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External speed–torque characteristics of Fiat 0.9 TwinAir petrol- and CNG-fuelled engine

The paper presents the results of the experimental study of the turbocharged spark ignition Fiat 0.9 TwinAir engine, with indirect, multipoint petrol injection system, powered by petrol and equipped with the injection system of the compressed natural gas (CNG) supplying gas into the intake manifold. The test results provide the comparison of the selected fuel-efficiency, energetic and ecologic indicators of engine work, obtained when it is powered by Pb95 petrol and the CNG gas. The paper compares the external torque-speed characteristics with factory-set engine controllers. Also presented are the concentration levels of harmful gases in the exhaust fumes: carbon monoxide (CO), nitric oxides (NO_x), hydrocarbons (HC) and carbon dioxide (CO_2). Results obtained on the engine powered by CNG are indicating lower power and torque, lower concentration of hazardous gases, in particular carbon monoxide and hydrocarbons as well as significantly lower consumption of the gas when compared to petrol.

Key words: *spark ignition engines, gas engines, gasoline engines, external characteristic, gas engines emissions*

1. Preface

Development of piston combustion engines and the requirements related thereto has manufacturers strive for decreasing the emission of hazardous components of the exhaust gases in order to meet the obligatory emission standards as well as to improve engines energy efficiency [8]. One of the methods to meet the rigorous standards is downsizing and using alternative gas fuels, in particular LPG and CNG. Vehicle owners are using this kind of fuels as they are usually much less expensive than other alternative fuels. Using gases as fuel in spark ignition (SI) engines requires an independent fuel supply system, operated by an additional ECU controller which receives information from the factory petrol supply ECU controller [10]. This paper presents the analysis of results of the selected engine's work parameters, which were obtained as the engine was powered by petrol and CNG. In the CNG fuel supply system, the injectors opening time was controlled on the basis of the signals controlling the petrol injectors [4, 11]. Given the differences between gas fuels and petrol in terms of physical and chemical properties, a scrupulous analysis is required to determine the influence of gas fuels on engine's work characteristics, in particular on the external characteristics, indicating the engine's maximum performance [3]. An important aspect is the attempt of rationalising the algorithm which controls the gas supply systems, commonly used in small turbo-charged petrol engines. The physical and chemical properties of fuels constitute an important area which needs to be studied in order to organise the process of controlling the engine's work. Its assessment and analysis should provide a significant possibility of reducing harmful impact of engines upon natural environment [2]. Another important aspect of improving engine performance are the electronic controls [6]. The results obtained in the tests of the Fiat 0.9 TwinAir engine suggest the necessity of modifying the maps of electronic control unit of the gas powered engine in order to develop required power and correct torque characteristics while maintaining or improving engine's ecological and economical properties at the same time. Using electromagnetic gas injectors controlled by an additional controlling unit allows a good flexibility in managing their opening times. It is also possible to improve the injection advance angle of fuel, depending on engine speed-torque working conditions. Precise dosage of gas fuel as well as maintaining good fuel atomisation provides conditions for proper combustion of the air-fuel mixture and for obtaining high energetic engine efficiency [7]. Using the sequence injection system has also it's disadvantages which is the impossibility of modifying the supercharging control parameters and controlling the inlet valves by the gas controller. It is also not possible to correct the ignition advance angle. Preliminary tests have shown that it is necessary to modify the above-mentioned parameters in order to improve the working characteristics of the engines fuelled by CNG, in particular to increase the power and torque.

2. Test object

The object under test was a two-cylinder, four stroke turbo-charged spark ignition Fiat 0.9 TwinAir engine. It is equipped with a multi-point indirect (MPI) fuel injection system as well as the compressed gas injection system providing the CNG into the intake manifold. The engine uses MultiAir technology, developed by Fiat. This technology allows to control the cylinder fulfilment rate, depending on speed-torque working conditions of the engine. In the Fiat 0.9 engine, cylinder filling process is carried out by means of mechanical -hydraulic timing system, controlling the operation of the engine's inlet valves and turbocharger wastegate [1]. Inlet valve opening is done by the pistons of the hydraulic system, shifted by engine oil located in a variable-volume closed chamber. The chamber volume is changed by electro-hydraulic valves, which are controlled with signals from the engine's electronic control unit.

The tested Fiat 0.9 engine reaches a maximum power of 85 bhp at 5500 rpm and maximum torque of 145 Nm at 1900 rpm. Table 1 presents the basic technical data of the tested engine.

Table 1. Technical data of the Fiat 0.9 TwinAir engine [1]

Parameter	Unit	Value
Cylinder arrangement	–	in-line, vertical
No of cylinders	–	2
Cylinder diameter	mm	80.5
Piston stroke	mm	86
Cylinder capacity	cm^3	875
Compression ratio	–	10 ± 2
Timing system	–	OHC, 4 valves per cylinder

3. CNG fuel supply system in Fiat 0.9 TwinAir engine

Engine under testing was equipped with sequential injection system of compressed natural gas, supplying CNG into the intake manifold. The scheme of the fuel supply system is presented on Fig. 1.

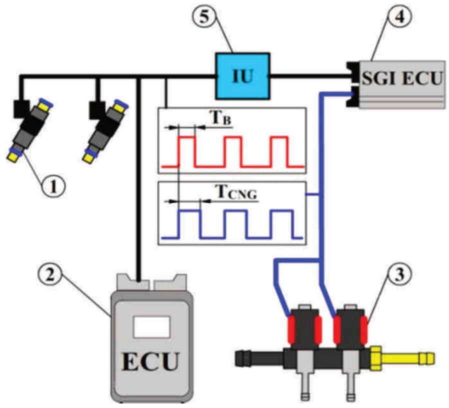

Fig. 1. Scheme of the sequential injector of gas controls [11]: 1 – petrol injector, 2 – engine control unit, 3 – gas injector, 4 – sequential gas injection electronic control unit, 5 – disconnecting injector interface unit, T_B – petrol injector opening time, T_{CNG} – gas injector opening time

Gas injectors are controlled by the electrical signals from additional Stella Elisa controller, manufactured by Elpigaz. The controller receives signals from the petrol injectors, then calculates and corrects the values of opening times according to the following formula [11]:

$$T_{CNG} = \{[T_B + Offset + f(D) + f(E)\} \cdot f(TR) \cdot f(P) \cdot f(TM)$$

where: T_{CNG} – gas injector opening time, T_B – petrol injector opening time, f(TR) – reducer's temperature dependence correction function, f(TM) – correction function, depending on gas temperature in the fuel rail, f(P) – correction function, depending on actual differential pressure in reducer-vaporiser, f(D) – correction function of fuel – air mixture composition, depending on nozzle diameter, E – correction coefficient, Offset – signal offset in the function of crank shaft angle, depending on the type of gas injectors.

4. Test stand

The tests were carried out on the Automex EMX 100/10000engine test bench, equipped with eddy current brake. The test bench is presented on Fig. 2. The brake control system is linked with the engine's electronic controller and enables setting the speed and torque working conditions of the engine. The measurement system of the test bench enables reading data in real-time and acquisition of measurement data and the engine's working parameters, such as the pressure and temperature of: lubricating oil, the air in air intake system before the turbocharger, the air after the intercooler and the exhaust fumes in the engines exhaust system.

Fig. 2. Test bench of the Fiat 0,9 TwinAir engine

The emission measurements of the key exhaust fumes components were carried out by the AVL DiCom 4000 emission tester. Petrol consumption was measured with the ATMX2040 ODIUT Automex gravimetric fuel gauge, whereas the consumption of the CNG was measured with the Emmerson Elite MicroMotion flow meter, which uses the Coriolis effect. The scheme of the test equipment is presented on Fig. 3.

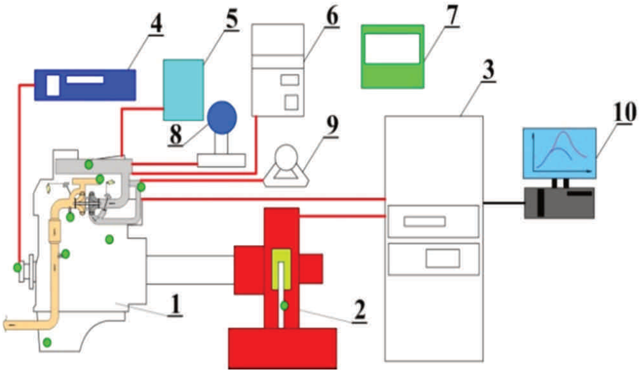

Fig. 3. Test bench scheme: 1 – Fiat 0,9 TwinAir engine, 2 – Automex AMX 100/1000 eddy current brake, 3 – control unit, 4 – AVL IndiSmart 612 cylinder pressure measurement system, 5 –ATMX2040 gravimetric fuel gauge, 6 –AVL DiCom 4000 exhaust analyser, 7 –KTS 540 diagnostic tester, 8 – ABB Sensy Flow air flow meter, 9 – EMERSON Elite gas flow meter, 10 – PC workstation

The test bench also enables to control the engine working parameters and ensures users safety. In addition, the test stand is equipped with a data processing module obtained from measurement files.

5. Characteristics of natural gas as a fuel for powering combustion engines

The spark ignition engines are mainly powered by petrol, which is the mixture of oil hydrocarbons, obtained in oil refining process. The second most popular fuel for spark ignition engines is the LPG gas, which is a mixture of oil hydrocarbons [9]. The quality requirements of the liquefied propane-butane gases (C_3–C_4) being used as a vehicle fuel are found in the Polish standard PN – EN 589+A1:2012. Over the recent years, the number of vehicles running on natural gas has been growing. There is an increasing amount of drivers who decide to equip their vehicles with the compressed gas fuel installation. The natural gas is one of the elementary natural sources of energy. As a mixture of light organic hydrocarbons, it is considered to be an ecologic fuel. It is about twice as light as air, very easily miscible with air which ensures a homogeneous combustion mixture [8]. The main component of natural gas is methane (CH_4). Engines are powered by the natural gas with high methane content, with the methane mass content exceeding 90% [5]. The gas for powering vehicles may be a gaseous phase (CNG – Compressed Natural Gas) and liquid phase (LNG – Liquified Natural Gas). It is considered to be an environmentally-friendly fuel as it does occur in the free state in nature [13]. A significant advantage of using natural gas as a vehicle fuel is low emission of the carbon dioxide and residual emission of exhaust solid particles. That makes the natural gas an excellent alternative for powering vehicles which are used in towns. The advantageous properties of the natural gas are also found when it rests in vehicle tanks. Unlike petrol or Diesel fuel, the natural gas trapped in a tight tank does not have a negative impact on the natural environment, since it releases no hazardous hydrocarbons to atmosphere. Thus, it is not necessary to use fuel absorber [5, 8]. The basic parameter which differentiates fuels is their chemical composition, determining a correct course of creating combustible mixture and providing the quality of combustible process, defined by such parameters as: ignition delay, combustion time, combustion temperature. These parameters determine the correct work of the engine while maintaining low concentration of hazardous exhaust substances. The key properties of natural gas and petrol are presented in Table 2.

Table 2. Selected properties of petrol and natural gas – comparison [3, 9]

Parameter		Unit	Fuel type	
			Petrol	Natural gas
Calorific value		MJ/kg	42.5–43.5	50
Calorific value of stoichiometric mixture		MJ/m^3	3.5	3.4
Octane number	research		95–98	100
	motor		85–88	110
Air demand for complete combustion		kg	14.7	17.2
Normal conditions density		kg/m^3	715	0.695
Laminar flame speed		m/s	0.3–0.6	0.34
Ignition temperature		°C	480–550	645
Boiling temperature		°C	35–210	–162
Evaporation heat		kJ/kg	350–380	510

The Polish standard specifies the required properties of gas fuels used for powering engines.

One of the advantages of the natural gas in that it does not require being delivered by vehicles to petrol stations located in town centres or towns with gas piping infrastructure, as it may be directly supplied by means of such infrastructure.

The number of vehicles, both in Poland and abroad, which are powered by gas fuels, is increasing. Poland is the leading country in regard to the amount of vehicles fuelled by LPG [13]. The number of CNG-powered vehicles is still low, with a ratio of merely 1.5%. This is mainly due to insufficient infrastructure of petrol stations which allow CNG refuelling. Currently, there are 26 such stations in Poland. The growing interest of using natural gas as a vehicle fuel may be proved by the ongoing extension works of the LNG port in Gdansk. The provisions of the Directive of the European Parliament and the Council 2014/94/EU introduce the strategy of developing infrastructure which allows for refuelling vehicles with natural gas and for increasing the share of alternative fuels on the market. The CNG fuel is increasingly more popular in public transport operators and transport companies [12].

In the future, CNG may revolutionise the fuel market, which is currently aimed at diversification of available oil-based products. In this context, there is another advantage of the CNG worth mentioning – the potential users may be very independent of petrol stations as they may use small compression aggregates to refuel vehicle. This solution, however, is still relatively expensive at the moment due to high prices of such devices.

6. Test schedule

The test schedule comprised the test bench examination of the Fiat 0,9 SGE engine, operating in accordance with the external speed characteristics and with the engine speed of correspondingly: 1500, 2500, 3500, 4500, 5500 and 6000 rpm. The characteristics have been set with the petrol engine fuelled by the lead-free 95 octane petrol (Pb95) as well as with compressed natural gas (CNG). During the tests with petrol fuelling, the engine was operating on the factory map settings of the Fiat 500c model. The external characteristics of the CNG-fuelled engine was carried out with gas injectors being controlled by the Elisa Stella controller, programmed as recommended by the manufacturer.

During the tests, the torque-speed working conditions were set and the measured values included the engine's power and torque, hourly fuel consumption as well as the concentrations of the following exhaust components: carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO_x) and hydrocarbons (HC).

7. Test results

The first external characteristic was made on the engine being fuelled by petrol, the second one – on the engine fuelled by CNG. The characteristics are presented on Fig. 4.

The acquisition system allowed determining the power generated by the engine at specific speed and torque working conditions. On the basis of the obtained characteristics, it has been established that there is a considerable effective power decrease across the entire rotational speed range when it was fuelled by CNG. The maximum effective power of the engine was 55 kW at the engine speed of n = 5300 rpm.

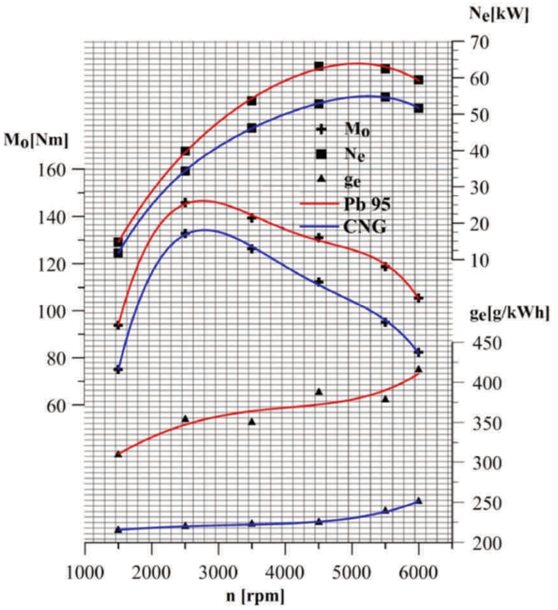

Fig. 4. External torque-speed characteristics of the Fiat 0.9 TwinAir engine, fuelled by Pb 95 petrol and CNG

When powered by petrol, the maximum effective power of the engine was 63 kW at n = 5050 rpm.

The torque of the CNG-powered engine was lower by about 16% when compared to the torque of petrol-fuelled mode.

The specific fuel consumption of the CNG-fuelled engine was decreased by approximately 40%.

The emission of the key exhaust components are presented in Figures 5–8.

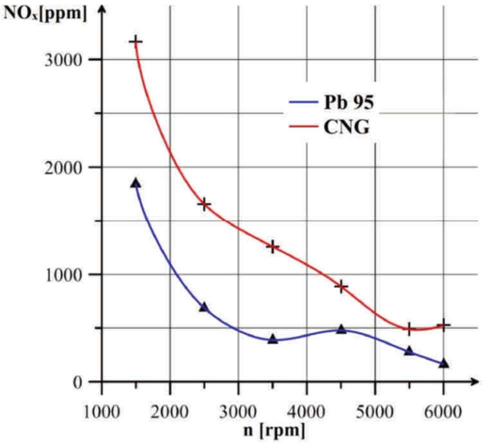

Fig. 5. Concentration of nitric oxides in the Fiat 0.9 TwinAir engine exhaust gases, working with external speed characteristics and fuelled by petrol Pb 95 and CNG

The concentration of the nitric oxides in the exhaust gases of the CNG-fuelled engine increased by max. 48% at the engine speed of n = 1500 rpm. With rotational speed higher than n = 4000 rpm, the concentration of this component was only slightly higher when compared to the concentration obtained with petrol-fuelled engine. In addition, the concentration of hydrocarbons in the CNG-fuelled mode was considerably lower, in particular at low and medium engine speeds.

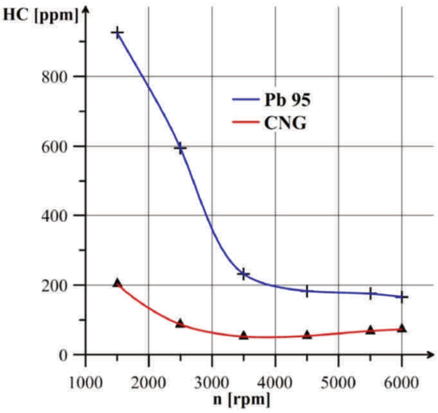

Fig. 6. Concentration of hydrocarbons in the Fiat 0.9 TwinAir engine exhaust gases, working with external speed characteristics and fuelled by petrol Pb 95 and CNG

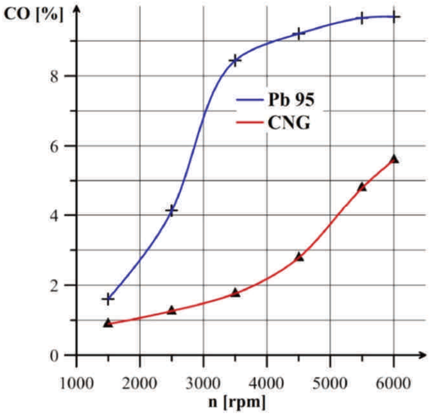

Fig. 7. Concentration of carbon monoxide in the Fiat 0.9 TwinAir engine exhaust gases, working with external speed characteristics and fuelled by petrol Pb 95 and CNG

The result of the engine being powered with CNG was the reduction of the carbon monoxide concentration across the entire range of crankshaft rotational speed as well as slight reduction in the emission of the carbon dioxide in the rotational speed range between n = 1500 and 2700 rpm. In the rotational speed range between n = 3000 and n = 6000, the concentration of carbon dioxide in exhaust fumes of CNG-powered engine was only slightly higher than that of petrol-fuelled engine.

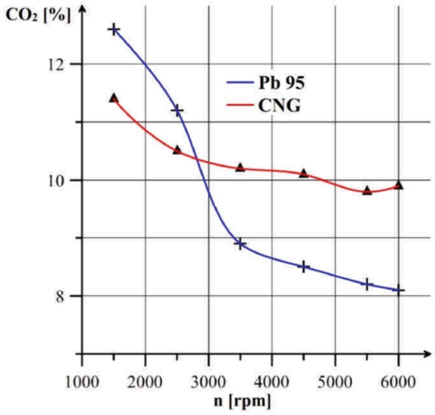

Fig. 8. Concentration of carbon dioxide in the Fiat 0.9 TwinAir engine exhaust gases, working with external speed characteristics and fuelled by petrol Pb 95 and CNG

Conclusions

The current development trends of the internal combustion engines prioritise minimisation of their harmful impact upon natural environment. The efficient method of meeting the rigorous fuel emission standards is powering engines with alternative gas fuels, in particular with natural gas. A significant interest of the researches who examine and assess the engine work figures, as well as positive results of the experiments which test the engines powered by gas fuels prove the rationality of using such fuels in powering all kinds of transport and industrial vehicles.

The results of the Fiat 0.9 TwinAir engine tests reveal both the advantages and drawbacks of the CNG used as a fuel. As regards the impact on natural environment, the tests demonstrate a considerable decrease in concentration of the harmful exhaust components, mainly hydrocarbons and carbon monoxide. On the other hand, the CNG-fuelled engine reached lower power and torque as well as increased emission of nitric oxides and carbon dioxide in higher ranges of crankshaft rotational speed. The CNG-fuelled engine had a much lower specific fuel consumption, which indicates a high energetic efficiency of the combustion process. Fuel consumption has a significant impact in terms of ecology and it is an essential criterion of choosing alternative fuel by vehicle users. Improving work performance in modern combustion engines, which are already very efficient constructions, is a difficult challenge in terms of electronic control of the engine's work processes and it requires an individual approach. Appropriate management of rationalisation of the regulation parameters of the engine powered by gas fuels will considerably enhance the diversification of oil-based fuels. In the future, natural gas may become a primary fuel for powering internal combustion engines.

Nomenclature

CNG	compressed natural gas
LNG	liquified natural gas
LPG	liquified petroleum gas
Pb95	95 octane petrol
MPI	multi point injection
ECU	electronic control unit
IDI	indirect injection
SI	spark ignition

Bibliography

[1] AMBROZIK, A., AMBROZIK, T., KURCZYŃSKI, D., ŁAGOWSKI, P. Conversion of Fiat 0.9 Multiair engine to multi-fuelling. *Journal of Kones*. 2013, **20**(4), 9-15.

[2] AMBROZIK, A., AMBROZIK, T., KURCZYŃSKI, D., ŁAGOWSKI, P. Modern experimental set-up for investigations into strategies for the control and fuelling of spark ignition engines. *Combustion Engines*. 2015, **162**(3).

[3] BACZEWSKI, K., KAŁDOŃSKI, T. Paliwa do silników o zapłonie iskrowym. *Wydawnictwo Komunikacji i Łączności*. Warszawa 2005.

[4] GAJEK, A., JUDA, Z. Czujniki. *Wydawnictwa Komunikacji i Łączności*. Warszawa 2015.

[5] GRZYB, R., KOTOWSKI, W. Nowe wymagania jakościowe na paliwa silnikowe. *Paliwa, Oleje i Smary w Eksploatacji*. 2001, **83**, 5-8.

[6] KNEBA, Z., MAKOWSKI, S. Zasilanie i sterowanie silników. *Wydawnictwo Komunikacji i Łączności*. Warszawa 2004.

[7] MAJERCZYK, A., TAUBERT, S. Układy zasilania gazem propan-butan. *Wydawnictwo Komunikacji i Łączności*, Warszawa 2004.

[8] MERKISZ, J., PIELECHA, I. Wymagania i kierunki rozwoju napędów zasilanych gazem ziemnym CNG/LNG. *Zeszyty naukowe Politechniki Częstochowskiej*, Mechanika **26**, 458-475.

[9] MERKISZ, J., KOZAK, M. Wymagania jakościowe stawiane benzynie przez nowe generacje silników o zapłonie iskrowym. (cz.1, cz. 2). *Paliwa, Oleje i Smary w eksploatacji*. 2002, **104**, 5-8; 2002, **105**, 23-26.

[10] ROMANISZYN, K. Alternatywne zasilanie samochodów benzyną oraz gazami LPG i CNG. *Wydawnictwa Naukowo-Techniczne*, Warszawa 2007.

[11] SKARPETOWSKI, B. Nowoczesne rozwiązania w samochodowych instalacjach gazowych. *Zeszyty naukowe Politechniki Częstochowskiej*. **162**, Mechanika 26, 504-509.

[12] WOŁOSZYN, R. Gaz ziemny jako przyszłościowe paliwo silnikowe w komunikacji miejskiej. *Autobusy*. Radom 2004.

[13] WOŁOSZYN, R., HOFMAN, P. Stacje tankowania gazu ziemnego. *Autobusy: technika, eksploatacja, systemy transportowe*. 2010, **3**, 20-22.

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