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Development and Mathematical Analysis of a Modular CNG Valve

A thesis presented in partial fulfilment of the

requirements for the degree of

Master of Engineering

Mechatronics

at

Massey University,

Albany, New Zealand.

Gordon Warren

2006

Masters Abstract

Development and Mathematical Analysis of a Modular CNG valve

With the rising cost of oil and uncertainty of supply, there has never been a greater opportunity to offer an alternative fuel into the automotive market than at this present time. Compressed natural gas (CNG) and liquid petroleum gas (LPG) are popular alternatives, producing less green house gasses after the combustion process that add to the raising global warming concern. With high performance fuel injected state of the art engines used in the majority of the late model vehicles, the problem when running on CNG or LPG is poor control of the air/fuel ratio throughout the engine's speed and load range using the conventional zero pressure regulator and mixer combination gas conversion equipment used previously for carburetted engines. This problem is completely eliminated with gas injection system.

The Harrison CNG Electronic Gas injection System control valve is a linear proportional valve. Testing on the valve has found that the response is linear under all operating conditions; however the valve exhibits occasional instances of hysteresis. Due to this unfortunate characteristic further analysis is required, in the form of a mathematical analysis, to determine the exact causes of this problem. Another point of concern is the complexity of the valve, due to the many moving parts, this results in high production costs and increased reliability concerns.

This masters project will include the mathematical analysis of the current Harrison CNG Electronic Gas injection system, further testing and refinement. The objective is to produce a modular system that can be retrofitted to any make of vehicle. Research will be directed in the development of mathematical equations to analyse valve operation for improvement of operation, to increase performance the valve will be redesigned to reduce complexity and ready it for production. The valve will be tested on a variety of vehicles from a 2 litre sedan to a 5.8 litre diesel engine that has been converted to operate on CNG, to prove the versatility of the valve and its ability to tailor the engine torque curve to that required for the vehicles unique operating requirements.

Acknowledgments

I would like to take this opportunity to thanks those that have helped me throughout the project. I would firstly like to thanks my parents, Ian and Lin, and also my brother, Graeme for their continuous support and encouragement. Secondly I would like to thank John Harrison the original inventor of the valve for opportunity to he awarded me when he approached Massey University for further development on the valve. Never in my wildest dreams did I think that I would travel to China to do diesel engine conversions at the beginning of the project. I would like to thank Jou and Lin Lee-Shian Ma for sponsoring the development of the valve and for the trips to China to prove the versatility of the valve and also for their tremendous patience during the development process.

To the Massey University staff of the engineering department, Dr Johan Potgieter, Dr Olaf Diegel, Eddy Rogers and Raymond Hoffman, I would like to express my gratitude for all their time spent in both the workshop making small intricate components and also the time spent listening to my complaints of why the valve isn't working during the development.

I would also like to thank my friends, Conan, Brendan, Travis, Johno, for the fun times spent to give the brain a chance to relax and for reckless behaviour over weekends. To all the other postgraduate students I would like to say thanks for the encouragement and also for the chance to exchange strange and wonderful ideas for future projects and also for the good laughs.

Lastly but by no means least to my girlfriend, Shu Chin, for all her endless encouragement and never-ending confidence in me, I would like to tribute this poem:

She Takes Me...

by William Thomas Kinsey

She takes me many places
that I have never been:
all I do is look at her
it's then she takes me in.

Into a new and different world
one I've heard mention of;
a world of grace and beauty
a world of endless love.

A world of peace and kindness
(the way the world should be),
with her I see it every day
she is that 'world' to me.

While with her life's a fantasy,
a dream world I would say;
yes, she makes my dreams come true
and she does it every day.

Her world of love is awesome,
it fills the poets pen.
All I do is look at her
and then... she takes me in.

Table of Contents

List of figures

List of tables

Chapter 1: Introduction

CNG is seen as the most promising alternative fuel at present, containing between 80% and 95% methane and some other heavier hydrocarbons. Methane has a simple structure and therefore better emissions after combustion; it also has a very high anti-knock value which allows one to increase the thermal efficiency of the engine. Recent surveys have found that the world resources of natural gas are estimated to be 6358.575 trillion cubic feet. At today's current level of consumption this is estimated to last for the next 70 years [3].

Due to methane having a high octane a rating of approximately 120 and also the extended flammability limits of 5-15%, natural gas is well suited to lean burn operation. A lean burn engine operates with an excess air, stoichiometric operation has an air/fuel ratio of 17.2:1 (lambda 1) for methane, if an engine operates with a lean burn condition then the air/fuel ratio is then greater than 17.2:1. The advantages of lean burn are that it decreases fuel consumption and reduces exhaust emissions. Current generator sets operate at lambda 2 (A/F = 34.4:1), but these engines have specially designed combustion chambers having a precombustion chamber that ignites a richer mixture and then the main combustion chamber that contains a very lean mixture. Lean burn operation is not only limited to natural gas, diesel engines operate with excess air due to emissions laws, if diesel engines were to operate with stoichiometric air/fuel mixtures, high particulate emissions (black smoke) are produced which is restricted by current emissions laws. Gasoline engines may also be operated at lean burn using technology known as GDI (Gasoline Direct Injection), this creates a stratified charge within the combustion chamber resulting in a richer mixture present at the spark plug to initiate combustion and a lean mixture throughout the rest of the combustion chamber. Natural gas will result in better emissions than both gasoline and diesel due to its simple structure. Studies have shown that NO_x reductions of 50-80% and particulate matter reductions of 80-90% are possible when heavy-duty vehicles are converted to operate on natural gas instead of diesel.

One of the major disadvantages of natural gas is its low energy density, therefore requiring large heavy storage cylinders. This can be overcome by liquefying natural gas, however natural gas only liquefies at -162°C thereby requiring cryogenic freezing which increases complexity of the system and also the cost. Other technologies have been introduced that use a porous absorbent material that is introduced into the cylinder that increases the energy density of the vessel. This technology uses low pressures of 3.5-5MPa to store 2/3 of the total

energy density present in a standard CNG cylinder filled at 20MPa, this allows the saving in cylinder cost, allows the storage devise to have a irregular shape and be made of a lighter material.

Natural gas has had an interesting history in New Zealand that saw New Zealand as a world leader in CNG technology in 1970-1985 after which the infrastructure unfortunately fell apart and today there is very little use or infrastructure present. However Europe and the United States have now seen a resurgence in natural gas technology with international OEM vehicle manufacturers introducing specially designed vehicles to operate with both natural gas and gasoline. With the stringent emissions laws currently in effect and the push by governments to reduce overall green house gases the opportunity for natural gas to become a dominant fuel is almost a reality.

The purpose of this master study was to examine and perfect a CNG (Compressed Natural Gas) fuel metering system. The metering system uses the vehicle's onboard electronic control unit (ECU) used to meter petrol into the OEM (Original Equipment Manufacturer) engine to create a reference signal that is then used to meter the required fuel for a given engine operating condition. This metering system is a mechanical system that has been in development independently for the last few years and was brought to Massey University for further development. The scope of the project included a mathematical analysis of the apparatus to determine the mostly likely cause of action, followed by further testing on a motor vehicle. This thesis will detail the advantages and disadvantages of natural gas and also look at the other alternative fuels that are presently available; it will also discuss some of the testing done to prove the versatility of the metering apparatus and some of the mathematical analysis done. There will be a brief description of the valve operation and a discussion on the results from testing, highlighting achievements and likely shortcomings that future development may eliminate.

The metering apparatus was designed to be a modular system that may be employed on a large variety of vehicles with very little modification to the OEM equipment so that the vehicle may then operate on CNG. The range of engines that can be operated using this apparatus range from a small 1 litre engine to a large 5.7 litre diesel engine that had been converted to operate on diesel. When converting a SI (spark ignition) engine to operate on CNG very little has to be modified to allow for this alternative fuel, the basic components required are:

- CNG cylinder
- Injector emulator
- Ignition advance unit
- CNG metering system
- Mixer unit

The components are easily installed and require no adjustments or calibration by the end users. The advantages of the system are that the vehicle performance is maintained with the alternative fuel operation due to precise metering of natural gas and that the vehicle operator experiences little if no evidence of vehicle operation on natural gas.

Chapter two will introduce natural gas, the history of natural gas in New Zealand, introduce other alternative fuels, testing procedures for emissions standards, exhaust after-treatment, onboard diagnostics, and the advantages and disadvantages of various control systems for engine operation. Chapter three will concentrate on the mechanical development of the valve, firstly describing the operation of the valve and then describe the development to improve the valve. Chapter four will concentrate on the electronic requirement for vehicle conversion to natural gas. Chapter five describes the testing and results of the vehicle conversions. Chapter six will detail future developments of the valve to ready it for production.