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Internal two-stroke combustion engine with pneumatic injection of liquid biofuel

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In this article the possibilities of liquid biofuel injection control in two-stroke engines are presented. This is a low cost in-cylinder fuel injection system for stratified charge engines which is much simpler than alternatives. The author worked out a system of pneumatic fuel injection by means of hot exhaust gases (according to conception Prof. St. Jarnuszkiewicz) drawn from one cylinder during the working stroke and, following the addition of fuel, forced into another cylinder during the compression stage. Spraying and injection of fuel by means of hot exhaust gases give additional possibilities of complete evaporation of light fuels, alternative fuels with extended fraction and heavier fuels, such as diesel oil, kerosene and vegetable oil. In the combustion system presented the process of preparing liquid hydrocarbon fuel for combustion is one of the main factors influencing the efficiency of the conversion of chemical energy contained in the fuel to mechanical energy. The most significant is the fuel phase transition, and especially a repeatability of the fuel dose per cycle. This process is inseparably associated with the physical properties of fuel, and changes of rate of pressure in gas duct. In practice, a two-stroke internal combustion engine with spark ignition and pneumatic injection accomplished by means of exhaust gases successfully uses liquid fuels with very different fractional and group composition, which may be very beneficial from the viewpoint of practical realization of utilization processes. The results of tests shown it is possible to reach a high repeatability of the fuel dose per cycle and maintaining uniform fuel doses for each cylinder.

1. Introduction

Today primary use of two-stroke engines is in an environment dominated by power - to-weight and minimal cost, with economy and emissions essentially unregulated. This covers recreational vehicles, small-capacity motorcycles, powertools and the large marine diesel engines. So, two-stroke engines are used mainly in off-road applications. At the present time with the introduction of restrictions and toxicity tests of exhaust gases, production of vehicles with such engines was terminated and scope of application was the result of high content of hydrocarbons in exhaust gases caused by the presence of air-fuel mixture in the discharge loss of these engines. Fuel injection after the closing of exhaust port eliminates fuel escape during the exhaust stage. Additionally, controlled height of this port, membrane-controlled intake into the crankcase as well as regulated resonance capacity and length of exhaust system give an advantageous engine torque curve maintained. Unfortunately the short injection time during the compression stroke left after the closing of exhaust port (about 90 degrees of crankshaft rotation) create significant problems. It is possible in solution with new injection systems, which are based on pneumatic injection of fuel, to provide better atomization of fuel and to permit much lower injection pressures. In all these solutions the fuel is supplied directly into the combustion chamber by means of compressed air. For example well known Orbital's X1HB three cylinder two-stroke engine. In order to spray the fuel, all new designs of pneumatic injection systems known apply compressed air taken from a separate compressor. These engines cannot be used as multi-fuel engines because when the fuel density increases, the spraying conditions worsen.

The author worked out a modified system of fuel injection by means of hot exhaust gases drawn from one cylinder during the working stroke and following the addition of fuel, forced into another cylinder during the scavenge stage. According to such scheme the beginning of injection is controlled by the edge of the piston uncovering port of gas duct connecting the working spaces of the cylinders. The end of injection is controlled by dynamic process of stabilization of pressure in cooperated cylinders.

2. Combustion system

To burn diesel fuel, vegetable oil, or alternative in relation to petrol in SI engines, one should properly modify system of combustion. Below the idea of such adaptation will be introduced from necessity in short. Analyzing process of creation of mixture and combustion in many-fuel engines with compression ignition it is easy to notice that quantity of fuel entering in reaction of combustion is regulated by intensity of vaporization of fuel from side of chamber of combustion. Also in presented system with pneumatic injection by means of exhaust gas there is a phenomenon of gradual entering of fuels in reaction of combustion. Presumably steps out several mutually penetrating factors here.

One of this is stratification of charge, as injection of exhaust gas-fuel mixture takes place to chambers of combustion placed in cylinder head from producing intensive of rotating (swirl) of charge.

Second factor is inevitable occurrence of separating in phase of gas being hydrocarbons of fuel, from particles of oxygen from charge of air.

Third factor is short time at disposal for the process of creation of mixture and combustion in two-stroke SI injection engine.

The course of combustion one can represent as follows. In the interior of combustion chamber before ignition there is heterogeneous mixture in consequence of rotation and activities of mass - powers. However, thanks to process of diffusion comes into being terminal zone, in which fuel with air produces mixture about nearing composition to stoichiometric. Location of zone, and probably of terminal zones in relation to electrodes of spark ignition is not stable. After ignition, which happens in terminal zone shifting in relation to electrodes, laminar and then turbulence diffusive flame holds up process of fuels entering in reaction of combustion. So, combustion has a diffusive character, as air diffuses to areas with large concentration of steams of fuel, and steams of fuel in opposite direction. Rate of combustion is controlled by intensity of this process. Such mechanism of mixture preparation in essential manner makes process of formation of additional places of self-ignition difficult, eliminating the occurrence of knocking. Schema of adapted system of combustion is presented in Fig. 1.

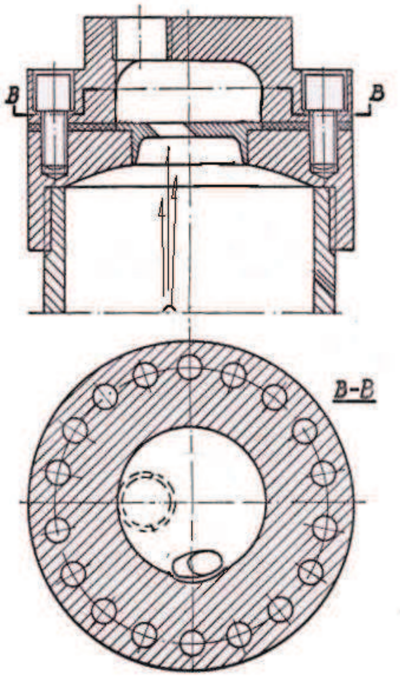

Fig. 1 Schema of combustion chamber.
Rys. 1. Schemat komory spalania.

3. Selection of control parameters of feed system

In the presented system of combustion one used off-distributor system of pneumatic injection by means of hot exhaust gas. Fig. 2 shows possibilities of selection of angle of injection depending on course of pressures in cylinder 1 and 2. As was established on the ground of earlier research, angle of injection should not be smaller than 40 degrees of crank angle. This is connected with general requirement of holding masses of dose of exhaust gas on the level warranting efficient way of transformations of phase condition of liquid fuels hydrocarbons. On drawing below one marked characteristic points describing process of injection.

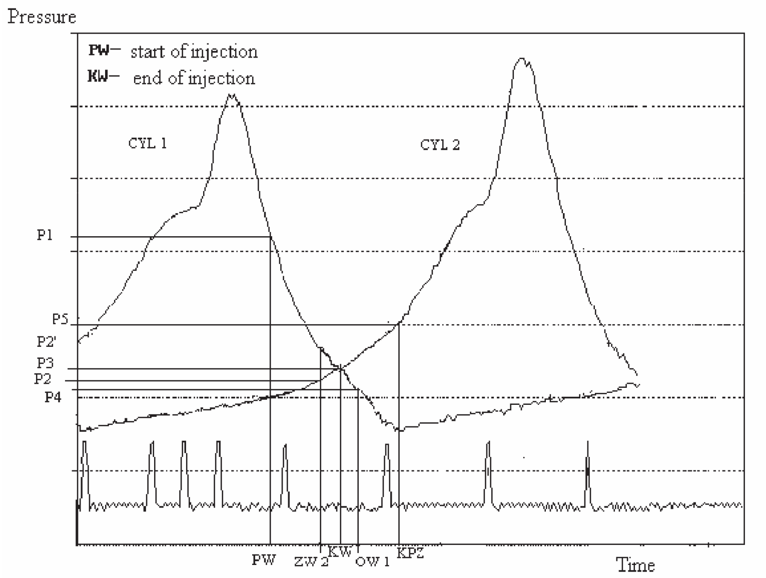

Fig. 2. Open indicated pressure diagrams in engine combustion chambers.
Rys. 2. Otwarte wykresy indykatorowe przebiegu ciśnień w cylindrach silnika.

Blow through of the exhaust-gas-fuel mixtures (that is to say injection) stops at the moment of equalization of pressures in cylinders - point KW at pressure P3. Local and periodic stability of this point is dependent on course of pressure mostly in cylinder to which injection takes place. Counting 40 degrees backwards from this place we mark theoretical beginning of injection – point PW at pressure P1. Stability of this point depends on geometry of injection's system which is defined by location of injection opening on smooths of cylinder. It depends also indirectly on load of engine and of course of expanding. A certain defect of off-distributor system is the occurrence of so-called back-blow through which takes place after the end of injection. This phase results from geometry of injection's system and from unfavourable difference of pressures. Height of pressures of compression in cylinder 2 is not however intensive, and in relationship to this loss of charge is omittably little - point KPZ at pressure P5. Organization of movement of gases in cylinder to which injection takes place assures obtainment of stratification of charge. This is an important requirement as injection takes place in phase of exchange of charge (scavenge stage) when organ of distribution are open. Only in point ZW 2 at pressure P2' in cylinder 1 and P2 in cylinder 2 closing of exhaust port follows. Injected exhaust gas-fuel mixture cannot penetrate the stream of gases leaving cylinder. Similar situation takes place also in phase of back-flow. After an opening of exhaust port in cylinder 1 - point OW1 at pressure P4, ongoing charge from cylinder 2 cannot penetrate the stream of gases leaving cylinder 1. This phase lasts about 25 degrees.

Basic parameters of technical system are as follows:

- geometrical angle of pneumatic injection - not smaller than 40 degrees.
- internal diameter of gas-duct - 2,8 mm
- system of dosage of fuel: low-pressure - 0,2 [MPa], periodic, synchronous, electromagnetic dosage with electronically controlled rectangular impulses with variable fulfillment.

4. Engine investigations

The engine investigations were executed on functional model of pneumatic injection system according to above description. Researches was steered on problems connected with qualification of optimum locations of phase of fuel dosage (FDP) in section of dosage (PDP) in system of pneumatic injection by means of hot exhaust gases in two-stroke SI engine. These study works were executed for obtainments of satisfactory repeatability of delivered doses of fuel on working cycle of engine.

Methodic of investigations are as follows:

- theoretical analysis of possibility mutual angle locations of blow through phase of exhaust gases (FPS) (phase of pneumatic injection) and dosages of fuel - specifying of variants and settlement criterion of usefulness - initial estimation of usefulness of each variants on engine stand - choice of variant,
- in select conditions of load of engine registration of courses: pressures into cylinders and into gas duct, rate of pressure into gas duct, duration of steering impulse of fuel dose put into gas duct,
- qualification of rate of pressure in gas duct and settlement of angle range of section of fuel dosage (PDP),
- qualification of optimum - locations of phase of fuel dosage (FDP) in section of dosage (PDP).

Point of load of engine was identified by qualification of rotational speed and manifold pressure. Location of PDP is definite in relation to stroke of piston in cylinder, from which takes place blowthrough of gases for executions of pneumatic fuel injection. As criterion one accepted condition formulated in figure of conjunction - in select states of load of engine possibility of obtainment of stable work and minimum values of fuel dosage per cycle (DPC).

On ground for realized measurements on engine stand one determined, that setting free of steering impulse, and also FDP to be able to take place not earlier than 55 degrees before B.D.C. into cylinder from which takes place blowthrough of exhausts gases.

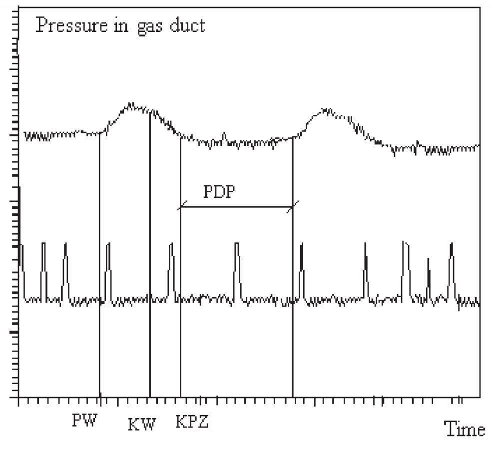

Fig. 3. Pressure in gas-mixture duct.
Rys. 3. Przebieg zmian ciśnienia w przewodzie gazowym.

In Fig. 3 one placed analysis of actual distribution phases of agent flow by the gas duct. FPS starts in point PW also remains by 45 degrees. From point KW until point KPZ takes place back-flow in gas duct which remains 25 degrees. This phenomenon is unprofitable because is keeping large influence on content of not burnt hydrocarbons in exhaust gasses. From point KPZ steps out direct stabilization of level of pressure profitable from way on repeatability values DPC. On base of experimental investigations one fixed, that location of point KPZ in relation to crankshaft angle is not stable. Other words distinct stabilization of pressure level steps out in variable angle section.

In aim of delimitation optimum of PDP values one executed a registration of course of rate of pressure into gas duct. On base of comparative analysis one fixed, that maximum value of rate of pressure (D_v) in section of dosage of fuel (PDP) to gas duct cannot exceed 1[kPa] /crankshaft angle. In result of investigations and analysis's one qualified a value of PDP as equal 100 degrees. One represented this in Fig. 4.

The evaluation of process of combustion was conducted on a routine methodology basing on measurements of pressure in combustion chamber, the analysis of rate of pressure, and as well as the qualitative estimate of cycle of initial ignition. It the mixture of unleaded motor petrol and vegetable oil as fuel was applied in proportion 1:1. It was marked as symbols B and B/OR (Figs 5 and 6.).

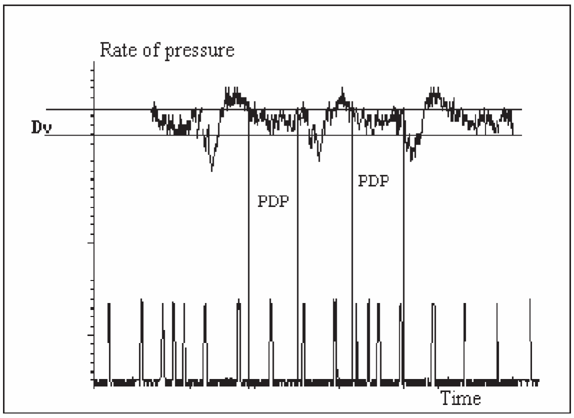

Fig. 4. Rate of pressure in exhaust duct.
Rys. 4. Przebieg zmian prędkości narastania ciśnienia w przewodzie gazowym.

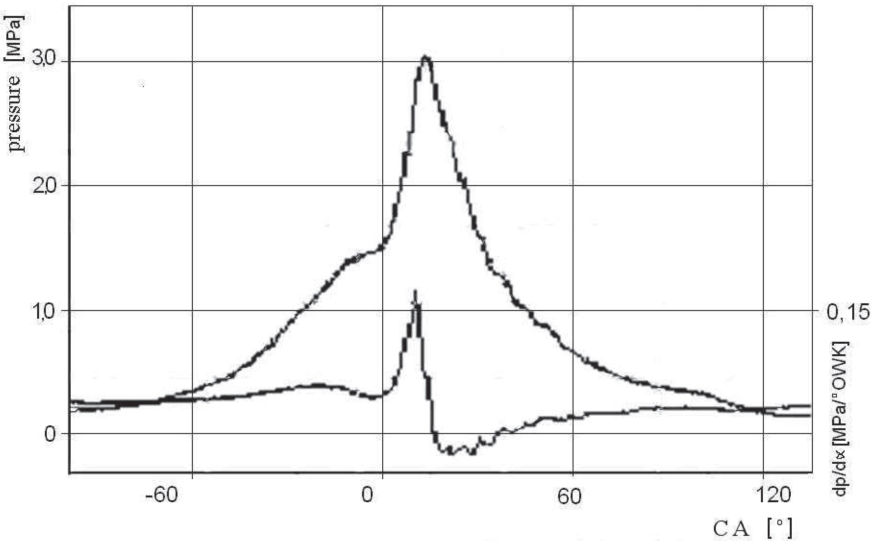

Fig. 5. Pressure in combustion chamber: $X(P_{max})$ = 3,1 MPa,
(dp/dα)max = 0,16 MPa/1°CA, fuel B.
Rys. 5. Wykresy indykatorowe ciśnień spalania: $X(P_{max})$ = 3,1 MPa,
(dp/dα)max = 0,16 MPa/1°OWK, paliwo B.

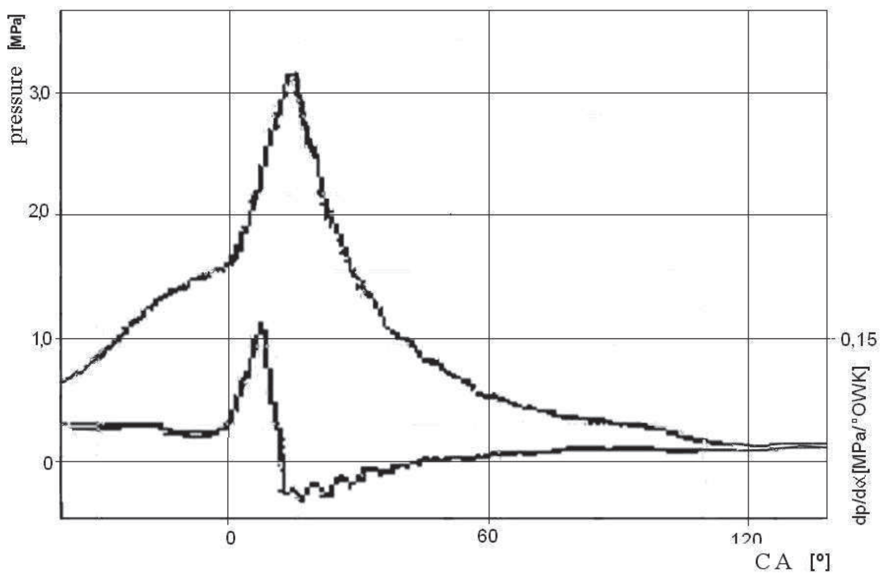

Fig. 6. Pressure in combustion chamber: $X(P_{max})$ = 3,3 MPa,
(dp/dα)max = 0,18 MPa/1°CA, fuel B/OR.
Fig. 6. Wykresy indykatorowe ciśnień spalania: $X(P_{max})$ = 3,3 MPa,
(dp/dα)max = 0,18 MPa/1°OWK, paliwo B/OR.

5. Recapitulation

On the base of executed experimental works and analysis's of results of investigations one formulated following conclusions:

- one obtained information about possibility of steering with dose of fuel in range of useful load of engine,
- in the lower load, where an engine spends the majority of its operating life, the requirement in relation assurances of fuel dosage repeatability are realized with reserve,
- in the lower load, one observed occurrence unprofitable changes of value coefficients of work of engine in due measure of retarding of beginning FDP in relation to beginning PDP phase.

In effect of these works the possibilities of fuel injection control in two-stroke engines became estimated. This is a low cost in-cylinder fuel injection system for stratified charge of engine. In the combustion system presented the process of preparing liquid hydrocarbon fuel for combustion is one of the main factors influencing the efficiency of the conversion of chemical energy contained in the fuel to mechanical energy. The most significant is the fuel phase transition, and especially a repeatability of the fuel dose per cycle. This process is inseparably associated with the physical properties of fuel, and changes of rate of pressure in gas duct. Spraying and injection of fuel, give additional possibilities of complete evaporation of light fuels, alternative fuels with extended fraction and heavier fuels, such as diesel oil, kerosene and vegetable oil, which may be very beneficial from the viewpoint of practical realization of utilization processes.

References

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Dwusuwowy silnik spalinowy z pneumatycznym wtryskiem ciekłych biopaliw

S t r e s z c z e n i e

W artykule zaprezentowano wyniki prac dotyczących zagadnień sterowania wtryskiem ciekłego biopaliwa w dwusuwowych silnikach spalinowych o zapłonie iskrowym. Badania przeprowadzono na dwusuwowym silniku spalinowym o zapłonie iskrowym wyposażonym w prosty konstrukcyjnie system wtrysku pneumatycznego umożliwiający uwarstwienie ładunku. Istota działania tego systemu (oparta na koncepcji prof. St. Jarnuszkiewicza) polega na wykorzystaniu energii części gazów spalinowych jednego cylindra dla dokonania wtrysku paliwa do drugiego cylindra. Uzyskuje się w ten sposób znaczną poprawę rozpylenia i odparowania dawki paliwa, w stosunku do rozwiązań alternatywnych, co stwarza potencjalne możliwości stosowania ciekłych paliw o tzw. rozszerzonej frakcji oraz paliw alternatywnych na bazie olejów roślinnych. W prezentowanym systemie zasilania i spalania proces przygotowania ciekłego paliwa węglowodorowego jest jednym z głównych czynników wpływających na sprawność zamiany energii chemicznej paliwa na energię mechaniczną. Najbardziej znaczącym jest proces zmiany postaci fazowej paliwa oraz powtarzalność dawkowania paliwa na cykl roboczy. Zagadnienia te są nierozerwalnie związane z fizycznymi właściwościami biopaliwa oraz przebiegiem zmian ciśnienia w przewodzie gazowym systemu wtrysku pneumatycznego. W efekcie przeprowadzonych prac uzyskano zadawalającą powtarzalność dawkowania oraz rozdziału paliwa dla każdego cylindra. W praktyce eksploatacyjnej silnik z prezentowanym systemem wtrysku może być zasilany paliwami o zróżnicowanym składzie frakcyjnym i grupowym, co stwarza dodatkowe możliwości z punktu widzenia praktycznej realizacji procesów utylizacyjnych.