UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

DEVELOPMENT OF ARDUINO SYSTEM FOR CYLINDER DEACTIVATION STRATEGY IN PERODUA MYVI SXi K3-VE ENGINE

Noor Affandy bin Abas

Master of Science in Mechanical Engineering

2020

DEVELOPMENT OF ARDUINO SYSTEM FOR CYLINDER DEACTIVATION STRATEGY IN PERODUA MYVI SXi K3-VE ENGINE

NOOR AFFANDY BIN ABAS

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this thesis entitled "Development of Arduino System for Cylinder Deactivation Strategy in Perodua Myvi SXi K3-VE Engine" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature	:	....
Name	:	NOOR AFFANDY BIN ABAS
Date	:	06 MAC 2020

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : ……………..

Supervisor Name : PROFESSOR. TS. DR. NOREFFENDY TAMALDIN

Date : 07 Mac 2020

DEDICATION

To my beloved wife and family.

ABSTRACT

Cylinder deactivation (CDA) is one of the fuel efficiency strategy that offer lower fuel consumption and exhaust emissions by allowing the multi-cylinder gasoline engine to run with smaller engine displacements at lower engine loads and speeds. Deactivating engine cylinders is really a challenging task. The cylinder deactivation system (CDS) should not only cut off the fuel injection but also account for the intake air associated with the induction stroke. Therefore, each firing cylinder needs more air by opening the throttle to give higher intake manifold pressures, which reduce the pumping loss of the engine. The objective in this study is to investigate the effect of normal engine problem associated with cylinder deactivation. Then, a development of manual CDA into CDS for fuel and emission improvement will take place and finally their effectiveness in term of fuel and emission will be accessed. A relay-based control system capable of deactivating the individual cylinder was built to investigate the effect on the engine performance and the engine stability at lower displacements. Thus, a controller named CDS using the Arduino microcontroller was designed for controlling cylinder deactivation using the skip fire cycle methodology. With the Arduino system, the engine cylinders were selectively deactivated based on a control strategy and were examined over a driving cycle without being loaded. A cost-effective CDS is implemented without cutting off the intake air by relocating the oxygen sensor at the exhaust runner. A racing-style 4-2-1 exhaust manifold was incorporated to a 1.3-liter, four-cylinder inline K3-VE gasoline engine, to improve engine breathing and performance at lower engine speeds. The significance of this study is the development of a manual CDA into a CDS for a small 1.3 liter four-cylinder inline engine base on the requirement for the UTeM Perodua Eco-Challenge 2013 (PEC2013). The results show that the effect of CDS control strategy are very significant to reduce the pumping losses, thus gives an improvement up to 8.13 percent in the average fuel consumption and CO_2 reduction up to 5.7 percent while HC up to 6.7 percent especially at around 56 Nm torque and 50 percent of the speed during low load operation. The critical improvement of this study is the effectiveness of the developed cost-effective CDS using Arduino platform and an excellent performance of cylinder deactivation in terms of fuel consumption and exhaust emissions. The developed system also allowed UTeM Perodua Eco Challenge 2013 team to win second place in PEC2013 competition with the longest distance travelled of 12.97 km per liter. Therefore, the outcome of this study shows the excellent performance of CDS in improving fuel consumption and emissions for Perodua Myvi K3-VE engine. It also provides some insight on deactivation strategies to design a microcontroller with integration of process signal sensor data and control system. The measurements show the improvements in fuel consumption and exhaust emissions at the expense of minimal engine power loss and vibration which would be beneficial for future engine CDS development.

ABSTRAK

Penyahaktifan silinder (CDA) merupakan salah satu strategi kecekapan bahan bakar yang menawarkan penggunaan bahan api dan pelepasan ekzos yang lebih rendah dengan membenarkan enjin petrol berbilang silinder beroperasi dengan sesaran yang lebih kecil pada beban dan kelajuan enjin yang rendah. Operasi bagi menyahaktifkan silinder amatlah mencabar. Sistem penyahaktifan silinder (CDS) tidak hanya perlu mematikan suntikan bahan api, tetapi juga mengambil kira kemasukan udara berkaitan dengan strok induksi. Oleh itu, setiap silinder penembakan memerlukan lebih banyak udara dengan membuka pendikit untuk memberi tekanan panca rongga yang lebih tinggi bagi mengurangkan kehilangan tenaga kerja enjin. Objektif kajian ini adalah untuk mengkaji kesan masalah enjin normal yang berkaitan dengan silinder penyahaktifan. Kemudian, pembangunan CDA manual menjadi CDS untuk penambahbaikan bahan bakar dan pelepasan dan akhirnya keberkesanannya dari segi bahan bakar dan pelepasan akan diakses. Sistem kawalan berasaskan geganti yang mampu menyahaktifkan silinder individu dibina untuk menyiasat kesan prestasi enjin dan kestabilan enjin pada peralihan yang lebih rendah. Oleh itu, pengawal yang dinamakan CDS menggunakan mikrokontroler Arduino direka untuk mengawal penyahaktif silinder menggunakan metodologi langkau kitaran pembakaran. Dengan sistem Arduino, silinder enjin dipilih secara deaktivasi berdasarkan strategi kawalan dan diperiksa melalui kitaran memandu tanpa beban. CDS yang kos efektif dilaksanakan tanpa memotong pengambilan udara dengan memindahkan sensor oksigen pada pelari ekzos. Sebuah pancarongga ekzos 4-2-1 gaya perlumbaan telah digunakan bagi dalam enjin petrol K3-VE berkuasa 1.3 liter dengan empat silinder selari, untuk meningkatkan pernafasan dan prestasi enjin pada kelajuan enjin rendah. Kepentingan kajian ini adalah pembangunan CDA manual menjadi CDS untuk enjin kecil berkapasiti 1.3 liter dengan empat silinder yang menepati syarat pertandingan Perodua Eco-Challenge 2013 (PEC2013) UTeM. Keputusan menunjukkan bahawa kesan strategi kawalan CDS sangat penting untuk mengurangkan kerugian pengepaman, dan penambahbaikan sehingga 8.13 peratus dalam purata penggunaan bahan api dan pengurangan CO_2 sehingga 5.7 peratus sementara HC berkurangan hingga 6.7 peratus terutamanya di sekitar tork 56 Nm dan 50 peratus kelajuan semasa operasi beban rendah. Peningkatan kritikal kajian ini adalah keberkesanan CDS yang kos efektif dan dibangunkan menggunakan platform Arduino serta prestasi silinder pengaktifan yang sangat baik dari segi penggunaan bahan api dan pelepasan ekzos. Sistem yang dibangunkan juga membolehkan pasukan UTeM Perodua Eco Challenge 2013 memenangi tempat kedua dalam pertandingan PEC2013 dengan jarak paling jauh iaitu 12.97 km seliter. Oleh itu, hasil kajian ini menunjukkan prestasi cemerlang CDS dalam meningkatkan penggunaan bahan api dan pelepasan untuk enjin Perodua Myvi K3-VE. Ia juga memberikan sedikit pandangan mengenai strategi penyahaktifan untuk merekabentuk mikrokontroler dengan integrasi proses data penderia dan sistem kawalan. Pengukuran menunjukkan peningkatan dalam penggunaan bahan bakar dan pelepasan ekzos dengan meminimakan kehilangan kuasa dan getaran enjin yang akan memberi manfaat kepada pembangunan CDS enjin masa depan.

ACKNOWLEDGEMENTS

Firstly, I would like to thank Professor Ts. Dr. Noreffendy Tamaldin and Dr. Ahmad Kamal bin Mat Yamin for their continuous guidance, advice, patience, and kindness as my advisors. My colleague members Mohamad Zaharudin bin Sariman and Muhammad Syahir bin Ali always give valuable input and encouragement to complete this study. I also want to thank Ridzuan bin Ahmad and Nor Izwan bin Junoh for their assistance during vehicle testing using chassis dynamometer and for sharing their valuable opinions. Last but not least, I want to thank my family especially my wife, Normiemy bte Mohammad, and friends. Without their endless support and encouragement, I could not complete my MSc program at UTeM. I always love you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ACT	-	Active Cylinder Technology
AFR	-	Air-Fuel Ratio
AMD	-	Aufrecht Melcher Grosbaspach
AVS	-	Audi Valvelift System
BMEP	-	Brake Mean Effective Pressure
BSFC	-	Brake Specific Fuel Consumption
BSNO	-	Brake Specific Nitrogen Oxide
BSCO	-	Brake Specific Carbon Oxide
BSP	-	British Standard Pipe
CDA	-	Cylinder Deactivation
CDA1 mode	-	One cylinder deactivated engine mode
CDA2 mode	-	Two cylinders deactivated engine mode
CDS	-	Cylinder Deactivation System
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
CRDI	-	Common Rail Diesel Injection
DAQ	-	Data acquisition
DOHC	-	Dual OverHead Camshaft
DVVT	-	Dynamic Variable Valve Timing
ECU	-	Electronic Control Unit

EEV	-	Energy Efficient Vehicles
EFI	-	Electronic Fuel Injection (EFI)
EGR	-	Exhaust Gas Recirculation
EUDC	-	Extra-Urban Driving Cycle
GDI	-	Gasoline Direct Injection
HC	-	Unburned Hydrocarbons
HD-FTP	-	The Heavy Duty Federal Test
IMEP	-	Indicated Mean Effective Pressure
ISO	-	International Organization For Standardization
iEGR	-	Internal exhaust gas recirculation
LCD	-	Liquid Crystal Display
LOMA	-	Lifter Oil Manifold Assembly
MAI	-	The Malaysian Automotive Institute
MAP	-	Manifold Absolute Pressure
N	-	Normal
NS	-	Normal-Skip
NNS	-	Normal–Normal-Skip
NVH	-	Noise Vibration And Harness
NEDC	-	The New European Driving Cycle
OHV	-	Overhead valve
SCS	-	Skip Cycle System
SI	-	Spark Ignition
SFC	-	Skip Fire Cycle
SPDT	-	Single Pole Double Throw Relay

SPST	-	Single Pole, Single Throw
STD mode	-	Normal engine running mode
TDI	-	Turbocharged Direct Injection
TSI	-	Turbocharged Stratified Injection
TPS	-	Throttle Position Sensor
UDC/ECE-15	-	Urban Driving Cycle
USB	-	Universal Serial Bus
VCM	-	Variable Cylinder Management
VTEC	-	Variable Valve Timing and Lift Electronic Control
VVT	-	Variable Valve Timing
VVA	-	Variable Valve Actuation
VSS	-	Vehicle Speed Sensor
WOT	-	Wide Open Throttle

LIST OF PUBLICATIONS

N. A. Abas, N.Tamaldin, A.K. Mat Yamin., 2019. Experimental Investigation of Cylinder Deactivation Impact on Engine Performance and Emissions for SI Engines. *ARPN Journal of Engineering and Applied Sciences*, No.2, Vol. 14.

N. A. Abas, N.Tamaldin, A.K. Mat Yamin., 2015. Cylinder Deactivation Impact on Engine Performance and Emission for SI Engines. *International Design and Concurrent Engineering Conference 2015*, Paper No 49.

CHAPTER 1

INTRODUCTION

1.1 Introduction to cylinder deactivation

Modern automotive engines in cooperation Spark Ignition (SI) and Compression Ignition (CI) evolution to new technology which proposed to emphasis on energy-saving strategies, which is consistent with the National Automotive Policy (NAP) to turn Malaysia into a regional hub for energy-efficient vehicles (EEVs). The Malaysian Automotive Institute (MAI) describes EEV as “vehicles that meet defined specifications in terms of carbon emission level (g/km) and fuel consumption (L/100 km)”. The cylinder deactivation (CDA) is one of the strategies to improve fuel consumption and CO_2 emissions in combustion engines without compromising on vehicle performance and comfort. The usage of cylinder deactivation at part-load is gradually common on large-capacity spark-ignition engines as a method to reduce pumping work and to improve the fuel economy. Improvements of around 8% over the New European Driving Cycle (NEDC) and a substantial 19% under real-world driving circumstances have been testified (Gush B et al., 2009).

Typical SI engines operate unthrottled at part-load and the pumping losses are higher, the requirement to control the air intake throttle wider open using a butterfly valve for increase stoichiometric combustion. The result could be obtained using CDA with an airflow reduction strategy or valve reactive strategy. The CDA technology also improves engine breathing to generate improvement of the fuel economy and decrease gas emissions of the vehicles.

In this project, the cylinder deactivation strategy is further to a small displacement engine, example the PERODUA 1.3-litre four-cylinder engine. The main issue with cylinder deactivation on small displacement engines is the vibration that occurs when some of the cylinders are shut down due to an uneven firing order that produces unacceptable levels of vibration. Hence, experiments were conducted with varying the number and sequence of the deactivated cylinder.

1.2 Research background

Other researchers have tested CDA using skip fire cycle (SFC) or similar concepts. It was found from Kutlar et al., (2007) and Yüksek et al., (2012), the SFC strategy is to decrease the effective stroke volume of an engine. The working principle of SFC is by cutting off fuel injection and spark ignition in part of the classical four-stroke cycles. It is proven that using rotary valves or upgrading the intake manifold method could be optimized for efficient fuel consumption and reduced emission. However, The brake-specific fuel consumption (BSFC) has decreased for the SFC mode at very low speed and loads. The SFC allows the engine to work at a lower idle speed of only 45% displacement downsizing without any instability problems. (Kutlar et al., 2007)

Referring to research Wilcutts et al., (2013) and Mohd Said et al., (2014), the CDA application via valves reactive strategies method are very significant on the engine performance. This method has optimized the intake and exhaust valve lift and timing for at part load conditions. Pumping losses are initiated to be reduced, thus improving fuel consumption and engine thermal efficiency.

Most recently, Volkswagen is the first car maker to implement cylinder deactivation technology on in small four-cylinder engine. The technology for 1.4 TSI of the Polo BlueGT was previously preserved for large eight or 12 cylinder engines, cut off the second and third cylinders during low and medium load states that decrease fuel consumption. Active Cylinder Technology (ACT) mode of operation is active over an engine speed range between 1,400 rpm and 4,000 rpm and torque outputs between 25 Nm and approximately 100 Nm. Volkswagen was also able to use a very narrow single-scroll compressor in turbocharger selection allowing accelerated pressure build-up significantly.

At present, Ford in collaboration with the Schaeffler Group is investigating a 1.0-liter three-cylinder EcoBoost engine. For the test, the engineers developed a system that combined the rolling cylinder deactivation, dual mass flywheel, a pendulum absorber, and a tuned clutch disc. This strategy enabled cylinder deactivation to run the engine in half-engine mode at a wider range of engine loads and speeds with minimizing noise, vibration and harshness levels. The benefit is a more well-balanced temperature level inside the combustion chambers and consistent firing intervals for three-cylinder engines operating in deactivation mode.

1.3 Problem statement

Advancement in-vehicle technology is increasingly concerned with the efficiency of the engine to reduce fuel consumption and vehicle emissions. Cylinder deactivation technology is one of the energy-efficient vehicle technologies that can meet these requirements. Cylinder deactivation technology has been developed by several manufacturers of vehicles that extend from the 6.5L V12 engine for the 3.5L V6 engine. Very few manufacturer has developed cylinder deactivation strategies for a small 1.4L inline four-cylinder engine. The effectiveness of the cylinder deactivation concept for small displacement depends on power to weight ratio, engine balancing, and other factors.