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Influence of In-Cylinder Movement on Diesel Engine Performance: A Review

V CVS Phaneendra[1], Dr. M V Mallikarjuna[2]
[1] Research Scholar (Ph.D), JNTUK, A.P, India
[2] Professor, Department of Mechanical Engg. QISCET, Ongole, A.P, India

Abstract: The fluid motion in an internal combustion engine is a complex phenomenon and is cryptic especially in diesel engines. Air movement inside the cylinder can improve fuel-air mixing, and thus brings more power with better fuel efficiency; which mainly depends on, inlet and exhaust valve profile, manifold design and combustion chamber configuration. The aim of this paper is to provide a review on the techniques employed for improving the in-cylinder movement for better engine power and reduced emissions.

I. INTRODUCTION

The fuel economy and emissions of internal combustion(IC) engines have become a top priority in today's world. This is mainly due to continuous tightened emission standards, increasing fuel price, and the demand for increased power. Strategies are being explored to achieve these requirements; among which implemented were with fuel modifications and engine-based technologies [1].Boosting the intake air pressure (supercharging or turbo charging) is one of the most common and effective strategies used today to improve the power and efficiency of IC engines. Air is directed into the cylinder through the inlet manifold and this air flow is one of the important factors, which governs the diesel engine performance and emissions.

It is the rotational air motion within the cylinder, enhances the homogeneous mixture formation within a short time. The motion of air or fuel-air inside the engine cylinder during working strokes is termed as in-cylinder motion. The in-cylinder fluid motion in IC engines is one of the most important factors controlling the combustion process. It governs the fuel-air mixing and burning rates in diesel engines. In-cylinder flow field structure in an IC engine has a major influence on the combustion, emission and performance characteristics. Fluid enters the combustion chamber of an IC engine through the intake manifold with high velocity. Then the kinetic energy of the fluid results in turbulence and causes rapid mixing of fuel and air, if the fuel is injected directly into the cylinder. With optimal turbulence, better mixing of fuel and air is possible which leads to effective combustion. The increased turbulence causes better cooling of the cylinder surfaces thereby reducing the heat loss to the surroundings. The heat from the cylinder walls gets absorbed by the air supplied during suction and used for reducing the delay period thereby increasing the thermal efficiency of the engine. The air motion in a diesel engine is generally caused either by the intake port during the suction stroke or by combustion chamber geometry during the compression stroke [2].

Swirl, Squish and Tumble are the different types of air motions inside the cylinder, which are differentiated with their rotational patterns. Swirl is organized rotation of the charge about the cylinder axis generated during the intake process in direct injection diesel engines by the intake port and subsequently by combustion chamber geometry during the compression stroke[2].

During compression air from the periphery of the cylinder is pushed to its centuries. Towards the recess in the piston crowner in the cylinder head. This radial inward movement of air is called squish. When the motion of air is perpendicular to the cylinder axis, motion is termed tumble [2].

Air motion in the cylinder is influenced by intake flow field, piston crown and cylinder head designs. This air motion can further be enhanced by pressurizing which is attainable by supercharging or by turbo charging. Various studies have made on turbo supercharging, intake flow field and piston crown designs in order to obtain better fuel efficiency and emissions.

II. LITERATURE REVIEW

A. Impact of swirl on in-cylinder heat transfer in a light-duty diesel engine

Alberto Broach, et al[3] analysed the heat transfer from an engine which has major impact on the efficiency. Swirl is the parameter that influences various in-cylinder variables relating to heat transfer. The heat transfer is influenced by the swirl and this swirl varies at different locations of cylinder space. These spatial temperatures were measured by thermocouples arranged in order. Some thermocouples have been arranged in the cylinder head in a configuration for the measurement of the axial component of heat flux through the material. The analysis is on 1.9 L 4-cylinder CRDI diesel engine with variable geometry turbocharger (VGT) and a high pressure EGR system having 4 valves per cylinder and re-entrant type piston bowl. Swirl number varied from 1.38 to 2.95. A thermal model was developed for comparison with the experimental results. Transducers and thermocouples were employed to obtain required input signal for the thermal model (CALMEC). Inputs required for the present model include geometrical characteristics of the engine and mean temperatures of the intake, exhaust gases and coolant oil. Measurements were recorded at two intermediate values of engine speed (1500 rpm & 200 rpm), load values from a low BMEP of 2 bar (10% load at 2000 rpm) to high load of 14 bar (80% load of 1500 rpm).

Swirl impact was found in the centre of foredeck with increased heat loss of 4-12% with a unit swirl number increase. In the outer area of cylinder head and on top of cylinder liner swirl impact was smaller & similar. According to the model high swirl ratios increased heat losses in chamber.

B. Experimental and numerical investigation of swirl enhancing grooves on the flow and combustion characteristics of a DI diesel engine

P. Prabhakaran, et al.[4]investigated on air motion with the aid of the piston bowl geometry involving six tangential inclined holes with 20^0 to the horizontal and 30^0 to the vertical. A vertical water cooled kirloskar DI diesel engine with a bore of 87.5 mm and stroke 110 mm having compression ratio 17.5:1 was used for experimentation. One important effect of providing slots is the uniformity of velocity vector. The increased air motion will result in higher turbulence. Additional grooves may tangentially enhance the flow velocity through the hole during the end stages of compression stroke between 330^0 to 360^0aTDC. Velocity field is vigorous for 3.5 mm hole and becomes less vigorous as the hole size decreases. The 2.5 mm grooved piston has the lowest velocity, combustion with an increased evaporation rate, heat release rate and combustion. Even though there is a better air motion in all the modified pistons the adverse effect of wall quenching or wall film formation in the holes more than offsets the benefits accrued due to higher air motion. Emissions were found to be the lowest in case of 2.5 mm hole piston. The CO levels were low within slight increase in CO_2 levels which implies better combustion.

The individual mathematical models for spray, combustion; Nox and soot modelling were used as necessary initial and boundary conditions for initiation of the simulation. The monotone advection and reconstruction (MARS) discretization schemeand upwind scheme (UD) were used for solving the u, v, w turbulence momentum and temperature respectively. The computational results using CFD were validated against experimental results at two stages: standard piston and modified piston. Flow and combustion processes were investigated with STAR-CD code. Theoretical investigation showed enhanced brake thermal efficiency with 2.5 mm hole piston of 2% increase at 80% load. But the 2.5 mm hole piston provides higher Nox emissions due to better combustion which has to be reduced by after treatment.

C. Combustion and emission characteristics of a lateral swirl combustion system for DI diesel engines under low excess air ratio conditions

XiangRong Li, et al. [5]studied lateral swirl combustion system (LSCS) at various excess air ratios and the results were compared with double swirl combustion system. The test was on 132 mm bore single cylinder DI engine with stroke 145 mm, nozzle diameter of 0.27 mm and 8 jets. Various sensing elements were used for measuring various parameters during operation of the engine.

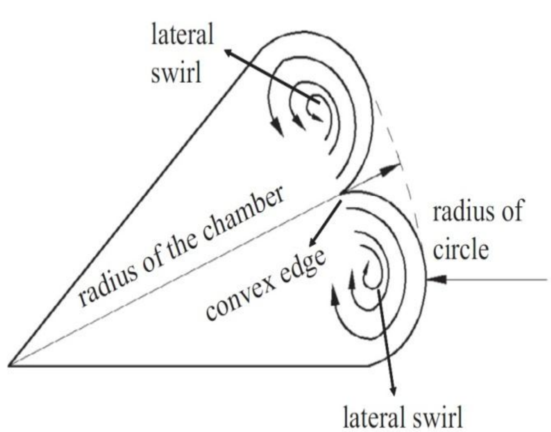

Fig.1

Fig.2

When the spray hit the convex edge, two lateral swirl vortices were formed on both sides of the convex edge and enhancing the utilization of the air in the chamber. The in-cylinder pressure was rapidly decreased by a decrease in the air ratio. The peak in-cylinder pressure can be reduced and the mechanical load can be improved by adopting LSCS. At higher excess air ratio of 1.3; Nox emissions were higher, soot levels decreased and lower BSFC with higher thermal efficiency. The combustion duration at various excess air ratios has decreased. LSCS has shown a positive influence on reducing the thermal load on the cylinder head and the piston push was increased.

D. Numerical investigation of piston bowl geometry and swirl ratio on emission from diesel engines

Abdul Gafoor C.P, et al. [6] investigated on the effect of initial swirl ratio and piton bowl geometry on engine performance and emissions. Variation in piston bowl geometry is by varying the value of ratio of the diameter of bowl (d) to diameter of the piston (D). A naturally aspirated air cooled four stroke DI diesel engine with a rectangular bowl in piston combustion chamber geometry is considered and the piston bowl has a initial swirl ratio of 1.5 and d/D ratio of 64% is opted as baseline case. The compression ratio, bowl volume, speed and mass of fuel injected are kept constant throughout the simulation. The meshing generation is done through AVL fire mesh generator. The number of possible combinations with swirl ratio and piston geometry is 35. A code for each set is made as B_xS_y where x stands for bowl geometry and y stands for initial swirl ratio.

Table.1

Configurations used for study.

	Diameter (d/D) ratio						
	80%	75%	70%	64%	60%	55%	50%
Initial swirl ratio							
0.5	B1S1	B2S1	B3S1	B4S1	B5S1	B6S1	B7S1
1.5	*B1S2*	*B2S2*	*B3S2*	*B4S2*	*B5S2*	*B6S2*	*B7S2*
2.5	B1S3	B2S3	B3S3	B4S3	B5S3	B6S3	B7S3
3.5	B1S4	B2S4	B3S4	B4S4	B5S4	B6S4	B7S4
4.5	B1S5	B2S5	B3S5	B4S5	B5S5	B6S5	B7S5

Initial swirl ratio of 1.5 with d/D ratios of 50 to 80% were selected for the investigation. Overall total kinetic energy distribution is good with lower d/D ratios. In B3S2 case pressure and temperature at TDC were found to be low, for B5S2 and B6S2 high temperature and pressure.

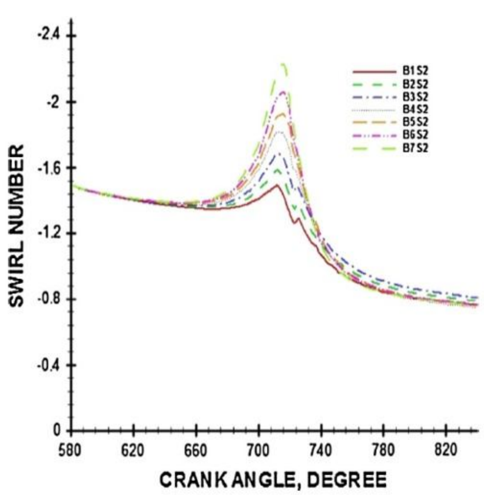

Fig.3

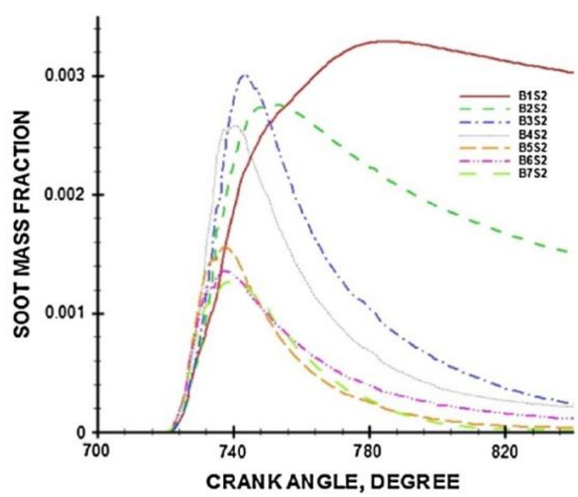

Fig.4

The swirls with B1S2 & B7S2 are low and high respectively. Good combustion has obtained by high initial swirl with high d/D ratios and by low initial swirl with low d/D ratios.CO emissions are found to be low for lower swirl and higher d/D ratios and for higher swirl & low d/D ratios.

E. The combustion and emission characteristics of a multi-swirl combustion system in a DI diesel engine

Xiangrong Li, et al. [7] combined Double swirl Combustion system (DSCS) and lateral swirl Combustion system (LSCS) for better air utilization during mixture formation and combustion. DSCS improves fuel distribution only in longitudinal and LSCS in only lateral direction; the gap between DSCS & LSCS was bridged by implementing MSCS. Using MSCS a longitudinal and lateral directional swirl are formed which accelerates the fuel diffusion over the entire chamber rendering more uniform air/fuel mixture and improved air utilization in the combustion chamber. The key factors in case of MSCS are the relative location between the fuel spray and the convex edge. In MSCS the flow is made to touch the convex edge and is made to flow into two sides of the convex edge and forms a lateral swirl in two opposite directions enlarging the distribution of fuel in lateral space. The basic parameters of both the MSCS & LSCS are the same; the process of combustion was same before the fuel spray touches the convex edge. The results were found deviated after TDC from 5 to 16. At 145^0 spray angle fuel consumption and emissions were found to be low as compares with 150^0, 155^0.

The effect of injection angle was also tested using MSCS through various experiments at four injection angles -11^0, -5.5^0, 0^0, 5.5^0 taking the standard operating conditions at 2100 rpm and brake power 50 kW, spray angle was set at 145^0;pressure versus crank angle, heat release rate and in-cylinder temperature were analysed.

Due to the improved air flow intensity in longitudinal space created by touching the circular ridge, little fuel acceleration was found around the chamber wall. MSCS increased diffusion space & BSFC is lower by 4-5 g/kWh, reduced fuel-rich regions and soot emissions were reduced by 60% as compared with DSCS.

III. CONCLUSION

It is well known fact that the air motion is the most primary influential factor in fuel air mixing of a diesel engine. Air motion has been studied through various theoretical and experimental works for a long period and still going on. The results through the works always shows better over one another and have lead to the improvements in the diesel technology. Initially the work involved cavities ob the piston and later supercharging has used for increased air movement, later on indirect combustion chambers were used for good mixing of fuel and air and lastly the piston geometry is again being modified for more air movement. It's never ending concepts (air motion) for achieving optimum level and through the literature during the recent times the multi swirl combustion swirl and holes on the piston has proved better. With the application of these two simultaneously for an engine configuration can improve the engine output standards to a certain level. Further some more techniques have to be employed for improving the emission level during rapid cruising condition.

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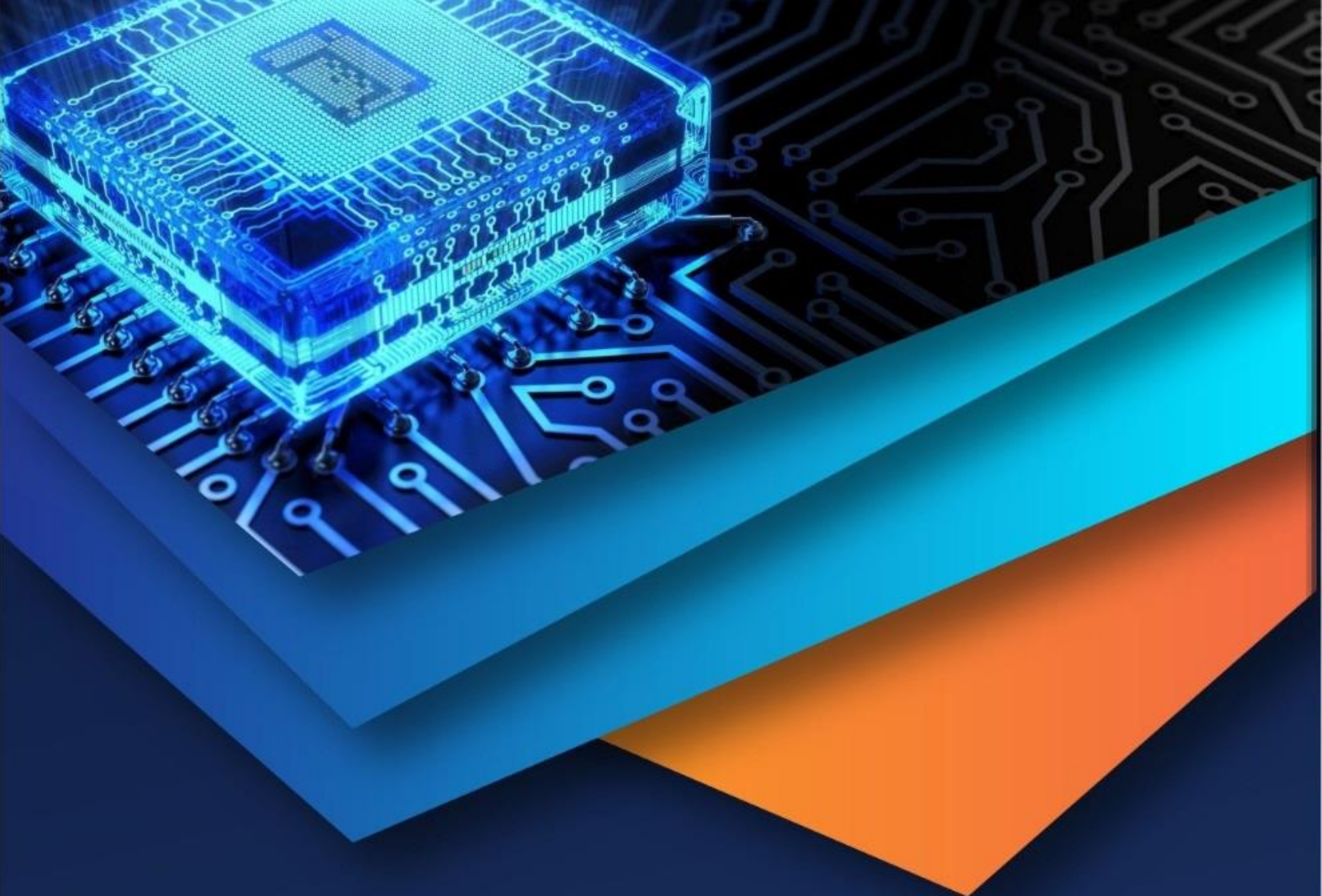

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