DEVELOPMENT OF INDUCTIVE QUARTER WAVE RADIO FREQUENCY COAXIAL RESONANT CAVITY FOR A COMPRESSED NATURAL GAS IGNITION

By

LIYTH AHMAD NISSIRAT

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

October 2006

DEDICATION

With appreciation and respect

this thesis is dedicated

to my parents,

to my brothers and sister.

I owe my country a great debt.

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Faculty: Engineering

The function of the ignition systems is to inject the required energy into the combustion chamber in order to ignite the air-fuel mixture. The amount of the injected energy depends on many factors such as the kind of combustion gas used, air-fuel ratio, and the combustion pressure. To meet the future fuel economy demands the vehicle engine manufacturers try to design engines that run on lean or ultra lean air-fuel ratios. These lean mixtures require more efficient energy injection mechanism to be ignited.

The conventional ignition systems use spark plugs with a narrow spark gap to ignite the air-fuel mixture. The spark plug ionizes the mixture in the gap volume between the electrodes by means of DC high voltage source which is established from the energy stored in a magnetic coil. The drawback of such systems to meet the lean mixture demands is the need to increase the DC voltage between the gap electrodes in

order to ignite the lean and ultra lean mixtures. The spark is localized around the spark plug volume and the size of the plasma channel is small. Moreover, going to higher DC voltage levels cause shorter life time for the spark plugs.

The use of high energy plasma to ignite the mixture has recently gained interest. Many researches have been carried out on studying the Quarter Wave Radio Frequency Coaxial Cavity (QWRFCC) as a microwave plasma generator. This plasma source has many advantages: the mixture has lower breakdown voltage when using microwave frequencies, the device is working as electric field amplifier, and there is no electrode degradation.

In this work a coaxial cavity is developed to be used as an ignition source. The cavity is intended to work at household microwave frequency range (2.45GHz). The dimensions of the cavity have been calculated along with lumped parameters to be used in the RLC electrical model to analyze the behavior of the cavity under the load variation. From simulation and experimental results, It is noted that the radio frequency cavity is able to initiate plasma kernel larger than the conventional spark plug with less input energy requirements. This cavity is planned to be used as an ignition source in a compressed natural gas engine (CNG engine) where the air-fuel ratio (φ) is around 25:1.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan Ijazah Master Sains untuk

PEMBANGUNAN RONGGA RESONAN INDUKTIF FREKUENSI RADIO GELOMBANG SEPEREMPAT SEBAGAI CADANGAN PALAM PENCUCUHAN CNG

Oleh

LIYTH AHMAD NISSIRAT

October 2006

Pengerusi: **Norman Bin Mariun, PhD PEng**

Fakulti: **Kejuruteraan**

Kegunaan sistem pencucuhan adalah untuk memberi tenaga yang diperlukan kepada kebuk pembakaran supaya membakar campuran udara dan minyak. Jumlah tenaga yang di suntik ditentukan oleh jenis gas pembakaran digunakan, nisbah udara-bahanapi dan tekanan pembakaran. Untuk mencapai keperluan ekonomi minyak masa depan pembuat engin automobil cuba mereka cipta engin yang berjalan dengan nisbah udara-bahanapi yang rendah atau amat rendah (ultra lean). Campuran kurang ini memerlukan mekanisma suntikan tenaga yang lebih effisien.

Sistem pencucuhan konvensional mengunakan palam pencucuh dengan sela bunga api yang kecil untuk membakar campuran udara-bahanapi. Palam pencucuh akan terion campuran dengan isipadu antara elektrod yang berpunca dari voltan DC tinggi atau dari tenaga yang tersimpan dalam gegelung magnet. Kekurangan dalam sistem

ini adalah sukar mencapai keperluan campuran rendah yang memerlukan kenaikan voltan DC antara ruang elektrod supaya pembakaran yang rendah dan campuran sangat rendah. Bunga api ditetapkan pada isipadu palam pencucuh dan saiz saluran plasma adalah kecil. Lebih lagi dengan mencapai aras voltan DC tinggi akan menyebabkan jangka hayat yang pendek pada palam pencucuh..

Pengunaan tenaga plasma yang tinggi untuk membakar campuran telah mendapat sambutan yang tinggi. Ramai saintis telah membuat penyelidikan dalam Quater Wave Radio Frequency Coaxial Cavity (QWRFCC) sebagai penjana plasma gelombang mikro.. Punca plasma in ada banyak kelebihan: campuran in ada takat voltan tepu yang rendah bila mengunakan frekuensi gelombang mikro, peralatan ini berfungsi sebagai penguat medan elektrik dan tidak ada penghausan elektrod.

Dalam kerja ini rongga sepaksi dibangunkan untuk digunakan sebagai punca pencucuhan. Rongga yang digunakan adalah diharapkan pada frekuensi gelombang mikro pengunaan dirumah (2.45GHz). Dimensi rongga telah dikira mengikut parameter tergumpal yang digunakan dalam model elektrik RLC supaya dapat menganalisis ciri-ciri rongga pada beban yang berlainan. Dari penyelakuan dan keputusan kerja makmal romgga frekuensi radio boleh membakar kernel plasma lebih besar dari palam bunga api biasa dengan tenaga yang kurang. Rongga ini adalah untuk kegunaan sebagai punca pencucuhan dalam gas asli termampat (CNG engine) dimana nisbah udara-bahanapi (φ) adalah dalam sekitar 25:1.

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I certify that an Examination Committee has met on 19th of Oct. 2006 to conduct the final examination of Liyth Ahmad Nissirat on his Master of Science thesis entitled “Quarter Wave RF Coaxial Resonant Cavity (QWRFRC) for CNG Ignition” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously concurrently submitted for any other degree at UPM or other institutions.

LIYTH AHMAD NISSIRAT

Date: 18 DECEMBER 2006

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LIST OF ABBREVIATIONS/SYMBOLS

List Of Abbreviations

ICE	Internal Combustion Engine
AFV	Alternative Fuel Vehicle
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel on Climate Chang
GHG	Greenhouse Gases
CARB	California Air Resources Board
TLEV	Transitional Low Emission Vehicle
LEV	Low Emission Vehicle
ULEV	Ultra Low Emission Vehicle
ZEV	Zero Emission Vehicle
CNG	Compressed Natural Gas
LPG	Liquefied Petroleum Gas
LNG	Liquefied Natural Gas
QWRFCC	Quarter Wave Radio Frequency Coaxial Cavity
CVCC	Compound Vortex Controlled Combustion
AAC	Avalanche Activation of Combustion
EGR	Exhaust Gas Recirculation
ATAC	Active Thermo-Atmosphere combustion
ARC	Active Radial Combustion

P&I	Piping and Instrumentation
LASER	Light Absorption by Stimulated Emission of Radiation
VCO	Voltage Controlled Oscillator
TWT	Traveling Wave Tube
TEM	Transverse ElectroMagnetic mode
FDTD	Finite Difference Time Domain
FEM	Finite Element Method
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List of Symbols

Symbol	Description	Unit
B	Outer Conductor Radius	m
A	Inner Conductor Radius	m
H	Antenna Width	m
W	Antenna Length	m
L	Cavity Length	m
λ	Microwave signal Wavelength	m
C	Speed of Light in Vacuum	(3×10^5) m/sec
f_{opr}	Operating Frequency	Hz
μ	Magnetic permeability	N/m^2
ε	Dielectric Constant	F/m
Z_{chr}	Characteristic Impedance	Ω
L_{cav}	Cavity Inductance	H
C_{cav}	Cavity Capacitance	F
Ω	Operating Frequency	rad/sec
R	Cavity Resistance	Ω
R_{skin}	Cavity Skin Resistance	Ω
R_{shunt}	Shunt Resistance (filling material resistance)	Ω
σ	Conductor Conductivity	S/m
E	Electric Field	V/m

J	Current Density	A/m^2
2r	Antenna wire Diameter	m
Q	Quality Factor	Dimensionless
VSWR	Voltage Standing Wave Ratio	Dimensionless