STUDY OF SIGNAL PROCESSING OF ENGINE KNOCKING ON VEHICLE

Submitted by

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.
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I would also like to express my gratitude to my parents that always pray for me to successfully accomplish this task. In addition, I would also like to thank my entire course mate who always help me and give moral support when I encountered with problem and always ready to give their help without hesitation. I am very appreciating for everything and who does understand me as long completing this project.

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LIST OF ABBREVIATIONS

CPS	Crank Position Sensor
RPM	Revolution Per Minutes
IC	Internal Combustion
EC	External Combustion
SI	Spark Ignition
CI	Compression Ignition
ECU	Engine Control Unit
DAQ	Data Acquisition
TDC	Top death Center
BDC	Bottom Death Center
AFR	Air Fuel Ratio
N_2	Nitrogen
CO_2	Carbon Dioxide

ABSTRAK

Enjin merupakan alat yang digunakan bagi mengubah satu bentuk tenaga ke dalam bentuk yang lain seperti dari tenaga haba kepada tenaga mekanikal. Walau bagaimanapun, semasa proses mengubah tenaga dari satu bentuk ke bentuk yang lain, kecekapan penukaran pembakaran memainkan peranan yang sangat penting. Penentuan nisbah bahan api udara adalah faktor utama di mana kecekapan pembakaran ini telah dikenal pasti dalam enjin.

Ketukan enjin ini telah lama menjadi fenomena yang diiktiraf di dalam industri automotif. Mengesan ketukan enjin membuka kemungkinan untuk maklum balas tidak langsung pembakaran dalaman enjin tanpa memasang transduser tekanan di dalam silinder. Pengesanan ketukan telah lama menjadi keutamaan digunakan untuk kawalan bunga api, membenarkan ia untuk mengawal enjin tertutup kepada had ketukan dalam carian untuk masa pencucuhan yang optimum.

Mengesan ketukan enjin membuka kemungkinan untuk maklum balas tidak langsung pembakaran dalaman enjin tanpa memasang transduser tekanan di dalam silinder. Kajian ini dilakukan dengan menggunakan penderia mengetuk yang bersesuaian dalam aliran ekzos selepas proses pembakaran. Menggunakan nisbah udara / bahan api yang standard bagi enjin petrol, pengaturcaraan telah ditunjukkan untuk mengawal suntikan bahan api ke dengan enjin pembakaran dalaman dibuat menggunakan pengawal Arduino. Selanjutnya, data yang dikumpul dan di analisis serta dibandingkan dengan data ujikaji lain.

Tesis ini telah diserahkan untuk keperluan sebahagian daripada projek tahun akhir yang dinamakan Kajian Pemprosesan Isyarat enjin Mengetuk pada Kenderaan Menggunakan Sistem ‘Litar Tertutup’. Petrol dan diesel enjin digunakan secara meluas dalam industri dan bidang pertanian, dan ia mempunyai prestasi pembakaran dan ciri-ciri getaran yang berbeza bagi enjin pembakaran dalaman. Projek ini dikaji berdasarkan perubahan pemprosesan isyarat enjin mengetuk untuk enjin petrol. Ketukan enjin ini telah lama menjadi fenomena yang diiktiraf di dalam industri automotif.

ABSTRACT

An engine is a device or machine designed to convert one form of energy into another form which is from thermal energy to mechanical energy. However, while transforming energy from one form to another form, the efficiency of conversion plays an important role. From this, the air fuel ratio is the main factor where the efficiency of combustion is determined inside the engine.

Engine knock has long been a well-recognized phenomenon in the automotive industry. Detecting engine knock opens up the possibility for an indirect feedback of the engine's internal combustion without installing a pressure transducer inside the cylinder. Knock detection has mainly been used for spark advance control, making it possible to control the engine close to its knock limit in search for the optimal ignition timing.

Detecting engine knock opens up the possibility for an indirect feedback of the engine's internal combustion without installing a pressure transducer inside the cylinder. The research were done on the suitable using the knocking sensor in the exhaust stream after the combustion process. Using the standard Air/Fuel ratio of the gasoline engine, the program for controlling the fuel injection into the internal combustion engine is made using the Arduino controller. Then, the data is collected and will be analyses and also compared with other data.

This thesis is submitted for the partial requirement of final year project named Study Signal Processing of Engine Knocking on Vehicle Using Closed Loop System. Gasoline and diesel engine are widely used in industry and agricultural field, and it has different performance, combustion and vibration characteristics in the internal combustion engine. This project will study based on signal processing of engine knocking for the gasoline engine. Engine knock has long been a well-recognized phenomenon in the automotive industry.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Today's engines have high demands on performance and emissions. An engine can be classified into two which are internal combustion engines (IC) and external combustion engines (EC) (such as steam engines). The most widely used are IC engine. This is because it has higher thermal efficiency that can be obtained with moderate maximum working pressure of the fluid in the cycle and the weight to power ratio is quite less compared to steam turbine power plant [1]. There are two type of internal combustion which is Spark Ignition (Gasoline) engine (SI) and Compression Ignition (Diesel) engine (CI). The Spark Ignition (Gasoline) engine was widely used in vehicles such as cars and motorcycles. The SI engine is four stroke engines where intake, compression, combustion and exhaust strokes take place to rotate the crankshaft of the engine [2].

Besides that, if the engine is to work successfully then it has to follow cycle operations on sequential manner. The sequence is quite rigid and cannot be changed. In the following sections the working principle of both SI and CI is described. SI engine work on Otto cycle while CI engine work on Diesel cycle. There are 2 types working principle of engines which are two-stroke engine and four-stroke engine. Two stroke engine develops twice power compared to four stroke engine because of one power stroke every revolution (compared to four stroke which need two revolution to produce one power stroke) [2]. Fig. 1.1 below shows the important part for the engine.

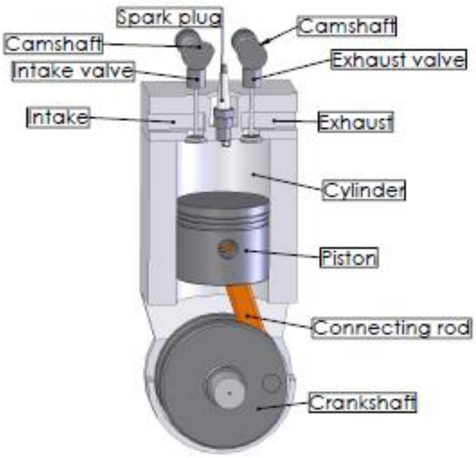

Fig. 1.1: The most important engine parts [1]

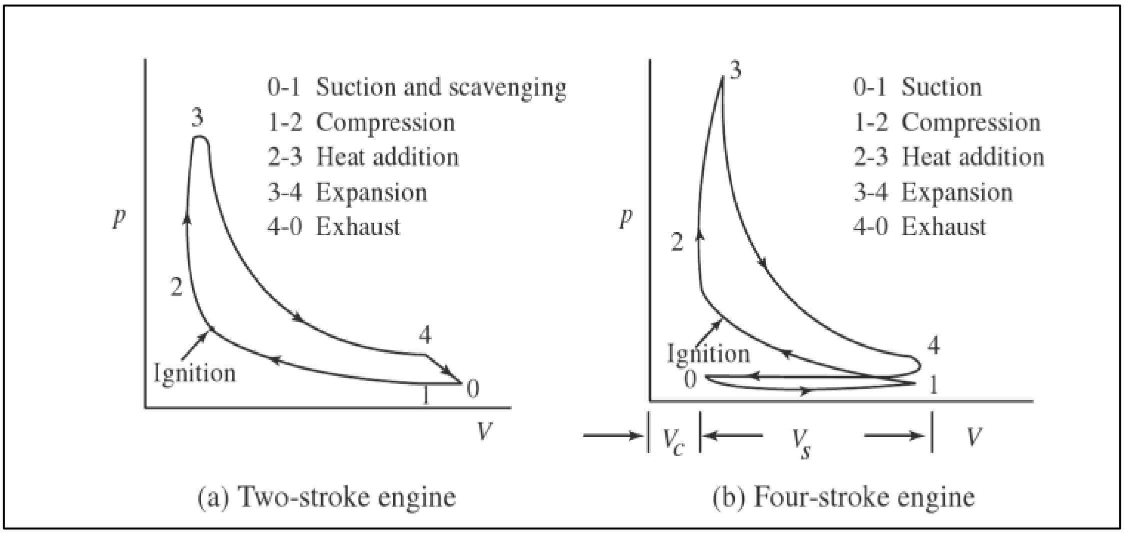

Fig. 1.2: p-V diagrams for Two Strokes and Four Strokes Engines [1]

In this Fig. 1.2 shows the p-V diagrams for two strokes and four strokes engines. The fuel injection is a system to introduce the fuel into the internal combustion engine. It uses fuel injector to spray into the engine of intake manifold instead of carburetor is used Bernoulli principle to feed the mixture to the chamber. Thus, the Air Fuel Ratio would not be precisely controlled. However, for fuel injection, pressure is not engine vacuum but is used to feed fuel into the engine [2]. This make the injection system very efficient due to the injection duration is controlled by Engine Control Unit (ECU).

Detecting engine knock presents a more direct feedback from the engine than engine speed tests. A knock sensor could therefore lead to a more efficient engine management control. The intensity of the engine knock is largely dependent on the current operating condition of the chainsaw. Thus, this thesis does not only focus on how the engine knock can be detected, but also shows how the intensity of the engine knock changes with engine temperature, detect knocking (oxygen & knock sensor) and ignition timings [3].

Engine knock is an important combustion phenomenon that sets an upper limit on the ability to maximize the engine power and fuel efficiency produced by a spark-ignition (SI) engine under given operating conditions [4]. Under combustion knock constrain, the engine cannot operate at its optimal spark timing because the engine's knock limited spark advance occurs before optimal combustion phasing. Advancing spark timing further would result in engine knock severe enough to result in unacceptable combustion generated noise, a decrease in combustion efficiency, and/or can cause engine damage [4].

1.2 Problem Statement

In this research, there are many problems that had to be faced for the completion of this project by using the 4 stroke spark ignition engine. Firstly, complete combustion is important to assess the ability of an engine this is because incomplete combustion will produce less energy compared to the complete combustion. It also makes the performance of the energy poor and less efficient. This is because there is not enough oxygen to react with fuel due to imbalance of air-fuel ratio.

Besides that, complete combustion of air-fuel mixture is very important for every engine. If the combustion were perfect in the engine, a mixture having more fuel than that in a chemically correct mixture and a mixture contains less fuel (excess air). However, if there is an incomplete combustion occurs inside the engine, there could cause many problems such as pollution of carbon dioxide.

Next, engine knock is caused by spontaneous auto-ignitions in the end-gas region ahead of the flame front in combustion engines. Leaner A/F mixtures tend to increase the combustion temperature which increases the engine's tendency to knock. . Over time knock can damage the piston or cylinder head.

Furthermore, the other problem for this project is engine test bed. The previous design has bigger engine test bed, need to use the vast space and also doesn’t suite with vibration control. It also needs to use more manpower. So, to solve this problem smaller engine test bed needs to be developed.

1.3 Research Objectives

The aim of this study is to detect the signal processing of engine knocking on spark ignition engine vehicle. To achieve this aim, the objectives of this study are:

1. To study signal response phenomena for engine knocking on 4 strokes spark ignition engine vehicle.
2. To design engine test bed suite with low vibration control.
3. To analyse performance of engine knocking on uncertainty behaviour.

1.4 Scope of Project

In completing this project, it is started from studying and research what had been done by previous researchers. A literature reviews are conducted before and also during the project in progress. Then, the scope of project mainly focuses on study how to detect the signal processing of engine knocking on vehicle. The scopes of study:

i. Study about type of engine used in this project.
ii. The sensor used (engine sensor or oxygen sensor).
iii. Matlab, SolidWorks and Ansys software application.
iv. Arduino controller application.
v. Fabrication for the engine test bed.

Besides that, focus of the project is to study the combustion inside the chamber of engine either perfect or not. The imperfect combustion inside the engine will causes air pollution due to harmful exhaust gases emitted to the environment that form from the imbalance chemical reaction between air fuel mixtures and also causes knocking on the engine. Perfect combustion means that the all the air fuel mixture inside the engine is converted to non-harmful gases and prevent engine from knocking. In this project, the knock sensor is used to detect the signal processing of engine knocking on vehicle through data acquisition (DAQ).

1.5 Thesis Outlines

In this thesis consists of five (5) chapters that fully describe the overall information and details from the introduction to conclusion of this project where the publishing of this thesis signify the completion of Final Year project with the title is Study of Signal Processing of Engine knocking on Vehicle.

In chapter 1, it is the introduction of this project, problem statement, objectives and scope of the project. Chapter 2 is the fundamental component of the project structure and in this chapter it is about the literature review and mainly about the research related to this project from the past journal, articles, books and webpages as references in completing this project. Detail explanation about the research is described in this chapter.

Chapter 3, explains about the methodology for implementation the project. The procedure, experiment and calculations will be explained briefly on how they conducted and needed to be included in the project.

Chapter 4, discusses about the results and the discussion of the study. Lastly, the chapter 5 is the final chapter in this thesis which is the conclusion of the project. The summary of the project implementation and achievement are included. The limitation of this project also included for next research to improve this system to be better in future. This entire thesis outline step had been shown as the Fig. 1.3.

CHAPTER 2

LITERATURE REVIEW

2.0 Engine

An engine is a device designed to transforms one form of energy into mechanical work. However, while transforming process energy from one to another, the efficiency of conversion plays an important role. Normally, most of the engine covert thermal energy to mechanical work called 'heat engines' which is meant a device that transform the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work [1]. They also can be divided into four-stroke engine and two-stroke engines then by means of working process such as fuel ignition they are divided into gasoline engines, carburetor engines and diesel engine. Fig. 2.1 below shows the classification of heat engines.

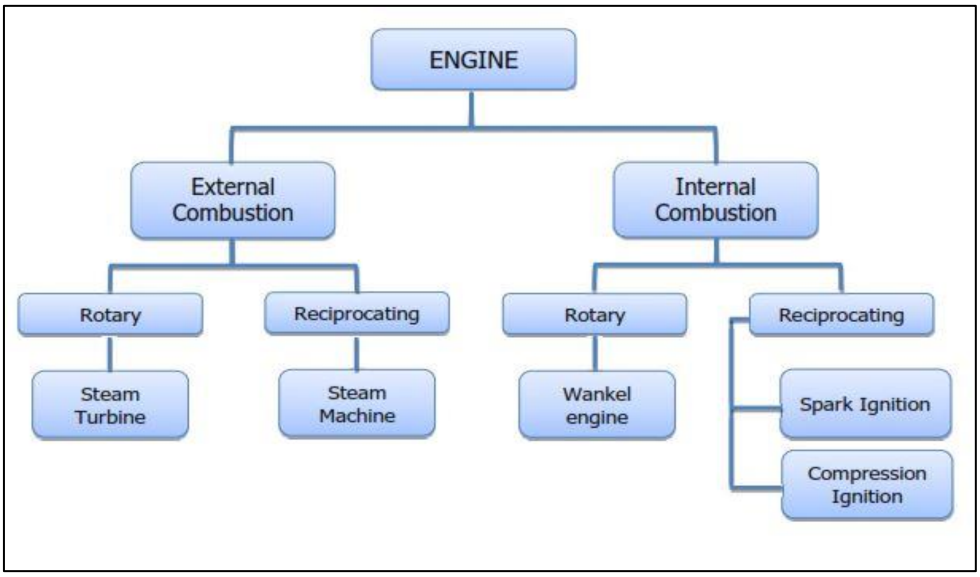

Fig. 2.1: Classifications of Heat Engines [1]

2.1 Internal Combustion Engine (I.C.E)

Internal combustion engine (IC) is a heat engine where the combustion of a fuel occurs in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine [2]. Heat produced due to combustion between air and fuel mixtures is then help moved the piston. Besides that, in internal combustion engine, higher thermal efficiency can be obtained with moderate maximum working pressure of the fluid in the cycle, and therefore, the weight to power ratio is quite less compare to external combustion engine. It also can develop very small power output with thermal efficiency and cost. Considering all the above factors the internal combustion engine have been found more suitable used in automobiles, motorcycles and power units of relatively small output. There are two type engines that can be classified in IC engine which is spark ignition and compression ignition engine [1]. In the table 2.1, there are differences between spark ignition and compression ignition engine.

a) Spark Ignition (SI) engine (Gasoline)

   Spark ignition (SI) engine, combustion occurs due to the triggering of a spark between the spark plug electrodes, which gives rise to the propagation of a flame front. In this category of IC engines, the combustion is said to be normal if it is triggered by the spark plug and propagates "gradually" in the entire combustion chamber. The combustion stage strongly affects engine power, fuel consumption and noise emissions [5].In any case, an irregular combustion can be happened to the auto-ignition of the air/fuel mixture when retained at high temperature and pressure for a long time. There are many disadvantages when the irregular combustion occurred and one of that is knocking. This knocking phenomenon because of sudden increment of cylinder temperature followed by pressure waves inside the combustion chamber that transmitted through the engine structure to the surrounding which can lead to damage piston [6].

b) Compression Ignition (CI) engine (Diesel)

   Compression (CI) engine, the fuels used is relatively higher reactivity such as diesel. In diesel engines, the energy addition occurs at constant pressure but energy rejection at constant volume. The temperature of CI engine generated is higher than the ignition temperature of diesel due to high compression ratio that why here spark plug is replaced by fuel injector. These fuels cannot be mixed with air and then compressed into the cylinder because the combustion can be igniting spontaneously during compression stroke. Therefore, before the combustion started, the fuel immediately injected as a high pressure liquid spray into the already compressed air [6].

Table 2.1: Differences between SI engine and CI engine [26]

Spark Ignition Engine (S.I Engine)	Compression Ignition Engine(C.I Engine)
Spark plug required	No spark plug required
The mixture of air and fuel is introduced into the cylinder from carburettor.	Only air is introduced into the cylinder.
These type of engines compresses air and fuel together in the cylinder	In these engines air is only compressed in the cylinder.
No fuel pump is used.	Fuel pump is used to inject fuel.
Fuel is mixed with air before compression starts.	Fuel is mixed with air once compression is complete.
Compression ratio is low.	Compression ratio is high.
This type of engine makes use of highly volatile liquid fuel.	This type of engine makes use of less volatile liquid fuel.
Less efficient.	More efficient.
Fuel used in this engine is expensive.	Cheaper fuels are used in these engines.
Higher fuel consumption in these engines for same power.	These engines have lesser fuel consumption for same power.
Engines are more compact and light.	Heavier and strong engines due to higher pressure involved
Initial cost is less	Initial Cost is high.
These engines have a smooth operation	Roughness in engine operation encountered, especially when the engine runs at high speed and low loads.

2.2 External Combustion Engine (E.C.E)

External combustion engine is a heat engine where working fluid, contained internally, fuel was burn outside the engine cylinder chamber and the heat generated then transferred to main working fluid to vaporizes it, and a high pressure is generated which helps to move the piston [7]. External combustion engine design and develop in the form of steam engine. Fig. 2.2 below shows the important part of external combustion engine:

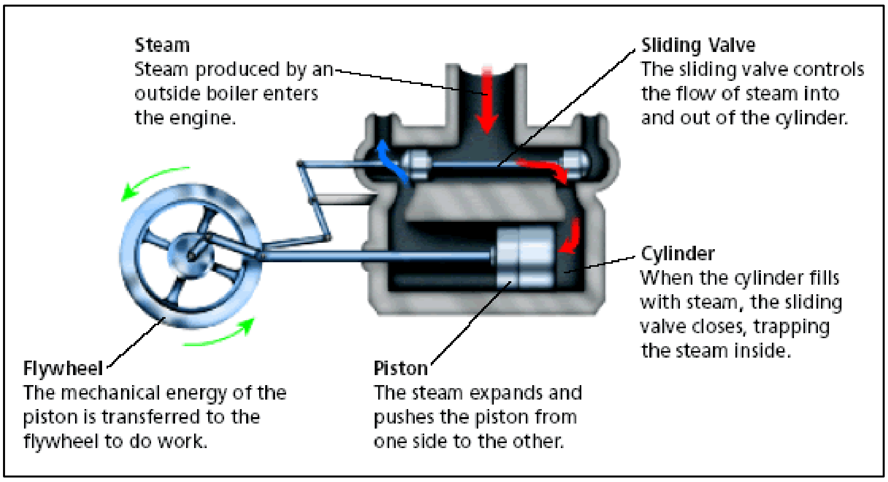

Fig. 2.2: External combustion steam engine

2.3 Working Principle of Internal Combustion Engine

There are two basic working principle in SI engine and CI engine which is two stroke engine and four stroke engine:

1. Two Stroke Engine

The small two stroke gasoline engines are used where simplicity and low cost of the prime mover are the main considerations. In such applications a little higher fuel consumption is acceptable. These motors are utilized as a part of such applications as garden cutters, earth bicycles, mopeds, and other comparative applications. Scooter and motorcycle, commonly used two wheeler transport, have generally 100-150cc. The basic component of two stroke engine shown in the Fig. 2.3 below:

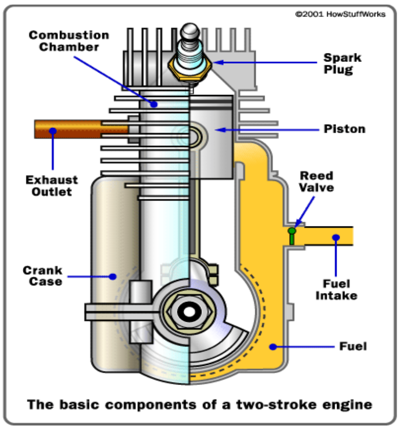

Fig. 2.3: Cross Section view of a 2 stroke engine. [25]

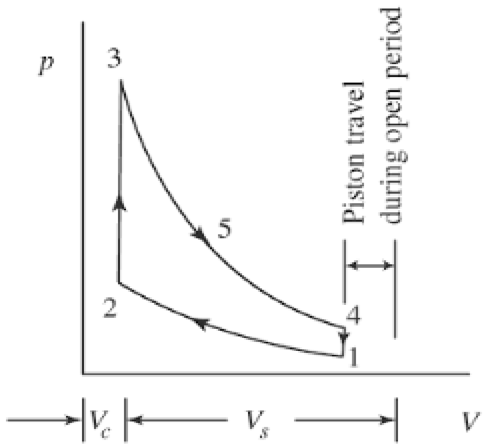

Fig. 2.4: Ideal p-V diagram of two stroke SI engines [1]

In this Fig. 2.4, it had shown the Ideal p-V diagram of two stroke SI engines. Two stroke engine was developed obtain higher output from the same size of engine. The engine has no valves and valve actuating mechanism making it mechanically simpler. Almost all two stroke engines have no conventional valves but only ports [1]. This makes two stroke engine more cheaper to produce and easy to maintain. The other advantages of two stroke engines are more uniform torque on crankshaft and comparatively less exhaust gas dilution.

However, when applied to the spark ignition engine the two strokes cycle has certain disadvantages which have restricted its application to only small engines suitable for motorcycles, scooter outboard engine etc. There are incoming charge consist air and fuel in the SI engine. During scavenging, as both inlet and exhaust open simultaneously for some time, there is a possibility that some of the fresh charge containing fuel escapes with the exhaust. This results in high fuel consumption and lower thermal efficiency [2].

2. <u>Four Stroke Engine</u>

Four stroke engine or also known as Otto cycle was first demonstrate by Nicolaus August Otto in 1876. Referring to the name, it consist of 4 stroke which is the one cycle of operation is completed in four strokes of the piston or two revolutions of crankshaft. During the four strokes, there are five events to be completed which are intake stroke, compression stroke, combustion, expansion and exhaust. Each stroke consists of 180^o of crankshaft rotation and hence four stroke cycle is completed through 720^o of crank rotation [1].

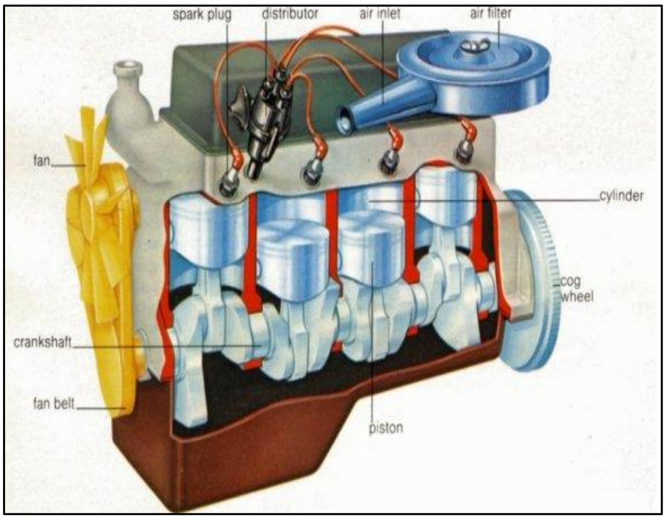

Fig. 2.5: Four stroke engine cross section [25]

Four Stroke Engine Mechanism:

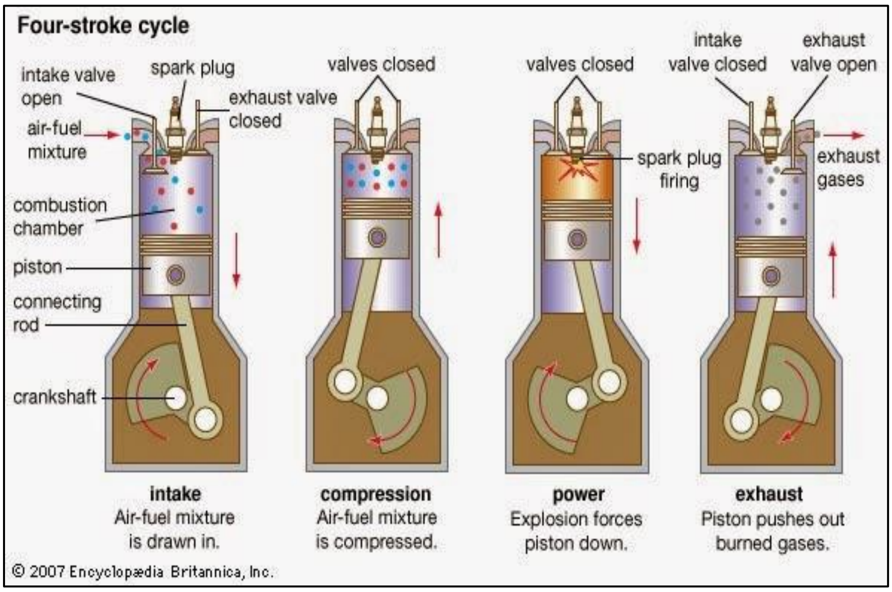

Fig. 2.6: Four stroke engine mechanism [25]

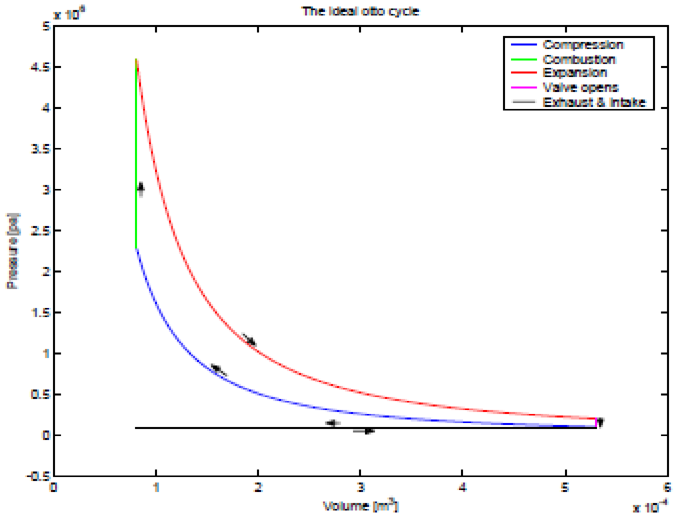

Fig. 2.7: Ideal p-V diagram of four stroke SI engines [2]

In this Fig. 2.7, it had shown the Ideal p-V diagram of four stroke SI engines. The working principle of this 4 stroke engine is suction, compression, expansion and exhaust.

i. ***Suction or Intake Stroke:*** This methodology can be described as isentropic compression. Isentropic means it is an adiabatic process which is also reversible which is the piston move downward from Top Dead Center (TDC) to Bottom Dead Center (BDC). Adiabatic means that no heat is transferred to or from the process. The pressure and temperature rises, as volume is compressed by the work done on the system by moving piston. Then, the high pressure inside the cylinder pulled air/fuel mixture (for SI engine) and only air (for CI engine) through the intake valve.

ii. ***Compression Stroke:*** This process is considered to take place instantly at TDC as heat added at constant volume. The heat is the energy released from the burning fuel and it will make the pressure and temperature rises.

iii. ***Expansion Stroke:*** During the expansion stroke, where the useful work is produced, is an isentropic process. As the volume expands, the pressure and temperature decreases, and work is leaving the system as forces moving the piston.

iv. ***Exhaust Stroke:*** when the piston reaches BDC, the gas is considered to return to its initial state by heat leaving with the exhaust gas. This is the end of the working otto cycle, but as we know, there has to be an exhaust and intake stroke to fill the cylinder with new mixture of fuel and air. Then, the exhaust and intake strokes take place at constant pressure.

2.4 Components of Engine and its Function

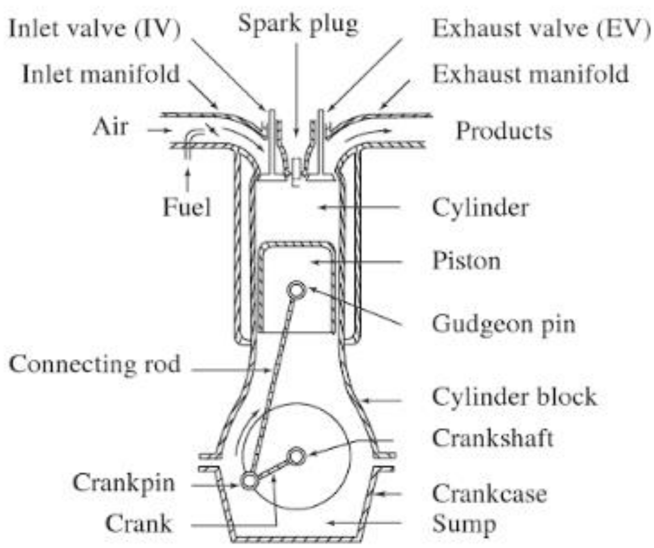

Fig. 2.8: Cross-section of spark ignition engine [1]

- ***Cylinder:*** As the name implies it is a cylindrical vessel or space in which the piston makes a reciprocating motion. The varying volume created in the cylinder during the operation of the engine is filled with the working fluid and subjected to different thermodynamic processes. The cylinder is supported in the cylinder block.
- ***Cylinder Block:*** It is the solid casting body which includes the cylinder and water jackets (cooling fins in the air cooled engines).
- ***Piston:*** It is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits perfectly into the cylinder providing a gas tight with the piston rings and lubricant.
- ***Combustion Chamber:*** The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called combustion chamber. The combustion of fuel and the consequent

release thermal energy results in the building up the pressure in this part of the cylinder.

- ***Exhaust Manifold:*** The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of the combustion escape into the atmosphere is called the exhaust manifold.
- ***Inlet Manifold:*** The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called inlet manifold.
- ***Inlet and Exhaust Valves:*** Inlet valve is the part of the engine where air or air-fuel mixture enters into the engine cylinder. Exhaust valve is that part of the engine through which exhaust gases go out of the engine cylinder. It is capable of withstanding high temperature of burnt gases. Both valves are fitted by the side of the cylinder head.
- ***Spark Plug:*** It is a component to initiate the combustion process in Spark Ignition (SI) engines and is usually located on the cylinder head.
- ***Connecting Rod:*** It interconnects the piston and the crankshaft and transmits the gas forces from the piton to the crankshaft. The two ends of the connecting rod are called as small end and the big end. Small end is connected to the piston by gudgeon pin and big end is connected to the crankshaft by crankpin.
- ***Crankshaft:*** It is the main shaft of an engine which converts the reciprocating motion of the piston into rotary motion of the flywheel. Generally the crankshaft is made of drop forged steel or cast steel. The space that backings the crankshaft in the cylinder block is called *main journal*, while the part to which connecting rod is appended is known as *crank journal*. Crankshaft is furnished with stabilizers all through its length to have offset of the unit.
- ***Piston Rings:*** piston rings, fitted into the slots around the piston, provide a tight seal between the piston and the cylinder wall thus preventing leakage of combustion gases.
- ***Gudgeon Pin:*** It links the small end of the connecting rod and the piston.
- ***Camshaft:*** It is a shaft which raises and lowers the inlet and exhaust valves at proper times. Camshaft is driven by crankshaft by means of gears, chains or sprockets. The speed of the camshaft is exactly half the speed of the crankshaft in four stroke engine. Camshaft operates the ignition timing mechanism,

lubricating oil pump and fuel pump. It is mounted in the crankcase, parallel to the crankshaft.

- ***Cams:*** These are made as integral parts of the camshaft and are so designed to open the valves at the correct timing and to keep them open for the necessary duration.
- ***Fly Wheel:*** The net torque imparted to the crankshaft during one complete cycle of operation of the engine fluctuates causing a change in the angular velocity of the shaft. In order to achieve a uniform torque an inertia mass in the form of a wheel is attached to the output shaft and this wheel is called fly wheel.

2.5 Engine Control Unit (ECU)

Electronic engine controls is the brain of the fuel injection system. It typically consists of sensor electronics, actuator electronic and microcontroller. It also is an embedded system in automotive which controls the real-time system of a vehicle, in e.g. engine, brakes and emission control. It uses sensors of different kinds to gather data from the vehicle to determine its behaviour. The data is used by the ECUs to perform necessary actions to achieve a desired behaviour. Information on the combustion efficiency may provide a strong tool regarding engine operation and may be profitably used for closed-loop electronic engine control [8] [9].

One of the first advanced ECUs was the engine control unit. It controlled parameters such as fuel injection and ignition timing which resulted in both improved engine performance and reliability.

Ideally the ECU tries to achieve the optimum air to fuel ratio of 14.7:1 (stoichiometric ratio) but the changing operating conditions require small changes to the ratio. At lighter loads the ECU can use leaner air to fuel mixtures (higher air to fuel ratio) to save fuel and user richer air to fuel mixtures (lower air to fuel ratio) to help reduce engine temperature or warm up the engine. An air to fuel ratio of 12.6:1 (rich) provides maximum power while a ratio of 15.4:1 provides the best fuel economy. Fig. 2.9 shows the power and fuel consumption curves versus the air to fuel ratio [8].

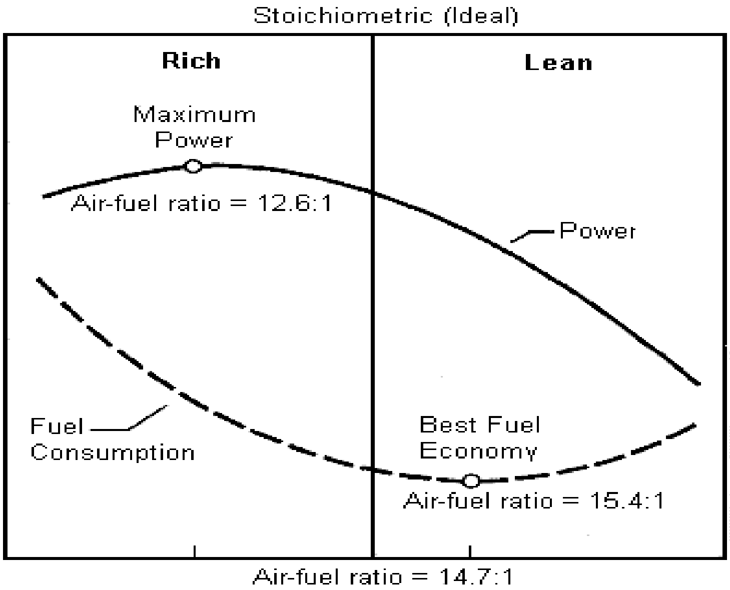

Fig. 2.9: Power and fuel consumption curves versus air to fuel ratio [8].

The stoichiometric ratio is a compromise between rich and lean mixtures with very little sacrifice of power or fuel economy and helps reduce emission of pollutant gases in the combustion process.

2.6 Arduino Controller

The Arduino microcontroller is an easy to use yet powerful single board computer that has gained considerable traction in the hobby and professional market. Arduino is an open-source electronics platform based on easy-to-use hardware and software. [9]. It consists of a pre-programmed microcontroller or integrated development environment, used to write the code and upload to the physical board. These devices are used to make communicating objects, taking data from different kinds of sensors and controlling the motors [10]. Fig. 2.10 shows the microcontroller Arduino board.

Fig. 2.10: Arduino board [10]

2.7 Air Fuel Ratio

The A/F equivalence ratio λ refers to an excess of air or fuel during the combustion. It is defined as the actual A/F ratio normalized with the stoichiometric A/F ratio:

$$\frac{A}{F} = \frac{mass\ of\ air}{mass\ of\ fuel} = 14.7\frac{MW_{air}}{MW_{fuel}} \qquad \text{(Eq.2.4.1)}$$

Then, where MW_{air} and MW_{fuel} are the molecular weights of air and fuel respectively [10]. The stoichiometric ratio describes the ratio between fuel and air which leaves no excess of fuel or air after combustion.

The air-fuel ratio has an important effect on engine efficiency, power, and emissions. The ratio of air in the combustible mixture is a key design parameter for gasoline engines. An air-fuel mixture that has exactly enough air to burn the fuel, neither air or fuel left over and has normalized air fuel ratio (λ). There are reasons for less heat loss, the higher compression ratios, lower throttling losses at part load and favorable thermodynamic properties in burned gases [11].

2.8 Engine Knocking

Knock is the resonance phenomenon caused by spontaneous auto-ignition in the end-gas region ahead of the flame front in a combustion engine. The end-gas region contains the unburned A/F mixture which the spark-ignited flame kernel propagates through until it is extinguished at the cylinder walls. The air-fuel mixture in a spark ignition engine is supposed to start burning between the electrodes of the spark plug, and then continues burning. This leads to a controlled pressure and temperature rise that follows a smooth curve. If the pressure wave, that travels faster than the flame front, causes the local temperature somewhere in the combustion chamber to rise beyond the ignition temperature of the fuel, a new flame front started. Due to the high local pressure increase, a pressure wave begins to propagate across the combustion chamber, which in turn causes the chamber to resonate at its natural frequencies [12].

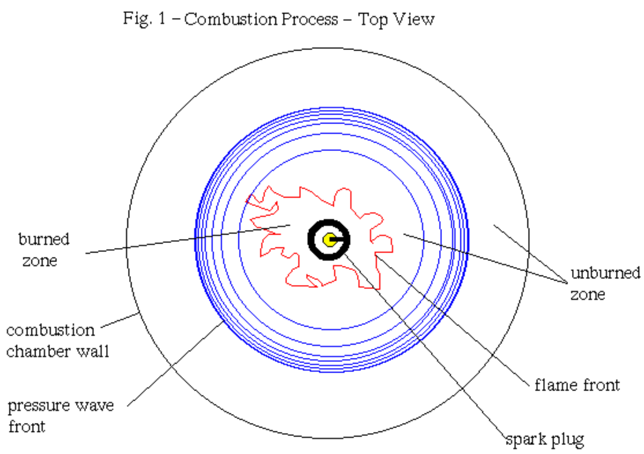

Fig. 2.11: The propagating flame front together with an auto-ignition seen from above the cylinder [13]

In this Fig. 2.11, it shows that auto-ignition theory indicates high temperature and pressure in the end-gas region causing auto-ignition. Under combustion knock constrain, the engine cannot operate at its optimal spark timing because the engine's knock limited spark advance occurs before optimal combustion phasing.

2.9 Knock Detection

Detecting knock is mainly done with four different methods. But in this project we had used two types of sensor to detect the knocking and also misfire which is knock sensor and oxygen sensor. Knock can be easily distinguished from the cylinder pressure trace.

2.9.1 Knock Sensor

The knock sensor is located on the engine block, cylinder head or intake manifold. This is because its function is to sense vibrations caused by engine knock or detonation. A knock sensor allows the engine to run with the ignition timing as far advanced as possible. The computer will continue to advance the timing until the knock sensor detects pinging or knock. The knock sensor responds to the spark knock caused by pre-detonation of the air/fuel mixture. As the flame front moves out from the spark plug ignition point, pressure waves in the chamber crash into the piston or cylinder walls resulting in a sound known as a knock or ping [14]. The engine control unit (ECU) uses this signal to alter the ignition timing and prevent detonation. It will compare this information with its pre-set tables to identify a valid knock or ping. If a ping is sensed, it will retard the ignition timing to protect the engine from this damaging pre-ignition. Fig. 2.1 and Fig. 2.2 shows the knock sensor and part of knock sensor respectively.

Fig. 2.12: Knock Sensor

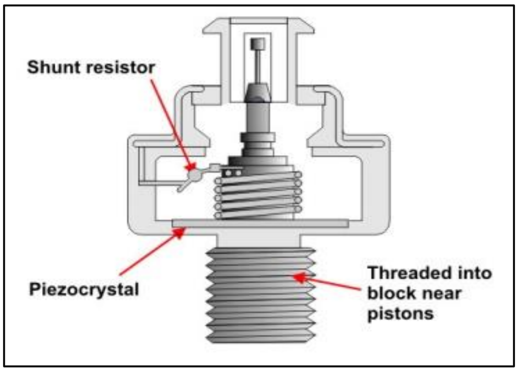

Fig. 2.13: Part of knock sensor

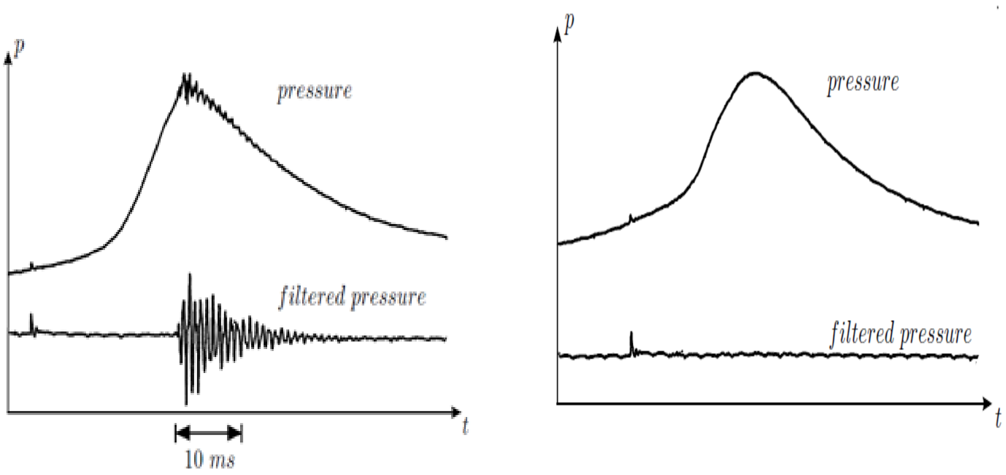

Fig. 2.14: a) Knocking combustion, b) Non-knocking combustion [14]

In this Fig. 2.14, it had shown the differences between (a) Knocking combustion and (b) Non-knocking combustion. The knock sensor is modelled on materials composition and function like in real use. Cover of sensor is made from plastic and electrodes are made from metal. Knock sensor is a piezoelectric sensor that contains a piezoelectric sensing crystal and a resister. This crystal creates a small amount of voltage when shaken. This sensor takes advantage of this unique property [15].

2.9.2 Oxygen Sensor

The purposes of oxygen sensors are for measuring air-fuel mixture concentration for internal combustion engines among many other industrial and scientific applications [16]. Now, the oxygen sensors have used the feedback control of the air-fuel (A/F) ratio of engine exhaust gas for reducing harmful emission components and improve fuel economy. The application of oxygen sensors is now expanding to other fields, such as monitoring the combustion of oil or gas stoves [17]. Based on the number of sensors in operation, the main function of oxygen sensors is in the control of air-fuel mixture in the combustion engine of the internal combustion engine [18].

Besides that, oxygen sensor also does not measure oxygen concentration in the exhaust, but it measure the difference between the amount of oxygen in the exhaust and ambient. There will be two condition of the gas mixture in the exhaust either rich or lean mixture. Rich mixture will causes an oxygen demand and increase the voltage due to transportation of oxygen ions through the sensor layer while lean mixture reduce the voltage because there is an excess oxygen in the exhaust [19]. This information on oxygen concentration is sent to the engine control unit (ECU) to adjust the amount of fuel injected into the engine to balance excess air or excess fuel. So, with that it can be reduce and prevent from knocking to occur. Fig. 2.15 below shows the type oxygen sensor.

Fig. 2.15: Oxygen sensor

2.10 Knock Control

The engine's tendency to knock is largely dependent on parameters deciding the temperature and pressure of the end-gas during combustion [20]. Another important parameter is the fuel's resistance to knock which is measured by its octane number. This is dependent on the chemical structure of the fuel. Fuels with higher quality have higher octane numbers and this will reduce the tendency to knocking occur.

AFR also can be used to control knocking. A rich mixture is less probable to knock than a lean mixture. The reason is that the fuel needs more energy to heat up than the air. The time constants for changing AFR are often longer than for ignition timing. The impact on the knock tendency is also less pronounced, than for ignition timing, and AFR is rarely used to control knocking directly.

Then, increase the fuel octane number by introducing antiknock additives to the fuel, like different ethers, alcohols or even water [21]. Ultrahigh molecular weight polymer permits a more uniform air/fuel mixture, which makes fuel to more efficient combustion, reduces the overall temperatures, and produces antiknock performance [22].

Engine rpm has a big impact on knock tendency. High rpm means higher tendency to knock. This is because the flame front propagation speed is independent of engine speed, and at higher rpm the piston has travelled further down the power stroke when the pressure peak is reached. Because the compression pressure falls as the piston travel downwards, the pressure peak is lower. In most case the electronic control unit has no control over the engine speed. The control strategy is to make the driver change gear. At low engine speed, knocking is prevented by ignition timing, and if the operator persists (the driver does not change to a lower gear), the fuel injection may be cut off to protect the engine, and so the engine stalls.

Furthermore, Increase the inert gases. The effects of the addition of inert gases can increase the knock limited spark timing, which could be very helpful to avoid knock. For instance, the additions of N_2 and CO_2 to the natural gas fuel have good knock prevention performance [23].

2.11 Signal Processing

In signal processing, one may improve the efficiency of data analysis, in particular of convolution, by using a Fourier basis via a discrete Fourier transform (DFT). A Fourier series is an expansion of a periodic function in terms of an infinite sum of sines and cosines. Fourier series make use of the orthogonality relationships of the sine and cosine functions. The Fourier transform can be applied to any practical function, does not require that the function be periodic, and for discrete data can be evaluated quickly using a modern computer technique called the Fast Fourier Transform (FFT).

The sine and cosine waves used in the DFT are commonly called the DFT basis functions. In other words, the output of the DFT is a set of numbers that represent amplitudes. The basis functions are a set of sine and cosine waves with unity amplitude. If you assign each amplitude (the frequency domain) to the proper sine or cosine wave (the basis functions), the result is a set of scaled sine and cosine waves that can be added to form the time domain signal.

The DFT basis functions are generated from the equations:

$$c_k[i] = \cos(2\pi ki/N) \qquad \text{Eqn. 1}$$

$$s_k[i] = \sin(2\pi ki/N) \qquad \text{Eqn. 2}$$

where: ck [i] is the cosine wave for the amplitude held in ReX [k], and sk [i] is the sine wave for the amplitude held in ImX [k].

The Fourier Transform for continuous signals is divided into two categories, one for signals that are periodic, and one for signals that are aperiodic. Periodic signals use a version of the Fourier Transform called the Fourier series, and are discussed in the next section. The Fourier Transform used with aperiodic signals is simply called the Fourier Transform.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 Introduction

Extensive research material is available that focuses on detecting knock by characterizing engine knock intensities, signal processing, and development of quantitative knock metrics including recent work related to the method discussed here. This project is done to find and get the data from the Yamaha LC135 engine when knocking occur in the engine by using the knock sensor which is connected to the oscilloscope (INTSTRUSTAR) in order to observe, record, collect and analysis the signal response. In this project, knock sensor had been attached to the cylinder head of the engine and it will sense knocking when engine was running and then convert it as a voltage signal that can be observed or read by using the oscilloscope. As the knocking is the resonance phenomenon caused by spontaneous auto-ignition in the end-gas region ahead of the flame front in a combustion engine, it had many disadvantage to the engine which is engine can damage. So, this is important to completing this experiment or project in order to study signal processing of engine knocking on vehicle using closed loop system and how to reduce this phenomena become worse in the future.