ELECTRONIC FUEL INJECTION CONTROLLER FOR NATURAL GAS VEHICLE MOTORCYCLE

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In The Name of Allah SWT the Most Gracious and The Most Merciful

"Evil (sins and disobedience of Allah etc) has appeared on land and sea because of what the hands of men have earned (by oppression and evil deeds, etc), that Allah may take them taste a part of that which they have done, in order that they may return (by repenting to Allah, and begging His Pardon)"

(Al-Quran, Ar-Rum:41)

Alhamdulillah. I praise and glorify be only to **Allah SWT** the Almighty, the Most Beneficent and the Most Merciful, whose blessings and guidance have helped me through my study and my life smoothly. There is no power, no strength save in **Allah SWT** the Highest, the Greatest. Peace and blessing of **Allah SWT** be upon to **Rasulullah Muhammad SAW**, who has given light to all mankinds in the world.

DEDICATION

This thesis is dedicated to:
My Father, H. Drs. Alamsyah Bakar, and my mother Hj. Rosidah thanks for all of their love, lots of cares and happiness

My beloved wife Hj. Yusnita Rahayu, ST.,M.Eng, thanks for your patience, kindness and full support over the entire period of my study.

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ABSTRACT

Smaller vehicles are a major source of both air pollution and congested roads. The use of natural gas is recommended by the United States Federal Clean Air Act Amendments of 1990, because it is environmentally friendlier than petrol engine. Therefore, this thesis presents the design and development of a low cost electronic fuel injection (EFI) for natural gas vehicle (NGV) motorcycle. The design consists of signal conditioning, microcontroller systems and the injector drive circuit. The output of this research is a prototype of EFI which has the capability to control output engine based on the given mapping table. Two types of mapping table are used to generate pulse width and timing injection. The first is injection pulse width corresponding to the rotation per minute (RPM) and manifold absolute pressure (MAP) and the second is RPM corresponding to encoder angle position. Both of these mapping tables are accessed concurrently within a single programming which reduces the use of extra microcontroller and memory. The EFI enables the mixing and combustion with 17.2:1 (by mass) air to fuel ratio (A/F). In injector measurement, the first large voltage of 35 V spike at 1.8 msec corresponds to the reduction in coil current from 4.5 A to 1 A. The pulse width resulted from the theoretical calculation can be used for the engine experiment between 3000 RPM and 8000 RPM. This is due to the air density value taken by the used formula.

ABSTRAK

Kenderaan kecil merupakan punca utama daripada polusi udara dan kepadatan jalan raya. Penggunaan natural gas ianya lebih efisien dan ramah lingkungan berbandingkan pemakaian petrol. Penggunaan natural gas (NG) telah disyorkan oleh *The United States federal Clean Air Act Amendments of 1990*, disebabkan ianya lebih bersahabat dengan lingkungan berbanding pemakaian petrol. Oleh sebab itu, tesis ini membentangkan reka bentuk dan pembangunan *electronic engine controller* pada *kendaraan berbahan bakar gas alam.* Perekaan meliputi *signal conditioning*, sistem mikrokontroler, dan injektor *drive.* Hasil keluaran yang diharapkan ialah sebuah reka bentuk prototaip EFI yang boleh mengontrol keluaran mesin berdasarkan tabel mapping. Terdapat dua macam *mapping*, yang digunakan untuk menghasilkan lebar pulsa dan pewaktuan injeksi. Pertama adalah lebar jalur injeksi berkaitan dengan perputaran setiap menit dan *manifold absolute pressure* (MAP) dan kedua adalah perputaran setiap menit berkaitan dengan posisi sudut encoder. Keduanya ditulis dan dijalankan dalam sebuah program secara bersamaan, sehingga mengurangkan penggunaan mikrokontroler dan memori. EFI memberikan pencampuran dan pembakaran dengan 17.2:1 (dengan jisim) pada perbandingan udara dan bahan api. Pada pengukuran injektor, tegangan keluaran mulai meningkat pada tegangan 35 V dan pada saat 1.8 msec berterusan dengan menurunnya arus di dalam koil daripada 4.5 A sampai 1A. Lebar jalur yang dihasilkan daripada perhitungan teori, boleh digunakan pada percubaan enjin pada kelajuan 3000 RPM sampai 8000 RPM. Ini disebabkan pada pengambilan nilai *air density* oleh rumus yang digunakan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A/F		Air to Fuel
A/D		Analog to Digital
ADC		Analog to Digital Converter
ATDC		After Top Dead Centre
CISC		Complex Instruction Set Computer
CO		Carbon Monoxide
CNG		Compressed Natural Gas
DSP		Digital Signal Processing
EGR	:	Exhaust Gas Recirculation
EEC	:	Electronic Engine Controller
EU		European Union
EFI		Electronic Fuel Injection
EMS		Engine Management System
EVC		Exhaust Valve Closing
EVO		Exhaust Valve Opening
EPROM		Erasable Programmable Read Only Memory
EEPROM		Electrically Erasable Programmable Read Only Memory
FI		Fuel Injection
HC		HidroCarbon
IVC		Intake Valve Closing
IVO		Intake Valve Opening
IAT		Intake Air absolute Temperature
I/O		Input Output
LPG		Liquid Petroleum Gas
LNG		Liquid Natural Gas
MAP		Manifold Absolute Sensor

NG		Natural Gas
NGV		Natural Gas Vehicle
NPN		Negative-Positive-Negative
NV		Non Volatile
PROM		Programmable Read Only Memory
PW		Pulse Width
PWM		Pulse Width Modulation
PCB		Printed Circuit Board
RISC	:	Reduced Instruction Set Computer
ROM		Read Only Memory
RAM	:	Random Access Memory
RPM		Revolution Per Minute
RPS		Revolution Per Second
SMEC	:	Single Module Engine Controller
SBEC	:	Single Board Engine Controller
SLSD		Sea Level on Standard Day
TDC	:	Top Dead Centre

LIST OF SYMBOLS

d_o		Absolute intake density
d_a		Intake air density
D		Engine displacement
F		Fuel
f		Input frequency
f_{MAX}		Maximum frequency
f_{MIN}		Minimum frequency
h_{FE}		Current gain
I		Current
I_c		Collector current
I_B		Base current
L_1		Injector inductance
m_i		Mass of air within the intake manifold
N		Variable
n_V		Volumetric efficiency
p		Intake manifold pressure
P_Q		Power comsumption
p_o		Absolute pressure
R_f	-	Flow rate
R_V		Volume flow rate
R_m		Flow rate of air
R_{fm}		Mass flow rate
R_L		Resistive load
R_S		Sense resistor
R_I		Injector resistance
SFR		Static flow rate

T	-	Temperature
T_o		Absolute temperature
T_i		Intake manifold air temperature
t_{high}		High period
t_{low}		Low period
t		Time
V_i		Volume of the intake manifold
V_{CE}		Voltage between collector and emitter
V_{CC}		Voltage collector
V_H		Sense input hold voltage
V_P		Sense input peak voltage
V_Z		Zener breakdown
V_{BATT}		Battery voltage
ρ_i	-	Pressure in the intake manifold

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The engine was the first major sub system of the vehicle to be turned over from mechanical to electronic control. Engine electronics was introduced in the 1970s for the control of ignition and exhaust gas recirculation (EGR) in gasoline engines [1]. In the 70's, engines relied on mechanically generated signals to ignite the fuel/air mixture.

Since that time, engine electronic controller (EEC) system has developed and changed greatly. In 1977, EEC II was introduced by Delco Remy [1]. It gave accuracy and flexibility and offered other advantages such as a reduced part count and a lower maintenance burden than its mechanical forebears. It was also as a response to the oil crisis and promised marginally better fuel economy.

Electronic controls have significantly improved engine performances relative to mechanical controls. The use of digital electronic control has also enabled this engine to meet the government regulations on exhaust emission and fuel economy by controlling the system accurately with excellent tolerance and flexibility.

EEC III was introduced in 1979 on the Lincoln Continental [2]. The most significant single change for EEC IV, 1982-1985, is the introduction of the diagnostic requirements [3]-[5]. The implementation of these requirements is estimated to have doubled the use of resources, measured in memory usage and processor throughput. The type of microcomputer is significantly different. A complex instruction set computer (CISC) 8 bit micro-computer has given way to a 32 bit reduced instruction set computer (RISC) device [2]. The increasing demand for functions and the legislative requirement have driven the pace of change and have forced changes in the system architecture.

In this thesis, An EEC for controlling the fuel injection is purposed and this is called as electronic fuel injection (EFI) controller. This prototype concerns on fuel injection problem and it consists of two modules such as logic module and power module. The separation is based on its function and signal generated. The logic module consisting of microcontroller and analog to digital converter (A/D) is responsible for signals processing from manifold absolute pressure (MAP) sensor. The power module consisting of Darlington transistor, injection driver and voltage regulator is responsible for producing the fuel injector pulses by regulating the alternator field coil to maintain proper voltage levels.

Basically, this electronic controller design is similar for gasoline, diesel, natural gas (NG), and alcohol powered engines, as well as hybrid-powered engines, a variety of cylinder, and fuel-delivery configurations. Principle of engine controller will be explained more detail in chapter II.

1.2 Research Scope and Objective

The goal of this thesis is to design and develop a low cost EFI for NG motorcycle application. The scope of work includes identifying the subsystem and integrating all subsystems into a complete EFI system. The EFI is measured in terms of input and output signals to meet the parameter requirements, hardware and software. For developing and testing mapping, the EFI prototype will be integrated with NG motorcycle engine and dynamometer to observe and determine its performance in terms of fuel injection problem.

This work offers the promise of an engine control system which is fully adaptive to changes in fuel flame speed caused by variable fuel (NG and gasoline) [6], operating conditions, engine wear, or other factors. The result of this project is expected to be used with more upgraded mechanical system for better system performance. Therefore the control system should be as flexible as possible so that the changes can be done through modifying the software with minimal modification in hardware. Thus the use of microcontroller is the best choice for this control system.

1.3 Research Background

Nowadays electrically-controlled motorcycle, electronic injection motorcycle, dual-fuel motorcycle and electric motorcycle are a hot topic in electronic automotive industry and academic. Their technologies are environmentally friendly, applicable for large and medium cities, low exhaust emission and fuel consumption. Recently, some country develop motorcycles, catering to the needs of the rural areas, which are suitable for poor road conditions with high load carrying capacity, reliable, low price and easy to repair.

The need for higher performance and more stringent emission requirements of engine control are constantly being investigated. Emissions of engine control become more important issue, as the possibility of carbon monoxide (CO) emissions and an increasingly significant proportion of the HC (unburnt hydrocarbons) involved. Emission of CO should meet standard regulation. Smaller vehicles such as auto-rickshaws, motorcycles, motor scooters and mopeds are a major source of both air pollution and congested roads, particularly in urban areas, where vehicle concentration is the greatest. They also contribute to global warming, accounting for a large and growing share of greenhouse gas emissions worldwide [7].

In the European Union (EU), two and three-wheeled motor vehicles are currently believed to be responsible for around 5 – 10% of overall HC and CO emissions, and it is anticipated that this proportion will increase to 15 – 20% by the year 2020 [7], [8]. In some large Asian cities, the situation is already more serious; the high popularity of motorcycles in Taiwan to be responsible for approximately 30% of overall HC and 40% of overall CO emissions [9]. Increased attention is therefore now being paid to reducing exhaust emissions from small vehicles, and one obvious means of achieving such a reduction is to apply EFI technology from the automotive sector [7]. EFI introduces other benefits such as reduced brake specific fuel consumption, increased full-load output and improved drive ability [7], [10].

Currently, NG is being used as fuel in automotive industry. In Malaysia, PROTON car has been converted from gasoline to bi fuel with NG as alternative [6]. There are three major reasons for using NG as transportation fuel [11]. The first reason is the NG has capability to improve the air quality. This is recommended by The United States federal Clean Air Act Amendments of 1990. Others reasons are the NG have economic advantages and improve our environment.

The use of gaseous fuels in internal combustion engines is nearly as old as the engine itself. For fuel and air management, carburetors, mixer, and fuel valves have been used. With liquid fuels, such as gasoline, electronic controls have been used since the late 1970’ [12] as a means of refining exhaust emission control techniques. First applied to carburetors, with analog electronic system, they were quickly replaced by the more reliable and more accurate digital electronic. The same technology is now appearing with fuel air management system for engines fuelled by NG and liquid petroleum gas (LPG) [12].

From previous research [6], natural gas vehicle (NGV) has obtained good performance. Its engine is more efficient and environmentally friendlier than petrol engine that most required after the cities are badly affected by pollution. However, most of the technology is less applicable for small engine such as motorcycle. It is known that people use motorcycle because of its lower cost and easier to handle. Two wheeled vehicles are popular in Malaysia for personalized transport.

The fuel economy and thermal efficiency will be enhanced and the emissions will be reduced observably by using compressed natural gas (CNG). This new fuel system would achieve low exhaust emission and maximize power extraction by utilising a throttle body fuel injection system. As the conventional EFI applied to motorcycles is bulky and costly, its application has been mostly in large motorcycles using multi-cylinder engines [15]. The chemical and physical property variation of NG from mainstream fuels generates the need for modification on existing fuel system employed on the existing mainstream fuel powered engines [16].

Honda has a goal to reduce the total emissions of HC from new vehicles to approximately 1/3 and to further improve the average fuel economy by approximately 30% from 1995 by the year 2005 [15]. To realize the goal, the small motorcycles used in many countries in the world should be improved further for clean exhaust gas and low fuel consumption. Accordingly, they have started development of the PGM-FI system for small motorcycles with engines of 125 cc or smaller including air-cooled engines [15].

The PGM-FI applied digitally controlled throttle body fuel injection (FI) technology to the stylish, Super Cub type "Wave 125i" motorcycle using an air-cooled, 4-stroke, single cylinder 125cc engine in Thailand. The scooter, "Pantheon/Pantheon 150" having a water-cooled 125/150cc engine are equipped this technology with the PGM-FI, in Europe [16].

In the newly developed PGM-FI, in order to apply to small displacement models, it used Honda's techniques to down-size components as well as making maximum use of the FI techniques attained from the large motorcycles. The compact PGM-FI offers new benefits such as the reduction of released environmentally detrimental substances and the improvement of drive ability, and economy [16].

Since 1996, Mitsubishi Electric Corporation has been involved in the development of volume-production of engine management system (EMS) for motorcycles in the reduction of exhaust emissions [17]. In Japan, target values representing significant emission reductions are set in place, to take effect from 2006. When compared with four-wheeled vehicles, motorcycles are particularly worthy of note for their high HC emissions. This is partly because motorcycle engines are required to achieve high-response engine characteristics similar to those of motorcycle racing engines, and there are layout constraints that come from the necessity to fit the engine into the body compactly [14].

1.4 Problem Statement

To ensure clean exhaust gas and high fuel economy, the control of combustion through an accurate fuel supply is a must. This research project therefore aims to design and develop a digital control system for NG motorcycle. The expected output of this research is a prototype of EFI which has capability to control output engine based on given mapping table using circuit, microcontroller and developed software.

The use of microcontroller as an EFI is essential in this system due to its widespread utilization in modern vehicle control system [13]. EFI is as new interface product that provide controller in output engine system such as assisting well the mixing and combustion. The control module consists of subsystem for fuel control to fulfill the basic requirement of an engine combustion process and government regulations in fuel economy and emission at any given speed and load.

The development of the four-stroke NG small engine prototype can be divided into two main stages, the theoretical design and the testing performance. A whole new set of conversion kit including a throttle body injector, EFI, a gas regulator, and a gas tank were developed.

1.5 Thesis Outlines

This thesis is organized into five chapters to completely cover the whole research activities. The following paragraphs describe each of the following chapters.

Chapter 2 provides literature review on the principle of engine controller. It includes the overview of engine management system which is required to reduce the exhaust emission by controlling the amount of fuel injection. It also discusses EFI system design with its overall block diagram, and the study on required parameters with critical comments in designing and testing EFI prototype. Overall EEC and its block diagram are presented as well.

Chapter 3 presents the design and implementation of EFI modules. Hardware design and development is discussed in detail. Engine mapping and lookup table methodology applied in this research are also given. It also presents the flowchart of EFI design.

Chapter 4 presents performance measurements and results. It includes the overview of test bed and its subsystems. Discussion analysis is done for both theoretical and experimental. Chapter 5 highlights the overall conclusion of the thesis. It also provides the recommendation for future study.

1.6 Summary

This is an introductory chapter that defines the literature review, the scope and objective, research background of the thesis and problem statement. The thesis structure is explained and highlighted. In the following chapters, the thesis research work performed is reported.