DEVELOPMENT OF VARIABLE VALVE TIMING MECHANISM FOR COMPRESSED AIR ENGINE

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UNIVERSITI SAINS MALAYSIA

2019

DEVELOPMENT OF VARIABLE VALVE TIMING MECHANISM FOR COMPRESSED AIR ENGINE

by

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Thesis submitted in fulfillment of the
requirements for the
Master of Science

June 2019

ACKNOWLEDGEMENT

bismi-llahi ar-rahman ar-rahim

(Dengan nama Allah, maha pemurah, maha penyayang)

(In the name of Allah, the most gracious, the most merciful)

assalamu 'alaikum

Firstly, I would like to express my utmost gratitude to my supervisor, Professor Dr. Hj. Zainal Alimuddin b. Zainal Alauddin (USM) for his priceless advice, guidance, motivation and patience, while doing this research project.

I would like to thank Majlis Amanah Rakyat (MARA), Kementerian Pendidikan Tinggi (MyBrain15), Kumpulan Wang Simpanan Pekerja (KWSP) and Professor Dr. Hj. Zainal Alimuddin b. Zainal Alauddin (USM) for their financial assistances in term of scholarship and loans. Thank you so much in making the thesis successfully.

I would like to thank Mr. M.Zainudin, Mr. Azren, Mr. Wadi, Mr. M.Shahril, Mr. Haszreeq, Mr. M.Shukor, Mr. Norsham, Mr. Rozdin, Mr. M.Nasir and Mr. M.Nizar from UniKL MSI, for their technologies expertise, Mr. Saharul, Mr. M.Riduan, Mr. Zainal, Dr. Shahril, Dr. Rahim, Dr M. Sazali, Dr. Rusli, from UniKL MSI, for their theoretical expertise. Mr. Azman for his technical support and all the others from Biomass and Bio-energy Lab, School of Mechanical, USM, for their assistant and all UniKL MSI staff that support during the period of this study are gratefully acknowledged.

Finally, I would like to express my truthful thanks to my parents, Tuan Hj. Ahmad bin Hj. Osman and Puan Hjh. Norishah binti Mat Thani for their love and support and to my beloved daughter, Nur Afrina binti Fathul Hazrimy for loving, understanding, praying and patience during the years.…

assalamu 'alaikum and Thank you

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LIST OF ABBREVIATIONS

A	Area
ABDC	After Bottom Dead Center
acc.	Accuracy
ATDC	After Top Dead Center
BBDC	Before Bottom Dead Center
BDC	Bottom Dead Center
BP	Brake Power
BTDC	Before Top Dead Center
CA	Compressed Air
CAE	Compressed Air Engine
CAV	Compressed Air Vehicle
cc	Cubic Centimeter
cm^3	Centimeter Cubic
CNC	Computer Numerical Control
dm^3	Decimeter cubic
dm^3 / min	Decimeter cubic / minute
DOE	Design of Experiment
Eq.	Equation
et al.	“and others”
etc	et cetera (and other similar things)
F	Force
FMS	Flexible Manufacturing System
FRL	Filter, Regulator and Lubricator
g / HP	gram / horsepower / hour
hour	
gpm	Gallon per minute
hp	Horsepower
Hz	Hertz
ICE	Internal Combustion Engine
IcEo	Inlet valve close Exhaust valve open
IDE	Integrated Development Environment

IoEc	Inlet valve open Exhaust valve close
kg	Kilogram
kgfm	Kilogram force per meter
kHz	Kilohertz
kmh	kilometer / hour
Kv	factor value
kW	Kilowatt
kWh	kilo watt / hour
L	Liter
LED	Light Emitting Diode
m^3 / min	meter cube / minute
ln	natural logarithm
m^3/h	Meter cubic / hour
m^3/s	Meter cubic / second
MJ	mega joule
MJ / kg	Mega joule / kilogram
MJ / L	Mega Joule / Liter
mm	Millimeter
ms	Millisecond
N	Speed (shaft)
Nm	Newton Meter
p	Pressure
P	Power
Pa	Pascal
p_a	ambient pressure
p_{abs}	absolute pressure
P_e	expansion power
psi	Pound per square inch
P_t	transmission power
Q	Flow rate
RPM	Revolution per minute
rps	Revolution per second
T	Torque
TCI	Transistor Control Ignition

TDC	Top Dead Center
VA	Volt Ampere
VA / W	Volt Ampere / Watt
W	Watt
η	Efficiency

PEMBANGUNAN PERANTI PEMASAAN INJAP BOLEH LARAS UNTUK ENJIN UDARA TERMAMPAT

ABSTRAK

Enjin udara termampat (CAE) dibahagikan kepada dua jenis. Jenis pertama ialah CAE direka untuk kenderaan mudah alih dan jenis kedua adalah menyalurakan udara termampat ke dalam Enjin Palam Pencucuh dan kebanyakan penyelidikan menumpukan pada jenis kedua. Penyelidik Penyaluran CAE mengunakan aci sesondol jenis lobus tetap seperti pada enjin palam pencucuk. Ini akan menjadikan sudut pemisahan antara injap masuk terbuka dan injap ekzos tertutup tetap dan di antara injap masuk tertutup dan injap ekzos terbuka tetap. Tujuan tesis ini adalah untuk merekabentuk dan membangunkan CAE yang menggunakan pemasaan injap masuk dan dan keluar pada enjin udara termampat untuk mengenal pasti masa dan tempoh injap terbaik. Ini dilakukan dengan mengawal sudut yang berbeza bagi masa injap untuk masuk dan keluar udara termampat menggunakan injap elektronik. Udara termampat dimasukkan ke dalam CAE dengan tekanan tertentu. Kekuatan brek digunakan perlahan-lahan dengan menggunakan Brek Prony. Tetapan susunan berbeza tekanan, sudut pembukaan dan penutup injap masuk dan keluar telah digunakan untuk mencari prestasi CAE. Penyelidikan bermula dari Pusat Mati Aatas (PMA) untuk pembukaan injap masuk, dan menutup di Pusat Mati Bawah (PMB) dan injap eksos akan bermula di PMB untuk pembukaan dan PMA untuk ditutup. Kuasa brek, kelajuan enjin, dan kecekapan, pada tetapan sudut injap dicatat. Tetapan sudut injap adalah dari 10 ° selepas PMA (SPMA) hingga 25 ° SPMA untuk injap masuk dan 140 ° SPMA ke PMB, untuk injap eksos dengan selangan 5 °. Penyelidikan yang menggunakan gabungan tetapan injap ini dilakukan 3 kali pada setiap keadaan. Penyelidikan CAE ini pada penetapan sudut injap pemboleh ubah membuat kaedah pemasangan yang digunakan untuk mengkaji tetapan sudut yang berlainan untuk masuk dan keluar untuk udara termampat pada CAE. Hasil terbaik dicapai pada 10 ° SPMA untuk pembukaan dan penutupan pada 170 ° SPMA untuk pembukaan injap masuk dan pembukaan lubang yang mempunyai kecekapan sebanyak 24.58 %. Penentuan tekanan untuk eksperimen ini adalah dari 1 bar hingga 3 bar dengan selang 0.5 bar.

DEVELOPMENT OF VARIABLE VALVE TIMING MECHANISM FOR COMPRESSED AIR ENGINE

ABSTRACT

Compressed air engine (CAE) is divided into two types. First type is the fabricated CAE for mobile vehicle and the second type is the retrofitting of compressed air into Spark Ignition Engine and most researches are concentrating on the second type. Retrofit CAE researches use a fixed camshaft lobe as in spark ignition engine. This will make the separation angle between inlet valves open and exhaust valve open fixed and between inlet valves close and exhaust valve close fixed. The purpose of this thesis is to design and develop a CAE that uses an independent valve timing and duration setting of inlet and outlet valves of a compressed air engine in order to identify the best valve timing and duration. This was done by controlling the different angles of valve timing for inlet and outlet compressed air using solenoid valves. Compressed air was fed into the CAE with a certain pressure. The brake power was applied slowly by using a Prony Brake. The different configurations settings of pressure, opening and closing angle of inlet and outlet valves were used in order to find the performance of the CAE. The experiments start from TDC for valve inlet opening, and closing at BDC and valve outlet will start at BDC for opening and TDC for closing. The brake power, the engine speed, and efficiency, at the valve angles setting were recorded. The valve angles setting were from 10° ATDC to 25° ATDC for inlet valve and 140° ATDC to BCD, for outlet valve with an interval of 5° interval. The experiment used a combination of these valve setting were performed 3 times at every setting. This CAE research on variable valve angle setting makes the methodology applicable for studying different angle setting for inlet and outlet of compressed air in the CAE. The best result achieved were at 10° ATDC for inlet opening and outlet closing and 170° ATDC for inlet closing and outlet opening which have an efficiency of 24.58 %. The pressures setting for this experiment were from 1 bar to 3 bar with an interval of 0.5 bar.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

In the energy studies, energy cannot be destroyed or created. It is a property of matters that can transform into other forms. Energy can be divided into two categories which are renewable and non-renewable resources. The examples of renewable resources are solar, biomass, wind, wave, hydro and tidal. While, for non-renewable resources the examples are: fossil fuel based oil, natural gas and coal. However, fossil fuel resources are limited due to the world's energy market relying heavily on them as sources of energy to power automobile, factory and power generation station.

1.2 Compressed Air

Atmospheric pressure is the state where the pressure value of regular air is measured. It is measured about 101,325 Pa at sea level. If the air was compressed by natural effect, the air will try to return to its initial state. The effect of the air to return to its initial state or decompression will produce energy. This energy is being used to drive the compressed air devices (Croser & Ebel, 2002).

Compressed air is categorized as one of the energy resources that can be directly converted into works. The energy of compressed air can do works without having to do any energy conversion. Compressed air devices are known as a high

power work application as they are known to be a power to weight or volume ratio work application (Croser & Ebel, 2002).

Between electrical and compressed air devices, response time of control is favor to electrical but between hydraulic, compressed air is much better. Compressed air has a wide range of applications because of its acceptable response time and fast speed makes it a favorable choice in many applications. When there's an option on selecting an energy storage system, compressed air has an advantage because of its prices, effectiveness and safety (Croser & Ebel, 2002).

Compressed air produces more consistent power conversion seamlessly, in contrast to equipment that involves changing power conditions for converting power. This is a built-in utility, so it has more control over other utilities. In addition, the compressed air are safe from electric shock risk and fire danger due to compressed air using solely air as compressed air is non-toxic and harmless to the environment.

1.2.1 Compressed Air Usage

Compressed air power can be used for different types of devices. It can be used to move a piston such as in a jackhammer, to open a small air turbine to rotate a shaft, as in an auger for the dentist, or it can be placed through the tip of a nozzle to create a high velocity jet, as in a paint sprayer.

For power tool application, pneumatic has been a choice in doing medium to heavy application. Jackhammers, nut runners, nail guns, grinder even a heavy vehicle use pneumatic in their braking system. These pneumatic tools use compressed air

that has a power to create force and torque to drive these machine and devices. A pneumatic tool has been designed in many forms, linear tooling devices uses in cylinder and also rotary tooling devices uses in air motor. Pneumatic linear tooling devices usually uses in presses or stamping, clamping devices for lathe and milling machines, automatic feeder uses in CNC tooling turret changer system and also the linear direct power for jackhammer uses for groundbreaking devices (Raghavan, 2014). Pneumatic rotary tooling devices usually uses in impact wrenches (Lucia et al., 2014), brake control for precision stopping a heavy - duty vehicles (B, et al., 2007) pneumatic gear shifting mechanism (Kumar et al., 2014), and also uses as a starter motor for diesel engine (Beyene et al., 1998).

1.2.2 Advantage of Air Power

There are many type of power energy; electrical power, hydraulic power and compressed air power. What does pneumatic or compressed air can offer that has the advantages that can overcomes others energy power? What does pneumatic power have that others do not have? Subchapter 1.2.3 and 1.2.4 explain the differences, advantages and disadvantages between these three power energy.

1.2.3 Compressed Air and Electric Power

1. **Cost**: The design of compressed air devices are simple compare to electrical devices, the design uses minimum parts that move in the devices. With minimum moving part it will lead to simple process operation and needed less maintenance services (Gonzalez, 2015).

2. **Flexibility**: In compressed air application, the distribution of air supply is by piping. Every compressed air station whether low pressure or high pressure of application are supply by the same pipe line. Other than electrical where single phase and three phases must have a separate supply line (Croser & Ebel, 2002).

3. **Maintenance**: compressed air systems are complete with lubrication in that being add to the compressed air itself. It is self lubricating makes the compressed air system component has a longer maintenance service time compare to electrical system. For electrical system, a continuous running of electrical motor will result of overheating the motor, increase wear and tear on the reduction gear. This will increase the maintenance service time to do the replacement (Gonzalez, 2015).

4. **Safety**: With air as the medium, compressed air can be considered to be the safest system. It has no shock hazard or even fire hazard. One of the most advantages is that the compressed air devices always being cooled by the air itself. The devices running cooled throughout the application. The devices can withstand full overload work without damaging the devices (Gonzalez, 2015).

5. **Weight**: The designs for compressed air device are simple. By the simple design, light materials are uses in fabricating the devices. With lightweight material, the working environment that has to move the devices from one place to another is quite easy (Croser & Ebel, 2002).

1.2.4 Compressed Air and Hydraulic Power

1. **Cost**: compressed air devices are cheaper than hydraulic devices (Ponomareva, 2006). Compressed air deal with low pressure compare to hydraulic. With low pressure medium, light weight material components are used. In term of servicing and maintenances, exhaust air in compressed air are vented to atmosphere, rather than piping of outlet oil in hydraulic. This makes pneumatic uses less part in its application than hydraulic. For power distribution, with a single compressor for compressed air supply, a large number of pneumatic stations can be supplied. Hydraulic system uses one pump per stations (Gonzalez, 2015).

2. **Flexibility:** in term of installations, Compressed air system has a simple approach rather than hydraulics; they can easily be changed to suit varies application where some application needed to changed tools frequently. In automation system, where flexible manufacturing system (FMS) prone to changed or expand their operations uses Compressed air as their application system (Croser & Ebel, 2002).

3. **Maintenance**: hydraulic system has a high downtime in maintenance servicing. Compressed air system has much simpler control systems than hydraulic system, with compressed air working area are much cleaner. Due to this, it makes compressed air system a long servicing operation (Croser & Ebel, 2002).

4. **Safety**: Hydraulic fluids are oil base substances. Most of hydraulic fluids are flammable. This is because the fluid itself is an anticorrosion agent. It has a petroleum base properties contain in them. With high pressure or temperature, the fluid can be able to burn or explode. Piping leaking makes a very dangerous for hydraulic system application. Oil leak in hydraulic systems can result a slippery, power failure or even complete system shutdown. Difference from compressed air a device that operates with lower system pressures and if an air leaks happen it will not release any contaminants (Merkel, Schrader & Thomes, 2003).

5. **Weight**: Compressed air has a high power-to-weight ratio and a compressed air tool contributes a lower operator fatigue versus hydraulic tools (Croser & Ebel, 2002).

1.3 Problem Statement

Previous studies on compressed air engine (CAE) focused on the valve timing (Mourya et al., 2014; Al Nur et al., 2012; Shah et al., 2013) which was modified from 4 stroke to 2 stroke in order to make the engine suitable for operating the CAE using 4 stroke internal combustion engine. In order to make CAE engine, the camshaft of 4 stroke engine has to be disable or dismantle from the engine. Pneumatic 2 / 2 way valve are installed in order to control the inlet and outlet of compressed air into the engine. The process of retrofit the CAE will be the inlet process where compressed air will push the engine piston downward. This process is done in the first stroke of the operation. The second stroke will be the outlet process

of the compressed air. The 2 / 2 way valve will control the inlet and outlet process of the CAE.

The inlet and outlet valve control is the crucial part of CAE. The valves control the timing and duration of opening and closing of compressed air that drive the engine piston upward and downward. Previous study controlled the inlet of compressed air into CAE. The outlet of CAE remains fixed to certain crankshaft angle (Kumar 2013; Yu et al., 2014). There is no record or study on inlet and outlet valve timing and duration being controlled at the same time and the CAE performance will be affected by changing the setting of the inlet and outlet valve.

In this work, the controlling of valve timing used a microcontroller (arduino) to control the inlet and outlet valve is used. Photo sensor is uses for sensing the crankshaft angle rather than reed switch that being uses in Kumar et al., (2013) studies or angular displacement sensor in Yu & Cai, (2015) studies. Previously the controller was done by using PLC (Yu & Cai, 2015) and angular displacement sensor. With the microcontroller and photo sensor, the performance of CAE can be identified and can provide more idea on CAE studies.

1.4 Objective

The objectives of this project are;

1. To design and fabricate a CAE prototype with photoelectric sensors which controlled by Arduino controller to vary the inlet and outlet valve timing and duration.

2. To determine the performance of CAE experiment result by comparing different parameters; input pressure, input open and close air timing and outlet open and close air timing into the CAE prototype.

1.5 Scope of the Work

For the CAE prototype, a 4 stroke Single Cylinder spark ignition engine of ICE was used to investigate the characteristic of the experiment result. The parameters that are focused are the input pressure, input flow rate, open and closing times of the input and output valves Some fabrication, modification and testing of the engine have been made to achieve the investigation on the prototype engine.

1.6 Thesis organization

This thesis is divided into five chapters. Chapter 2 provides a technical study review of relevant literatures on CAE previous research and component parts. Chapter 3 provides a detailed account of the materials and method used in this research. Chapter 4 provides the result and discussion for the experiments and Chapter 5 provides the conclusion and suggestion for future.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A study of previous works on CAE is presented in this chapter to provide a background for the present study. The chapter will explain the background of internal combustion engine, and previous study on CAE. The working principle of CAE is similar to the internal combustion engine working principle and most of previous studies on CAE using internal combustion engine process, such as intake expansion and exhaust processes.

2.2 Internal Combustion Engine

The best known engine in the world is the reciprocating ICE. Practically everyone driving an automobile or uses a lawnmower has somehow used or experienced an internal combustion engine. The type of internal combustion engine used the spark ignition to ignite the mixture of air and fuel in the engine. Niklaus Otto discovered this internal combustion engine theoretical cycle and was called the "Otto cycle".

Another discovery of reciprocating engine concept was made by Rudolf Diesel. The engine was for heavy industry application such as lorry, truck and buses. This engine substitutes the steam engine that powered a locomotive. The diesel engines has replaced the steam engine up till today.