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Investigations On In-Cylinder Tumble Flows Of Internal Combustion Engine Using Shear Stress Transport Model.

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Abstract

The aim of this project is to investigate Intake-generated tumble motion is proposed in this project work to enhance the turbulence level during compression stroke to promote the combustion rate and reduce operational parameter variations. Investigations of the in-cylinder tumble flows in an IC engine and its influence on different in-cylinder engine parameters like pressure, temperature, velocity and turbulence intensity can be carried out with flat and bowl-in-pistons[4] . Tumble flow analysis of IC engines is carried out by considering the combustion space on a vertical plane passing through cylinder axis. To characterize the tumble flow, tumble ratio has to be estimated and flow characteristics are analysed using commercially Computational Fluid Dynamics (CFD) software. The theoretical results obtained are validated against experimental values. Shear stress transport turbulence model is used to simulate in-cylinder flow dynamics. The variation in parameters like pressure, temperature, velocity etc. for tumble flow is studied. These results are useful to optimize the turbulence level [1,2]and hence to get better combustion characteristics to reduce the emissions[3]

Keywords: IC engine, In-cylinder motion, Tumble, Flat piston, Bowl piston, CFD, SST Model.

1. Introduction

The necessity of tumble motion is to increase the turbulence level which favours proper and quick mixing of fresh charge which leads to effective combustion with reduced emission. Generating a significant vortex flows in an IC engine cylinder during the intake process generates high turbulence intensity during the later stage of compression stroke. The in-cylinder tumble flows are very much dependent on the shape of the piston surface, location of the piston-cavity, orientation of the intake manifold, compression ratio, engine speed etc. More recently Haworth et al. (1990) reported that during compression, tumble is found to be more effective than swirl both in extracting energy from the piston and in transferring kinetic energy of mean motion in to turbulence. Therefore, a good understanding of the in-cylinder flows in an IC engine is very much essential for the optimization of the engine parameters. Turbulence can be defined as the random motion of fluid particles in the fluid flow, but vortex generation in the combustion chamber is the rotational movement of air will be helpful in providing proper mixing of air and fuel than the other turbulence motion.

B.Murali Krishna and J.M.Mallikarjuna [2] to analyze the tumble flows, ensemble average velocity vectors are used and to characterize it, tumble ratio is estimated. From the results, generally, we have found that tumble ratio varies mainly with crank angle position. Also, at the end of compression Stroke, average turbulent kinetic energy is more at higher engine speeds.

Yang-Liang Jeng et.al [5] have done tumble flows analysis for bowl-in-piston . A small-scale vortex will be reserved inside the bowl in piston. The use of bowl-in-piston may or may not help in the generation and the maintenance of the tumbling flow pattern depending on the part of intake valve shrouded. The study of the topological characteristics of the PIA-detected flow fields can help significantly in the understanding of the formation and dissipation mechanism of the tumbling motion.

Kern Y. Kang et.al [6] have done a study on Turbulence characteristics of tumble flow in a four-valve engine. A strong tumble flow was found to enhance itself at the mid-stage of the compression process through conservation of its angular momentum and to become gradually weaker until TDC, while a weak tumble starts to break down from the beginning of the intake process. The tumble which persisted through the compression stroke enhanced the turbulence intensity by a factor of two relative to that of weak tumble, and also made the turbulence intensity distribution more homogeneous in the combustion chamber, both of which aspects have proved to be beneficial to the combustion process in spark-ignition engines.

2. Methodology

The geometric model of the intake manifold, intake valve, combustion chamber, flat piston and bowl-in-piston is created by using the software ANSYS WORKBENCH. Geometric decomposition and meshing of intake manifolds using the pre-processor tool ICEMCFD are shown in figure2.1 and figure2.2. Simulation of flow through a Stationary Engine Inlet Valve with inlet Manifold using ANSYS Fluent and validation of results with Experimental results. Study the effect of inlet valve, manifold, flat piston and bowl-in-piston on the in-cylinder flow-(Only intake and compression stroke) using dynamic mesh option using ANSYS Fluent. Compare the Effect of different piston (flat piston and bowl-in-piston) configurations on pressure, temperature, velocity, turbulence, and tumble ratio in the engine. The engine specifications are taken from experimental work [2] is shown in Table: 2.1, with that the model has been created. Valve lift is considered to be the main advantage to generate tumble flows inside the combustion chamber.

In this study, inlet condition is given at atmospheric temperature and pressure. In this only cold flow simulation is carried out (i.e.,) only for suction stroke and compression stroke. The cold flow simulation is done for two different combustion chambers with flat piston and bowl-in-piston. During piston motion the layers above the piston will increase when the piston move from top dead center to bottom dead center and the layers will decrease when piston move from bottom dead center to top dead center. This will be helpful to identify the motion of airflow inside the cylinder. This study is completely done under shear stress transport model for both the combustion chambers. The modelled engine is made to run at 400 rpm for both the combustion chambers. The simulation is conducted under transient condition. From this simulation, we can find the variation in parameters like pressure, temperature, velocity and turbulent kinetic energy. In fluent, fluid medium, material and boundary condition should be defined. The engine parameters are mention in the dynamic mesh settings and valve lift program can be uploaded for valve movement and default piston motion can be selected from the fluent. In the fluent solver settings, we can select the PISO method. Default operating condition is used to run the simulation. Then required number of time steps can be mention to run the transient simulation. In this transient analysis, every time step will be equal to 0.5 crank angle degrees. Based on this time steps should be mention in the transient simulation.

3. Results and Discussions

In general, in-cylinder flows in an IC engine are of two types viz. flow parallel (swirl) and perpendicular (tumble) to the cylinder axis. These flows are generated in the combustion chamber during the intake stroke due to piston shape, intake manifold orientation, intake valve lift and engine speed, etc. For most of the modern stratified charge and direct injection SI engines, tumble flows are more crucial than the swirl flows for the proper mixing of air and fuel, and for high flame propagation rate. Also a well defined (single vortex) swirl or tumbling flow structure is more stable than other large scale in-cylinder flows and they may break up later in the cycle giving higher turbulence during combustion (Khalighi, 1991). The tumble motion is generated during suction stroke due to air flow towards the cylinder wall get diverted towards piston and again it strikes cylinder head forming angular momentum which is perpendicular towards cylinder axis. In figure 3.1 and figure 3.2 shows the contour plot for flat and bowl-in-piston. In figure 3.1 and 3.2 shows velocity contour of flat and bowl-in-piston at 30 crank angle degrees.

3.1 Variation of Pressure and Temperature

Distribution of pressure and temperature at various crank angle degrees are shown in figure 3.3 and figure 3.4 at intake and compression stroke for flat piston. The increment of time step is taken 0.5crank angle degree. Piston starts from top dead center about 0 degrees and the maximum pressure reaches at 360 degree. The pressure increases from 0.5crank angle degree to 360crank angle degree and reaches its maximum value at 360crank angle degree. The Maximum pressure at the end of compression stroke is 32bar and temperature is 625 K.

Distribution of pressure and temperature at various crank angle degree are shown in figure 3.5 and figure 3.6 at intake and compression stroke for bowl-in-piston. The increment of time step is taken 0.5 crank angle degrees. Piston starts from top dead center about 0 degrees and the maximum pressure reaches at 360 degree. The pressure increases from 0 crank angle degree to 360 crank angle degree and reaches its maximum value at 360 crank angle degrees. The Maximum pressure at the end of compression stroke is 37 bar and temperature is 720 K. The maximum value of pressure and temperature for bowl-in-piston is greater than flat piston.

3.2 Variation of Velocity

The velocity magnitude for different crank angle is shown in figure 3.7 at intake and compression stroke for flat piston. It shows that flow is maximum at fully opened valve position. Turbulence is higher at starting crank angle degrees of intake stroke and it will decrease during compression stroke. Velocity will increase at starting crank angle degrees because of small flow passage between inlet manifold and inlet valve. It will act as a air jet and send the air at higher velocity. Velocity will start to decrease when the valve is at fully open position.

The velocity magnitude for different crank angle is shown in figure 3.8 at intake and compression stroke for bowl-in-piston. Velocity will increase at starting crank angle degrees because of small flow passage between inlet manifold and inlet valve. It will act as a air jet and send the air at higher velocity. Velocity will start to decrease when the valve is at fully open position. Flat piston cylinder is having higher velocity than bowl-in-piston.

3.3 variation of turbulent kinetic energy

The variation of Turbulent Kinetic Energy (TKE) at various crank angles for flat piston is shown in figure 3.9 for flat piston. The inlet manifold configuration and valve lift control affects the turbulence of the fluid inside the cylinder. The maximum flow is attained at the time of fully opened valve position. The variation of Turbulent Kinetic Energy is probably due to different level of air induced through the inlet manifold. The variation in Turbulent Kinetic Energy is because of deforming volume of the cylinder. During suction stroke, gradual opening of valve will take place, which will provide very small space between manifold and valve for the air to enter. Due to restriction in the flow passage turbulence in the flow tend to increase and piston also will move from top dead center to bottom dead center which has a slightly greater volume than clearance volume it is also the reason for variation in turbulence.

The variation of Turbulent Kinetic Energy at various crank angles for flat piston is shown in figure 3.10 for bowl-in-piston. The inlet manifold configuration and valve lift control affects the turbulence of the fluid inside the cylinder. The maximum flow is attained at the time of fully opened valve position. Flat piston combustion chamber has higher turbulent kinetic energy than bowl-in-piston combustion chamber.

3.4 variation of tumble ratio

Tumble ratios is defined as the ratio of the angular momentum of the in cylinder flow about each of the three orthogonal axis. The variation of Tumble Ratio inside the cylinder with respect to crank angle degrees for flat piston configurations at 400 rpm for intake and compression stroke for flat piston is shown in Figure 3.11. It is observed that the TR ratio changes its magnitude (positive to negative or vice versa) indicating overall air movement changes its direction during entire cycle with crank angle degrees. The reasons for this could be: (i) change in the overall tumble flow pattern due to low pressure and bifurcation zones, (ii) change in piston speed with CAD, and (iii) change in the direction of the piston movement during suction and compression strokes Tumble ratio will increase with increase in engine speed [2]. The maximum tumble ratio is attained at 120 crank angle degrees. At high tumble ratio, more turbulence will be generated which will induce proper and quicker mixing of air and fuel. This quick mixing will force the rich mixture towards spark plug at time of ignition, which leads to faster burning rate.

The variation of Tumble Ratio inside the cylinder with respect to crank angle degrees for bowl-in-piston configurations at 400 rpm for intake and compression stroke is shown in Figure 3.12. Tumble ratio will increase with increase in engine speed [2]. Tumble is generated inside the combustion chamber by controlling valve timing, manifold configuration and piston movement. The maximum tumble ratio is attained at 330 crank angle degrees. Bowl-in-piston configuration has a lower tumble ratio than the flat piston. It is clear from the graph flat piston configuration will create more turbulence than bowl-in-piston configuration.

4. Conclusions

Control of charge motion is one of the important factors, which improve and controls the engine performance and emission in stratified charge engines. Hence good knowledge in in-cylinder flows will helpful to improvise the performance and emission. In this project work, the internal flow characteristic in the combustion chamber is investigated computationally for flat piston and bowl-in-piston configurations.

The overall flow field inside the combustion chamber and various quantities, such as pressure, velocity distribution and tumble ratios were examined for two piston configuration. Swirl and tumble ratios can be obtained quite accurately for both production and research engines using computational fluid dynamics. The summary of the comparison is as follows:

- Flat piston creates higher tumble motion than bowl-in-piston.
- Flat piston creates higher turbulent kinetic energy than bowl-in-piston.
- Pressure and temperature distribution for bowl-in-piston is higher than flat piston.

Flat pistons are suggested to use than bowl-in-piston in favour of generating tumble flows.

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Bore X stroke (mm)	87.5X110
Compression ratio	10:1
Rated engine speed	1500
Maximum valve lift (mm)	7.6
Intake and exhaust port diameter (mm)	28.5

Table.2. 1 Specification of the combustion chamber

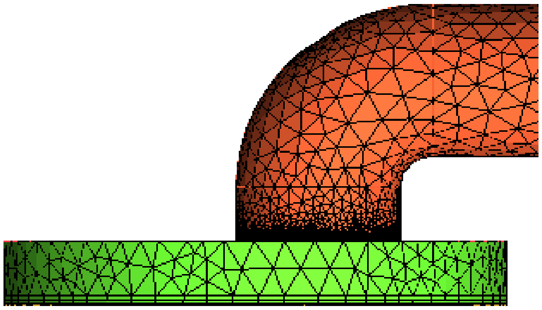

Figure 2.1: Meshed model of flat piston

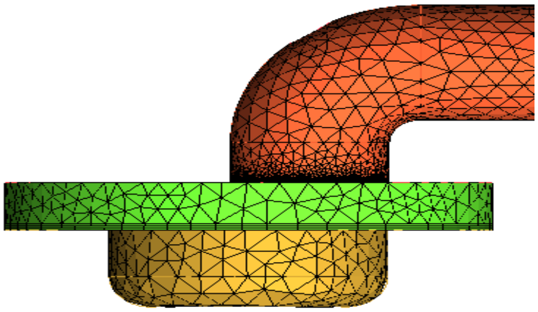

Figure 2.1: Meshed model of bowl-in-piston

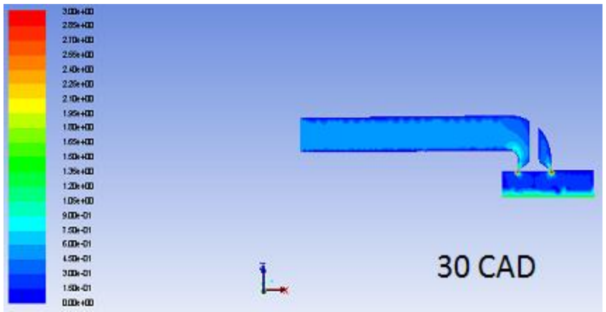

Figure 3.1: velocity contour of flat piston 30CAD

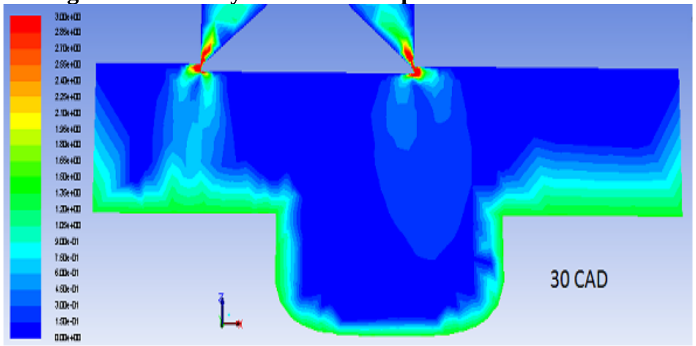

Figure 3.2: velocity contour of bowl-in- piston 30CAD

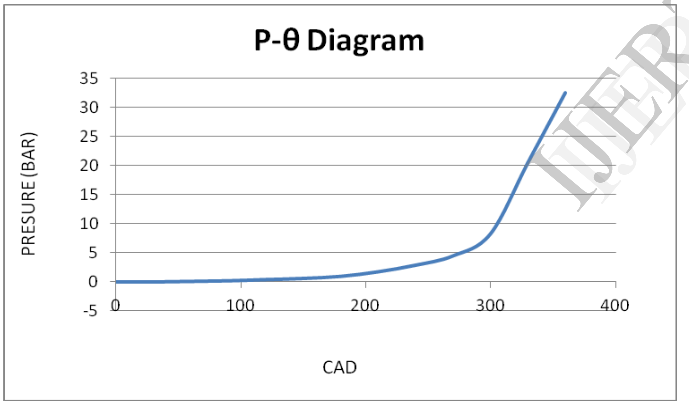

Figure.3. 3: Pressure Vs crank angle degree for flat piston

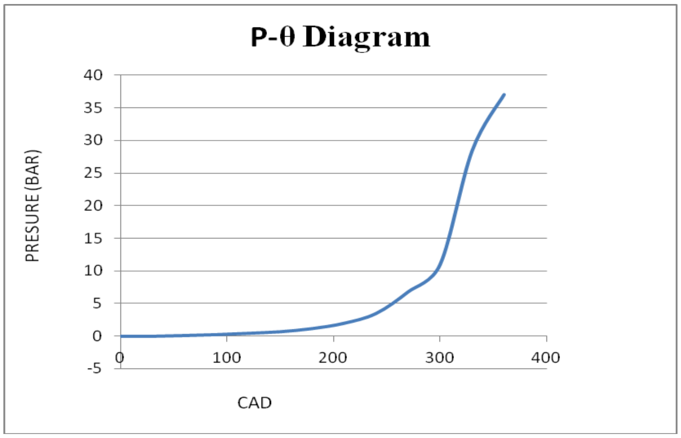

Figure.3. 4: Pressure Vs crank angle degree for bowl-in-piston

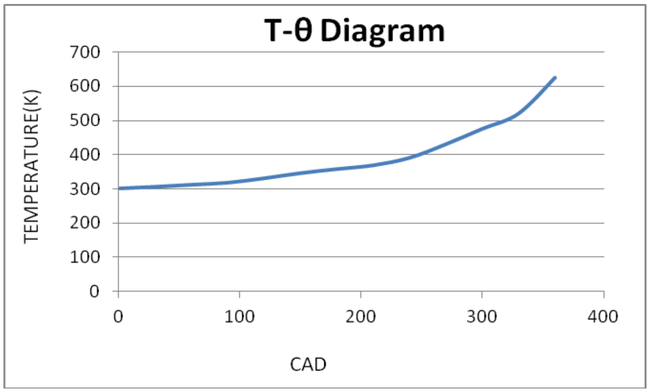

Figure.3. 5: Temperature Vs crank angle degree for flat piston

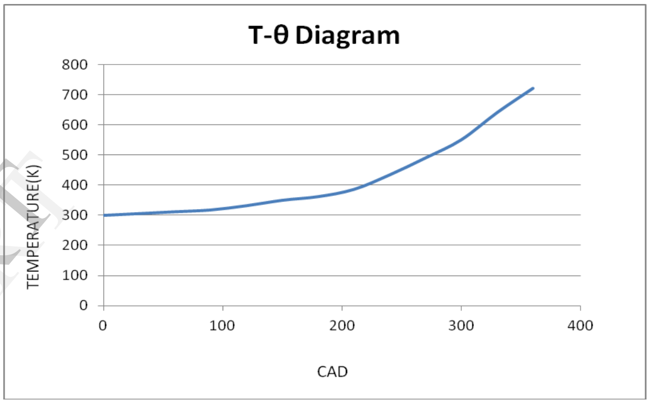

Figure.3. 6: Temperature Vs crank angle degree for Bowl-in-piston

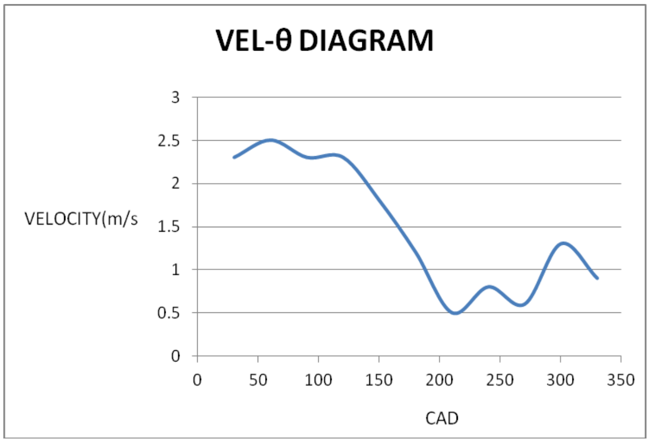

Figure.3. 7: velocity Vs crank angle degree for flat piston

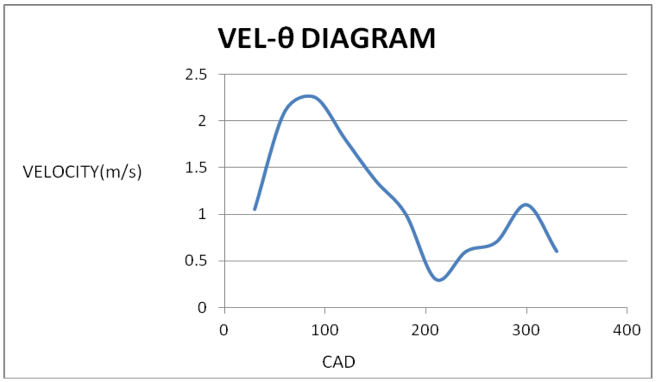

Figure.3. 8: velocity Vs crank angle degree for bowl-in-piston

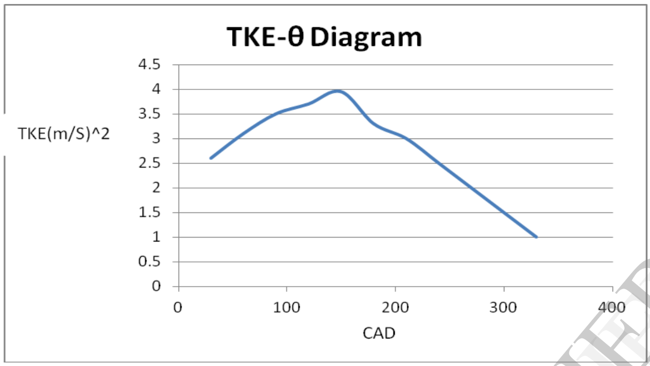

Figure.3. 9: Turbulent Kinetic Energy Vs crank angle degree for flat piston

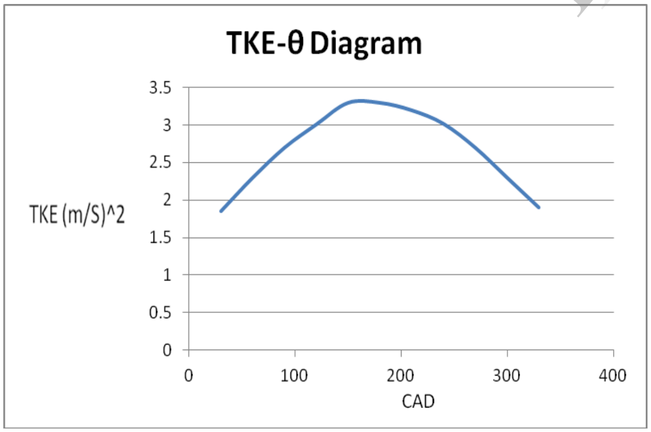

Figure.3.10: Turbulent Kinetic Energy Vs crank angle degree for bowl-in- piston

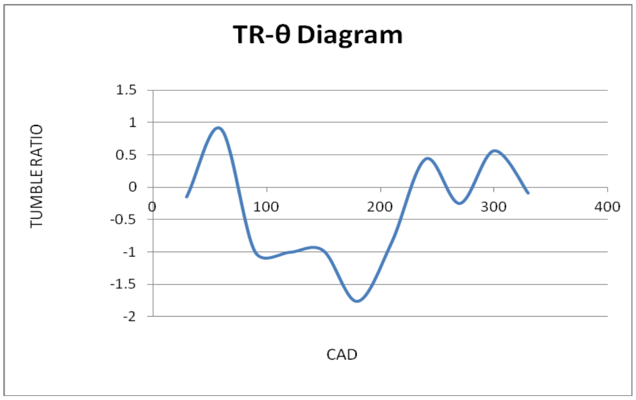

Figure.3. 11: Tumble ratio Vs crank angle degree for Flat piston

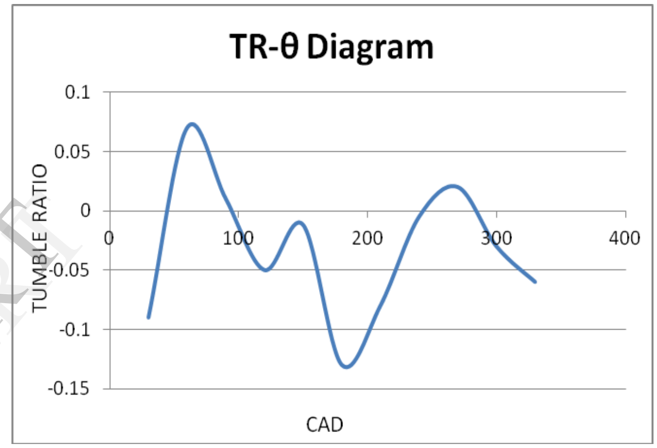

Figure.3. 12: Tumble ratio Vs crank angle degree for Bowl-in-piston