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System of electronic control of changing ignition from spark-ignition to compression-ignition in a four-stroke engine

Abstract: Article presents thorough analysis of implementation of an electronic control system of change from spark ignition to ignition initiated from a pilot dose injection and on the contrary: from auto-ignition to spark ignition. Idea of such controller concerns application of values of parameters such as engine coolant temperature t_{ec}, engine load – torque T and also rotational speed n. Condition of switching from spark ignition to auto-ignition is realised after exceeding certain value of function, which it is possible to write $A_1=f(t_{ec},T,n)$. In this case electronic system simultaneously activates system of direct injection of ignition dose and switch off supplying of group of ignition coils. In case of reverse switching, takes place to on this same principle on the basis of function's value $A_2=f(t_{ec},T,n)$, i.e .ignition system is switched on and system of ignition injection is switched off. Electronic system is controlled by means of computer and determines kind of ignition in the purpose of obtaining the greatest value of total efficiency.

Keywords: *two-cycle internal combustion engine, auto-ignition, spark ignition, increasing total efficiency of internal combustion engine*

Elektroniczny system sterowania zmianą rodzaju zapłonu z iskrowego na samoczynny w czterosuwowym silniku spalinowym

Streszczenie: Artykuł przedstawia gruntowną analizę wprowadzenia elektronicznego systemu sterowania przy zmianie z obiegu iskrowego na samoczynny i odwrotnie: z samoczynnego na iskrowy. Idea takiego sterownika polega na wykorzystaniu wartości porametrów takich, jak temperatura cieczy chłodzącej silnik, obciążenie oraz prędkość obrotowa. Warunek przełączania z zapłonu iskrowego na samoczynny odbywa się po przekroczeniu pewnej wartości funkcji, którą można zapisać $A_1=f(t_{ec},T,n)$. W tym przypadku elektroniczny system jednocześnie uruchamia układ wtrysku bezpośredniego dawki zapłonowej i wyłącza zasilanie zespołu cewek zapłonowych.W przypadku przełączania odwrotnego, odbywa się to na tej samej zasadzie w oparciu o wartość funkcji $A_2=f(t_{ec},T,n)$, tzn. włącza się układ zapłonowy, a wyłączany jest system wtrysku zapłonowego. Układ elektroniczny sterowany komputerem określa rodzaj zapłonu w celu uzyskania największej wartości sprawności ogólnej.

Słowa kluczowe: *silnik dwuobiegowy, zapłon iskrowy i samoczynny, zwiąkszenie sprawności ogólnej silnika spalinowego*

1. Introduction

In hitherto carried out researches of increasing of total efficiency of two-cycle Otto - Diesel engine, the change from spark ignition to auto-ignition was executed manually in dependence from recognition of person carried out researches, however the present article analyses implementation of the system of electronic control of change from spark ignition to auto-ignition and otherwise: from ignition initited by injection of pilot fule dose to spark ignition. Idea of such controller concerns application of values of parameters such as engine coolant temperature t_{ec}, engine load – torque T and also rotational speed n.

The condition of switching from spark ignition to ignition initiated from ignition dose is realised after exceeding of certain of value of function, which it is possible to write $A_1=f(t_{ec},T,n)$. In this case electronic system simultaneously activates system of direct injection of ignition dose and switches off supplying of group of ignition coils. In case of reverse switching it is realised on this same principle on the basis of value of function $A_2=f(t_{ec},T,n)$, i.e. ignition system is switched on, and system of ignition injection is switched off.

The electronic system is controlled by means of computer and determines kind of ignition in the purpose of obtaining of the greatest value of total efficiency.

2. The test stand

The test stand was built on the basis of naturally aspirated, four-cylinder, four-stroke spark ignition engine of displacement 1,298 dm^3 descended from

passenger car Toyota Yaris. The nomenclature of the engine manufacturer is identified as 2SZ-FE [5].

The combination of essential technical data of the test engine was presented in Table 1.

Tab. 1. Specifications of the test engine
Tab. 1. Dane techniczne silnika badawczego

The number of cylinders	4 in row, first cylinder from side of drive of camshaft
Valves and valvetrain	4 valves per cylinder, system of variable valve timing for intake valves
Ignition system	direct ignition, separated coils for every cylinder
Cylinder bore	72,0 mm
Piston stroke	79,7 mm
Crank radius	39,85mm
Connecting rod length	129,5 mm
Compression ratio	10,0
Rated power	64 kW
Rotational speed of rated power	6000 RPM
Maximal Torque	122 Nm
Rotational speed of maximal torque	4200 RPM
Firing order	1-3-4-2
Fuel	Petrol RON 95

The test engine was installed on dynamometer test stand with eddy current brake of type Automex AMX 200. Nominal power of this device equals 100 kW. The brake is controlled by means of measuring - control system the same producer. The basic functions of control system of brake is to maintain the adjusted load and rotational speed of engine, measure of above mentioned quantities and also fuel consumption.

In Fig. 1 general view of test stand of engine Toyota 2SZ-FE was presented.

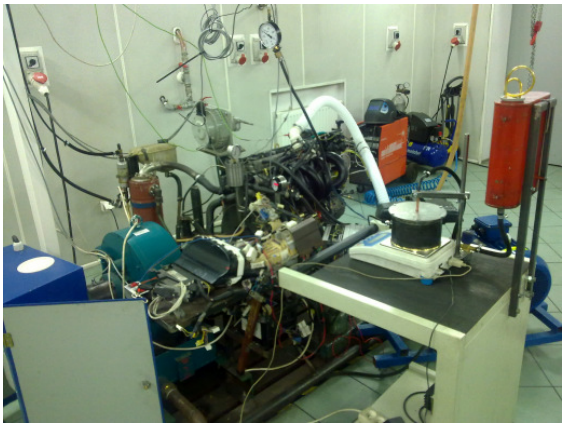

Fig. 1. General view of test stand of engine 2SZ-FE
Rys. 1. Widok ogólny stanowiska badawczego silnika 2SZ-FE

3. System of change of engine mode

Analysis of structure of software implemented in programmable engine management system (firmware) manufactured by AEM indicated on possibility of application to automatic change of mode by means of module [1], which nominally is applied to service of variable valve timing system VTEC applied in engines manufactured by Honda .

The control of changes of engine mode is realized by means of output HS1 of programmable controller of engine. This is high-side output. It means, that in active state on this output is voltage approximate to supplying voltage of controller, however if transistor of power is not controlled, voltage measured between output HS1, and ground of system is close zero [3]. This is also output of type dedicated, i.e. in software of controller is not possible subordination output HS1 of service of device other than system VTEC, neither too system VTEC can not be controlled by means of other output than HS1. This configuration determines defined building and completing of system of automatic change of engine mode from spark ignition to work with initiation of combustion from pilot dose of fuel

On Fig.2 window of user's interface of programmable controller of engine applied to changes of settings of mentioned system were presented.

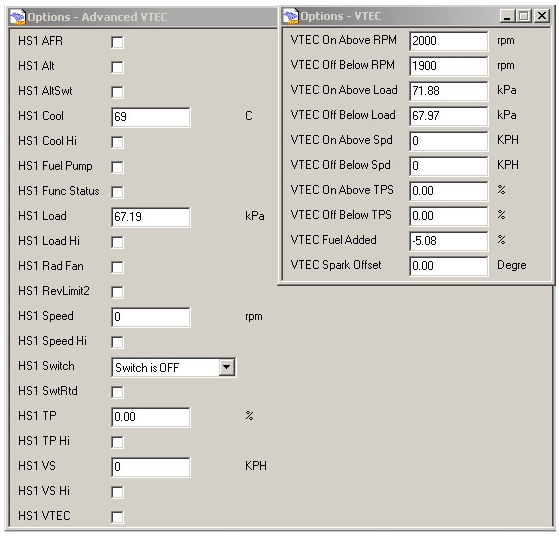

Fig.2. The window of user interface of programmable engine management system applied to configuration of automatic system of change of kind of ignition from spark ignition to ignition initiated from pilot dose of fuel
Rys. 2. Okno interfejsu użytkownika programowalnego sterownika silnika użyte do konfiguracji automatycznego systemu zmiany rodzaju zapłonu ładunku z iskrowego na samoczynny od dawki pilotującej paliwa

The left side of the Fig.2 shows the parameters, which determine set of indispensable conditions, which fulfillment enable activation of HS1 output of programmable controller of engine. During the tests HS1 Cool and also HS1 Load proved to be important, what means, that system of change of engine mode stands inactivate to obtaining of engine coolant temperature equal 69 ºC, and also below computational load of engine 67,19 kPa. Setting of „Switch is OFF" in area of choice „HS1 Switch" means lack of additional external switch enabling the activation of output HS1. The right side of the Fig.2 shows the parameters, according to which activation and deactivation of system of automatic change of combustion system from spark ignition on initiation of combustion process by pilot dose injection follows.

Change of mode of engine operation concerns mainly on analysis of current values of two basic input quantities, i.e. rotational speed (RPM) and also computational load (Load). During tests the criterion of speed of drive (Speed) was not taken into account from understandable respects. The condition of determined opening of throttle of intake air was omitted because of lack of throttling in points of engine operation map considered in this paper. The throttle was fully open, however change of load was realized by change of absolute pressure in intake manifold. During work with initiation of ignition from pilot dose, how this is visible on Fig.2, for all four criteria is possibility of setting of hysteresis loop of transition's moment from spark ignition to auto-ignition and on the contrary. Definition of differences of rotational speed and computational load for switching on and switching off of system caused, that instability work of engine did not appear at change of operation mode in one as well as second direction. The diagram of automatic system of change of operation mode: spark ignition – initiation of combustion by the injection of pilot dose of fuel was presented on Fig.3.

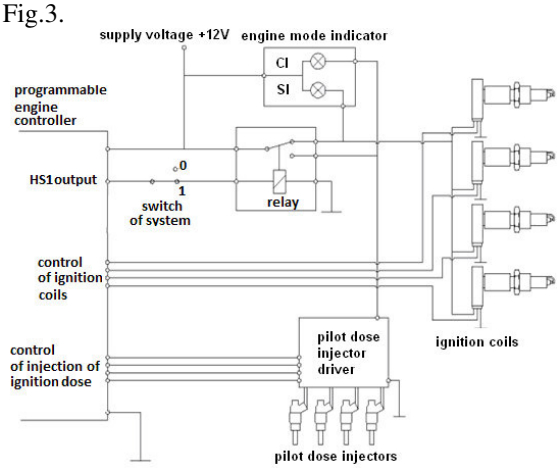

Fig.3. The system of automatic change of operation mode of engine: spark ignition – auto-ignition ignition

Rys.3. Układ automatycznej zmiany trybu pracy silnika: zapłon iskrowy – zapłon samoczynny

In operation mode with spark ignition, when transistor of output power HS1 of programmable controller of engine is not controlled, current flows by normally close contacts of relay and supplies four ignition coils. During work with initiation of combustion from ignition dose fuel, at output HS1 voltage +12V appears enabling controlling of relay coils, what causes switching supplying from group of ignition coils on control module of high-pressure injectors.

It is possible deactivation of automatic system of change of engine operation mode by means of switch interrupting circuit of control of relay coil. In such situation engine works all the time in work's mode with spark ignition, independently from this, or output HS1 responsible for change of ignition mode was controlled, or not. The switch of system of automatic change of operation mode was installed on panel of control brake - Fig.4.

Fig4. The view of part of control panel of dynamometer test stand

Rys4. Widok fragmentu panelu sterowania hamulcem

Besides this system of automatic change of kind of mixture ignition was equipped in visual signaling equipment of chosen work mode. During work of engine with spark ignition on control panel of dynamometer brake red lamp is on, however when ignition of mixture follows from pilot dose of fuel green signaling bulb is on. The general view of system of signaling equipment of chosen engine operation mode and also switch of system of operation mode choice was presented on Fig.4.

Realization of change of operation mode by automatic control system was realized by means of alternative supplying of group of ignition coils during work with spark ignition or driver of injectors of pilot dose in case of work with auto-ignition. In this purpose switching relay about acceptable current load of working contacts 30A was applied.

4. Experimental tests

Engine operation conditions were determined on the basis of initial results of researches (T, n), above which deactivation of spark ignition and transition on initiation of combustion from pilot dose of brought real profits in form of obtaining of increasing engine performances with simultaneous improvement of general efficiency. It was observed, that during work with spark ignition at rotational speed 2000 RPM engine generated 106 Nm at absolute pressure in intake manifold equal 0,13 MPa. During the transition to auto-ignition from pilot dose for constant rotational speed and pressure in intake manifold equal 0,14 MPa torque increased to 113 Nm. It was created profitable conditions to building of system of automatic change of spark ignition to ignition from dose of fuel at increasing of engine's load.

In Fig.5, values of obtained torque and effective power for two modes of operation were presented.

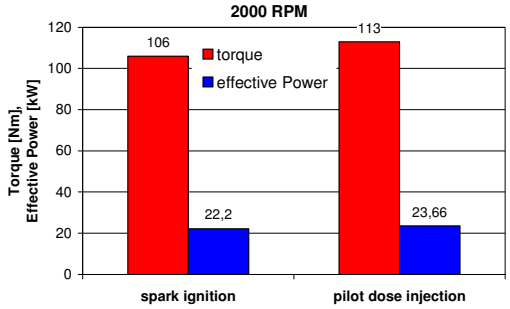

Fig. 5. Values of torque and effective power for both operation modes.

Rys. 5. Wartości momentu obrotowego i mocy efektywnej uzyskane podczas pracy silnika w obu trybach

In Fig.6 values of fuel consumption in the distribution to fuel injected into intake manifold and injected as pilot dose for both engine operation mode were presented.

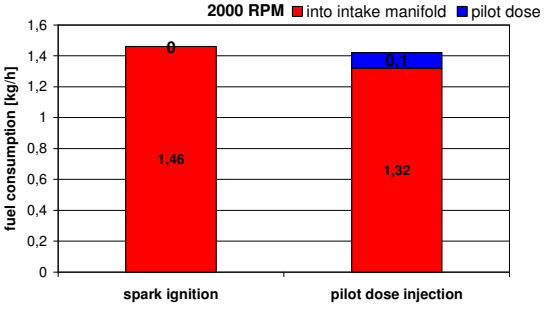

Fig. 6. Fuel consumption in the distribution to fuel injected into intake manifold and injected as pilot dose for both engine operation mode

Rys. 5. Godzinowe zużycie paliwa silnika w obu trybach pracy w rozbiciu na strumień paliwa wtryskiwanego do kolektora oraz jako dawka pilotująca

Fig. 7 presents the comparison of values of specific fuel consumption obtained during tests of engine in both ignition modes.

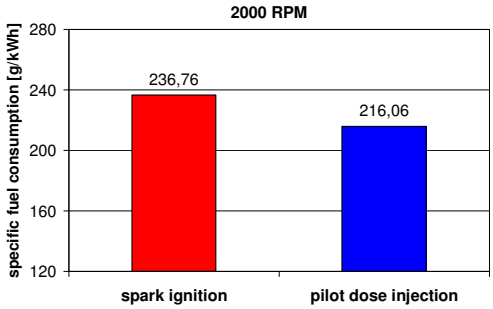

Fig.7. Comparison of values of specific fuel consumption obtained for both engine operation modes

Rys. 7. Porównanie wartości jednostkowego zużycia paliwa uzyskanych w obu trybach pracy silnika

Basing upon the results of specific fuel consumption the values of engine total efficiency were calculated. The results of calculations were presented in Fig. 8.

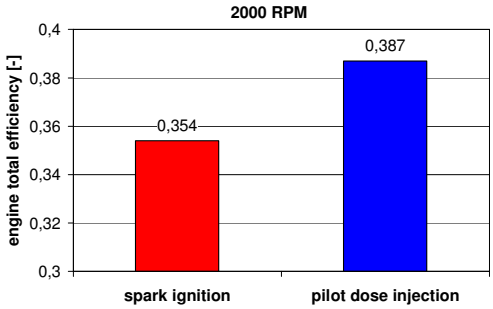

Fig. 7. Comparison of values of engine total efficiency derived during the tests for both ignition modes

Rys. 8. Porównanie wartości sprawności ogólnej silnika uzyskanych podczas badań dla obu sposobów zapłonu

5. Conclusions

As a result of carried out the analysis it is worth to underline, that settings of system of automatic change of operation mode obtained on empirical way during tests. For their ultimate values transition from spark ignition onto auto-ignition, as well as and on the contrary, took place in exceptional mild way, without noticeable fluctuation of torque and rotational speed. This fact gives bases to putting conclusion, that engine being object of present work according to patent Prof. B. Sendyka equipped in system of automatic change of operation mode can become applied with success to traction applications.

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Nomenclature/*Skróty i oznaczenia*

CI	Compression Ignition/*zapłon samoczynny*
HS	high side/*stopień mocy z tranzystorem pnp*
n	rotational speed/*prędkość obrotowa*
RON	Research Octane Number/*badawcza liczba oktanowa*
SI	Spark Ignition/*zapłon iskrowy*
T	Torque [Nm]/*moment obrotowy*
t_{ec}	engine coolant temperature/*temperatura cieczy chłodzącej silnk*
VTEC	Variable valve Timing and lift Electronic Control system/*elektronicznie sterowany system zmiany faz rozrządu i wzniosu zaworów dolotowych*

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