Cold Flow Study at 330 CAD for Control of Emission with Different Intake Manifolds of a Single Cylinder Internal Combustion Engine

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ABSTRACT-The modern spark ignition (SI) internal combustion (IC) engines like stratified charged and gasoline direct injection (GDI) engines are becoming very popular now a days because of their *low fuel consumption and low exhaust emissions*. GDI engine, main requirement is to create charge stratification, which is achieved by well guided in-cylinder air flows. For optimization of modern IC engines, it is very much essential to understand in-cylinder air flow behavior under different operating conditions and configurations of IC engine. Today, an optical tool like Particle Image Velocimetry (PIV) is extensively used for in-cylinder flow measurements. This paper deals with experimental study of in-cylinder flow structures of a single-cylinder Internal Combustion (IC) engine with original and modified intake manifolds, at 330 crank angle degrees (CADs) during cold flow using Particle Image Velocimetry (PIV). To characterize the tumble flow, tumble ratio (TR) and average turbulent kinetic energy (ATKE) are used. At the end of compression stroke, original intake manifold shows two times higher TR and 4.3 times higher ATKE compared to modified.

Keywords: *Manifold, Modified, Piston, Standard, Vector field.*

I. INTRODUCTION

Today, stratified lean-burn spark-ignited (SI) engines are extensively used in many applications due to their better fuel economy and lower emissions. The most practical approach for improving engine stability under lean mixture conditions is to shorten combustion duration through enhanced mean flow and turbulence of the mixture. The formation of a tumbling vortex is an effective way to enhance preignition turbulence and promote faster burning rates [1 and 3]. The in-cylinder flows are unsteady and influenced greatly by orientation of the intake system, combustion chamber shape, compression ratio, engine speed, etc. Generating a significant vortex flows inside the IC engine cylinder during the intake process generates high turbulence intensity during the later stages of compression stroke leading to fast burning rates [2]. The in-cylinder swirl and tumble flows should be maximized in order to maximize the turbulence for achieving good combustion [5]. In the literature, there is a limited study on the effect of intake manifold orientation on the in-cylinder tumble flow characteristics. Therefore, the present study deals with the PIV investigations on in-cylinder tumble flow structures of a motored IC engine equipped with pentroof piston with different intake manifold orientations at 1000 rev/min., at 330 crank angle degrees (CADs) during clod flow (suction and compression strokes) using PIV.

II. EXPERIMENTAL WORK

In this study a single-cylinder, four-stroke, two-valve, air-cooled engine used and specifications are given in the following Table1. The experimental setup is shown in Fig.1. The engine is coupled to an induction motor of 3.7 kW through an electronic speed controller. The motor along with the engine is run at a speed of 1000 rev/min. In order to facilitate the PIV measurements, an extension of the cylinder liner is made using a transparent cylinder ring. It facilitates a field of view (FOV) of size 87.5 by 35 mm; accordingly maintained the required compression ratio of 10:1. The intake manifold of the engine is connected to a plenum to mix and supply the air and seeding particles with uniform mixing. In this study, analysis with different manifold orientations is done using a pentroof piston. First orientation is the standard (original) one and second is the modified one as shown in Fig.2, which is perpendicular to the standard orientation. The PIV system used 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). The triggering signals for the laser and camera are obtained by a crank angle encoder mounted on the engine crankshaft with a resolution of one crank angle degree (CAD) and are supplied to the controllers via a signal modulator. A master signal of the crank angle encoder is set to occur at the suction top dead center (TDC) of the engine (considered as a zero CAD). The triggering signals for laser and camera at the required CAD can be set within the software. A seeding unit is used to generate the fine particles of one micron size with di-ethyl-hexyl-sebacat ($C_{26}H_{50}O_4$) as a seeding material. The seeding density is controlled accurately by varying pressure of air supplied to the seeding unit. In this study, in-cylinder tumble flow measurements are done during suction (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. The time interval (Δt) between the successive images is evaluated based on the pixel shift (5), FOV, maximum expected velocity of the fluid flow in FOV and the resolution of the camera [6 and 8]. To minimize the light reflections, a band-pass filter of central wavelength of 532 nm is mounted on the CCD camera. During post-processing, interrogation window size of 32 by 32 pixels with multi-pass cross-correlation algorithm is used. The ensemble average velocity vectors are computed from

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

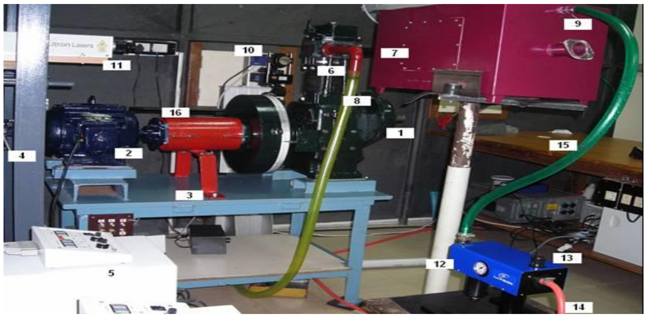

Fig.1: Photographic view of experimental setup

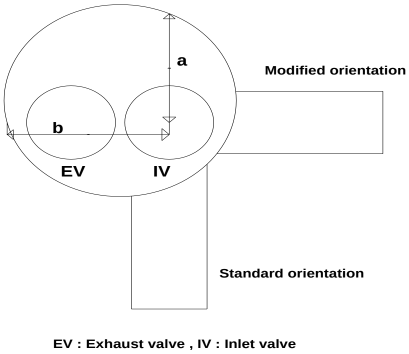

Fig.2: Position of standard and modified manifolds

Table I. Engine specifications

Bore x stroke (mm)	87.5 x 110
Engine type	4-stroke, 2-valve
No. of cylinders	1
Compression ratio	10:1
Rated engine speed (rrev/min.,)	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

III. RESULTS AND DISCUSSION

This paper mainly focuses on the in-cylinder tumble flow characteristics at the end of compression stroke (330 CAD), at which the fuel injection and spark supply occurs. The ensemble average velocity vector plots of in-cylinder tumble flows with superimposed streamline patterns at 330 CAD are shown in Fig.3, which are obtained from instantaneous velocity vector fields. In all the ensemble average velocity vector plots, a constant length for the velocity vector is used with a colour scale to represent their magnitudes. It is observed that, during suction stroke, in both the cases of intake manifold orientations, when the intake valve open for about 60% (at about 60 CAD), the strong predominant clockwise (CW) and counter clock wise (CCW) tumble vortices form. This may be due the impingement and deflection of air jet emerging from the intake ports on the cylinder wall and piston surfaces [5]. Generally, during compression stroke, it is observed that, the tumble vortex formed during the suction stroke gradually reduce in size with the crank angle position. This may be due to the global compression of the in-cylinder flows as a whole by the upward moving piston. It may be also due to the reduced cylinder space above the piston top. However, irrespective of the formation of vortex and air flow movement at the earlier stages of the cycle, a favorable air flow pattern needs to occur at 330 CAD which is very much needed for the stratified charge and direct injection SI engines [1and 3]. From Fig.3, it is observed that the standard intake manifold shows a better tumble vortex formation compared to modified intake manifold. It may be due to the favorable inclination of the standard intake manifold to create the better tumble vortex than modified intake manifold. However, for better comparison, TR and ATKE are estimated from ensemble average velocity fields are used as follows.

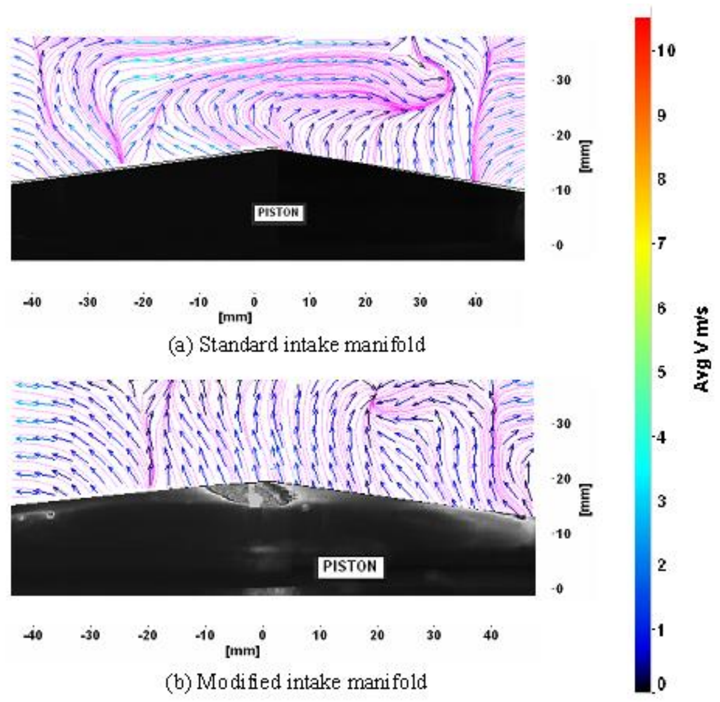

Fig.3: Velocity vectors with different intake manifolds at 330 CAD

A. *Variation of Tumble Ratio*

In this study, the quantitative analysis of the tumble flows is done by using TR as per *Huang et al.* [4]. 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 shaft. The negative or positive value of TR indicates the direction of the overall in-cylinder tumble flows in a given plane as CW or CCW respectively. Figure 4 shows the temporal variation of TR at different CADs during suction and compression strokes for different intake manifolds considered. From Fig.4, it is observed that the TR ratio is changing from negative to positive value or vice versa indicating the overall air movement changing from CCW to CW direction or vice versa. This may be due to the generation, stabilization, spin-up and decaying phenomena of the tumble flows which are due to conservation of the angular momentum [4 and 7]. At 330 CAD, the standard intake manifold shows TR of about 0.16, whereas modified intake manifold shows about 0.08. The TR is twice for standard manifold compared to that of modified one.

B. *Variation of Average Turbulent Kinetic Energy*

Figure 5 shows the variation of the ATKE with various CADs during suction and compression strokes for different intake manifolds considered. The ATKE of the flow indicates its strength as a whole and higher the value of it means higher strength of the flow. From Fig.5, it is observed that, ATKE is gradually increasing upto 60 CAD (at about 60% opening of the intake valve) and reaches the peak in all the cases. Then it drops rapidly upto 180 CAD and then gradually upto the end of compression stroke. It may be due to the fluid and wall friction at the cylinder wall. This may be attributed to the fact that, up to 60 CAD, the piston accelerating downwards with increase in inlet valve opening allowing more mass of air to enter into the cylinder space thereby increasing ATKE. However, after 60 CAD, the valve opening continues to increase, but piston starts decelerating; additionally cylinder is already filled with sufficient air causing flow to reduce resulting in reduced ATKE.

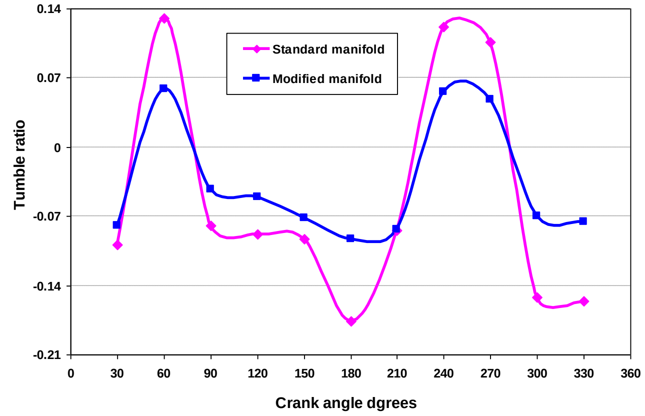

Fig.4: Tumble ratio with crank angle positions for different manifolds

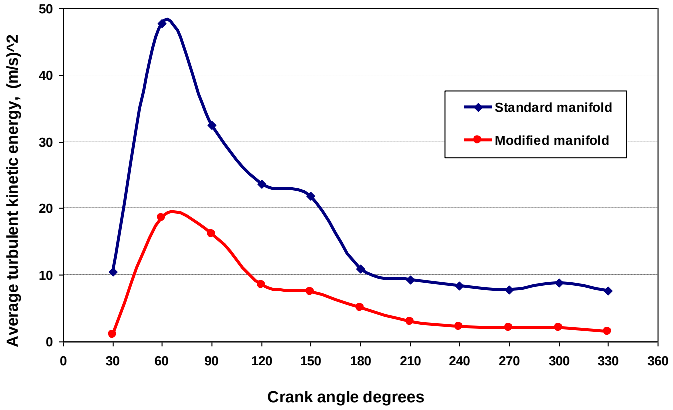

Fig.5: ATKE with CADs for different manifolds

From the analysis of results, it is found that, at end of compression (330 CAD), the standard intake manifold shows an ATKE of 7.6 m^2/s^2 compared to 1.51 m^2/s^2 of the modified intake manifold. The standard orientation with pentroof piston shows almost about 4.3 times higher ATKE compared to modified intake manifold orientation.

IV. CONCLUSIONS

From the PIV experimental study on tumble flows in an IC engine, conclusions drawn; the standard intake manifold showed two times higher TR and 4.3 times higher ATKE compared to modified intake manifold at 330 CAD.

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