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UNIFORMITY OF DIESEL OIL DOSAGE IN DUAL FUEL ENGINES

RÓWNOMIERNOŚĆ DAWKOWANIA OLEJU NAPĘDOWEGO W SILNIKACH DWUPALIWOWYCH*

Adaptation of compression ignition engines to dual fuel supply can be accomplished both in case of modern engines equipped with common rail system and older engines equipped with classic injection system (piston pumps). Due to big differences in price of gaseous and liquid fuels there is observed a natural tendency to use very small initial doses. At current level of introduction of gaseous fuels to powering of traction engines there is a need to provide alternating fuelling of the engine with the Diesel only and in dual fuel system. It requires usage of original injection systems in the dual fuel engines, what largely restricts possibility of reduction of the initial doses. In the paper are presented investigations concerning uniformity of the dosing by in-line piston pump of the P56-01 type and two types of injectors with common rail system. The investigations have shown that the P56-01 pump adjusted for nominal doses shows big non-uniformity of the dosage in area of small doses. Improved uniformity of the dosage can be attained in result of adjustment for a smaller doses, what allows reduction of the dose to about 15-20% of nominal dose and improves smoothness of engine operation. Also in case of the injectors in common rail system, reduction of the doses is limited due to worsening of uniformity of the dosing from one cycle to another, and failure of the dosing. It results from the fact, that minimal doses in dual fuel system are smaller than the ones present in case of idling speed when the engine is run on the Diesel oil only. In case of the injectors in common rail system, minimal initial doses possible to be obtained are equal to 10-15% of the nominal dose.

***Keywords**: dual fuel engine, initial dose, uniformity of dosage, ignition of gas, combustion.*

Adaptacja silników o zapłonie samoczynnym do zasilania dwupaliwowego może być dokonywana zarówno dla nowoczesnych silników z systemami common rail jak i starszych silników wyposażonych w klasyczną aparaturę wtryskową (pompy tłoczkowe). Ze względu na duże różnice cen paliw gazowych i ciekłych występuje naturalna tendencja do stosowania bardzo małych dawek inicjujących. Na obecnym poziomie wprowadzania paliw gazowych do zasilania silników trakcyjnych istnieje konieczność zachowania przemiennego zasilania silnika samym olejem napędowym i w systemie dwupaliwowym. Wymaga to zastosowania w silnikach dwupaliwowych oryginalnej aparatury wtryskowej co ogranicza w znacznym stopniu możliwość zmniejszania dawek inicjujących. W pracy przedstawiono badania równomierności dawkowania tłoczkowej pompy rzędowej P56-01 oraz dwóch typów wtryskiwaczy układu common rail. Badania pokazały, że pompa P56-01 wyregulowana dla dawek znamionowych wykazuje dużą nierównomierność dawkowania w zakresie małych dawek. Poprawę równomierności dawkowania można uzyskać przez regulacją pompy dla dawek mniejszych, co pozwala zmniejszyć dawkę do około 15-20% dawki znamionowej i poprawia równomierność pracy silnika. Również w przypadku wtryskiwaczy common rail zmniejszanie dawek jest ograniczone z powodu pogorszenia równomierności dawkowania z cyklu na cykl i zaniku dawkowania. Wynika to z faktu, że minimalne dawki w systemie dwupaliwowym są mniejsze od występujących dla wolnych obrotów przy zasilaniu samym olejem napędowym. W przypadku wtryskiwaczy common rail minimalne dawki inicjujące jakie można uzyskać wynoszą 10-15% dawki znamionowej.

***Słowa kluczowe**: silnik dwupaliwowy, dawka inicjująca, równomierność dawkowania, zapłon gazu, spalanie.*

1. Introduction

Dual fuel supply of compression ignition engines with CNG gas and Diesel oil results from many benefits offered by this type of fuelling. To the most important can be included:

- possibility to maintain the engine power output at unchanged level [6, 8],
- high engine efficiency [1, 3, 4, 6, 8, 12],
- possibility of alternate fuel supply – in dual fuel system or with Diesel oil only,
- possibility of combustion of gas-air mixtures in wide range of change of the excess air ratio [2, 8, 12],
- lower operational costs of the engine.

The last from the above mentioned factors is the most decisive when decision about gaseous fuelling of the engine is to be taken. It results from big difference in price of gaseous and liquid fuel, being worldwide on a similar level for decades. Generation of unit engine work in case of gaseous fuelling is two times cheaper than in case of fuelling with Diesel oil. Due to the above, in adaptation of the engines to dual fuel supply is seen a tendency to maximal reduction of liquid fuel consumption. It results in natural tendency to usage of small initial doses.

Size of the doses depends on whether the engine is to be run alternatively on Diesel oil and in dual fuel system, or serial injection system is to be used, or the engine is to be specially prepared to small doses. Depending on type of the adaptation, one uses the following initial doses, specified as percentage portion to energy of unit dose of Diesel oil in nominal conditions Q_{jzn}:

- $15 \div 25\% Q_{jzn}$ – when serial injection system and piston pumps are used [1, 6, 12],
- $10 \div 15\% Q_{jzn}$ – when serial high pressure systems of common rail type are used [13],
- about $5\% Q_{jzn}$ – when additional pumps and injectors of initial dose are used [8, 11],

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

- 1,0÷1,5%Q_{jzn} – when special apparatus for unit dose injected to ignition pre-chambers is used [9, 11].

At present prevalence of CNG filling stations network, issue of alternate engine operation in dual fuel system and in traditional system is very important, because it allows for continuous engine operation in case of shortage of the gas or failure of gas supply system, what in many applications is of a fundamental meaning.

Significant economic benefits coming from utilization of gaseous engines result in profitable adaptations of both modern engines with common rail systems and an older engines with classic injection systems [5, 7, 10].

In case of adaptation of compression ignition engines equipped with classic injection systems and remained traditional fuelling with Diesel oil only, serial injection pump and injectors are left, as a rule, in the engine. In multi-cylinder engines, uniformity of the dosing by the pump is adjusted at nominal doses, limiting size of maximal and minimal dose. At partial engine loads, size of the dose is changed simultaneously for all cylinders by change of position of toothed bar of the pump. Worsening of uniformity of the dosage by the pump in such conditions is not significant due to lower combustion pressures in the cylinders.

From application in dual fuel engine point of view, injection pump should fulfill the following conditions:

- should enable injection of possibly small initial dose,
- the sections should inject similar doses for nominal load,
- the sections should inject the same dose in such range of change of the rotational speeds, for which fuelling with the gas is anticipated.

In the paper is presented issue connected with uniformity of the dosing of Diesel oil when small doses are used in classic piston pumps (on example of the P56-01 pump) and in modern systems of common rail type.

2. Analysis of test results

Uniformity of the dosing by the P56-01 pump was investigated on the test bench, measuring average doses injected by individual sections, 1-6, for 1000 successive injections, with various adjustments of the toothed bar (what corresponded to various values of average dose calculated for all sections) and different rotational speeds of the pump.

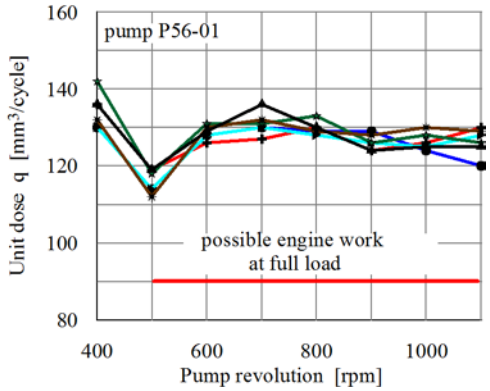

Fig. 1. Dosing of the sections, 1-6, of the P56-01 piston pump adjusted at nominal doses: maximal displacement of the toothed bar

Investigations of the P56-01 pump used in the SW680 engine have shown, that the pump adjusted at nominal dose and full displacement of the toothed bar assures satisfactory uniformity of the dosing in range of rotational speeds of 600÷1100 rpm (Fig. 1 – individual lines in the Fig. 1-3 correspond to values of the doses injected by individual sections), at which the engine can operate at full load. In range of rotational speeds specified above, a characteristic of the dosing is nearly flat, while change of size of the dose for an individual section doesn't exceed 13%.

Together with reduction of the dose (Fig. 2) occurs a significant worsening of uniformity of the dosing, especially at lower rotational speeds. Doses injected by the sections decrease distinctly together with reduction of the rotational speed (especially clearly visible for rotational speed of 500 rpm), what may cause failure of the dosing at the lowest speeds. It results from increased portion of leaks in the sections in total volume of the fuel injected by the injectors. Such phenomena increase when the doses are smaller than 30 mm^3/cycle, Fig. 2c

If the dose is further diminished to average value of about 20 mm^3/cycle, failure of the dosing occurs at a higher rotational speed (Fig. 2d). It results in non-uniform engine operation and increased emission of the THC. The phenomena described here disable further reduction of the initial dose.

On the base of the test results presented in the Fig. 2 it is possible to ascertain that the P56-01 pump adjusted according to parameters specified by the producer doesn't comply with any condition required for dual fuel supply.

Improved dosing by the pump can be achieved by adjustment of dosing uniformity for a smaller dose. For instance, after performed adjustment for the dose 40 mm^3/cycle at 600 rpm, one obtained a considerable improvement of uniformity of the dosing at doses of 20÷25 mm^3/cycle, Fig. 3a. It enabled substantial improvement of engine operation when the engine was powered with the gas. The SW 680 en-

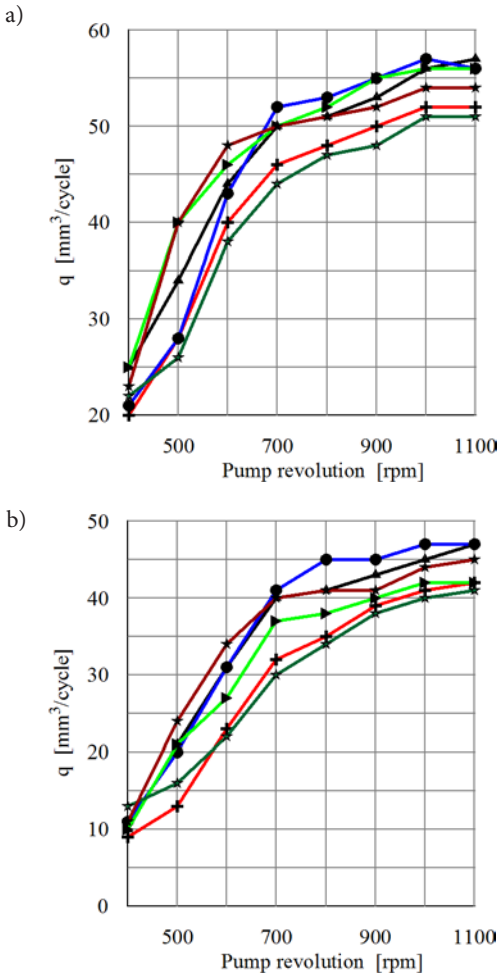

Fig. 2. Non-uniformity of the dosing by the sections, 1 – 6, of the P56-01 piston-type injection pump with relief valves – DV 86g1: a) adjustment of the toothed bar for about 48 mm^3/cycle of average dose for all sections at 700 rpm, b) adjustment of the toothed bar for average dose of about 35 mm^3/cycle at 700 rpm

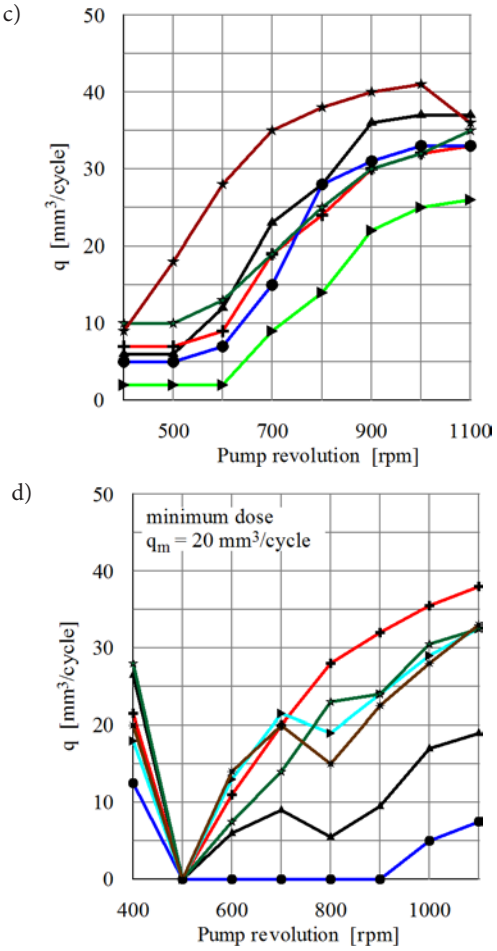

Fig. 2. (continued) Non-uniformity of the dosing by the sections, 1–6, of the P56-01 piston-type injection pump with relief valves – DV 86g1: c) adjustment of the toothed bar for average dose of about 25 mm³/cycle at 700 rpm, d) adjustment of the toothed bar for minimal dose

gine showed smooth operation in case of various rotational speeds and loads, both in steady states and during rapid changes of performance parameters.

Simultaneously, however, uniformity of the dosing by the pump was worsened after shift of the toothed bar to position of nominal dose (Fig. 3b), what corresponds to fuelling with the Diesel oil only. Differences in dosing by the pump for the nominal dose are presented in the Table 1.

Worsening of the dosing by the pump at a bigger doses should not create any serious problem in operation of dual fuel engines, because engine operation on the Diesel oil only should be considered as emergency fuelling (lacking of the gas or failure of the installation). Frequency of its usage should decrease together with development of CNG filling stations network. It is necessary therefore to suppose, that worsening of uniformity of the dosing at a bigger doses should not have any effect on operational durability of the engine due to small percentage of run on pure Diesel oil in total time of engine operation.

Proposed adjustment of the dosing by the P56-01 pump at a smaller doses enables substitution of liquid fuel in nominal conditions at the level of about 85%. However, due to possibility of overheating of the injectors by minimal initial dose, one proposes to increase it to about 20%Q_{jzn}. Comprehensive investigations performed on the SW 680 and SB3.1 engines by the author in the years 1995-2005 showed that use of such doses in conditions of long lasting engine operation at maximal loads doesn't result in any distinct symptoms of spray nozzles wear and overheating of the injectors. Such adjustment can be used, therefore, in traction conditions of engine operation.

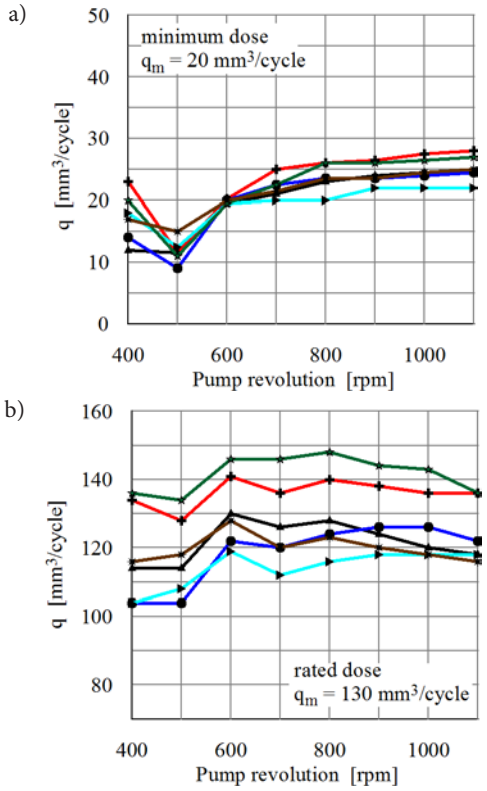

Fig. 3. Dosing by the sections, 1–6, of the P56-01 pump after adjustment of uniformity of the dosage for the dose of 40 mm³/cycle at 600 rpm: a) adjustment of the toothed bar for dose of about 20 mm³/cycle at 600 rpm, b) adjustment of the toothed bar for about 130 mm³/cycle at 600 rpm

Table 1. Differences in dosing of a section of the P56-01 pump after adjustment of uniformity of the dosing for the dose of 40 mm³/cycle at 600 rpm. Position of the toothed bar corresponding to nominal dose of 130 mm³/cycle

Pump revolution	q_{max}-q_{min}	$(q_{max}$-$q_{min})/q_m$
[rpm]	[mm³/cycle]	[%]
400	30	25,4
500	30	25,5
600	27	20,6
700	26	20,5
800	22	16,9
900	26	20,2
1000	25	19,7
1100	18	14,5

Use of common rail system with maintained condition of periodical operation of dual fuel engine on the Diesel oil only doesn't solve all problems connected with minimal initial dose. Indeed, use of factory injectors enables reduction of the dose to percentage of energetic portion of 10÷15%, but further reduction of the dose is connected with risk of non-uniformity, or failure of the dosing.

Investigations performed on two types of electromagnetic injectors used in an engines to Mercedes and Isuzu cars have shown, that at small doses a nonlinearity on characteristics of the dosage is present (Fig. 4), while at too small doses is seen a failure of the dosing. It disables decrease of the dose to a value required for robust ignition of the gas only. It denotes that when factory injectors are used, it isn't possible to obtain a high substitution of liquid fuel by the gas. This problem especially concerns partial engine loads, because dose of the

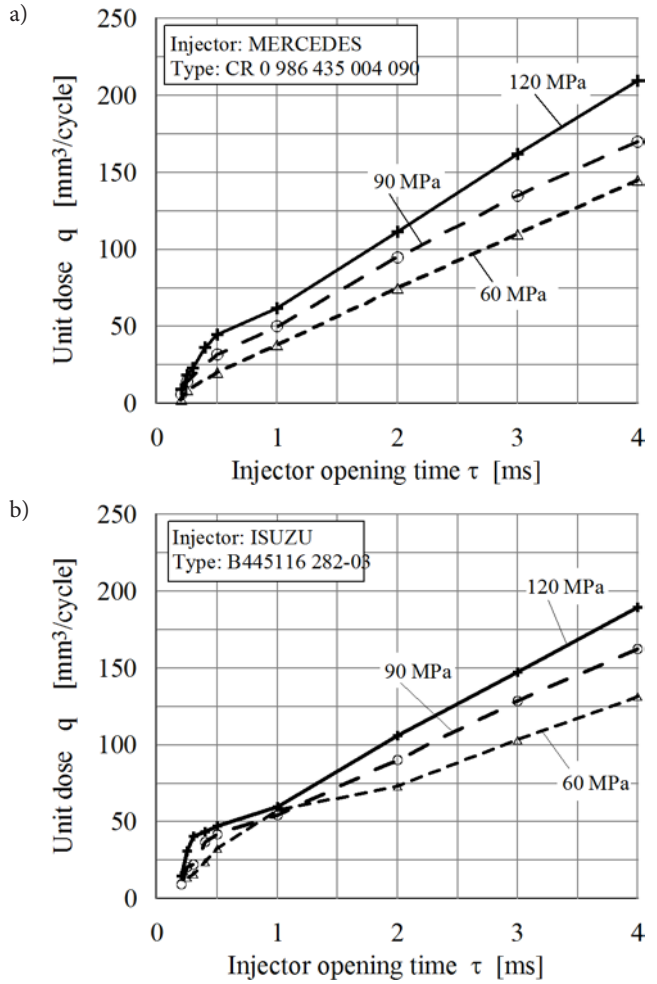

Fig. 4. Dosing by the injectors in common rail system in function of opening time of the injector for different pressures in fuel rail: a) injector from Mercedes engine, b) injector from ISUZU engine

Diesel oil remains constant due to hazard of interruptions in the dosing, and energy of the gas decreases. In traction engines such situation leads to substantial reduction of portion of the gas in operational consumption of the fuels.

3. Summary

On the base of performed investigations it is possible to make the following observations concerning fuel supply systems of dual fuel engines:

- at actual stage of introduction of the gases to fuelling of traction engines it is necessary to maintain versatility of powering of dual fuel engine, what denotes engine operation on pure Diesel oil only with maintained full engine performance;
- in case of liquid fuel powering, it is necessary to maintain correct characteristics of the injection, in range of injection angle and quality of atomization, in complete field of engine operation determined by change of engine rotational speed and load;
- in case of dual fuel operation, size of minimal dose of the liquid fuel should be selected to assure repeatable injection from one cycle to another, and proper atomization of the fuel in all conditions of engine operation;
- size of the initial dose should take into account thermal load of the injectors in nominal operational conditions;
- fulfillment of traditional and dual fuel supply conditions is possible by serial injection systems of the most engines regardless of injection systems used;
- in big stationary engines one should use a dual installations to injection of the main dose at traditional fuelling and to initial dose at dual fuel supply;
- in a high-speed stationary low-power engines, the injection systems used to fuelling with the Diesel oil should be left in the engine, and in case of dual fuel supply, size of minimal dose should be adapted to its injection capacity, taking into consideration repeatability and reliability of injections;
- in piston-type injection pumps, change of size of the dose occurs together with growth of rotational speed at constant position of the toothed bar; due to it, maintaining of constant initial dose requires changed position of the toothed bar together with change of rotational speed, what is difficult due to sensitivity of the adjustment;
- in small engines with classic injection systems it is recommended to use a fixed position of the control bar, at dual fuel supply, while size of the dose should be selected for less advantageous conditions of injectors' operation;
- adjustment of uniformity of the dosing by the pump should be performed for small doses, what improves quality of the dosing at dual fuel supply; occurring in such case worsening of dosage's quality when fuelling with pure Diesel oil should not have any effect on durability and increase of operational costs of the engine, because such type of engine fuelling should be considered as emergency mode;
- in high-pressure injection systems of common rail type at dual fuel supply, one should reduce injection pressure, what improves characteristics of the dosage and extends control time of opening of the injector.

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