Cold Flow Study at Combustion Space for Engine Low Emissions using Different Pistons

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Abstract **-** This paper deals with analysis of in-cylinder tumble flows at combustion space (330 CAD) of single-cylinder engine with four different pistons using PIV. To analyze the flow, ensemble average velocity vectors are used and characterized by tumble ratio (TR) and turbulent kinetic energy (TKE). It is found that, tumble flow structure is strongly dependent on piston shape. At the end of compression stroke, flat with bowl piston showed good improvement in TR and TKE compared to other pistons studied. This study will be useful in understanding effect of piston shape on in-cylinder flow in modern engines to reduce emissions.

Keywords*-Piston, Cavity, In-cylinder, Velocity, PIV.*

I. INTRODUCTION

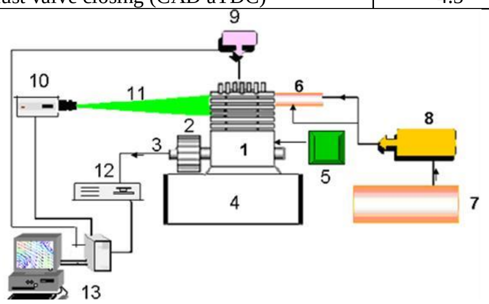
Optimization of IC engines is very much essential to understand in-cylinder air flow behavior under different conditions. The modern spark ignition (SI) internal combustion (IC) engines like stratified charged and gasoline direct injection (GDI) engines are popular because of their low fuel consumption and emissions. In a GDI engine, gasoline is injected directly into the cylinder late during compression stroke. In these engines, main requirement is to create charge stratification i.e., rich mixture near the spark plug and overall lean mixture. Generally, charge stratification is achieved by well guided in-cylinder rotating air flows [1]. Generating a significant vortex flow inside IC engine cylinder during intake stroke generates high turbulence during later stage of compression stroke leading to fast burning rates [2]. The rotating flows can significantly increase turbulence during combustion period leading to reduced burning time and increased thermal efficiency in the premixed SI engines [3]. The various PIV experimental measurements on various types of IC engines reported that flow structure changes substantially along cylinder length due to geometry of intake port and occurrence of tumble motion during intake stroke [4-6]. By using digital PIV technique on in-cylinder flows in a single-cylinder engine one can estimate the parameters like turbulent length scale, vorticity and strain rate distribution, etc. [7].The present study is to measure the in-cylinder tumble flow structures in a single-cylinder, two-valve, IC engine with four different pistons under motored conditions at an engine speed of 1000 rev/min., at 360 crank angle degrees (CADs) using PIV.

II. EXPERIMENTAL SETUP AND EXPERIMENTS

A single-cylinder, vertical, two-valve, air-cooled engine (Table 1) was coupled to an induction motor through an speed controller. In this study, the motor along with the engine was run at a speed of 1000 rev/min. In order to facilitate the PIV measurements, an extension of the cylinder liner was made using a transparent cylinder for a field of view (FOV) and maintained compression ratio of 10:1. Intake manifold of engine was connected to a plenum to mix and supply air and seeding particles for uniform distribution. The schematic diagram of the experimental setup is shown in Fig.1. The PIV system consists of a double pulsed ND-YAG laser, CCD camera and controllers with a data acquisition system and software. The laser sheet was aligned with and camera was placed to view the FOV which was set on a vertical plane passing through axis of cylinder. In this study, in-cylinder tumble flow measurements have been carried out at combustion space (330 CAD), at every measuring point 500 image pairs were recorded and processed using DAVIS (Data acquisition and visualization software) [8-10]. The ensemble average velocity vectors were computed at required CAD with an objective to study the effect of piston shape on in-cylinder flows. The pistons with different crown shapes used in this study are shown in Fig.2. All the piston shapes were fabricated such that a compression ratio is unaltered.

Table 1. Engine specifications

Bore x stroke (mm)	87.5 x 110
Compression ratio	10:1
Rated engine speed (rpm)	1500
Maximum valve lift (mm)	7.6
Intake/exhaust port diameter (mm)	28.5
Intake valve opening (CAD bTDC)	4.5
Intake valve closing (CAD aBDC)	35
Exhaust valve opening (CAD bBDC)	35
Exhaust valve closing (CAD aTDC)	4.5



1. Engine, 2. Motor, 3. Encoder, 4. Test bench, 5. Speed controller, 6. Intake plenum, 7. Air compressor, 8. Seeder, 9. Camera, 10. ND-YAG Laser, 11. Laser sheet, 12. Signal modulator, 13. Data acquisition system

Fig.1. Line diagram of experimental setup

Flat piston (F)	Flat bowl piston (F_b)	Inclined piston (I)	Inclined bowl piston (I_b)

Fig.2. Pistons with different crown shapes

III. RESULTS AND DISCUSSION

For modern stratified charge engines, tumble flow is more crucial than the swirl. Figure 3 shows ensemble average velocity vectors of in-cylinder tumble flows with superimposed streamline patterns 330 CAD for flat piston (F) as sample.

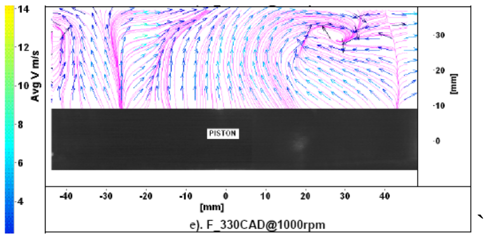


Fig.3. Ensemble average velocity vector filed at 330 CAD

In the Figure 3, it is to be noted that piston position is shown over velocity vector fields just to represent the relative position of them. The intension of having bowl in the flat piston is to orient the tumble vortex almost on the cylinder axis around the spark plug position. In this case, the tumble flow pattern is almost similar to that of flat piston, except that the variation in ensemble average velocity vector magnitudes. Inclined piston (I) is used to provide more space at the cylinder right side where more air flow takes place such that the air jet entering the cylinder would strike the piston top surface at a longer distance than that of flat piston. This may assist in the formation of a larger in-cylinder tumble vortex compared to that of flat piston. Normally, in the stratified charged and direct injection SI engines, the spark plug is located at the center of the combustion chamber. Therefore, once ignition starts, the turbulence of the flow in the combustion space would aid proper flame propagation leading to effective combustion. However, the effect of the piston shape on the in-cylinder tumble flows can be better understood with the help of tumble ratio and turbulent kinetic energy of the flow discussed in the following sections.

A.Tumble Ratio

Unlike the swirl ratio, tumble ratio must be evaluated under transient conditions due to the significant effect of the piston shape and its motion on the in-cylinder tumble flows. Also, during compression, tumble flow is found to be more effective than swirl, both in extracting the energy from the piston and transferring it into turbulence. In this study, in-cylinder tumble flows are characterized by tumble ratio, calculated as per *Huang et al.* [11]. Here, the TR is defined as the ratio of the mean angular velocity of the vortices on the target plane to the average angular velocity of the crank. The negative or positive magnitudes of TR indicate that the overall direction of in-cylinder tumble flows in a given plane as CW or CCW respectively. Figure 4 shows TR for various piston shapes, it is observed that the overall air movement at the end of compression stroke gives a better idea for the engine designers to fix the position of the spark plug and the fuel injector in modern SI engines. It is good to have more air movement at 330 CAD for better air-fuel mixing and combustion. Good charge stratification is crucial and it is achieved with strong tumble flow.

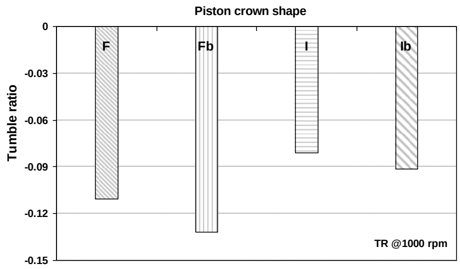


Fig.4. Variation of tumble ratio at 330 CAD

From Fig.4, it is observed that, at 330 CAD pistons with bowl have higher TRs compared to their corresponding plain pistons. Stronger the tumble motion during the suction stroke; more the turbulent kinetic energy released by its breakdown during late compression stroke. It guarantees the higher turbulence levels at the time of ignition [**1**]. Among the four piston shapes considered in this study, flat with bowl piston (F_b) exhibit more TR. It may be due to that, in case of this piston, the guiding effect of the piston bowl helps to retain the tumble vortex generated during suction stroke till the end of compression stroke. However, this is not true in the case of inclined with bowl (I_b) piston. It may be because that, with this piston shape, the cylinder space is not uniform from left to right of the cylinder, thereby the rotating motion of the air is obstructed and vortex is destroyed. It is found that, F_b and I_b piston shapes have resulted in 19 and 14 % improvement in TR respectively compared to their respective plain pistons.

B.Turbulent Kinetic Energy

Figure 5 shows average TKE at 330 CAD for different piston shapes, which is proportional to level of the flow velocities within the cylinder. The TKE of the flow indicates its strength as a whole. It is evident that the average TKE is more for F_b compared to other piston shapes. It is also evident that both F_b and I_b pistons have more average TKE compared to their corresponding plain pistons. They showed an improvement in average TKE of about 48 and 38 % respectively compared to their corresponding plain pistons. However, conventional flat piston shows more average TKE compared to inclined piston. This may be because, in the case of inclined piston, due to non-uniform cylinder space from left to right side of the cylinder, the entire tumble flow pattern dragged towards exhaust valve side. In summary, F_b piston shows a good improvement in average TKE at the end of compression stroke compared to other piston shapes.

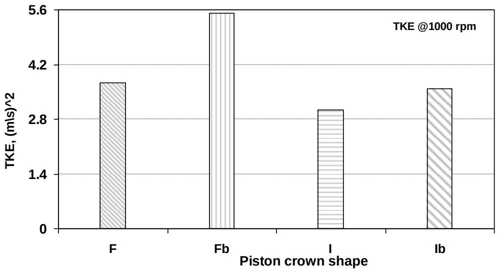


Fig.5. Variation TKE at 330CAD

IV. CONCLUSIONS

Based on experimental study at 330 CAD**,** flat with bowl and inclined with bowl pistons showed an improvement in TR by 19 and 14 %; average TKE by 48 and 38 % respectively compared to their corresponding plain pistons**.** On the whole, flat with bowl piston showed a good improvement TR as well as average TKE at the end of compression stroke compared to other pistons.

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Dr. B. Murali Krishna received his PhD from Department of Mechanical Engineering, **IIT Madras**, Chennai in 2010; Post graduation from **NIT Warangal**, Graduation in Mechanical engineering from **Institution of Engineers (India)**, Calcutta. He was fellow and life member of FIE, ISTE, IAENG, ISAET, IACSIT etc. His total research and teaching experience was 19 years at various positions: Engineer-R&D, Assistant Professor, Associate Professor, Professor, HoD, Professor and Principal; at present working for Sri Sivani College of Engineering, Srikakulam, AP, India as a Professor and Principal. Published more than **75** Research papers, Articles, Book chapters of reputed at national and international level (ASME, SAE, SPRINGER, IEEE, JAFM, AIP, EBSCO International, Tata Mac-Graw Hills, and Pearson etc). Visited few of the countries for presenting research work like Paris and London. He was Awarded/Selected/Nominated for Best paper award for World congress on Engineering, London; Best Indian educationist and Bharat Excellence awards with gold medals received from honorable Governor of Sikkim, Indira Gandhi Gold medal award, National Award of Excellence, Green ThinkerZ-Outstanding Researcher Award for his contribution in the relevant fields of engineering and service. His research interests include thermal Engineering-Internal Combustion Engines, Automobile pollution, CFD, In-cylinder Flow studies, Image processing, Alternate fuels, Renewable energies etc.