Exergy Based SI engine Model Optimisation

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Abstract

In this thesis, exergy based SI engine model optimisation (EBSIEMO) is studied and evaluated. A four-stroke bi-fuel spark ignition (SI) engine is modelled for optimisation of engine performance based upon exergy analysis. An artificial neural network (ANN) is used as an emulator to speed up the optimisation processes. Constrained particle swarm optimisation (CPSO) is employed to identify parameters such as equivalence ratio and ignition time for optimising of the engine performance, based upon maximising "total availability". In the optimisation process, the engine exhaust gases standard emission were applied including brake specific CO (BSCO) and brake specific NOx (BSNOx) as the constraints.

The engine model is developed in a two-zone model, while considering the chemical synthesis of fuel, including 10 chemical species. A computer code is developed in MATLAB software to solve the equations for the prediction of temperature and pressure of the mixture in each stage (compression stroke, combustion process and expansion stroke). In addition, Intake and exhaust processes are calculated using an approximation method. This model has the ability to simulate turbulent combustion and compared to computational fluid dynamic (CFD) models it is computationally faster and efficient. The selective outputs are cylinder temperature and pressure, heat transfer, brake work, brake thermal and volumetric efficiency, brake torque, brake power (BP), brake specific fuel consumption (BSFC), brake mean effective pressure (BMEP), concentration of CO2, brake specific CO (BSCO) and brake specific NO_x ($BSNO_x$). In this model, the effect of engine speed, equivalence ratio and ignition time on performance parameters using gasoline and CNG fuels are analysed. In addition, the model is validated by experimental data using the results obtained from bi-fuel engine tests. Therefore, this engine model was capable to predict, analyse and useful for optimisation of the engine performance parameters.

The exergy based four-stroke bi-fuel (CNG and gasoline) spark ignition (SI) engine model (EBSIEM) here is used for analysis of bi-fuel SI engines. Since, the first law of thermodynamic (the FLT), alone is not able to afford an appropriate comprehension into engine operations. Therefore, this thesis concentrates on the SI engine operation investigation using the developed engine model by the second law of thermodynamic (the SLT) or exergy analysis outlook (exergy based SI engine model (EBSIEM))

In this thesis, an efficient approach is presented for the prediction of total availability, brake specific CO (BSCO), brake specific NO_x ($BSNO_x$) and brake torque for bi-fuel engine (CNG and gasoline) using an artificial neural network (ANN) model based on exergy based SI engine (EBSIEM) (ANN-EBSIEM) as an emulator to speed up the optimisation processes. In the other words, the use of a well trained an ANN is ordinarily much faster than mathematical models or conventional simulation programs for prediction.

The constrained particle swarm optimisation (CPSO)-EBSIEM (EBSIEMO) was capable of optimising the model parameters for the engine performance. The optimisation results based upon availability analysis (the SLT) due to analysing availability terms, specifically availability destruction (that measured engine irreversibilties) are more regarded with higher priority compared to the FLT analysis.

Keywords: Engine Modelling, Exergy, ANN, CPSO, Engine Performance Optimisation

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This thesis is dedicated to my wife, my daughter, my parents and mother in law.

Disclaimer

I originally carried out this thesis and submitted it for receiving PhD degree. Moreover, it has not been submitted to any other person or organisation for any other degree.

The following technical papers have published and submitted based on this thesis:

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Abbreviations:

A	Area exposed to heat transfer	(m^2)
A	Availability or exergy	(J)
A_f	Flame front area	(m^2)
A_{fch}	Fuel chemical availability	(J)
A_Q	Availability transfer with heat	(J)
A_{tm}	Thermo-mechanical availability	(J)
A_w	Availability transfer with work	(J)
A_{tot}	Total availability	(J)
aBDC	After BDC	____
aTDC	After TDC	____
ANN	Artificial neural network	____
b	Bore of cylinder	(m)
b	Bias	____
bBDC	Before BDC	____
bTDC	Before TDC	____
C_p	Specific heat at constant pressure	($kJ.kg^{-1}.k^{-1}$)
C_b	Blow by coefficient	(s^{-1})
E	Total energy	(kJ)
EVO	Exhaust valve opening	____
EBSIEM	Exergy based SI engine model	____
EBSIEMO	Exergy based SI engine model optimisation	____
FLT	First law of thermodynamics	____
h	Specific enthalpy	($kJ.kg^{-1}$)
h	Heat transfer coefficient	($W.m^{-2}.K^{-1}$)
IGT	Ignition (spark) time	____
IVC	Inlet valve closing	____
m	Mass	(kg)
mse	Mean square error	____
P	Pressure	(Pa)
PPM	Particle per million	____
PSO	Particle swarm optimisation	____
Q	Heat transfer	(kJ)
R	Specific gas constant	($kJ.kg^{-1}.K^{-1}$)

Abbreviations:

R_f	Radius of flame	(m)
R	Universal gas constant=8.314	(kJ.kmole^{1}.K^{-1})
s	Specific entropy	(kJ.kg^{-1}.K^{-1})
SLT	Second law of thermodynamics	____
T	Temperature	(K)
u_p	Engine piston speed	(m/s)
u_L	Laminar flame speed	(m/s)
u_t	Turbulent flame speed	(m/s)
υ	Specific volume	(m^{3}.kg^{-1})
υ_{ij}	Particle's velocity	(m/s)
V	Volume	(m^{3})
W	Work done	(kJ)
w	Inertia weight	____
w_i	Weight element for the i^{th} layer	____
WOT	Wide open throttle	____
x	mass fraction	____
x_i	Input vector of a neuron	____
x_i	Search domain	____
x_{ij}	Particle's position	(m)
y	Molar fraction	____
ϕ	Equivalence ratio	____
φ_{ed}	Charge up efficiency	____
γ_r	Mole fraction	____
ω	Angular velocity	(rad.s^{-1})
η_I	The FLT efficiency	%
η_{II}	The SLT efficiency	%
ω	Angular velocity	(rad.s^{-1})
θ	Crank angle	(°CA)
θ_o	Start of combustion	(°CA)
$\Delta\theta$	Total combustion duration	(°CA)
μ	Chemical potential	(J.kmol$^{-1)}$