ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1137330

THE EFFECT OF PRESSURE IN A COMMON RAIL ACCUMULATOR ON ENGINE OPERATING PARAMETERS

Wawrzyniec Gołębiewski

West Pomeranian University of Technology in Szczecin
Department of Automotive Vehicles Operation
Piastów Av. 17A / Room 308A, 70-310 Szczecin, Poland
tel.:+48 91 4494045, fax: +48 91 4494045
e-mail: wawrzyniec.golebiewski@zut.edu.pl

Abstract

The issues addressed in this paper concern the effect of pressure in the Common Rail accumulator on the engine operating parameters such as its torque, power output, rotational speed as well as its hourly and specific fuel consumption. Here, the research methods were performed by using the engine test bench strictly in accordance with the specific standards but particularly according to the requirements specified by these standards. The research station was the Fiat Multijet 1.3 JTD engine with turbocharging and direct injection, used as a power unit in the motor cars. Additionally, the experimental tests were run by using also (1) the HP-made measuring set for measurements the high pressure (up to 2,500 bars) in the Common Rail system, and (2) the CDIF/2 diagnostic interface.

All relationships are presented in the form of graphs, and what is found here is the increasing linear relationship between the p rail pressure and the engine speed: with an increase in speed comes a decrease in the total injection time. The torque and its power output were a function of both the pressure in the Common Rail accumulator and the speed. It was found that the highest total engine efficiency (fuel consumption per unit) was for the rail pressure ranging from 1,000 to 1,100 bars. The findings come up for discussion about the apt choice of pressure in the rail, together with the total injection time and the turbocharger highest efficiency, for the specified speed of a car power unit.

Keywords: *Common Rail fuel injection system, accumulator pressure, engine-operating parameters*

1. Introduction

The most popular Common Rail accumulator fuel injection systems were developed by FIAT under the name of Unijet and used in motor cars Alfa Romeo 1.9 and 2.4 JTD. This company, when designing a series of Multijet engines, increased the number of fuel injection phases from two to five (pilot injection, pre-injection, main injection, after-injection and post-injection). This number of fuel injection phases allowed silent and smooth operation of engine [4].

The possibility of many fuel injections during one working cycle allows flexible formation of fuel injection characteristics. The most important parameters affecting the accuracy of dosing are fuel injection pulse, fuel rail pressure and fuel temperature. While the fuel injection pulse can be accurately controlled by a system controller, the fuel pressure and temperature being found in the system change dynamically, affecting the dose size and the whole injection characteristics and the same the engine parameters [1, 2].

Balawender et al. [2] undertook the problem of multi-phase injection effect on selected parameters of Common Rail fuel injection systems. Each test series was carried out in a measuring chamber at a fixed temperature of injected fuel, fuel pressure in fuel rail and working frequency of fuel injectors, which followed from the rotational speed n of high-pressure pump shaft. Among others, Fiat's fuel injectors being used in the 1.3 JTD Multijet engine were tested. Experiments consisted in the examination of fuel expenditure on pilot and main dose injection, depending on the rotation degree of fuel injection pump shaft between fuel injections for the fixed fuel injection pulse t = 1.0 ms (0.5 ms – pilot dose, 0.5 ms – main dose) and rotational speed of high-pressure pump shaft n = 600 rpm.

A similar problem connected with the fuel expenditure and the accumulator rail pressure was taken up in the paper by Ustrzycki and Kuszewski [7]. Two fuel types were compared in it, which were diesel oil ON and biodiesel B20 (mixture of 80% diesel oil +20% rapeseed oil methyl ester). Experiments were carried out for 4 types of fuel injectors. One of them was fuel injectors from the Fiat 1.3 JDT Multijet engine, marked as 0 445 110 083 (W083). Tests were made at the engine speed n = 1000 rpm and for different fuel injection pulses tijn = 1 ms and tijn = 3 ms and different accumulator pressures rail = 75 MPa, rail = 100 MPa and rail = 125 MPa.

Based on these data, comparative characteristics for two fuels were made, being the fuel expenditure [mg/injection] to the Common Rail pressure [MPa] relationships. Fuel injectors W083 were characterised by slightly higher expenditure (within 5 mg/injection) of biodiesel B20 when compared to standard diesel oil for both fuel injection pulses.

The effect of Common Rail accumulator pressure on engine operating parameters has not been taken up in literature yet, therefore the author of this paper decided to undertake this research problem.

2. Research objective and methods

The objective of this research project was to determine the effect of Common Rail pressure on the achievement of operating rates by compression-ignition, direct fuel injection, turbo-supercharged engine designed to drive motor cars. Research methods were conducted in conformity with the Polish standards PN-ISO 15550, PN-ISO 3046-1 and PN-ISO 3046-3 [11-13]. Experiments were performed according to the requirements specified in them using an engine test bench. Test points were prepared for feeding an engine with a full fuel dose, being determined by the system controller.

A normative reference [11] reproduced the German standard DIN, according to which engine power output had been measured.

This was an indicated power output reduced by the losses resulting from bearing friction and ancillary equipment drive, such as for instance AC generator or coolant pump.

Engine power output, also called gross power, was described according to the following formula [8]:

$$N_e = p_e\, V_s\, i\, n\, \tau, \tag{1}$$

where:

p_e – effective pressure being obtained in a cylinder [Pa],
V_s – displacement volume [m^3],
i – number of cylinders,
n – engine speed [min^{-1}],
τ – engine timing rate, for two-stroke engines = 1, for four-stroke engines = 0.5

3. Test bed

The test bed consisted of the following components:

a) fuel tank (diesel oil) – a 750 litre fuel tank designed for diesel oil, made of plastic,
b) fuel pump – to ensure fuel pressure from fuel tank and introduce it into fuel line system,
c) Automex gravimetric fuel flow meter – a necessary component for measuring fuel consumption over time by means of the gravimetric method; the fuel being not burned by engine went back into it,
d) eddy current brake EMX 100 manufactured by Elektromex (Poland) – a device for power take off and measurement in combustion engines place on test beds,
e) programmer with power panel, fuel gauge, Fiat Panda 2 indicator kit with a software, and a Common Rail high-pressure measurement kit, engine and brake operation control with the reading of main parameters, such as power, engine torque and the data obtained from sensors. An additional element attached to this kit was CDIF/2 diagnostic interface with a firmware.

Fig. 1. CDIF/2 graphical interface

The Common Rail high-pressure measurement kit consisted of a manometer, a T-connection with nozzles, vent and stopper, a measuring hose, fuel pipes, a reduction and a venting hose.

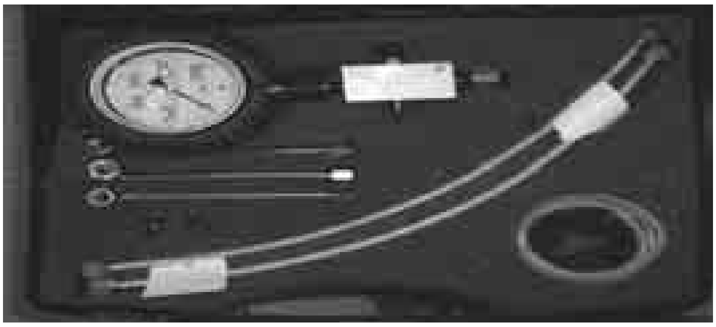

Fig. 2. HP-made Common Rail high pressure measurement kit

f) Fiat 1.3 JTD Multijet engine – a compression-ignition, four-stroke, turbo-supercharged, direct fuel injection engine with fuel feed system of the Common Rail type. It was equipped with four cylinders arranged in-line. Each cylinder had four valves that were controlled through hydraulic followers by two camshafts being placed in the head. Camshafts were driven by a power chain with pulley. Fuel injection was controlled electronically with air supercharging by turbo-supercharger and air cooler. The engine was controlled by means of electronic high pressure injection system designed by Magneti Marelli [10].

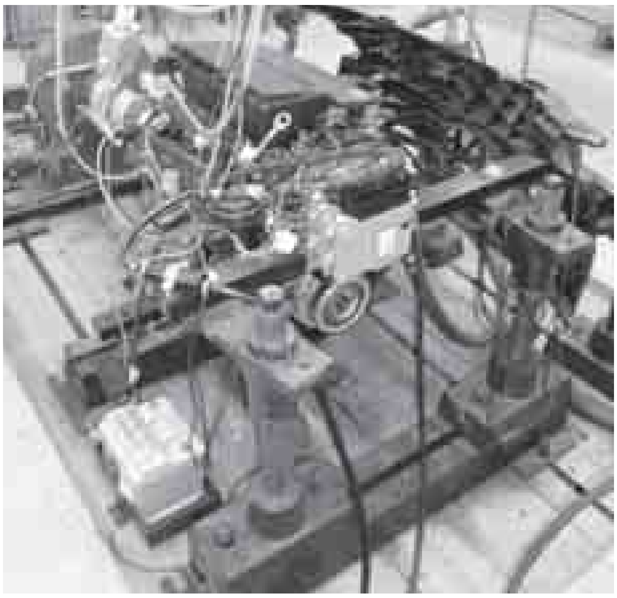

Fig. 3. The view of Fiat 1.3 JTD 16 V Multijet engine connected with eddy current brake EMX 100 by means of drive shaft

In Tab. 1 below, engine details are given according to manufacturer's data.

Tab. 1. Engine details according to manufacturer's data [10]

Make: FIAT		Type: 1.3 JTD 16 V Multijet
Work cycle		4-stroke
Cylinder diameter	[mm]	69.6
Piston travel	[mm]	82
Compression ratio		18.1
Number of cylinders		4
Arrangement of cylinders		in-line
Injection sequence		1-3-2-4
Engine capacity	[cm^3]	1248
Maximum power	[KM/kW]	1 19/51
Rotational speed at maximum power	[min^{-1}]	4000
Maximum torque	[Nm]	145
Rotational speed at maximum torque	[min^{-1}]	1750

4. Results

The obtained measurement results are summarised in Tab. 2 and presented in Figs 4, 5 and 6. The engine was fed with a full dose of ON EKODIESEL fuel of the Cetane number 51.1. Ambient parameters during the test were as follows:

– ambient temperature T_a = 294 K,
– ambient pressure p_a = 98.5 kPa,
– relative humidity = 40%.

The engine torque and engine power output being measured was corrected according to the relations comprised in the standard PN-ISO 15550 [11].

Tab. 2. Measurement results for engine parameters

	n	Ttq	Pd	B	B	b	rail	accumulated fuel injection pulses
Item	[rpm]	[Nm]	[kW]	[g/s]	[kg/h]	[g/kWh]	[bar]	[ms]
1	1000	71.4	7.50	0.59	2.106	279.0	550	1.272
2	1500	124.4	19.5	1.39	5.004	253.5	750	1.097
3	1700	139.6	24.9	1.65	5.922	234.0	750	0.992
4	1900	140.1	27.9	1.78	6.399	225.7	800	0.985
5	2000	138.1	29.0	1.85	6.651	226.9	850	0.958
6	2200	137.7	31.7	2.01	7.227	225.1	950	0.923
7	2400	135.2	34.1	2.08	7.497	217.4	1100	0.873
8	2500	134.4	35.2	2.20	7.920	222.4	1150	0.850
9	3000	134.6	42.3	2.75	9.891	231.1	1200	0.834
10	3500	124.2	45.6	3.08	11.088	240.3	1300	0.815
11	4000	115.1	48.3	3.38	12.150	248.7	1400	0.754
12	4500	94.6	44.7	3.25	11.691	260.4	1400	0.695

where: Ttq – corrected engine torque, Pd – corrected engine power output, B – specific fuel consumption and hourly fuel consumption, b – specific fuel consumption, rail – Common Rail pressure;
R^2 – coefficient of determination (squared coefficient of correlation)

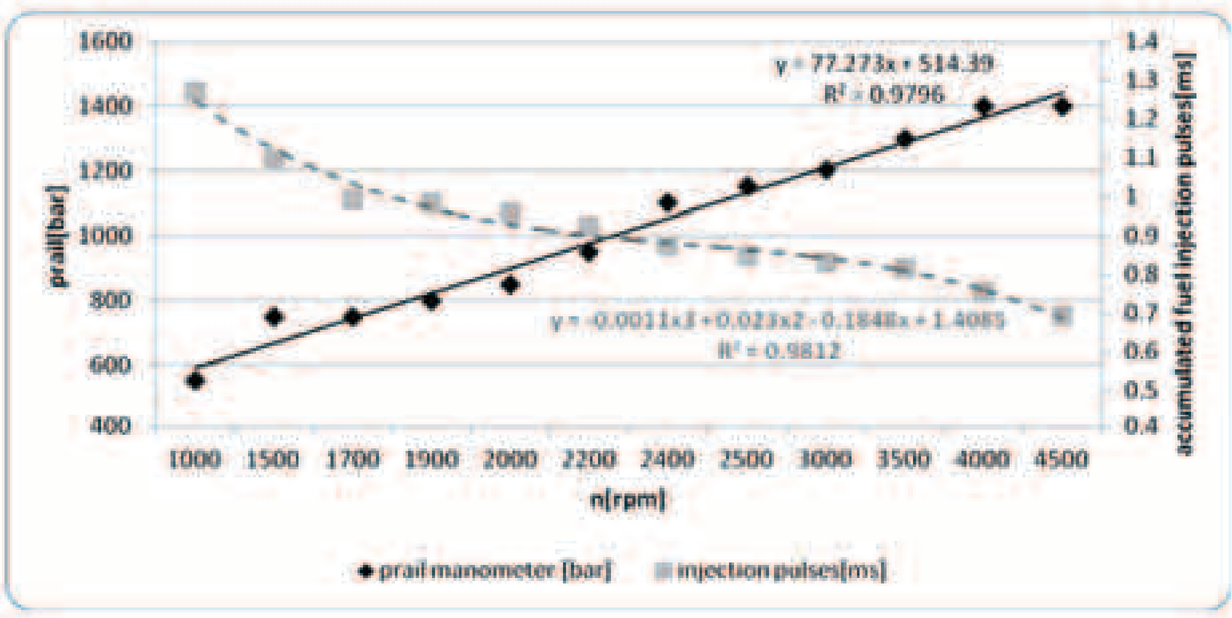

Fig. 4. CR pressure and accumulated fuel injection pulse to engine speed relationship

Fuel injection pulse decreased for more and more higher engine speeds. A different situation was in case of the pressure rail, which showed an upward trend. The matching of trend curves (first degree straight line – Common Rail pressure, third degree curve – accumulated fuel injection pulses) with high values of the coefficients of determination R^2(0.9796 and 0.9812 for the pressure rail and accumulated fuel injection pulses, respectively) was an evidence of a good fitting of theoretical values to the actual ones.

The next parameters taken into account during measurements were engine torque and its power output.

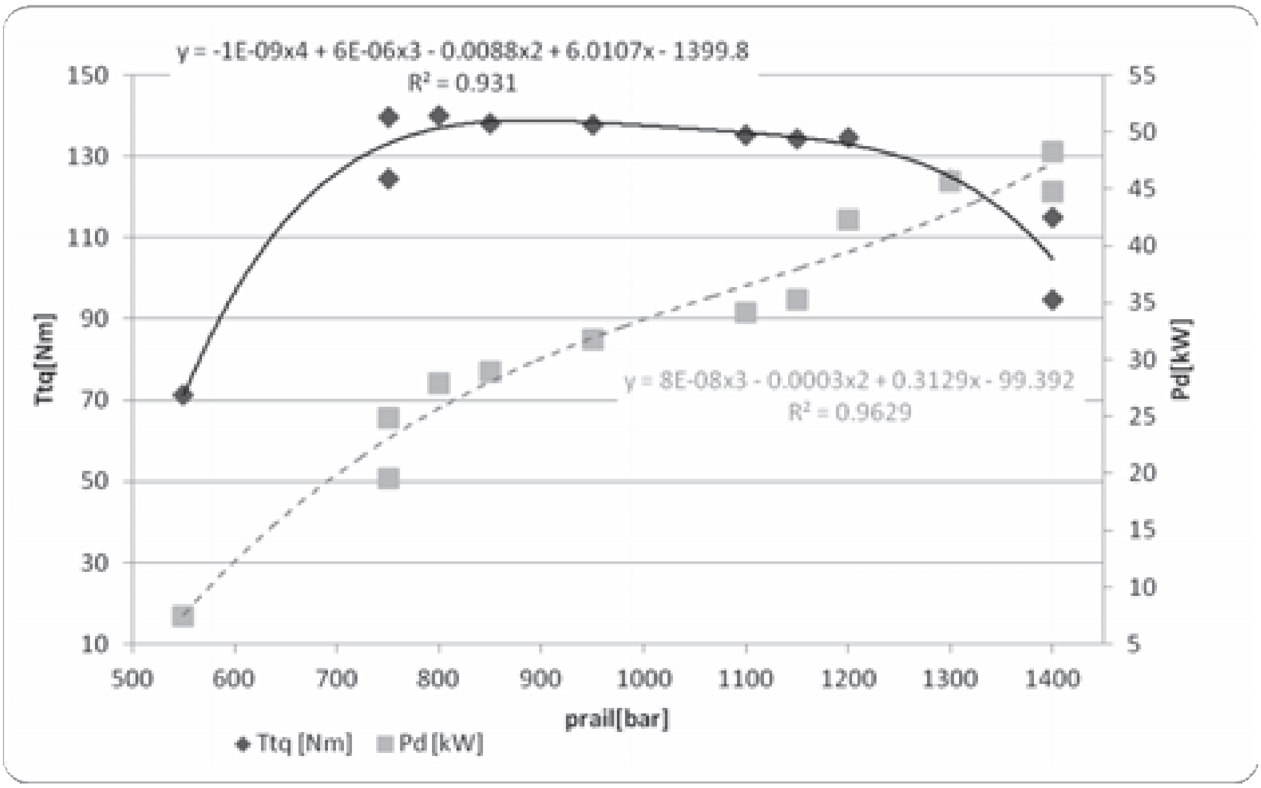

Fig. 5. Torque and engine power output to CR pressure relationship

The characteristics being illustrated above resemble the course of external characteristic curve for engine torque and its power output in relation to its speed. Thus, this confirms the linear relationship from Fig. 4, which is evidence of a growing linear relation of the pressure rail in relation to rotational speed.

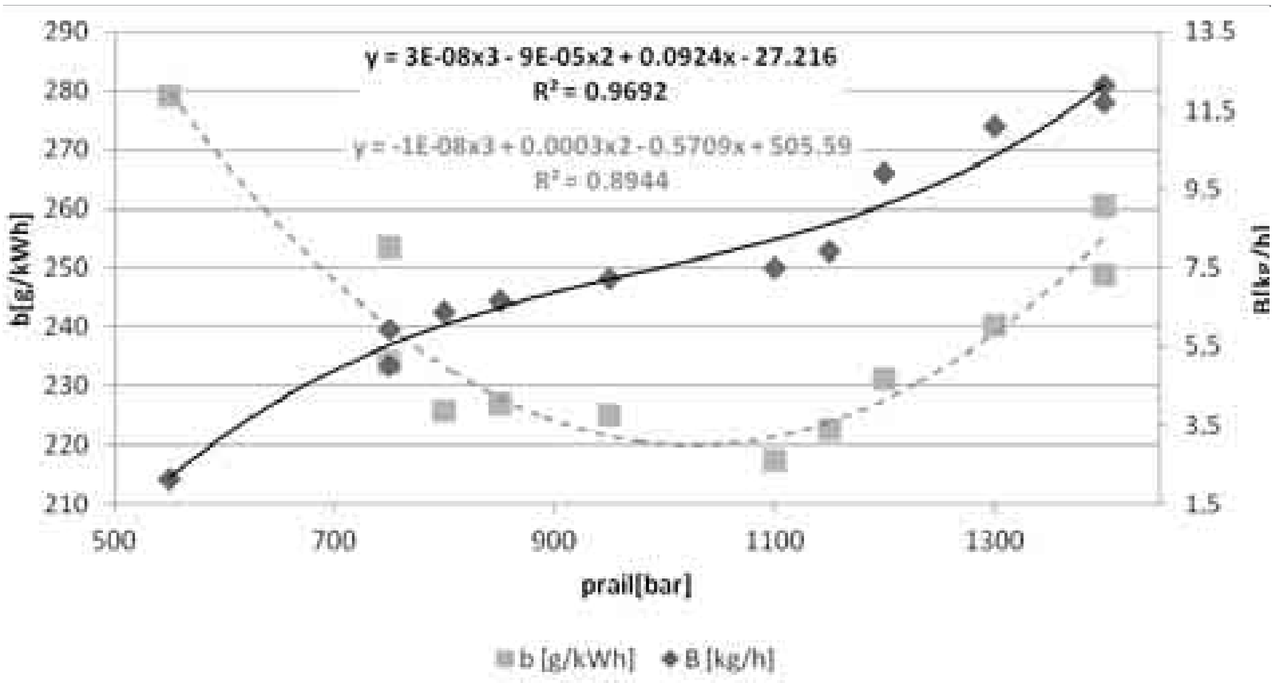

Fig. 6. Specific and hourly fuel consumption to CR pressure relationship

The measure of total engine efficiency, and therefore the specific fuel consumption according to actual measurements is the lowest at the pressure rail = 1100 bar, but it would be found near the pressure rail = 1050 bar when taking into consideration the matching of trend curve. The hourly fuel consumption increases with the increasing values of accumulator pressure. These indices satisfy the most significant ecological function; therefore, it is worth considering how to match the pressure rail with fuel injection pulse and the highest efficiency of turbo-supercharger. This could result in lesser and lesser fuel consumption.

5. Conclusions

The Common Rail type systems are the most vigorously developing fuel systems in compression-ignition, turbo-supercharged engines with direct fuel injection Continuous evolution in the construction of power units with these systems allows achievement of fuel injection pressures just above 200 MPa. The value of pressure in a Common Rail accumulator is of significant importance for fuel injection pressure. It is that what have a significant influence on the course of engine torque curve and consequently on the course of in-time work capability curve, and therefore on engine power output.

Depending on the matching of engine to a vehicle and its destination, the accumulator pressure should be gradually increased but it is also worth considering if a longer accumulated fuel injection pulse would not be a better solution in terms of engine durability (valve group and piston-rings-cylinder assembly). A pursuit to achieve optimum CR pressures together with controlled co-operation of turbo-supercharger considerably increases total engine efficiency (specific fuel consumption), which results in the achievement of specific power from smaller quantity of consumed fuel.

References

[1] Balawender, K., Kuszewski, H., Lejda, K., Ustrzycki, A., *The effect of angle position of main, pilot and preinjection fuel dose on NOx formation in compression ignition engine with Common Rail system,* Journal of KONES, Powertrain and Transport, Vol. 15, No. 3, 2008.

[2] Balawender, K., Kuszewski, H., Lejda, K., Ustrzycki, A., *Wpływ wielofazowości wtrysku na wybrane parametry systemu zasilania Common Rail,* Silniki spalinowe, Wydawnictwo PTNSS, Nr 4/2008, Bielsko-Biała 2008.

[3] Gunther, H., *Układy wtryskowe Common Rail w praktyce warsztatowej*, WKŁ, Warszawa 2010.

[4] Janiszewski, T., Mavrantzas, S., *Elektroniczne układy wtryskowe silników wysokoprężnych,* WKŁ, pp. 46, Warszawa 2010.

[5] Pietras, D., Świątek, P., *Dobór kalibracji sterowania silnika 1.3 Multijet w aspekcie jego osiągów i składu spalin,* Silniki spalinowe, Wydawnictwo PTNSS, Nr 2/2008, Bielsko-Biała 2008.

[6] Praca zbiorowa, *Zasobnikowe układy wtryskowe Common Rail*, WKŁ, Warszawa 2009.

[7] Ustrzycki, A., Kuszewski, H., *Comparative study of fuel injection at Common Rail system using different types of fuel,* Journal Of KONES Powertrain and Transport, Vol. 18, No. 3, Warsaw 2011.

[8] Wajand, J. A., Wajand, J. T., *Tłokowe silniki spalinowe*, WNT, pp. 130, Warszawa 2005.

[9] Wisłocki, K., Pielecha, I., Czajka, J., Maslennikov, D., *Jakościowa analiza rozpylania paliwa ciekłego w wysokociśnieniowych piezoelektrycznych układach wtryskowych*, Silniki spalinowe, Wydawnictwo PTNSS, Nr 4/2010, Bielsko-Biała 2010.

[10] Zembowicz, J., *Fiat Panda,* WKŁ, pp. 12, 92, Warszawa 2005.

[11] PN-ISO 15550, *Silniki spalinowe tłokowe, Określenie i metoda pomiaru mocy silnika, Wymagania ogólne,* PKN, Warszawa 2009.

[12] PN-ISO 3046-1, *Silniki spalinowe tłokowe, Osiągi. Część 1: Deklaracja mocy, zużycia paliwa i oleju smarującego oraz metody badań, Dodatkowe wymagania dotyczące silników ogólnego zastosowania,* PKN, Warszawa 2009.

[13] PN-ISO 3046-3, *Silniki spalinowe tłokowe, Osiągi, Część 3: Pomiary podczas prób*, PKN, Warszawa 2009.

[14] www.automex.pl.

[15] www.elektromex.arg.pl.