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Method of the fuel dosage management in the direct-injection system of the internal-combustion engine in the cogeneration unit

Abstract: In the article a description of the concept and results of the chosen research works concerning the application of the control system and dosages of fuel to the system of the pneumatic injection were presented, as electronically controlled electromagnetic dispenser. The described concept is directed at the extension of the possibility of applying a distributor less pneumatic injection system in internal-combustion engines. In the system which is an object of the interest of authors, the satisfying invariability (from a point of view of the criterion of the toxicity of the exhaust gasses) doses of fuel to the working cycle of the engine, is connected with the issue of the stabilization of the value pressure in a gas pipe of the system of pneumatic injection (where a fuel is being dosed to). Preliminary studies showing that this natural changeable value of pressure in combination with the proper selection of the moment and the time of fuel dosage, can be used as the regulating factor (in the real time) of fuel dose to the cycle.

Keywords: *pneumatic fuel injection management, internal combustion engine, micro-CHP*

Metoda sterowania dawkowaniem paliwa, w systemie wtrysku bezpośredniego w silniku spalinowym układu kogeneracyjnego

Streszczenie: W artykule przedstawiono opis koncepcji oraz wyniki wybranych prac badawczych dotyczących aplikacji układu sterowania i dawkowania paliwa do systemu wtrysku pneumatycznego jako sterowanego elektronicznie dozownika elektromagnetycznego. Opisywane rozwiązanie ukierunkowane jest na rozszerzenie możliwości stosowania bezrozdzielaczowych układów wtrysku pneumatycznego w tłokowych silnikach spalinowych. W układzie, który jest przedmiotem zainteresowania autorów zadowalająca powtarzalność (z punktu widzenia kryterium toksyczności spalin) dawki paliwa na cykl roboczy silnika, związana jest z zagadnieniem stabilizacji wartości przeciwciśnienia w przewodzie gazowym systemu wtrysku pneumatycznego, (do którego dawkowane jest paliwo). Wstępne prace studialne wykazały, że ta naturalna zmienna wartość przeciwciśnienia w połączeniu z odpowiednim doborem chwili i czasu dawkowania paliwa mogą być wykorzystane jako czynnik regulujący (w czasie rzeczywistym) dawkę paliwa na cykl.

Słowa kluczowe: *wtrysk pneumatyczny – sterowanie, kogeneracja, silnik spalinowy, micro-CHP*

1. Introduction

Industrial use of internal combustion engines for power generation is associated with the requirement of obtaining of high total efficiency of 40% by these engines at rated operating load conditions. This is due to the fact that electricity production is the primary project objective. We are dealing here with the situation of utilization of waste heat in the associated power system. Supply of this system is not considered as a factor in optimization, but rather as a limiting factor. The capital cost of such solutions is estimated at about 1 million zł.

At the same time should be satisfied with the government and interest groups to diversify sources of energy supply [7]. It seems appropriate to propose small cogeneration systems that provide heat with the greatest possible efficiency using a variety of gaseous and liquid fuels. Conversion efficiency is considered as a factor in the optimization process. Small two-stroke internal combustion engines with spark ignition, is distinguished from other internal combustion engines relatively low overall efficiency of about 25%. However, they are perfect as a base for multi-fuel engines [1–6, 8]. If we assume that the production of electricity at maximum efficiency, will be not the primary task of a cogeneration system, it is possible to create a new application cogeneration system with multi-fuel engine, designed for optimized heat production from various fuels, with a significantly reduced (to larger engines) emissions of toxic exhaust gases components.

2. Description of the management conception

Control of fuel dosage should be carried out in compliance with demands of the current energy needs of the forcing system and postulate minimize toxic exhaust emissions. These issues will be examined on the engine equipped with the system of the homogeneous fuel-air mixtures combustion with the application of catalytic converter of the exhaust gases [1]. As a novelty in the proposed functional model of the power system and fuel flexible-fuel engine, will be connecting the regulation of the dose of fuel with getting the stability of the rotational speed of the crankshaft for value 3000 1/min in the changeable operation points of load and with the stabilization of the rate of lambda coefficient in the period 0.97 to 1.03 based on the composition of the exhaust gases measured behind catalytic converter.

Such a configuration of the power and combustion system forces different approach of fuel dosing from those normally used to control the quantitative power control. Because the verification of the current composition of air to fuel mixture usually based on the composition of the exhaust gases takes place through the measurement of the oxygen content in front of the catalytic converter. The measurement behind the converter in this case carried out is simultaneous exclusively for exploitation-diagnostic purposes. However in the suggested solution on account of the specificity of the process of the charge exchange in a 2-stroke engine (there is current oxygen in the exhaust gases in front of the catalytic converter because charge of air which in the process of loading the cylinder before the fuel injection is getting to the exhaust port) on the current composition of the exhaust gases in front of the catalytic converter it isn't possible to obtain information for lambda coefficient values.

However, taking into account the fact that the inspected engine will be allocated to the work in the cogeneration unit, it is possible to apply the proposed method of the regulation of the dose of fuel, because the efficiency of the exchange of the chemical energy of fuel for the useful work isn't an operational research criterion in this case. It is possible to get the precise manner of the regulation of the dose of fuels thanks to that about the changeable chemical composition and the calorific value, including on one hand the forcing system into load of this engine, on the other the minimization of emission of toxic components of the exhaust gases, which are a main carrier in this case of energy exploited in the process of the recycling of the waste heat in cogeneration units.

It results from the possibility of using oxygen in the exhaust gases for oxidizing hydrocarbon elements of the outlet loss and products of the incomplete combustion of fuel in the exothermic reaction in the engine cylinder. Next, for providing the maximum fitness of the reduction in nitric oxides in the scheme for the power regulation of engine in appropriately narrow range, a quality regulation will be used. It is associated of course with the requirement of the presence of the carbon monoxide in the right concentration in the exhaust gases in front of the catalytic converter.

Creating and applying the mechatronic control system in flexible-fuel spark ignition engine, which could be used in cogeneration units, is a purpose of the work. Additionally, the study of the mechatronic system will be performed by a comparative analysis of the influence of the type of the algorithm on the stability of the engine operating point connected on the one side with the caloric requirement of the forcing system, on the other side with minimization of exhaust gases toxic components emission.

The result is an advanced algorithm developed for controlling fuel dosing of fuel-flexible spark ignition engine. It will enable fulfilling demands for the one range control unit by the mechatronic system. This system acts as the dosage equipment of liquid hydrocarbon fuels on diversified group and fractional composition.

To achieve the aim of the study is modeled dose adjustment system and fuel injection start time in Windows/Matlab/Simulink (with adaptive features). The control system will be implemented on the basis of operating in real-time measurement and control card RT-DAC3. RT-DAC3 card is based on the Xilinx measure processor. All functions programmable Xilinx processor are available with standard programming languages. Xilinx processor card is compatible with control packets in real-time RT-CON and RealTime Workshop. RT-CON package integrates all the features of I/O cards RT-DAC3 and very convenient functionality of MATLAB/Simulink. The system is therefore efficient and effective platform for creating customized applications and provides full integration with the environment for processing, archiving data, and visualization. RT-DAC3 card will work through the I/O modules with transmitters:

- throttle angle position sensor,
- the speed of the crankshaft,
- engine load,
- engine temperature,

and actuators:

- electromagnetic injector.

Operation of the system in the environment Windows/MATLAB/Simulink is supported by a software tool RealTime Workshop and card RT-DAC dedicated package RT-CON. Such a configuration of hardware and software allows control of the internal combustion engine in real time using a classic PC, at the phase of research and development. RT-DAC provides both full process control as well as easy and rapid modification of the control system, quick registration, data processing and visualization and ultimately generate object code for future digital controller. The software supplied with RT-DAC helps user to configure hardware and software during testing phase of the control system in real time. Fig. 1 shows a schematic diagram of the test bench.

3. Object of research

A two cylinder, two stroke, air-cooled engine 155.1 by Dezamet of displacement volume 246 cm^3

was the investigation object. In its factory version, the engine is equipped with a carburetor feeding system. The basic technical data of the engine are listed in Table 1. Adaptation of the engine for research needed to make some changes. The main modification consisted in application of pneumatic injection system into the cylinder. The engine was also equipped with a mass air flow meter, Kistler system of pressure measurement, and a DiGas 4000 light emission analyzer.

Table 1. Basic technical data of the tested engine

Model and producer of engine	155.1 Dezamet
Type	Two stroke, spark ignition, air-cooled
Cylinder number	2
Bore mm	52
Stroke mm	58
Displacement ccm	246
Compression ratio	8
Ignition system	electronics
Spark plug number	2
Fuel	petrol, vegetable oil, alcohol
Rating kW/RPM	4.9/3000
Brake specific fuel consumption g/kWh	364

Dezamet – Zakłady Metalowe "DEZAMET" S.A. Bumar Group company

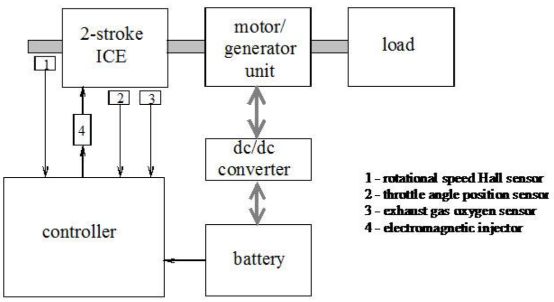

Fig. 1. Diagram of the test bench
Rys. 1. Schemat stanowiska badawczego

4. Opportunities to achieve the application

Fig. 2 shows the effect of air excess coefficient regulation on the composition of exhaust gases behind the catalytic converter. Experiment was conducted for permanent and fixed throttling valve opening at the rotation speed 3000 1/min. The values of the torque and the power were depended on the dose of fuel. This dose which was established by the control system according to the criterion of the minimization value of the injection time and the content of HC in the exhaust gases. For such accepted conditioning during tests of mentioned above fuels the disposable range of the power was included in the range of 4.78 to 4.92 kW [1].

Fig. 2 depicts the "sensitivity of the catalytic converter" to the oxygen content in the exhaust gases feeding it. The problem of the use of information about the presence quality and quantitative meaning of oxygen in the exhaust gases behind the catalytic converter in the form of the decision-making parameter to set the amount of fuel in the set point of the engine load, will be an object of future works. During this process the temperature of the exhaust gases increased from level 550 to 950 °C [2].

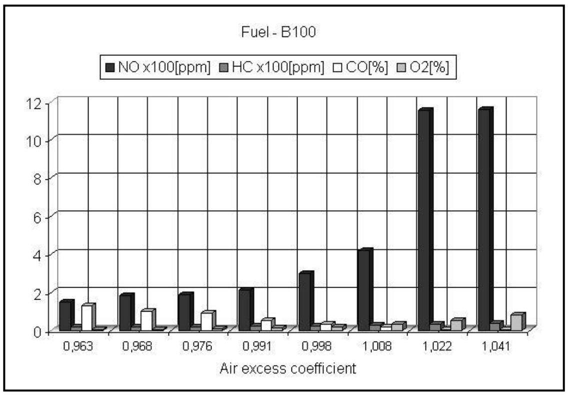

Fig. 2. Effect of air excess coefficient regulation on NO, HC, CO_2 and CO measured behind the catalytic converter
Rys. 2. Wpływ wartości współczynnika nadmiaru powietrza na stężenie składników spalin NO, HC, CO_2 i CO za konwerterem katalitycznym

5. Adjusting the fuel dose

Electrical energy generated by the motor/generator unit is then processed in a DC/DC buck-boost converter. Because the battery and motor/generator voltage varies during system operation, it is necessary to use the DC/DC buck-boost converter. The purpose of the converter is processing voltage from motor/generator unit to the actual battery voltage level. The buck-boost converter consist of an inductor, which accumulate energy, IGBT transistor, which work as a switch controlled by Pulse Width Modulation (PWM) element, and diode, which conducts current in one direction, as also capacitor connected in parallel to the load resistance (battery) and is working typically in continuous coil current flow. In boost mode (voltage increasing), part of the input energy is transferred to the battery via diode during transistor conduction and part of the energy is stored in a coil magnetic field. During open state of the transistor, this stored energy is transferred to the battery. This action is the basis for increasing the converter output voltage.

Based on the analysis of possible controls and results of previous work, adjusting of the fuel dose will be possible through:

a) by a signal from the oxygen sensor;

The base fuel dose (injector opening time) is determined by a Look-up-Table stored in controller non-volatile memory. Address of the cell storing injection base time is determined by measured engine rotational speed (n) and throttle angle position (αT). The base injection time is then adjusted by a factor enriching the mixture obtained by integrating the voltage of the oxygen sensor during the measurement cycle, and compare the average value of the oxygen sensor voltage with reference voltage set for the required composition of the mixture. The mixture composition is determined by the proper operation of the catalytic converter. The amount of fuel (injector opening time) is modified by the increase ($+ \Delta T$) or decrease ($-\Delta T$) in each calculation cycle (i) - Fig. 3. The moment of opening the injector is chosen in correlation with the angular position of the crankshaft. The end of the injection must occur before the end of low pressure in the gas pipe.

b) through the impact of pressure with the lambda correction;

An alternative method of rate control is to synchronize the start of the injection with the angular position of the crankshaft to a forced end of the injection by pressure increase in the duct. In addition, dose correction will be performed (injector opening time) based on the signal from the exhaust gas oxygen sensor in the according to the procedure shown in Fig. 3.

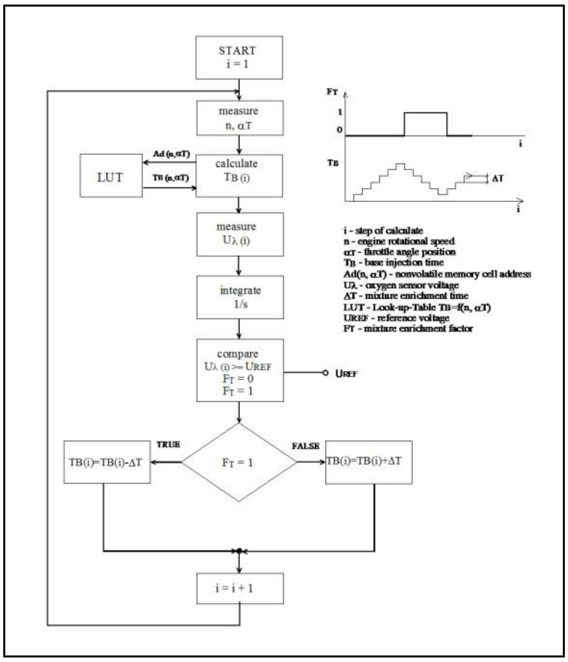

Fig. 3. Fuel rate control algorithm
Rys. 3. Algorytm sterowania dawką paliwa

6. Summary

The aim of the work is the creation and use of mechatronic control system in multi-fuel engine with spark ignition, which could be used in cogeneration. In addition, the study of mechatronic systems will be performed a comparative analysis of the impact of the algorithm on the stability of the operation associated with one hand, forcing the energy requirements of the load, and on the other hand, minimizing the toxic exhaust emissions.

The result is an advanced algorithm developed for controlling the fuel dosing, which allows the development of mechatronic systems in order to meet the requirements of the single-range controller for dosing liquid and gaseous fuels. Based on authors past experience, the practical implementation of single range controller is expected for the assumed load conditions of the engine. Preliminary experiments carried out by the authors indicate that the expectation to obtain the desired result the proposed solution is fully justified. An important result of the current work was to obtain a basic structure for details on manual setting version of control system. This is illustrated by Fig. 2.

Nomenclature/*Skróty i oznaczenia*

B-100 without additives 95 RON petrol/*benzyna handlowa*
IGBT Insulated Gate Bipolar Transistor/*tranzystor bipolarny z izolowaną bramką*
RT–CON Real-Time Connection/*oprogramowanie*
RTW Real Time Workshop/*oprogramowanie*
LUT Look-Up-Table/*tablica sterująca*

Bibliography/*Literatura*

[1] Marek W., Research analysis of applying the catalytic converter for flexible fuel engine, Technical Transactions, 5-M/2012, Issue 10, Year 109, Kraków 2012.

[2] Marek W., Mitianiec W.: Reduction of exhaust gas emission in a two-stroke engine with pneumatic fuel injection, SAE 2002-01-21682181, Automotive Transport Technology Congress (2002).

[3] Marek W.: The analysis of fuel vaporization in a distributorless pneumatic injection system of a two stroke spark ignition engine, 2008-SS2-203, Combustion engines, No 2/2008, Polish Scientific Society of Combustion Engines.

[4] Marek W.: Internal two-stroke combustion engine with pneumatic injection of liquid biofuel, The Archives of Automotive Engineering, No 1/2008, Polish Society of Automotive Engineering.

[5] Marek W., Problems of cooperation of a two-stroke combustion engine with electric machine in cogeneration system, The Archives of Automotive Engineering, No 1/2008, Polish Society of Automotive Engineering.

[6] Marek W., Flexible fuel engine based on pneumatic fuel injection by means of hot exhaust gases, International Congress on Automotive and Transport Engineering, (2010), Conat 20105005

[7] Markussen, M. V., Østergård, H., Schmidt, J. E., Oleskowicz-Popiel, P., Pugesgaard, S. Energy and emergy evaluation of Danish organic dairy farms: potentials for energy self-sufficiency by production of biogas, bioethanol or biodiesel, 1st Nordic Organic Conference 2009.

[8] Jarnuszkiewicz S., Wybrane zagadnienia silników hybrydowych, Politechnika Krakowska 1981.

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