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PRELIMINARY TESTS ON AN INTEGRATED LABORATORY CONTROL SYSTEM FOR THE FEEDING SYSTEM OF A DUAL-FUEL DIESEL ENGINE AND ITS LOAD

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Abstract

Comprehensive testing of diesel engines currently requires not only a control system for the feeding system of the engine, but also a system ensuring precise control of its load and providing constant measurement conditions. Additionally, it is necessary during the tests to record a considerable number of operating parameters of both the engine and the loading system. The currently available stands for diesel engine tests, the so-called "engine test beds", are standardly-equipped with special systems controlled using computer applications to ensure the maintenance of the assumed engine operation parameters. For compression-ignition engines, this most often takes place by control of the accelerator pedal position. In this solution, the engine is controlled by the engine controller, which controls the fuel charge based on the measurement of the rotational speed and the accelerator pedal position depending on the assumed control algorithm. The shortcoming of this solution is no possibility of controlling selected fuel feeding parameters, such as fuel pressure or the injection advance angle. This paper presents preliminary tests on an integrated control system for both engine load and the parameters of fuel fed to a compression-ignition engine. The developed control system enables engine test bed control, which, depending on the measurement variant, ensures the maintenance of a constant rotational speed or a constant engine load as well as control of the Common Rail system actuators.

Keywords: *CI engine, engine test bed, CR system, control system, combustion engine tests*

1. Introduction

The development of new electric and thermal energy generation technologies is one of the main directions of research conducted in the world. One of the potential energy sources is biogas, which can be obtained from different sources. Biogas as fuel can be used directly in spark ignition engines and can also be used in dual-fuel compression-ignition engines.

The use of biogas as a fuel for compression-ignition engines requires a dual-fuel feeding system, in which the biogas-air mixture ignites from the pilot liquid fuel charge injected into the combustion chamber. The development of a control system for a dual-fuel engine requires tests to determine the basic parameters of the injected liquid fuel charge, such as its value, pressure and injection advance angle [5, 6].

The aim of the conducted tests is to develop an algorithm for control of a compression-ignition engine driving a cogeneration unit, in which the main fuel charge is fed in the form of biogas. The conducted tests aim to determine the basic parameters of the pilot liquid fuel charge depending on engine load and the chemical composition of biogas.

The 11-mode test designed by ISO is currently in force for combustion engines operating under non-road conditions, including in co-generation systems (Fig. 1) [3]. For engines driving power generators (engines operating at a constant rotational speed), this test is limited to the first five modes. The mean emission of individual toxic exhaust gas components is determined on the basis of this test.

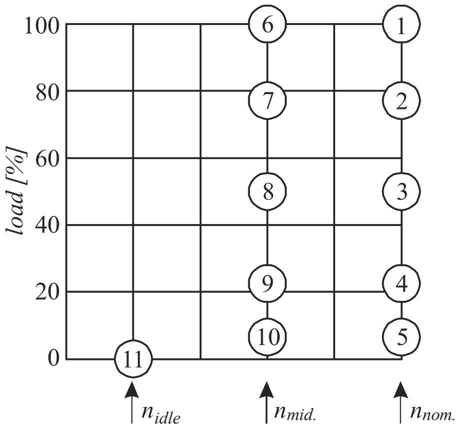

Fig. 1. 11-mode test designed by ISO for engines with non-road applications [3]

Conducting engine tests on engine test beds requires the integration of the brake control system with the engine feeding control system. In standard solutions of this type of system, this most often consists in the application of a special controller for the accelerator pedal of the engine controlled by the brake controller. Depending on the selected load variant, the brake controller maintains the set rotational speed of the engine or its load and a change of the fed fuel charge is possible by changing the setting of the accelerator pedal position [6].

However, it should be stressed that such engine control during tests allows comprehensive testing of ready engine solutions and aims to determine engine characteristics and the level of toxic compound emission to the atmosphere. Such a solution is not sufficient for the development of a compression-ignition engine control algorithm because of no possibility to control the basic parameters of the injected fuel charge, such as fuel pressure, the fuel injection advance angle or fuel charge distribution in time [8].

The development of a dual-fuel biogas-fed compression-ignition engine control algorithm requires tests on special stands enabling the measurement of the basic engine operation parameters such as rotational speed or torque, but also the measurement of the toxic compound emission level [6].

The aim of the conducted tests was to develop an integrated control system allowing simultaneous engine test bed control, ensuring constant engine operation conditions as well as precise control of the parameters of the fuel charge fed to the engine.

2. Description of the test object

The developed control system is designed to control an Automex AMX2110 engine test bed and a YANMAR L100N6CA1T1CAID engine mounted on the test bed.

The AMX2110 test bed is standardly-designed for the comprehensive testing of small spark ignition combustion engines. It has an eddy current brake which is the engine load. The brake settings are adjusted via the test bed control system, which communicates with the operator panel via a CAN network. The control system allows test bed operation stabilization in five modes [1]:

mode 1 – stabilization of the set engine revolutions by the brake exciting current – setting the throttle valve opening angle,

mode 2 – stabilization of the set torque by the brake exciting current – setting the throttle valve opening angle,

mode 3 – stabilization of the set engine revolutions by the brake exciting current – stabilization of torque by the throttle valve position,

mode 4 – stabilization of the set torque by the brake exciting current – stabilization of revolutions by the throttle valve position,

mode 5 – stabilization of torque by the brake exciting current according to square characteristics, setting the throttle valve opening angle.

Despite its designation for testing spark ignition engines, this test bed can be adapted after modification for testing compression-ignition engines. In compression-ignition engines with a mechanical feeding system this change consists of the replacement of the throttle valve control system with an injection pump toothed-bar position control system.

The above-described test bed was used to test dual-fuel compression-ignition engines with the main fuel charge fed in the form of a mixture of methane (CH_4) and carbon dioxide (CO_2), the main biogas components. A single cylinder YANMAR compression-ignition engine was used for the tests [4].

The tested engine is standardly-equipped with a mechanical fuel feeding system, which prevents precise control of the basic parameters of the injected liquid fuel charge. To adapt the engine for the conducted tests, the standard injection system was replaced with a laboratory system constructed on the basis of Common Rail system components. This solution enables precise control of the stream parameters of liquid fuel injected into the combustion chamber.

3. Design assumptions and description of the designed system

The designed stand control system should be an autonomous device, with the possibility of control by a computer application and the following characteristics [6]:

– control of engine test bed parameters (selection of its mode of operation and depending on the selected mode, the possibility of setting constant engine revolutions or a constant braking torque),
– control of fuel pressure in the tank and its stabilization at the level set by the user,
– generation of an electromagnetic (or piezoelectric) injector opening pulse with changes consistent with the standard voltage and current changes on this type of components with the possibility of shaping control current changes,
– possibility of step-less control of the injector control pulse feeding angle (adjustment of the fuel charge injection advance angle),
– possibility of controlling gas flow adjusters,
– recording of selected stand parameters during the measurements.

Moreover, the designed system should have an open structure with the possibility of expansion with further measurement system components, e.g. recording of temperatures at selected engine locations.

A National Instruments cRIO programmable controller was selected for the implementation of the above design. Its most important characteristics, which determined its selection, include:

– the possibility of real-time autonomous operation and system parameterization from the computer application level using the Ethernet protocol,
– relatively high computational power and the possibility of integration with subsequent modules of this type by the Ethernet protocol,
– wide selection of different types of universal input/output cards, which enables their practically free configuration and support of different sensors, actuators as well as communication with other systems by different communication standards,
– availability of special dedicated cards for typical components of the tested system, e.g. a card controlling electromagnetic or piezoelectric injectors,
– the possibility of programming the system from the LabVIEW level, which makes the system open and modifiable as needed.

A general view of the complete test stand is presented in Fig. 2. A laboratory stand was used to implement fuel injection pressure control, constructed on the basis of typical Common Rail system components, controlled by actuator modules dedicated to this purpose (Fig. 3). To eliminate engine loading by the high pressure pump drive, the fuel feeding system was driven by an electric motor. The developed system allows fuel pressure to be adjusted in the range of 40–130 MPa with an accuracy of up to 1 MPa.

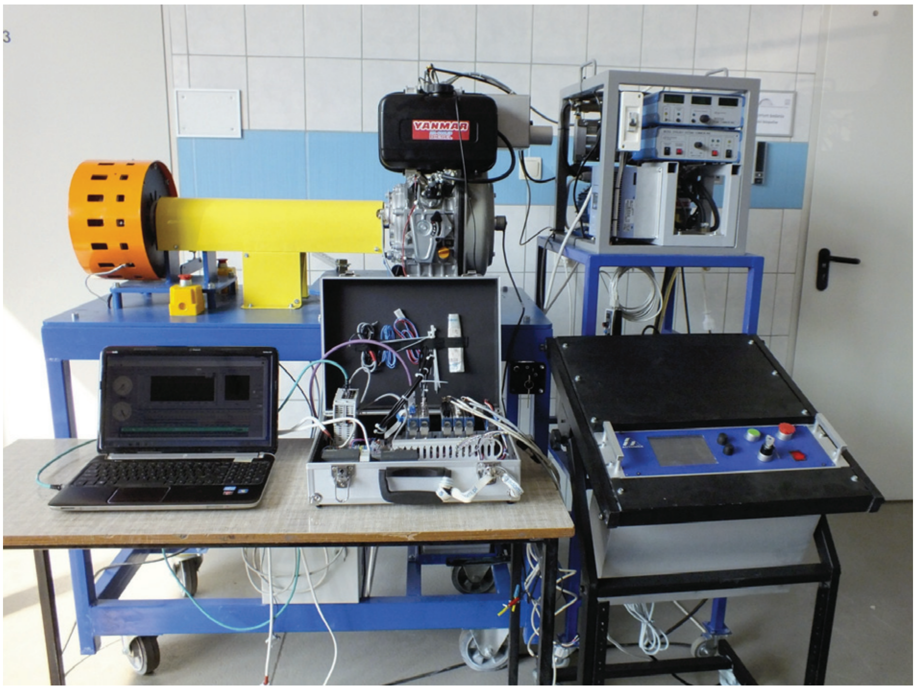

Fig. 2. View of the complete test stand

Fig. 3. View of the high pressure pump control module

Fig. 4. View of the tested engine with mounted encoder and suction valve position sensor

The tested engine was also subjected to modifications. To ensure the possibility of precise fuel injection, it was necessary to mount an encoder on the free end of the crankshaft, which enables the synchronization of the moment when the injector control pulse is fed with the instantaneous position of the crankshaft. The applied encoder allows the injector control pulse to be controlled with an accuracy of up to 0.35°. It was also necessary to mount an additional sensor enabling the identification of the camshaft's position. An additional inductive sensor was mounted for this purpose, which enables valve timing identification on the basis of the valve rocker's position (Fig. 4). The used injector in the feeding system also changed – the standard mechanical injector was replaced with an electromagnetic injector controlled from the level of the developed controller.

A Drivven DI card was used as the output stage controlling the injector [2]. This card is a programmable card dedicated for cRIO controllers designed for control of both electromagnetic and piezoelectric injectors. The program calibration and control module added to this card enables the parameterization of the injector control signal from the level of an application developed in LabVIEW. This allows the control signal to be adapted to a given injector type [7].

An application enabling control of individual systems of the unit was developed on the basis of the LabVIEW environment for control of the constructed stand. The developed application has a modular structure, which enables the testing of single system components as well as the whole system. Fig. 5 presents the main window of the control application, from whose level it is possible to control the basic parameters of the whole system. The configuration and testing of individual systems is possible from the level of the control cards of these systems. The block structure of selected control modules of selected systems is presented in Fig. 6.

Fig. 5. Main window of the developed application

a) b) c) d)

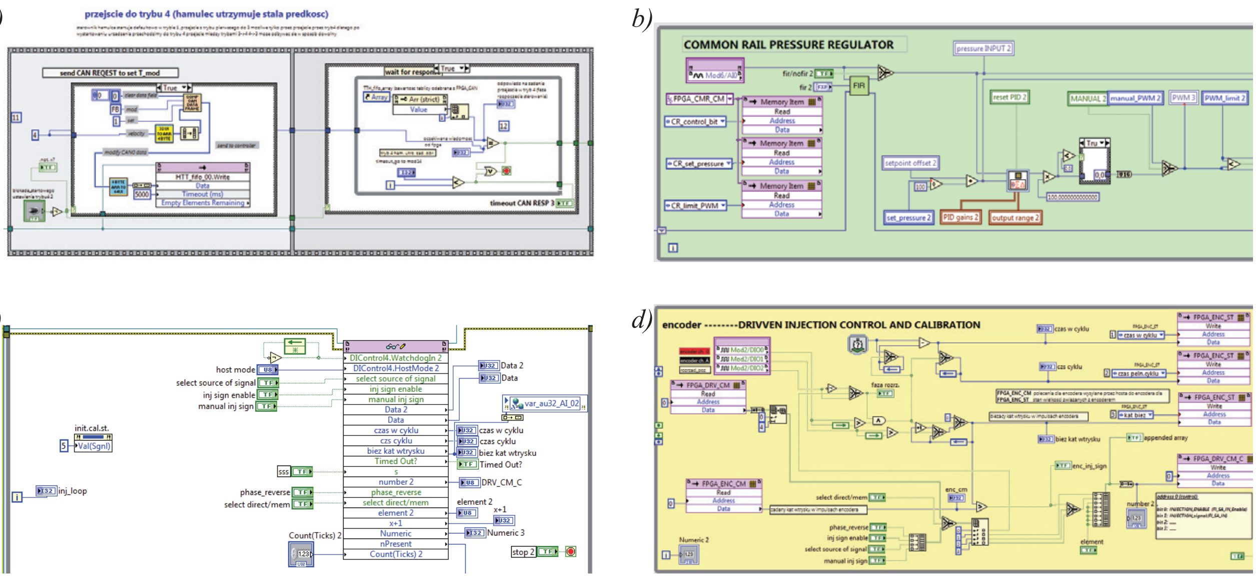

Fig. 6. Selected control modules of individual actuator systems developed in LabVIEW: a) module maintaining constant brake speed, b) fuel pressure control module, c) electromagnetic injector control module, d) injector control signal calibration module

4. Preliminary tests on the developed integrated control system

The developed control system for both a combustion engine as well as an engine test bed was tested to check the correct operation of individual system components. These tests also aimed at possible fine-tuning of the whole system to ensure constant measurement conditions. First, the injector control signal was calibrated by testing to determine the effect of individual injector control signal parameters on the value of the injected fuel charge. The results of these tests are presented in [7] and Fig. 7 presents example voltage and current changes at the coil of the applied injector. The control signal obtained with the constructed system is consistent with the changes described in literature.

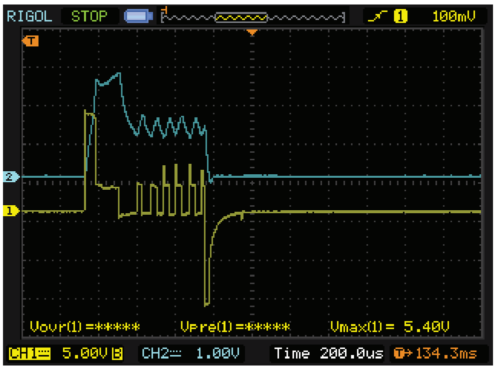

Fig. 7. Example injector control voltage (blue) and current changes (yellow) obtained with a Drivven DI card

The correct operation of the test bed control system was then checked. The correct maintenance of constant engine revolutions or a constant torque by the brake (depending on the selected mode of operation) was checked above all during the tests. Fig. 8 presents the recorded rotational speed and torque changes for the engine obtained during the tests. The recorded changes of the measured values confirm the correct operation of the tested system, which guarantees the maintenance of constant measurement conditions in the course of the tests.

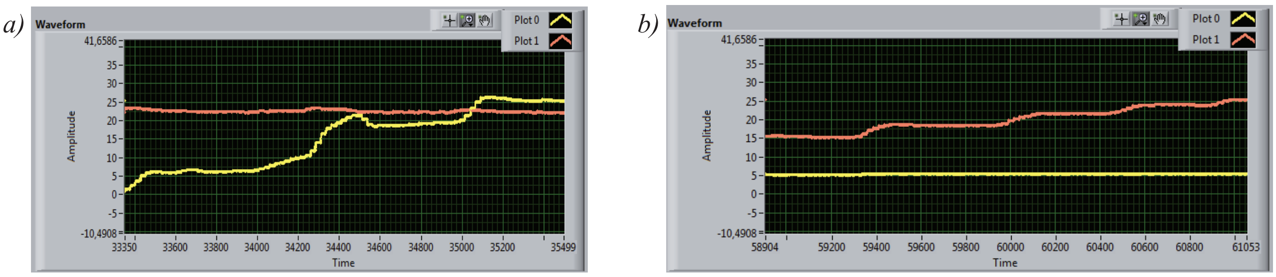

Fig. 8. Recorded rotational speed (red) and torque changes (yellow) in the mode of operation: a) constant rotational speed, b) constant torque

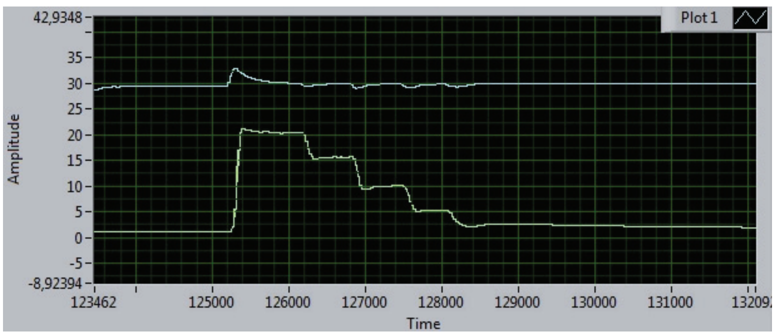

Fig. 9. Rotational speed (blue) and torque changes (green) during the performance of the shortened 5-mode test

After testing and configuration of individual modules of the developed software, the correct operation of all modules during the operation of the whole system was tested. The correct engine reaction to changes in the basic parameters of the injected fuel charge as well as the brake operation parameters was checked during the conducted preliminary tests on the engine at the test stand. Example recorded engine load changes during the performance of the shortened 5-mode test (engine operation in one mode was 20 s), typical for an engine driving power generators.

5. Summary

Summing up the results of preliminary tests on the developed integrated control system for a compression-ignition engine and its load system presented above, it should be concluded that:

- the developed system allows a Common Rail engine feeding system to be controlled, enabling control of the basic parameters of the injected fuel charge such as: pressure, the charge value, its distribution in time and injection advance angle,
- the Drivven DI card applied in the system for electromagnetic injector control enables obtaining voltage and current changes typical for this component, which guarantees its correct operation,
- the constructed control system allows precise control of the operation parameters of the brake loading the engine, which ensures obtaining constant engine operation conditions,
- because of the open software structure, it is easily possible to expand the system with further actuating units as well as sensors monitoring the operation of individual units.

Further work on the developed control system will be aimed at the development of modules controlling the feeding of individual components of gas fuel with which the engine is to be ultimately fed and expansion of the system monitoring the operation of the tested engine.

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