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Adaptive Control Strategy for Dual–Fuel Stationary Spark Ignition Engines

Fuel availability is an issue that will become ever more important in the future. Therefore, fuel systems will be required to ensure proper operation with a variety of fuel types. The main idea of this study is to develop a control strategy that ensures high fuel conversion efficiency and low emissions levels when employing dual–fuel operation in a micro–cogeneration installation powered by a spark ignition engine. Biogas was considered as the main fuel, while liquid fuel is used to compensate for eventual variations in the gaseous fuel flow. Stoichiometric air-fuel ratio is required at all times so that a three way catalytic converter can be used to simultaneously reduce carbon monoxide, unburned hydrocarbon and nitrogen oxide emissions.

Keywords: *biofuels, spark ignition engine, dual–fuel, emissions control*

1. Introduction

Reducing air pollution has become a major issue for most decision makers around the world. Until recently, the efforts of reducing emissions were concentrated on exhaust gas treatment for reducing particulate emissions, carbon monoxide (CO), nitrogen oxides (NO_x) and unburned hydrocarbons (HC). Even if it is not a toxic gas, carbon dioxide (CO_2) contributes to global warming through the green house effect it produces. For this reason, a reduction of CO_2 emissions is sought after as much as possible. To this end, the European Union adopted a plan to reduce by 20 % green house gas emissions, improve energy efficiency by 20 % and increase the share of renewable energy by 20 %, all by the year 2020, compared to 1990 [1]. Biofuels are a source of renewable energy. Even if they contain carbon, and their combustion releases carbon dioxide, biofuels feature "neutral" CO_2 emissions, as they are obtained from biomass. Compared to other biofuels, biogas has the advantage of a relatively simple and cost competitive production technology. Following fermentation, as a result of the activity of anaerobic bacteria, a gas mixture mainly containing methane and carbon dioxide is produced. CH_4 concentration varies between 50-85 %, depending on feedstock and anaerobic digestion parameters [2].

One issue of using biogas for fueling a small size spark ignition (SI) engine is that volumetric efficiency drops slightly compared to gasoline operation [3]. However, given that stationary engines used for power generation are operated at loads up to ~ 75 %, maximum rated power can be achieved even with gaseous fuel at a higher load value.

2. Dual–fuel system and emissions control

By using a three way catalytic converter combined with a very precise fuel delivery control, high fuel conversion efficiency and reduced emissions can be achieved. Up to ~ 98 % of CO, HC and NO_x emissions can be reduced by running the engine very close to a stoichiometric air–fuel ratio and keeping the catalytic converter above its light–off temperature [4]. Simple fuel flow control devices such as carburetors cannot keep the relative air–fuel ratio within tight limits. Therefore, an electronically controlled injection system is used. This fuel system features an oxygen sensor that enables highly accurate control within a narrow relative air–fuel ratio band of λ ~ 0,99..1,01. The oxygen sensor needs to be fitted upstream of the catalytic converter, so that quick response is ensured.

Using biofuels has the advantage of significantly reducing CO_2 emissions, but raises specific problems for different types of fuel. A specific problem for small size biogas installations is that the flow of gas varies greatly, as well as the fuel quality, with regard to the concentration of methane. For these reasons, micro-cogeneration systems fueled with biogas produced in such small size facilities, require dual fuel systems to be employed. In this way, a second fuel, such as gasoline from another source would be delivered and ensure good engine running characteristics (figure 1).

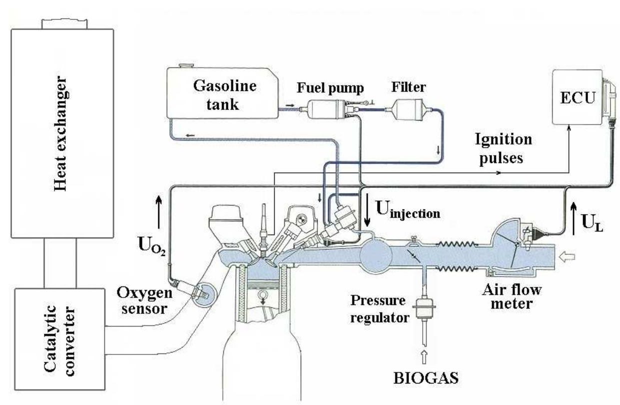

Figure 1. Biogas–gasoline dual fuel system for micro–cogeneration applications

Dual–fuel systems that simultaneously use both fuel types, are generally fitted to compression ignition engines and rarely used with SI engines. The control startegy for such a fuel system would use biogas as well as gasoline, or other liquid fuels, to fuel a SI engine. Biogas fuel flow would require a gross adjustment, while air-fuel ratio fine tuning would be done on the liquid fuel side.

Small size SI engines generally feature fixed timing, with the ignition current being generated by a magneto. Therefore, ignition pulses could be used to generate the signal controlling injection timing, and eliminate the need for an engine speed sensor. Fuel flow is controlled by adjusting the time that the injector is open. An air flow meter can be used to evaluate the quantity of air entering the engine. Based on this evaluation, a basic injection time can be calculated, while fine adjustments can be performed based on the reading from the oxygen sensor. Other information such as engine working temperature can be acquired through signal analysis and thus lowering the overall cost of the injection system. Sensor failure detection and fault mode operation can be achieved in a similar manner, by employing different control algorithms [5].

3. Proposed control strategy

Electronic fuel injection systems usually rely on a three dimensional map that stores injection times for different load and engine speed values. Figure 2 shows a typical control strategy for a fuel system that fires the injectors once every crank–shaft revolution.

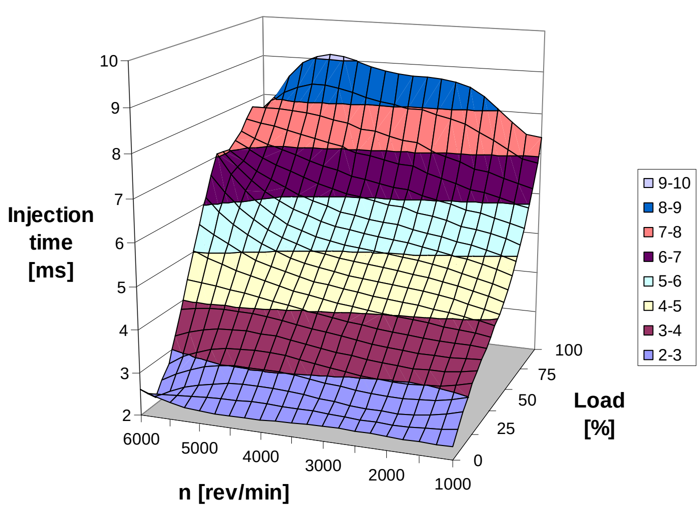

Figure 2. Three dimensional map of injection timing

Additional adjustments to this basic injection timing are performed by the ECU, based on readings from several sensors, such as throttle valve angle, oxygen sensor voltage, coolant temperature sensor and so on. One limitation of this control strategy is that it can only be setup for one type of fuel and adjustments are possible within a relatively narrow range [6]. Changing the fuel would require the entire map to be rewritten with modified injection timing.

Most electronic injection systems employ a basic control algorithm as the one illustrated in figure 3. Even though some information might seem redundant, the use of multiple sensors ensures a very precise fuel flow control and enables failure and out of range values detection.

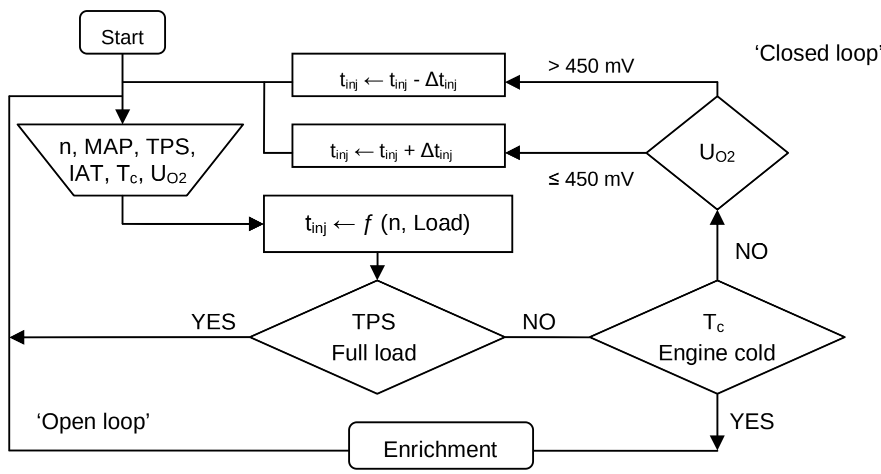

Figure 3. Basic injection control algorithm

Injection pulses are generated based on readings from the engine speed (*n*), manifold absolute pressure (*MAP*), intake air temperature (*IAT*), throttle positioning signal (*TPS*), coolant temperature (T_c) and oxygen (U_{O_2}) sensors (figure 3). Stoichiometric operation is employed at all times, unless the engine is cold or has to deliver maximum power. Load is evaluated based on readings from the engine speed and *MAP* sensors, and a basic injection time is assigned using a three dimensional map such as the one shown in figure 2. Fine adjustments are performed to this basic injection time in a so called 'closed loop' strategy when the engine is run on a stoichiometric mixture.

A continuously adapting strategy is proposed by the present study. Such a control strategy would allow a much wider range for the injection time and essentially enable the engine to run on a numerous fuel types. Of course, there is physical limitation to the actual minimum and maximum fuel flow. Each injector has a lower injection time limit given by the time it actual takes the needle valve to open and close, while the maximum fuel flow is given by pressure supplied by the fuel pump.

The main difference between the usual injection control strategy and the one proposed in this study is that the basic injection time assignment is performed in a dynamic way rather than relying on stored values (figure 4). Basically, if the *MAP* remains constant, so does the basic injection time. Only the time that the engine is actually powered–up requires that the injection time is assigned in an arbitrary mode with a certain value.

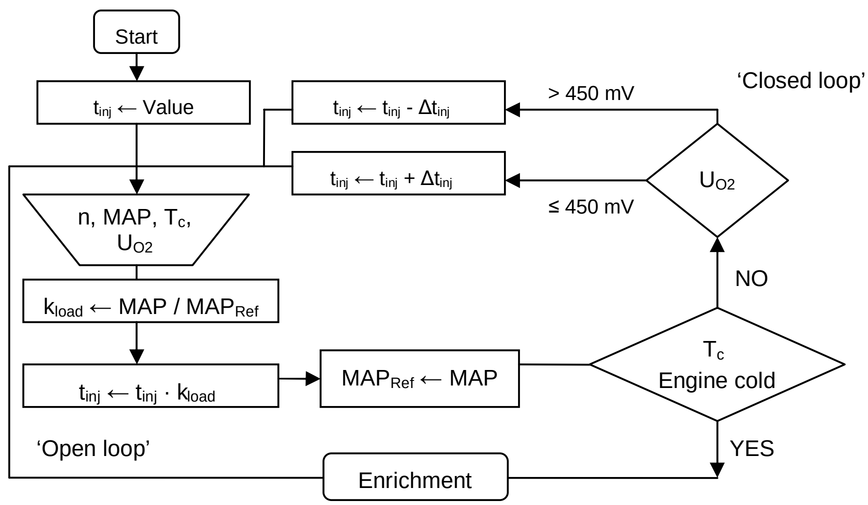

Figure 4. Proposed control algorithm for the basic injection time

Given that stationary power units are operated at constant engine speed in order to ensure the correct electrical power frequency, the number of sensors can be, in theory, considerably reduced without hampering performance [5]. Together with properly developed control software, the proposed simplified fuel injection system can ensure good engine running characteristics, increased fuel economy and reduced emissions, all with a minimum number of sensors, thus reducing overall costs.

4. Conclusions

As fuel availability will be an important issue in the future, an adaptive control strategy was developed for dual–fuel spark ignition engines. A gross fuel control was considered for the gaseous fuel side, while precise injection control is proposed on the liquid fuel side, in order to achieve stoichiometric operation, with high fuel conversion efficiency and reduced emissions.

A simple control algorithm was developed in order to ensure proper engine operation without the need for an injection timing map stored in the electronic control unit. Such a control strategy would allow any type of liquid fuel to be used. The only limitation identified by the theoretical considerations was the upper and lower injection time limits stemming from the actual fuel delivery parameters, such as injector needle lift–closure time and fuel pressure.

Acknowledgement

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