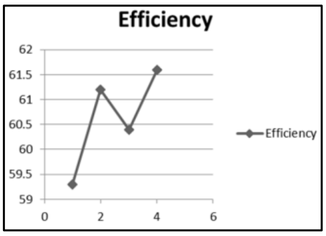

Fig. 32: Scatter Graph for Efficiency

From the above analysis and theoretical calculation the rectangular slotted fin could give the increased efficiency (61.6%) than the all other slotted and non-slotted fins, here we conclude that with the slotted fins the air contact area can be increased and then the usage of material for the manufacturing of the fins is also reduced, so for the better efficiency and the minimal usage of the material we can go for the fins with the rectangular slots.

XI. FUTURE SCOPE

- By varying the materials and the circular shape of the fin arrangement we can increase the efficiency and reduce the material usage.
- Placing of the cylinder with the high heat conducting material like copper, nickel will increase the heat transfer from the cylinder to the fins.
- Introducing of wavy curves along the edges of the circular profile the air contact area will increase.
- Further by modifying the above changes it will increase the heat transfer rate and efficiency of the engine, then it will increase the lifetime of the engine aslo.

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