TWO STROKE SMALL ENGINE TEST RIG DESIGN AND ITS ENGINE PERFORMANCE ANALYSIS

ROSMAN RAZALI

A report submitted in partial fulfillment
of the requirements for the award
of the degree of
Bachelor Of Mechanical Engineering

Faculty of Mechanical Engineering
University Malaysia Pahang

NOVEMBER 2009

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive.

Signature:
Name of Supervisor:
Position: Lecturer
Date: 24 November 2009

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature:
Name: Rosman Bin Razali
ID Number: MH06025
Date: 24 November 2009

Dedicated to my beloved

Father,

Mother,

and Friends

Acknowledgements

In the name of Allah, the Most Benevolent and the most Merciful. Every sincere appreciation and gratitude is only to God. Only by His Kindness and Guidance that this thesis is finally completed .In preparing this thesis, I was in contact with many people and academicians. They have contributed toward my understanding, thought, and also guidance. In particular, I wish to express my sincere appreciation to my main thesis supervisor, P. Madya Dr. Rosli Bin Abu Bakar and my co-supervisor Mr. Aguk Zuhdi Muhammad Fathallah for their valuable guidance, advice and continuous encouragement, constructive criticism and suggestion throughout this project. Without their continued support and interest, this thesis would not have been the same as presented here.

My sincere also extends to all my beloved family especially my parents, Razali Bin Hussin and Rokiah Binti Bakar because if not of their prayer and support I would not be here and done this thesis. Moreover, I would like to thanks for all my colleagues and other who has provides assistance at various occasions. Their view tips are useful indeed in helping me to achieve doing this thesis.

My dedicated also fly to all Mechanical's Engineer Assistant for provide guidance for me to accomplice this task especially to Mr. Ujang and Mr. Nizam. Not forgot also to Pakcik Mat, KK2's hostel cleaner who is very supporting person. Because of his courageous, I can still stand to complete this thesis. With his experience, I gain too many knowledge in conducting this experiment. Hence, to all people that direct or indirectly involve accomplishing my thesis I been sincerely thankful.

Abstract

This thesis is about how to perform an analysis of 30.5cc two stroke engine without using dynamometer. As we know, dynamometer is very expensive in the market and some way need to be build to perform engine performance analysis based on functionality of dynamometer. Hence, dynamometer been replaced with alternator where it is very cheap and easy to find in market. So, engine test rig had been designed before can proceed to fabrication process. Some sketches software had used like autocad and solidwork to draft out the shape of engine test rig. Materials selection also included in this designed process. Variable loads will be given at constant engine speed to see whether performance of engine will decrease or increase. Here, we can analyze at which engine speed is the optimum of performance from this small engine. So, some losses like power and fuel can be decrease.

Abstrak

Tesis ini adalah mengenai bagaimana cara untuk menganalisis prestasi enjin dua lejang 30.5cc tanpa mengunakan dynamometer. Sebagaimana yang kita ketahui, harga dynamometer di pasaran adalah sangat tinggi. Tambahan pula, saiz enjin yang kecil adalah tidak dapat ditampung oleh saiz dynamometer yang besar. Oleh yang demikian, satu alternatif lain dikaji. Alternator telah diguna bagi menggantikan dynamometer. Tambahan pula, ia senang diperoleh dan harganya murah di pasaran. Dengan menggunakan Auto-Cad dan solidwork, draf atau gambaran asal mengenai reka bentuk 'rakit' enjin dapat diihat dengan jelas. Pemilihan dalam memperoleh setiap barang seperti alternator juga termasuk di dalam mereka bentuk 'rakit' enjin sebelum dapat meneruskan uji kaji. Pada kelajuan enjin yang tetap, variasi beban akan diberikan kepada enjin untuk mengukur sejauh mana keupayaan enjin tersebut berfungsi. Di sini juga, kita dapat lihat kuasa dari enjin akan berkurang atau meningkat setelah diberikan sejumlah beban. Oleh yang demikian, kehilangan keupayaan enjin seperti kuasa dan minyak dapat dikurangkan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVITIONS

AC	Alternating current
BHP	Brake horse power
bmep	Mean effective pressure, brake
DC	Direct current
EC	Eddy current
ICE	Internal combustion engine
imep	Mean effective pressure, indicated
PAU	Power absorber unit
RPM	Rotational per minute
SFC	Specific fuel consumption
SI	Spark ignition
SVM	Support vehicle machine
VCR	Vehicle compression ratio

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The performance of engine study is very important to improve engines product, research, and to make service for customer. Every product of engine has it own performance. However, this engine needs to test using engine test bed. Now days engine test bed or some time call as engine test rig are spiritedly from medium to large. These test bed are best to used for test medium to large engine. Seemly not sufficient for very small engine, not only more money need to invest but also less precisian resulted. For that reason, it needs to design small engine test rig to study the performance of small engine.

Most of engine test beds are available to test from medium to large engine. It is very difficult to test performance of a small or a very small engine. Although it is possible to test a small engine using larger engine test rig but it will be insufficient result. Because imprecision performance result of small engine could be inflict for the customer. Usually to study performance of small engine are using simulation. Although the result can predicted performance of engines but for perfect result is using experiment methods.

To test a small engine should use a small engine test rig. It could have more accurate result. However, lately it is very difficult to look small engine test rig in the market. Because the demand are very small they do not product small engine test rig. If we would like to test performance of small engine we should design by own engine test rig. This research will be study a performance vary small engine using experiment technique with small engine test rig. To conduct the performance engine should be start from to design small engine test rig, fabricated the design, and finally an analysis performance of the engine. The capacity of cylinder of an engine is about 30 CC. For that reason it is need specific small engine rig design.

1.2 PROBLEM STATEMENT

How to studies the performance a small two stroke engine with experiment technique. The budget of the research is limited but the result should be accurate.

1.3 OBJECTIVE

a. To design small engine test rig for two stroke 30 CC engine test rig using alternator as dynamometer.
b. To build the small engine test rig
c. To test a performance of the engine

1.4 SCOPE

1. Literature reviews
2. Survey to mechanical engineering laboratories and also to shop market.
3. To design small engine test rig using solid work software.
4. To collect and select cheapest components and materials of engine test rig.
5. To build a small engine test rig.
6. To do experiment for conducting data
7. To study the performance of the engine.
8. To analysis of the performance
9. To write of the report

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about basic concept of engine performance, foundation of engine performance testing, the importance of engine performance testing, development of engine performance testing, principle of dynamometer and a few related studies and journals that have been done by current researchers. All this information is important before furthering to the analysis and study later.

2.2 BASIC CONCEPT OF ENGINE PERFORMANCE

Engine performance characteristics are convenient graphical presentation of an engine performance. They are constructed from the data obtained during actual test runs of the engine and are particularly useful in comparing the performance of one engine with that of another. In this section some of the important performance characteristics of the SI engine are discussed.

It is to be noted that there is a certain speed, within the speed range of particular engine, at which charged inducted per cylinder per cycle will be the maximum. At this point, the maximum force can therefore be exerted on the piston. For all practical purpose, the torque or engine capacity to do work also will maximum at this point.

As the speed of the engine is increased above this speed the quantity of the indicated charge will decrease. However, the power output of the engine increases with the speed due to more number of cycles is executed per unit time. It should be note that the air consumption will continue to increase with increased engine speed until some point is reached where the charge per cylinder per stroke decreases very rapidly than the number of the strokes per unit time is increasing. Engines are so designed that the maximum air consumption point is not reached within the operating speed of the engine. Increase in air consumption means that the increased quantities of fuel can be added per unit time increasing the power output.

2.3 FOUNDATION OF ENGINE PERFORMANCE TESTING

Engine performance is really a relative term. Normally it is represented by typical characteristic curves which are functions of engine operating parameters. The term performance usually means how well an engine is doing its job in relation to the input energy or how effectively it is provides useful energy in relation to some other comparable engines.

Most of the testing of engines for their performance characteristics takes place under laboratory condition. The engine is connected to a power-absorbing device, called a dynamometer (G. P. Blair, 1996). However, the performance characteristics of power, torque, fuel consumption rate, and air consumption rate, at various engine speeds, are recorded (J.B. Heywood, 1988). There are so many types of dynamometers; the principle of any dynamometer operation is to allow the casing to swing freely (A.J. Martyr and M.A. Plint, 2007). The reaction torque on the casing, which is exactly equal to the engine torque, is measured on a level length, L, from the centerline of the dynamometer as force, F. This restrains the outside casing from revolving, or the torque and power would not be absorbed (G. P. Blair, 1996 and A.J. Martyr and M.A. Plint, 2007).

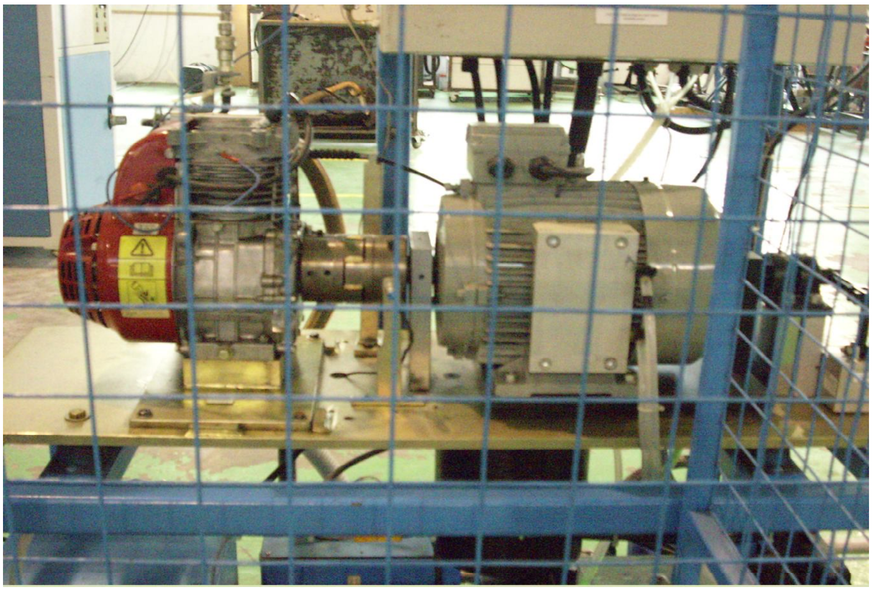


Fig 2.1: Example of medium engine test rig

According to reference, engine performance theory could be divided to two areas such as to learn performance engine using dynamometer (G. P. Blair, 1996, J.B. Heywood, 1988 and A.J. Martyr and M.A. Plint, 2007), and to repair and maintain engine trough diagnostic analysis system with the result is the efficient operation of engines of all designs (J. Erjavec, 2006). Both theories have different objectives. First, to learn performance engine used dynamometer. The goal is could be developed engine performance or may be also give service to customers for selected an engine. Second, is to monitoring of engine in order to have the efficient operation using diagnostic techniques.

Then, there are several factors that must considered in evaluating the performance of the engine. Most of them are maximum power or torque available at each speed within the useful range of speed. Some range of the power output at constant speed for stable operation of the engine must be decided. The different speeds should be selected at equal intervals within the useful speed range. After that, specific consumption at each operating condition must be specified within the useful range of operation.

Dynamometers have been widely used for evaluating the performance of many kinds of internal combustion engines. Many different types of dynamometer systems are in use today and detailed descriptions of the various types can be found in many book. While dynamometers make measurements of engine performance at specific loads, a large number of numerical simulations have also been developed to model the engine cycle and predict engine performance. An important advantage of these codes is that they allow the researcher to investigate the effects of specific aspects of the operating physics like friction, heat transfer and the chemistry involved in the combustion process.

2.4 THE IMPORTANCE OF ENGINE PERFORMANCE TESTING

The two stroke engine was developed only in two opposite fields, namely, large marine engines which use a separate scavenging pump, and small engines for various applications such as power tool. In the former case, high efficiency is desired; in the letter case, lightness, simplicity, and high power output are sought (M. Nuti, 1998). The two stroke cycle engine was invented by Sir Dugald Clerk in England at the end of the 19^{th} century. The form of the engine is using crankcase compression for the introduction process, including the control of the timing and area of the exhaust, transfer and intake ports by piston (G. P. Blair, 1996).

Fig 2.2: Titan Test Stand

Today the most common power source is the well-known two-stroke engine. This type of engine has been the natural choice due to low cost and high power density. The two-stroke engine, as we know it today is not able to comply with future emission demands due to its massive hydrocarbon pollutant. However, in the future engine manufactures must come up with new cost-efficient engine technologies that still deliver the same or improved performance for customer satisfaction (M. Bergman, 2003).

Power and torque measurements obtained at different loading conditions show the same general trends for most conventional scale engines. As figure 1 show, both parameters increase with increasing engine speed and reach a flat peak before decreasing at higher speeds. Engine torque is usually found to peak first followed by a peak in the engine power. Transmission systems in automobiles and other applications are designed to allow the engine to operate in the relatively narrow regimes where it yields maximum power, torque and efficiency.

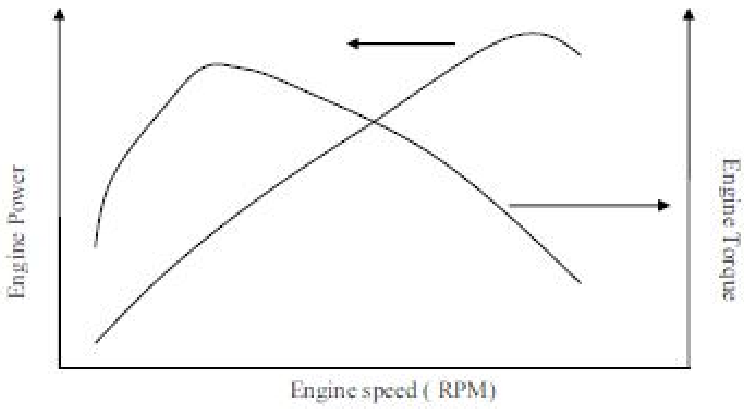


Fig 2.3: Typical shape of power, torque characteristics of a conventional size 2/4 - stroke engine

Waltermann and Neuendorf from University Paderborn, Germany, have been developed a test bed for the design and the optimization of a series hybrid drive train (P Waltermann and N Neuendorf, 2006). For test bed control a powerful real-time environment is applied that comprises component control and the simulation of different component models as well as the operating strategy and the emergency system. All important components of a series hybrid drive are mounted. The individual components (combustion engine, generator, battery and traction drives) were controlled with the different modules.

2.5 DEVELOPMENT OF ENGINE PERFORMANCE TESTING

There are so many research developments on two stroke engine. One of them has been conducted by Merrit and Bennett. The research describes a new stratified charge burn combustion management system based on the invention of a new gas dynamic segregation system (D Merritt and M C Bennett, 2006). The principles leading to high thermal efficiency are explored in relation to their adoption in the new system. Some test results taken on two different Merritt Engine prototypes are shown.

Thermal efficiency values obtained compare very favorably with the latest published result for advanced automobile. There are shown at this current stage of development and it is reasonable to expect further improvements. Improvements should follow the availability of a suitable fuel injection system, improved combustion chamber design, further reduction of combustion chamber heat losses and of course turbo charging in suitable applications.

Another research has been developed by Gordon. 100 cc of two stroke diesel engine was used to investigate the drawbacks of the injection system. The ultimate performance was limited by a mechanical fuel injection system (RL Gordon, 2005). The weakness could be consisted by used a high pressure pump, and electromagnetically actuated, balanced valve and a miniature fuel injector, as the result successfully demonstrated to offer full flexibility in injection timing and fuel delivery. A weight saving of up to 25% was also shown, proving the viability of the new, miniature fuel injection system concept.

A new piston-crank system incorporating a multiple-link mechanism to obtain the optimum compression ratio (VCR) mechanism can be installed without increasing the engine size or weight substantially by selecting a suitable type of link mechanism and optimizing the detailed specifications (Ryosuke, Shunichi and Takanobu, 2006). The effect of these characteristics on fuel economy and maximum power under part load operation was maximum power under part load operation was made clear in terms of combustion stability, time loss, cooling loss and friction.

Research towards improving the performance of internal combustion engines is important because they are ubiquitous. From Michael Anthony Prados, he concluded that it is possible to replace crankshaft from linear motion into rotary motion, to generate electric power (Michael, 2004). The advantage of this technology is easier to define a motion of piston. He used four stroke engines to gain his results because consist of a single unopposed cylinder, which mean this engine has small scale. However, this engine cannot produce too much power but this is good because from experiment conduct, it will be a platform to improve linear engine for power generation.

Vong Chi-man and Wong Pak-Kin had design and model of modern automotive petrol engine performance. They used Support Vector Machines to utilize the results. With an emerging technique, Support Vector Machines (SVM), the approximate performance model of a petrol vehicle engine can be determined by training the sample engine performance data acquired from the dynamometer (Vong and Wong, 2004). They found that current practice of engine tune-up relies on the experience of the automotive engineer, and tune-up is usually done by trial-and-error method and then the vehicle engine is run on the dynamometer to show the actual engine performance. The authors found that the number of dynamometer tests for an engine tune-up can therefore be reduced because the estimated engine performance model can replace the dynamometer tests to a certain extent.

2.6 DYNAMOMETER

Dynamometer is a device to measure force, torque, or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm). In standard emissions testing cycles, dynamometers are used to provide simulated road loading of either the engine (using an engine dynamometer) or full powertrain (using a chassis dynamometer). In fact, beyond simple power and torque measurements, dynamometers can be used as part of a test rig for a variety of engine development activities such as the calibration of engine management controllers, detailed investigations into combustion behavior.

2.6.1 Principle of Operation

An absorbing dynamometer acts as a load that is driven by the prime mover that is under test. The dynamometer must be able to operate at any speed and load to any level of torque that the test requires. An Absorption dynamometer is usually equipped with some means of measuring the operating torque and speed, like engine. An absorption unit consists of some type of rotor in housing. The rotor is coupled to the engine or other equipment under test and is free to rotate at whatever speed is required for the test. Some means is provided to develop a braking torque between dynamometer's rotor and housing. The means for developing torque can be frictional, hydraulic, and electromagnetic according to the type of absorption or driver unit.

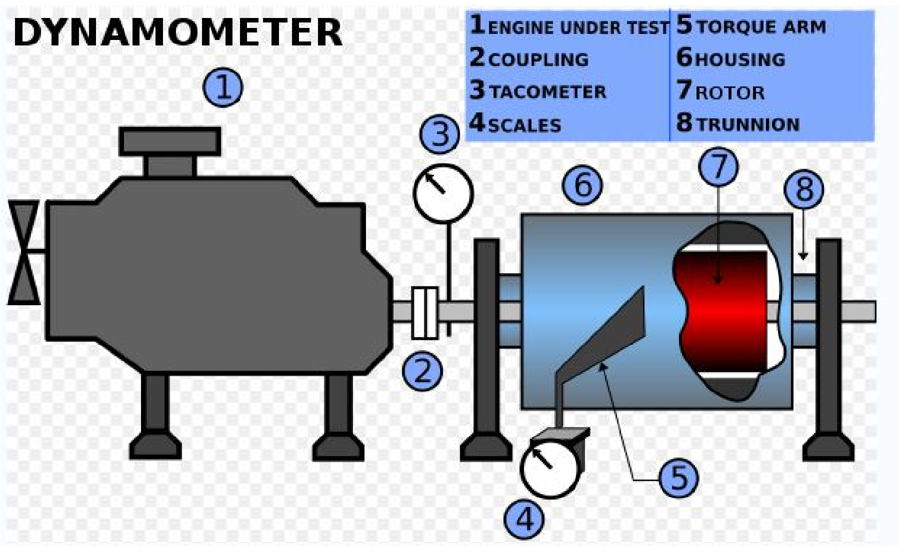


Fig 2.4: Electrical dynamometer setup showing engine, torque measurement arrangement and tachometer

One means for measuring torque is to mount the dynamometer housing so that it is free to turn except that it is restrained by a torque arm. The housing can be made free to rotate by using trunnions connected to each end of the housing to support the dyno in pedestal mounted trunnion bearings. The torque arm is connected to the dyno housing and a weighing scale is positioned so that it measures the force exerted by the dyno housing in attempting to rotate.

Another means for measuring torque is to connect the engine to the dynamometer through a torque sensing coupling or torque transducer. A torque transducer provides an electrical signal that is proportional to torque. With electrical absorption units, it is possible to determine torque by measuring the current drawn or generated by the absorber or driver.

This is generally a less accurate method and not much practiced in modern times, but it may be adequate for some purposes. A wide variety of tachometers is available for measuring speed. Some types can provide an electrical signal that is proportional to speed. When torque and speed signals are available, test data can be transmitted to a data acquisition system rather than being recorded manually. Speed and torque signals can also be recorded by a chart recorder or plotter.

2.6.2 Types of Dynamometer

Dynamometers can also be classified by the type of absorption unit or absorber/driver that they use. Some units that are capable of absorption only can be combined with a motor to construct an absorber/driver or universal dynamometer. The following types of absorption/driver units have been used:

- Eddy current or electromagnetic brake
- Magnetic Powder brake
- Hysteresis Brake
- Electric motor or generator
- Water brake

2.6.2.1 Eddy Current Type Absorber

Eddy Current (EC) dynamometers are currently the most common absorbers used in modern chassis dynamometer. The EC absorbers provide the quick load change rate for rapid load settling. Most are air cooled, but some are designed to require external water cooling systems. Eddy current dynamometers require an electrically conductive core, shaft or disc, moving across a magnetic field to produce resistance to movement. Iron is a common material, but copper, aluminum and other conductive materials are usable. The electromagnet voltage is usually controlled by a computer, using changes in the magnetic field to match the power output being applied.

2.6.2.2 Magnetic Power Brake

A powder dynamometer is similar to an eddy current dynamometer, but a fine magnetic powder is placed in the air gap between the rotor and the coil. The resulting flux lines create "chains" of metal particulate which are constantly built and broken apart during rotation creating great torque. Powder dynamometers are typically limited to lower engine speed (rpm) due to heat dissipation issues.

2.6.2.3 Hysteresis Brake

Hysteresis dynamometer use a steel rotor that is moved through flux lines generated between magnetic pole pieces. This design, as in the usual "disc type" eddy current absorbers, allows for full torque to be produced at zero speed, as well as at full speed. Heat dissipation is assisted by forced air. Hysteresis and "disc type" Eddy Current dynamometers are one of the most efficient technologies in small dynamometers (less than 150 kW). A hysteresis brake is an eddy current absorber which, unlike most "disc type" Eddy Current absorbers, puts the electromagnet coils inside a vented and ribbed cylinder and rotates the cylinder, instead of rotating a disc between electromagnets. The potential benefit for the hysteresis absorber is that the diameter can be decreased and operating rpm of the absorber may be increased.

2.6.2.4 Water Brake

The water brake absorber is sometimes mistakenly called a "hydraulic dynamometer". Water brake absorbers are relatively common, having been manufactured for many years and noted for their high power capability, small package, light weight, and relatively low manufacturing cost as compared to other, quicker reacting "power absorber" types.

The schematic shows the most common type of water brake, the variable level type. Water is added until the engine is held at a steady rpm against the load. Water is then kept at that level and replaced by constant draining and refilling, which is needed to carry away the heat created by absorbing the horsepower. The housing attempt to rotate in response to the torque produced but is restrained by the scale or torque metering cell which measures the torque.

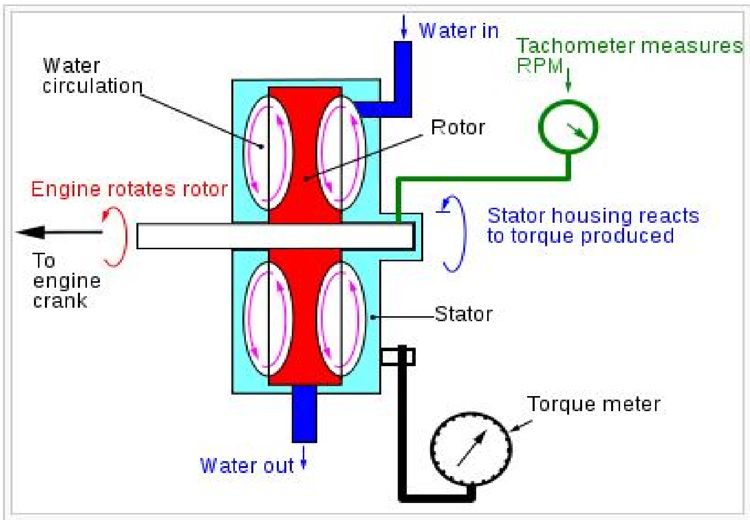


Fig 2.5: Schematic shows of a water brake which is actually a fluid coupling with the housing restrained from rotating and similar to a water pump with no outlet.

2.6.2.5 Electric Motor or Generator

Electric motor/generator dynamometers are a specialized type of adjustable-speed drives. The absorption/driver unit can be either an alternating current (AC) motor or a direct current (DC) motor. Either an AC motor or a DC motor can operate as a generator which is driven by the unit under test or a motor which drives the unit under test. When equipped with appropriate control units, electric motor/generator dynamometers can be configured as universal dynamometers.

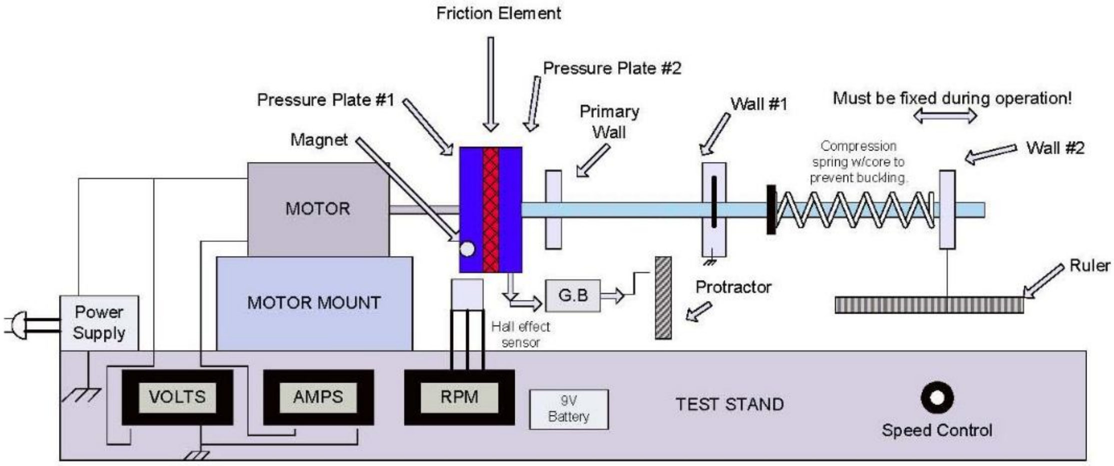


Fig 2.6: Example of Electric Motor Dynamometer

The control unit for an AC motor is a variable-frequency drive and the control unit for a DC motor is a DC drive. In both cases, regenerative control units can transfer power from the unit under test to the electric utility. In engine testing, universal dynamometers can not only absorb the power of the engine but also, drive the engine for measuring friction, pumping losses and other factors. Electric motor or generator dynamometers are generally more costly and complex than other types of dynamometers.

2.6.3 Performing Engine Testing Using Dynamometer

Dynamometers are useful in the development and refinement of modern day engine technology. The concept is to use a dynamometer to measure and compare power transfer at different points on a vehicle, thus allowing the engine or drivetrain to be modified to get more efficient power transfer. For example, if an engine dynamometer shows that a particular engine achieves 400 N·m of torque, and a chassis dynamo shows only 350 N·m, one would know to look to the drivetrain for the major improvements. Dynamometers are typically very expensive pieces of equipment, reserved for certain fields that rely on them for a particular purpose.

2.6.3.1 General Testing Methods

A ‘brake’ dynamometer applies variable load on the engine and measures the engine's ability to move or hold the rpm as related to the "braking force" applied. It is usually connected to a computer which records the applied braking torque and calculates the power output of the engine based on information from a "load cell" or "strain gauge" and rpm (speed sensor)

An ‘inertia’ dynamometer provides a fixed inertial mass load and calculates the power required to accelerate that fixed, known mass and uses a computer to record rpm and acc. rate to calculate torque. The engine is generally tested from somewhat above idle to its maximum rpm and the output is measured and plotted on a graph.

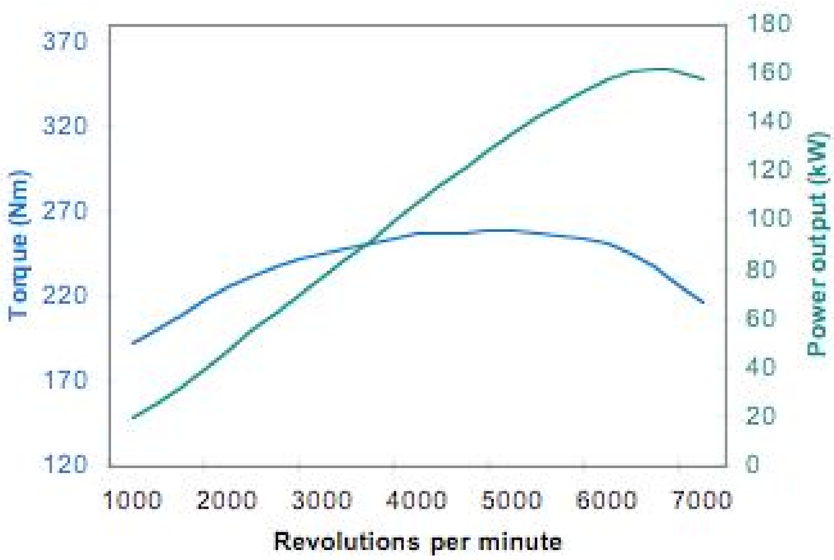


Fig 2.7: Example plotted graph

There are essentially only 2 types of dynamometer test procedures:

1. Steady State (only on brake dynamometers), where the engine is held at a specified rpm (or series of usually sequential rpm) for 3–5 seconds by the variable brake loading as provided by the PAU (power absorber unit).

2. Sweep Test (on inertia or brake dynamometers), where the engine is tested under a load (inertia or brake loading), but allowed to "sweep" up in rpm in a continuous fashion, from a specified lower "starting" rpm to a specified "end" rpm.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will further describe the study about testing the real performance of small two stroke engine without using any simulation software. In order to complete this project, one of the most important things to be considered is methodology to ensure that the project run smoothly and will get expected result which is needed. In this chapter, it will be discussing about the process of this project due to flow chart.

In this chapter also, there are several steps must followed step by step to ensure that the objective of this project can be achieved start from literature finding until submit the report. First step is selecting the materials and some components and it will be discuss later. For second step, small engine test rig must be design to make all parts and components work smoothly after assembles. Software's design like AUTOCAD and solid-work can be use to illustrate how this final small engine test rig project can be done.

After get all the components and parts, next step is to build an engine test rig before can assemble all this components. Engine test rig is made from metal plate that been welded. This engine test rig should stand on the table without movement to make sure that all data collected is persisting.

For the last step is about collecting data, analyze data and discussion about result for this experiment or project. Before explaining details on this methods used, flowchart and Gantt chart will a little information on the process flow.

3.2 DEVELOPMENT OF DYNAMOMETER

Dynamometer has been widely used for evaluating the performance of many kinds of internal combustion engines. The approach that we will take here is to develop a dynamometer that is capable of making reliable measurements of torque, engine speed, and fuel consumption. These are the critical measurements for determining an engine's power output and fuel efficiency. However, to understand the operation of the engine and to help explain the power and efficiency data, measurements of other engine operating parameters like fuel/air ratio, engine operating temperature, throttle position and mixture setting are also important. These measurements will enable some preliminary conclusions to be drawn about the factors that limit engine performance and how engine performance scales with engine size. Finally, recommendations for how the measurement system can be improved will be made.

For this experiment, dynamometer would not be used and other alternative way has been build to perform the similar function as dynamometer. Dynamometer will be replaced with alternator. Alternator will be coupling to the small engine with belt. When small engine running, it produced power and will be delivered to alternator. Alternator will convert mechanical energy to electrical energy. From here, current will be produce from alternator. Voltmeter and ammeter need to be use to take the reading of voltage and current so power can be calculated.

3.3 FLOW CHART AND GANTT'S CHART

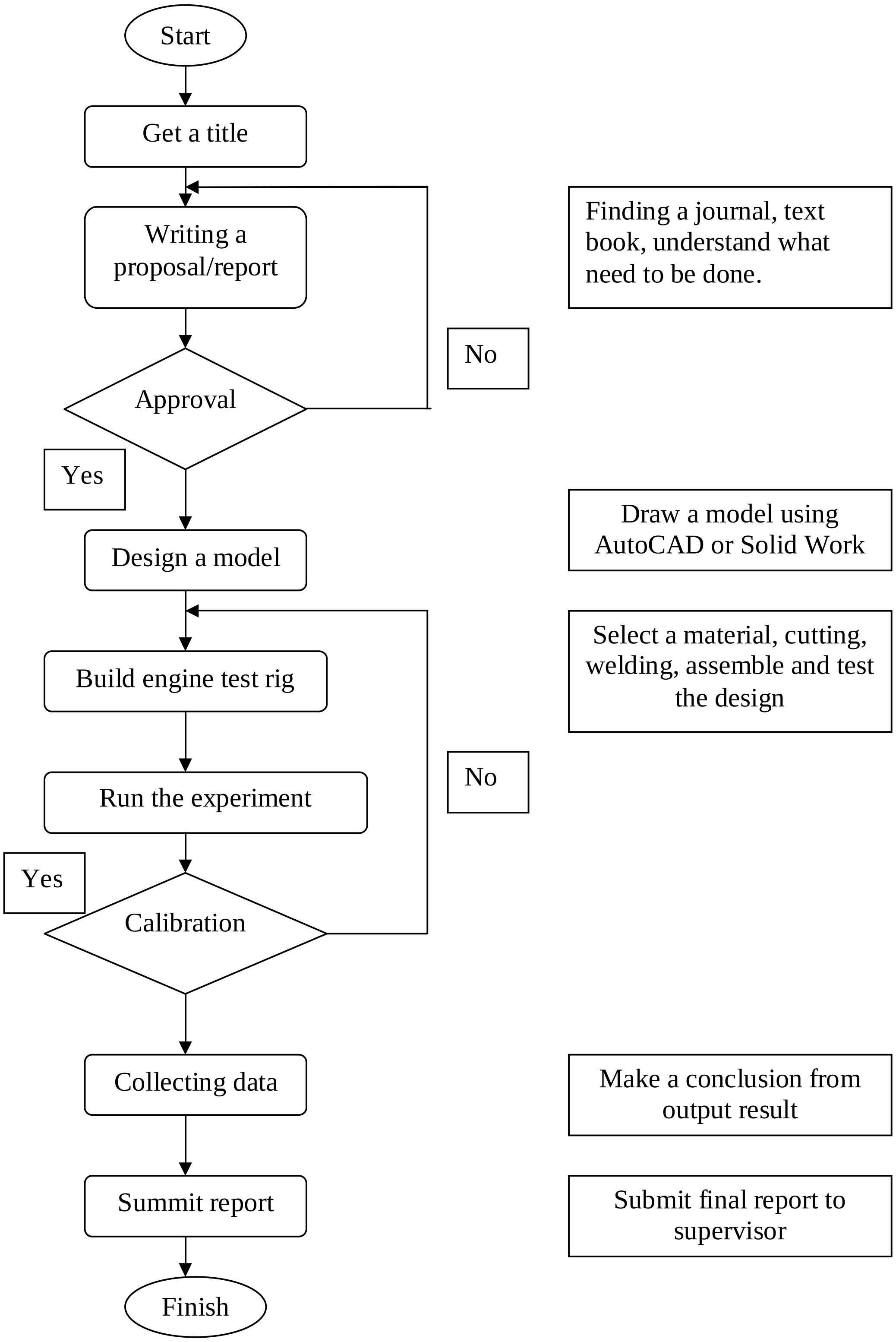


Fig 3.1: Flow chart

3.4 MATERIALS SELECTION

This task is very importance part before proceed to fabrication of small engine test rig. The characteristic of each part need to be study properly to ensure that all data when doing experiment is correct. Moreover, it also can prevent some part from damage when higher speed from engine was given. This process also can be included as designing small engine test rig.

Material selections also a part of small engine test rig designing. All parts need to be choosing correctly to prevented incorrect data collected. Moreover, it can reduce the cost from buying unnecessary material.

3.4.1 Engine Specifications

The main thing that needs to know is how much small engine can produce the maximum power. The maximum value of power from small engine can be getting from this engine specification itself. This engine can produce maximum power about 810 Watt at 6000 rpm.

Table 3.1: Engine specification

Model	**BG-328**
Engine	
Type	2 cycle, single cylinder, forced air cooled, gasoline engine
Displacement	30.5 cc
Max. Output	0.81 kW/ 6000 rpm
Carburetor	Float type
Ignition system	IC Ignition (Solid state)
Ignition plug	BM-7A or CHAMPION CJ6
Fuel	Mixed fuel of gasoline and 2 cycle oil at 25:1
Fuel tank capacity	1.2 liters

Body	
Drive	Flexible shaft, drive shaft, pinion and gear
Rotational direction of cutter (viewed from the top of the cutter)	Counter clockwise
Dimension (Length x Width x Height)	345 x 280 x 401 mm (Back loaded part only)
Dry weight	9.4 kg

3.4.2 Alternator Selection

Choosing the right alternator is most important thing because alternator must support the power produced from small engine. Hence, consideration needed when choosing the right alternator. By using equation of power, P= IV where I is current and V is voltage produced from alternator, it should produce more than 810 Watt. Table below show some alternator that can easily to be found in market, with alternator output and their range of prices.

Table 3.2: Several model of alternator

Manufacturer	Alternator output	Price
Proton Satria Neo-1.35cc	12V/60A	Rm 150
Proton Perdana-2.0cc	12V/90A	Rm 240
Proton Wira 1.5cc	12V/75A	Rm 160
Honda Accord 2.0cc	12V/80A	Rm 280

So, Proton Wira's alternator with 12V/75A can be use and it will produce around 900 Watt and can support the power from small engine. Moreover, the price for this alternator is cheaper than compare to other alternator which can produce higher output.

However, alternator with output 12V/65A also can be use because the range of voltage can be produce from alternator usually until 14.5V. Then the maximum power can produce from alternator will be 942.5 Watt.

3.4.3 Other Materials

Other important thing is what type of menthol should be used as load. The voltage produce from alternator will exceed more than 12V, and it will go to around 14.5V at higher engine speed. So it is very important to select the right menthol to be used. It may cause some of the menthol damage when voltage produced overload that 12V. Here menthol with 24V was selected.

3.5 DESIGNING SMALL ENGINE TEST RIG

To design this small engine test rig, the functional of each component needs to know before proceeded to fabrication process. For example, alternator can produce the voltage either its pulley move in clockwise or other way. Hence, engine can be place either at the right or left of alternator. Other consideration is fuel tank must be put at higher place to make sure fuel flow to carburetor is smooth.

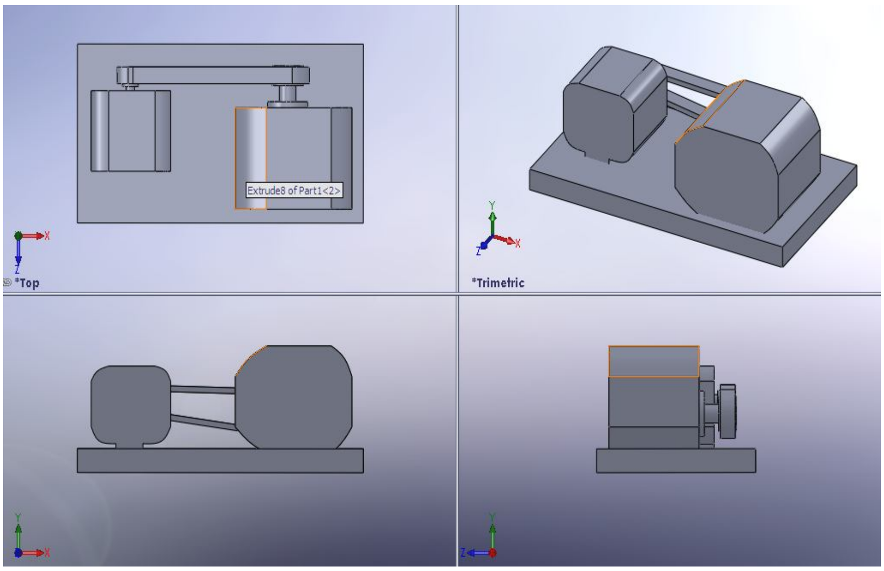


Fig 3.2: Initial draft of small engine test rig

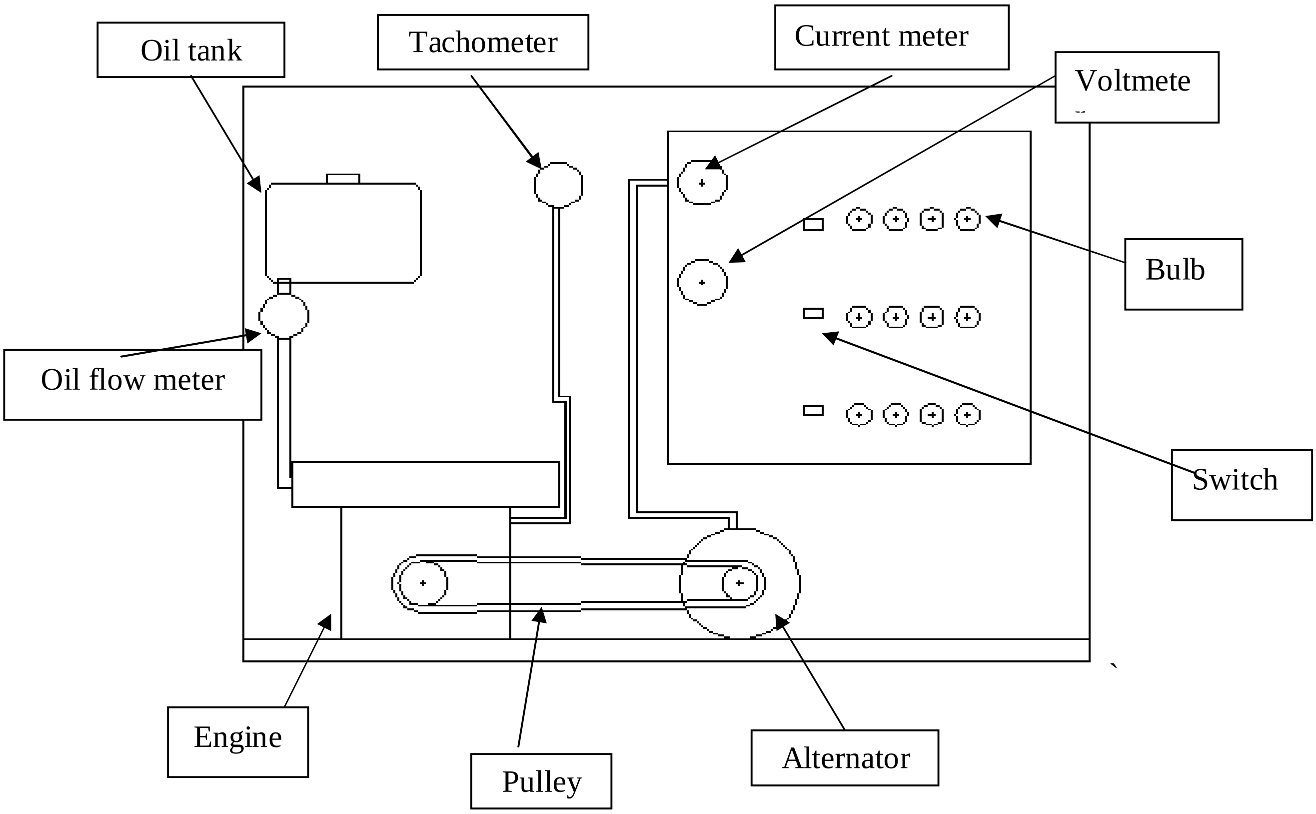


Fig 3.3: Draft of engine test rig

3.6 FABRICATION OF SMALL ENGINE TEST RIG

Next process is test rig fabrication. In this process, all work need to be done without doing a mistake to make sure all component can be assemble correctly. After got a metal plate as platform of test rig, the fabrication began. The dimension of the platform is 55cm x 3.8cm x 29.5cm (length x height x wide). Metal plate was selected because it is light weight and easy to install the engine and alternator.

Fig 3.4: Small two stroke engine used

Some modifications need to be done at the engine shaft to make sure it can be connected to alternator. Then, the shaft is replaced with a pulley (figure 3.5) and type of pulley must be similar with pulley at alternator. To make sure alternator do not slip from the test rig, a holder had been build at the end of the test rig. This is very important because timing belt might be pulling out from the pulley.

Fig 3.5: Modification on shaft by putting the pulley

Fig 3.6: Alternator holder

Fig 3.7: Installing the alternator

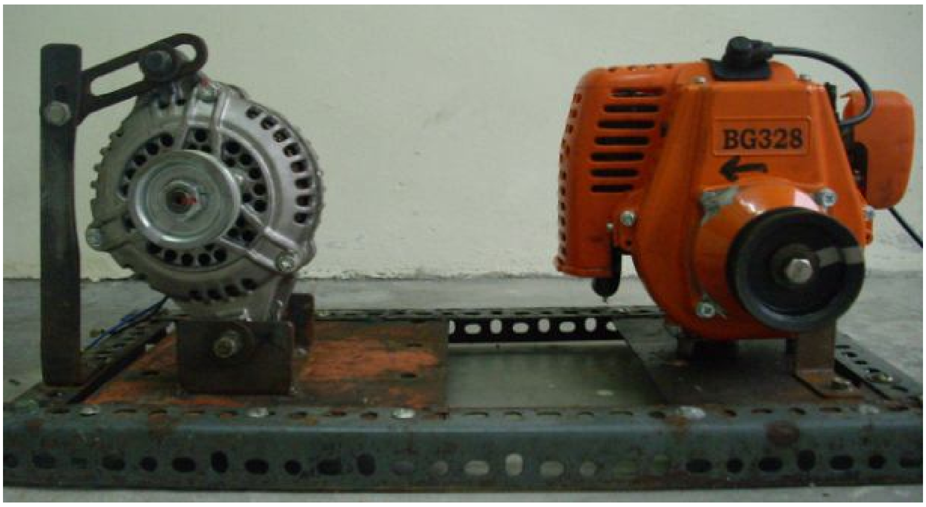


Fig 3.8: Front view of test rig without timing belt

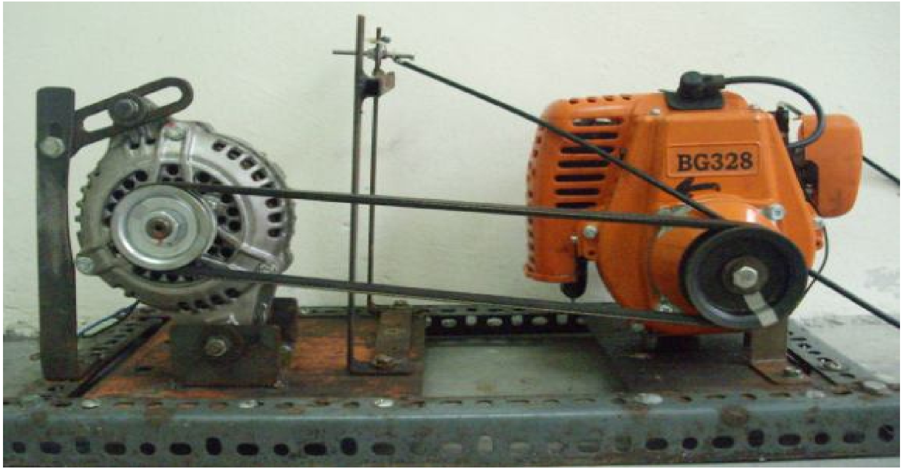


Fig 3.9: Front view of test rig with timing belt

Fig 3.10: Upper view of engine test rig

Fig 3.11: Electric circuit as load

To check the engine performance with load given, an electrical circuit had been built. Parallel circuit is selected because of safety factor. When one of the bulbs is broken due to extreme voltage, others bulb does not affected. It is also easy to control the amount of bulb that wants to be used.

Fig 3.12: Engine test rig setup

3.7 FORMULA

Power is defined as the rate of doing work. If the engine rotation rate is rpm, revolutions per minute, and the two-stroke engine has a working cycle per crankshaft revolutions, so the power delivered to piston is called the *indicated power output*, P_i, where:

$$P_i = \text{imep x } V_{iv} \text{ x } \frac{rpm}{60} \quad (3.1)$$

The power, P, delivered by the engine and absorbed by the alternator is the product of torque and angular speed:

$$P = 2\pi NT \quad (3.2)$$

Power also can be calculated from electrical device where alternator convert the mechanical energy from engine to electric energy, where

$$P = I \text{ x } V \quad (3.3)$$

The reaction torque on the casing, which is exactly equal to the engine torque, is measured on a lever of length, L, from the centerline of the dynamometer as a force, F. This restrains the outside casing from revolving, or the torque and power would not be absorbed. Consequently, the reaction torque measured is the brake torque, T_b and is calculated by:

$$T = F \text{ x } L \quad (3.4)$$

From equation (4.2), we also can get the value of torque, where:

$$T = \frac{P_i}{2\pi N} \quad (3.5)$$

The value of engine power measured as described above is called *brake power*, P_b. This power is the usable power delivered by the engine to the load which means in this case, a “brake”.

The common usage in engineering practice is the concept of specific fuel consumption, is measured as a flow rate, mass flow rate per unit time, $\dot{m}_f$. A more useful parameter is the specific fuel consumption, sfc, the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work:

$$SFC = \frac{\dot{m}_f}{P} \quad (3.6)$$

3.8 CALIBRATION

Calibration is a measurement process that assigns values to the property of an artifact or to the response of an instrument relative to reference standards or to a designated measurement process. The purpose of calibration is to eliminate or reduce bias in the user's measurement system relative to the reference base.

3.8.1 Engine Speed Calibration

The speed at engine’s rotor is different with alternator’s rotor. Some energy losses occur during power transmitted from engine to alternator. At this stage we need to make sure that the speed of each rotor is constant for accurate data. The radius of engine is larger than rotor of alternator. Hence, the speed of alternator’s rotor should higher. However, angular velocity of engine’s rotor is larger than alternator’s rotor. Table 3.3 shows the angular velocity of engine’s rotor and alternator’s rotor.

Table 3.3: Calibration of angular velocity

Engine’s rotor	Alternator’s rotor	Percentage error (%)
10.2772 rad/s	10.2002 rad/s	99.25
11.9008 rad/s	11.7653 rad/s	98.86
14.8377 rad/s	14.5317 rad/s	97.93

So, the average speed of error is 98.68%.

3.8.2 Engine Power Calibration

They are two type of voltmeter and ammeter that had been used, analog and digital where digital also known as multimeter. So, multimeter will give more accurate data compare to analog devise.

Table 3.4: Calibration of voltmeter

Multimeter (V)	Voltmeter (V)	Percentage error (%)
8.6	8	93.02
12.3	12	97.56
14.7	14	95.24

Average error of voltage: 95.27%

Table 3.5: Calibration of voltmeter

Multimeter (A)	Voltmeter (A)	Percentage error (%)
24.1	23	95.44
43.4	42	96.77
18.8	18	95.74

Average error of current: 95.98%

3.9 DATA COLLECTING

After all the process had done, all data that been record before are been research or observe. So the comparison can be making for different speed of the engine (rpm). The data also can be described by plotting into graph and clearly can see the different between all the results or data collected.

There many way to get the data of fuel flow rate. The easier way is by using tube that is place at the ruler. This tube must be transparent so that easy to take the reading when fuel were using during experiment. Time need to be taken when running the experiment to measure the quantity of fuel that been used.

Tachometer will be use to take the data for speed of engine or rpm. There two ways to measure the speed of engine. Tachometer can directly connected to the pulley of engine. The spindle at tachometer will rotate depends on the speed of engine. Other way is just shot the laser from tachometer to the pulley at engine. A piece of paper that acted like detector will detect the rotational of pulley.

Fig 3.13: Tachometer's laser detection

Fig 3.14: Conducting the tachometer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter represents the details results of two stroke engine performance analysis by using experiment method and the data collected is shown and described briefly. The calculated result is then converted into graph. The optimum engine performance can be getting by comparing all graphs.

4.2 RESULTS

All the results taken during conducted the experiment is shown in the table and is differentiating by each engine speed. Then the fuel flow rate, specific fuel consumption and torque are calculated.

Table 4.1: Result of engine speed for 1000 rpm

Number	Load (W)	Voltage (V)	Current (A)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	25	5.2	15	0.03952	4095.73	0.23873
2	50	5.0	14	0.03968	2056.15	0.47746
3	75	4.8	12	0.03984	1376.30	0.71620
4	100	4.5	12	0.03995	1035.07	0.95493

5	125	4.6	10	0.04009	830.96	1.19366
6	150	4.3	9	0.04025	695.23	1.43239
7	175	4.1	9	0.04038	597.84	1.67113
8	200	3.9	9	0.04051	524.79	1.90986

Table 4.2: Result of engine speed for 2000 rpm

Number	Load (W)	Voltage (V)	Current (A)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	50	8.1	27	0.04939	2559.31	0.23873
2	100	8.1	25	0.04962	1285.61	0.47746
3	150	8.0	24	0.04983	860.70	0.71620
4	200	7.9	22	0.05004	648.25	0.95493
5	250	7.8	20	0.05034	526.78	1.19366
6	300	7.6	18	0.05083	438.99	1.43239
7	350	7.5	18	0.05137	380.27	1.67113
8	400	7.3	17	0.05191	336.24	1.90986
9	450	7.2	17	0.05236	301.47	2.14859
10	500	7.0	16	0.05302	274.74	2.38732

Table 4.3: Result of engine speed for 3000 rpm

Number	Load (W)	Voltage (V)	Current (A)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	100	13.9	35	0.06097	1579.68	0.31831
2	200	13.9	33	0.06154	797.23	0.63662
3	300	13.7	31	0.06227	537.79	0.95493
4	400	13.8	30	0.06301	408.13	1.27324
5	500	13.7	28	0.06389	331.07	1.59155
6	600	13.5	30	0.06461	279.00	1.90986
7	700	13.5	29	0.06544	242.21	2.22817
8	800	13.3	28	0.06601	213.78	2.54648
9	900	13.1	28	0.06728	193.68	2.86479
10	1000	12.9	25	0.06815	176.57	3.18310

Table 4.4: Result of engine speed for 4000 rpm

Number	Load (W)	Voltage (V)	Current (A)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	100	14.3	37	0.06895	1785.94	0.23873
2	200	14.2	38	0.06975	903.58	0.47746
3	300	14.1	36	0.07056	609.38	0.71620
4	400	14.0	36	0.07140	462.48	1.10409
5	500	14.0	34	0.07225	374.39	1.19366
6	600	13.9	33	0.07335	316.74	1.43239
7	700	13.8	31	0.07487	277.12	1.67113
8	800	13.8	30	0.07610	246.46	1.90986
9	900	13.5	30	0.07745	222.96	2.14859
10	1000	13.5	28	0.07909	204.92	2.38732

Table 4.5: Result of engine speed for 5000 rpm

Number	Load (W)	Voltage (V)	Current (A)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	100	14.9	42	0.08382	2171.71	0.19098
2	200	14.9	43	0.08528	1104.77	0.38197
3	300	14.7	43	0.08631	745.41	0.57296
4	400	14.6	42	0.08756	567.15	0.76394
5	500	14.6	41	0.08976	511.65	0.95492
6	600	14.5	41	0.09143	394.81	1.14591
7	700	14.6	39	0.09394	347.70	1.33690
8	800	14.3	39	0.09672	313.24	1.52789
9	900	14.1	38	0.09854	283.68	1.71887
10	1000	14.0	38	0.10056	260.54	1.90986

Table 4.6: Result of engine speed for 6000 rpm

Number	Load (W)	Voltage (V)	Current (A)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	50	15.3	48	0.10923	5660.12	0.07958
2	100	15.3	47	0.11062	2866.07	0.15915
3	150	15.3	46	0.11156	1926.95	0.23873

4	200	15.1	44	0.11284	1461.80	0.31831
5	250	15.0	43	0.11399	1181.35	0.39789
6	300	15.0	43	0.11550	997.50	0.47746
7	350	14.8	42	0.11670	863.89	0.55704
8	400	14.9	41	0.11740	760.43	0.63662
9	450	14.7	39	0.11954	688.26	0.71620
10	500	14.7	37	0.12272	635.91	0.79577
11	550	14.6	35	0.12407	584.46	0.87535
12	600	14.4	33	0.12586	543.49	0.95493
13	650	14.6	34	0.12854	512.36	1.03451
14	700	14.4	33	0.13112	485.32	1.11408
15	750	14.2	32	0.13403	463.01	1.19366
16	800	14.1	32	0.13707	443.69	1.27324
17	850	14.1	30	0.14050	428.26	1.35282
18	900	13.8	31	0.14544	418.69	1.43239
19	950	13.7	29	0.14903	406.45	1.51197
20	1000	13.4	27	0.15460	400.56	1.59155

Table 4.7: Result of engine speed for 7000 rpm

Number	Load (W)	Voltage (V)	Current (I)	Fuel flow rate (cm^3/s)	SFC (g/kW.h)	Torque (N.m)
1	100	14.8	46	0.14763	3824.97	0.13642
2	200	14.7	45	0.15191	1967.93	0.27283
3	300	14.5	43	0.15677	1353.93	0.40925
4	400	14.4	43	0.16261	1053.27	0.54567
5	500	14.2	40	0.16782	869.62	0.68209
6	600	14.2	39	0.17414	751.97	0.81851
7	700	14.1	37	0.18097	669.83	0.95493
8	800	13.8	37	0.18744	607.05	1.09135
9	900	13.7	37	0.19537	562.42	1.22777
10	1000	13.5	36	0.20294	525.80	1.36418

4.3 SAMPLE CALCULATION

Here the sample calculation for speed of engine with 7000 rpm. The diameter of tube is 1cm and length is 10cm when the time taken. Fuel flow rate can be getting by divide the volume of fuel with time taken. Know that density of fuel is 0.7197g/cm^3, so multiply it with fuel flow rate to get mass flow rate. The brake power from engine is equal to voltage produce at alternator multiply with current. Then torque can be calculated with divide the brake power to angular velocity of engine. The brake specific fuel consumption is mass fuel flow rate divide with brake power.

Engine speed: 7000 rpm

Load given: 100 Watt

$$\text{Volume of fuel} = \frac{(1cm)^2 \times \pi \times 10cm}{4}$$

$$= 7.85398cm^3$$

$$\text{Fuel flow rate} = \frac{7.85398cm^3}{53.20s}$$

$$= 0.14763cm^3/s$$

$$\text{Mass flow rate} = 0.14763cm^3/s \times 0.7197g/cm^3$$

$$= 0.10625g/s$$

$$\text{Specific fuel consumption} = \frac{0.10625g/s}{0.1kW} \times \frac{3600s}{1\ hour}$$

$$= 3824.97g/kW.h$$

$$\text{Torque} = \frac{100W \times 60s}{2\pi \times 7000rpm}$$

$$= 0.1364$$

4.4 DATA ANALYSIS AND DISCUSSION

To make the analysis clearer, the data then is interpreted to graph. The graphs represent the small engine performance parameters with some description on it. Here we can find easily the optimum performance from this small engine.

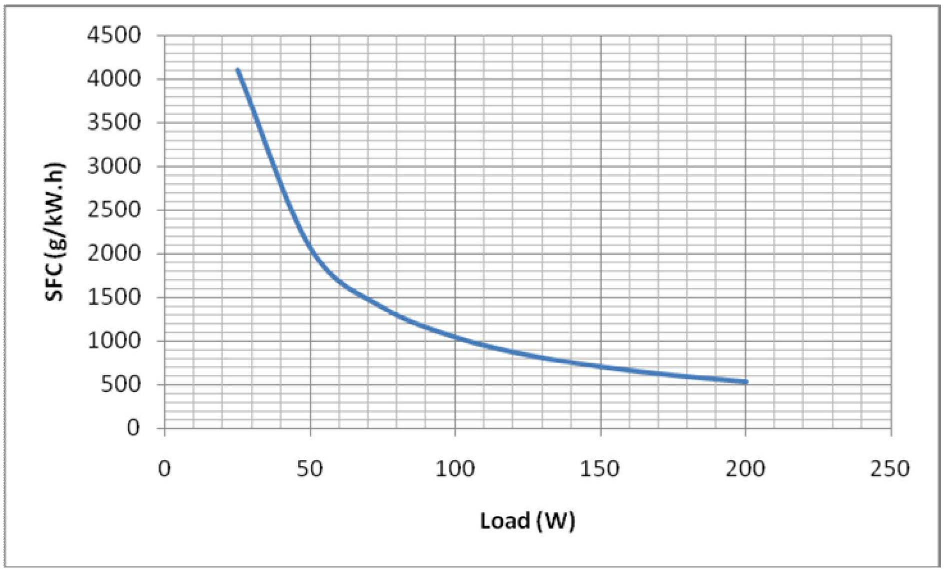


Fig 4.1: Graph of SFC against Load for speed 1000 rpm

For the speed of 1000 rpm, maximum load had been used is 200 Watt where the increment of the load is about 25 Watt. The reason is to make sure the engine not to blow off if the load is bigger. The maximum specific fuel consumption is around 4000 g/kW.h when the load is 25 Watt. The drastic drop from load of 25 Watt to 50 Watt ad then the graph is going to be a constant line. The maximum specific fuel consumption occur at the load of 200 Watt where the value is 500 g/kW.h.

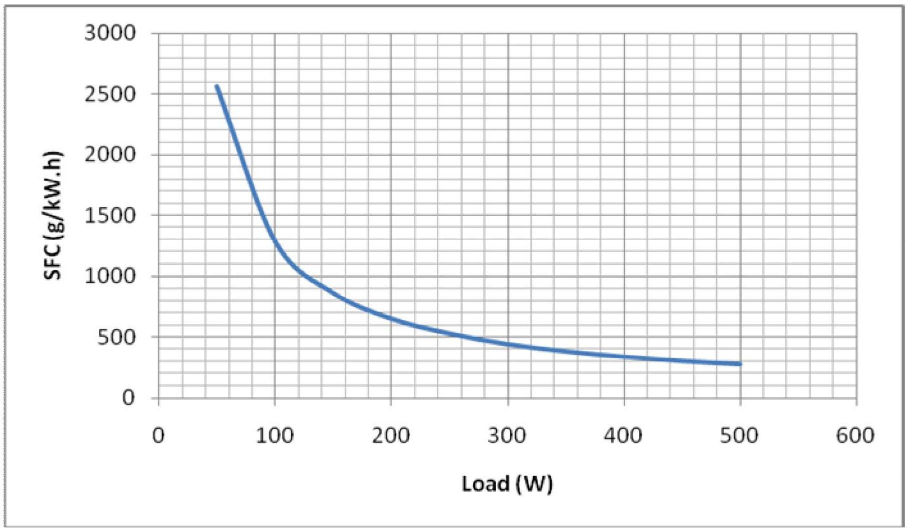


Fig 4.2: Graph of SFC against Load for speed 2000 rpm

The drastic drop of graph start when the load given is 50 Watt until 200 Watt. For speed of 2000 rpm (fig 4.2), the increment of load is increase to 50 Watt where the maximum load given is 500 Watt. The maximum value of specific fuel consumption is around 2500 g/kW.h and the minimum value is 275 g/kW.h. From graph, engine full load will be in range 300 Watt to500 Watt.

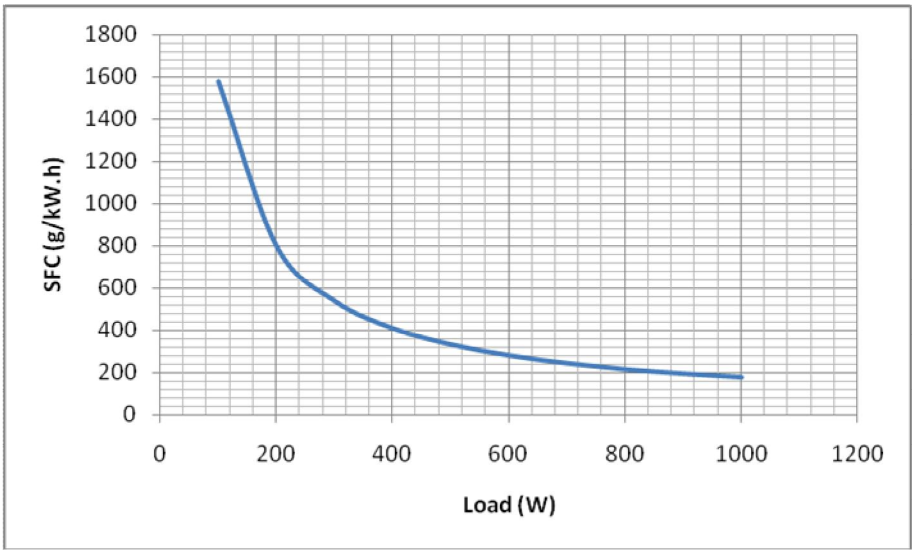


Fig 4.3: Graph of SFC against Load for speed 3000 rpm

From the fig 4.3, the slop of the graph showed that the drastic drop is from load for 100 Watt to 500 Watt. After that point, the graph begine to constant. At this point, the engine showed the simpton for full load. Here, the maximum value of specific fuel consumption is 1580 g/kW.h and the minimum value is around 200 g/kW.h.

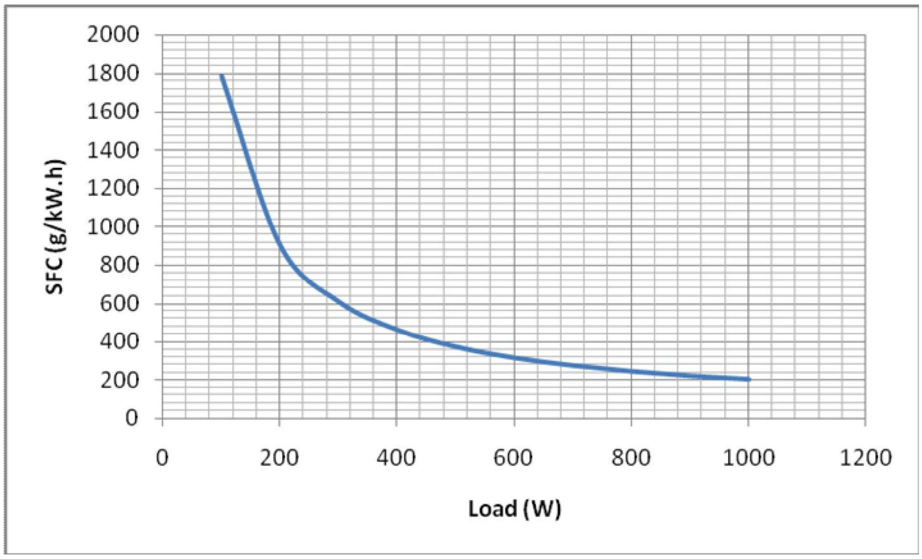


Fig 4.4: Graph of SFC against Load for speed 4000 rpm

Maximum load used for 400 rpm is 1000 Watt. From figure 4.4, the drastic drop begin from 100 Watt until 600 Watt and engine full load going to happen after this point. The maximum value of specific fuel consumption is around 1800 g/kW.h and the minimum value is 200 g/kW.h.

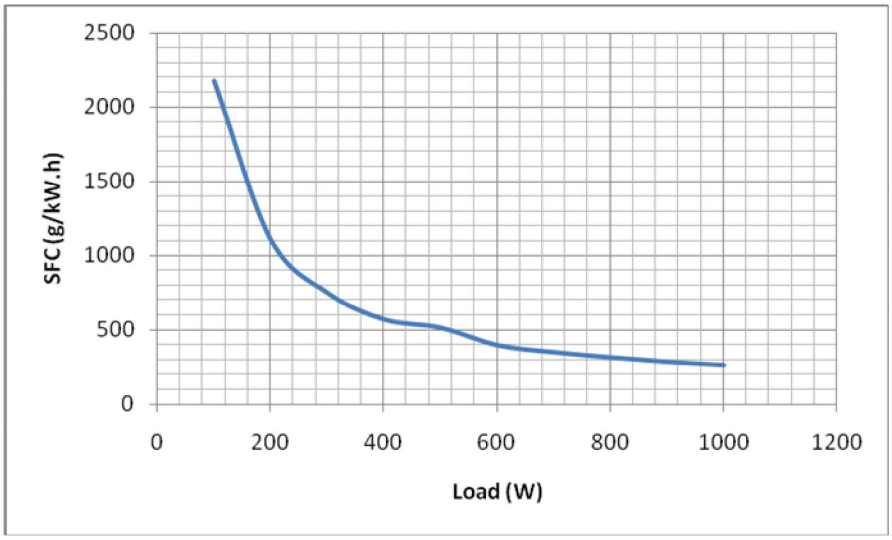


Fig 4.5: Graph of SFC against Load for speed 5000 rpm

From figure 4.5, the maximum value of specific fuel consumption is around 2200 g/kW.h and the minimum value specific fuel consumption is 260 g/kW.h. The drastic drop of specific fuel consumption start from 100 Watt until 400 Watt. However for this graph, the range of full load is start from 600 Watt to 1000 Watt and its line is not to constant.

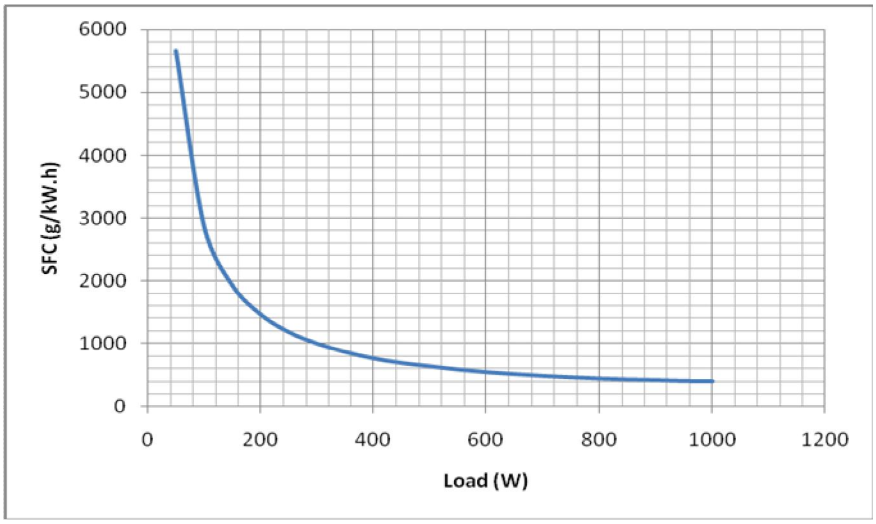


Fig 4.6: Graph of SFC against Load for speed 6000 rpm

For speed of 6000 rpm, the increment of load is decrease from 100 Watt to 50 Watt. From figure 4.6, the graph showed the smooth line where the drastic drops occur in range of 50 Watt to 400 Watt. The maximum value of specific fuel consumption is 5660 g/kW.h and the minimum value is around 500 g/kW.h. For this graph, engine full load possiblely occur 500 Watt to 800 Watt.

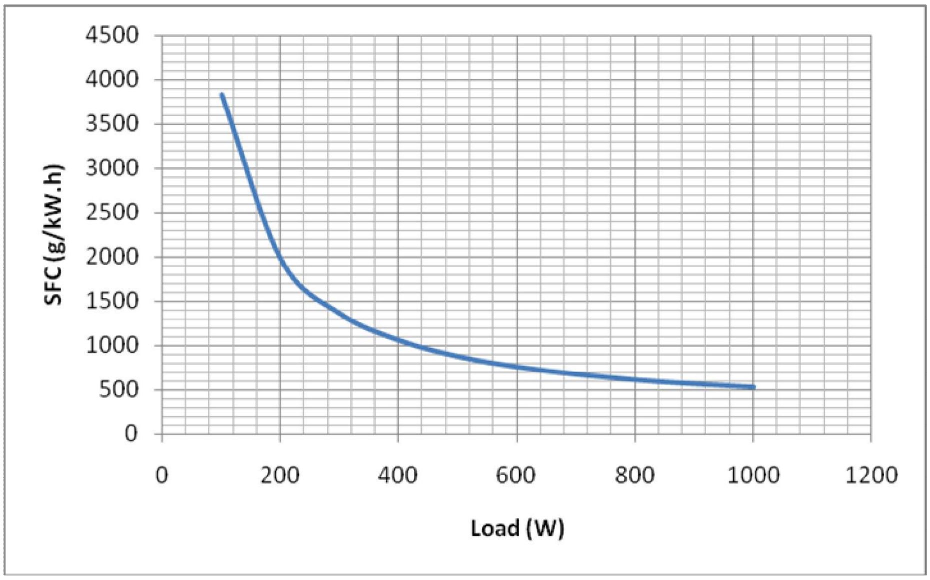


Fig 4.7: Graph of SFC against Load for speed 7000 rpm

The maximum value of specific fuel consumption for speed of 7000 rpm is 3824 g/kW.h and minimum value is 525 g/kW.h. the drastic drop occur from 50 Watt to 400 Watt. After that point, the graph do not show the constant line where full load would occur. At this speed, error of measuring the data might happen.

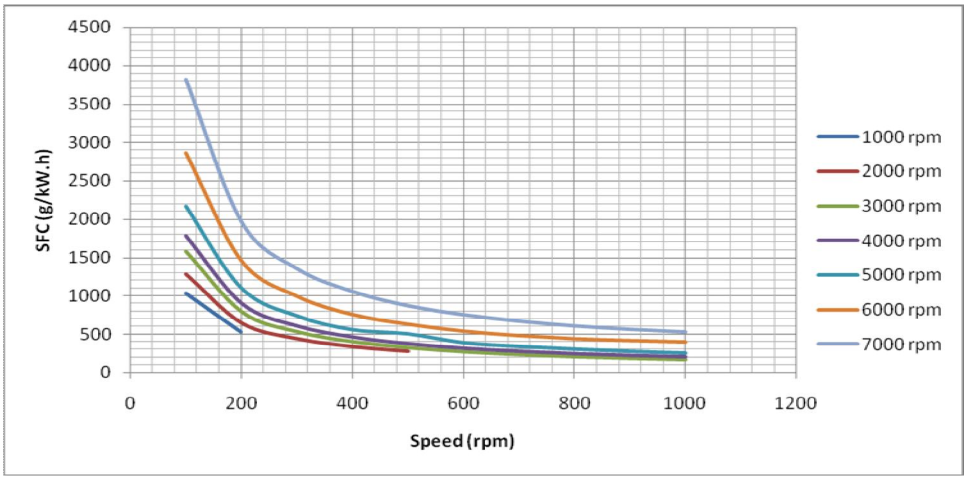


Fig 4.8: Comparison of SFC with variable speed

Figure 4.8 show the specific fuel consumption with variable engine speed. The optimum specific fuel consumption is at 3000 rpm where the graphs show the minimum value at 176 g/kW.h. The line also nearly touches the line at speed 400 rpm. So, the optimum specific fuel consumption might be as well around speed 3000 rpm to 4000 rpm.

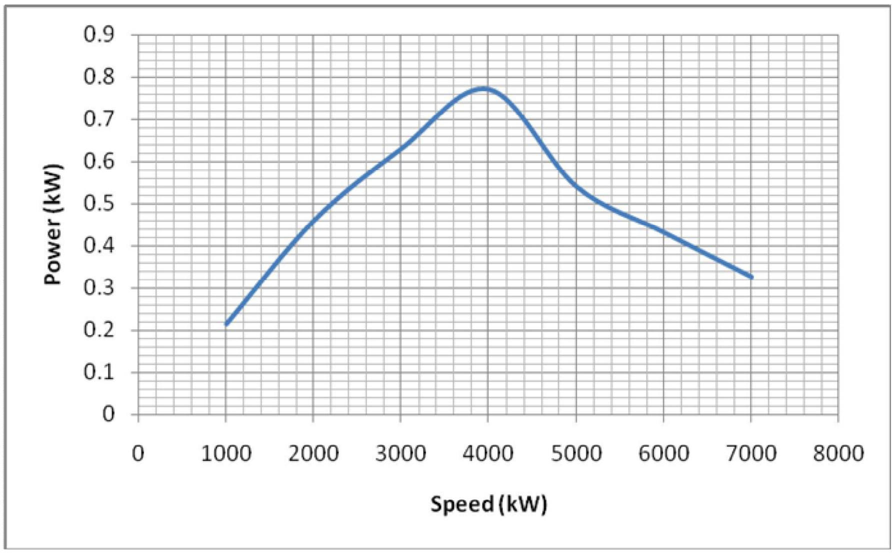


Fig 4.9: Graph of Power against Speed at full load

From the data of specific fuel consumption in figure 4.8, the graph of power optimum from engine full load can be show. Figure 4.9 show that graph of power against variable speed and give the maximum value of power around 0.77 kW. The slop increase from speed 1000 rpm until 4000 rpm. At this point, the graph give the maximum value of power. Then, the slop is decrease rapidly to 5000 rpm.

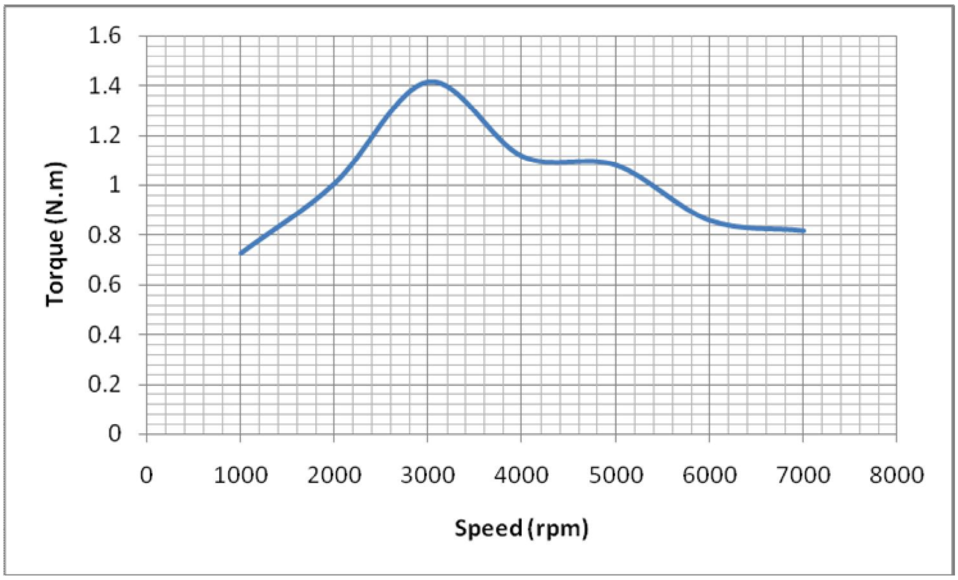


Fig 4.10: Graph of Torque against Speed at full load

The optimum value of torque for engine full load is 1.4 N.m and the minimum value is 0.73 N.m at 1000 rpm. The graph is increase from speed of 1000 rpm to 3000 rpm where the maximum value of torque is situated. Then, the slop is going down and gives the value of torque about 0.82 N.m at 7000 rpm. At speed 4000 rpm until 5000 rpm, the line of graph become a linear and gives the value around 1.1 N.m.

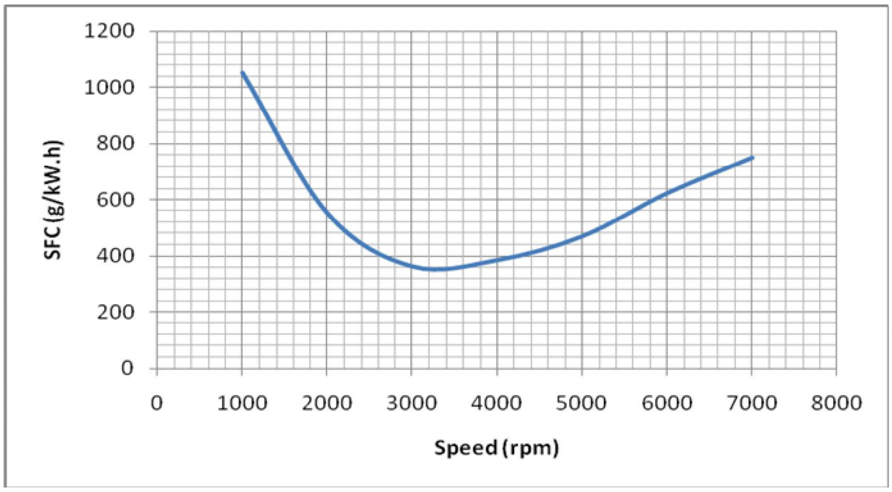


Fig 4.11: Graph of SFC against Speed at full load

Figure 4.11 shows that the graph of specific fuel consumption against speed at full load where the value is interpolate from the data. The maximum value of specific fuel consumption is 1053.28 g/kW.h at 1000 rpm. The slop is decrease until 3000 rpm and give the minimum value of specific fuel consumption about 365.6 g/kW.h. Then, the line is going up until 7000 rpm and give the value 751.97 g/kW.h for specific fuel consumption. By comparing with figure 4.10, the optimum value of specific fuel consumption and torque occur at speed of 3000 rpm where the optimum power at 4000 rpm.

By comparing the study results of small two stroke engine performance by using simulation, this data can be comparing to see whether the result is having of engine performance trends or not. The previous results are using GT-Power software to simulate the engine performance. At optimum specific fuel consumption, the simulation analyses give the data about 440.5 g/kW.h at 3000 rpm while the experiment gives about 365.3 g/kW.h at 3000 rpm. The percentage error is 82.93%.

For the optimum torque from simulation, it's give the result about 2.6 N.m at speed of 2000 rpm. From the experiment results, the optimum value of torque occurred at 3000 rpm where the value is 1.42 N.m and the percentage of error is about 54.62%. The percentage of error might be larger if the experiment can be repeated for several times. The method of measuring the data can be improved and the best data can be got. For optimum power, the experiment method give the value about 0.77 kW and the simulation give show around 0.7 kW. So the percentage of error is 90.91%. The optimum power from simulation result occurs at speed of 3000 rpm while the experiment method is 4000 rpm.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter summarized the conclusion and recommendations for the overall objective of the project based on small two stroke engine performance analysis.

5.2 CONCLUSION

The small two stroke engine test rig design and its performance analysis have been presented. The model or draft of small two stroke engine had been designing by studying from some references. Materials selection for this engine test rig also included in designing process where the right materials had been chooses. The small engine test rig completely fabricated with the dimension of test rig about 55cm x 29.5cm x 3.8cm (length x wide x height) and all the parts of engine test rig work successfully. The dynamometer can be replaced with alternator to conducting the engine performance where the condition is the alternator must support the power produced from the engine. From the analysis conducted, several conclusions can be drawn. The calibration showed that all the instruments can give a good data because there are no major data losses during the experiment are running. So the optimum engine performance is been analyzed and comparing with the simulation result by using GT-Power software. The percentage of error for engine specific fuel consumption, torque and power is about 82.93%, 54.62% and 90.91%.

5.3 RECOMMENDATION

The experiment would not usually give the same result when it is repeated. This is because parallax errors occur like the way of person in charge of conducting the experiment definitely different. So, the best way for getting an accurate data is by repeating the experiment for several times. Then, take the average from all results. Weather also gives influence to the data taken. The experiment should be repeated in different weather because ambience pressure, temperature and humidity will affect the results. Hence the average data will show the true value of result. Two stroke engine produced more vibration than four stroke engine. When these occur during running the experiment, it is more a bit difficult to take the data. By put some damper like washers between the join of each test rig part would reduce the vibration produce from the engine. Engine performance can be improve by using high quality two stroke engine (2T) like SHELL VSX or SPRINTA 5000 where it can improve the combustion process and reduce the pollution.

REFERENCES

This guide is prepared based on the following references;

G. P. Blair, 1996, Design and Simulation of Two-Stroke Engine, Society of Automotive Engineer inc. pp: 6-46

J.B. Heywood, 1988, Internal Combustion Engine Fundamentals, McGraw-Hill, International edition. Pp: 42-59; 838-859

A.J. Martyr and M.A. Plint,2007, Engine testing: theory and practice, Society of Automotive Engineers, Warren dale , PA.

J. Erjavec, 2006, Engine Performance Natef standards job sheets (A8), 2nd Ed, Thomson Delmar Learning, USA

M. Nuti, 1998, Emission from two stroke engines, Society of Automotive Engineer, Inc. pp:3-13

M. Bergman, R. U. K. Gustafson, B. I. R. Johnson, 2003, Emission and performance evaluation of a 25 cc stratified scavenging two-stroke engine, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, USA, 2003-32-0047

P Waltermann, N Neuendorf, 2006, A Test bed for the Design and the Optimization of a Series Hybrid Drive Train. Mechatronics Laboratory Paderborn (MLaP), University of Paderborn, Germany.

D Merritt, M C Bennett, 2006, The Merritt cycle gasoline engine – description and performance data. MCC Engines Limited, Coventry, UK.

RL Gordon, 2005, the design, manufacture and demonstration of a simple, yet effective, common rail fuel injection system for 100cc engines. Ricardo Consulting Engineers Limited, Shoreham-by-Sea, UK

Ryosuke Hiyoshi, Shunichi Aoyama, Shinichi Takemura, Kenshi Ushijima and Takanobu Sugiyama, 2006, A Study of a Multiple-link Variable Compression Ratio System for Improving Engine Performance.

Michael Anthony Prados, 2004, Towards a Linear Engine. Department of Mechanical Engineering of Stanford University

Vong Chi-man and Wong Pak-Kin, 2004, Modeling of Modern Automotive Petrol Engine Performance, Department of Computer and Information Science, University of Macau.

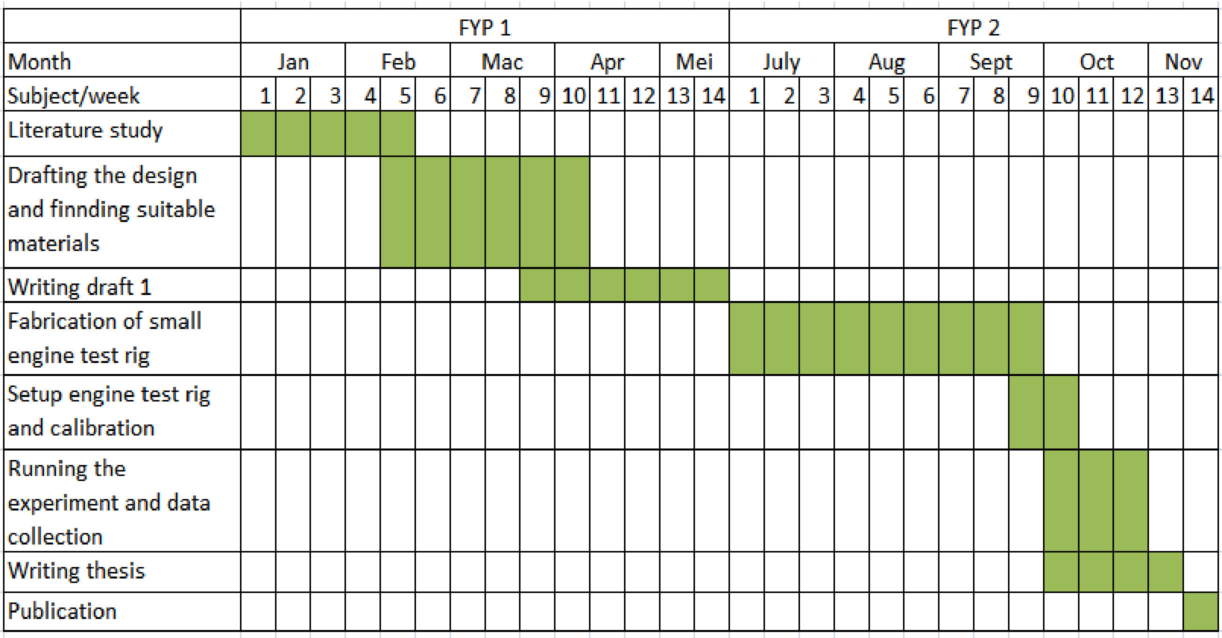
Winther, J. B, 1975, Dynamometer Handbook of Basic Theory and Applications. Cleveland, Ohio: Eaton Corporation

C. R. Ferguson and A. T. Kirkpatrick (2001), "Internal Combustion Engine, Second Edition", Applied Thermosciences, John Wiley & Sons, Inc.

Gordon P.Blair, 1994, Design and Simulation of Two Stroke Engine, Society of Automotive Engineers, Inc. Warrendale, Pa.

James D.Halderman and Chasey D.Mtchell, Jr, 2005, Automotive Electricity and Electronics, Pearson Education, Inc.

APPENDIX



Gantt’s Chart for final year project