UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF CONTROL STRATEGY OF ELECTRONIC CONTROL UNIT FOR COMPRESSED NATURAL GAS DIRECT INJECTION ENGINE

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

May 2011

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

DEVELOPMENT OF CONTROL STRATEGY OF ELECTRONIC CONTROL UNIT FOR COMPRESSED NATURAL GAS DIRECT INJECTION ENGINE

By

MOHD KHAIR HASSAN

May 2011

Chairman : Associate Professor Ishak Aris, PhD

Faculty : Engineering

This research is focused on the development of a new control strategy for compressed natural gas (CNG) engine with direct injection system known as CNGDI. The CNGDI engine implements; central direct injection, 40kV individual spark plug, 20 bars pressure CNG at common rail, compression ratio of 14 and a dedicated electronic control unit (ECU).

This thesis presents the simulation results of single cylinder and four-cylinder, experimental results and the objective oriented control strategy scheme for CNGDI engine. Prior to experimental exercises, the potential of CNGDI was examined by simulating the engine performance using Lotus Simulation Engine (LSE). The single cylinder engine model was developed and validated experimentally. Then four models of four-cylinder engine were developed. The effect of compression ratio of four engine models with different fuel and injection method was studied and observed. The four models are; petrol with port injection (PI) and compression ratio (r_c) equivalent to 10,

CNGPI with r_c equivalent to 10, CNGPI with r_c equivalent to 14 and CNGDI with r_c equivalent to 14. The CamPro 1.6 liters was selected as the basis for CNGDI engine. Thus, aforementioned to model validation process, the engine geometry of CNGDI model was verified with CamPro 1.6 liters petrol fuelled engine controlled by original equipment manufacturer (OEM) ECU. It was confirmed with a third party universal ECU. The CNGDI four-cylinder engine model was verified experimentally. The influenced of ignition, injection and lambda (λ) was studied on single and four-cylinder engine. An objective-based control strategy scheme was developed for CNGDI engine. It was constructed using two stage regression technique from the engine mapping data. The torque and brake specific fuel consumption was modeled from this technique to envelop the strategy scheme. The models provide flexibility for multiple responses over the input space. Finally, comparison study was carried out between CNGDI, CNGPI and CamPro 1.6 liters to grant the potential of CNGDI engine. In terms of brake power, the CNGDI engine produces 21.65 kW higher than CNGPI engine but 2.82 kW lower than CamPro engine at all over speed range. The maximum brake power for CNGDI engine is 74 kW. The maximum brake torque for CNGDI engine is 124 Nm. At all over engine speed range it produces 26.5 Nm higher than CNGPI but 13 Nm lower than CamPro engine. In conclusion, the simulation results and experimental results with the developed control strategy have shown positive prospective of CNGDI engine as one of the alternative engine towards greener environment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN STRATEGI KAWALAN BAGI UNIT KAWALAN ELEKTRONIK UNTUK ENJIN SUNTIKAN TERUS GAS ASLI TERMAMPAT

Oleh

MOHD KHAIR HASSAN

Mei 2011

Pengerusi : Profesor Madya Ishak Aris, PhD

Fakulti : Kejuruteraan

Kajian ini memberi fokus kepada satu pembangunan baru bagi strategi kawalan sebuah enjin gas asli termampat (CNG) dengan menggunakan sistem suntikan terus dikenali sebagai CNGDI. Enjin CNGI menggunakan; suntikan terus berpusat, palam pencucuh individu 40kV, rail serata tekanan CNG pada 20 bar, nisbah mampatan 14 dan sistem kawalan elektronik (ECU) tersendiri.

Tesis ini mempersembahkan keputusan simulasi bagi satu silinder dan empat silinder, keputusan ekperimen bagi satu silinder dan empat silinder dan skim kawalan strategi berteraskan objektif bagi enjin CNGDI. Sebelum experimen dijalankan, potensi CNGDI telah diuji dengan menjalankan simulasi bagi prestasi enjin menggunakan perisian Lotus Simulation Engine (LSE). Model enjin satu silinder telah dibangunkan dan disahkan secara eksperimen. Kemudian empat model simulasi empat silinder direkabentuk. Kesan nisbah mampatan bagi kesemua empat model yang berbeza bahan bakar dan teknik suntikan telah diperhatikan dan dipelajari. Empat model tersebut adalah; petrol dengan

suntikan liang (PI) dan nisbah mampatan (r_c) bersamaan dengan 10, CNGPI dengan r_c bersamaan dengan 10, CNGPI dengan r_c bersamaan dengan 14 dan CNGDI dengan r_c bersamaan dengan 14. Satu enjin CamPro 1.6 liter telah dipilih sebagai asas kepada enjin CNGDI. Oleh itu, sebelum model disahkan, geometri enjin diverifikasikan dengan CamPro 1.6 liter yang dikawal oleh ECU dari peralatan pengeluar asli (OEM). Ia juga disahkan dengan menggunakan ECU universal pihak-ketiga. Model enjin empat silinder CNGDI telah disahkan secara eksperimen. Pengaruh pencucuhan, suntikan dan lambda (λ) telah diselidik bagi enjin satu dan empat silinder. Satu skim kawalan strategi berteraskan objektif telah dibangunkan untuk enjin CNGDI. Ia dibentuk dari pemetaan data eksperimen yang menggunakan teknik regresi dua aras. Daya kilas dan penggunaan bahanapi spesifik dimodelkan dari teknik ini untuk merangkumi skim strategi. Model ini menyediakan kebolehsuaian sambutan pelbagai ruang masukan. Akhir sekali, satu perbandingan prestasi telah dijalankan antara CNGDI, CNGPI dan CamPro 1.6 liter untuk menentukan potensi sebenar enjin CNGDI. Dari segi kuasa brek, enjin CNGDI menghasilkan 21.65 kW lebih tinggi dari CNGPI tetapi 2.82 kW lebih rendah dari CamPro pada semua kelajuan enjin. Kuasa brek maksima bagi CNGDI enjin adalah 74 kW. Daya kilasan brek bagi CNGDI adalah 124 Nm. Pada semua kelajuan enjin ia menghasilkan 26.5 Nm lebih tinggi dari CNGPI dan 13 Nm lebih rendah dari enjin CamPro. Sebagai kesimpulan, keputusan simulasi dan eksperimen dengan pembangunan strategi kawalan telah menunjukkan prospektif positif CNG sebagai alternatif enjin dalam menuju persekitaran hijau.

ACKNOWLEDGEMENTS

Bismillahhirrahmannirrahim. In the Name of Allah, the Most Beneficent, the Most Merciful.

My heartfelt thank goes to my supervisor, Associate Professor Dr. Ishak Aris. I sincerely believed that this work would not have existed without his inspirations. His constant encouragements, intuitive wisdoms and resolute leadership were instrumental in completing this work. A special thank goes to all my supervisory committees; Associate Professor Dr. Senan Mahmod and Associate Professor Dr. Roslina Sidek, who have always given fruitful ideas during the course. Their guidance and supports made this work possible.

I am indebted to the Compressed Natural Gas Direct Injection Engine and Transmission Program which had provided the opportunity to work and gain immeasurable experience in advanced automotive industry. I believed the program has successfully initiated a solid mutual understanding of various researchers from various universities. I would like to thank to all CNGDI members especially to Khairul Nizam, Nik Anis Alina, Dr. Ibrahim from ECU group for their valuable suggestions and friendly chats during my studies. I am forever indebted to them.

There were many days during two years of calibration and tuning experimental stage that I found myself working innumerous hours in the engine dynamometer laboratory. The laboratory became my second home, meanwhile Muhammad Redzwan Umar, Dr. Md.Abul Kalam and Sulaiman Ariffin became my family. I want to thank them for their willingness to help with any problems that arose and I wish them all the best. A special thank also goes to Waiz and Yuli, the two most experienced and handy technicians which were very helpful during dynamometer engine setting-up.

I am also gratefully acknowledged the financial support of the Jabatan Perkhidmatan Awam Malaysia, who had provided a scholarship of Skim Latihan Akademik Bumiputra

(SLAB) and Universiti Putra Malaysia for the opportunity of pursuing my degree. A special thank to Ministry of Science of Technology and Innovation for providing the research grant under the project entitled: CNG/DI Engine and Transmission: Development of Electronic Control Unit and Its Diagnostic Kit with project number: IRPA 03 02 04-0561-PR-0030-10-06.

And finally, my ultimate thank goes to my loving wife Nor Nadiah Abdul Karim Shah, who had encouraged and stood by my side all these years with our energetic kids, Muhammad Iman and Mia Sarah. Thank you so much.

This thesis is dedicated to my late mother, Allahyarhamah Hjh Maimunah Bte Hj. Wan, who had encouraged all my ambitions since I was little kid. To my late father Allahyarham Hj. Hassan B. Ali and to all my brothers and sisters, who had always given morale supports throughout my study.

Alhamdulillah, I have accomplished my PhD journey, finally!

Wassalam.

I certify that a Thesis Examination Committee has met on 5th May 2011 to conduct the final examination of Mohd Khair Hassan on his Degree of Doctor of Philosophy thesis entitled "Development of Control Strategies of Electronic Control Unit for Compressed Natural Gas Direct Injection Engine" in accordance with the Universities and University Colleages Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Degree of Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declared that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

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MOHD KHAIR HASSAN

Date: 5th May 2011

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