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COLD FLOW SIMULATION IN AN IC ENGINE

Rohith S
Assistant Professor
Department of Mechanical Engineering,
ATMECE, Mysuru, India

Swarna kiran S
Assistant Professor
Department of Mechanical Engineering,
ATMECE, Mysuru, India

Thej kumar J
Assistant Professor
Department of Mechanical Engineering,
ATMECE, Mysuru, India

ABSTRACT

Fluid flow dynamics inside an engine combustion cylinder plays an important role for air-fuel mixture preparation. IC Engine model is developed using CATIAV5R20 tool. The model is then imported to Finite Element pre-processing tool HYPER MESH for the meshing analysis. The model is then imported to Finite Element solver tool. ANSYS FLUENT is used for post processing the results. The flow dynamics inside the cylinder for different minimum valve lift is studied using FEA. Dynamic motion is visualized and velocity magnitude is plotted for different crank angle from 0° to 730°. Finally velocities and crank angles for various valve lifts are compared.

KEYWORDS: Cold Flow Simulation, Flow dynamics, Valve lift

INTRODUCTION

The areas of technical challenges in Internal Combustion (IC) Engine are design and manufacturing. For next generation of engines, focus is on development of compact, flexible, light and powerful engine. The complex fluid dynamics of turbulent is the central challenge in design which interacts with the parts such as valves, cylinder, piston and intake/exhaust manifold. Computational Fluid Dynamics (CFD) is emerging as a useful tool in understanding fluid dynamics properties like velocity, mass flow rate and turbulence energy [1].

IC Engine System available in the CFD software includes

- Powerful geometry modeling tools in design modeler.
- Bidirectional CAD connectivity to mainstream CAD systems.
- Flexible meshing using ANSYS Meshing.
- Solution using ANSYS Fluent.
- Powerful post processing in CFD-Post.

COLD FLOW IN-CYLINDER ANALYSIS

Cold flow analysis involves modelling the airflow and possibly the fuel injection in the transient engine cycle without reactions. The goal is to capture the mixture formation process by accurately accounting for the interaction of moving geometry with the fluid dynamics of the induction process. The changing characteristics of the airflow jet that tumbles into the cylinder with swirl via intake valves and the exhaust jet through the exhaust valves as they open and close can be determined, along with the turbulence production from swirl and tumble due to compression and squish.

The pre-processing from geometry to solver setup is typically time consuming and challenging to separate or decomposes the geometry into moving and stationary parts. Typically, the intake ports are split off from the cylinder and valves. The combustion chamber and piston region may be also decomposed or separated into smaller parts. Then each part can be meshed accordingly for the solver setup. Any errors at this stage can lead to failures downstream during the solution process.

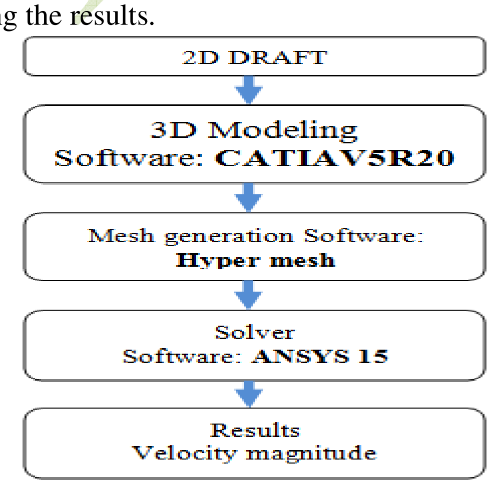
The run times for solver runs can be fairly long since the motion is typically resolved with small time steps (approximately 0.25 crank angles) to get accurate results and the simulation is run for two or three cycles to remove the initial transients. Finally, the large volume of transient data that results from the CFD solution needs to be post processed to obtain useful insight and information. Thus cold flow analysis would also benefit from design automation and process compression.

OBJECTIVE

- To create IC Engine model using CATIA V5R20 tool and solve by ANSYS FLUENT.
- To study the flow dynamics inside the cylinder for different valve lift using FEA.
- To compare the valve lifts of 0.1mm and 0.2mm for different velocities.

METHODOLOGY

Finite Element analysis was used to determine the characteristics of the IC Engine. For the purpose of this study, the IC Engine model were developed using CATIAV5R20 tool. The model was then imported into Finite Element pre-processing tool HYPER MESH for the meshing analysis. The model was then imported into Finite Element solver tool ANSYS FLUENT for post processing the results.



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Parts created by CATIA tool is assembled as shown in Fig.6. The model is prepared with CAD software. The engine is four stroke single cylinder diesel engine with canted valves namely inlet valve and exhaust valve. It is an in-cylinder engine having piston and cylinder in line. Valve seats are provided in both the valves. By using Scheme file it automatically sets up necessary motions for valves and pistons along with solution parameters for the in-cylinder simulation

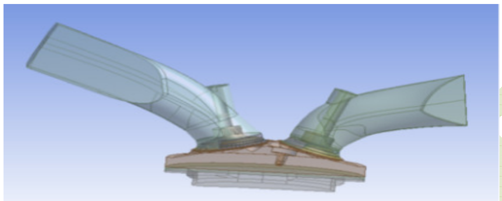


Figure.1 Assembled part of Engine

The next stage is to create a proper "meshing" for the 3D model. "The discritzation of a continuous system with infinite degree of freedom (DOF) to finite degree of freedom (DOF) by nodes and elements is known as meshing". The accuracy of the analysis is purely based on the level of meshing attained by the designer. Hyper mesh tool is used to carry out the meshing as shown in Fig.7.

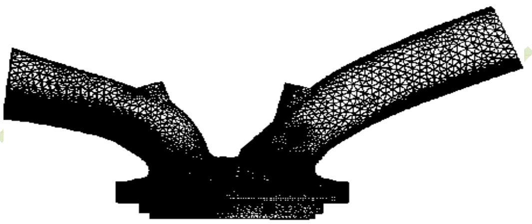


Figure.2 Mesh structure for the geometry

Technical specifications considered for an IC Engine (Diesel Engine) for fluid dynamic analysis purpose [2] is as shown in Table 1.

Table 1: Specifications of Engine model

SN	PARTS	DIMENSIONS
1	Connecting rod length	144.3 mm
2	Crank radius	45 mm
3	Wrench	0
4	Engine speed	2000 rpm
5	Minimum lift	0.1 mm

VELOCITY CONTOURS FOR VALVE LIFT OF 0.1MM

Dynamic meshing of the IC Engine fluid computational domain was done and analysis was performed. Then velocity magnitudes for different crank angle were plotted.

Fig.9.a shows contours of velocity magnitude. At this stage expansion stroke takes place. Maximum velocity obtained at 3.75° is 1.80m/s.

Fig.9.b shows contours of velocity magnitude at 90°. Maximum velocity obtained at 90° is 11.6m/s.

Fig.9.c shows the contours of velocity magnitude at 182.5°. At this stage exhaust stroke takes place where the piston is at bottom dead centre (BDC). There is a slight opening in the exhaust valve so that compressed air fuel mixture will be exhausted. Maximum velocity obtained at 182.50° is 81.3m/s.

Fig.9.d shows the contours of velocity magnitude at 272.5°. At this stage completely exhaust valve is opened and the air-fuel mixture will be exhausted through it. Maximum velocity obtained at 272.5° is 120m/s.

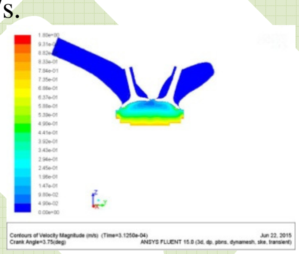
Fig.9.e shows the contours of velocity magnitude at 361.25°. At this stage it completes half cycle of four stroke diesel engine. Piston will be in TDC position where the exhaust valve will remain closed and the inlet valve will be open i.e., beginning of intake stroke. Maximum velocity obtained at 361.25° is 23.6m/s.

Fig.9.f shows contours of velocity magnitude at crank angle 450°. The interaction of jet with the walls and piston head clearly indicate that there is a significant acceleration considering the abrupt restriction for the passing jet. The turbulence levels seem to grow with the fuel mixture during this stroke. Maximum velocity obtained at 450° is 89.2m/s.

Fig.9.g shows the contours of velocity magnitude at 540 deg. This stage is beginning of compression stroke where both the inlet and exhaust valve will be closed, the piston returns to TDC by compressing the air fuel mixture into the cylinder head. The maximum velocity obtained at 540° is 52.6 m/s.

Fig.9.h shows contours of velocity magnitude at 632.5°. At this stage mixture seems to have attained a uniform mixing process with high turbulence. Maximum velocity obtained at 632.5° 16.9 m/s.

Fig.9.i shows contours of velocity magnitude at 730°. Maximum velocity obtained at 730° is 8.14m/s.



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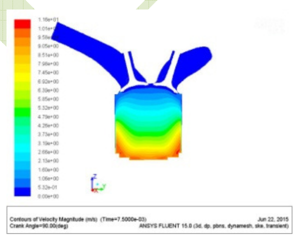

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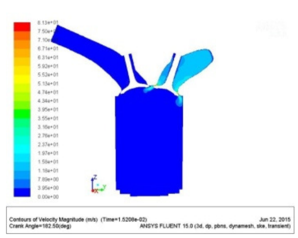

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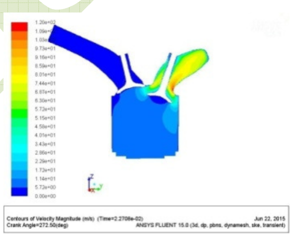

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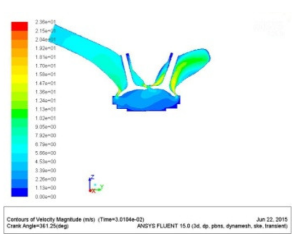

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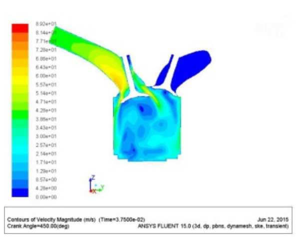

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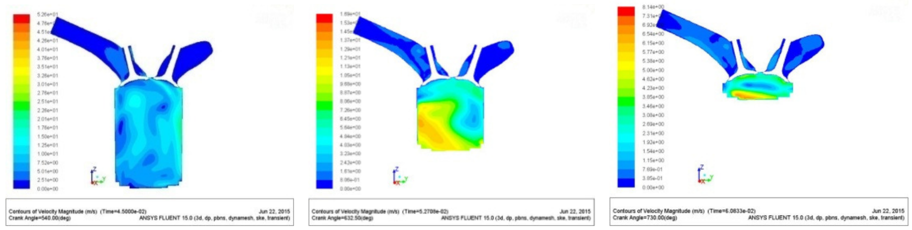


3.g 3.h 3.i

Figure.3 Velocity magnitude for different Crank angles at valve lift of 0.1mm

The plots of velocity magnitude for different crank angle from 0° to 730° at valve lift of 0.1mm are shown in Fig.10. X-axis indicates Crank Angle in "degrees" and Y-axis indicates Velocity Magnitudes in "m/s". Maximum velocity obtained is 120m/s at 272.5°.

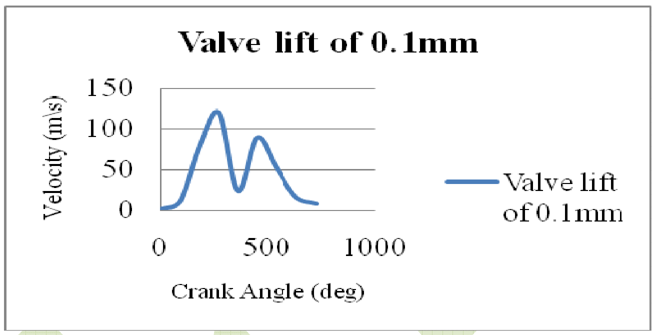


Figure.4 Crank Angle vs. Velocity Magnitude

VELOCITY CONTOURS FOR VALVE LIFT OF 0.2MM

Valve lift for the same IC Engine model was changed from 0.1mm to 0.2mm. Technical specifications considered for an IC Engine (Diesel Engine) for fluid dynamic analysis purpose for valve lift of 0.2mm is same as shown in Table 1 except for minimum valve lift.

At 3.75° expansion stroke takes place, at this position both the inlet and exhaust valves remains closed. Now the piston is at top dead centre (TDC) and moves to bottom dead centre (BDC) with the increase in volume of cylinder. The maximum velocity obtained at 3.75° is 0.98m/s as shown in Fig.11.a.

Fig.11.b shows the contours of velocity at 90° crank angle. At this stage expansion stroke takes place where the piston is at middle of cylinder i.e., which moves from TDC to BDC. The maximum velocity obtained at 90° is 10.6m/s.

Fig.11.c shows the contours of velocity magnitude at 182.50°. At this stage exhaust stroke takes place where exhaust valve open and creates interface between valve layer and chamber. Also time step is reduced for solution stability. The maximum velocity obtained at 182.50° is 78.9 m/s.

Fig.11.d shows the contours of velocity magnitude at 272.50°. At this stage exhaust valve opens so that the fluid inside the chamber deforms and makes fluid as rigid. The maximum velocity obtained at 272.50° is 114 m/s.

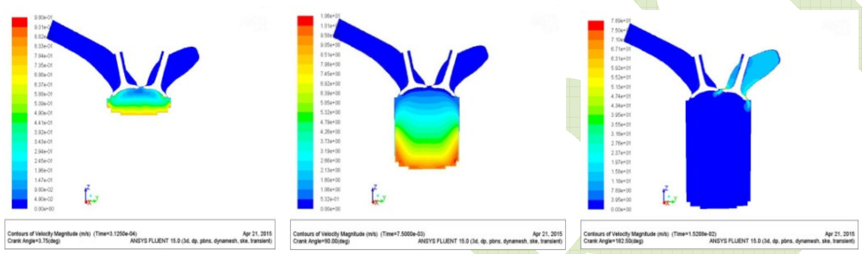
Fig.11.e shows the contours of velocity magnitude at 361.25°. This represents that the end of the exhaust stroke and even completes half cycle of 4-stroke diesel engine. The maximum velocity obtained at 361.25° is 22.6 m/s.

Fig.11.f shows the contours of velocity magnitude at 450°. Air fuel mixture is drawn inwards to form an annular jet. The spread and mix of the jet can also be noticed. The maximum velocity obtained at 450° is 85.9 m/s.

Fig.11.g shows the contours of velocity magnitude at 540°. At this stage both the inlet and exhaust valve is closed. The maximum velocity obtained at 540° is 50.1 m/s.

Fig.11.h shows the contours of velocity magnitude at 632.50°. This represents start of compression stroke. The piston returns to the top of the cylinder compressing the air/fuel mixture into the cylinder head. The maximum velocity obtained at 632.50° is 16.1 m/s.

Fig.11.i shows the contours of velocity magnitude at 730°. This represents the end of compression stroke and also ends of one full cycle of four stroke diesel engine. The maximum velocity obtained at 730° is 7.69 m/s.



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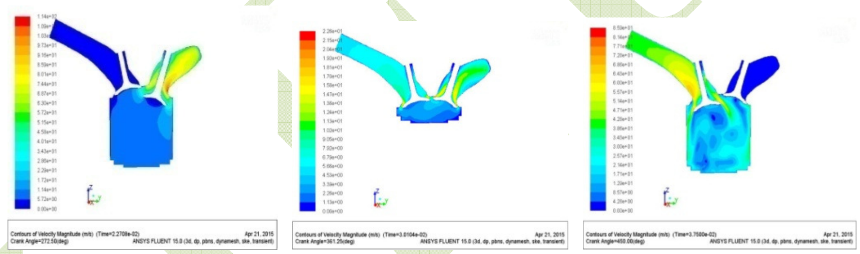

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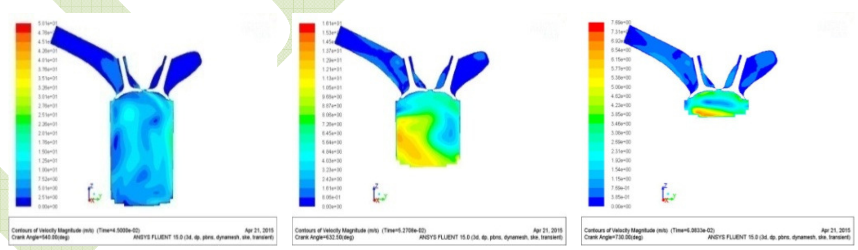


5.g 5.h 5.i

Figure.5 Velocity magnitude for different Crank angles at valve lift of 0.2mm

The plots of velocity magnitude for different crank angle from 0° to 730° at valve lift of 0.2mm is shown in Fig.12. X-axis indicates Crank Angle in "degrees" and Y-axis indicates Velocity Magnitudes in "m/s". Maximum velocity obtained is 114m/s at 272.5°.

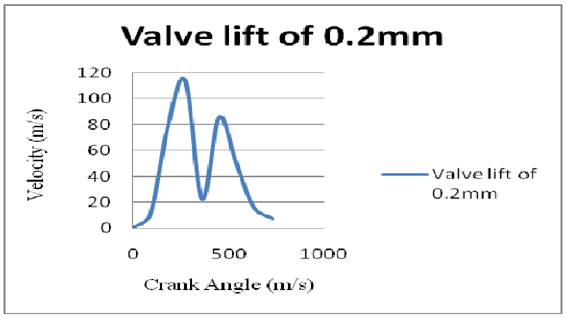
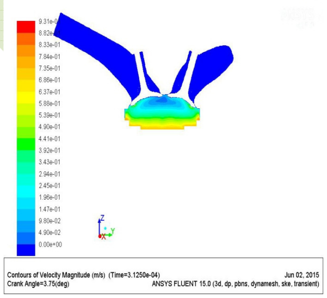


Figure.6 Crank Angle vs. Velocity Magnitude

VELOCITY CONTOURS FOR VALVE LIFT OF 0.3MM

Valve lift for the same IC Engine model was changed from 0.2mm to 0.3mm. Technical specifications considered for an IC Engine (Diesel Engine) for fluid dynamic analysis purpose for valve lift of 0.3mm is same as shown in Table 1 except for minimum valve lift.
Fig.30 shows the contours of velocity magnitude at 3.75° crank angle. Maximum velocity obtained at 3.75° is 0.931m/s.
Fig.31 shows contours of velocity magnitude at 90° crank angle. Maximum velocity obtained at 90° is 10.1m/s.
Fig.32 shows contours of velocity magnitude at 182.5° crank angle. Maximum velocity obtained at 182.5° is 75 m/s.
Fig.33 shows contours of velocity magnitude at 272.50° crank angle. Maximum velocity obtained at 272.50° is 109m/s.
Fig.34 shows contours of velocity magnitude at 361.25° crank angle. Maximum velocity obtained at 361.25° is 21.5m/s.
Fig.35 shows contours of velocity magnitude at 450 deg crank angle. Maximum velocity obtained at 450° is 81.4m/s.
Fig.36 shows contours of velocity magnitude at 540° crank angle. Maximum velocity obtained at 540° is 47.6m/s.
Fig.37 shows contours of velocity magnitude at 632.5° crank angle. Maximum velocity obtained at 632.5° is 15.3 m/s.
Fig.38 shows contours of velocity magnitude at 730° crank angle. Maximum velocity obtained at 730° is 7.31 m/s.



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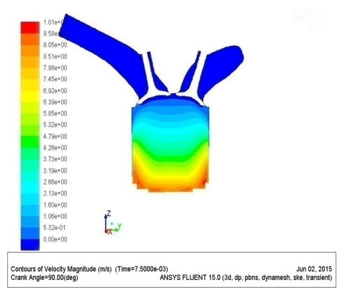

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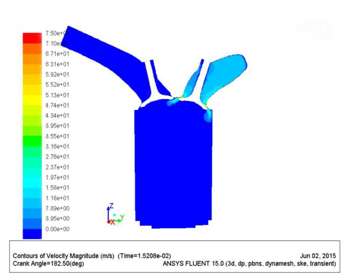

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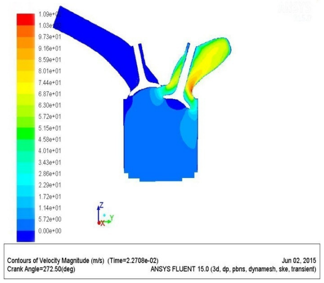
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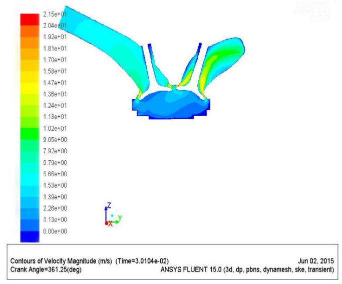
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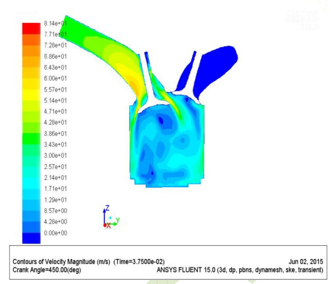
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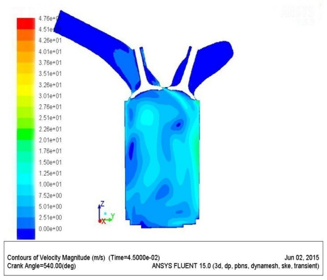
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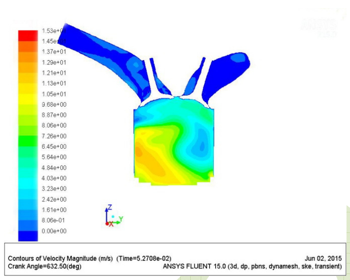
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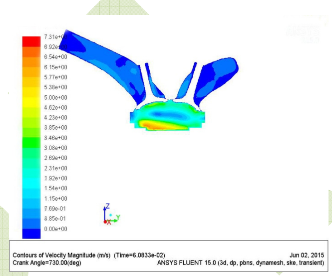
7.i

Figure 7 Velocity magnitudes for different Crank angles at valve lift of 0.3mm

The plots of velocity magnitude for different crank angle from 0° to 730° at valve lift of 0.3mm is as shown in Fig.39. X-axis indicates Crank Angle in "degrees" and Y-axis indicates Velocity Magnitudes in "m/s". Maximum velocity obtained is 109m/s at 272.5 deg.

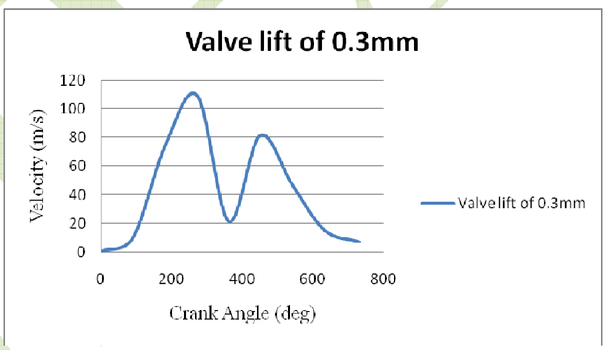

Figure.8 Crank Angle vs. Velocity Magnitude

COMPARISON FOR VALVE LIFTS OF 0.1MM, 0.2MM AND 0.3MM

Fig.40 shows the plots of velocity magnitude for various crank angles at different valve lifts. X-axis indicates Crank Angle in "degrees" and Y-axis indicates Velocity Magnitudes in "m/s". For first half cycle 270° is the highest peak and for second half cycle, 450° is the highest peak Fig.40 indicates that as valve lift increases the velocity decreases.

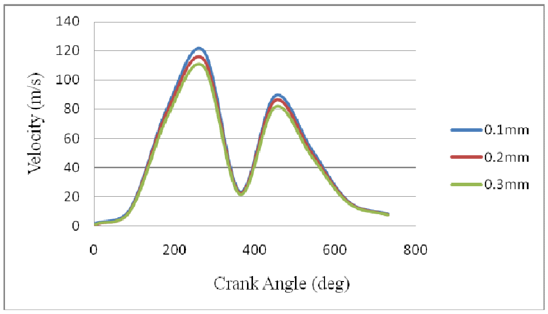

Figure.9 Comparison of Valve lifts

CONCLUSIONS

All four strokes and their effect on in cylinder air motion in an IC engine are studied effectively and following conclusions are obtained:

- Dynamic motion is visualized and velocity magnitude is plotted for different crank angle from 0° to 730°.
- When the valve lifts increases velocity obtained decreases.
- Air mixing and turbulence in the combustion chamber is influenced by exhaust stroke.
- To fix the parameters related to engine performance CFD tool can be used.

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