DESIGN AND DEVELOPMENT OF MOTORED ENGINE FOR TWO-STROKE SPARK IGNITION (SI) ENGINE

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Report submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechanical Engineering with Automotive Engineering

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project report 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 Engineering.

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STUDENT'S DECLARATION

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

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ABSTRACT

The two stroke engines have been around for more than a century and have survived so far, primarily in portable applications. From the beginning, two stroke engines have suffered from poor fuel economy and high fuel emissions compared to the larger, heavier, but more efficient than four stroke design. The scavenging process in the two-stroke engine has direct influence on engine performance on their combustion process and remains one of the important strategies towards improvement of fuel efficiency and reduction of pollutant. The new of engine test rig was design and fabricate for motoring concept a single cylinder 30.5 cc two strokes spark-ignition. Then measurement installation was done to the test engine. It will be the platform for further study in investigation the in-cylinder characteristic whiles the scavenging process for motored condition. The result of this project is a new engine test rig with motored condition for two-stroke spark ignition (SI) engine with instrument installation for data measurement.

ABSTRAK

Enjin dua lejang telah lama digunakan lebih daripada satu abad dan sehingga kini masih lagi digunakan, terutamanya dalam penggunaan yang mudah dan pada skala yang kecil. Sejak dari dulu lagi, enjin dua lejang telah bermasalah dari segi penggunaan bahan bakar yang tidak cekap dan pencemaran yang tinggi berbanding dengan besar, berat tetapi lebih cekap daripada enjin empat lejang. Proses pertukaran gas ekzos yang telah terbakar dengan campuran udara dan bahan bakar yang baru dalam enjin dua lejang telah mempengaruhi prestasi enjin secara langsung melalui proses pembakaran dan menjadi satu rancangan yang penting dalam penambah baikan penggunaan bahan bakar dan pengurangan pencemaran. Satu platform atau pelantar penguji enjin dua lejang satu silinder berkapasiti 30.5cc pembakaran melalui percikan api dengan konsep menggerakkan enjin menggunakan motor telah dibina. Kemudian pemasangan peralatan pengukuran dibuat kepada enjin. Ia akan menjadi pemangkin kepada kajian yang lebih mendalam mengenai sifat di dalam silinder sewaktu proses penggantian gas ekzos yang telah terbakar kepada campuran udara dan bahan bakar yang baru diantara lubang masukan dan ekzos di masa hadapan. Hasil kajian ialah sebuah pelantar penguji enjin dua lejang satu silinder pembakaran melalui percikan api dengan konsep menggerakkan enjin menggunakan motor beserta dengan pemasangan peralatan dan sensor bagi mengambil data.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρ_a	Density of air
SEv	Scavenging efficiency
TEv	Trapping efficiency
CEv	Charging efficiency
SR	Delivery (scavenging) ratio
Vta	Volume of delivered air retained
Vex	Volume of trapped cylinder charge
Vcy	Trapped volume x ambient density
Vas	Volume of delivered air per cycle

LIST OF ABBREVIATIONS

DAQ	Data Acquisition System
BDC	Bottom Dead Center
TDC	Top Dead Center
SI	Spark Ignition
CI	Compression Ignition
IC	Internal Combustion
BSFC	Brake Specific Fuel Consumption
CA	Combustion Analyzer
ATDC	After Top Dead Center
MIG	Metal Inert Gas
AC	Actuating Current
Bmep	Brake Mean Effective Pressure
POT	Part Open Throttle
TDC	Top Dead Center
WOT	Wide Open Throttle

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The scavenging process in the two-stroke engine has direct influence on engine performance on their combustion process and remains one of the important strategies towards improvement of fuel efficiency and reduction of pollutant. Purpose of this study is to understand the flow mechanism thoroughly of an engine design where gas flow motions in a two stroke engine directly control the performance characteristic of the engine. During experiment setup, measurement installation to collect the parameters was done. Further study need investigate the in-cylinder characteristic while the scavenging process for motored condition through experiment testing, the different variation of pressure was collected and applied to the scavenge port pressure, exhaust port pressure and in-cylinder pressure at 1000 rpm, 1200 rpm, and 1400 rpm. The new of an unfired engine test-rig was developed include the data acquisition system (DAQ) and sensors for data collection.

1.2 PROBLEM STATEMENT

To improve the performance and durability of such an engine, crankcase pressure, volume and temperature are some of the important parameters to optimize. Investigation of the pressure histories have been done with reference to pressure fluctuations, backflow, list approximation, ring sticking, crankcase volume, crankcase temperature, cylinder barrel temperature, engine speed and physical parameters of the engine [1]. Scavenging process is required in two-stroke engines in assuring the appropriateness of combustion. But it will result in the short-circuiting of fresh charge (flow directly from the engine’s transfer to the exhaust port) which is suffered from poor fuel economy and high unburned hydrocarbons emission compared to the larger, heavier, but more efficient than four-stroke design. The scavenging process in the two-stroke engine has direct influence on engine performance on their combustion process and remains one of the important strategies towards improvement of fuel efficiency and reduction of pollutant [2] [3].

From the previous study in motored concept [3], there is not clear and only a few technical paper study about the motored concept of an unfired for two-stroke engine. So that, this research will study more deeply and detail with combine the result from other previous research in motoring concept.

1.3 OBJECTIVES

The objective of this project is to design and fabricate of new engine test rig for motoring concept (unfired condition) a single cylinder 30.5 cc two-strokes spark-ignition (SI) engine and measurement installation.

1.4 SCOPES

The Scopes of the project are:

i. Literature review about two-stroke engine.
ii. Design, fabrication and development of motoring engine testing for two-stroke engine.
iii. The instrumentation for scavenging measurement was installed at the engine model.

1.5 THESIS ORGANIZATION

Chapter 2: The review of recent works is important to provide the understanding of two-stroke engine and technologies such as the scavenging systems, motored and firing testing conditions. The other previous technical papers and journal which are published will assist the author in motored condition testing development. Besides, there are several books on two-stroke engines which will provide first hand knowledge in designing engine test rig especially in motored condition.

Chapter 3: This chapter will explain the methodology of this research including design and fabrication of engine test for two-stroke engine. Besides that, it also explains the experiment setup, instrumentation installation and measurement.

Chapter 4: This chapter will explain about result of the engine test rig including the engine test rig parts and the measurement equipment. It also explains the experiment procedures and conditions.

Chapter 5: This chapter will conclude and summarize overall the project. Recommendations for the future works are also presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The objective of this chapter is to descript detail of literature review done regarding to the research, investigation of motored engine performance test for two-stroke (SI) engine. In this chapter, fundamental of internal combustion engine and two stroke engine was discussing deeply base on research done. Including type of two-stroke engines and classification based on scavenging process.

2.2 INTERNAL COMBUSTION ENGINES

The internal combustion (IC) engines date back to 1876 when Nicholas A. Otto first develop the spark-ignition engine and 1892 when Rudolf Diesel invented the compression-ignition [4]. An engine is a device which transforms one form of energy into an-other form. Normally, most of the engines convert thermal energy into mechanical work and therefore they are called ‘heat engines’. Heat engines can be broadly classified into two categories [5].

(i) Internal Combustion Engines (IC Engines)
(ii) External Combustion Engines (EC Engines)

Internal Engines are two types, first Rotary engines and second Reciprocating engines. The most widely used ones are the reciprocating internal combustion engines [6]. In internal combustion engine, the heat engine that converts chemical energy in a fuel into mechanical energy. Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine [4] [19]. This thermal energy raises the temperature and pressure of the gases within the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft. One end of a connecting rod is attached to the bottom of the piston by a joint, the other end of the rod clamps around a bearing on one of the throws, or convolutions, of a crankshaft, the reciprocating motions of the piston rotate the crankshaft, which is connected by suitable gearing to the drive wheels of the automobile which is the output of the engine [2] [3] [5] [20].

The advantages of reciprocating engines are absence of heat exchanger in the passage of working fluid, its component work at an average temperature which is much below the maximum temperature of the working fluid in the cycle. Therefore the weight to power ratio is less. The main disadvantage is problem of vibration caused by the reciprocating components [5] [21] [22].

The most common internal-combustion engine is the piston-type gasoline engine used in most automobiles [23]. They are several type of cylinder arrangement which is in-line engine, V-engine, W-engine, radial and opposed piston [2] [4]. The IC engine are used in many application and various sector such as automobile, truck, locomotive, light aircraft, marine, power generator and many mores [24].

Besides, there are two categories for the internal engine design, which are spark ignition (*SI*) engine and diesel engine. Spark ignition engine is an engine which the combustion process in each cycle is started by use of a spark plug. Diesel engine is also called as compression ignition (*CI*) engine which the combustion process starts when the air-mixture self ignites due to high temperature in the combustion chamber caused by high compression [5] [25].

2.2.1 History Of Two-Stroke Engines

The two stroke engine is as old as the concept of the heat engine. Which has served mankind for over 460 years. George Medhurts, an English engineer in 1800 was the first to propose a two stroke engine with a controlled cyclic repetition of the working processes. The two-stroke cycle is hardly new concept, in fact all internal combustion engine developed before Nicolaus Otto inverted the four-stroke cycle engine in 1876 operated on two-stroke cycle [1]. The idea to build a two-stroke engine goes back to the year 1879 and the short-circuit loss of fresh charge has been known since two-stroke engines were first made by Sir Dugald clerk in 1879. [2] [3] [5] [7] [8].

2.3 TWO-STROKE ENGINE

In two stroke engine, there is one important process that known as scavenging. Various different scavenging systems have been designed. Today, three main categories are generally accepted which: loop scavenging, cross scavenging and uniflow scavenging [9] [10] [11]. A two stroke engine is one which completes its cycle of operation in one revolution of the crankshaft or in two strokes of the piston [26] [27]. In this engine the functions of the intake and exhaust processes of the four-stroke engine are taken care of by the incoming fresh charge which is compressed either in the crankcase or by means of a separate blower while the engine piston is near the bottom dead center [4] [5]. The engine piston needs only to compress the fresh charge and expand the product of combustion. Since a two-stroke engine will have twice as many cycles per minute as a four-stroke engine, the power output of this engine also depend upon the number of kilograms of air per minute available for combustion [4] [28].

For the crankcase scavenged engine, as the piston moves down, it first uncovers the exhaust port, and the cylinder pressure drops to atmospheric level as the combustion product escape through these ports [3] [4] [5]. Further, downward motions of the piston uncover the transfer port, permitting slightly compressed mixture or air (depending upon the type of the engine) in the crankcase to enter the engine cylinder [8] [12] [29] [30].

The top of the piston and the port are usually shaped in such a way that the fresh air is directed towards the top of the cylinder before showing towards the exhaust ports. This is for the purpose of scavenging the upper part of the cylinder of the combustion products and also to minimize the flow of the fresh fuel-air mixture directly through the exhaust ports [5] [13] [14]. The projection on the piston is called the deflector [10].

As the piston returns from bottom center, the transfer ports and then the exhaust ports are closed and compression of the charge begins. When the exhaust slot is uncovered near the end of the power stroke, immediately followed with an intake process of compressed air or air-fuel mixture [15]. Motion of the piston during compression lowers the pressure in the crankcase so that the fresh mixture or air is drawn into the crankcase through the inlet reed valve [5] [16] [17]. Ignition and expansion take place in the usual way, and the cycle is repeated. Due to the flow restriction in the inlet reed valve and the transfer ports the engine gets charged with less than one cylinder displacement volume [2] [5] [8] [18].

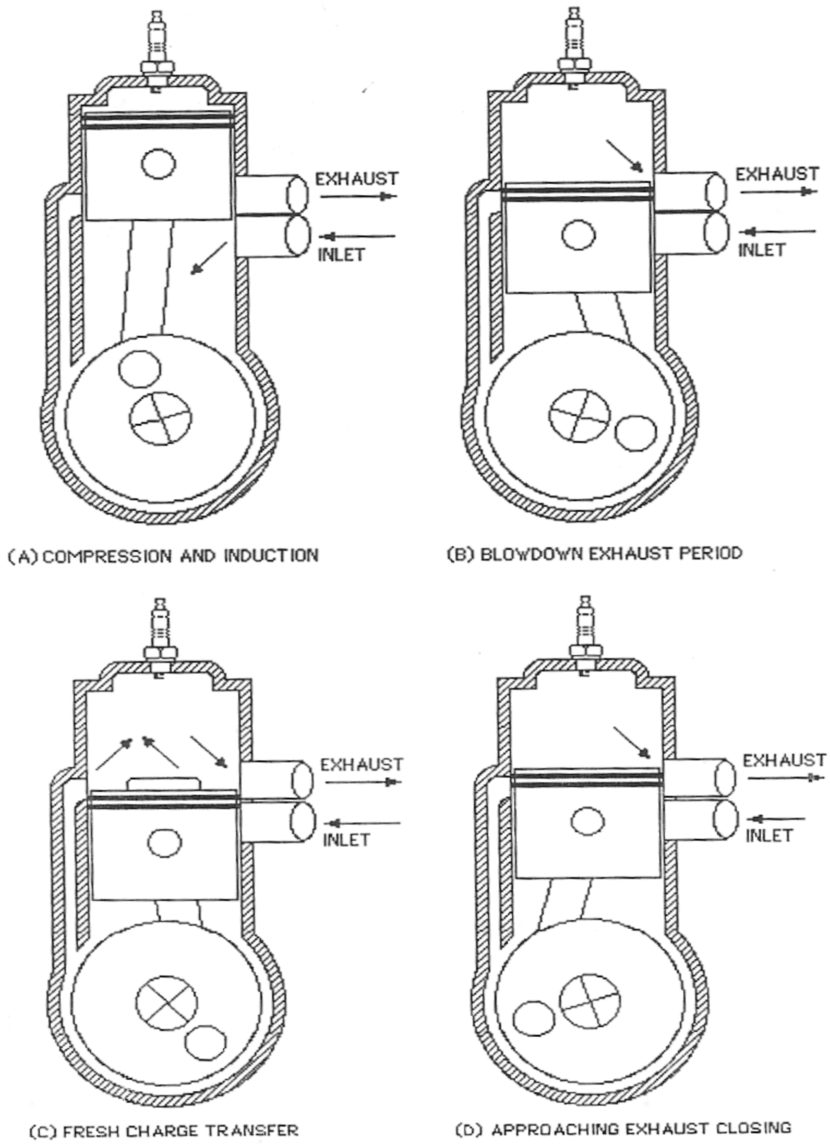

Figure 2.0: Two-Stroke Engine [24]

2.4 SCAVENGING PROCESS

Scavenging process is the process where the cylinder's burned gases are replaced with a fresh charge using both the high blow down pressure of the expanded combustion gases and the fluid dynamics of the incoming charges. This process requires only a fraction of the piston's stroke to complete, with the exhausting and recharging events occurring simultaneously, and is critical to ensure that the cylinder gases are adequately prepared for the next combustion cycle. Scavenging system is defined as a method used to accomplish the charge-changing process in a two-stroke engine [2] [4].

There are two general methods of putting air into the cylinders: through normal intake valves which is separately scavenged engine and through intake slots in the cylinder walls which is crankcase scavenged engine [2] [3] [4] [5].

2.4.1 Crankcase Scavenging Engine

Crankcase scavenging engine is one of the simplest types of two-stroke engine. There are three ports in this engine [7] [9] [10].

(i) intake port at the crankcase
(ii) transfer port
(iii) exhaust port.

In a conventional crankcase-scavenged two-stroke engine, the combustion products from the previous cycle are forced from the cylinder with a new air/fuel charge. This charge is compressed in the crankcase by the underside of the piston and then enters the cylinder when the piston uncovers the transfer port. Unfortunately, the exhaust port is opened during the entire time that caused the part of the air fuel mixture to "short circuiting" through the cylinder during the scavenging process. This is the major source of the high hydrocarbon emissions from crankcase-scavenged engines. When short-circuiting occurs, lower scavenging efficiencies result even though the volume occupied by the short-circuiting flow through the cylinder does displace an equal volume of the burned gases [2] [3] [4] [5]..

Another phenomenon which reduces scavenging efficiency is the formation of pockets or dead zones in the cylinder volume where burned gases can become trapped and escape displacement or entrainment by the fresh scavenging flow. These un-scavenged zones are most likely to occur in region of the cylinder that remains secluded from the main fresh mixture flow path. Several methods for charging the cylinder have been proposed. The top of the piston and the ports are usually shaped in such a way that the fresh air is directed toward the top of the cylinder before flowing towards the exhaust ports. This is for the purpose of scavenging the upper part of the cylinder of the combustion products and also to minimize the flow of the fresh fuel-air mixture directly through the exhaust ports. The projection of the piston is called the deflector [2] [3] [4] [5].

2.4.2 Separately Scavenging Engine

Another type of engine which uses an external device like a blower to scavenge the products of combustion is called the externally or separately scavenged engine. Air fuel mixture is supplied at a slightly higher pressure at the inlet manifold. As the piston moves down on the expansion stroke it uncovers the exhaust ports at approximately 60º before bottom center. About 10º later, when the cylinder pressure has been considerably reduced, the inlet ports are uncovered and the scavenging process takes place. The inlet ports are shaped in such a way that most of the air flows to the top of the cylinder on the inlet side and move down on the exhaust side forming a loop before reaching the exhaust ports. The scavenging process is more efficient in these types of engines than in the usual crankcase scavenged engine with deflector piston [2] [3] [4] [5].

2.5 CLASSIFICATION OF TWO-STROKE CYCLE ENGINES BASED ON THE AIR FLOW

Another classification of two-stroke cycle engines is based on the air flow. The most common arrangement is cross scavenging, loop or reverse scavenging and uniflow scavenging [5] [29].

2.5.1 Cross-Scavenged

This is the original method of scavenging proposed by Sir Dugald Clerk and widely used for outboard motor to this very day. The transfer and exhaust ports are opposite one another. The incoming air is directed upward, and then directed down to force out the exhaust gases through the oppositely located exhaust ports. A deflector on the piston routes the fresh charge in the direction of the arrow and expels the residual gases from the previous stroke. However, the flow follows the direction of the wall at the first instant only. Proper piston head design is required to assure that the intake air deflects up without short-circuiting and leaving a stagnant pocket of exhaust gas at the head end of the cylinder. At piston bottom dead center, it pursues the shortest path, with the result that a considerable amount of fresh gas is expelled instead of the residual gas. Due to the very high charge losses, cross scavenging is used with inexpensive, light-duty engines only [2] [5] [16] [31].

2.5.2 Loop-Scavenged

The loop scavenging was invented by Schnurle in Germany about 1926. The objective was to produce a scavenge process in a ported cylinder with two or more scavenge ports directed toward that side of the cylinder away from the exhaust port, but across a piston with essentially a flat top. The fresh air first sweeps across the piston top, move up and then down and finally out through the exhaust [4] [5]. The difference between the loop-scavenged two-stroke cycle engine and the cross-scavenged is the design of the piston head. The loop scavenged piston is flat because the intake parts are located directly across from each other and 90° from the exhaust port. The entering gas streams travel across the piston, up the far side of the barrel and curl over and down to complete the scavenging process. This resulting turbulence cleans the combustion chamber of all exhaust gases. The fresh gases flowing into the cylinder from ports on either side of the exhaust port are directed upward in the direction of the opposite cylinder wall and expel the exhaust gases from the cylinder as shown in the center diagram. The scavenging losses are less than with cross scavenging; however, a small proportion of the fresh gases are expelled directly, in spite of the necessary diversion. A core of residual gas remains at the center of the cylinder. Loop scavenging is more favorable for gasoline injection, where in principle the exhaust and transfer ports are interchanged [2] [3] [4] [5] [32].

A different arrangement, where in the M.A.N type of loop scavenge, the exhaust and inlet ports are on the same side, the exhaust above the inlet as shown in Figure 2.0 (b). In this design, the fresh charge stream is directed toward the unported wall, flows toward the cylinder head, changes its direction, and continues toward the exhaust port. The long path of the entering charge requires high momentum jets and one would expect, therefore, that this type of engine perform better at wide-open throttle (*WOT*). For this reason, this *MAN*-loop scavenging system is well suited to diesel engines where load is controlled by the amount of fuel injected rather than a throttle valve [4] [5] [33].

In this approach, the ports are side by side. The fresh charge is directed toward the opposite side of the cylinder to the exhaust port, across a piston with an essentially flat top. Instead of the single scavenge port placed diametrically opposite the exhaust port, a pair of scavenging ports were located symmetrically around the exhaust port on the same level as the exhaust port as shown in Fig 2.0 (c). In this arrangement, the fresh charge path is shorter than in the *MAN*-type loop scavenging. The *Schnurle* loop-scavenging system is better at throttled conditions, and mixing between the fresh charge and burned gases is reduced. This type of scavenging system is widely used in small-bore *SI* engine. Figure 2.1 shows the various port plan layout of the *Schnurle* type loop scavenging. Another method is Curtis type of scavenging. It is similar to the schuerle type, except that upwardly directed inlet ports are placed also opposite the exhaust ports [2] [4] [5] [34].

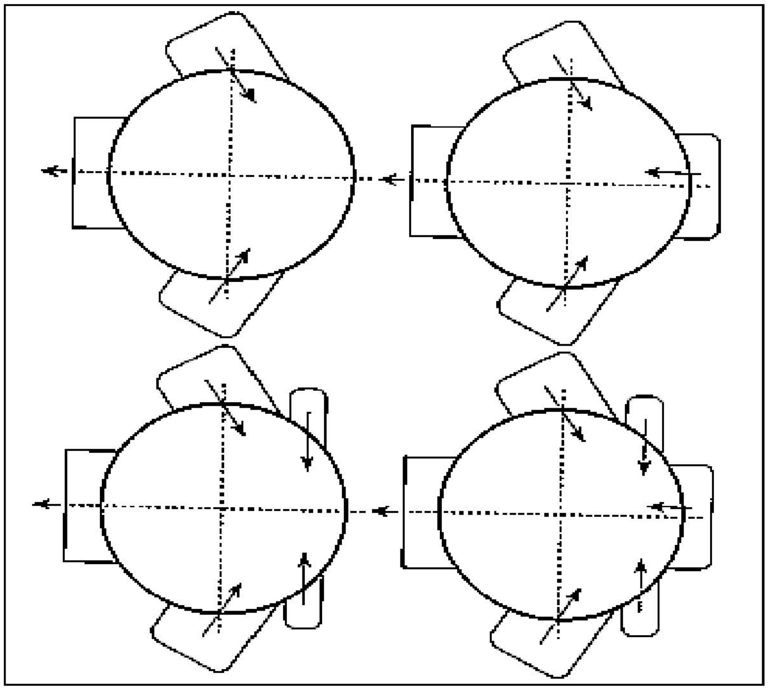

Figure 2.1: Various port plan layout of *Schnurle* type loop scavenging [2] [36].

2.5.3 Uniflow-Scavenged

The most perfect method of scavenging is the uniflow method. Where the fresh air charge is admitted at one end of the cylinder and the exhaust escape at the end. The air flow is form end to end, and little short-circuiting between the intake and exhaust openings is possible. There are three arrangements for uniflow scavenging which are poppet valve, opposed piston and sleeve valve. A poppet valve is used in to admit the inlet air or for the exhaust. In opposed piston, the inlet and exhaust ports are both controlled by separate pistons that move in opposite directions. While sleeve valve function with the inlet and exhaust ports are controlled by the combined motion of piston and sleeve. In all alternative arrangement one set of ports is controlled by the piston and the other set by a sleeve or slide valve. All uniflow systems permit unsymmetrical scavenging and supercharging [2] [4] [5].

While for reverse flow scavenging, the inclined ports are used and the scavenging air is forced on to the opposite wall of the cylinder where it is reserved to the outlet ports. One obvious disadvantage of this type is the limitation on the port area. For long stroke engines operating at low piston speeds, this arrangement has proved satisfactory [9] [35] [36].

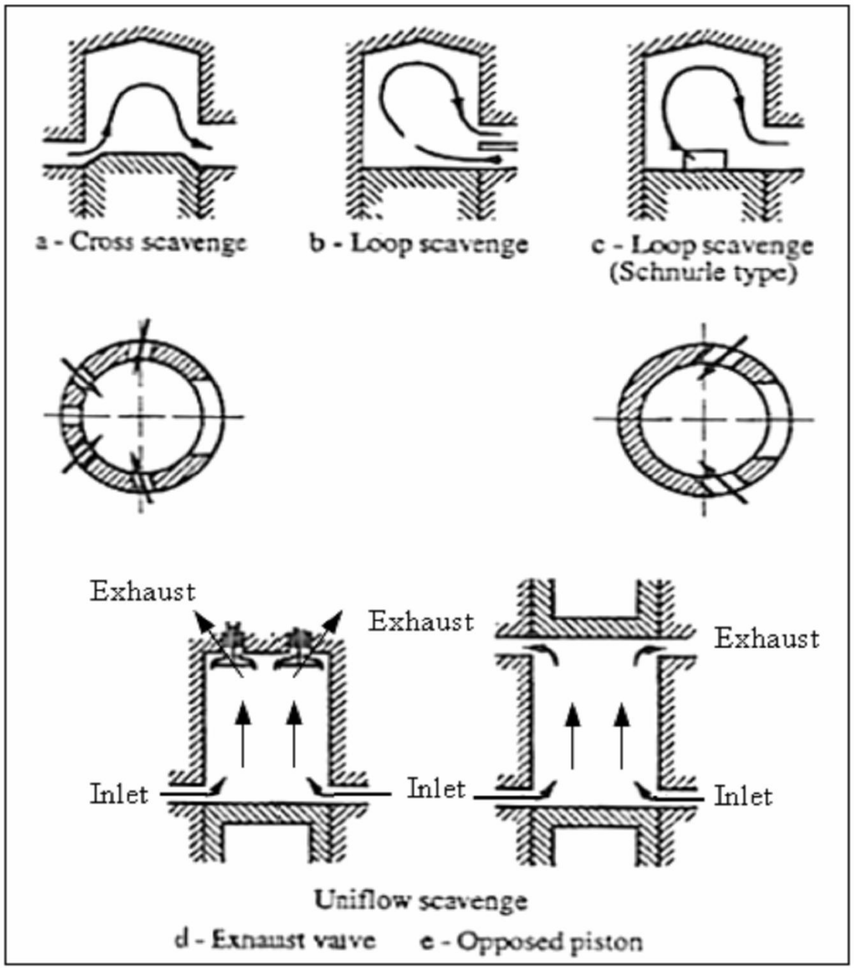

Figure 2.2: Scavenged arrangement [2]

2.5.4 Comparison of Scavenging Methods

In fact specific output of the engine is largely determined by the efficiency of the scavenging system and is directly related to the brake mean effective pressure. Cross scavenging is least efficient and gives the lowest brake mean effective pressure. The main reason for this is that the scavenging air flows through the cylinder but does not expel the exhaust residual gases effectively. Loop scavenging method is better than the cross scavenging method [2] [4] [16] [37].

Table 2.0: Classification of different scavenging methods [2]

Method	Advantages	Drawbacks	Applications
Cross	Good scavenging at partial throttling and low speeds Low engine volume for multi cylinder arrangements Low manufacturing cost	High BSFC (brake specific fuel consumption) at high throttle opening and high speeds High tendency to knock limits compression ratio	Small outboard engines, and some other specific applications.
Loop, MAN-type	Good scavenging at Wide Open Throttle (WOT) Low surface to volume ratio combustion chamber Low manufacturing cost	Poor scavenging at part-throttle operation	Large-bore marine CI engines
Loop, Schnurle-type	Good scavenging at Wide Open Throttle (WOT) and medium engine speed Fair scavenging at part open throttle and other than medium engine speeds Low manufacturing cost	High bsfc at part throttle operation	SI engines for a large variety of applications
Uniflow, exhaust valve	Very good scavenging at WOT for high stroke-to-bore ratio Excellent bsfc	Need for exhaust valves; thus more complex and higher manufacturing cost	Large-bore low-speed CI marine and stationary engines
Uniflow, opposed piston	Very good scavenging at WOT for high stroke-to-bore ratio	Need for mechanical coupling between two crankshafts	Sometimes used in large-bore low-speed CI marine engines

2.6 SCAVENGING PARAMETRIC

The incoming scavenge air can enter either a space called the ‘displacement zone’ where it will be quite undiluted with exhaust gas, or a ‘mixing zone’ where it mix with exhaust gas, or it can be directly short-circuiting to the exhaust pipe providing the worst of all scavenging situations [6].

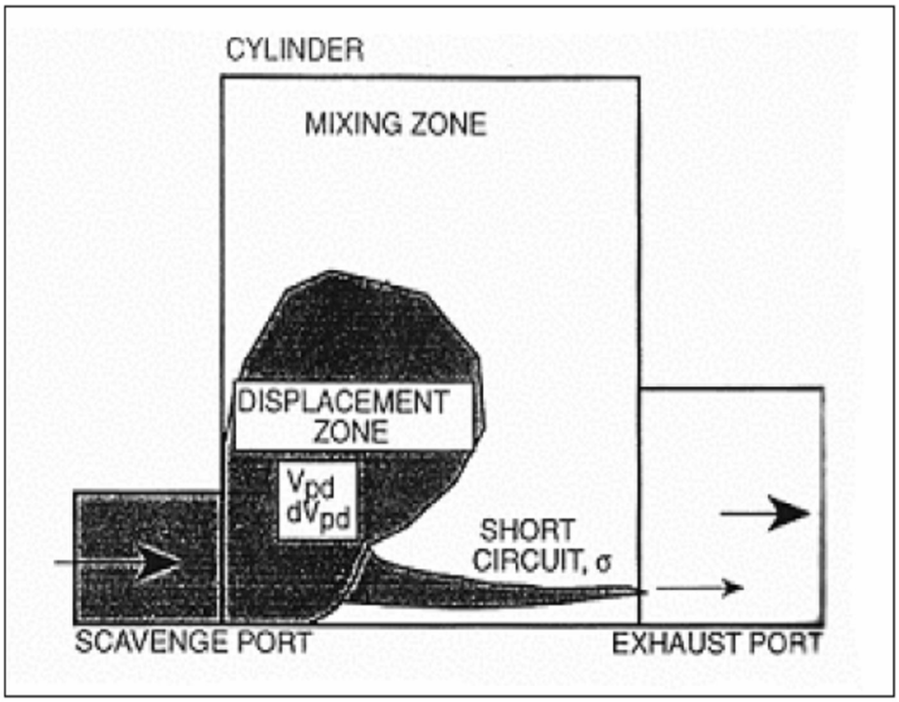

Figure 2.3 Physical representation of isothermal scavenge model.

2.6.1 The Scavenging Efficiency

Indicates to what extent the burnt residuals have been replaced with fresh charge at any given instant.

$$SE_v = \frac{\text{Mass of delivered air retained}}{\text{Mass of trapped cylinder charge}} = \frac{\rho_a V_{ta}}{\rho_a V_{ta} + \rho_a V_{ex}} = \frac{V_{ta}}{V_{ta} + V_{ex}} = \frac{V_{ta}}{V_{cy}} \tag{2.1}$$

2.6.2 The Trapping Efficiency

Defines the amount of short-circuiting of fresh charge to the exhaust.

$$TE_v = \frac{\text{Mass of delivered air retained}}{\text{Mass of delivered air}} = \frac{V_{ta}}{V_{as}} \tag{2.2}$$

2.6.3 The Charging Efficiency

Represent the ability of the engine to fill the cylinder trapped volume.

$$CE_v = \frac{\text{Mass of delivered air retained}}{\text{Trapped volume x ambient density}} = \frac{\rho_a V_{ta}}{\rho_a V_{cy}} = \frac{V_{ta}}{V_{cy}} \tag{2.3}$$

2.6.4 The Delivery (Scavenging) Ratio.

Compares the actual mass of delivered fresh charge at any given instant to the total amount required in an ideal charging process, the reference mass.

$$SR = \frac{\text{Mass of delivered air per cycle}}{\text{Trapped volume x ambient density}}$$

$$= \frac{V_{as}}{V_{cy}} \qquad (2.4)$$

2.6.5 The Ideal Scavenging Process

There is no short circuiting of fresh charge occurring. It is clear from manipulation of the above equations the charging efficiency and scavenging efficiency is identical:

$$CE_v = SE_v$$

$$TE_v = \frac{SE_v}{SR_v} \qquad (2.5)$$

2.7 ADVANTAGE AND DISADVANTAGE OF TWO-STROKE ENGINES.

Two-stroke engine have certain advantages as well as disadvantages compared to four-stroke.

Advantages of two strokes engines [2] [4]:

1. Two-stroke working stroke for each revolution, the power developed will be nearly twice that of a four-stroke engine of the same dimensions and operating at the same speed.
2. The work required to overcome the friction of the exhaust and suction strokes is saved

3. There is a working stroke in every revolution, a more uniform turning moment is obtained on the crankshaft and therefore a lighter flywheel is required.
4. Two-stroke engines are lighter than four-stroke engines for the same power output and speed because did not have intake and exhaust valves.
5. For the same output, two-stroke engines occupy lesser space.
6. The construction of a two-stroke cycle engine is simple because it has ports instead of valve. This reduces the maintenance problems considerably.
7. In case of two stroke engines because of scavenging, burnt gases do not remain in the clearance space as in case of four-stroke engines.

Disadvantages of two-stroke engines [2] [4]:

1. High speed two strokes engines are less efficient owing to the reduced volumetric efficiency.
2. With engines working on Otto cycle, a part of the fresh mixture is lost as it escapes through the exhaust port during scavenging. This increases the fuel consumption and reduces the thermal efficiency.
3. Part of the piston strokes is lost with the provision of the ports thus the effective compression is less in case of two-stroke engines.
4. Two-stroke engines are liable to cause a heavier consumption of lubricating oil.
5. With heavy loads, two-stroke engines get heated due to excessive heat produced. Also at the light loads, the running of the engine is not very smooth because of the increased dilution of charge.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter will explain detail in methodology from the beginning until the end of the project. This project had pass through step by step in order to successful such as conceptualization, design, fabrication and measurement installation. All the steps need to plan with precisely to achieve the objective of the project.

These steps must follow the gantt chart in order to achieve the milestone. The main methods are a design and fabricate the engine test rig. This methodology will explain base on the chart below with the explanation of each steps provided. Starting with title and proposal confirmation from the supervisor, literature study was done base on research field. Then determining the required equipment of this project to continue the conceptualization. Several designs have proposed and choose the best one. Fabrication process takes part with define for material use until instrument installation for data measurement. Finally are documentations of the project.

The methodology applied in the implementation of this project was as follows:

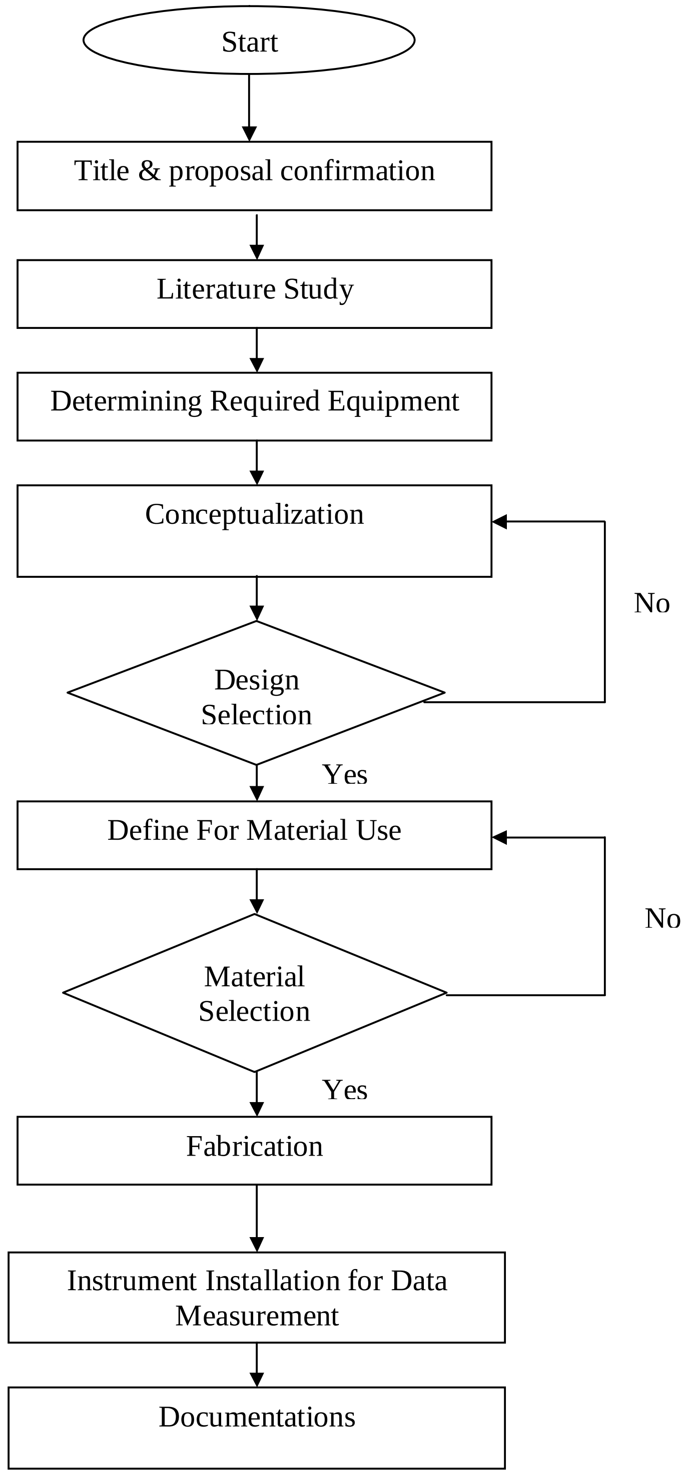

Figure 3.0: Flow chart of project implementation

3.2 TITLE & PROPOSAL CONFIRMATION

This project begins with receive the title that had chosen. Then supervisor give the explanation of the scopes of study, objective, project background, overview and field of research of the project. This information is important to provide the understanding of the advancements of two-stroke engines technology such as the scavenging systems.

3.3 LITERATURE STUDY

During this step, make a study, analysis and research about two stoke spark ignition engine especially in motoring condition through other thesis, technical paper, web site, journal, books and many more. The review of recent works is important to provide the understanding of two-stroke engine and technologies such as the scavenging systems, motored and firing testing conditions. The other previous technical papers and journal which are published will assist the author in motored condition testing development. Besides, there are several books on two-stroke engines which will provide first hand knowledge in designing engine test rig especially in motored condition and analysis.

3.4 DETERMINING REQUIRED EQUIPMENT

Before go through the fabrication progress, first we must determining required equipment such as how this engine test rig perform including location of data acquisition system (DAQ), vertical plain panel for displaying inverter and lastly base of engine including engine, sensor location and AC motor. Others parameter that need to considered were height, wide, material usage, effect during experiment such as vibration, reduce space, flexibility and wasting material.

3.5 CONCEPTUALIZATION

With the knowledge and overview obtained from supervisor and literature study, a design concept of engine test rig for two-stroke engine was proposed. The design was drawing using SolidWorks 2005. The concept and idea of engine test rig, we interpretation it into several design. After discussion with supervisor and considered several factor such as vibration effect, toughness, flexibility and stability, final design was concept with detail drawing are prepared for the fabrication works.

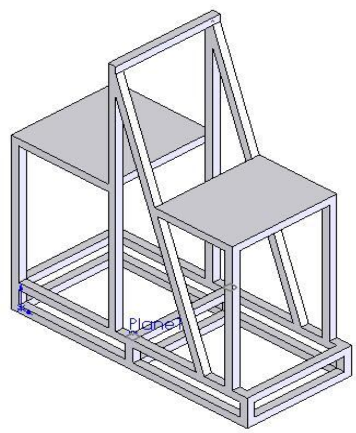

Figure 3.1: First Design of Engine Test Rig

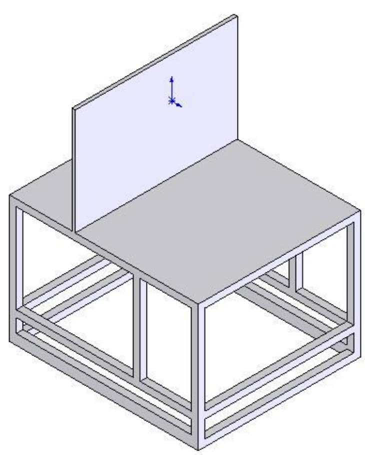

Figure 3.2: Second Design of Engine Test Rig

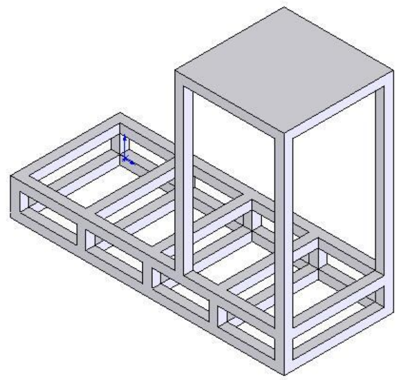

Figure 3.3: Third Design of Engine Test Rig

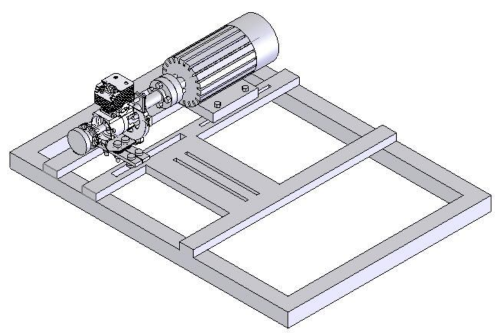

Figure 3.4: Structure Base of Engine Design

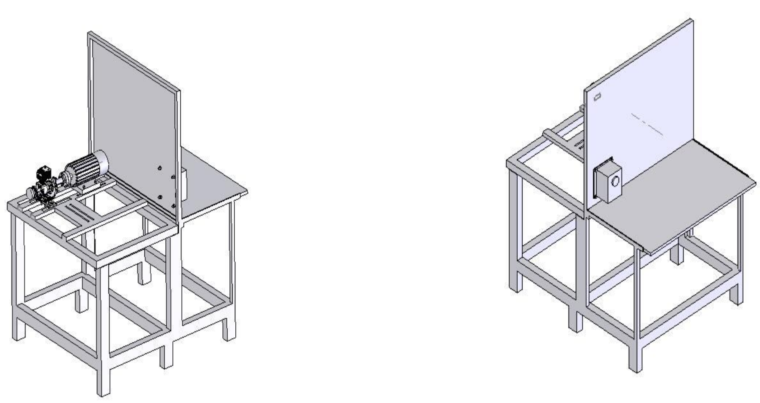

Figure 3.5: Final Design of Engine Test Rig

3.6 DEFINE FOR MATERIAL USE

The next step is defining the material use. Selecting material was made according congruent of the design. Selecting materials is very important in order to make sure the toughness of the test rig. For the entire part of test rig including lower part and engine side, tubular steel bar 3 inches x 3 inches was used. It is quite bigger in order to endure the heavier engine besides avoid the vibration. While for the DAQ location, hollow rectangular steel 1 inch x 1 inch was used. It is enough to absorb the weight of DAQ.

3.7 FABRICATION

Next step is starting to fabricate. This progress was done step by step such as cutting material followed by grinding the sharp edge of material. Then welding process was done to join between the materials according to the design. Lastly finishing process takes path. During finishing, the test rig was paint with black colour. Fabrication process takes a long time because precision and accuracy needed to make sure this engine test rig did not face any problem.

After frame of engine test rig was completed build, installation of engine, inverter, motor and gearbox had done onto the base of engine. These components were connecting each other by coupling shafts which tighten by screw and nut. Table below show the raw material that been used in this project.

Table 3.6: Table of Raw Material Usage

No	Part Name	Material	Quantity	description
1	Engine Stand	Tubular Steel Bar	12	3 x 3 inch
2	DAQ Stand	Tubular Mild Steel Bar	4	1 x 1 inch
3	Inverter Panel	Mild Sheet Metal	1	35 x 31.5 inch
4	DAQ Holder	L Iron	2	3 x 4 inch
5	DAQ base	Plywood	1	19 x 40 inch
6	Hex Bolt	Mild Steel	4	M10 x 50 mm
7	Hex Bolt	Mild Steel	10	M4 x 30 mm
8	Hex Bolt	Mild Steel	2	M6 x 40 mm
9	Washer	Iron	16	M10
10	Washer	Iron	18	M4
11	Shaft Coupling	Iron	2	Diameter 90mm with center of 24 mm, 17 mm, 15 mm

3.8 MEASUREMENT INSTALLATION FOR DATA COLLECTION FOR MOTORED CONDITION

After the engine test rig was completed assembled, the instrumentations for the scavenging measurement were installed at the engine such as pressure transducer and crank angle encoder. Analysis through experimental was carry out for data collection.

3.8.1 Taking the Measurement of Motoring Experiment

In motoring test, there a few methods to collect and measure the data [39]. There are using:

(a) Laser
(b) Sensor
(c) Visualization

Using laser, crank angle-resolved measurements of pressure, gas temperature and water vapor concentration are made during the compression stroke of engine with a novel diode laser absorption sensor. The measurements sample a short path region (6 mm) of the in-cylinder gases near the spark plug, which has been modified to provide optical access. Hence, the sensor can be installed in nearly any engine via the spark plug port. Measurements taken in a range of temperatures and pressures from 500 K to 1050 K and 1 atm to 50 atm at a bandwidth of 7.5 kHz. Crank angle-resolved measurements are performed in unfired and fired engine cylinders [40] [41] [42].

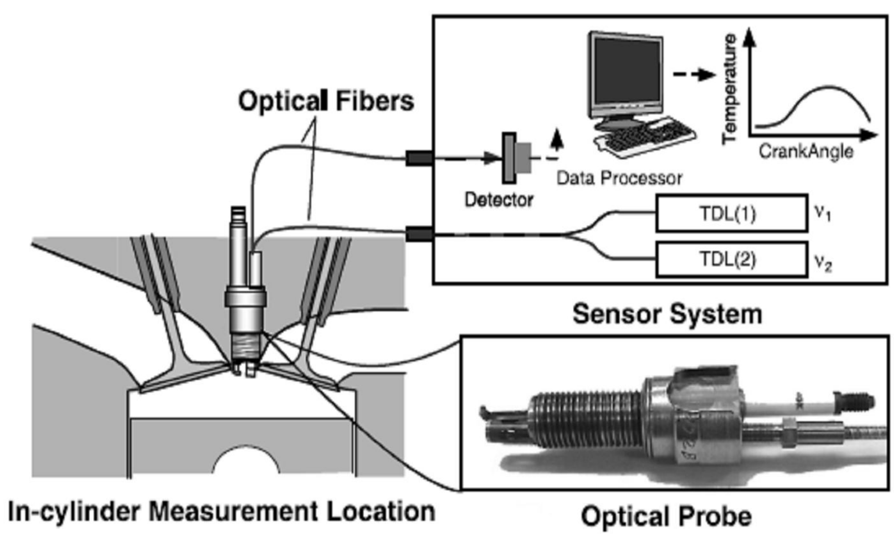

Figure 3.7: Using Laser mount top of the cylinder with spark plug [41] [42].

While using sensor, pressure traces were simultaneously recorded at in cylinder heat pressure transducer mounted in the engine system. This sensor was used to measure cylinder pressure and it was flush mounted in the cylinder head. The flush mounting was preferred in order to minimize the lag in the pressure signal to avoid pipe connecting passage resonance [3] [40] [41].

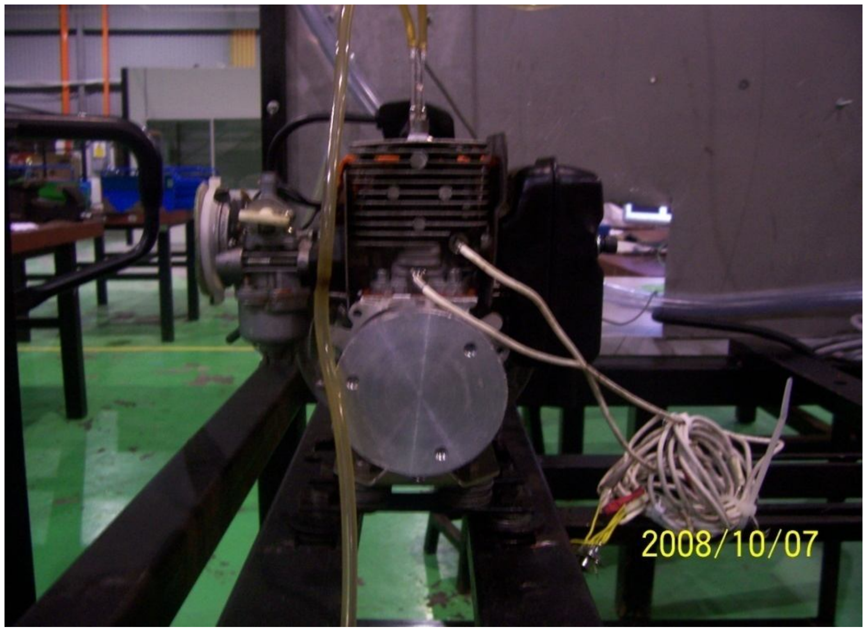

Figure 3.8: Pressure transducer at cylinder and intake port [3].

While using visualization, experimental set-up that allows the examination of large-scale models of two-stroke cylinders. The experiment fulfills the law of similarity, because the model is scaled according to the Reynolds, Strouhal and Euler Numbers. The principle at work allows full optical and visual access to the flow inside the transfer channels and the cylinder itself. The conceptual design of the experiment is closely linked to the design process of the cylinder, which guarantees fast interaction and produces powerful results about the flow structure during the scavenging process. This has been demonstrated by modifying the model under investigation at the test rig [29] [42] [43].

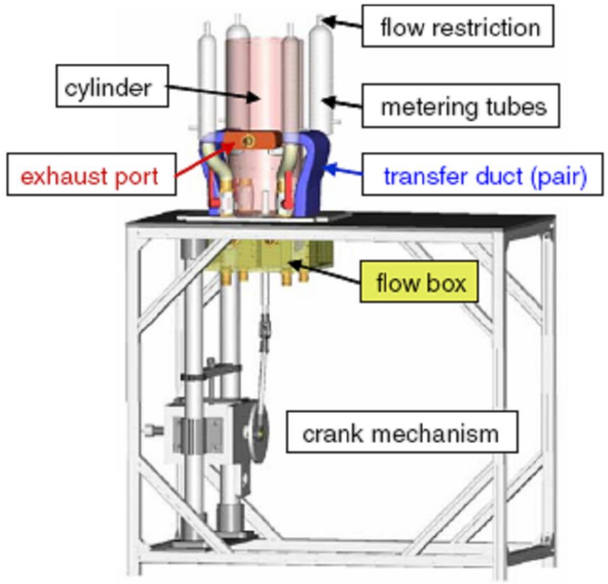

Figure 3.9: Experiment Set-Up of Visualization Method [35].

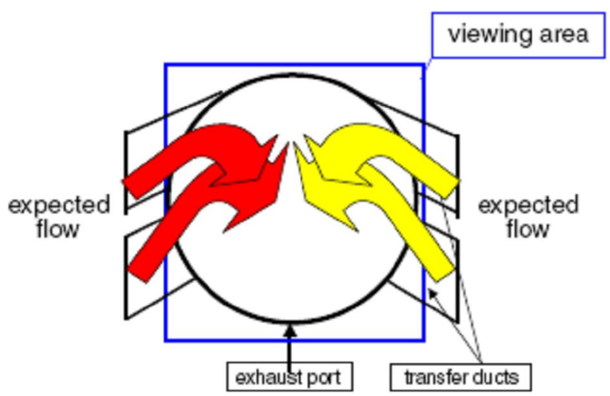

Figure 3.10: Sketch Of The Viewing Area And Details Of The Cylinder In Top View For The Set-Up With Natural Scavenging Flow In Visualization [35].

3.9 DOCUMENTATIONS

Documentation and report writing will be the last progress in project. While doing the documentations, all the reliable sources will be the references to ensure the project and report writing will satisfy.

3.10 EXPERIMENT SETUP

The scavenging test rig was developed to analyze the actual scavenging process. The unfired condition of test rig which mean testing without combustion was build and engine will generate by external power which is motor. The fabrication work took about 7 months to finish. During fabrication, it needs step by step to build the engine test rig [3] [38].

The engine test rig components are first drawn in Solidworks 2005. In this project, the scavenging test rig was developed to analyze the actual scavenging process for un-firing condition. There are several parts in engine test rig including firing condition concept which are panel board location, data acquisition system (DAQ) location, and engine part. Engine parts consist from 3 phase AC motor, inverter, a coupling of connection and the engine. The 3-phase AC motor will convert electric energy to mechanical turning torque to run the engine model at a predetermined speed. The detail drawing provide the information of the components dimensions, orthographic view and the isometric view of the assembly as well are illustrated in appendix.

During assemblies which are welding the joint, we needs weld the base first. Make sure the joint are perpendicular or 90º angle so that the precision frame we get. After that, pillar was welding stand upward include DAQ location pillar, engine location pillar and panel pillar.

Figure 3.11: Engine Test Rig

3.11 ENGINE TEST RIG COMPONENTS

3.11.1 Testing Engine

The engine that used in this project is BG 328A Tanaka Engine. This is single cylinder piston-ported two-stroke engine loop-scavenged crankcase compressed. The piston surface is flat form. The specifications of engine are shown below [3]:

Table 3.12: 328 A Tanaka Engine Specifications [3] [44].

Parameter	**Size/ Feature**
Cylinder type	Single cylinder, piston ported
Compression type	Crankcase compression
Displacement	30.5 cm^3
Scavenging concept	Multi port-loop scavenged
Bore x Stroke	36 x 30 mm
Exhaust port opening / closing	101 CA ATDC / 259 CA ATDC
Scavenged port opening / closing	140 CA ATDC / 220 CA ATDC

Figure 3.13: Tanaka Engine BG-328A

3.11.2 Pressure Transducer

Pressure traces were simultaneously recorded at location using pressure transducer mounted in the engine system [1].

For the in cylinder pressure measurement installation, cylinder pressure was recorded with a Kistler Type 6041A water cooled which is mounted in the cylinder head at top side. The sensor Type 6041A may be screwed directly into a M8x0.75 hole, either flush mounted with the wall of the combustion chamber or mounted with recessed diaphragm. The Collected of cylinder pressure data at the average over 120 consecutive cycles with a crank angle encoder having resolution of 0.4º CA. [3] [45] [46] [47].

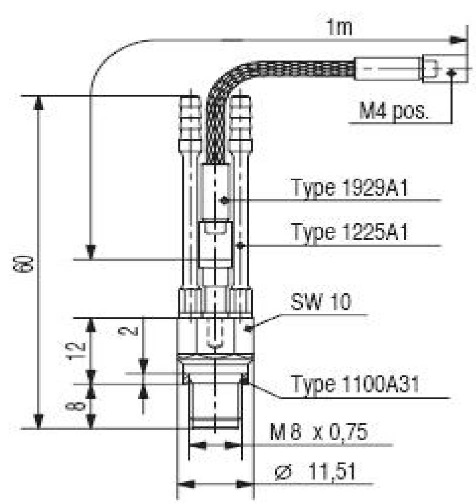

Figure 3.14: Kistler Type 6041A Pressure Transducer [31]

Table below show the technical data Kistler Type 6041A pressure transducer.

Table 3.15: Technical data Kistler Type 6041A pressure transducer.

Technical Data	Unit	Range
Measuring range	Bar	0...250
Sensitivity	pC/Bar	≈-20
Natural Frequency	kHz	≈70
Non linearity	% FSO	<±0.5
Operating temperature range	°C	-50...350
Sensitivity shift, cooled	%	±0.5 50 °C +/- 35 °C
Sensitivity shift, uncooled	%	<±2 200 °C +/- 150 °C
Thermal shock DP (short time)	Bar	<±0.25
Thermal shock DP mi	%	<±2
Thermal shock DP max	%	<±1
Acceleration sensitivity	Bar/g	<0.012 axial
Thread		M8x0,75
Cooling		water cooled
Front diameter	mm	11.51
Length	mm	8
Cable length		Standard length 1 m
Connector		M4x0,35 pos.
PiezoSmart (TEDS)		no

For the scavenged and exhaust port pressure measurement installation, both port pressure was recorded with a XPM5 Miniature Pressure Transducer which is mounted at scavenge and exhaust port. The XPM5 Miniature Pressure Transducer may be screwed directly into a M5x0.8 hole. The collected of pressure data at the full scale range which is between 2 to 350 bar [3] [45] [46] [47].

Table 3.16: Technical Specification of XPM5 miniature Pressure Transducer.

Technical Specification	**Range**
Range(F.S)	0-350 Bar
Over range Without Damage	2 x F.S
Over range Without Destruction	5 x F.S
Accuracy Non Linearity	+- 0.25 % F.S. (+- 0.35% for < to 10 bar model
Temperature range	-40˚ to 120˚
Supply Voltage	10 Vdc
F.S output	30 mV
Zero Offset	< +- 10 mV
Input Impedance	1500 Ω
Output Impedance	500 to 800 Ω
Insulation Under 50 Vdc	> 100 MΩ

3.11.3 Crank Angle Encoder

The crank angle encoder use to determine the crank angle position proportional to the pressure sensors and measurement the speed. It is optical sensing device suitable for testing engine application. The Kitsler crank encoder type 2613 B will use for all crank-angle-related measurement of internal combustion engine [48]. It is consist of an angle encoder and signal conditioner. The crank angle encoder contains a precision marker disk with a trigger mark and 360 angle marks which is scanned by a transmission photoelectric cell. The speed range of 1 to 20 000 rpm the encoder can be used on a large variety of engines [45]. Coupled usage of the crank angle encoder and the spark plug type of combustion pressure sensor during cranking phase will allow determination of the zero crank angle position based on maximum compression pressure during non-firing condition [3] [49].

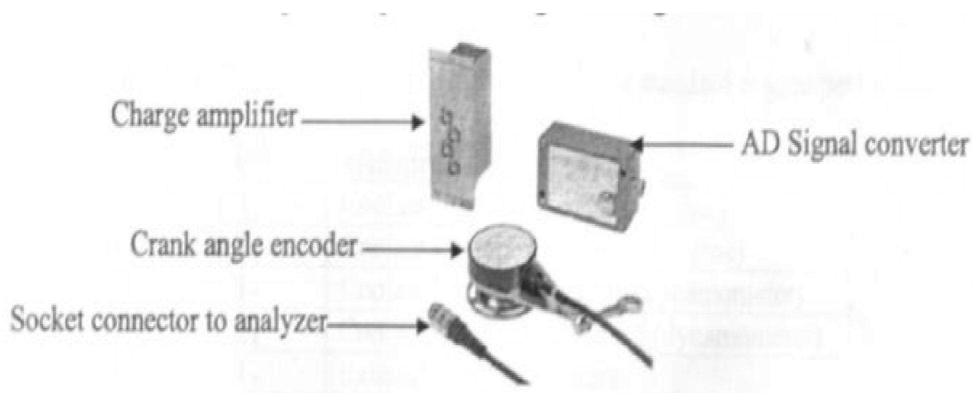

Figure 3.17: Crank angle encoder and data acquisition kit [3] [38]

Table 3.18: Technical specification of crank angle encoder [3] [38]

Kistler Crank Encoder type 2163B		
TTL crank angle signal Resolution	o	0,1………..6
Dynamic accuracy at 10000 1/min (signal delay)	o	+0.02
TTL trigger signal (TRG) Resolution	o	0,1………6
Speed range	1/min	1……….20000
Operating temperature range		
Encoder and amplifier	^{o}c	-30…60
Connection flange	^{o}c	-30…60
Power supply		
With stabilized voltage	VDC	5+/-.25
Current consumption	mA	200
With unstabilized voltage	VDC	6……..24
Current consumption	mA	200…..400
Mounting diameter of encoder	mm	69
Encoder weight	g	460
Amplifier dimensions	mm	98 X 64 X 37
Amplifier weight	g	300

3.11.4 Data Acquisition System (DAQ) for Data Collection

The usage of pressure sensor is made simpler with the integration of Dewetron CA 5000, a computerized based combustion analyzer. Data logging capability was required to recorded pressure and crank angle signals with sampling speed of 9600 bits/second. The voltage signal from the sensor is directly send to the Dewetron CA software and interpreted as the data in Excel file [3] [49]. Below are picture of data acquisition (DAQ).

Figure 3.19: Data Acquisition System (DAQ)

3.11.5 AC Induction Motor

The AC induction motor is a rotating electric machine designed to operate from a three-phase source of alternative voltage. The stator is a classic three phase stator with the winding displaced by 120º. The most common type of induction motor has a squirrel cage rotor in which aluminum conductors or bars are shorted together at both ends of the rotor by cast aluminum end wings. When three currents flow through the three symmetrically placed windings, a sinusoidal distributed air gap flux generating the rotor current is produced. The interaction of the sinusoidal distributed air gap flux and induced rotor currents produces a torque on the rotor. The mechanical angular velocity of the rotor is lower then the angular velocity of the flux wave by so called slip velocity [38].

Figure 3.20: 3-phase AC induction motor

Motor Specification:	**Value:**
Max Voltage	415V
Frequency	50 Hz
Max Speed	1480 rpm
Max Current	5.4 A
Max Power	1.5 kW, 2.0 Hp

3.11.6 Three Phase Inverter

A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform. This creates a line-to-line waveform that has six steps. The six-step waveform has a zero voltage step between the positive and negative sections of the square-wave such that the harmonic that are multiples of three are eliminated. To construct inverter with higher power ratings, two six step three-phase inverters can be connected in parallel for a higher current rating or in series for a higher voltage rating. Although inverters are usually combined for the purpose of achieving increased voltage or current ratings, the quality of the waveform is improved as well [38].

Figure 3.21: Yaskawa Juspeed-F P300

Inverter Specification:	**Value:**
Max current	120 mA
Max Frequency	60 Hz
Max power	1.5 kW
Source:	200 V – 220 V / 50 Hz
	200 V – 230 V / 60 Hz

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the detail of fabrication process was explained including measurement installation until experiment setup. The objective has successfully achieve which is to design, development and fabricate of new engine test rig for motoring concept a single cylinder 30.5 cc two strokes spark-ignition engine and measurement installation.

The engine test rig was developed to analyze the internal flow of scavenge process base on pressure taken. From the pressure measure, we can see the detail where the different pressures cause the flow in the engine and the scavenge process is then analyzed. Thus, we can detect the short-circuiting phenomena where causes the poor fuel efficiency and high emission of hydrocarbon. For a preliminary design of engine geometry, it is sometimes easiest to evaluate the scavenging characteristics on the basis of a single cycle rather than several successive cycles.

4.2 FABRICATION PROCESS

During fabrication process, there are several process needed which is conceptualization, design, material selection, marking the material, cutting the material, joining the material, assembly the component and measurement installation. In this chapter will explain the detail about material selection until measurement installation.

4.2.1 Material Selection

During material selection process, we must consider the strength of material and toughness of that material. It is because to hold the weight of engine, AC induction motor and absorb vibration during testing. Square Tubular Bar Steel 3 x 3 inch and square Tubular Mild Steel 1 x 1 inch had been chosen for the engine stand component and the reason that material strong enough and easy to perform the mechanical work.

4.2.2 Marking and Cutting the Material

Marking the raw material is the next process. Marking was done by using measurement tape with iron marker according to the final design of engine test rig. In this process needed high concentration to get precise and accurate dimension in order to make sure this engine test rig did not face any problem. After marking process finish, the raw then been cut out into several parts according to the length of the each part and dimension in the design drawing by using disc cutter. The sharp edge was removed by hand grinder in order to get precise dimension and remove serrated.

Figure 4.0: Raw material for engine test rig

Figure 4.1: The disc cutter

Figure 4.2: Cutting the raw material process

4.2.3 Welding the Raw Material

Welding process is to joining the parts of the raw material. The welding that has been use is MIG (Meal Inert Gas) welding because this kind of permanent joining is strong and tough. Welding process took about 2 month to complete assemble all the join of the engine test rig part. During the welding process, it is important to make sure the entire angle between joint are 90° to make sure the test rig is stable enough during testing, avoid structure slanting and reduce the vibration due to incorrect precision joining.

Figure 4.3: Metal Inert Gas Welding (MIG)

Figure 4.4: Test rig after welding process complete

4.2.4 Assembly the Component

After test rig complete build, the test rig was spray with black color. Then the entire component including inverter, 3 phase motor and engine was installing. Inverter was located on the panel for easiest control engine speed. At the engine side, engine connected with AC motor by using shaft coupling. We must make sure all the connection especially nut and screw was tighten to avoid failed occur during testing. Figure below show the installation all components with engine test rig.

Figure 4.5: Inverter located at board of panel

Figure 4.6: Coupling between AC motor and engine

4.3 MEASUREMENT INSTALLATION

4.3.1 In-Cylinder Pressure Measurement

Measurement Installation was done after all components completely install and engine completely mounting. The detail of sensor was explained at chapter 3. For the in-cylinder pressure measurement installation, cylinder pressure was recorded with a Kistler Type 6041A with water cooled which is mounted in the cylinder head at top side. The sensor Type 6041A may be screwed directly into M8x0.75 hole, either flush mounted with the wall of the combustion chamber or mounted with recessed diaphragm. There have a water tank at the top of engine test rig to supply the water for cooling the sensor. Sensor then connected to the DAQ with cable.

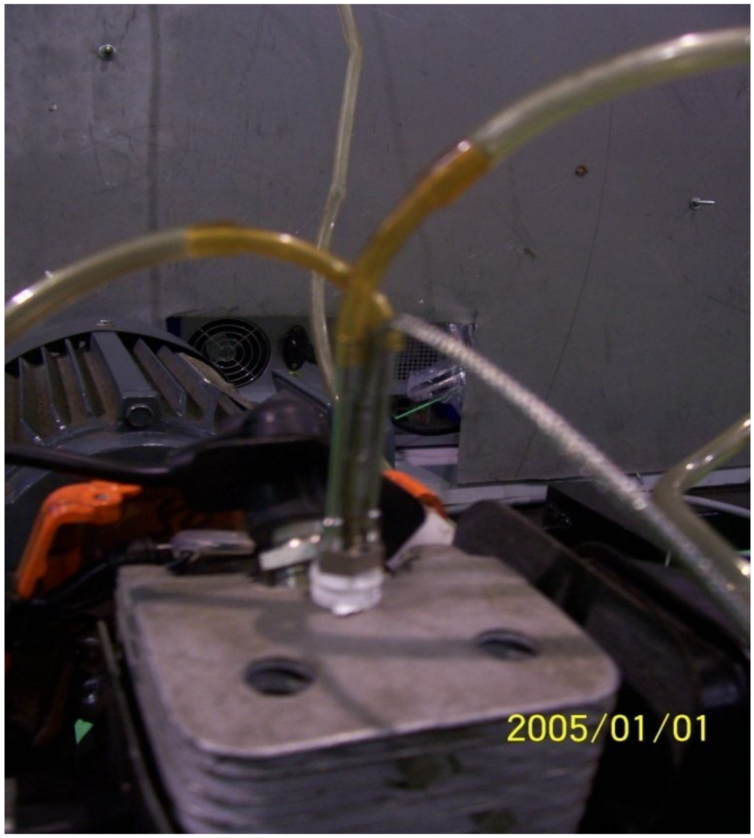

Figure 4.7: Pressure transducer to measure in cylinder pressure.

4.3.2 Scavenge and Exhaust Port Pressure Measurement

For the scavenged and exhaust port pressure measurement installation, both port pressure was recorded with a XPM5 Miniature Pressure Transducer which is mounted at scavenge and exhaust port. The XPM5 Miniature Pressure Transducer may be screwed directly into a M5x0.8 hole. And then those sensors will connect to the DAQ for data collection. This kind of sensor doesn't have water cooled because it operates at low range temperature.

Figure 4.8: XPM5 miniature pressure transducer

Figure 4.9: Sensor mounted to the engine to measure scavenge and exhaust port pressure

4.3.3 Crank Angle Detection

In order to determine the crank angle position proportional to the pressure sensors and measurement the speed, we use crank angle encoder with mounting the engine. The Kitsler crank encoder type 2613 B will use for all crank-angle-related measurement of internal combustion engine [48]. It is consist of an angle encoder and signal conditioner. Before that, we must do the crank angle mounting as scarf between engine and crank angle encoder. Figure below show the crank angle mounting.

Figure 4.10: Crank Angle Encoder Mounting

Crank angle encoder consists of several parts. There are amplifier, adapter, wire connector and crank angle holder. First, mount the crank angle encoder with crank angle mounting using the screw M8. And then to avoid crank angle encoder rotate together with engine rotation, we must apply the crank angle holder to the test rig body and tighten it.

Figure 4.11: Crank Angle Encoder mount to the engine

Figure 4.12: Crank Angle Holder

Figure 4.13: Crank Angle with the cable

4.4 FULLY ASSEMBLY OF ENGINE TEST RIG FOR MOTORING CONDITION

After complete component installation and measurement installation, engine test rig ready to testing. We must do the double checking all the screw and the nut in order to avoid some part losses. A brief test for the engine was been carried out and there was no serious vibration occur during the testing.

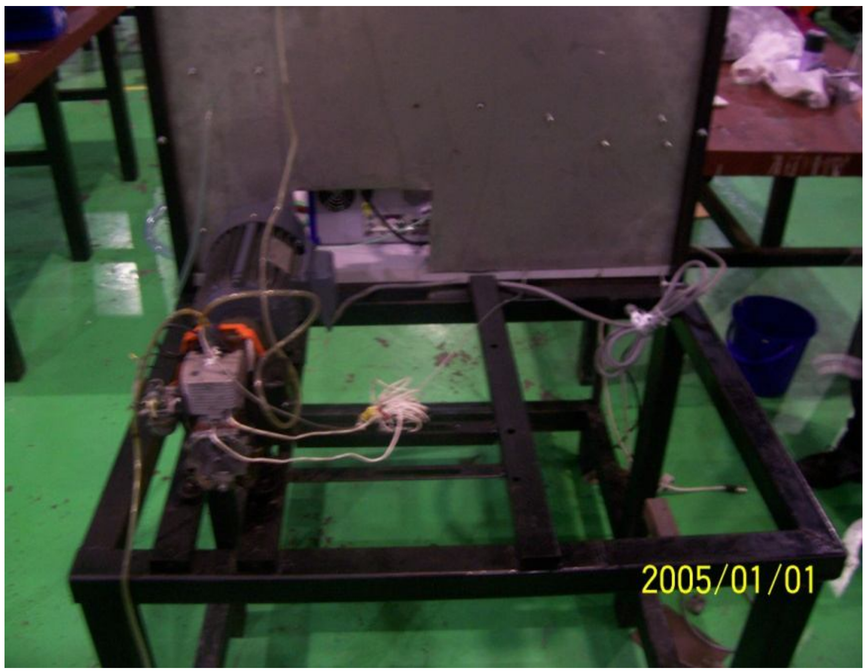

Figure 4.14: Overall Assembly View Engine Testing For Motoring Condition

Figure 4.15: Complete Assembly of the Measurement Installation

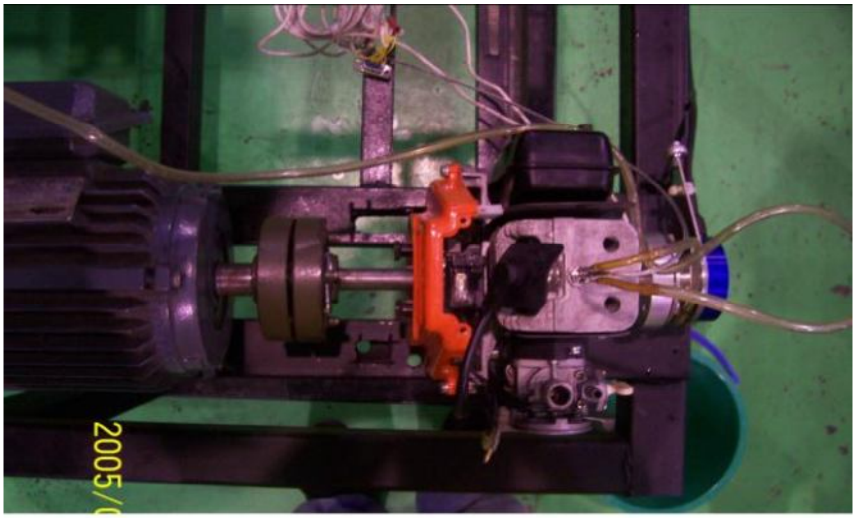

Figure 4.16: Engine testing complete with measurement installation

4.5 EXPERIMENT CONDITIONS

The main objective in designing and development of this test rig is to collect the pressure data simultaneously with crank angle revolution of motoring concept for small engine two stroke engines. During this process, speed of AC motor was controlled by inverter to achieve the desire speed. Then rotation from AC motor will driven and generate the rotation of the engine by using shaft coupling.

During the testing process, we test the engine at three different rpm, and data is collected based on constant engine speed. The engine speed is directly controlled by inverter by means of changing frequency value.

4.6 EXPERIMENT METHOD AND PROCEDURES

4.6.1 Experimental Study by Motored Engines (Non Firing)

With motored engine tests, it is presumed that the scavenging characteristics are only weakly dependent on the combustion process. The engine itself, or a model of the engine, is driven by external motor and the scavenging process is then analyzed. It is sometimes easiest to evaluate the scavenging characteristics on the basis of the single cycle rather than several successive cycles [3] [4] [50].

In using static model test, the cylinder is subjected to a steady air flow through its ports while the piston is locked at bottom dead center (BDC) [43]. Static or steady flow model test are mainly used to study the flow direction and distribution of the entering fresh charge, without introducing the effects of the moving piston and unsteady nature of the process on the scavenging characteristics [4] [24].

In using dynamic model tests, there are mainly used to investigate possible ways of modifying particular port geometry to improve its scavenging characteristics [28]. The engine itself or a model of the engine is driven by an external motor, while the scavenging characteristics are evaluated by sampling, visualizing or other measurement techniques [4].

4.6.2 Data Collection

In taking the data, the engine operating is controlled by inverter to certain rpm. During experiment, the measurements take at three different rpm which is 1000, 1200 and 1400 rpm. For each testing is run about 5 minutes. For the motored experiment, the analysis focuses on flow behavior affected on in-cylinder pressure from intake to exhaust ports. The AC motor will convert electric energy to mechanical turning torque to run the engine model at a predetermined speed [3].

The in cylinder pressure was recorded during experiment using pressure transducer had install. In the same time crank angle encoder recorded the crank angle rotation of the engine from top deck center until bottom deck center. The data interpret from sensor through signal to Dewetron CA 5000 and will be analyze. Figure below show the schematic diagram of engine test rig and it arrangement of the components [2] [3].

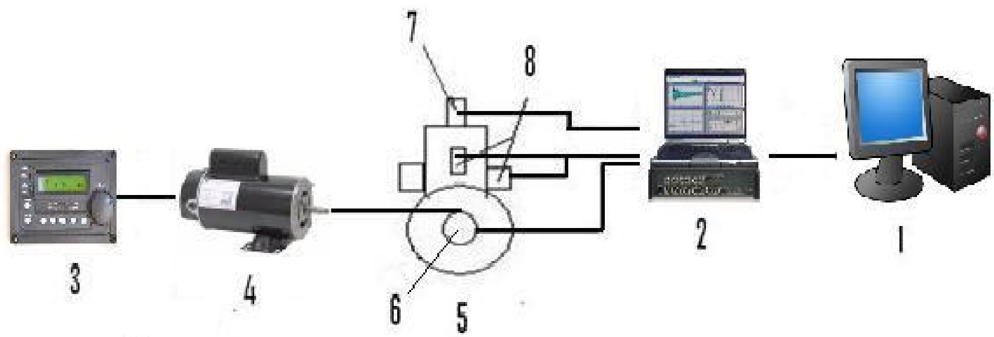

Figure 4.17: Schematic Diagram for Engine Test Rig [3] [38]

1) Computer
2) Data acquisition system
3) Inverter
4) AC Motor
5) Engine
6) Crank angle encoder
7) Pressure transducer M8
8) Pressure transducer M5

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following salient points are the major outcomes of the work carried out:

1. The fabrication process of two stroke engine test rig for motoring concept has successfully proposed and developed. The engine test rig was designed in Solidwork 2005 after considered the entire factor such as vibration, safety, human ergonomic, stability, flexibility and toughness.

2. The engine test rig is designed by adapting the motoring mechanism where engine driven by three phase AC motor and controlled by inverter. Inverter convert the single phase to three phase current to supply current for motor and control the motor speed.

3. The installation of measurement data experiment through unfired or motoring mechanism was done with the pressure transducer and crank angle encoder was installed to measure the in cylinder and scavenged port pressure and crank angle revolution. Engine test rig was complete and successful build. All the measurement equipment was complete install. .

5.2 RECOMMENDATIONS

Some of the immediate work to be carried put to further enhance the performance of the project will be:

1. During the testing, there are limit in engine speed due to motor capability. For better future work, use a high capability power of motor or coupling it with gear box as speed increaser to get high rpm.

2. The method of coupling maybe produce loses such as friction and need more force to initiate the rotation. For future recommendation, we can use other method to reduce this problem such as belting, chain and gear and others method.

3. During fabrication also, make sure that the test rig have tough enough to avoid vibration and some components yanked out.

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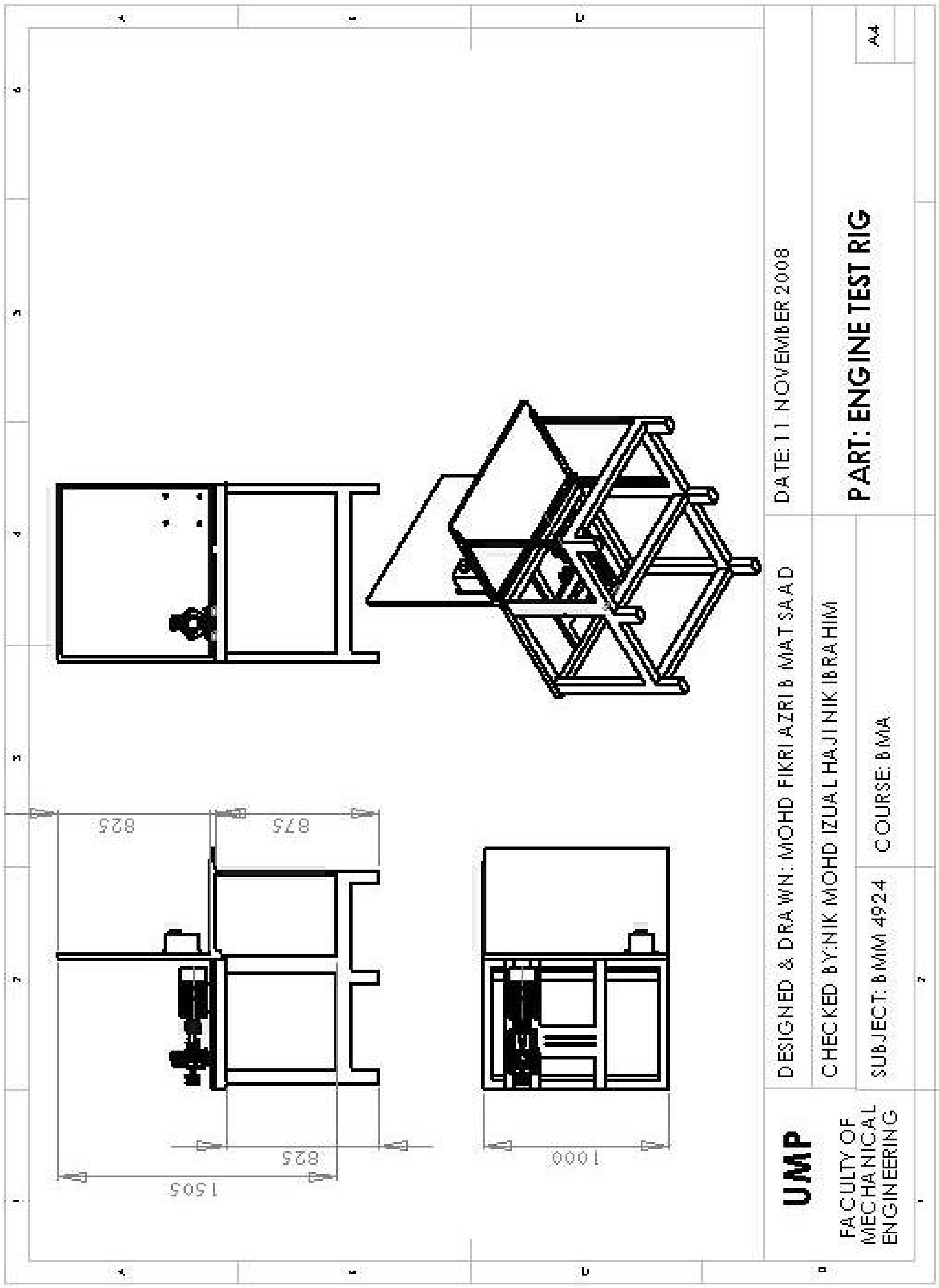
APPENDICES

APPENDIX A



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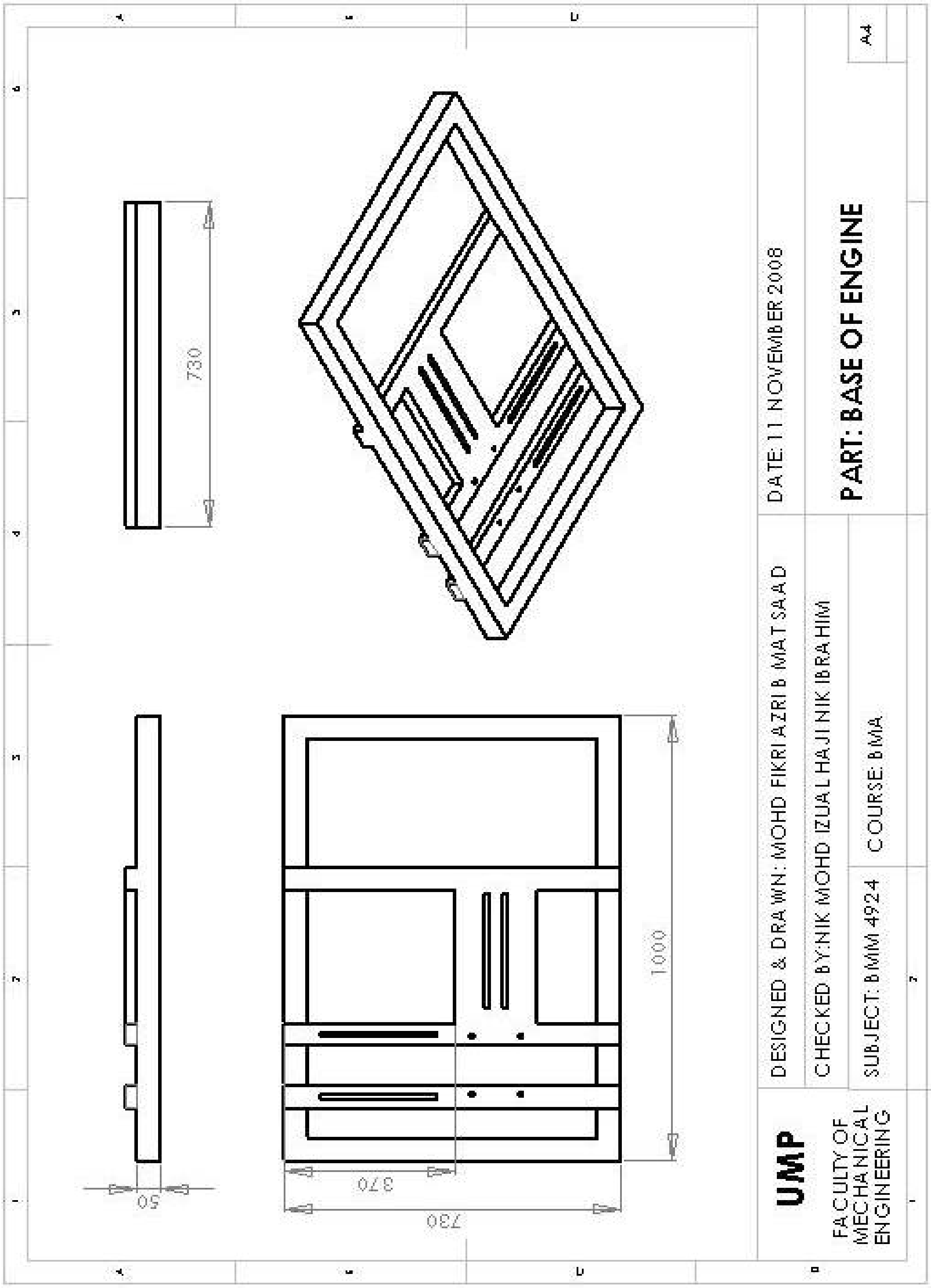
UMP
FACULTY OF MECHANICAL ENGINEERING

APPENDIX B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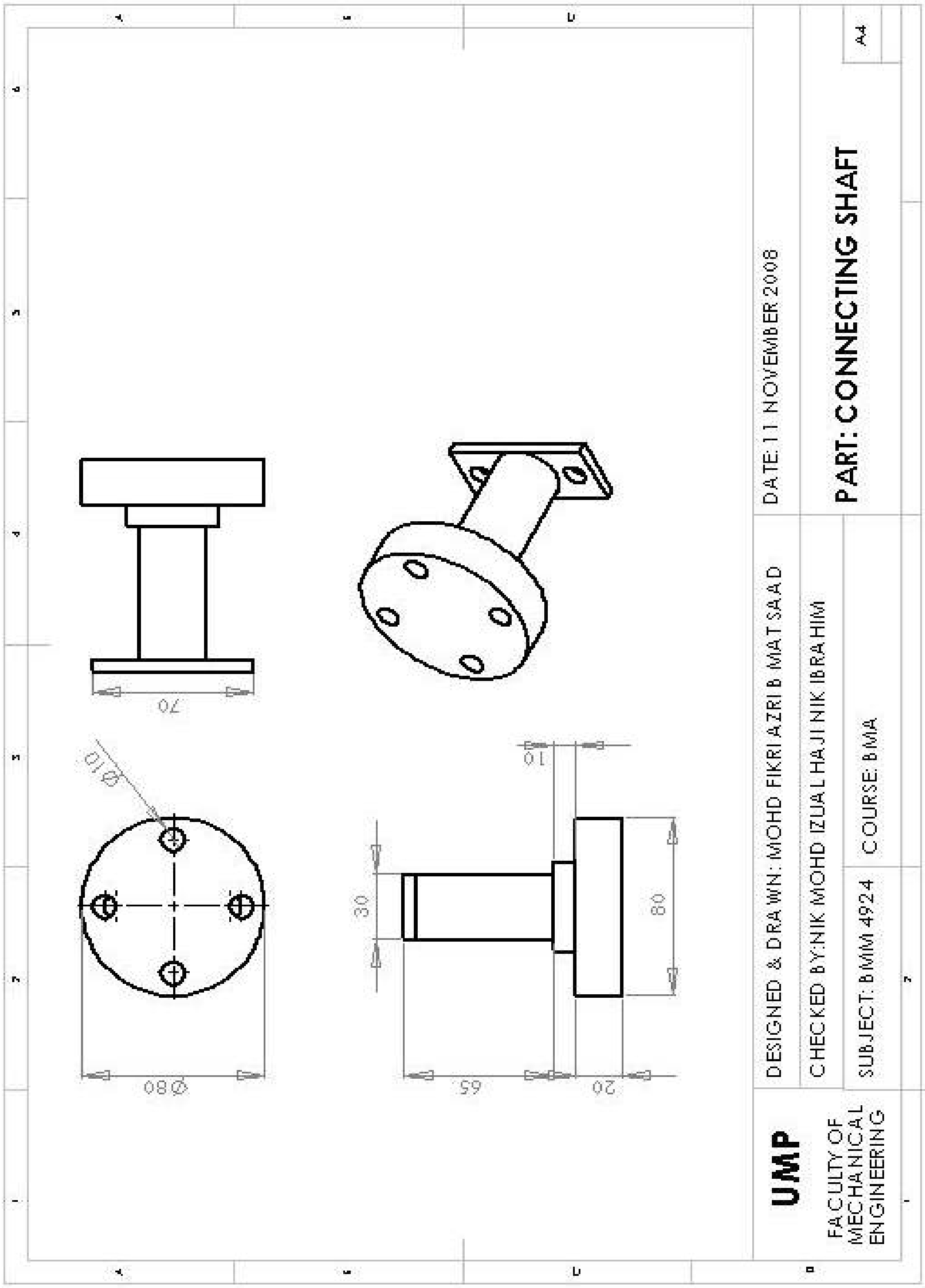
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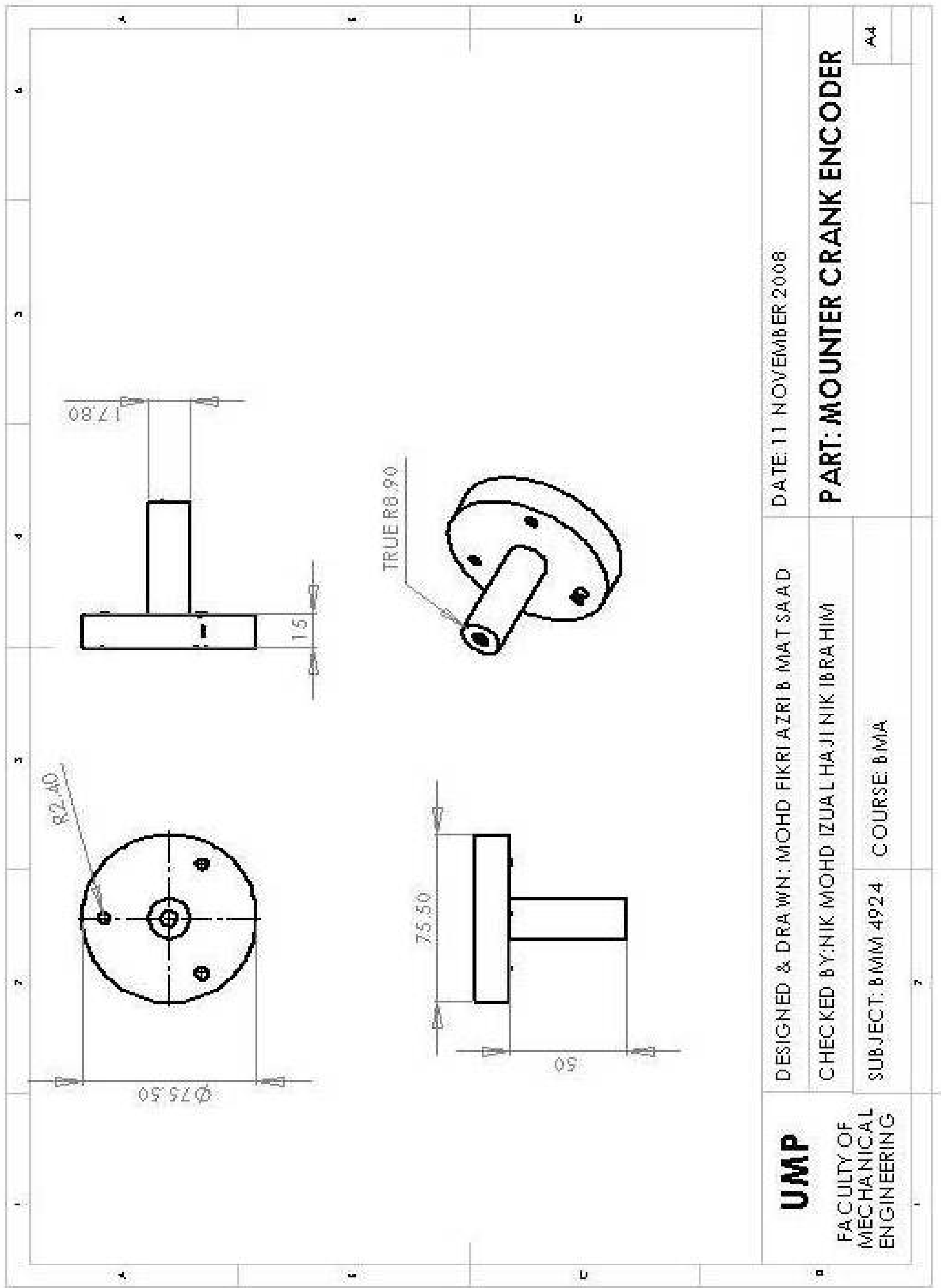
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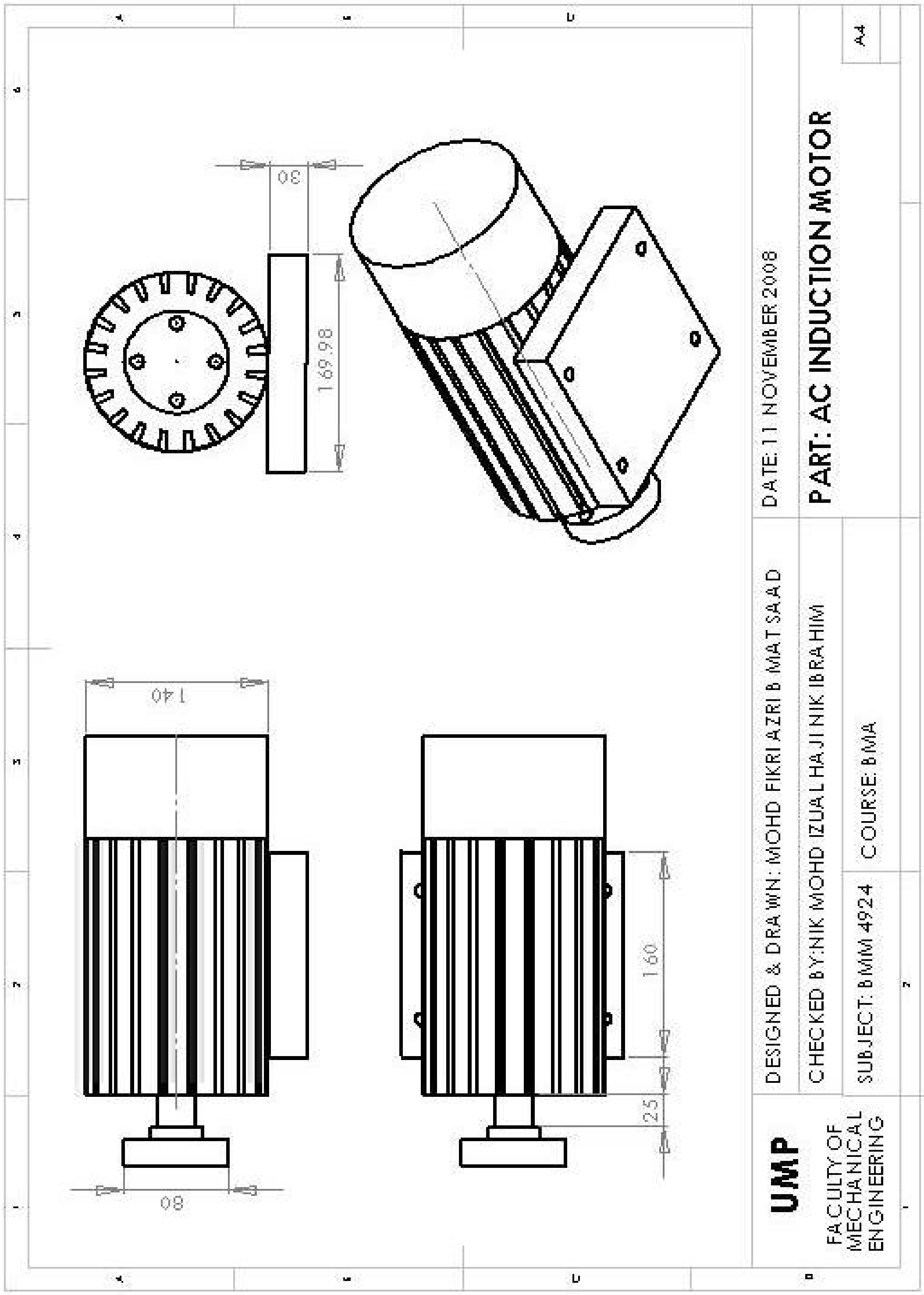
APPENDIX E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FACULTY OF
MECHANICAL
ENGINEERING