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Spark Ignition Internal Combustion Engine Efficiency Improvement - a Variable Compression Ratio Option

A thesis submitted by

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Abstract

Pressure to reduce energy consumption is increasing. The problem of vehicle fuel consumption and emissions is approached by exploring various vehicle propulsion options, assessing their net effectiveness on a energy conversion basis and on a usability (consumer appeal) basis. Life Cycle Assessment (LCA) of various options indicates that internal combustion engine powered vehicles compare favourably because of low production cost in spite of only achieving modest energy conversion efficiency in operation. Spark ignition (SI) homogeneous charge engines have dominated as passenger vehicle power plants, and are likely to maintain their prevalence for passenger vehicle propulsion into the future, but efficiency improvements are required and achievable. Throttling losses are a significant contributor to reduced efficiency at low load for SI engines which is the load range most employed in standard driving behaviour. An Induction Air Motor (IAM) was conceived, designed, simulated and prototyped to evaluate the potential to recover some of the work the engine does to reduce its intake air pressure for low load operation. The prototyped IAM produced work which potentially could contribute to the engine output while reducing the intake pressure resulting in improved efficiency. However, further effort is required to reduce the friction in the IAM and optimise the work produced by the IAM. An alternative strategy for efficiency improvement involves high Compression Ratio (CR) in conjunction with a reduced compression stroke volume achieved by Late Valve Closing (LVC). Such an arrangement of the Atkinson cycle is shown by simulation to produce improved brake efficiency in SI engines. In this configuration, the maximum power produced by the engine is considerably lower than the maximum power that is achieved by the same displacement for a full compression stroke. To achieve both the improved efficiency at low load using the Atkinson configuration and the power achievable from a full induction stroke, the engine requires

Variable Compression Ratio (VCR). Assessment of VCR concepts from literature and patents identified that the complexity of continuously variable compression ratio designs prevented their development to production-ready configurations. A simulation of fuel consumption over a standard driving cycle showed that a two-position VCR arrangement produces the same benefit as a continuously variable CR for physically achievable piston-rod-crank configurations. Experiments with supporting simulations were performed for a previously patented two-position VCR device, an eccentric link in the big-end of the connecting rod. This work concludes that the eccentric link is not a viable VCR mechanism. An alternative VCR device involving a hydraulic connecting rod was prompted by further experiments and simulations which identified the behaviour of oil when compressed at high rates in a hydraulic cylinder impacted by a falling mass. The oil impact work suggested that oil chambers of cross-sectional area that could be arranged in a conventional connecting rod could readily support the loads experienced by the rod in a conventionally configured engine, so the design and prototyping of a hydraulic connecting rod proceeded. Experiments and simulation confirmed that a relatively easily manufactured hydraulic connection rod can be successfully operated in an engine, achieving controllable two-position VCR. Further development of the hydraulic connecting rod control device and improved production techniques are recommended for this new two-position hydraulic VCR device.

Associated Publications

The following publications were produced during the period of candidature:

Malpress, R. and D.R. Buttsworth, 'Air motor for improved engine brake efficiency: design and preliminary experiments', in 3rd *International Conference on Energy and Environment 2009: Advancement Towards Global Sustainability (ICEE 2009)*. 2009, IEEE: Malacca, Malaysia.

Malpress, R. and D. Buttsworth. 'A comparison of two-position variable compression ratio with continuously variable compression ratio using numerical simulation' in *American Society of Mechanical Engineers, 2009 Internal Combustion Engine Division, Fall Technical Conference*. 2009. Lucerne, Switzerland: American Society of Mechanical Engineering.

Malpress, R. and D. Buttsworth. 'Assessment of an eccentric link in the connecting rod of a spark ignition engine intended for variable compression ratio operation' in *6th Australasian Congress on Applied Mechanics, ACAM 6*. 2010. Perth, Australia.

Malpress, R. and D. Buttsworth. 'Internal combustion engines: a role to fill for transport in an energy conscious environment' in *2010 Southern Region Engineering Conference (SREC 2010)*, 2010, Toowoomba, Australia

A patent application has been lodged for the hydraulic connecting rod described in Chapter 8. (Malpress 2011)

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.
I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Date

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Acronyms & Abbreviations

ATDC	After Top Dead Centre
BDC	Bottom Dead centre
BEV	Battery-powered Electric Vehicle
BICERI	British Internal Combustion Engine Research Institute
BMEP	Brake Mean Effective Pressure
BTDC	Before Top Dead Centre
CI	Compression Ignition
CO_2	Carbon Dioxide
CR	Compression Ratio
CSHEV	Charge-Sustaining Hybrid Electric vehicle
CVT	Continuously Variable Transmission
ESM	Engine Simulation Model
ESP	Engine Simulation Program
FEA	Finite Element Analysis
GCR	Geometric Compression Ratio (GCR)
GDI	Gasoline Direct Injection
HC	Hydro-Carbons
HEV	Hybrid Electric Vehicle
HV	Heating Value
IAM	Induction Air motor
IC	Internal Combustion

ICE	Internal Combustion Engine
LCA	Life Cycle Assessment
LIVC	Late Intake Valve Closing
LVCR	Late Valve Closing Ratio (defined in Appendix A)
MEP	Mean Effective Pressure
NEDC	New European Driving Cycle
NO_x	Nitrous Oxides
ODE	Ordinary Differential Equation
PHEV	Plug-in Hybrid Electric Vehicles
ProE	ProEngineer
	(Parametric Technology Corporation (PTC) solid modelling)
RHC	Rockwell Hardness, C
rpm	revolutions per minute
SI	Spark Ignition
SIDI	Spark Ignition Direct Injection
TDC	Top Dead Centre
VCR	Variable Compression Ratio
VVT	Variable Valve Timing
WOT	Wide Open Throttle