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STATE OF THE ART OF PLASMATRON FUEL REFORMERS FOR HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINES

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Abstract: *The homogeneous combustion combines the main advantages of the gasoline and diesel engines. Unlike conventional internal combustion engines, homogeneous charge compression ignition (HCCI) engines don't have a direct mechanism for starting the combustion, like the spark in the gasoline engines and the fuel injection in the diesel engines. The paper presents a method for obtaining hydrogen rich gas onboard the vehicles to control the combustion process in the HCCI engines and for improving the emissions behaviour.*

Key words: *homogeneous charge compression ignition engines, plasmatron fuel reformers, hydrogen enhanced combustion.*

1. Introduction

In the last years, the internal combustion engines had a very fast evolution. Due to the more restrictive standards of pollution and to the necessity to combine the main advantages of the spark ignition engines (the homogeneous charge which determinates lower cylinder temperatures during combustion and lower emissions) with the main advantages of the compression ignition engines (higher compression ratios which determinates higher efficiencies and throtlleless operation to reduce gasodynamic losses during the intake stroke).

Unlike conventional internal combustion engines, HCCI engines don't have a direct mechanism for starting the combustion, like the spark in the spark ignition engines and the fuel injection in the compression injection engines. To control the ignition timing on the HCCI engines different mechanism which are modifying the temperature from the cylinder are used. Variable compression ratio, exhaust gas recirculation and variable induction temperature are the most used methods to control the ignition timing on HCCI engines. The main problem is that this method requires very complex mechanisms.

The plasmatron fuel reformers are used to obtain the hydrogen onboard the vehicles. The hydrogen rich gas is obtaining from gasoline, diesel, natural gas or bio fuels.

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2. Fuel Reformation

The hydrogen rich gases are obtained passing the air-fuel mixture through an electrical discharge. This leads to the partial oxidation of the fuel, obtaining a gas composed with hydrogen and carbon monoxide.

The plasmatron fuel reformers are also used to increase the enthalpy of the gases and to accelerate the reactions. Increasing the reaction speed the size of the plasmatron can be reduced keeping the same production of hydrogen rich gas.

If the partial oxidation is obtain under stoichiometric conditions, the following reaction occurs:

$$C_nH_m + \frac{n}{2}O_2 \rightarrow nCO + \frac{m}{2}H_2 . \quad (1)$$

The partial oxidation reaction is exothermic. If liquid fuels are used, approximately 15% of the heating value of the fuel is release during the partial oxidation reaction [2].

The efficiency of the partial oxidation reaction (the report between the heating value of the hydrogen rich gas and the heating value of the fuel) vary from about 60% to 80%.

The quantity of hydrogen obtained with the plasmatron fuel reformer can be increase adding water. The water transforms the carbon monoxide into carbon dioxide releasing the hydrogen:

$$CO + H_2O \rightarrow CO_2 + H_2 . \quad (2)$$

Using water the efficiency can be increase almost to 90%.

The total engine efficiency is higher because only a part of the fuel is reformed with the plasmatron. Equation (3) is used to calculate the total engine efficiency (η_T) depending on the fuel fraction reformed (FFR) and the efficiency of the partial oxidation (η_p). For example, if only 20% of the fuel is passing through the plasmatron and the partial oxidation efficiency is 80% the total efficiency is 96%:

$$\eta_T = 1 + FFR \cdot (\eta_p - 1) . \quad (3)$$

The electric power used by the plasmatron to produce hydrogen rich gas is very small compared to the energy of the fuel (about 1-2%). This leads to a power loss (3-5%) of the fuel energy to produce the electricity.

For example, if the power loss due to the electricity needed for the plasmatron is 5%, than the total efficiency is 91.2%.

If the total efficiency of the engine using normal fuel is 35%, when using hydrogen rich gas will decrease to almost 32%, which means a power loss of 3%.

Using the hydrogen rich gas the compression ratio can be increased which leads to a higher thermodynamic efficiency.

The onboard plasmatron fuel reformer concept is presented in Figure 1.

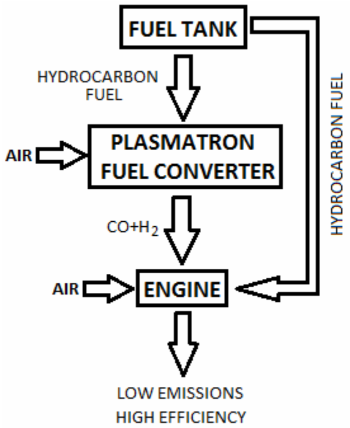

Fig. 1. *Onboard plasmatron fuel reformer concept*

The fuel from the tank is passing through two fuel pipes. The main one is going directly to the engine. The second one is passing through the plasmatron. The fuel is mixed with air before it passes through the electrical discharge. After the partial oxidation reaction the hydrogen rich gas is entering in the engine. The hydrogen rich gas can be mixed inside or outside the engine, depending of the fuel system.

Using the hydrogen the NO_x and the soot emissions can be reduced substantially.

The main parts of the plasmatron fuel reformer designed at the Department of Automotives and Engines from *Transilvania* University of Braşov are the electrodes. They are separated by an insulator. The ground electrode (Figure 2) is also the body of the plasmatron. In it is the pipe which is providing the hydrocarbon fuel and air mixture.

The ground electrode can be formed from one piece or can be composed from two pieces, depending of the way it is manufactured.

In extension of the ground electrode the reaction cylinder is positioned. In the reaction cylinder the partial oxidation takes place.

The electrode may be a spark plug without the ground electrode.

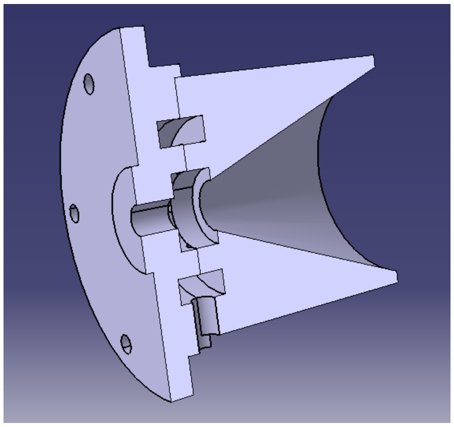

Fig. 2. *The ground electrode*

In Figure 3 the construction of the plasmatron fuel reformer is presented.

3. Homogeneous Charge Compression Ignition Control

The ignition timing determines the main combustion phasing which has a very strong influence on the operating range and on the efficiency of the engine. A stable combustion can be obtained only at low and partial load

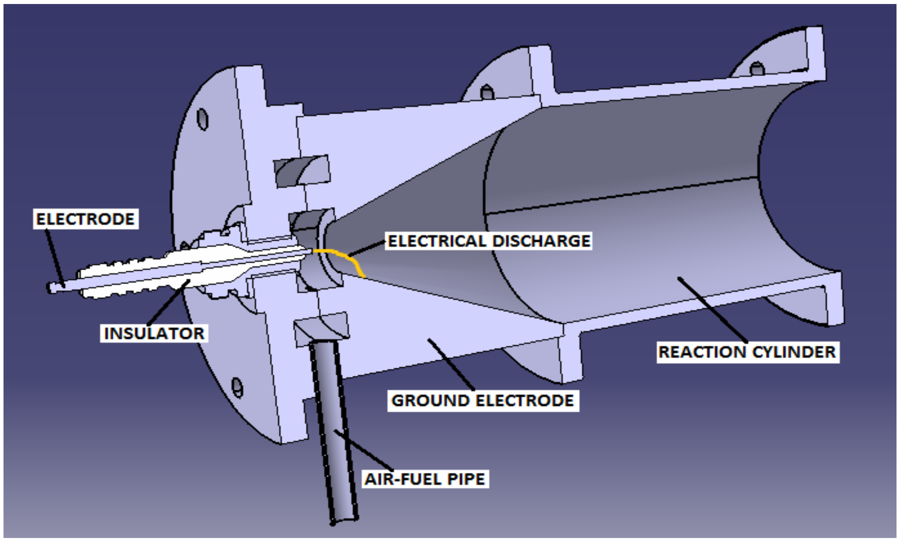

Fig. 3. *The plasmatron fuel reformer designed at Transilvania University of Braşov*

using lean fuel-air ratios and large amounts of exhaust gas recirculation (EGR).

Unlike the conventional gasoline and diesel engines, a direct control mechanism of ignition timing using the spark or the start of injection obtaining a very short and well-known ignition delay is not possible. The start of combustion is strongly influenced by the low temperature chemistry, which depends on the time-temperature history of the charge [1].

The diesel fuel applications are having problems with the premature ignition. Cooled EGR or reduced compression ratios are used to increase the ignition delay.

With the development of fully flexible high-pressure electronic fuel injection systems, direct fuel injection into the cylinder before TDC has been the most popular approach to achieve HCCI combustion in diesel engines [4], [6], [7].

The most successful HCCI diesel system in production is achieved using the late injection after top dead centre (TDC) [8].

The gasoline fuel applications require measures like intake air heating or non-cooled internal EGR to obtain a reliable ignition because of the reduced ignitability of gasoline and the generally lower compression ratios of these engines.

The most important parameters which determinate the beginning of the combustion, are:

- The intake temperature,
- The compression ratio,
- The EGR rate,
- The air excess coefficient,
- The air-fuel homogenization,
- The auto-ignition properties of the fuel,
- The volatility of the fuel,
- The heat transfer to the engine.

In order to control combustion phasing, two main groups of approaches can be distinguished which are shown in Figure 4 [5].

The first group are methods used to alter the time-temperature history of the mixture. It includes the fuel injection timing, the variation of the intake air temperature, the variation of the compression ratio (CR) and the variable valve timing.

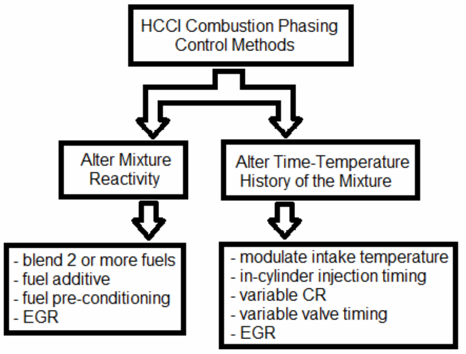

Fig. 4. *HCCI combustion controlling methods*

The methods from the second group are used to control the reactivity of the charge by varying the fuel properties, the fuel-air ratio or the amount of intake oxygen by EGR.

4. Homogeneous Charge Compression Ignition Control Using the Plasmatron Fuel Converter

Two features of the plasmatron fuel converters are very useful for the combustion control in HCCI engines.

First is the exothermically partial oxidation reaction which can be used for heating the incoming air. This method has a very fast response because there is no need for a heat exchanger since the heat is deposited directly into the gas.

When the engine is cold, the conventional methods like the EGR and the heat exchangers driven by the exhaust gas or the cooling liquid do not work. The plasmatron fuel converter has a faster response and can be used to instantaneously increase the charge temperature to the values that are required.

When the engine is warm the EGR and the heat exchangers are used to increase the temperature of the gas in the cylinder, the plasmatron fuel reformer is used to obtain precisely the charge temperature, using a device with fast response.

In Figure 5 is shown the plasmatron HCCI control scheme.

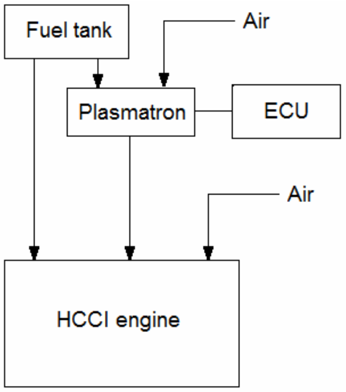

Fig. 5. *HCCI Control Using the Plasmatron Fuel Converter*

The second feature is that the octane value of the fuel can be modified either by using the hydrogen and the carbon monoxide as a fuel additive, or by the production of C_2 compounds, mainly ethylene when operating the thermal plasmatron fuel converter at low oxygen to carbon (O/C) ratios [3].

When the plasmatron fuel reformer is operating at O/C > 1.2, the reformate has a composition similar to synthesis gas, with H_2 and CO, and small concentration of CO_2, C_2s, water, and the balance nitrogen. Because the hydrogen has a very high octane value and the carbon monoxide has an octane value similar to the one of the methane the synthesis gas can be used to increase the octane number of the fuel. In this case a substantial part of the fuel has to be reformed.

When operating with the O/C report smaller than 1.2, the plasmatron can generate a substantial concentration of C_2 compounds. The C_2 compounds have a very low octane number. In this case the plasmatron fuel converter is used to lower the octane number of the fuel.

5. Conclusions

Because it combines the characteristics of the gasoline engines (the homogeneous mixture) with the characteristics of the diesel engines (compression ignition) the HCCI engines are obtaining the main advantages of both types of conventional engines.

The tests made on both gasoline and diesel HCCI engines showed that the nitrous oxide (NO_x) and the soot emissions are reduced substantially.

The plasmatron fuel converter designed at *Transilvania* University of Braşov can be easily mounted on any type of internal combustion engine without minor modifications made on the intake circuit.

Using the plasmatron fuel reformer the combustion timing can be control much smoother. It can use both main approaches because it can alter the mixture reactivity and it can alter the time-temperature history of the mixture.

The plasmatron fuel reformer can be used by itself or in parallel with the conventional methods of altering the time-temperature history of the mixture like the EGR and the heat exchangers.

The plasmatron fuel reformers provide also a method for improving the cold start of the HCCI engines which is another problem of those types of engines.

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