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THE EFFECT OF INTAKE PORT INCLINATION ON IN-CYLINDER FLOW OF SMALL MOTORCYCLE ENGINE

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ABSTRACT

In-cylinder air flow structures are known to strongly impact on the performance and combustion of internal combustion engines (ICE). Therefore, the main objective of this study is to analyze the in-cylinder flow field characteristics of a single-cylinder small engine to see the effect of intake port inclination at equivalent rated engine speed using simulation model under various intake valve lift conditions. The variation of intake port inclination is -15˚, 0˚, 11.5˚, 15˚, 30˚ and 45˚. The engine geometry was created using SolidWorks, then exported and analyzed using commercial CFD method, CONVERGE. The result shows that the change of intake port inclination give effect to swirl ratio to be irregular shape. The bigger the inclination of intake port the smaller the irregular shape of swirl ratio. The change of intake port inclination also give effect to tumble ratio where the maximum tumble ratio occurs at -15˚. The bigger the inclination of intake port the smaller of the tumble ratio. The result shows that the in-cylinder flow structure is greatly influenced by the intake port inclinations irrespective of intake valve lift. Maximum Turbulent Kinetic Energy (TKE) was highest at full intake valve lift irrespective of the inclination. Also, the maximum TKE was the highest for -15˚ intake port inclination compared to other inclinations irrespective of the intake valve lift at equivalent rated engine speed. Based on the visualization of air flow in-cylinder engine, the air flow has the same tendency where vortices formation occurs below the intake valve. However, the change in the intake port inclination give effect to the change of the velocity magnitude. The bigger the inclination of the intake port the smaller the velocity flow at the in-cylinder engine will be. The maximum velocity occurs at the middle of in-cylinder engine. Finally, it is concluding that the analysis carried in this work is useful in predicting the flow and in-turn optimizing combustion chamber of modern internal combustion engines.

Keywords: intake port inclination, in-cylinder flow, small engine, motorcycles, converge

NOMENCLATURE

ICE	internal combustion engines
RNG	renormalized group
TKE	Turbulent Kinetic Energy
TR	Tumble Ratio
SR	Swirl Ratio

1. INTRODUCTION

In the last decades, internal combustion engine is the best available reliable power source for many sectors and applications especially in transportation sector. The big issue arises at the internal combustion engine efficiency. Every effort made to improve the internal combustion engines tends to get the maximum efficiency.

As it is well known that the intake and compression stroke process are two of the most important processes which influences the pattern of air flow structure coming inside cylinder during intake stroke. Especially for intake manifold, a deep knowledge of the intake processes in intake manifold is basic science to design and optimize modern internal combustion engines efficiently. Intake port is the important component of the internal combustion engine intake system which structure directly influence the air volume of entering cylinder, air velocity distribution and turbulence conditions [1, 2]. The development of the intake port systems efficiency is a key role in reducing exhaust emissions and fuel consumptions [3, 4].

Basically, there are two types of in-cylinder flow, swirl and tumble. The Swirl flow is a rotation of the charge about the cylinder axis and the tumble flow is a rotation orthogonal to the cylinder axis [5].

The flow field model in-cylinder engine can be measured using some tools like laser doppler anemometry (LDA) [6], hot wire anemometry (HWA) [7] and particle image velocimetry (PIV) [8], [9]. Another option to visualize the flow field model in-cylinder engine is using numerical method such as computational fluid dynamics (CFD). The advantages of this method are it gives accurate result, it easily detects the problem in engine design and it speeds up the phase of a project. Another advantage of CFD methods is a good chance to obtain detailed flow information about the whole flow field that may be difficult to get in experimental methods. CONVERGE is one of the CFD programs that omits the problem in grid generation from the process of simulation. Unlike others CFD programs, CONVERGE will produce a truly orthogonal and structured grid at runtime condition based on user-defined grid control parameters. This grid generation method completely eliminates the need to manually generate a grid [10].

The objective of this study is to analyze the in-cylinder flow field characteristics of a single-cylinder small engine to see the effect of intake port inclination at equivalent rated engine speed using simulation model under various intake valve lift conditions.

2. METHODOLOGY

2.1 Geometrical details

In this study, a 125cc single-cylinder gasoline engine with four strokes, four valves, and a flat piston was chosen for the CFD analysis. The detailed specifications of the engine are shown in Table 1. The engine geometry was created using SolidWorks. The geometry was then exported and modified in CONVERGE to produce an engine model for simulation calculations. The features of the geometrical model of original engine are showed in Fig. 1. Figure 2 shows the engine modification with different inclination of intake port.

Table 1 Engine Specification

Parameter	Value
Bore	57 mm
Stroke	48.8 mm
Displacement	125 cm^3
Compression ratio	10.2: 1
Diameter intake valve	22.03 mm
Maximum lift of intake valve	6.46 mm
Intake Valve Open/ Intake Valve Close	94º bTDC/70º aBDC

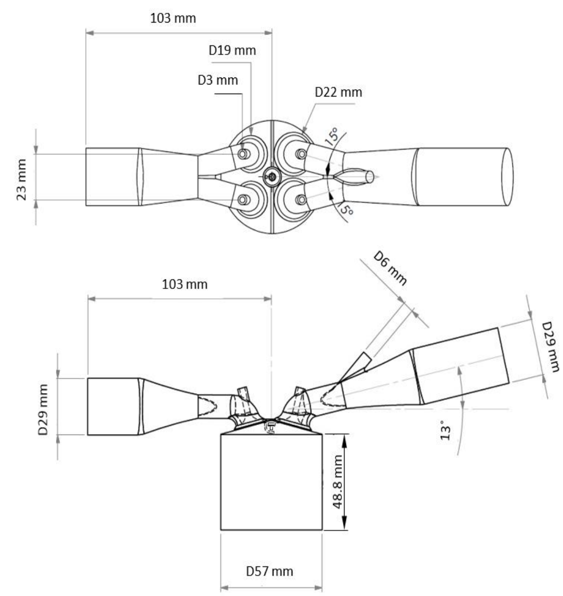


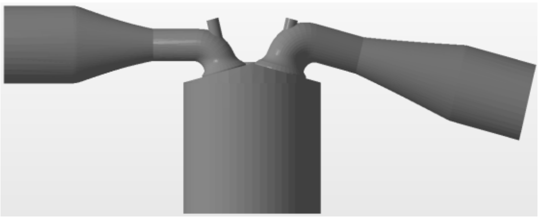
Fig 1 Geometry model of original engine

2.2 Boundary Condition

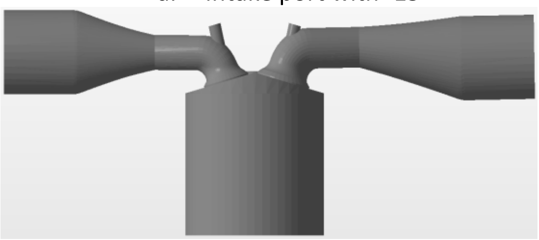
In this study, all boundaries were defined as stationary boundaries, except the valves and piston, which were defined as moving boundaries. The domain of the engine was divided into three regions i.e. cylinder, intake and exhaust. These three regions were connected, based on events described by the valve closing and opening with cyclic control type where all events were repeated over the specified period, 720 degrees. The inlet and outlet temperature and pressure were defined at 300 K and 1 bar, respectively. A summary of the boundary conditions is given in Table 2.

Table 2 Boundary Condition

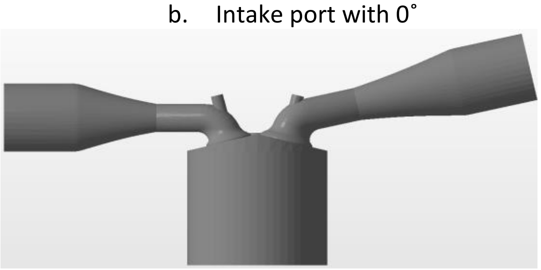
Parameter	Value
Inlet	Pressure inlet at 1 bar 300K
Outlet	Pressure outlet at 1bar 300K
Piston and valves	Moving walls
Cylinder, intake and exhaust ports	Stationary walls



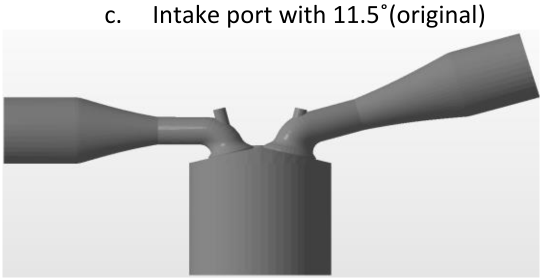
a. Intake port with -15˚



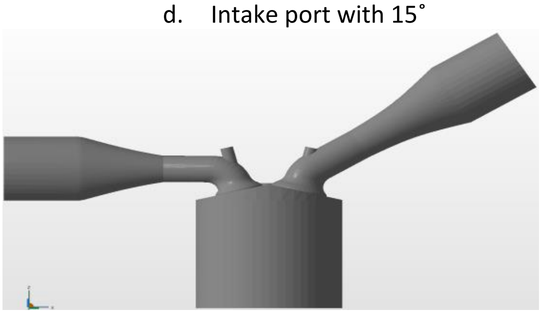
b. Intake port with 0˚



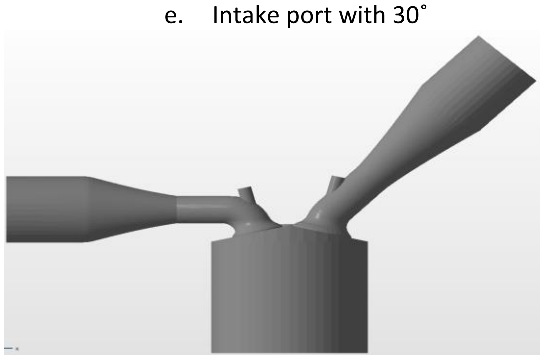
c. Intake port with 11.5˚(original)



d. Intake port with 15˚



e. Intake port with 30˚



f. Intake port with 45˚

Fig 2 The engine modification with different inclination of intake port

3. *RESULTS AND DISCUSSION*

In this section, some parameters of the in-cylinder flow of small engines based on the modification of intake port inclination (including swirl ratio, tumble ratio, TKE, and velocity magnitude) during the intake and compression strokes under motoring conditions, are presented and discussed.

3.1 In-cylinder swirl ratio

In this study, swirl flow was analyzed under motoring conditions at six different inclination of intake port. The comparison of the swirl ratios according to the crank angle at six different inclination of intake port (-15˚, 0˚, 11.5˚(original), 15˚, 30˚ and 45˚) during the intake and compression strokes is shown in Fig. 3. The swirl began to appear and form during the early phase of the induction process. This flow was up and down until around 500 °CA. The maximum swirl ratio was achieved at the middle stage of the intake stroke, around 450 °CA, and began to decrease after that point. However, the swirl ratio became stable and constant in the beginning of the compression stroke, until around 630 °CA. The change of intake port inclination give effect to swirl ratio to be irregular shape. The bigger the inclination of intake port the smaller the irregular shape of swirl ratio.

3.2 In-cylinder tumble ratio

In this study, the tumble flow was analyzed using the numerical simulation method. The change of in-cylinder tumble flow according to the crank angle can be seen in

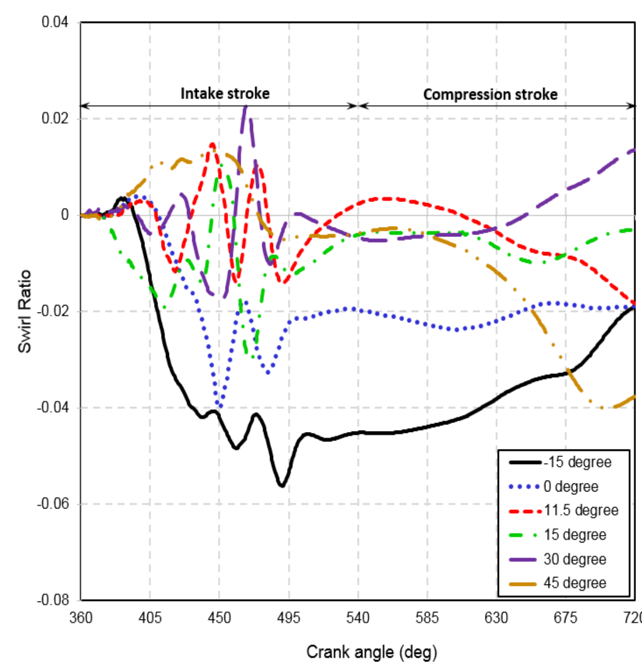


Fig 3 Swirl ratio

Fig. 4. Figure 4 shows the comparison of the tumble ratio with the crank angle for six different inclination of intake port (-15˚, 0˚, 11.5˚(original), 15˚, 30˚ and 45˚) during the intake and compression strokes under motoring conditions.

In-cylinder tumble flow can be divided into three phases: the generation phase, the stabilization-spin up phase, and the destruction phase. In this study, the generation phase occurred during the early stage of the intake stroke, increased up to 380 °CA, then began to fade out, and became zero at 400 °CA. From this point, the phase of stabilization-spin up began and achieved the top point at around 460 °CA as the intake valve achieved its maximum lift position. Then a progressive decrease occurred until intake valve closure around 540 °CA, as the incoming flow momentum to the cylinder through the valves decreased, and the cylinder volume increased to BDC. The tumble flow increased again during the compression stroke, up to 630 °CA, due to the conservation of angular momentum. The process of decreasing and increasing is called the stabilization-spin up phase because the tumble ratio changes its magnitude from negative to positive and vice versa, expressing the change in the direction of the overall air movement during the cycle. The next phase in tumble flow is the destruction phase, which occurred at the last stages of the compression stroke, from 630 °CA up to 720 °CA. There was a rapid decrease in the tumble ratio due to dissipation.

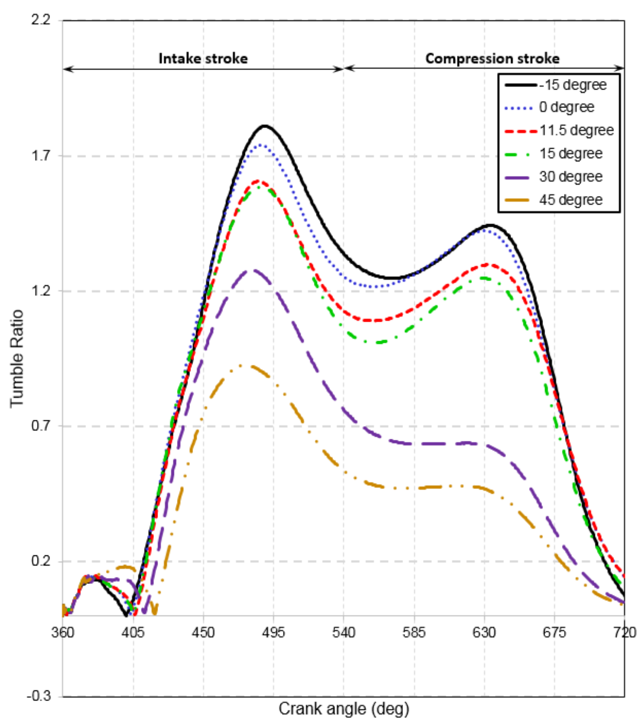


Fig 4 Tumble ratio

Regarding the effect of modification of intake port inclination, it can be observed that the change of intake port inclination also give effect to tumble ratio where the maximum tumble ratio occurs at -15°. The bigger the inclination of intake port the smaller of the tumble ratio.

3.3 In-cylinder turbulent kinetic energy (TKE)

TKE is the average value of kinetic energy per unit mass in the turbulent flow, which is physically characterized by the measure of the root-mean-square (RMS) from velocity fluctuations. TKE is an in-cylinder flow parameter important in determining turbulent viscosity. Figure 5 shows the comparison of TKE versus CAD for six different inclination of intake port (-15˚, 0˚, 11.5˚(original), 15˚, 30˚ and 45˚) during intake and compression strokes under motoring conditions. From Fig. 5, it can be observed that there were two peaks in the TKE. The first peak was reached in the middle of the intake stroke, around 460 °CA. However, it then rapidly dropped, and rebounded to achieve the second peak at around 680 °CA. The second peak appeared lower than the first peak and occurred at the last stages of the compression stroke process. Regarding the effect of modification of intake port inclination, it can be observed that the change of intake port inclination also give effect to TKE where turbulent kinetic energy (TKE) of intake port with -15° has the biggest value. This intake port model also has a clearly of two-peak of TKE if compare to the other model.

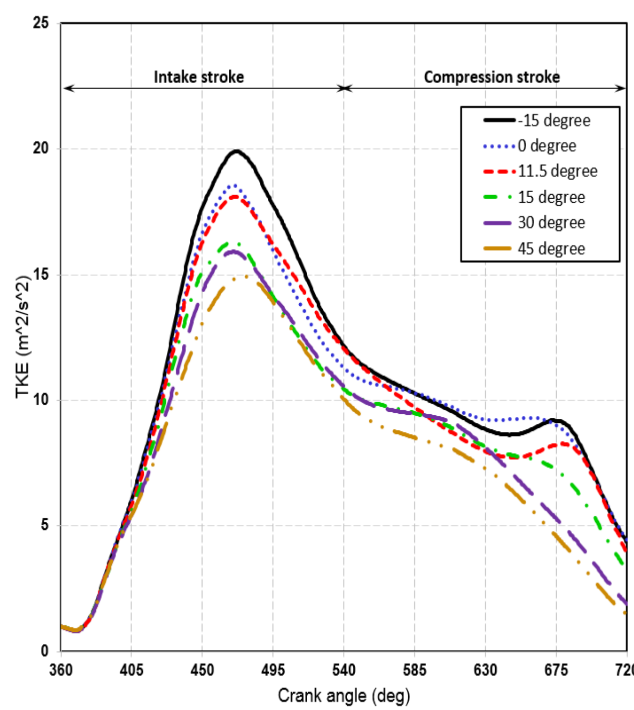


Fig 5 TKE

3.4 Velocity magnitude for in-cylinder flow pattern

Figures 6 show the comparison of velocity magnitude for in-cylinder flow field with different crank angles, along a sectional x-y plane (z=-5.4 mm) passing through the in-cylinder small engine, for six different inclination of intake port (-15˚, 0˚, 11.5˚(original), 15˚, 30˚ and 45˚) under motoring conditions during intake and compression strokes. Based on the visualization of air flow in-cylinder engine, the air flow has the same tendency where vortices formation occurs below the intake valve. However, the change in the intake port angle give effect to changes the velocity magnitude. The bigger the angle of the intake port the smaller the velocity flow at the in-cylinder engine. The maximum velocity occurs at the middle of in-cylinder engine

4. CONCLUSIONS

From the results, the following conclusions were established:

- The change of intake port angle give effect to swirl ratio to be irregular shape. The bigger the angle of intake port the smaller the irregular shape of swirl ratio.
- The tumble ratio maximum occurs at intake port with -15°. The bigger the angle of intake port the smaller of the tumble ratio.
- Similar with tumble ratio, turbulent kinetic energy (TKE) of intake port with -15º has the biggest value. This intake port model also has a clearly of two-peak of TKE if compare to the other model. The second peak of TKE is important thing for ignition process in-cylinder engine.
- Based on the visualization of air flow in-cylinder engine, the air flow has the same tendency where vortices formation occurs below the intake valve. However, the change in the intake port angle give effect to changes the velocity magnitude. The bigger the angle of the intake port the smaller the velocity flow at the in-cylinder engine. The maximum velocity occurs at the middle of in-cylinder engine

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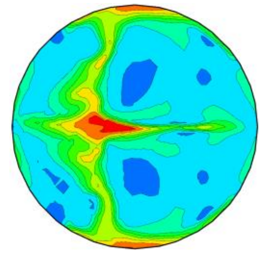
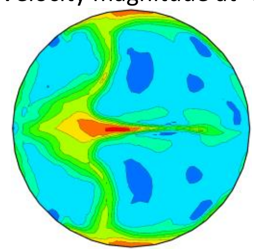
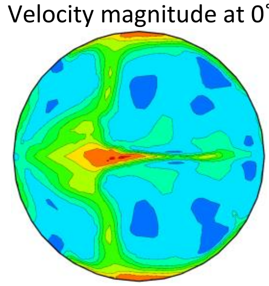


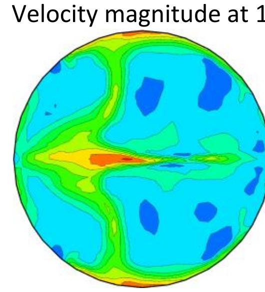
a. Velocity magnitude at -15˚



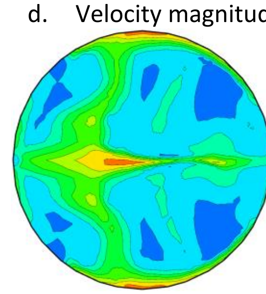
b. Velocity magnitude at 0˚



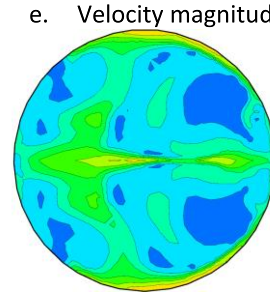
c. Velocity magnitude at 11.5˚(original)



d. Velocity magnitude at 15˚



e. Velocity magnitude at 30˚



f. Intake port with 45˚

Fig 6 The Velocity magnitude

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