SHELL ECO-MARATHON FUEL CONSUMPTION ENGINE MAP

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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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LIST OF ABBREVIATIONS

AFR	Air to Fuel Ratio
BDC	Bottom Dead Center
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CI	Compression Ignition
ECU	Electronic Control Unit
FI	Fuel Injection
HCCI	Homogeneous Charge Compression Ignition
I/O	Input-Output
ICE	Internal Combustion Engine
SI	Spark Ignition
TDC	Top Dead Center
USM	Universiti Sains Malaysia
VMI	Visual and Mechanical Inspection

ABSTRAK

Peta Penggunaan Bahan Api Enjin Shell Eco-Marathon ialah satu kajian untuk menemui profil operasi enjin yang digunakan sebagai pacuan dalam Cabaran Shell Eco-Marathon. Sebagai peserta, pasukan USM dikehendaki membina prototaip kenderaan jimat bahan api yang boleh dipandu lebih jauh sambil mengekalkan penggunaan bahan api yang sedikit. Enjin Honda 110 cc telah dipilih untuk digunakan sebagai pacuan kenderaan prototaip tersebut. Walau bagaimanapun, maklumat teknikal mengenai profil operasi enjin agak terhad menyebabkan kesukaran untuk mengoptimumkan kenderaan prototaip untuk perbatuan bahan api terbaik. Untuk mengoptimumkan penggunaan bahan api sebuah enjin, enjin tersebut mesti dioperasikan dalam 'titik manis' peta penggunaan bahan api pada kebanyakan masa. Objektif utama projek ini adalah untuk menerokai penggunaan bahan api, penggunaan bahan api brek khusus, dan kecekapan brek terma untuk enjin tersebut. Mengetahui parameter ini adalah amat penting kerana ia boleh digunakan untuk mencari titik optimum peta enjin di mana enjin mampu mencapai kecekapan termal tertinggi. Projek ini melibatkan pengubahsuaian enjin, fabrikasi, eksperimen dan pengaturcaraan. Sebelum ujian enjin boleh diadakan, pengubahsuaian pemadaman ‘centrifugal clutch’ dilakukan ke atas enjin untuk meminimumkan kehilangan tenaga mekanikal semasa ujian dynamometer enjin. Beberapa alat pengukur telah direka untuk memudahkan proses pengumpulan data. Ujian dinamometer enjin dilakukan dengan menggunakan Dinamometer Arus Eddy yang terdapat di Makmal Automotif di Pusat Pengajian Kejuruteraan Mekanik USM. Semasa eksperimen, prestasi dan penggunaan bahan api enjin direkodkan pada kelajuan dan beban enjin yang berbeza. Keputusan eksperimen menunjukkan bahawa enjin tersebut mampu menghasilkan tork maksimum 7.31 Nm pada 5500 RPM dan kuasa brek maksimum 5.33 kW pada 7500 RPM. Zon operasi enjin yang cekap berlaku pada penggunaan bahan api khusus brek terendah iaitu 347.3 g/kWj yang direkodkan pada 5000 RPM dengan beban 5.42 Nm. Kecekapan terma tertinggi yang dicapai oleh enjin ialah 23.87%. Data yang diperoleh daripada eksperimen dianalisis menggunakan MATLAB untuk membina graf 3-D bagi peta penggunaan bahan api, peta penggunaan bahan api brek khusus dan peta kecekapan brek terma untuk enjin tersebut. Penemuan profil pengendalian enjin adalah penting kerana ia boleh digunakan untuk mengoptimumkan nisbah pemacu transmisi dan strategi pemanduan kenderaan prototaip Shell Eco-Marathon pasukan USM.

ABSTRACT

The Shell Eco-Marathon Fuel Consumption Engine Map is a study to discover the operating profile of an engine that was used as a drivetrain in the Shell Eco-Marathon Challenge. As the participant, the USM team is required to build a fuel-efficient vehicle prototype that can be driven further while consuming the least amount of fuel. A Honda 110 cc engine has been chosen to be used as the drivetrain for the prototype vehicle. However, technical information regarding the engine operating profile is quite limited causing difficulties in optimizing the prototype vehicle for the best fuel mileage. To optimize the fuel consumption of the engine, the engine must be operated in its 'sweet spot' of the fuel consumption map most of the time. The main objective of this project is to discover fuel consumption, brake-specific fuel consumption, and brake thermal efficiency for that particular engine. Knowing these parameters is important as it can be used to find the engine map optimum point where the engine is capable to achieve the highest thermal efficiency. This project involves engine modification, fabrication, experiments, and programming. Before the experiment can be conducted, an automatic centrifugal clutch delete modification is performed toward the engine to minimize the mechanical losses during dynamometer engine testing. A few measuring instruments were fabricated to make the data collection process easier. The dynamometer engine testing is performed by utilizing an Eddy Current Dynamometer that is available at the Automotive Laboratory, School of Mechanical Engineering, USM. During the experiments, the performance and fuel consumption of the engine was observed at different engine speeds and loads. The experiment's result shows that the engine was capable of producing a maximum torque of 7.31 Nm at 5500 RPM and maximum brake power of 5.33 kW at 7500 RPM. The efficient operating zone of the engine occurred at the lowest brake-specific fuel consumption was 347.3 g/kWh which was recorded at 5000 RPM with a 5.42 Nm load. The highest thermal efficiency achieved by the engine is 23.87%. MATLAB programming software was used to construct a 3-D graph of fuel consumption map, brake-specific fuel consumption, and brake thermal efficiency for that particular engine. The finding of the engine operating profile is important as it can be used to optimize the transmission drive ratio and driving strategy of the USM team Shell Eco-Marathon prototype vehicle.

CHAPTER 1 INTRODUCTION

1.1 Research Background

With an ever-increasing demand for energy outstripping supply, the world is on the verge of a serious energy crisis. Oil and gas have already become economically unfeasible, and they are on their way to extinction[1]. The increasing reliance on automobiles as a form of personal mobility has resulted in massive usage of gasoline[2]. The oil crisis in 1973 has shown the world that the fuel shortage can be a global threat and since then the demand for fuel-efficient vehicles has been increasing drastically. Even though electric vehicles seem as future of transportation, the world still does not ready to fully switch from conventional Internal combustion (IC) engines as the infrastructure for EVs is quite limited. By realizing that situation, there is still room for improvement for IC engines since the market for the engine is enormously huge. The Shell Eco-Marathon Challenge is one of the platforms to improve ICE performance and it is organized annually to stimulate innovation in fuel-efficient vehicles.

In order to compete in the Shell Eco-Marathon Challenge, the USM team was required to build a prototype vehicle that has high fuel efficiency. Fuel efficiency for vehicles that use an internal combustion engine as the drive train is referred to as thermal efficiency which defines as the ratio of work to heat input that converts the chemical potential energy contained in fuel (gasoline) into kinetic energy. In the context of transportation, fuel efficiency may also refer to the ratio of distance travelled by the vehicle per unit of fuel consume. The USM team has chosen the Honda 110cc engine to be used as the drive train of the vehicle. This engine is chosen due to its specification which has a small displacement and is fed by a fuel injection system which was good for low fuel consumption usage.

The fuel injecting mechanism into the combustion chamber is controlled electronically by the Engine Control Unit (ECU), due to that electronic fuel injection engine can feed the engine with a precise air-to-fuel ratio mixture that helps the fuel completely burn in the combustion chamber thus making it more efficient compared to carburettor engine that has the same displacement. Moreover, using a fuel injection system give the advantage of feeding the engine with different air-to-fuel ratio for example the engine will have a rich mixture when accelerating and a lean mixture when cruising. The ratio of fuel mixture varies depending on the engine speed and throttle angle that were pre-set in the engine fuel consumption fuel map that was installed in the ECU. Theoretically, when the throttle is wide open and the engine speed is increasing, a rich mixture will be fed into the combustion chamber to support the drastically increase engine speed during acceleration while when the throttle is open steadily a lean mixture of fuel will be fed into the combustion chamber to lower the fuel usage during cruising in constant speed.

To optimize the fuel consumption of the engine, the engine must be operated in its ‘sweet spot’ of the fuel consumption map most of the time. The sweet spot is referring to the most fuel-efficient zone in the fuel consumption map where the engine produces high torque with minimum mechanical losses. The engine will be tested on a low-power dynamometer to observe the torque and power output produced by the engine at different throttle angles and engine speeds. Then the collected data obtained from the experiment will be processed using MATLAB programming software to construct a 3-D fuel consumption map, brake-specific fuel consumption (BSFC) map, and thermal efficiency map for that particular engine.

This study is crucial to find the stock fuel mapping for the Honda 100cc engine as the finding of these studies will be used by the USM Shell Eco-Marathon team to build their prototype vehicle since the fuel consumption map for this engine is unknown as there is no information provided upon the stock fuel mapping that was installed by the manufacturer (Honda) in the stock ECU. It is important to know the fuel consumption engine map as it will be the final puzzle piece to optimize the transmission drive ratio and the driving strategy to improve the fuel efficiency of the prototype vehicle

1.2 Problem Statement

Every year, the automotive industry seeks to improve vehicle fuel efficiency. Improving the internal combustion engine efficiency does not only increase the travel distance with less fuel but it is also able to lower the impact on the environment due to low CO2 emissions which also contribute to climate changes. There are many parameters that affect fuel efficiency, and one of them is fuel consumption. Every internal combustion engine has its optimum operating point which defines as the most fuel-efficient zone for an engine to operate where the engine produces high torque with minimum mechanical losses. However, the fuel-efficient zone is unknown and varies among different models of engines. Due to that, the engine fuel consumption map is crucial as it can be used to optimize the driving strategy and the final drive ratio to maximize fuel efficiency.

1.3 Objective

- To perform dynamometer engine test to the Shell Eco-Marathon prototype vehicle's drivetrain using Eddy Current Dynamometer.
- To construct fuel consumption, BSFC, and brake thermal efficiency engine maps to understand the engine operating profile.

1.4 Scope Of Research

The focus of this project is to understand the operating profile of a Honda 110cc motorcycle engine. The project involved hands-on engine assembly and utilizing programming knowledge to set up experiments. The experiments are held to discover the engine performance and its fuel consumption in various engine speeds and loads. This study will cover some parameters such as brake-specific fuel consumption (BSFC) and thermal efficiency but does not cover emissions emitted by the engine

CHAPTER 2 LITERATURE REVIEW

2.1 Fundamental of Spark Ignition Engine

Internal combustion engines that run on gasoline or also refer to as spark ignition (SI) make use of the Otto cycle, which requires ignition to be supplied externally [3]. In the process of converting the chemical energy contained in the fuel into kinetic energy, the SI engine burns a mixture of air and fuel. Nowadays, most of internal combustion engines utilized as automotive powertrain are four-stroke. The four-stroke concept controls the exhaust-and-refill cycle via gas-exchange valves [3]. These valves open and seal the intake and exhaust channels of the cylinder, so controlling the supply of fresh air-fuel mixture and the expulsion of burned gases.

The fundamental of a four-stroke engine comprises four stages of the engine cycle which are induction, compression, power, and exhaust. The induction starts when the piston is at the Top Dead Center (TDC), the piston is descending and increases the volume of the combustion chamber to allow fresh air for the direct injection engine or fresh air-fuel mixture for the manifold injection engine is fed into the combustion chamber past the opened intake valve [3]. The engine compression starts when the gas-exchange valves are closed, and the piston in the cylinder is rising [3]. This decreases the volume of the combustion chamber and compresses the air-fuel mixture. At the end of the induction stroke on manifold-injection engines, the air-fuel mixture has already reached the combustion chamber. In contrast, depending on the operating mode of a direct-injection engine, the fuel is first injected near the end of the compression stroke.

The ignition stage begins prior to the piston reaching Top Dead Center (TDC), a spark plug ignites the air-fuel combination at a predetermined ignition point (ignition angle). This type of ignitor is known as externally supplied ignition [3]. The piston has already exceeded TDC before the mixture has entirely burned. The gas-exchange valves stay closed, and the combustion heat raises the cylinder pressure to the point where the piston is driven downward [3]. Finally, the exhaust stage occurs shortly before Bottom Dead Center (BDC) where the exhaust valve opens. The hot exhaust gases leave the cylinder through the exhaust valve under high pressure caused by the piston's upward motion. Figure 2.1 show the four-stroke engine cycle that comprises induction (a), compression (b), ignition (c), and exhaust (d).

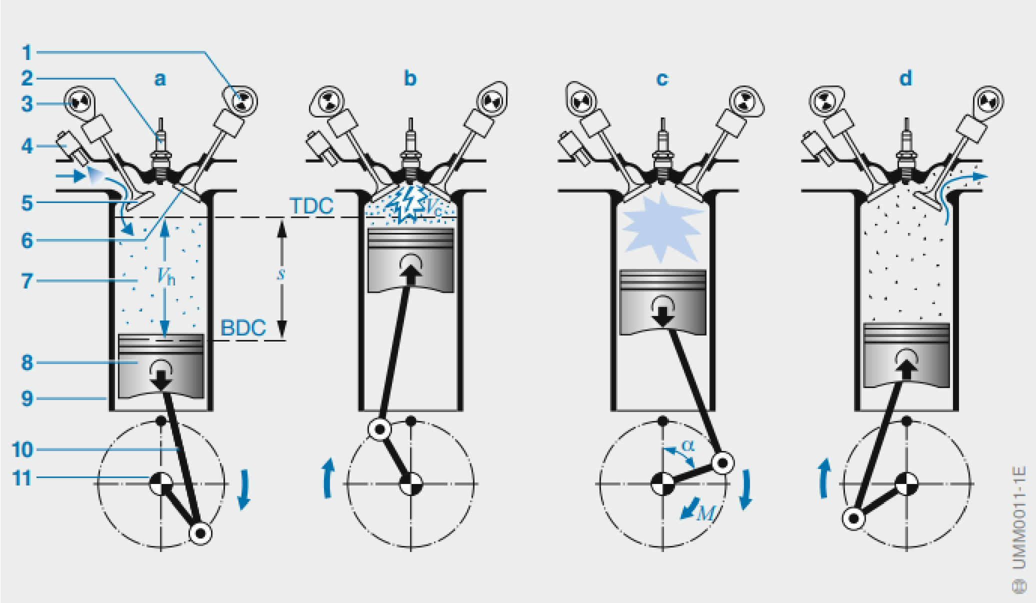

Figure 2.1. Four-stroke cycle; (a) induction, (b) compression, (c) ignition, and (d) exhaust [3].

2.2 Efficiency Of Internal Combustion Engine

The traditional internal combustion engines (ICE) rely on a thermodynamic cycle specifically the Otto cycle for spark-ignition (SI) engines to generate mechanical power [4]. According to Martin et al, the SI engine particularly have limitation in term of thermal efficiency, it has a maximum thermal efficiency usually not more than 35% [5]. Not all thermal power produced during fuel burning can be transformed into useful work, roughly only one-third of the amount of fuel injected into the combustion chamber is used to generate mechanical power and the rest is lost within the engine cooling and exhaust gases [5]. There is a limit to how much thermal efficiency an engine may have, which is related to the temperature of the burning fuel and, specifically for SI engines, is directly related to the compression ratio. The higher the compression ratio and the higher the maximum combustion temperature, the higher the engine efficiency [5]. However, it is not possible to increase the compression ratio as much as the diesel engine as the gasoline that was used in the SI engine is volatile which causes auto-ignition that results in engine knock occurring at a high compression ratio [6].

Brake-specific fuel consumption is a measurement of the fuel efficiency of a combustion engine that burns a fuel-air mixture and drives the crankshaft. The BSFC reflects the engine's ability to convert provided fuel into effective work[7] and it can be utilized to compare the fuel efficiency of different engines. According to Reif Ed, brake-specific fuel consumption is the amount of fuel required by an internal combustion engine to do a specific amount of work. The BSFC is usually measured in unit gram per kilowatt-hour (g/kWh). This parameter gives a more precise measurement of the energy taken from each unit of gasoline than the words litres per hour, litres per 100 kilometers, or miles per gallon[3]. BSFC can be expressed as the ratio of the rate of fuel consumption, $\dot{m}_f$ in g/h to the engine brake power in kW as shown in the following equation [8].

$$BSFC = \frac{\dot{m}_f}{Brake\ Power}$$

Brake thermal efficiency (BTE) is defined as the ratio of nett work to the heat input. In the case of an Internal combustion engine, BTE is refer to the ratio of the brake power to the energy supplied to the engine [9]. The BTE can be utilized to describe the conversion efficiency of heat work. However, the internal combustion engine does not turn all the chemical energy stored in the fuel into mechanical work, resulting in some energy loss. In relation to the second law of thermodynamics, a thermal engine gets heat from a hot reservoir and loses heat to a cold reservoir; hence, a thermal engine is incapable of achieving 100% efficiency [5]. BTE is entirely dependent on engine design, and fuel type [9]. Compared to a CI engine, a SI engine generally has a lower thermal efficiency due to a low compression ratio. The thermal efficiency can be derived from the BFSC of an engine as shown in the following equation where the BSFC is in kg/ kWh and CV is the fuel calorific value which refers to the fuel's lower heating value, LHV (12.06 kW/kg for gasoline).

$$\eta_{bt} = \frac{1}{BSCF \times CV} \times 100$$

Several studies have been done to improve the spark-ignition engine efficiency. According to Martins et al, the efficiency of a SI engine can be improved by downsizing the engine capacity while increasing intake pressure (force induction: turbocharging and supercharging), using a lean and ultra-lean mixture, and using Homogenous Charge Compression Ignition (HCCI) [5]. The turbochargers and superchargers are commonly used in modern internal combustion engines, the turbochargers use exhaust gases to spin a turbine which spins the compressor while the supercharger source the power via a belt that is connected directly to the engine, this eventually will raise the pressure of air or air-fuel mixture that is to be supplied into the combustion chamber.[6] The forced induction leads to engine downsizing to improve fuel efficiency while keeping the driving performance [6].

Eventually, the main concern is forced induction engine produces more heat compared to a normal SI engine because it required a better cooling system otherwise it will affect the engine reliability. Homogeneous Charge Compression Ignition (HCCI) can be achieved by premixing the air-fuel mixture uniformly and compressing it until the temperature and pressure are high enough for autoignition to occur[10]. Due to a combination of highly lean operations resulting in a high specific heat ratio and decreased pumping losses, typically higher compression ratio, and shorter combustion duration, HCCI technology can provide a significant fuel economy benefit [6]. However, the HCCI concept is challenging to be applied to public cars due to its ignition timing and combustion rate which are difficult to control[3]. The easiest way to increase fuel efficiency without changing the SI engine operating principle is using the ultra-lean air-fuel mixture however the performance of the engine will be sacrificed if the lean mixture is used throughout every engine speed.

2.3 Air-Fuel Ratio (AFR)

The air-fuel ratio (AFR) is a mass of air to fuel present during combustion. The Stoichiometric mixture ratio is obtained when the mixture of air and fuel is balanced combined with an approximately 14.7: 1 air to fuel ratio for SI engines that uses gasoline as the fuel [11]. An air-fuel mixture is considered rich if the AFR mixture is less than 14.7:1, the rich mixture is not optimum for the SI engine because there will be fuel left over after combustion due to a lack of oxygen occurring in the combustion chamber that will be causing wasted in fuel and bad performance. If the air-fuel mixture is more than 14.7:1, the AFR mixture is considered lean. The high amount of air present will take up space in the fuel. This type of mixture is undesirable because it produces more nitrogen-oxide emissions, and it can also cause poor performance and even engine damage in some situations [11]. The mixture of fuel for the internal combustion engine is commonly delivered by two mechanisms which are carburettor and electronic fuel injection. The operations carburettor relies on Bernoulli's principle which states that the velocity of a fluid passing through a tube is inversely proportional to the pressure created by it. Meanwhile, Electronic Fuel Injection (EFI) is comprised of a complex set of electronics and sensors. In the fuel Injection system, the pressurized fuel is atomized by a fuel injection nozzle which is controlled by the Engine Control Unit (ECU) as a homogenous mist into the combustion chamber, allowing for more efficient and clean combustion.[10]

The engine's activities are controlled by the ECU as it provides signals to the injectors that govern the amount of gasoline that enters the combustion chamber by determining how long the fuel injector should stay open [12]. Injectors come in a variety of sizes to fit a variety of engines. It's crucial to have injectors that are the right size for the engine that is used because the engine will not operate at its best if the injectors are too big or too small. Every injector has a maximum fuel capacity and a minimum fuel capacity [12]. When the injector is entirely open or at full throttle, the upper limit is reached. When the time it takes for the injector to open is longer than the time it needs to be open (it starts to close before it finishes opening), the lower limit is reached. The injector flow rate is also affected by the size of the injector valve. Less gasoline will be sprayed if the valve opening is smaller. The injector flow rate is also affected by pressure from the fuel pump. When the pressure is lower, less fuel is sprayed into the engine than when the pressure is higher [12].

The ECU gets data in the form of voltage from a variety of sensors to make small alterations to optimize the engine's performance. The majority of sensors are resistors that change their resistance in response to changes during engine activity. Positional sensors, exhaust gas composition sensors, temperature sensors, pressure sensors, and air-metering sensors are the common sensors found in electronic fuel injection engines. The ECU then makes the necessary adjustments based on data provided by the sensors to achieve the optimal AFR for that particular engine speed and load, for example, if there is too much oxygen after combustion the ECU will send data that would allow more fuel to be put into the air-fuel mixture [12].

2.4 Shell Eco-Marathon Prototype Vehicle’s Drivetrain

The aim of participating in the Shell Eco-Marathon Challenge is to develop a fuel-efficient vehicle that can travel the farthest distance with the least amount of fuel possible. To fulfil this requirement a small displacement four-stroke engine was chosen to be the drivetrain of the vehicle. The reasoning behind the engine selection is due to four-stroke engines being generally more fuel efficient compared to two-stroke engines and small displacement engines, in theory, consume less fuel compared to a larger displacement engine [13]. An engine from Honda Dash 2017 was chosen to be the drivetrain of the prototype vehicle. This engine is a 110 cc single-cylinder, four-stroke engine with the capability to produce a maximum output power is 8.46 hp (6.2 kW) at 8460 RPM, and the maximum torque is 8.59 Nm at 5500 RPM. Table 1 shows the technical specification of the Honda Dash 100 cc engine.

Table 1 Shell Eco-Marathon drivetrain specification.

Specification	
Brand	Honda
Model	Dash 110 fi
Type	Four-stroke
Number of cylinders	1
Bore x Stroke	50.0 mm x 55.6 mm
Displacement	109.2 cc
Compression ratio	9.0:1
Fuel system	Electronic Fuel Injection
Camshaft Configuration	Single overhead camshaft (SOHC)
Maximum torque	8.59 Nm @ 5500 RPM
Maximum power	6.22 kW @ 7500 RPM
Cooling system	Air-cooled

The internal combustion engine runs within a particular speed range that is restricted by the idling speed and top speed [3]. Maximum power and torque are only provided in certain ranges and are not produced evenly [14]. when the engine operates out of its powerband, the power output will be low, and it also can affect the fuel efficiency. Moreover, an engine could be destroyed if it runs higher than its maximum rated speed. Therefore, transmission is needed to change the engine torque and engine speed in line with vehicle traction needs so that power remains relatively constant [3]. Most motorcycles use an internal transmission in which the transmission's components were stored inside the engine crankcase. The engine that was used in this project used an internal four-speed constant mesh transmission multi-plate and automatic centrifugal wet clutch. Table 2 shows the technical specification regarding the Honda Dash transmission.

Table 2. transmission technical specification

Specification	
Clutch Type	Automatic Centrifugal & Multi-plate Wet Clutch
Transmission	4 Speed Constant Mesh
Primary Reduction Ratio	4.059 (69/17)
1st Gear	2.615 (34/13)
2nd Gear	1.555 (28/18)
3rd Gear	1.136 (25/22)
4th Gear	0.916 (22/24)
Final Reduction Ratio	2.642 (37/14)

The Multi-plate wet clutch and the automatic centrifugal clutch are types of friction clutch that engaged through friction to transfer a rotational force to another body member [15]. The multi-plate clutch is a spring-loaded component that attaches to the engine's main shaft. When the spring is pressed it released the pressure between the clutch housing and the main shaft separating the load from the engine thus allowing a smooth gear changing. Meanwhile, the automatic centrifugal clutch is actuated by centrifugal force, which pushes the clutch onto the drum and connects it to the transmission main shaft [16]. The centrifugal clutch transfers kinetic energy from the spinning crankshaft to the transmission, which will eventually send the energy to the wheels [16]. The advantage of using an automatic centrifugal clutch is it allows the engine to idle even though the transmission is in gear. However, the automatic centrifugal clutch can cause mechanical losses at low engine speed simply due to less centrifugal force to push the clutch onto the drum. In this project, an automatic centrifugal clutch delete is performed to avoid mechanical losses during a dynamometer engine test. Figure 2.2 show the multi-plate wet clutch and Figure 2.3 show the working principle of an automatic centrifugal clutch.

Figure 2.2. Multi-plate wet clutch [15].

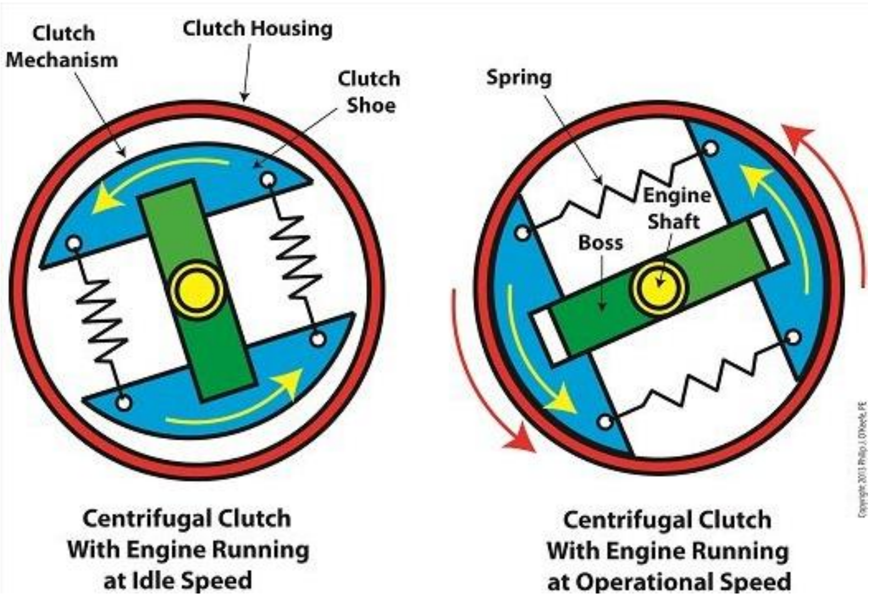

Figure 2.3.Automatic centrifugal clutch working principle.

2.5 Experiment Apparatus

The Eddy current dynamometer can be used to measure the force, torque, or power produced by an engine, an electric machine, or transmission, by measuring simultaneously the torque and the rotational speed [17]. It can be used to determine an engine's power characteristics as well as its fuel consumption. The eddy current dynamometer relies on the principle of Faradays' Law of electromagnetic induction which stated whenever there is a relative displacement between a set of conductors and a magnetic field, an emf is induced on the set of the conductor [8]. When electrical current flows across coils that surround the disc, it causes a magnetic resistance to the dynamometer disc's motion thus creating resistance to the engine's rotation. A dynamometer will be referred to as an Engine Dynamometer if it is mounted to the engine's output shaft while Chassis Dynamometer is referred to as the dynamometer that is mounted to the vehicle's driving wheels. A strain measuring device (strain gauge) resists the force exerted on the dynamometer casing. The strain gage's force signal, F in N can be used to calculate torque, T by multiplying it by the distance between the shaft's center and the strain gage's pivot point, R in m):

$$T = R \times F$$

Then the brake power of the engine can be calculated by multiplying the torque, T in Nm obtained with shaft speed, N in rad/s:

$$P = N \times T$$

The fuel consumption of an engine is an important parameter during dynamometer engine testing. However, it is hard to measure the amount of fuel consumed precisely during the test as the EFI engine required a fuel pump to operate and a complex fuel tank that has a fuel pump mount and a precise mechanism to measure fuel is required to build. Eventually, there is another easier option that is possible to do which is by measuring simultaneously the weight of fuel in the tank using a load cell. A load cell is a type of transducer that converts mechanical force into an electrical signal [18]. The electronic circuitry processes the sensor output, which detects the force (or weight) of the goods. A spring material and a strain gauge are the main components of a load cell. The applied force causes a strain in the spring material, and the strain gauge alters its resistance in response to the change in strain. The strain gauge can be used together with a microcontroller such as the Arduino Uno to a device that is reliable enough to measure the fuel consumption of an engine. In this setup, an *HX711* Amplifier was used to amplify the signal produces by the load cell signal before it was sent to the Arduino controller, then the Arduino microcontroller will process the signal to display the amount of fuel available in the fuel tank [18].

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Overview

This chapter contains the approaches that have been taken to find the Shell Eco-Marathon fuel consumption engine map. There are a few preparations that need to be done before the experiment can be run. First, the engine was disassembled, and an automatic centrifugal clutch delete is done to reduce the mechanical loss during the dynamometer engine test. Then a measuring instrument is made to collect experiment parameter data. A fuel scale device is built to measure the engine fuel consumption and a throttle controller is built to control throttle body flap angle and at the same time measure the throttle body flap angle. A data acquisition program also was built to make the data recording more organized. Two experiments were done in this project, the first experiment is a wide-open throttle engine test to obtain the engine performance and the second experiment is an engine fuel consumption test where the engine is run at variable load and engine speed to observe the fuel usage.

3.2 Engine Assembly and Modification

The centrifugal clutch can be accessed by disassembling the engine's right crankcase cover. Firstly the 10 bolts (part number 17 in Figure 3.1) are required to be unscrewed using an 8 mm socket wrench. All the bolt is taken out and organized in a place to avoid confusion during the assembly process. Then the right crankcase cover can be pulled out, a pry bar might be needed to pry out the right crankcase since there was a gasket adhesive applied on both sides of the right crankcase cover gasket. Pulling out the right crankcase cover will expose the engine components with parts number 3, 5, 6, 7, and 8 in Figure 3.1. The exposed engine part then is taken out from the crankcase and organized carefully in one place. The multi-plate clutch and one-way bearing then can be accessed as shown in Figure 3.2.

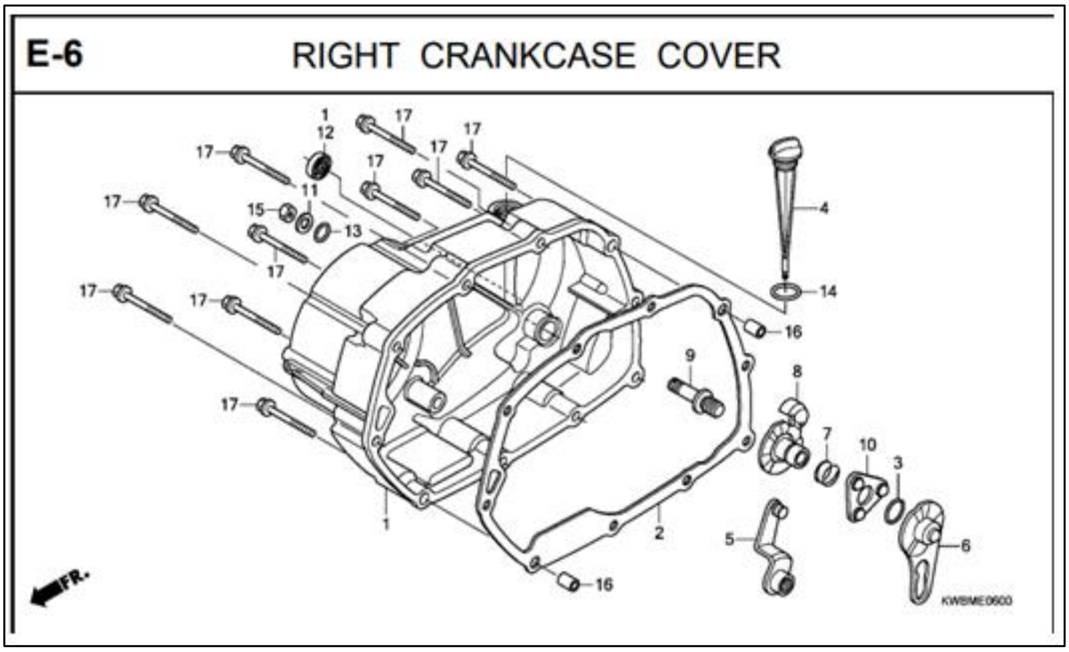

Figure 3.1. Right crankcase components

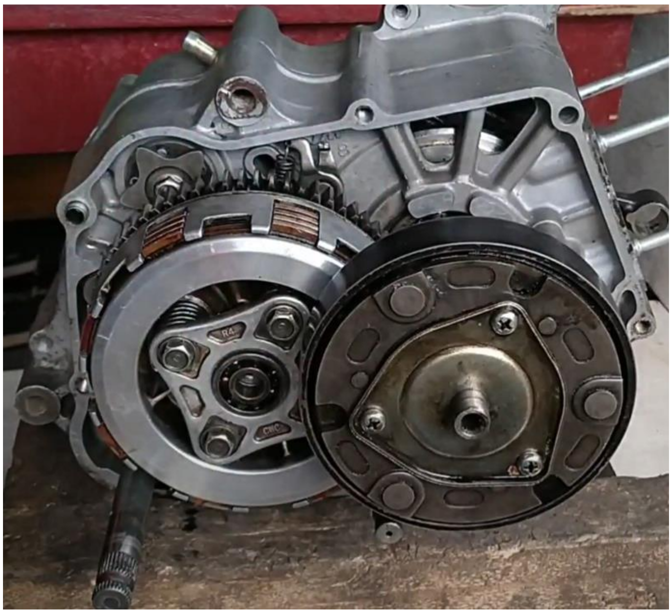

Figure 3.2. Right crankcase assembly without cover.

The multi-plate clutch and the centrifugal clutch are required to be removed simultaneously, to do so there are a few bolts and nuts that need to be unscrewed. Two bolts holding the oil separator plate (part no: 15 in Figure 3.3) are removed first to free up the space for taking out the clutch unit. Then the radial ball bearing (part no: 16 in Figure 3.3) is pulled out to allow access for unscrew the 14mm lock nut that holding the clutch unit.

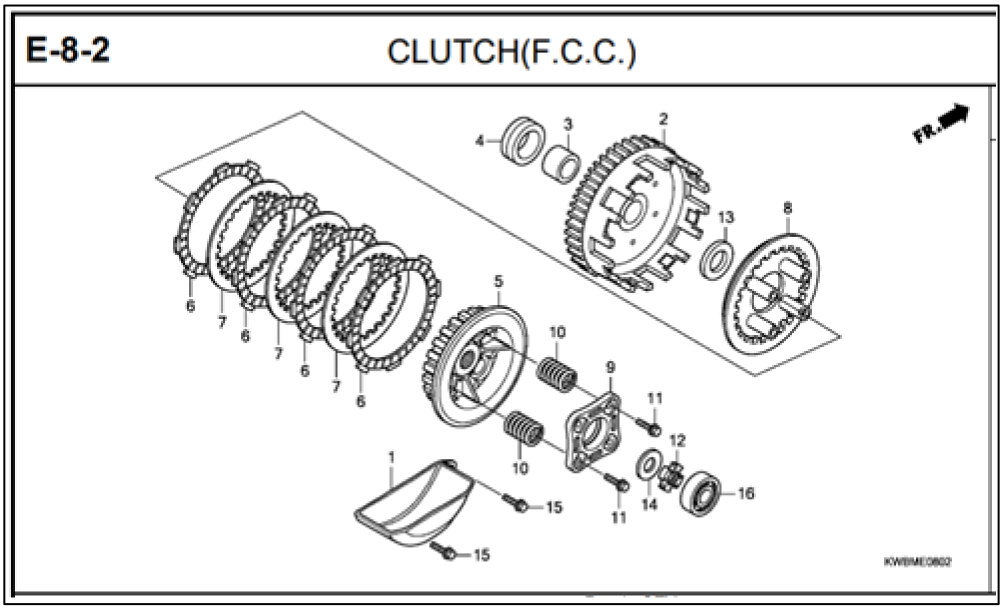

Figure 3.3. Clutch component assembly diagram.

Furthermore, removing the centrifugal clutch unit required unscrewing the 14 mm lock nut (part no: 21 in Figure 3.4). The lock nut can be accessed by unscrewing the three screws that hold the centrifugal clutch cover (part no: 1 in Figure 3.4). After both lock nuts for the multi-plate clutch unit and the centrifugal clutch unit are removed, both components can be pulled out easily from the engine crankcase. Figure 3.5 shows the crankcase of the engine after removing the multi-plate clutch unit and the centrifugal clutch unit.

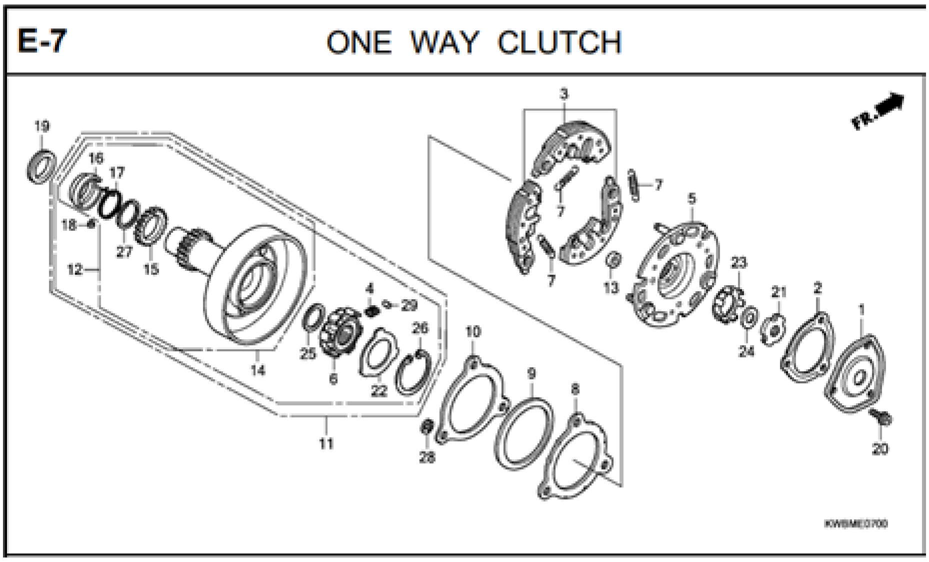

Figure 3.4. one-way clutch component assembly diagram.

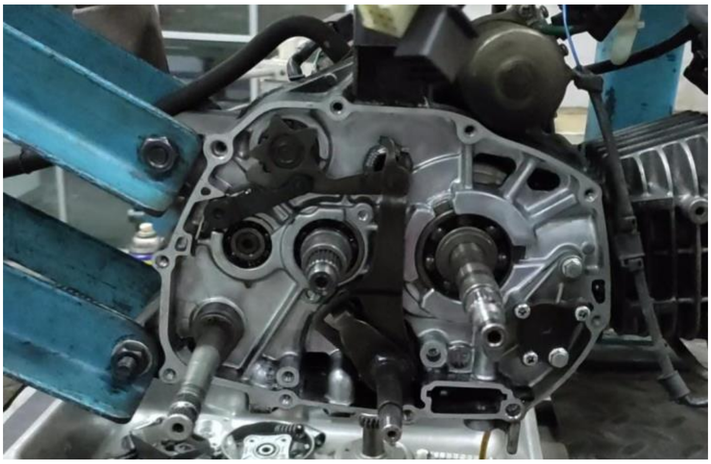

Figure 3.5. Engine crankcase without clutch and one-way clutch.

In this project, the centrifugal clutch delete is done to avoid mechanical losses caused by centrifugal clutch slippage. The slippage mostly occurs when the engine is operated with a high load at low engine speed. The centrifugal clutch delete is done by removing the one-way clutch and replacing it with a weight balancer unit. Replacing the centrifugal clutch with a weight balancer will eliminate the ability of the clutch unit to spin independently with the crankshaft at that low RPM.

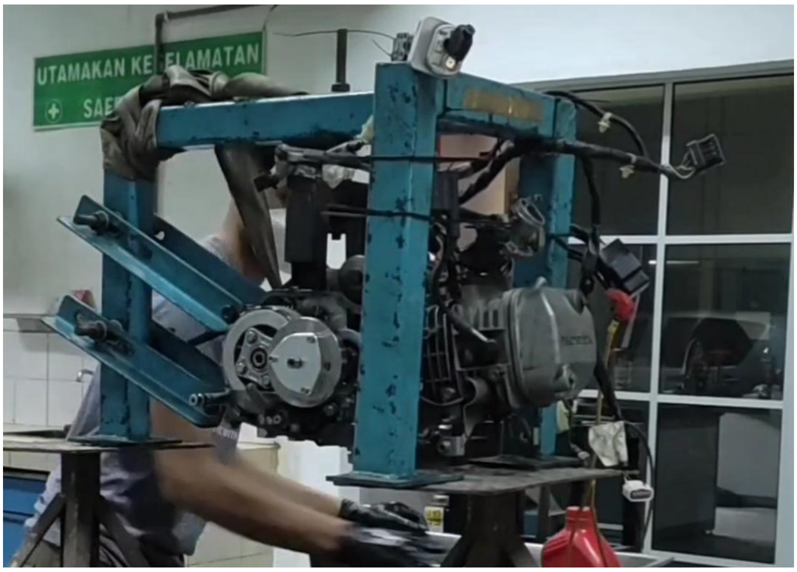

Figure 3.6. Engine crankcase with multi-plate clutch and weight balancer.

The assembly process was continued by putting together all engine components that has been taken out. The assembly process is start with putting the multi-plate clutch and weight balancer unit in their designated position and then tightening the lock nuts for both components. Then the oil separator and gear changing mechanism parts (part no: 3, 5, 6, 7, and 8 in Figure 3.1) were placed to their original placement and secured by their specific bolts and nuts. Before assembling the right crankcase cover, a new gasket is placed on the meeting surface between the crankcase and the right crankcase cover to avoid engine oil leakage. Finally, the right crankcase cover can be fastened by tightening the 10 bolts using an 8mm socket wrench with 10 Nm torque.

Figure 3.7. Fully assemble the engine.

3.3 Fabrication of Fuel Scale

Fuel consumption of the engine during the dynamometer engine test is a vital parameter for this project. However, it is hard to measure fuel consumption precisely because the motorcycle fuel tank geometry is not uniform, and it is hard to measure fuel usage even though a uniform geometry vessel is used as the fuel injection engine required a fuel pump to operate. In this project, the fuel usage will be measured by weighing the fuel tank before and after the dynamometer engine test. To make data collection easier, a fuel measuring device was made by using the load cell, load cell amplifier model *HX711*, and Arduino microcontroller.

Table 3. Material and components used to build the fuel scale device.

No	Material / component	Quantity
1	2 mm Mild steel sheet (30 cm x 45 cm)	2
2	M10 threaded stud	4
3	M10 nut	4
4	Arduino UNO microcontroller	1
5	Load cell (rated mass 10 kg)	1
6	Load cell amplifier *HX711*	1

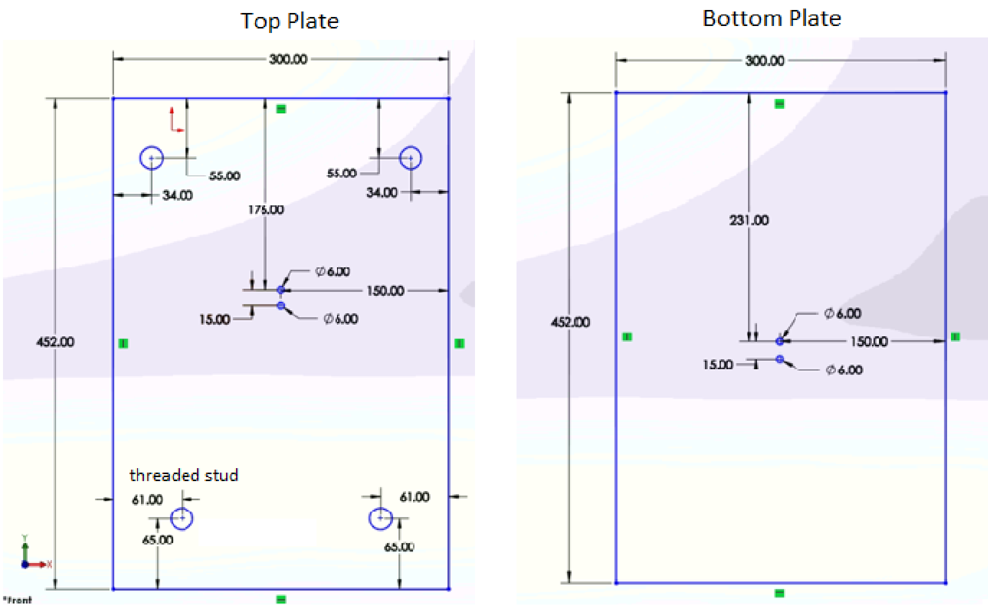

Figure 3.8. Fuel scale top plate and bottom plate measurement.

A sheet of 2 mm mild steel was cut to form two metal sheets with a dimension of (30 x 45) cm. The mild steel sheet was chosen due to its properties that can withstand the weight of the fuel tank with less deflection. Two holes on each top and bottom plate were drilled using a hand drill with a 6 mm drill bit and the holes were drilled at the position shown in Figure 3.8. The holes are drilled to allow to plate to be fastened together to loadcell. Another advantage of using a mild steel sheet is it can weld with the threaded studs. Four threaded studs were welded perpendicular to the top plate at the position shown in Figure 3.8 to allow the fuel tank securely placed on the weight scale. Figure 3.9 shows the fully assemble fuel scale, the top plate is linked to the bottom scale via the load cell. When the fuel tank is placed on it will deflect the load cell and the load cell deflection can be used to measure the weight of fuel.

Figure 3.9. The setup of the weight scale device.

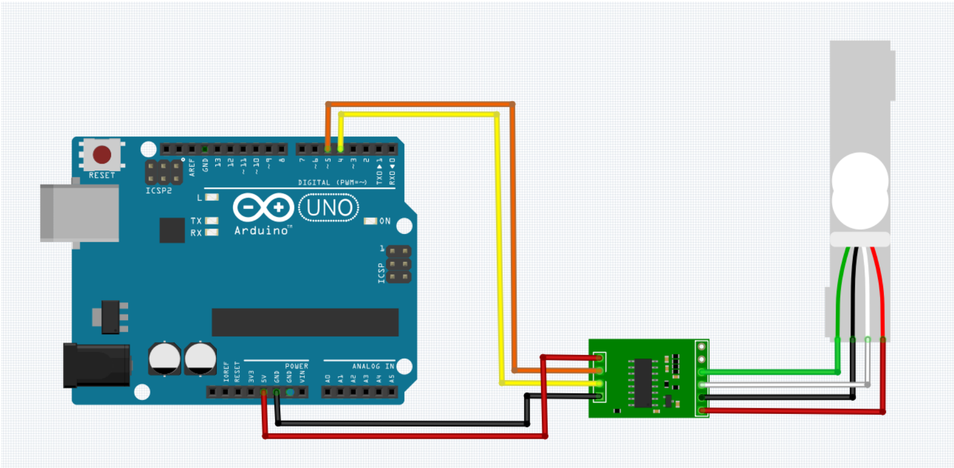

Figure 3.10. Fuel scale schematic diagram.

Table 4. Fuel scale hardware connection.

COMPONENT	LABEL	CONNECTION	INPUT/OUTPUT
Load cell amplifier	E+	Red wire (load cell)	-
	E-	Back wire (load cell)	-
	A-	White wire (load cell)	-
	A+	Green wire (load cell)	-
	GND	GND (Arduino)	-
	VCC	VCC (Arduino)	-
	DT	4	Input
	SCK	5	Input

Figure 3.10 shows the schematic diagram for the fuel scale and Table 4 shows the pin connection for the hardware that was used. An Arduino programming code is made to work together with the load cell and load cell amplifier model *HX711* with the purpose to measure the fuel consumption of the engine during the dynamometer engine test. The programming code made was able to measure the mass of fuel in the fuel tank in real-time and it will convert from mass to volume unit measurement. The fuel measure then is displayed on the monitor screen. The Arduino programming code for the fuel scale can be viewed in Appendix B.

3.4 Fabrication of Throttle Controller

The throttle body is a component in the fuel injection engine that controls the amount of air entering the combustion chamber. Inside the throttle body, there is a butterfly valve that allows more air to regulate into the engine as its opening angle increase. More air enters the combustion chamber more fuel will be injected thus allowing the engine to rev at a higher speed and produce more power. The engine used in this project has a mechanical throttle body where the throttle opening is control manual by a user via a throttle cable. In this project, a throttle controller was built to consistently control the throttle angle (butterfly valve) of the throttle body to be open at a precise angle.

Table 5 shows the materials and components that were used to fabricate the throttle controller.

Table 5. Material and components used to build the throttle controller.

No	Material / component	Quantity
1	10 mm acrylic plate (10.5 cm x 12.5 cm)	1
2	Aluminium bracket	2
3	M6 bolt	4
4	M2.5 bolt	4
5	M2.5 nut	4
6	Throttle cable retainer	1
7	Arduino UNO microcontroller	1
8	Servo motor	1

An acrylic plate with a thickness of 10 mm was cut into a smaller plate with a dimension of (10.5 cm x 12.5 cm) using a handsaw. The acrylic plate was used because it is sturdy as a platform while still easy to cut, drill holes, and tap a thread. Four holes were drilled using a 5 mm drill bit at the position shown in Figure 3.11, followed by tapping the holes with an M6 thread tapping tool. Then a 2 mm aluminium sheet was cut into the dimension as shown in Figure 3.12 to form two brackets. On the servo motor bracket, four holes were drilled using a 7 mm drill bit and another four holes were drilled using a 3 mm drill bit at the position shown in Figure 3.12 to fasten the servo motor on the platform. On the throttle cable retainer bracket, two holes were drilled using a 5 mm drill bit and one hole was drilled using an 8 mm drill bit at the position shown in Figure 3.12. Both servo motor bracket and throttle retainer bracket were bent to 90º.

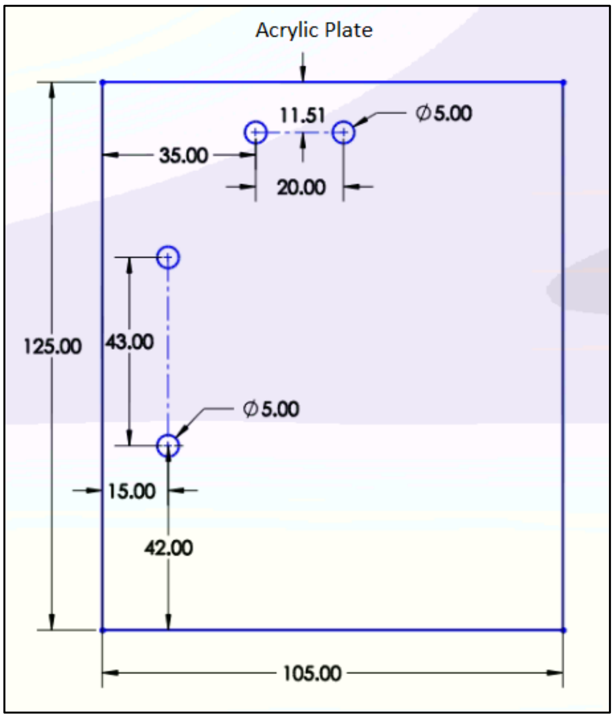

Figure 3.11. Acrylic plate measurement in unit mm.

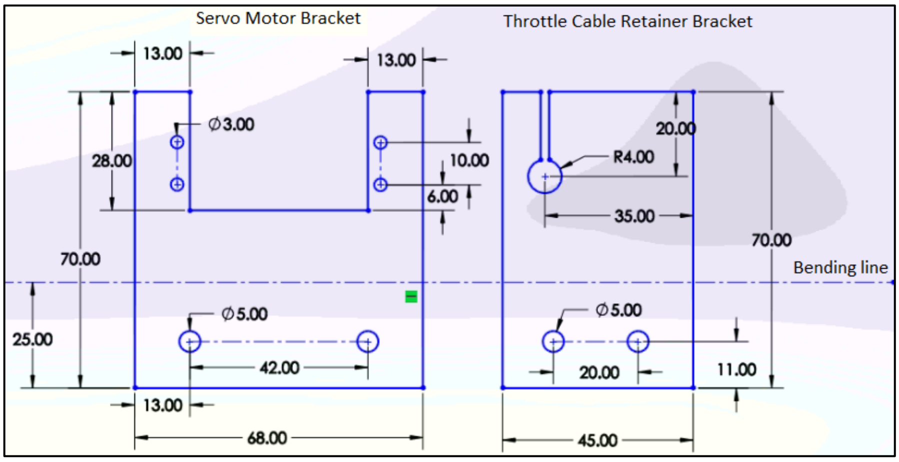

Figure 3.12. Bracket measurement for servo motor and throttle cable retainer in-unit mm.

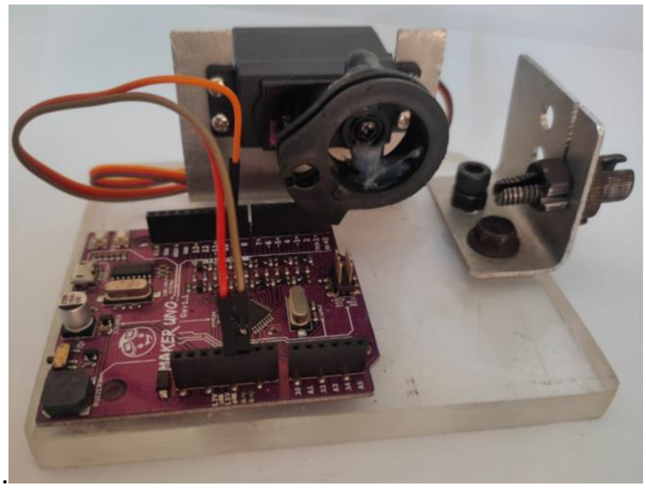

Figure 3.13. Fully assemble throttle controller.

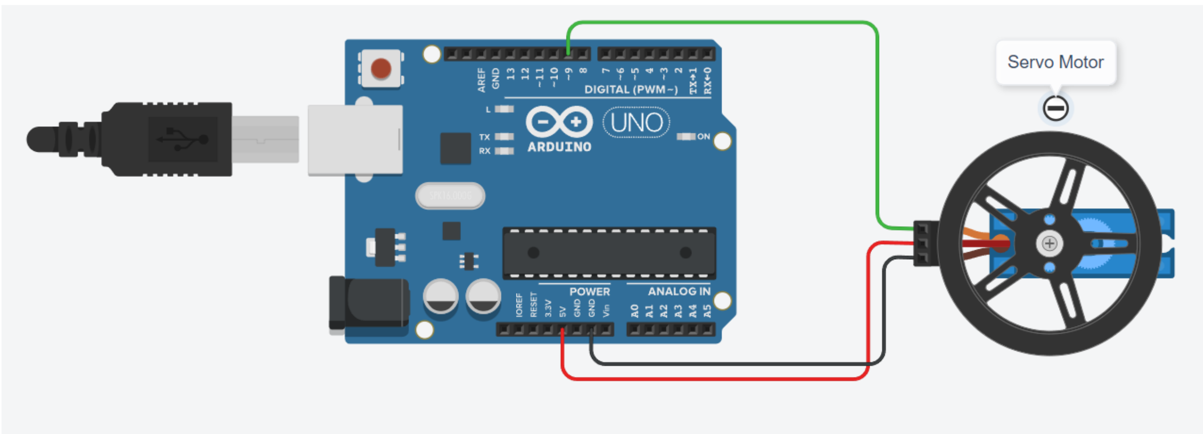

Figure 3.14. Throttle controller schematic diagram.

Table 6. Throttle controller hardware connection.

COMPONENT	LABEL	CONNECTION	INPUT/OUTPUT
Servo motor	GND	GND (Arduino)	-
	VCC	VCC (Arduino)	-
	signal	9	output

Figure 3.14 shows the schematic diagram for the fuel scale and Table 6 shows the pin connection for the hardware that was used. An Arduino programming code was made using the "servo. h" library to make the servo motor able to be rotated to the defined angle by the user and display the real-time throttle angle. In this setup, it was found that the throttle angle reaches the maximum opening angle at 90^{o} when the servo motor pulls the throttle cable at 103^{o}. In the programming code, the minimum throttle angle (0^{o}) was set equal to 0^{o} servo motor rotation while the maximum throttle angle (90^{o}) was set equal to 103^{o} servo motor rotation as shown in Figure 3.15 by using the map function. The Arduino programming code for the throttle controller can be viewed in Appendix B.

```
  angle = map(Output, 0, 90, 0, 73);    // scaling the throttle angle value to angle value for servo
  servo_test.write(angle);              //command to rotate the servo to the specified angle
  delay(10);
}
```

Figure 3.15. The map function is used to define minimum and maximum throttle angle relative to servo motor angle.

3.5 Developing Data Acquisition Program

Multiple parameters need to be recorded during dynamometer engine testing. The parameter such as torque and the dynamometer's input shaft rotation speed were obtained using a strain gauge and hall effect sensor through the dynamometer controller. The mass and volume of fuel used were obtained via the fuel scale while the throttle angle is obtained via the throttle controller. A data acquisition program was built to log all stated parameters from the dynamometer controller, fuel scale, and throttle controller to the computer. The data acquisition program was made using LabView and it enables the experiment data to be displayed in real-time, organized, and save.

The block diagrams of the program were built by utilizing the VISA programming function blocks which is a standard I/O language for instrumentation programming. The VISA configure serial port block is used to initialize the port connection to which the device was connected, the VISA write function block is used to write data from the write buffer to initialized device, and the VISA read function block is used to reads the specified number of bytes from the device, and the VISA close function block used to close device operation loop.

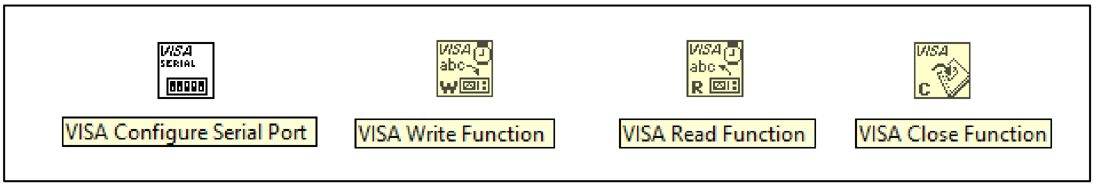

Figure 3.16. Main function block that was used in the block diagrams.

3.5.1 Data Acquisition from Dynamometer Controller

Figure 3.17 shows the block diagram that was made to log in data from the dynamometer controller. The dynamometer controller produced an output parameter such as speed setpoint, dynamometer shaft rotation speed, and toque. Then engine actual speed is derived from the dynamometer shaft rotation speed by multiplying it by the transmission gear ratio. The engine brake power is derived from the dynamometer shaft rotation speed, and torque using the below equation.

$$P = \frac{2\pi NT}{60000} = (1.0472 \times 10^{-4})NT$$

Where,

P = Brake power in kW

N = Dynamometer input shaft rotation speed in RPM

T = Torque in Nm