



UNIVERSITI PUTRA MALAYSIA

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

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**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
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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

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May 2011

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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**

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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 eksperimen bagi satu silinder dan empat silinder dan skim kawalan strategi berteraskan objektif bagi enjin CNGDI. Sebelum eksperimen 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.

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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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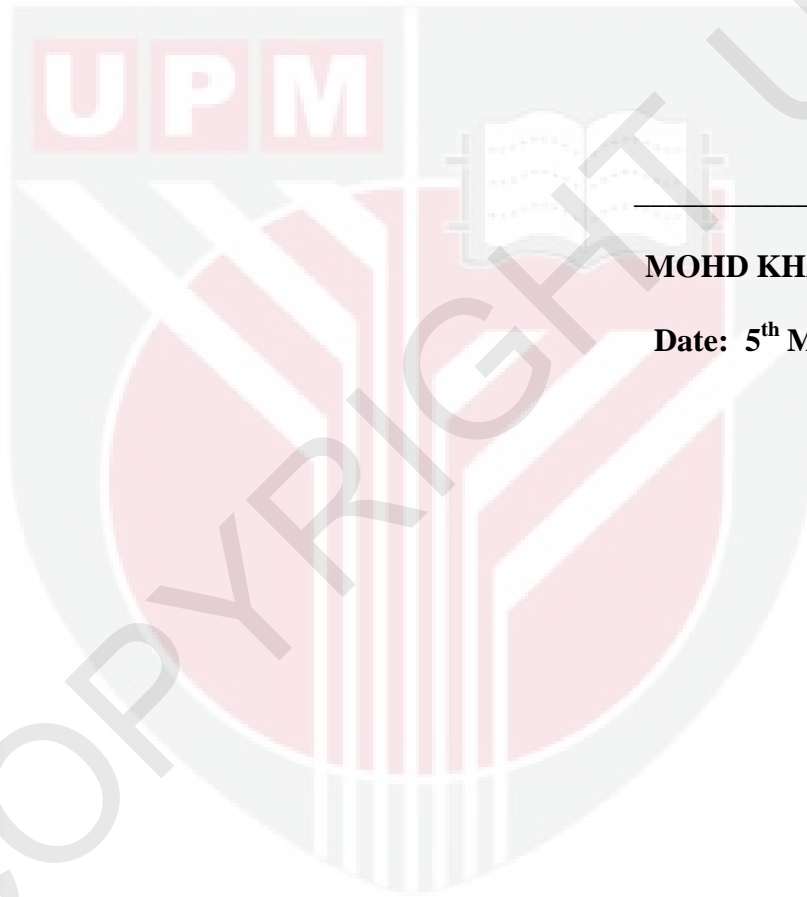
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DECLARATION

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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Date: 5th May 2011

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