DESIGN AND SIMULATION OF PRECHAMBER WITH HIGH PRESSURE CNG INJECTOR SYSTEM FOR SINGLE CYLINDER FOUR STROKE ENGINE

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ABSTRACT

This thesis presents an ignition system to improve engines efficiency. The method used in this study is by using a prechamber as a pre-ignition system for the engine, where the prechamber is located at the top of cylinder head. Prechamber is an ignition technology which can improve engines efficiency. Previous research indicates that the prechamber is responsible for engine out emission. In this project, four concepts of prechamber designs are developed with objective to improve the engines efficiency. The design variable is the volume of the prechamber. Solidworks 2010 software was used for designing process while Ansys 12.1 software was used to perform the simulation of the engine with prechamber. The results of maximum in cylinder pressure and temperature from the simulation are used to determine the best prechamber model. Yamaha FZ150i engine has been chosen as the baseline engine for this project. The engine are disassembled for the measurement process and then modelled in solidworks as a computational domain for the simulation process. The engine is simulated at engine speed of 2000 rpm. The simulation process can be divided into two types which are cold flow simulation and combustion simulation. The result from the simulation shows that the prechamber model that have lowest volume give the maximum in cylinder pressure and temperature which are 19.12 bar and 360.425 K for the cold flow simulation while for the combustion simulation the maximum in cylinder pressure and temperature are 47.54 bar and 2620.7384 K. This results shows that when the volume of the prechamber is low, the compression ratio of the engine is kept high. Compression ratio is the main factor that affecting the value of in cylinder pressure and temperature.

ABSTRAK

Tesis ini berkaitan dengan sistem pencucuhan untuk meningatkan kecekapan enjin. Kaedah yang digunakan dalam kajian ini ialah dengan menggunakan pra kebuk pembakaran sebagai sistem pencucuhan bagi enjin dimana pra kebuk pembakaran tersebut di pasang di atas kepala silinder. Pra kebuk pembakaran adalah satu teknologi yang dapat meningkatkan kecekapan enjin. Kajian terdahulu menunjukkan bahawa pra kebuk pembakaran mempengaruhi pelepasan gas dari enjin. Dalam projek ini, empat reka bentuk pra kebuk pembakaran telah dicipta dengan tujuan untuk meningkatkan kecekapan enjin. Kesemua reka bentuk pra kebuk pembakaran tersebut mempunyai isipadu yang berbeza. Perisian solidworks telah digunakan bagi tujuan merekabentuk pra kebuk pembakaran tersebut manakala perisian Ansys 12.1 digunakan bagi tujuan membuat simulasi pada pra kebuk pembakaran yang telah dipasang pada enjin. Keputusan daripada simulasi iaitu tekanan dan suhu yang paling tinggi akan digunakan untuk menentukan reka bentuk pra kebuk pembakaran yang paling bagus. Yamaha FZ150i telah dipilih sebagai reka bentuk asas model enjin. Enjin dibuka bagi tujuan pengukuran dan di model menggunakan solidworks untuk menjalankan proses simulasi. Simulasi enjin dijalankan pada kelajuan enjin 2000 rpm. Proses simulasi boleh dibahagikan kepada dua jenis iaitu pembakaran simulasi dan tanpa pembakaran simulasi. Keputusan daripada simulasi menunjukkan bahawa model pra kebuk pembakaran yang mempunyai isipadu yang rendah menghasilkan tekanan dan suhu yang tinggi di dalam silinder enjin iaitu 19.12 bar and 360.425 K untuk tanpa pembakaran simulasi manakala untuk pembakaran simulasi, tekanan dan suhu yang paling tinggi ialah 47.54 bar dan 2620.7384 K. keputusan ini menunjukkan bahawa apabila isipadu pra kebuk pembakaran rendah, nisbah mampatan enjin tersebut akan meningkat. Nisbah mampatan ialah faktor utama yang mempengaruhi tekanan dan suhu di dalam enjin.

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LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
ATDC	After top dead center
BTDC	Before top dead center
ABDC	After bottom dead center
BBDC	Before bottom dead center
CA	Crank angle
CFD	Computational Fluid Dynamics
CO_2	Carbon dioxide
CH_4	Methane
MPI	Multi-point injection
DI	Direct injection
ICE	Internal combustion engine
K	Kelvin
NO_x	Nitrogen oxides
SI	Spark ignition
CI	Compression ignition
TDC	Top dead center

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter gives a short description of the project background including the approaches taken to achieve the objective of study. This chapter then introduces objectives, scopes, problem statement and the importance of this study on the design and simulation of a different prechamber model with high pressure CNG injector system for single cylinder four-stroke engine.

1.2 Project Background

The internal combustion engine is the one of the most challenging fluid mechanics problems to model because the flow is turbulent, compressible, unsteady, cyclic, and non-stationary, both spatially and temporally (Borman, 1987). The combustion characteristics are influenced by the fuel preparation process and the distribution of the fuel in the engine that is controlled by the in cylinder fluid mechanics. Traditionally, fuel was supplied into the engine combustion chamber through the carburettor. Latest technology uses the injector for the purpose of introduced fuel into the engine combustion chamber. Fuel injection system allows the injection quantity to be varied based on an input from sensors. This allows for more rapid engine response to throttle position change, more precise control of the equivalence ratio during cold-start warm-up, more uniform fuel distribution and improved volumetric efficiency (Han Z, 1997).

Conventionally, a four stroke engine is fuelled by drawing the air-fuel mixture into the combustion chamber through the intake manifold. The air and fuel is mixed at the intake manifold and then delivered to the combustion chamber. This process gives a homogeneous charge or homogeneous mixture of air and fuel. Homogeneous charge is where the air and fuel are uniformly mixed. A stoichiometric mixture contains the exact amount of air that necessary for combustion of the fuel (Lipatnikov, 2002). The homogeneous mixture give stable combustion, but give some reduction on engine's efficiency commonly fuel economy and emissions. Therefore, many of research attempts to improve fuel economy and emission of the engine. One way to improve engine's efficiency is by using stratified charge engine. The principal of stratified charge is where the combustion chamber has locally rich fuel and air mixture that close to the ignition source and leaner charger further away from the ignition source. The operation of stratified charge engine is by concentrating spraying of the fuel close to the spark plug rather than throughout the whole of the combustion chamber (Marble, 1977). Previous study has proved that this method deliver a reduction in fuel consumption that can reach 40% when the engine is running at very low charge (Schubert, 2005). Moreover, in stratified charge engine, the fuel is injected just before the ignition. This allows for the high compression ratios without "knock," and leaner air and fuel mixtures than in conventional internal combustion engines. Many of research attempts to improve fuel economy by running a lean mixture results in unstable combustion thus impact on power and emissions.

As an alternative, the use of prechamber or pre combustion chamber is one way to obtain stratified charge and achieve stable combustion (Shojaeefard, 2008). So the importance of this study is to analyze the combustion in single cylinder of four-stroke spark ignition engine with prechamber running compressed natural gas (CNG) as a fuel using Computational fluid dynamic (CFD) software. This simulation will simulate the fluid flow inside the engine. Hopefully this thesis will contribute to the development of more efficient and more environmental friendly internal combustion engines. This study focus on the performance of prechamber used in internal combustion engines burning very lean charge (much air and less fuel). Very lean premixed charge gives lower peak combustion temperature and less NOx will produce.

1.3 Problem Statement

Nowadays, many of research attempts to improve engine efficiency by running a lean mixture or stratified charge engine. The use of prechamber is one way to improve engine efficiency by running a lean mixture or stratified charge. So the main objective of this project is to design different geometry of prechamber and simulate it using Computational fluid dynamic software (CFD). The engine model used for this project is Yamaha FZ150i. This engine use indirect injection system which means the air and fuel mixture is mixed at the intake manifold and then flow to combustion chamber. This engine also uses gasoline or petrol as a fuel. So the purpose of this project is to convert this engine to use prechamber as pre ignition system but maintaining the cylinder head geometry which means no modification made to the cylinder head. Moreover, this engine will running compressed natural gas (CNG) as a fuel and use high pressure injector for the fuelling system.

1.4 Project Objective

1. To design and simulate different pre combustion chamber design for single cylinder four stroke engine.

1.5 Scope of Project

This project is fixed on four stroke single cylinder spark ignition engine running compressed natural gas (CNG) as a fuel. The type of engine used is liquid-cooled 4-storke, SOHC, 4-valve (Yamaha, 2010). The high pressure injector used is HDEV 5 Bosch injector model. The dimension of the engine is taken manually and modelled using third party software which is Solidworks 2010 software. Then computational domain model is meshed using Ansys Workbench software. The model then transfer to Fluent solver for further analysis. In order to reduce the computational time, the computational domain is developed in two-dimensional. The simulation for the model will consist of cold flow and combustion simulation.

1.6 Project Flow Chart

The flow chart of the overall procedure of the study is shown in Figure 1.1

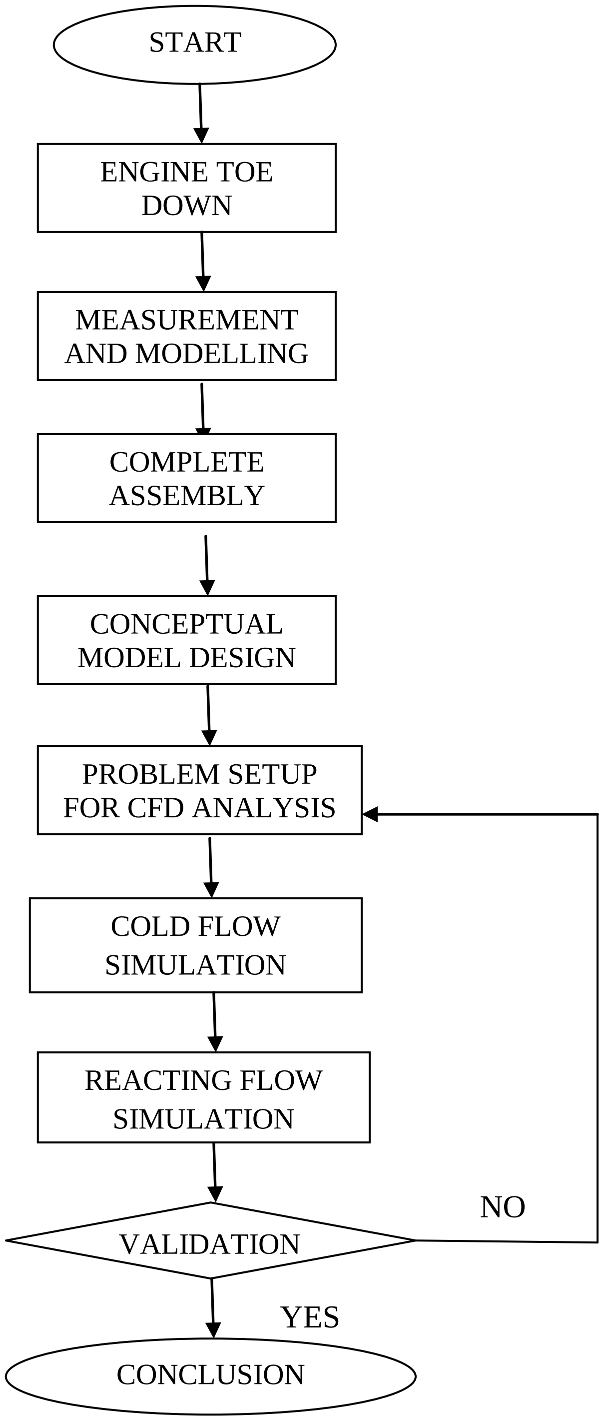

Figure 1.1: Project flow chart.

1.7 Summary

The used of prechamber as a pre-ignition system is the alternative to improve engine's efficiency which means reduce emission and fuel consumption. For fuelling system, the use of high pressure injector can help reduce fuel consumption. Using compressed natural gas as a fuel can help to reduce emission from the engines. The main goal of this project is to design and simulate different prechamber geometry for single cylinder four-stroke engine using Computational fluid dynamic software (CFD) or more specific using Ansys 12.1 software. A clear understanding of the fluid motion and dynamics process are needed to improve the design of prechamber.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to provide a review of past research effort related to internal combustion engine analysis of four-stroke single cylinder spark ignition engine using CNG as a fuel. This chapter will also include the research related to prechamber design and combustion modelling using CFD.

2.2 Background of Internal combustion engine

Internal combustion engine is refer to high energy of fuel enter the combustion chamber and mixed with air then have ignited and release incredible amount of energy (Pulkrabek, 1997). The most common fuels use for power generation are made up of hydrocarbons and are derived mostly from petroleum for examples diesel fuel, compressed natural gas (CNG), gasoline and petroleum gas, and the rarer use propane gas. The purpose of internal combustion engine is to produce mechanical power from the chemical energy contained in the fuel. Internal combustion engine is different from external combustion engine as the for internal combustion engine, the energy released from the fuel is inside the engine or inside the cylinder. The air-fuel mixture before the combustion and the burned products after combustion are the actual working fluid. The work or desired power outputs are transfer from this working fluid to the mechanical component of the engine. The internal combustion engine can be classified into two types of ignition system which are spark-ignition engine and compression ignition engine. Spark ignition engine (SI engine) used a conventional spark plug to ignite the air-fuel mixture inside the engine. For compression ignition engine, the combustion starts when the temperature inside the engine is high enough to ignite the air-fuel mixture inside the engine (Yasar, 2001).

2.2.1 Stratified charge engine

The stratified charge engine are commonly applies to direct injection petrol engines. It operations involves concentrating spraying the fuel close to the spark plug rather than throughout the whole combustion chamber (Pulkrabek, 1997). As a result this engine will produce a lean mixture of air and fuel. From previous research, this type of engine delivers a reduction in fuel consumption that can reach 40% when the engine is running at very low charge. The principle of stratified charge engine is to deliver a mixture that is sufficiently rich (much of fuel) for combustion closer to the spark plug and deliver a mixture that is lean (much air) throughout the whole combustion chamber. Traditionally, an air-fuel are mixed at the intake manifold then delivers to the combustion chamber. On an engine with stratified charge, the deliver power is no longer controlled by the quantity of air enter the combustion chamber, but by the quantity of fuel injected to the combustion chamber.

2.2.2 Basic Parameters of internal combustion engine

Bore and Stroke

For conventional internal combustion engine, the piston reciprocates in the cylinder between two fixed positions usually called the top dead center (TDC) and the bottom dead center (BDC). These two types of position are important to determine the location of the piston inside the cylinder. TDC is the position of the piston when it forms the smallest volume in cylinder and BDC is the position of the piston when it forms the largest volume in the cylinder. The diameter of the piston or cylinder is called the bore while the distance between the TDC and BDC is called the stroke of the engine.

Compression Ratio

There are also some other terms that must be understood first in order to making a research about an engine. The minimum volume formed when the piston is at TDC position is called the clearance volume. The volume between the piston at TDC and BDC is called displacement volume or swept volume. The compression ratio is the ratio of maximum volume formed in the cylinder to the minimum volume as shown in equation 2.1 (Pulkrabek, 1997):

$$r = \frac{Vmax}{V\ min} \tag{2.1}$$

Mean Piston Speed

A parameter that important for calculation the engine behaviour as a function of speed is the mean piston speed. The formula is as shown in equation 2.2 (Pulkrabek, 1997):

$$Up = 2LN \tag{2.2}$$

where *L* stand for stroke and *N* stand for rotational speed of crankshaft.

Air/Fuel Ratios

Air-fuel ratios are the ratio of air and fuel that mixed inside the combustion chamber. In engine testing, the air mass flow rate and fuel mass flow rate are measured. The ratio of these flow rates can be defined as shown in equation 2.3 (Pulkrabek, 1997):

$$AF = \frac{ma}{mf} = \frac{\dot{m}a}{\dot{m}f} \tag{2.3}$$

where *ma* stand for mass of air and *mf* stand for mass of fuel.

Brake Torque and Power

Torque is a measure of an engine's ability to do work and power is the rate at which work is done. The term brake power w_b, is used to specify that the power is measured at the output shaft, this is the usable power delivered by the engine to the load. The brake power is less thatn the power generated by the gas in the cylinders due to mechanical friction and parasitic loads. The brake torque can be measured using the equation 2.4 (Pulkrabek, 1997):

$$T = Fb \tag{2.4}$$

Where *F* stand for force and *b* stand for the distance between centre of rotor and force.

Power can be defined as the rate at which work is done. The brake power can be calculated using the equation 2.5 (Pulkrabek, 1997):

$$P = 2\text{p}\ NT \tag{2.5}$$

where p stand for angular speed, *N* stand for crankshaft rotational speed and *T* stand for torque.

Mean Effective Pressure (MEP)

This is the important terms that used to predict the engine efficiency and performance. Mean effective pressure is a fictitious constant pressure that would produce the same work per cycle if it acted on the piston during the power stroke. MEP can be calculated using equation 2.6 (Pulkrabek, 1997):

$$MEP = \frac{W\ net}{Vmax - Vmin} \tag{2.6}$$

2.2.3 Spark-ignition engine operation

Conventionally, in spark ignition (SI) engines, the air and fuel are mixed in the intake manifold then flow to the engine combustion chamber. The fuel is supplied through carburettor or injection system. The term spark-ignition engine means that the air-fuel mixture is ignited with a spark to start the combustion (Yasar, 2001). The term contrast with compression-ignition engines, where the heat from the compression will ignites the air-fuel mixture. Spark ignition engine can be either two-stroke or four-stroke engine.

2.2.4 Four stroke engine

The four stroke engine was first demonstrated by Nikolaus Otto in 1876, hence it is also known as the *Otto cycle*. The technically correct term is actually *four stroke cycle*. The four strokes is referring to intake stroke, compression stroke, combustion or power stroke, and exhaust stroke. The four-stroke engine will produce one power for two cycles or two crankshaft rotation where the two-stroke engine will produce one power for single cycle.

Basic operation of four stroke engine

The four-stroke engine most commonly use in all kind of vehicles such as cars, motorcycles, trucks, machinery and many others. The stroke is referring to intake stroke, compression stroke, combustion or power stroke, and exhaust stroke that occur during two crankshaft rotations per working cycle of the engine.

Intake

During the intake stroke, the piston is moving downward and draws a fresh charge of vaporized air-fuel mixture from the intake manifold to the combustion chamber. The air-fuel mixture enters the combustion chamber because of the vacuum created inside the combustion chamber. The pressure of the air-fuel mixture at the intake manifold is higher than the vacuum inside the combustion chamber thus forcing the mixture to enter the combustion chamber.

Compression

Compression stroke start when the piston is start moving upward from the BDC to the TDC. The piston is compressing the air-fuel mixture until the piston reach TDC.

Power

Before the piston reaches the TDC about 50 degree crank angle BTDC, the spark plug fires and ignites the compressed mixture. The energy released from the combustion will convert to usable work to move the piston downward.

Exhaust

At the bottom of the power stroke, the exhaust valve is opened by the cam/lifter mechanism. The upward stroke of the piston drives the exhausted gases that produce from combustion process out of the cylinder.

2.2.5 Indirect injection

The term indirect injection refers to internal combustion engine where the fuel is injected not directly into the combustion chamber. Usually, conventional gasoline engine are equipped with indirect injection system, where the fuel is injected at some point before the intake valve. An indirect injection diesel engine delivers fuel into a chamber off the combustion chamber called a prechamber. The pre ignition starts at the prechamber and then the hot gaseous spread into the main combustion chamber and ignite the mixture inside the combustion chamber. The prechamber is carefully designed as to ensure adequate mixing of the atomized fuel with the compression heated air. In an indirect injection system, the air is moving fast, mixing the fuel and air. So for indirect injection system, it is simpler to manufacture and more reliable because it is use low pressure injector. For direct injection system, its operation uses slow moving air and fast moving fuel thus need high pressure injector.

2.3 Combustion chamber design

To achieve maximum efficiency of the engine, the fuel that is injected into the combustion chamber must be mixed thoroughly with the compressed air and distributed as evenly as possible throughout the combustion chamber. There are several types of combustion chamber design that commonly and currently in use which are open chamber, precombustion chamber, and turbulence chamber.

2.3.1 Open combustion chamber (Direct injection system)

This is the simplest form of combustion chamber design as shown in figure 2.3. This type of combustion chamber is suitable only for slow speed, four-stroke cycle engines, but is widely used in two-stroke cycle diesel engines. This type of combustion chamber can also be called direct injection system. In the open combustion chamber, the fuel is injected directly into the combustion chamber.There are no special pockets, cells, or passages to aid the mixing of the fuel and air. This type of chamber requires a higher injection pressure and a greater degree of fuel atomization than is required by other combustion chambers to obtain an acceptable level of fuel mixing.

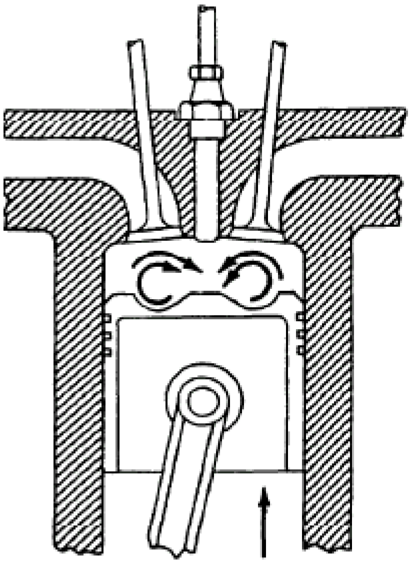

Figure 2.1: Open combustion chamber

Source: Pulkrabek, 1997

2.3.2 Precombustion chamber

The precombustion chamber is an auxiliary chamber at the top of the cylinder that is connected to the main combustion chamber by a restricted throat. The precombustion chamber acted as a pre ignition system to improve engine's efficiency. The following steps occur during the precombustion process. During the compression stroke of the engine, air is forced into the precombustion chamber and because the air is compressed, it is hot. At the beginning of injection, the precombustion chamber contains a definite volume of air. As the injection begins, combustion begins in the precombustion chamber. The burning of the fuel, combined with the restricted passage to the main combustion chamber, creates a tremendous amount of pressure in the combustion chamber. The pressure and the initial combustions cause a super heated fuel charge to enter the main combustion chamber at a high velocity. The entering mixture hits the hollowed out piston top, creating turbulence in the chamber to ensure complete mixing of the fuel charge with the air. This mixing ensures even and complete combustion. This chamber design provides satisfactory performance with low fuel injection pressure and coarse spray patterns because a large amount of vaporization occurs in the precombustion chamber. This chamber also is not very susceptible to ignition lag, making it suitable for high speed operations.

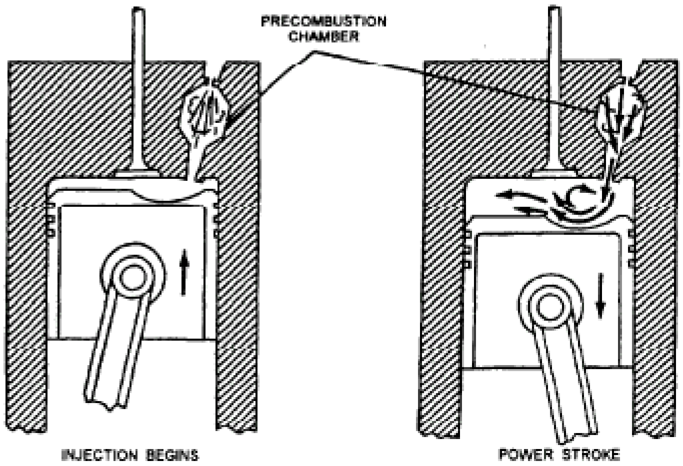

Figure 2.2: Precombustion chamber

Source: Pulkrabek, 1997

2.3.3 Turbulence chamber

The turbulence chamber(fig 2.5) is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so a high percentage of the air between the piston and cylinder head is forced into the turbulence chamber during the compression stroke. The chamber is usually spherical and the small opening through which the air must pass causes an increase in air velocity, as it enters the chamber. This turbulence speed is about 50 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is greatest. This ensure a thorough mixing of the fuel and air, causing the greater part of combustion to take place in the turbulence chamber. The pressure, created by the expansion of the burning gases, is the force that drives the piston downward on the power stroke.

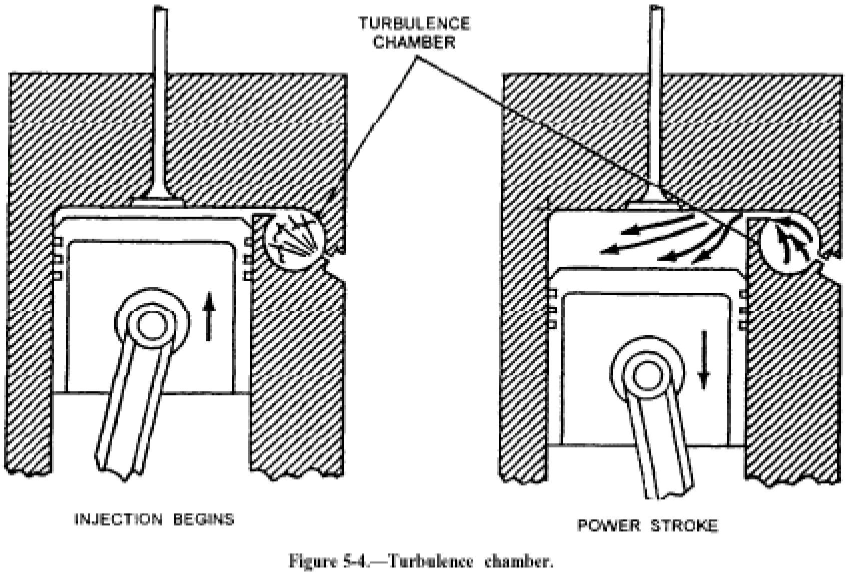

Figure 2.3: Turbulence chamber

Source: Pulkrabek, 1997

2.3.4 Advantages of prechamber

There are several advantages of using prechamber as ignition system to the engine for examples as an amplification of ignition energy level in main combustion chamber, for fast and complete combustion process, to reduced combustion pressure variations, to improved engine efficiency, to reduced NO_x emission level, lower voltage requirement for the spark ignition, high durability without maintenance, and better engine performance due to lower wear rates.

2.4 Compressed Natural Gas

Over the past 150 years, natural gas has been well accepted as the energy for the world of today and tomorrow to replace coal and oil. The public do not only need the energy for their living but they also want a better choice for the environment. Natural gas is the fuel that gives both heat and light and can be used as fuel in many sectors such as transportation, industrial, and agricultural.