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Design Modification in Engine Exhaust

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Abstract— The system aims at modifying the position and diameter of the exhaust valve in order to reduce the probability of knocking (both in SI and in CI) and lessen the dilution of charge because of the small size of exhaust valve when compared to the size of inlet valve.

The size of the exhaust valve is smaller when compared to the size of inlet valve. It is done so because the region closer to the exhaust valve is at a higher temperature compared to that of the temperature surrounding the inlet valve. Now if the exhaust valve size is increased there will be higher possibility of knocking because the charge coming inside the combustion chamber has a higher probability of combusting at exhaust valve's surface (due to large surface area). On the other hand if the size is too small then, there will be greater possibility of dilution in the intake charge because there is no enough space for the burnt gas to leave the chamber.

To reduce these problems, modifications in the engine is proposed. In general inlet and exhaust valves are positioned vertically along the axis of the combustion chamber. Now if the exhaust valve is placed along the horizontal axis (i.e. perpendicular to the cylinder axis) and if the size of the valve is increased then there will be less possibility for the dilution. But the probability of knocking increases. Since the exhaust valve is placed along the horizontal axis, the outer surface of the exhaust valve will be in contact with the water cooling system of the combustion chamber (outside the chamber). Thus this cooling system or the coolant will be able to release the heat at the outer surface of the exhaust valve and transfer heat from the seat surface of the exhaust valve (commonly in tappet valves). The rate of Heat Transfer will be high because the surface area perpendicular to heat flow direction is large thereby enhancing heat transfer. The possibility of the dilution is reduced because, during the piston movement from BDC (Bottom Dead Center) to the TDC (Top Dead Center) the piston pushes the burnt gases outside through the exhaust valve since the size of the exhaust valve is increased, it is easier for the burnt gases to escape due to low density with higher temperature inside the combustion chamber. And the charge from the inlet will also push the gas outside due to the concept of scavenging. But the inlet charge won't escape through the exhaust because of the valve opening timing is so small and also the density of the charge is high.

The rate of heat transfer can also be increased by changing the type of material used in valve seat. For material with high heat transfer rate, the density increases, but it won't affect the performance of the engine because the increase in weight is negligible. Since the size of the exhaust is increased, the rate of exhaust air moving per stroke also increases and hence this high exhaust velocity can be used in turbochargers which increase the overall efficiency when compared to the efficiency obtained before.

Index Terms— Internal Combustion Engine, Exhaust Valve, Dirichlet's Boundary Condition, Conduction Heat Transfer, Convection Heat Transfer, Turbo Chargers, Al-Mg-Si and Chrome Steel, Valve Actuation.

1 INTRODUCTION

THE internal combustion engine is generally a heat engine which works on the principle of combustion for producing power. The term Combustion is saved for the reactions which take place very rapidly with large conversion of chemical energy to sensible heat. The burnt gases after expansion should be pushed out from the chamber. The purpose is for reducing the dilution rate of the intake charge. At present all IC engines are operated by valves for opening and closing of intake and exhaust fluids. The inlet and exhaust valves, generally operated by cam shaft for opening and closing are of various types. Few of the popular types of valves are sleeve valve, rotary valve and tappet valve. The valves are designed with various considerations for reducing the knocking possibilities inside the cylinder. Te exhaust valve is made smaller in size than the inlet valve. The exhaust valve is made smaller because the exhaust valve is generally positioned in a high heat region i.e. the region with more possibility of hot spot and its possibility increases more with the its surface area (seat portion of the valve). As the seat area increases, the high temperature region inside the combustion chamber increases which results in increased possibility of knocking. Knocking is a phenomenon caused inside the engine which results in abnormal increase of pressure and temperature inside the combustion chamber causing serious damages to the engine. To avoid the following issues the exhaust valve is made smaller than the inlet valve.

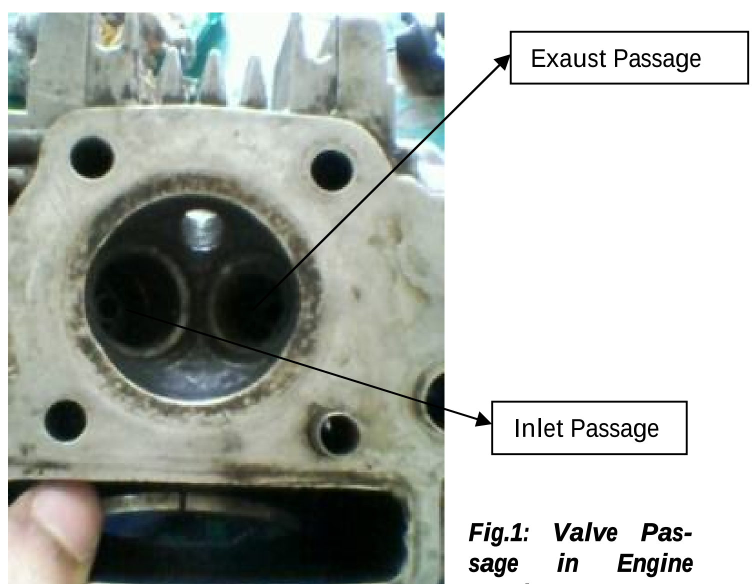


Fig.1: Valve Passage in Engine Head

2 Disadvantages of Small Sized Exhaust Valves

The opening of the exhaust valve is made smaller in size when compared to the inlet valve as discussed earlier. By using small sized exhaust valve the knocking is reduced but due to small opening on the cylinder head the exhaust gases completely won't escape through the manifold during exhaust stroke. This result in occurrence of exhaust gases inside the combustion chamber. During intake stroke, when the fresh fuel mixes with the exhaust gas, the charge gets diluted and this results in unburnt charges left inside the chamber after expansion. These unburnt charges give out hydrocarbon emissions. The unburnt mixtures also results in increased fuel consumption of the engine. The performance of the engine is affected.

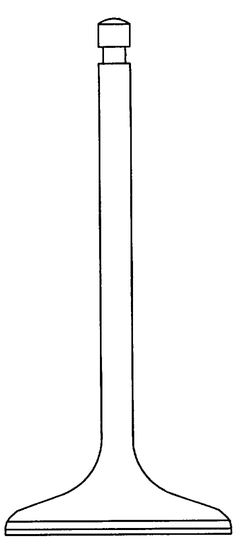
The smaller size of the valve permits only controlled amount of gas to escape through the exhaust manifold which gives only less turbine efficiency in turbo chargers.

3 Purpose for Modification of Exhaust

- To reduce the dilution of charge inside the combustion chamber thereby reducing the emission and utilizing the fuel completely.
- To reduce the rapid pressure rise inside the combustion chamber (knocking)
- To increase the turbine efficiency in turbo chargers.

4 Modification on the Exhaust Valve

The main purpose to modify the exhaust valve is to control the emission from the engine and also to improve the fuel cy. The modification is to be made to reduce the dilution of the charge. The dilution of the charge is reduced by increasing the exhaust valve opening which permits large amount of gas to escape through the exhaust manifold. The modification results in increased possibility of pressure rise (knocking) due to high surface high temperature region on the seat of the exhaust valve.



The possibility of knock is reduced by changing the material used in exhaust valve. The material with high thermal conductivity is selected to increase the heat transfer rate from the chamber. The exhaust valves are generally made of high resistance material like chrome steel whose thermal conductivity is 72.7W/mK. Aluminium alloy (Al-Mg-Si) is selected as an alternative for the material. Al-Mg-Si has high thermal conductivity when compared to chrome steel (177.0W/mK). The density of this material is also less (2707 kg/m³) when compared to the chrome steel (7689 kg/m³). The conductive and convective heat transfer studies for the material are as follows.

5 Heat Transfer Studies

The rate of heat transfer mainly depends on the cross sectional area on which the heat transfer is taking place and the thermal conductivity of the material. Aluminum has more thermal conductivity when compared to chrome steel and in addition the large surface area increases the heat transfer. The heat transfer rate on a material by conduction can be given by Fourier's law of heat conduction equation.

$$Q = [-kA(T_H - T_L)]/L$$

Where,
Q= Heat Transfer Rate
k= Thermal Conductivity of the Material
A= Cross Sectional Area (Area perpendicular to Heat Flow)
T_H= High Temperature Region
T_L= Low Temperature Region
L= Length

For two different materials with same dimensional data and similar boundary conditions, the thermal conductivity alone varies. Thermal analysis for different cases with same boundary condition is undergone.

Assumptions:

- Boundary Condition: Dirichlet's Boundary Condition (1st Kind)
- Highest Temperature (Valve Seat Portion): 1273K
- Lowest Temperature: 303K
- Element Type: Solid 87
- Meshing Parameters: Free Mesh- Division 6- Tetra

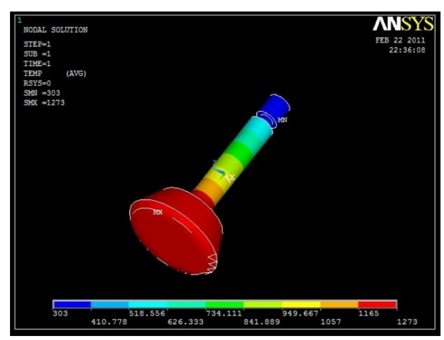


Fig.2: Temperature Distribution in Aluminium Alloy

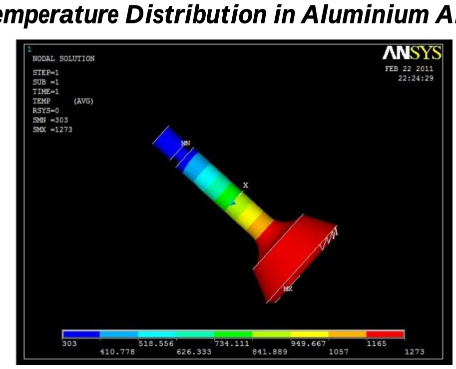


Fig.3: Temperature Distribution in Chrome Steel

The measurements of the exhaust valve of Herohonda CD100 are taken and the modifications are made. Exhaust Seat Diameter is 2 centimeters and the length of the stem is 66 centimeters. The diameter is modified to 2.35 centimeters (inlet valve's diameter of the same vehicle) and length is same. Due to the increase in cross sectional area and increase in thermal conductivity, the rate of heat transfer is increased which in turn reduced the hot spot- high temperature region on the valve seat there by reducing knocking possibilities. Thermal analyses are made for the modified valves with same assumptions made above.

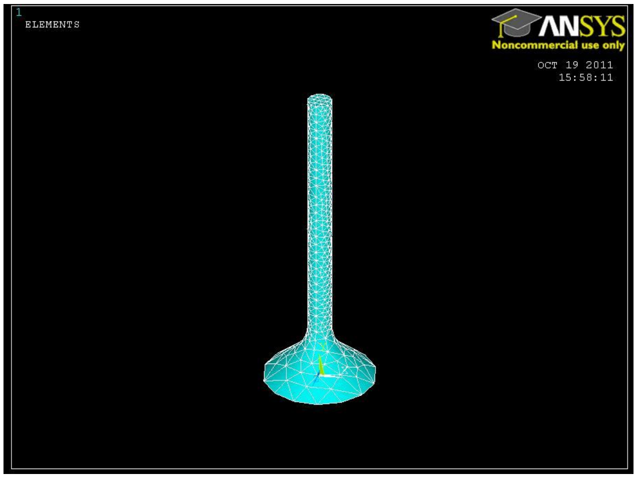


Fig.4: Free Tetra meshing for the large sized exhaust Valve (2.3 cm)

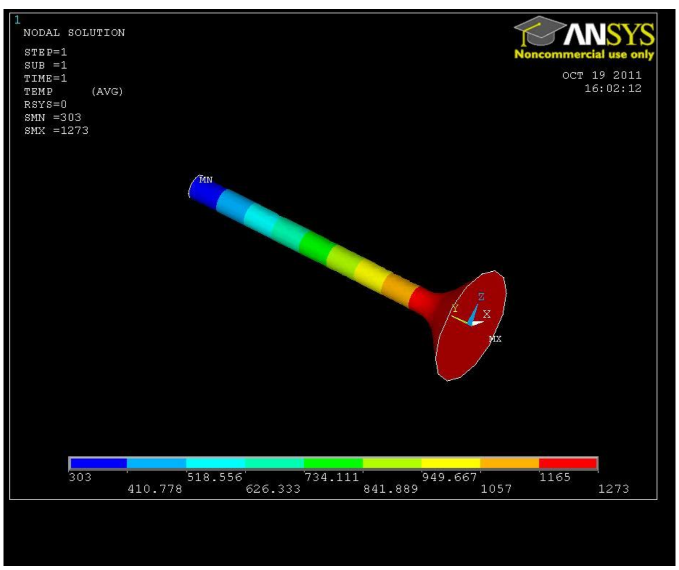


Fig.5: Nodal Analysis for the large sized exhaust valve

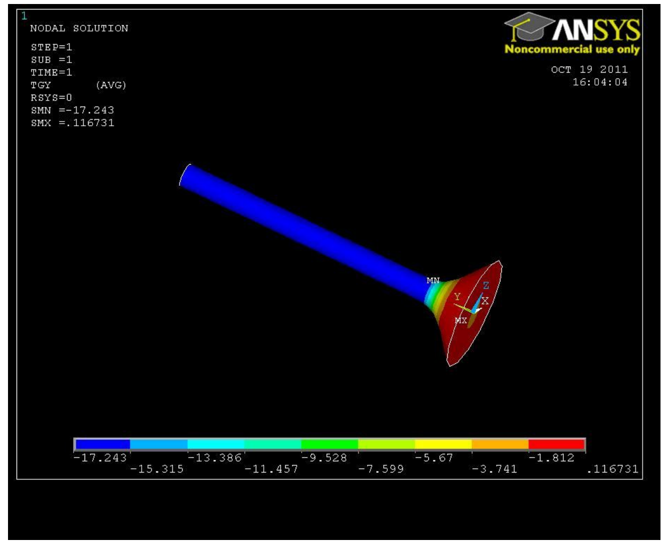


Fig.6: Heat Flux Variation in large sized exhaust valves

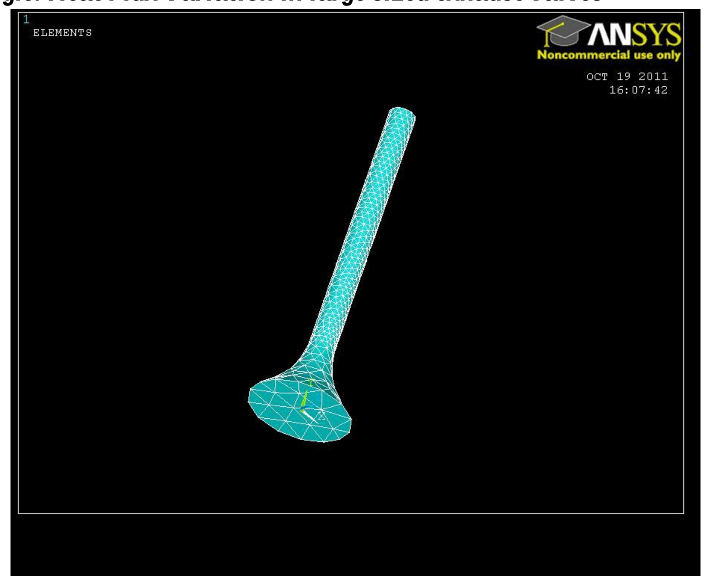


Fig.7: Free Tetra meshing for small sized exhaust valve (2 cm)

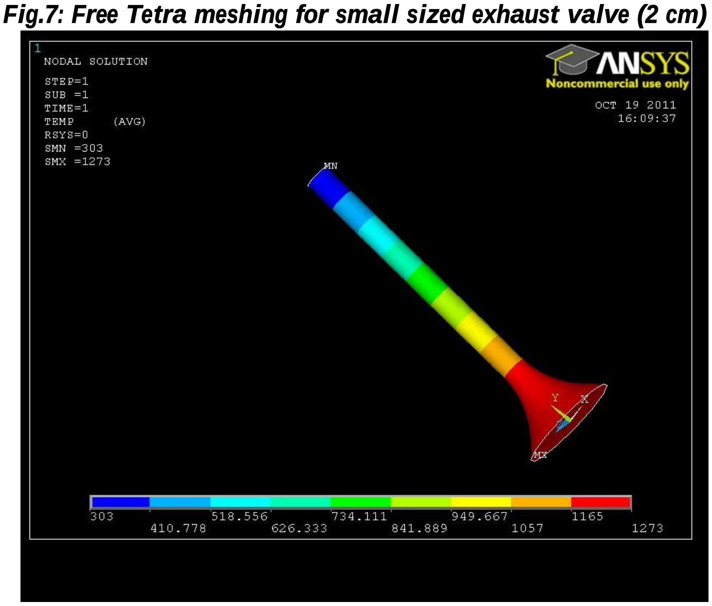


Fig.8: Nodal Analysis for the smaller exhaust valve

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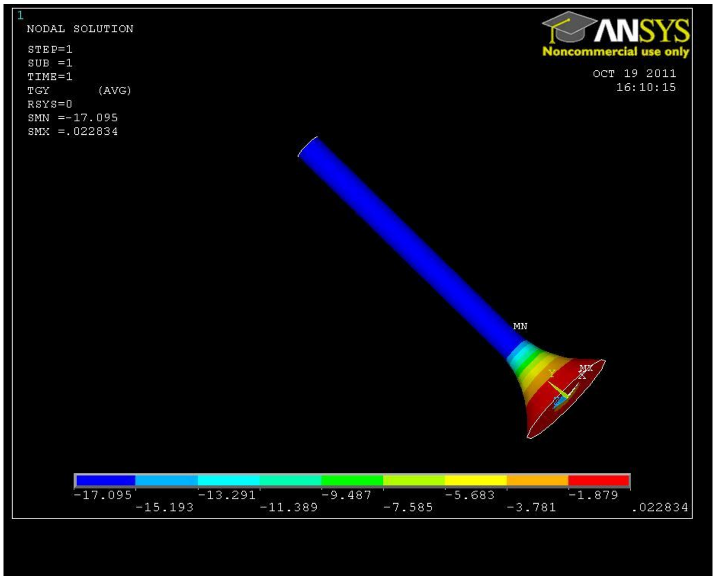

Fig.9: Heat flux variation in small sized exhaust valve

The position of the valves is also varied in addition to the dimensional variation and change of material. The valve is positioned along the horizontal axis on the cylinder block instead of the cylinder head. The purpose is to further increase the rate of heat transfer. The heat from the valve is transferred to the face of the manifold pipe by the process of convection. In this stage, this generally acts like a fin increasing the rate of heat transfer.

Assumptions:

- Cylinder temperature during expansion: 588K
- Exhaust Gas Temperature: 578 K
- Room Temperature: 298 K
- Coolant Temperature: 303 K
- Exhaust manifold material: Stainless steel (cr 15%, Ni 10%)
- Thermal conductivity of the material: 19.1 W/mK
- Specific Heat: 461 J/Kg K
- Density of the Material: 7865kg/m^3

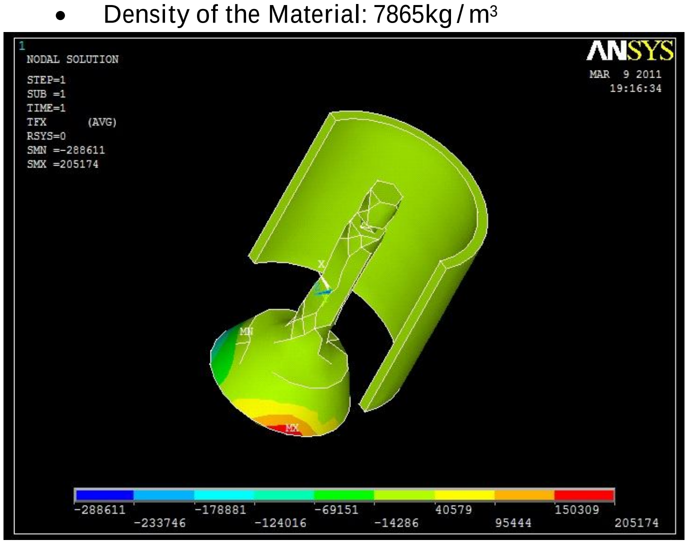

Fig.10: Convection Heat Transfer

The change in position of the valve in horizontal position affects the clearance volume of the engine affecting its volumetric efficiency. The positioning of the valve in horizontal position is shown below.

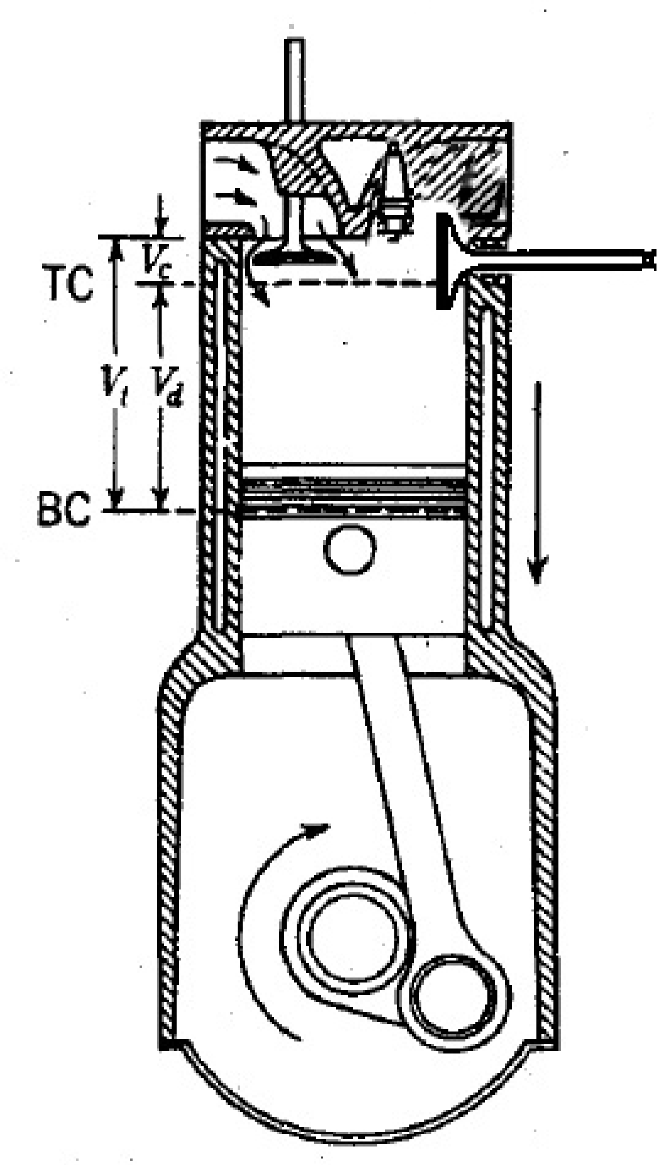

Fig.11: Position of the exhaust valve in horizontal position.

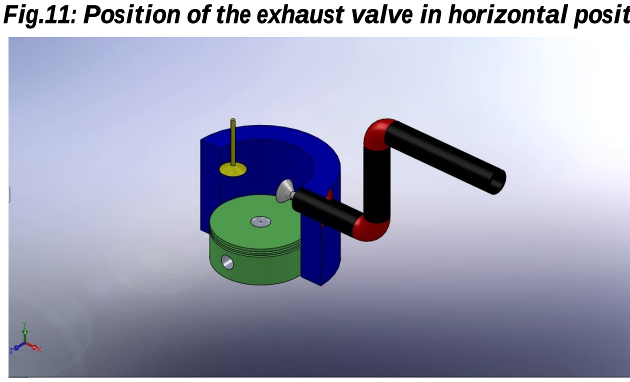

Fig.12: Pictorial Representation of the horizontal positioned exhaust valve in an inline engine.

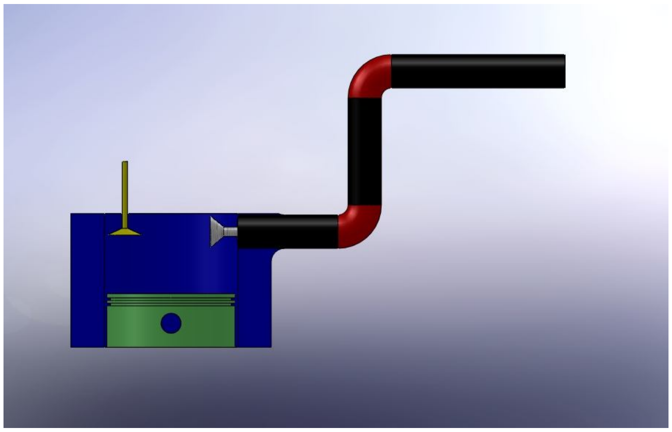

Fig.13: Exhaust valve's position in an inline engine

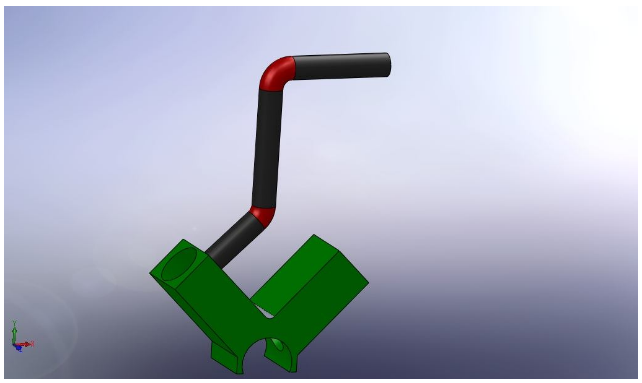

Fig.14: Exhaust valve's position in V- Engine

Operating the opening and closing of the valve in horizontal position can be achieved by double rack double pinion mechanism. The effect of reduction in volumetric efficiency because of the change in clearance volume can be reduced by designing the valve in a curved manner with respect to the circumferencial diameter of the cylinder bore such that the valve closes completely when the piston approaches the valve when it moves from bottom dead centre to the top dead centre during exhaust stroke. The valve timing and profile of the cam has to be designed such that the piston won't hit the valve during exhaust stroke. The conduction heat transfer studies for the exhaust valve with curved seat portion are done.

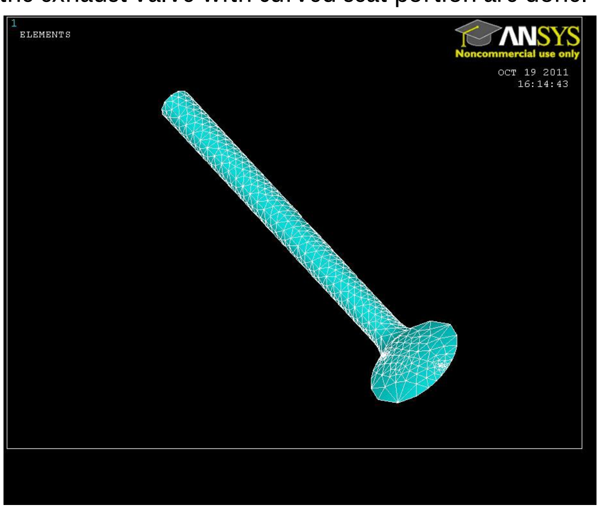

Fig.15: Free Tetra meshing for curved exhaust valve

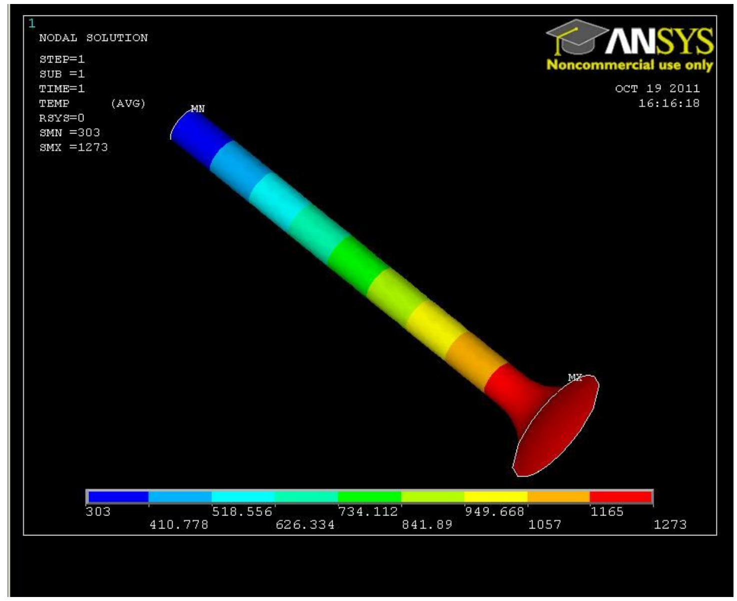

Fig.16: Nodal Analysis of Curved Exhaust Valve

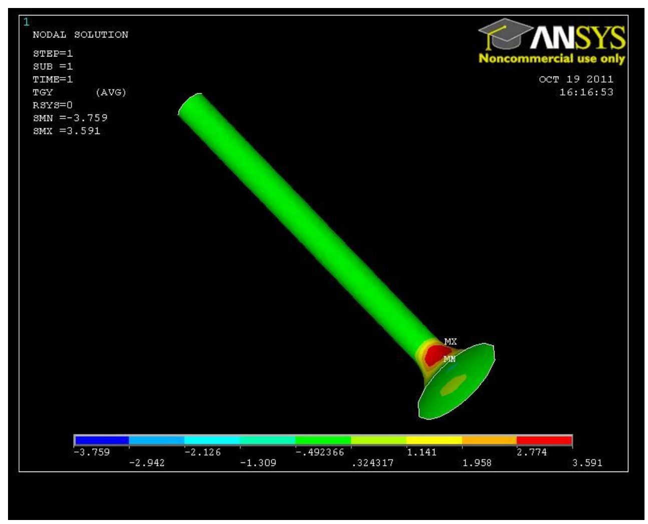

Fig.17: Heat flux variation in curved exhaust valves

Fig.18: Exhaust valve of Herohonda CD100

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4 Conclusion

The modification in the exhaust valve by varying its position size and shape and with particular thermal and structural considerations helps in increasing the rate of heat transfer from the seat portion of the exhaust valve thereby reducing the possibility of knocking. In addition, the increased size of the exhaust valve pushes large amount of exhaust gas outside through the manifold which reduces the dilution inside the engine's combustion chamber. The reduced dilution reduces the amount of unburnt mixture/charge inside the chamber which reduces the hydrocarbon emissions coming out of the engine. The reduced emissions help in development of the emission standards. Reduction in unburnt fuel inside the chamber results in increased power with less consumption of fuel thereby increasing its fuel efficiency. Large amount of gas escapes due to larger size of the exhaust valve and hence the heat energy coming out will be more which can be completely utilized for turbochargers thereby increasing its turbine effeciency. These advantages can be achieved by using large exhaust valve by doing few modifications discussed before for good and smooth running of the engine.

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