

Effect of Manifold Orientation on Non-Reacting In-Cylinder Tumble Flows in an IC Engine with Pentroof Piston - An Investigation Using PIV

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ABSTRACT

This paper deals with experimental study of in-cylinder tumble flows in a single-cylinder, four-stroke, two-valve internal combustion engine using a pentroof-offset-bowl piston under non-reacting conditions with four intake manifold orientations at an engine speed of 1000 rev/min., during suction and compression strokes using particle image velocimetry. Two-dimensional in-cylinder tumble flow measurements and analysis are carried out in combustion space on a vertical plane passing through cylinder axis. Ensemble average velocity vectors are used to analyze the tumble flows. Tumble ratio (TR) and average turbulent kinetic energy (TKE) are evaluated and used to characterize the tumble flows. From analysis of results, it is found that at end of compression stroke, 90° intake manifold orientation shows an improvement in TR and TKE compared other intake manifold orientations considered. Also, 90° intake manifold orientation shows an improvement in TR and TKE are higher by about 2.8 and 1.2 times respectively compared to standard intake manifold orientation. The present study will be useful in understanding effect of intake manifold orientation on the in-cylinder tumble flows under real engine conditions..

Keywords

In-cylinder tumble flow, Intake manifold, Velocity vector field, PIV

INTRODUCTION

In-cylinder flows in an internal combustion (IC) engine have a direct bearing on engine combustion, performance and emissions characteristics. Now-a-days, lean-burn combustion has become one of the most promising concepts for

improving fuel economy and reducing exhaust emissions in modern spark ignition (SI) engines. However, lean burning is associated with high cycle-by-cycle combustion variations due to reduced flame initiation and propagation rates and also associated with high hydrocarbon emissions. Engine stability under lean operating conditions can be improved by reducing combustion variations through enhanced mean flow and turbulence of mixture. In conventional SI engines also, proper in-cylinder flows are very much essential in order to promote flame propagation speed. Formation of a tumbling vortex is an effective way to enhance pre-ignition turbulence and promote faster burning rates [1, 2]. In-cylinder flows are highly complex and are greatly influenced by intake manifold orientation, combustion chamber shape, compression ratio, engine speed, etc.

Heywood reported that generating a significant vortex flows inside an IC engine cylinder during intake process generates high turbulence intensity during later stages of compression stroke leading to fast burning rates [3]. Khalighi used flow visualization and particle tracking velocimetry (PTV) to study in-cylinder flows in a four-valve engine during intake process [4]. He reported that in-cylinder flows during intake process were comprised of several large-scale vortex motions. Also he reported that swirl and tumble flows should be optimized in order to optimize turbulence for achieving good combustion. Kent *et al.*, and Hill and Zhang studied intake-generated in-cylinder flows and subsequent combustion characteristics [5, 2]. They reported that burn duration decreased with increase in tumble or swirl strengths. Arocoumanis *et al.*, reported that generation of a strong tumble motion resulted in release of higher turbulent kinetic energy during its breakdown at later stages of compression stroke [1]. Hardyono *et al.*, investigated in-cylinder swirl and tumble flows using a model of a single-cylinder, compressed natural gas (CNG) direct injection engine with two piston



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shapes [6]. They reported that combustion chamber shape basically did not alter global in-cylinder air motion, but it affected velocity fields closer to piston top surface at later stages of compression stroke, where fuel and spark were supplied. *Margary et al.*, investigated effect of intake manifold length on volumetric efficiency and in-cylinder flows by laser doppler velocimetry (LDV) in a four-stroke, single-cylinder direct injection (DI) diesel engine [7]. They reported that mass flow rate of air and pressure drop across port were functions of manifold length and engine speed. Also, they reported that turbulence intensity was less affected by intake conditions. *Kern et al.*, made measurements using LDV in a small four-valve engine to understand formation and decay mechanism of tumble flows and their effect on turbulence [8]. *Lee et al.*, optimized intake port shape for development of a high efficiency gasoline engine [9]. They varied distance from base of combustion chamber to centre of intake port entrance from 40 to 60 and 80 mm. This significantly affected intake air flow rate and the tumble flows. *Kim et al.*, studied the in-cylinder flows during intake and compression strokes in a four-valve, pentroof, SI engine under motoring conditions and compared results with those of LDV [10]. They reported that tumble ratio and average fluctuating velocity remain approximately constant or marginally increased owing to spinning up phenomenon near top dead centre (TDC) after rapid decay of strong intake flow and turbulence during compression stroke. *Payri et al.*, studied 3D flow calculations of intake and compression stroke of a four-valve DI diesel engine with different combustion chambers using computational fluid mechanics (CFD) and compared with LDV measurements [11]. Their results confirmed that the piston geometry had little influence on the in-cylinder flows during the intake stroke and first part of the compression stroke. However, the piston bowl shape plays a significant role near TDC and in early stage of the expansion stroke by controlling both the ensemble-averaged mean and the turbulence velocity fields.

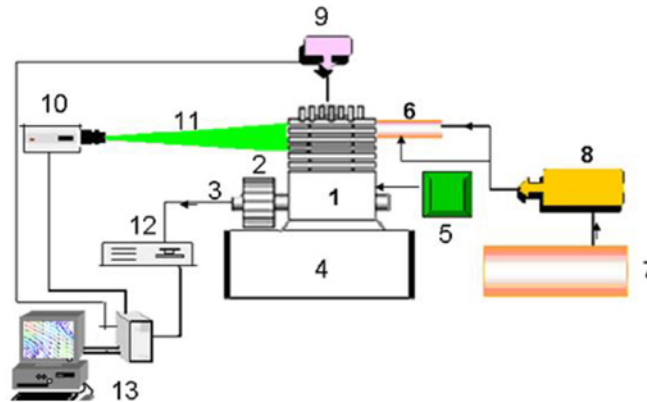
Previous investigations show that a good understanding of in-cylinder flow structures in an IC engine is very much essential in order to optimize the engine parameters. It seems that there is a limited study on effect of intake manifold orientation on in-cylinder tumble flow characteristics. Therefore, present study deals with investigations of in-cylinder tumble flow structures in a single-cylinder, two-valve, IC engine using a pentroof-offset-bowl piston. Type of piston shape used in this study is similar to that of pentroof pistons used in 4-valve engine [12, 13]. Therefore, same terminology has been used throughout with different intake manifold orientations under non-reacting (motoring) conditions at an engine speed of 1000 rev/min., at various crank angle degrees (CADs) during suction and compression strokes using PIV. In this study, even though two-valves are used, the primary intension of the present study is to analyze how the orientation of the intake manifold affects the in-cylinder tumble flows. If four-valves are used, the tumble

generation may be enhanced further compared to two-valves which basically magnifies the effect.

EXPERIMENTAL SETUP AND EXPERIMENTS

In this study, a single-cylinder, four-stroke, two-valve, air-cooled engine is used for conducting experiments. The specifications of engine are given in [Table 1](#) of [Appendix](#). The engine is coupled to an induction motor of 3.7 kW with maximum speed of 1500 rev/min., through an electronic speed controller. In this study, engine is run at a speed of 1000 rev/min. In order to facilitate the PIV measurements, an extension of cylinder liner is made using a transparent cylinder ring of plexiglass to a height of 35 mm above original metal liner. It facilitates a field of view (FOV) of size 87.5 by 35 mm ([Fig.3a](#)). In order to maintain required compression ratio of 10:1, piston crown height is raised accordingly. Intake manifold of engine is connected to a plenum to mix, and supply the air and seeding particles with uniform distribution. Schematic and photographic view of experimental setup is shown in [Figs.1](#) and [2](#) respectively. In this study, analysis with different intake manifold orientations is done using a pentroof-offset-bowl piston. In this study, for all the intake manifold configurations, intake pressure is maintained equal to atmospheric and intake temperature equal to 28°C. To measure volumetric efficiency of engine, an air surge tank with a positive displacement dry meter is connected to the engine for the purpose of measuring air flow rate. It was observed that the volumetric efficiencies at an engine speed of 1000 rev/min., was about 92.5, 92.2, 92.6 and 92.6% corresponding to zero, 30, 60 and 90° of intake manifold orientations respectively.

The PIV system consists of a double pulsed ND-YAG laser with 200 mJ/pulse energy at 532 nm wave length, a charge coupled device (CCD) camera of resolution 2048 by 2048 pixels with a frame rate of 14 per second and a set of laser and camera controllers, and a data acquisition system and a software ([Fig.1](#)). Triggering signals for the laser and the camera are generated by a crank angle encoder mounted on engine crankshaft with a resolution of one crank angle degree (CAD) and are supplied to controllers via a signal modulator. A master signal of crank angle encoder is set to occur at suction top dead center (TDC) of engine (considered as a zero CAD). Scheme of triggering for laser and camera can be set within the software. A seeding unit is used to generate fine particles of one micron size with di-ethyl-hexyl-sebacat ($C_{26}H_{50}O_4$) as a seeding material. Seeding density is controlled accurately by varying the pressure of air supplied to seeding unit. Laser sheet of 0.5 mm thickness is aligned with and camera is placed to view the FOV which is set on a vertical plane passing through axis of engine cylinder ([Fig. 3b](#)).



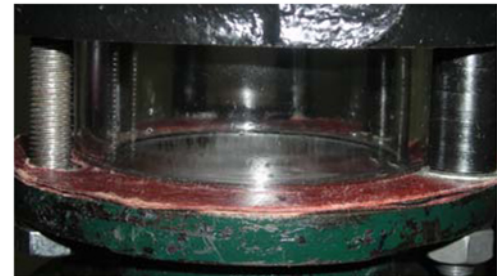
1. Engine, 2. Motor, 3. Encoder, 4. Test bench, 5. Speed controller, 6. Intake plenum, 7. Air compressor, 8. Seeder, 9. Camera, 10. ND-YAG Laser, 11. Laser sheet, 12. Signal modulator, 13. Data acquisition system

Fig.1. Schematic diagram of experimental setup

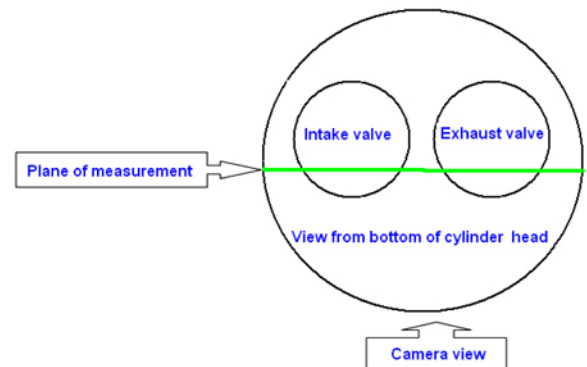
In this study, in-cylinder tumble flow measurements are done during intake (30 to 180 CADs) and compression (210 to 330 CADs) strokes in a step of 30 CAD. At every measuring point, 500 image pairs are recorded and stored. Time interval (Δt) between two successive images is evaluated ($10\ \mu\text{s}$ for suction and $12\ \mu\text{s}$ for compression strokes) based on the pixel shift of 5, FOV, maximum expected velocity of fluid in FOV and resolution of the camera [14,15,16,17]. To minimize the light reflections, a band-pass filter of central wavelength of 532 nm is mounted on the CCD camera. During PIV recording, camera focus is set to 8 to obtain sharp particle images with less noise. LaVision's DAVIS (data acquisition and visualization software) is used for image acquisition and data post-processing. During post-processing, interrogation window size of 32 by 32 pixels with multi-pass cross-correlation algorithm is used [18]. The ensemble average velocity vectors are computed from 500 raw image pairs at required CAD.

Main objective of the present study is to investigate effect of intake manifold orientation on in-cylinder tumble flows. The layout of the cylinder head showing relative position of valves is as shown in Fig.4. The schematic diagrams of different intake manifold orientations used in this study are as shown in Fig.5. Angle of orientation, Φ , is defined as angle between horizontal plane and axis of intake manifold. Photographic views of various intake manifold orientations in assembled position are shown in Fig.6. In the Fig.6, a green lines with red ellipses show zero and 90° intake manifold orientations. In this study, it is to be noted that, angles of port and intake manifold are kept the same. For all the intake manifold orientations, compression ratio of 10:1 is used.

<figure 2 here>



(a). Transparent cylinder liner for optical access



(b). Green line showing plane of measurement

Fig.3. Optical window and plane of measurement



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|---------------------|-------------------------|---------------------------|
| 1. Engine | 6. Transparent cylinder | 12. Seeder |
| 2. Motor | 7. Intake plenum | 13. Regulator |
| 3. Test bench | 8. Exhaust | 14. Compressor connection |
| 4. Encoder | 9. Air intake | 15. Seeding supply |
| 5. Laser controller | 10. CCD Camera | 16. Coupling |
| | 11. Laser | |

Fig.2. Photographic view of the test rig