MOTORED TEST RIG DESIGN AND FABRICATION FOR SMALL ENGINE TESTING

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ABSTRACT

Performance of a two-stroke engine is largely dependant on scavenging and trapping efficiency of a designed cylinder and port geometry. A motored test rig built specifically for high speed application is designed for 2-stroke spark ignition engine to allow further study and have better understanding of flow mechanism of the engine at high speed condition which will influence trapping and scavenging efficiency. A new concept and design is developed. Current available test rig in University Malaysia Pahang is limited to a low speed range of maximum of 1480rpm which is the main constraint to further experiment and understanding. A rigid designed test rig to allow assembly of small two-stroke engine, gearbox and induction motor and amplify induction motor rotating speed to provide wide RPM output using gearbox to provide a predetermined condition of operating two-stroke cycle engine to allow data acquisition on condition boundary for CFD simulation and experimental data. This new design of motored test rig will have the capability of testing engine at high speed by assembling a gearbox to multiply the speed of driving electric motor shaft of 1480 rpm into transmission input shaft to a maximum speed over 6000rpm at the transmission output shaft. Under motored condition, pressure transducer is applied and flush mounted at inlet port, scavenge port and cylinder. A crank encoder is used to define the condition to each crank angle of a rotation. As a result, data can be collected over a broader engine speed from data acquisition computer.

ABSTRAK

Keupayaan sesebuah enjin dua lejang amat bergantung kepada kecekapan "scavenging" dan "trapping" sesebuah design geometri port dan silinder. Sebuah radas menguji yang ditujah motor dibuat khas untuk menguji kecekapan yang dinyatakan sebuah enjin dua lejang nyalaan pencucuh dalam aplikasi keadaan kelajuan tinggi untuk membenarkan kajian yang lebih teliti untuk kefahaman yang lanjut tentang mekanisme pengaliran udaran pada kelajuan tinggi dimana dipercayai akan mempengaruhi kecekapan "scavenging" dan "trapping". Satu konsep dan design radas menguji dibina dan diperkembangkan. Radas yang sedia ada di Universiti Malaysia Pahang terhad kepada kelajuan yang rendah iaitu kelajuan maksimum 1480 putaran seminit batasan utama untuk kajian dan kefahaman lanjut. Radas yang dibina mempunyai ciri seperti kukuh untuk proses pemasangan komponen-komponen seperti enjin diuji, motor elektrik, kotak gear dan kelajuan putaran elektrik motor ditambah dengan menggunakan kotak gear untuk kelajuan putaran yang lebar untuk menyediakan keadaan yang ditentukan lebih awal untuk operasi kitar enjin dua lejang untuk proses memperolehi data untuk simulasi CFD dan data eksperimen. Radas menguji ini mempunyai keupayaan untuk menguji enjin pada kelajuan putaran yang tinggi dengan menggunakan kotak gear untuk menambahkan kelajuan yang dikeluarkan motor elektrik kepada kelajuan maksimum 6000 putaran seminit. Dalam keadaan yang dikilas, transducer tekanan dipasang pada bukaan penyalur, bukaan "scavenge" dan dalam silinder. Encoder engkol digunakan untuk menentukan keadaan setiap darjah putaran engkol. Sebagai keputusan, data boleh diperolehi dari berbagai kelajuan melalui komputer pencatat data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATION

DAQ	Data Acquisition System
LDV	Laser Doppler Velocimetri
TDC	Top Dead Center
BDC	Bottom Dead Center
SMAW	Shielded Metal Arc Welding
MIG	Metal Inert Gas
AC	Alternate Current
IMEP	Internal Mean Effective Pressure

CHAPTER 1

INTRODUCTION

1.1 Introduction Two-Stroke Cycle

The two stroke cycle is not new concept where automotive or power generation engines developed before Nicolaus Otto who invented the four stroke cycle engine in 1876 operated on a two-stoke cycle [Heywood, 1988]. Today, the two-stroke engine is a refined power unit that offers high performance while being compact, simple and lightweight.

The cycle begins by compression stroke which starts by closing the inlet and exhaust ports, and then compressed the cylinder contents and draws fresh charge into the crankcase. As the piston approaches top center, combustion is initiated either by spark ignition or compression ignition. The following stroke known as power stroke or expansion stroke, which starts with the piston at top center and ends at bottom center as the high temperature, high-pressure, gases push the piston down until piston approaches bottom center when first the exhaust ports and then the intake ports are uncovered. Most of the burnt gases exit the cylinder in an exhaust blowdown process. When the transfer port are uncovered, the fresh charge which has been compressed in the crankcase flows into the cylinder to start another cycle.

One power stroke per revolution. Doubling the number of power strokes per unit time relative to the four-stroke cycle increases the power output per unit displaced volume. It does not however increase by a factor of 2. The outputs of two-stroke engines range from only 20% to 60% above those of equivalent-size four-stroke units (Blair, 1996). This lower increase in practice is a result of the poorer than ideal charging efficiency that is incomplete filling of the cylinder volume with fresh air.

1.2 Background of the Project

The flow processes of intake, compression, and exhaust of two stroke engine are all conducted in an unsteady manner (Blair, 1996). A flow is defined unsteady gas flow is where pressure, temperature and gas particle is a pipe or duct varies with time constant (Blair, 1996). As gas flow motions in a two-stroke engine directly control the performance characteristic of the engine, designers are required to understand the flow mechanism thoroughly of an engine after designing.

A motored test rig specifically for high speed application is to be design for 2-stroke spark ignition engine to allow us to further study and have better understanding of flow mechanism of the engine at high speed condition. Current available test rig in University Malaysia Pahang is limited to a low speed range of maximum of 1480 rpm which is the main constraint to further experiment and understanding. This new design of motored test rig will have the capability of testing engine at high speed by assembling a transmission to multiply the speed of driving electric motor shaft of 1480 rpm into transmission input shaft to a maximum speed over 6000 rpm at the transmission output shaft. As a result, data can be collected over a broader engine speed from data acquisition computer.

The design of the motored test rig should be compact and applicable on various 2-stroke engine designs and made of strong and light weight material like alloyed steel. The setup of the motored test rig should be easy and requires as little tool as possible. Each component will be fitted and assembled as rigid as possible as juddering and severe vibration maybe cause component to loosen. It will be dangerous if a component got lose during the experiment is carried out in high speed.

1.3 Problem Statement

Inherent in the two-stroke cycle is the process of scavenging the burned gases from the engine cylinder with fresh charge. This gas exchange process has several consequences. Charging losses are inevitable. Under normal operating conditions in a typical two-stroke engine, about 20% of the fresh charge that enters the cylinder is lost due to short-circuiting to the exhaust. The importance and complexity of the gas exchange process in two-stroke engines should already be apparent. There is the obvious complexity of the in-cylinder flow as the fresh charge displaces and also mixes with the burned gases, and partially short-circuits the cylinder by flowing directly into the exhaust. In addition, a reverse flow of the cylinder charge through the intake manifold occurs at low engine speed and a reverse flow of cylinder charge through the intake manifold occurs at high engine speed. These flows are partly responsible for the deterioration of the cylinder charging process at off-design engine speeds which in turn results in fall off in torque.

1.4 Objectives

Produce a rigid designed test rig to allow assembly of small two-stroke engine, gearbox and induction motor and amplify induction motor rotating speed to provide wide RPM output using gearbox to provide a predetermined condition of operating two-stroke cycle engine to allow data acquisition on condition boundary for CFD simulation and experimental data.

1.5 Scopes

The test-rig is designed using engineering software like SolidWork to draw concept designs for conceptualization process and dimensions of finalized concepts to provide complete technical drawing. The finalized concept with technical drawing is fabricated using industrial machine and engineering tools.

1.6 Project Organization

1.6.1 Chapter 2 - Literature Review

Initial process of this project started with literature study of present test-rig both for motored and firing testing to acquire better understanding of the importance and function of engine test-rig. Each special component or design of the studied test-rigs is listed for future use.

1.6.2 Chapter 3 - Methodology

The following process is determine the objective of the project and motored test-rig. Required component for the test-rig is chosen based on the objective. Each dimension of the component is defined using measuring instrument for determining the dimension of fabricated part (main frame) to allow is component to assemble together.

1.6.3 Chapter 4 - Result and Discussion

A new test rig concept and design built to collect pressure data via pressure transducer placed on the inlet port, scavenge port, and cylinder. Crank encoder connected to crankshaft to collect crank angle of the engine. Greatest challenge faced in this process was shaft misalignment and was successfully overcome.

1.6.4 Chapter 5 - Conclusion and Recommendations

A new concept and design of test rig was built based on dynamic model test of experimental methods for quantifying scavenging process. An engine testing is recommended to study engine flow characteristic and collect boundary condition data can be carried out for CFD simulation later. This data will allow further investigation of two-stroke engine scavenging characteristic to improve exhaust emission and fuel consumption.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will provide detail description of literature review done regarding the project title of motored test-rig design and fabrication for small engine testing. In this literature review, it started with the functions and fundamentals of internal combustion engine and also the variant. Definition of internal combust is defined in the first topic. In the following topic, the popular four stroke cycle or more commonly known as Otto cycle is briefly discussed along with basic understanding of the four-stroke engine operation together with innovation of Otto cycle is the better designed 2-stroke engine is discussed in detail as the test-rig is targeted to cater of this kind of engine. Some study on experimental method of quantifying scavenging process revealed categories of tests that had been done to collect valuable data. Final topic in this chapter is mostly about different types of test setup that maybe relevant topic the project title.

2.2 Introduction to Internal Combustion Engine

Generally, combustion engines are a device that converts chemical energy contained in the fuel to mechanical power. There are two types of combustion engine which are external combustion engine and internal combustion engine in which internal combustion engines are distinct from external combustion engines where energy is released by burning or oxidizing the fuel inside the engine either by spark ignition or compression ignition. The fuel-air mixture before combustion and the burned products after combustion are the actual working fluids. The work transfers which provide the desired power output occur directly between these working fluids and the mechanical components of the engine. However, the gas turbine is also by this definition is an internal combustion engine. Conventionally, the term is used for spark ignition and compression ignition engines. The operating principles of gas turbines are fundamentally different, and they are not discussed.

According to unpublished French patent issued in 1862 to Alphonse Beau de Rochas, maximum efficiency in an internal combustion engine could be achieved with combination o largest possible cylinder volume with minimum boundary surface, greatest possible working speed, greatest possible expansion ratio and greatest possible pressure at the beginning of expansion (Heywood, 1988). The first two conditions hold heat losses form the charge to a minimum, the third condition recognizes that the greater the expansion of the post combustion gases, the greater the work extracted and the fourth condition recognizes that higher initial pressures make greater expansion possible and give higher pressures throughout the process both resulting greater work transfer.

2.2.1 Otto Engine – Four Stroke Cycle

The majority of reciprocating engines operate on what is known as the four-stroke cycle often called the Otto cycle after its inventor Nicolaus Otto who built the first engine operating on these principles in 1876 (Heywood, 1988). Each cylinder requires four strokes of its piston – two revolutions of the crankshaft to complete the sequence of the events which produces one power stroke. The sequence of events required to produce a power stroke start with the intake stroke followed by compression stroke, power stroke and finally exhaust stroke. An intake stroke, which starts with the piston at top center and ends with the piston at bottom center draws fresh charge into the cylinder. To increase the mass inducted, the inlet valve opens shortly before the stroke starts and closes after it ends.

A compression stroke takes place when both intake and exhaust valve closed and the mixture inside the cylinder is compressed to a small fraction of its initial volume. Toward the end of the compression stroke, combustion is initiated and the cylinder pressure rises rapidly. A power stroke or expansion stroke, which starts with the piston at top center and ends at bottom center as the high temperature, high pressure, gases push the piston down and force the crank to rotate. About five times as much work is done on the piston during the power stroke as the piston had to do during compression. As the piston approaches bottom center, the exhaust valve opens to initiate the exhaust process and drop the cylinder pressure to close to the exhaust pressure. An exhaust stroke where the remaining burned gases exit the cylinder because the cylinder pressure maybe substantially higher than the exhaust pressure and as they are swept out by the piston as it moves toward top center. The exhaust valve opens as the piston approaches top center and closes just after top center and the cycles continue.

The four-stroke cycles requires two crankshaft revolution of each cylinder for each power stroke. To obtain a higher power output from a given engine size, and a simpler valve design, the two-stroke cycle was developed.

2.2.2 Two-Stroke Engine

Further development followed fast once the full impact of what Otto had achieved became apparent. By 1880s several engineers (e.g. Dugald Clerk, 1854-1913, and James Robson, 1833-1913, in England and Karl Benz, 1844-1929, in Germany) had successfully developed two-stroke internal combustion engines where the exhaust stroke and intake processes occur during the end of the power stroke and the beginning of the compression stroke (Heywood, 1988).

As the two-stroke cycle lacks separate intake and exhaust strokes, a scavenging pump is required to drive the fresh charge into the cylinder. In one of the simples and most frequently used types of two-stroke engine designs, the bottom surface of the piston in conjunction with that portion of the crankcase beneath each cylinder is used as the scavenging pump.

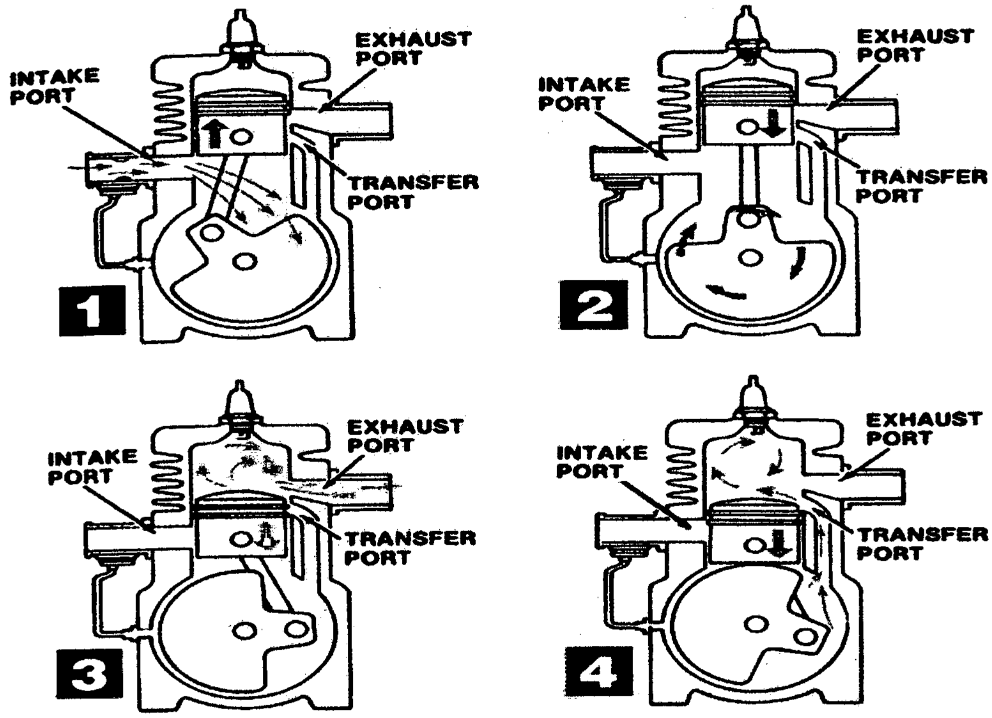

Figure 2.1: Two-stroke cycle event (Dave Mann, 2000)

The cycle begins while the piston is traveling upward toward the top center crank position, and the crankcase intake port is uncovered by the piston. Fresh charge enters into the crankcase through the intake manifold while the charge within the cylinder continues to be compressed by the upper part of the piston. The charge is then ignited either by and electrical discharge in a spark-ignition engine or by a spontaneous ignition process in diesel, combustion occurs and the burned gases in the cylinder expand as the piston travels toward bottom center. At the same time, as the crankcase volume decreases and the intake port is still open, some of the fresh charge may escape to the atmosphere through the intake port is still open, some of the fresh charge may escape to the atmosphere through the intake manifold in a reverse flow. Approximately 60° after top center, the inlet port closes and the fresh mixture in the crankcase is then compressed (Sher, 1999). The in-cylinder gas exchange process begins as the exhaust port is opened. As the piston continues its downward travel, it then opens scavenge or transfer ports. When both scavenge or transfer port and exhaust ports are open, the cylinder is subjected to a pressure gradient that simultaneously governs the inflow and outflow streams through the exhaust port. During this period known as scavenging period, the compressed fresh charge in the crankcase flows through the transfer ducts into the cylinder and scavenges the burned combustion products out of the cylinder through the exhaust port. The ports and the projection on the piston are shaped so that most of the fresh charge will sweep up to the top of the cylinder before flowing to the exhaust port. This is done to scavenge the combustion products more completely from the upper part of the cylinder and prevent significant amounts of the fresh charge from flowing directly to the exhaust port which as process called short-circuiting. In the second half of this period, the piston travels upward, the crankcase volume increases and a reverse flow from the cylinder to the crankcase through the scavenge ports may occur depending on the charging pressure and engine speed. The gas exchange process is completed when the piston covers up and closes the exhaust port.

An alternative using crankcase to compress the fresh charge prior to scavenging is to employ an external pump. A positive displacement Roots blower can be used, or a centrifugal compressor, driven from the crankshaft. In larger two-stroke engines a flower and a turbocharger can be combined together. The crankshaft driven blower provides compression for starting, and at lower speed while at higher speeds, the turbocharger provides higher air flow rates and hence higher power for a given size engine.

The most efficient gas exchange process will completely replace the products of combustion by fresh charge, at charge pressure and temperature without wasting any fresh charge through the exhaust. In practice, the gas exchange process is from this perfect displacement process although part of the fresh charge does displace combustion products without mixing or loss, another part mixes with the combustion products and other portions short-circuit directly to the exhaust port. The success of the scavenging process is a function not only of the geometry of the cylinder and port assembly, but also a factors such as how the fresh charge is introduced into the cylinder, engine speed, engine load, and atmospheric condition.

2.3 Experimental Methods For Quantifying Scavenging Process

The performance of a two-stroke engine is strongly dependant on how well the burnt gases are scavenged from the cylinder volume and replaced with fresh charge which is on the efficiency of the scavenging process and on the amount of fresh charge trapped inside the cylinder at the end of the process (Sher, 1999). For the same pumping power input, a cylinder that is better scavenged will produce a higher engine brake power. Improved scavenging will minimize losses of fresh charge to the exhaust port through short-circuiting and therefore in engines with premixed charge will reduce fuel consumption and hydrocarbon emissions. Lower fuel consumption at low engine load can also be achieved with a well-controlled scavenging process, often with appropriate stratification of the fresh charge within the cylinder to facilitate good combustion under lean and/or high residual gas operating conditions.

The characteristics of the scavenging process, that is the scavenging flow details, its overall efficiency, and the distribution of the charge retained in the cylinder at the end of the process, depend very much on the operating condition of the engine. Important parameters are the engine speed, engine load, and ambient conditions. For example, the typical convex shape of the torque versus engine-speed curve is often attributed to the sensitivity of the scavenging efficiency to engine speed. Also, the scavenging flow behavior in two-stroke engine employing a Schnurle-type scavenging system, is strongly dependant on ambient conditions, which limits their suitability for high-altitude applications.

Therefore, it is important for the engine designer to obtain reliable information about the engine's scavenging process over a wide range of operating conditions. Due to its complexity, the scavenging flow behaviours cannot be accurately predicted. So experimental measurements is although difficult to obtain, are essential to engine development and design. As there is no direct method for determining the mass of fresh charge trapped inside the cylinder at the commencement of the compression process in a firing engine, several indirect methods have been developed. These may be classified into two main categories: measurements in motored engines and measurements in fired engines.

2.3.1 Measurement in Motored Engines

With motored engine tests it is presumed that the scavenging characteristics are only weakly dependant on the combustion process (Sher, 1999). The engine itself, or a model of the engine is driven by an external motor and the scavenging process is then analyzed. 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. Static model test, in which the cylinder is subjected to a steady air flow through it ports while the piston is locked at bottom center are also used.

2.3.1.1 Static Model Test

Static or steady flow model tests are mainly used to study the flow direction and distribution of the entering fresh charge, without introducing the effects of the moving piston and the unsteady nature of the process on the scavenging characteristic. Jante found that scavenging ports can be designed to give an efficient scavenging process using a test on the engine with the cylinder head removed (Sher, 1999). Jante propose that the fresh charge be introduced to the cylinder as a steady flow and that the velocity profile of the scavenging flow be measured just above the open cylinder. He argues that to minimize port short circuiting, the upward flow from the scavenge port toward that cylinder head should be concentrated on the wall opposite the exhaust port. A zero velocity interface between upward and downward streams should be located about halfway across the cylinder or slightly farther from the exhaust side. The area of the interface available for turbulent mixing between the two streams should be minimized if the zero velocity contour appears on the diagram as a straight line perpendicular to the plane of geometrical symmetry.

Although the coefficient of discharge of the scavenge port as well as the inclination angle of the incoming charge depend on piston speed, piston position, and pressure difference across the cylinder, steady flow model have been found to be useful indicator of the effect of pressure ratio across the cylinder on the airflow rate though the cylinder. Also, by comparing the profile of the axial velocity component at two distinct cross sections of the cylinder, steady flow models have also found valuable for estimating the fresh charge losses to the exhaust port (short-circuiting)in loop and cross scavenging engines.

Steady flow methods are also a useful tool for visualizing key features of the scavenging flow. An impression of the flow inside the cylinder with a particular design of ports (and piston) maybe obtained by using simple flow visualization technique. Although these steady flow engine and model test have been found useful by many engine manufacturers as a first step in engine port geometry design, the conclusion drawn form such test should be care fully examined for their applicability to real engines for the following reasons (Sher, 1999):

1) The phenomena associated with scavenging process are unsteady and can only be partially simulated by a steady flow process.
2) In the engine, the movement of the piston and the blowdown process do affect various stages of the flow field inside the cylinder.
3) The velocity and the inclination angle of the incoming charge depend on the piston speed, the piston position, and the pressure difference across the cylinder that may vary with time.

2.3.1.2 Dynamic Model Test

Dynamic model tests are mainly used to investigate possible ways of modifying a particular port geometry to improve its scavenging characteristics (Sher, 1999). With this approach, the engine itself or a model of engine is driven by an external motor, while the scavenging characteristics are evaluated by sampling, visualizing or other measurement techniques. The experimental apparatus is usually constructed so it provides an inexpensive means to obtain valuable design information relative to the expense of a full prototype.

To obtain useful conclusions form an experimental simulation, the experimental apparatus should be designed so that the proper relationships between