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THE CONCEPT OF AN INTEGRATED LABORATORY CONTROL SYSTEM FOR A DUAL-FUEL DIESEL ENGINE

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Abstract

The need to limit greenhouse gases emissions and to increase the share of renewable fuels in the general energy balance forces people to look for new alternative energy sources. Methane or biogas, in which methane is the main combustible component, is one of such fuels, which is believed to be a promising diesel engine fuel. It is worth emphasizing that biogas might be believed to be one of the cleanest fuels due to the fact that it can be produced from waste, which in normal conditions decomposes releasing methane into the atmosphere.

Methane (biogas) combustion in diesel engines requires a dual-fuel feed system, in which the liquid fuel initiating auto-ignition will be injected into the combustion chamber. It comes as a consequence of a relatively high spontaneous combustion temperature of methane, which is not able to self-ignite in the chamber without an external source of ignition.

This article presents a concept of constructing an integrated laboratory control system, which will provide optimal feed control of complex composition gaseous fuel and of the injection of an appropriate pilot dose of a liquid fuel into the combustion chamber. The solution proposed to control a dual-fuel diesel engine, which was mounted on the test bed, enables performing comprehensive diesel engine research, ensuring not only stable working conditions for the engine, but also granting an opportunity to smoothly regulate the composition of the artificial biogas which feeds the engine and to control basic parameters of the liquid fuel pilot dose.

Keywords*: biogas, diesel engine, dual- fuel feed system, microprocessor engine control system*

1. Introduction

Factors such as limited resources of crude oil, increasing care about the natural environment, and thus tightening norms limiting toxic compounds emissions from diesel engines force people to look for new sources of energy. Biogas is one of the potential fuels, which can be used as a source of energy in engine drive systems. It can be produced from biomass as a result of biochemical processes and from communal, industrial or agricultural waste. Special attention should be paid to the opportunity of retrieving biogas from all kinds of waste, thanks to which a thus produced fuel may be called a renewable second generation fuel, i.e. a fuel whose production does not diminish the world's food production [5].

Retrieved from various sources, biogas does not have constant chemical composition, which decidedly limits its applications in any engine. Methane is the main combustible component of biogas and it comprises 35 to 75% of the latter. Apart from that, there is also hydrogen, whose percentage share is definitely smaller and amounts to 1 to 5%. Moreover, biogas contains a relatively high amount of ballast (non-combustible compounds), such as carbon dioxide, whose content varies from 20 to 55%, and nitrogen, whose share amounts to 20%. Biogas also contains other compounds in trace quantities, which are dependent on the biogas production methods, its processing (purifying), and the material used in the production process [5, 8].

2. A dual-fuel diesel engine feed system

A considerable share of methane in biogas determines the latter's combustion properties. Methane is most often used as a fuel in spark ignition engines due to its properties [5, 7, 10].

A relatively high auto-ignition temperature of methane (app. 630 °C) limits its application in SI engines. Nevertheless, because diesel engines show higher efficiency and lower sensitivity to fuel quality, there are studies into biogas or methane applications as their alternative fuel. Such engines constitute a growing share of the road vehicles market; they are estimated to constitute 50% of all the exploited engines in Europe. It is worth emphasizing that modern diesel engines meet stringent norms for toxic emissions into the atmosphere, thanks to state-of-the-art feed systems and exhaust gas purification systems [7, 8].

Since methane has a high auto-ignition temperature, its combustion in diesel engines requires applying a dual-fuel feed system, in which gaseous fuel is most often delivered to the intake manifold, while during compression a small dose of liquid fuel is injected into the combustion chamber. The dose initiates auto-ignition in the chamber, which in turn enables combusting the main dose of gaseous fuel.

Variable chemical composition of biogas makes it more difficult to control the engine during its performance, especially with reference to a variable content of methane, which requires taking into consideration a momentary biogas composition.

Today, diesel engines are most often fed with the use of Common Rail system, which has become a standard feed system in modern engines. Advantages of this system include virtually limitless combinations of fuel doses injected into the combustion chamber and the fact that the pressure of fuel injection is independent of the rotational speed of the engine. Thus, modern diesel engines meet stringent norms of toxic emissions and prove to have a higher general efficiency, which in turn lowers the costs of their exploitation.

The common Rail system comprises three main systems [5, 7, 8]:

- a low pressure system, responsible for delivering appropriately purified fuel under pressure to the high pressure pump which, depending on the applied solution, reaches in some systems 0.7 MPa,
- a high pressure system, which comprises a high pressure pump, a fuel container and injectors. This system is responsible for generating a required pressure and delivering it to the injectors, which spray the fuel in the combustion chamber,
- an electronic control system responsible for controlling all the elements of the system, which comprise a controller, sensors constantly informing the controller about performance parameters of the engine and the actuators, which are responsible for changes in the sets of working elements.

Controllers of the modern Common Rail systems are themselves complex control systems rather than simple actuators in the feed system [6]. They also fulfill additional control and diagnostic functions. A typical architecture of a modern engine controller is presented in Fig. 1.

In order to facilitate comprehensive analysis of dual-fuel diesel engines, a concept of a test bed extension was designed, so that it would be possible to identify the influence of all biogas components as well as liquid fuel pilot dose parameters on the efficiency of dual-fuel diesel engine's performance.

The test bed presented in Fig. 2 features systems, which independently fulfill their functions, including:

- a liquid fuel feed system,
- a gaseous fuel feed system,
- an engine load system,
- the object of the research – a diesel engine,
- a control system.

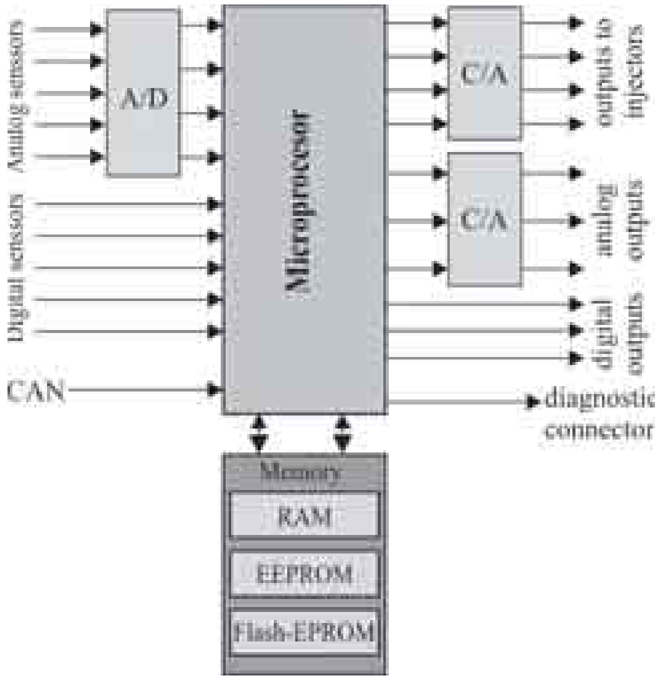

Fig. 1. A diesel engine's controller - a sketch of architecture

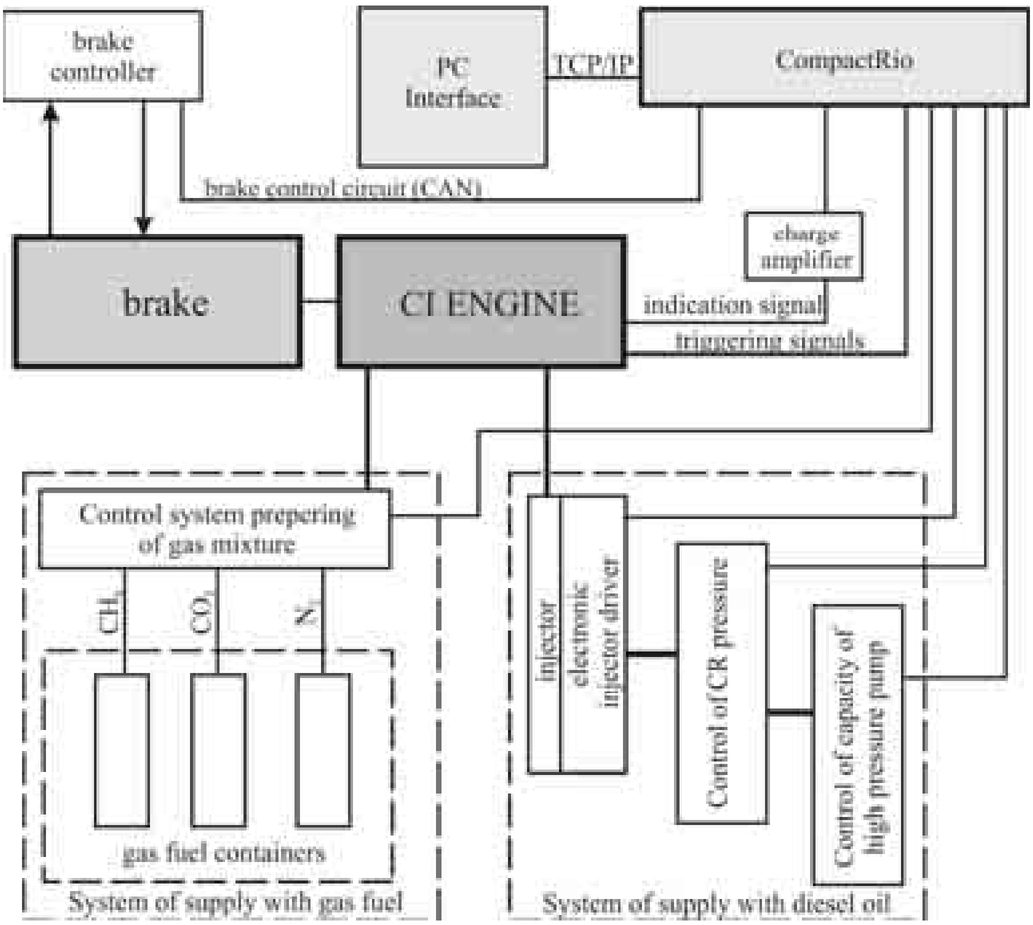

Fig. 2. Scheme of control system

The main controller, which works in the real time mode, is responsible for integrating the performance of particular subsystems and data acquisition. It also functions as a gate in the HMI system and as a database. All the systems can communicate through the CAN network and by sending data through individual signal lines directly to the input controls of measurement devices and from output controls. Efficiency of using CAN in research test stands was approved in works such like [4].

Such an open concept ensures high flexibility of the test bed, since it is easy to modify or reconfigurate every element, at the same time registering a lot of variables describing the object and controlling signals and set parameters.

3. The object of the research

A one-cylinder diesel engine produced by YANAR company was used as the object of this research. Its basic parameters include:

- maximum rotational speed: 3600 rpm,
- cylinder capacity 435 cm^3,
- compression ratio: 20,
- maximum power: 7.4 kW,
- kind of injection: direct,
- cooling system: air.

4. The brake system

The engine is mounted on the test bed with an air-cooled electro whirl brake AMX211 produced by AUTOMEX S.A (Fig. 3). Thanks to such an engine load, it is possible to make it work in two basic modes:

- at constant stabilized rotation,
- at constant engine load.

Introducing CAN network communication in the brake control system between the control module and measurement module of the test bed enables not only registering current parameters on-line, but also remote controlling the changes in the parameters.

Fig. 3. View of stand

5. The liquid fuel feed system

A standard mechanical feed system for YANMAR engine was replaced with a specially designed independent Common Rail system, which constituted an element of a liquid fuel feed system. In order to control the performance of the system two elements were implemented: an electric drive of the high pressure pump and a pressure regulator designed by Mechatronika company, which enables independent controlling of the following parameters (Fig. 4):

– rotation of the high pressure pump,
– efficiency of the high pressure pump,
– fuel pressure in the fuel accumulator.

The applied regulator of the high pressure pump controlling and the pressure regulator in the accumulator facilitate external controlling of the performance parameters of the system, thanks to which it is possible to smoothly control the pressure of the fuel in the accumulator.

Fig. 4. View of CR supply module

6. The gaseous fuel feed system

The system delivering gaseous fuel to the suction manifold of the analyzed engine comprises bottles with every component of biogas, reducers and Brooks 4850 regulators of gas mass flow The possibility to control the engine applying RS232 communication standard allows the researchers to obtain a mixture of gases of complex chemical composition, which is then delivered to the suction manifold. Such a solution makes it possible to conduct the experiment knowing that the composition of the gaseous mixture will vary, and thus to determine the influence of particular biogas elements on the performance parameters of the analyzed engine.

Fig. 5. Brooks 4850 regulator of gas mass flow

7. The central controller

In order to control the pilot dose injection system, the feed system delivering a proper amount of preset composition gaseous fuel, as well as setting an appropriate performance mode of the brake, and reading current engine performance parameters at the same time, the system communicates with the central controller.

All the above mentioned functions are to be coordinated by one test bed, so in order to design it, a few approaches were analyzed:

- application of typical engine controllers and devices to reparametrize them which are available on the market. The reparametrization amounts to modifying the so called injection maps. This kind of controllers belong to the group of the so called dedicated controllers, which limits research opportunities, because of stiff on board control algorithms optimized by producers for certain purposes, such as controlling an engine fed with oil or petrol,
- construction of the controller on the basis of specialized microcontrollers dedicated to automotive applications, equipped with a series of peripheral devices, such as highly advanced timer systems, memory control systems, or typical automotive network interfaces. Modern systems of this kind, e.g. Freescale systems for PC Power Architecture, are characterized by great calculation power and considerable memory. The offer of programming environments (e.g. CodeWarrior) seems to be one of the advantages of such a solution, enabling optimalization and control of the program code in line with numerous certifying institutions' requirements, for instance ISO 26262. This approach is yet extremely time consuming, due to a natural need to introduce several modifications at the software as well as hardware level during research processes,
- the last presented solution makes it possible to control the research object on a sufficiently low level to ensure adjusting the controller to various control conditions – these are fast prototyping software packages, among which xPC Target, part of Matlab environment, and Labview based real time realizations are most know. Clear and graphically fast editing of the required control algorithms in connection with rich libraries of the ready-made devices used to activate data and monitor the condition of the engine permit to adopt a very flexible approach to the broadly understood control of the test bed, which is so necessary.

Having analyzed all the above solutions, the LabView platform was chosen. In comparison with other similar environments, Labview offers definitely more opportunities of cooperation with other devices.

Taking into consideration a chance to continue the laboratory tests on mobile objects, the equipment configuration was based on the Crio controller, which - thanks to modern FPGA systems - makes it possible to realize the programmed control algorithms very quickly, and which in another way can be powered by the installation of the vehicle and set in a portable body, in case of using it in an engine working in real conditions. Application of LabView environment in controlling of engines described in papers [1-3].

CompactRIO platform is the implemented hardware configuration, which is characterized by the following parameters:

- CPU timing – 400 MHz,
- DRAM memory – up to 256 MB,
- non-volatile memory – up to 512 MB,
- 1 Ethernet communication port,
- RS232serial port,
- 8 in/out module ports,
- single DC power supply 9 – 30 VDC,
- operating temperature range: 20-55°C.

Fig. 6. View of central control module

8. Conclusion

The above presented concept of an integrated dual-fuel diesel engine control system enables controlling all the basic parameters of the feed system, such as the pilot dose amount or gaseous fuel chemical composition. Integrating the injection system with the brake system facilitates determining the influence of different amounts and proportions of particular biogas components on the performance parameters of the engine in various load conditions.

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