CONVERSION OF FIAT 0.9 MULTIAIR ENGINE
TO MULTI-FUELLING

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Abstract

The development of human civilisation has always been related to an increase in energy demand. The growth of transportation and an increase in the number of automobile vehicles in service produce a rising demand for fuel. Before piston IC engine is replaced with a different effective power source, it is necessary to use gaseous fuels on a larger scale than ever before. The natural resources of gaseous fuels are estimated to be much higher than crude oil reserves. Additionally, engines can run on biogas, i.e. gaseous renewable fuel. The use of gaseous fuels means lowering the harmful effect engines produce on the natural environment. Multi-fuelling, i.e. switching from one fuel to another, could be an advantageous feature of automobile combustion engine, both from the user's standpoint and with respect to environmental concerns. Gaseous fuels have desirable properties that are especially suitable for fuel of spark ignition engines. The paper presents the engine test bench constructed at the Laboratory of Heat Engines of the Kielce University of Technology. The test stand comprises modern spark ignition engine Fiat 0.9 MultiAir and the eddy-current brake. At the test stand, the engine was converted to fuelling with three fuels, namely petrol, LPG gas blends and compressed natural gas (CNG). The engine could run alternatively on the three fuels mentioned above. The stand is equipped with an external unit to control the engine work, which makes it possible to extend the range of the engine investigations.

Keywords: combustion engines, fuels, fuel supply system, liquefied petroleum gas, natural gas

1. Introduction

Investigations on engine fuels constitute an important issue in piston IC engine research. They aim at satisfying the requirements imposed on engines with respect to the environmental protection [9]. Presently, engine fuel research focuses on two key areas. The first concerns hydrocarbon fuels commonly used for engine fuelling. The fuel composition is modified to obtain more effective and economical combustion. Increasingly complex technologies for crude oil processing are developed and implemented. Different additives are designed to assure advantageous properties of fuels. In Poland, the production of fuels with improved environmental properties started in the 1990. Those included Ekodiesel and ONM Standard diesel oils. Leaded petrol began to be gradually withdrawn. The other research area dealt with seeking alternative fuels which could gradually replace the conventional ones [1, 3, 8, 14, 19]. As piston IC engines have become highly advanced, a perfect solution would be to use such alternative fuels that do not require extensive changes in the construction of engines that are presently in service.

The requirements for piston IC engine fuels are defined, in detail, by international and domestic legal regulations and by standards that characterise the values of basics parameters with respect to the fuel quality. The standards are modified depending on presently binding requirements, which mainly concern the exhaust gas toxicity. Such actions are intended to determine such fuel properties, for which the pattern of combustion will be the most effective and the environmental impact of engine work will be minimised. Currently, a trend can be observed to compile uniform

worldwide fuel specifications [6, 11, 20]. Those results from quality issues related to advanced engine technologies, the necessity to lower the emissions of exhaust gas toxic components, and to reduce fuel consumption. Consequently, the global, negative impact of motorisation on the natural environment could be diminished.

2. Fuels for spark ignition engines

Fuels for modern piston combustion engines can be categorised as conventional and alternative. Conventional fuels have been used since the beginnings of motorised transport. For years, their properties been modified to follow the requirements posed for engines. On the other hand, the engine design has been adjusted to assure the effective combustion of conventional fuels. Spark ignition engines are designed to run on petrol as opposed to compression ignition engines, which are fuelled by diesel oils. Alternative fuels are those that can be used as petrol or diesel oil replacement.

Petrol is a mixture of hydrocarbons with the boiling point ranging from 30 to 215°C [2, 15]. Petrol contains aromatic, naphtene, and paraffin hydrocarbons and their derivatives. Because it is necessary to obtain fuel that is highly resistant to combustion knock, it is advantageous to have a high content of isoparaffin and aromatic hydrocarbons produced in the reforming process. Petrol also contains unsaturated hydrocarbons, usually olefins. They reduce petrol shelf-life because they facilitate the formation of resins. The literature on the subject summarises the development trends in modern petrol used as fuel for spark ignition engines [2, 11, 12, 18]. Those involve the reduction in the content of sulphur, aromatic hydrocarbons, benzene, olefins, and heavier hydrocarbons. They also intend to decrease vapour pressure, increase the content of oxygen compounds, and to design a new generation of washing additives.

LPG is commonly used in Poland to fuel spark ignition engines. It is a mixture of two hydrocarbons: propane C_3H_8 and butane C_4H_{10}. It also contains small amounts of other hydrocarbons, e.g. ethane and butane isomers. The fuel is considered more environmentally friendly because it allows reduced emissions of carbon oxide CO, carbon dioxide CO_2 and hydrocarbons HC [7, 10, 19]. The fuel offers other advantages like high resistance to combustion knock, easy air-fuel mixing in the engine cylinder, no content of sulphur, benzene or multi-ring aromatic hydrocarbons. The disadvantages of LPG involve, among others, higher ignition energy and lower rate of combustion, which results in prolonged combustion process. Spark ignition engines equipped with an additional LPG fuelling system are not optimised with respect to the maximum utilisation of the properties of this fuel. Petrol still remains the basic fuel for spark ignition engines.

Natural gas is another gaseous fuel that could be widely used for piston IC engine fuelling in the future [3, 4, 16, 19]. Extracted from the Earth, it is found in separate deposits, or associated with crude oil. Once the natural gas has been extracted, it must be dehumidified and, sometimes, desulphurised. Depending on the origin of the natural gas, the methane content in this fuel ranges from 85 to 99%. It also contains ethane, propane, butane and various amounts of other hydrocarbons, and impurities: nitrogen, carbon dioxide, hydrogen sulphide, argon and others [5, 13]. For automotive engine fuelling, the natural gas with above 90% methane content is used. It can be stored in two forms: as compressed natural gas CNG, and liquid natural gas LNG. Currently, CNG is more often used for engine fuelling than LNG. In Poland, natural gas is not widely used for IC engine fuelling in transport. The main reason is the lack of infrastructure for filling vehicle fuel tanks with natural gas. In the world, however, this fuel is increasingly more often used for fuelling railway engines. A number of engines in service running on natural gas is growing, both in lorries and in passenger cars. Manufacturers offer factory-built vehicles, including passenger cars, busses and lorries, running of natural gas. Natural gas fuelling makes it possible to comply with rigorous standards on the exhaust gas emissions without applying complex systems for the exhaust gas purification. In the future, natural gas can become one of the basic fuels for combustion engines, also in Poland. This fuel has a number of advantages: it is widely available, it makes it possible not to rely on

crude oil, it produces lower emissions of the exhaust gas toxic components: carbon oxide CO, carbon dioxide CO_2, nitrogen oxides NO_x and particulate matter PM. Also, it is cheaper and the operation of the engine running on natural gas is quieter.

3. Fuel systems for spark ignition engines fuelled with LPG and CNG

The engine that can run on gaseous fuels must be equipped with the fuel system, which will make it possible to deliver the fuel to the cylinders, and to control the composition of the air-fuel mixture. Presently, designs of fuel systems for engines running on gaseous fuels are well developed. Their construction and control are compliant with the requirements on the design of modern IC engines. The development of fuel systems for engines running on gaseous fuels is related to the general advancement in combustion engines and their fuel systems technologies, which in turn is caused by environmental concerns. Depending on the design of the IC engine, five generations of the fuel systems for spark ignition engines running on LPG and natural gas are found [17, 10]. The first-generation fuel systems were designed for engines, in which petrol was delivered to the inlet manifold with a carburettor or in the injection systems where lambda probe was not used. They could be installed in engines with more modern petrol injection systems after lambda probe emulator was used. In those systems, the gaseous fuel was delivered to the intake system with a mixer. The quality of the mixture composition control was usually lower than with the carburettor. The second-generation fuel systems were also mixer systems intended for fuelling the engines, in which air-fuel mixture is controlled to obtain stoichiometric composition using lambda probe in the engine exhaust system. Those systems were converted to operate with engines that were factory-equipped with SPI and MPI petrol injection systems. The quality of the mixture composition control in such systems is usually lower than in an average petrol injection system. In the third-generation systems, gas delivery is performed by injecting it, in the volatile form, to the inlet manifold. Such a system type of is used in engines working in the feedback loop controlled with the lambda probe. The control of the combustible mixture in such system is similar to that in petrol injection systems. The fourth-generation injection systems, like those third-generation ones perform the injection of LPG or CNG in the volatile phase. The difference is that the injection is sequential and performed with electromagnetic injectors. The new systems resulted from the introduction of on-board diagnostics. They were converted to operate in engines with OBD, especially when they performed active functions and the "cheating" in the form of emulators could not be used. In such systems, the LPG controller uses the control signal of petrol injectors to generate the control signal for LPG injectors. They can be installed without using emulators, which indicates a comparable quality of LPG-air and petrol-air mixtures control. The fifth-generation injection systems provide sequential injection in the LPG or natural gas liquid phase. They have all the characteristics and advantages of the fourth-generation systems. Additionally, they assure better cylinder filling, an increase in power and torque, and a reduction in the fuel volumetric consumption. The most modern LPG fuel systems are geared towards specific designs of spark ignition engines with direct petrol injection. In those systems, LPG in the liquid phase is injected directly into cylinders with the same injectors as it is the case with petrol injection.

4. The engine test bed with Fiat 0.9 MultiAir engine

The research stand presented below consists of the Lounge 0.9 8v SGE Turbo (Fiat 0.9 MultiAir) spark ignition IC piston engine, Elektromex EMX-100/10000 eddy-current brake, fuel mass flow meter manufactured by Automex Company, sensors for temperature and pressure measurements in different engine systems, and the control system for the whole stand operation. Fiat 0.9 MultiAir is the most modern design of spark ignition engine developed by Fiat and manufactured in Poland. It is compliant with presently binding EURO 5 exhaust emission standards. The engine, the eddy-current brake, and all the components necessary for the stand operation are located on the common frame.

Fiat 0.9 MultiAir is a two-cylinder engine with a displacement volume of 875 cm^3. It is equipped with multipoint indirect fuel injection to the inlet manifold. The engine is equipped with a turbo-charger and it gains the maximum brake horsepower of 62.5 kW at the crankshaft rotational speed 5500 rpm, and the maximum torque of 145 Nm at the crankshaft rotational speed 1900 rpm. The system for valve control is an unconventional solution. In the timing gear system, cams mechanically control outlet valves, whereas inlet valves are controlled by electro-hydraulic system connected with the cam mechanism. The cam only transmits the motion to the hydraulic system equipped with the electro-magnetic valve. In the position when the valve is closed, the timing gear system operates as a typical mechanical system. The electro-magnetic valve opening leads to an oil decrease in the hydraulic chamber, and in this way, it is possible to control the pattern of opening of the inlet valves. The amount of air delivered to the cylinders of Fiat 0.9 MultiAir engine is determined by direct, elastic control of inlet valves. The design solutions in the engine under consideration suggest that engines of this type will be widely used to power automotive vehicles in near future.

In addition to the original installation for fuelling with petrol, the engine is provided with installations for fuelling with LPG and CNG. The conventional fuel consumption is measured with fuel mass flow meter manufactured by Automex company, whereas for the consumption of gaseous fuel, Coriolis flow meter is used. The block diagram of the stand is presented in Fig. 1. In addition to factory-made control system, the stand is also equipped with research-dedicated external control unit, i.e. NIRA engine management system with input ignition. It offers access to configuration (regulation, change) of parameters controlling the engine work that are selected in the ECU management of the engine control functions (control of the ignition system, the fuel system, namely fuel injection times and phases, fuel injection pressure, the supercharging system, variable timing gear phases, exhaust recirculation and other actuators).
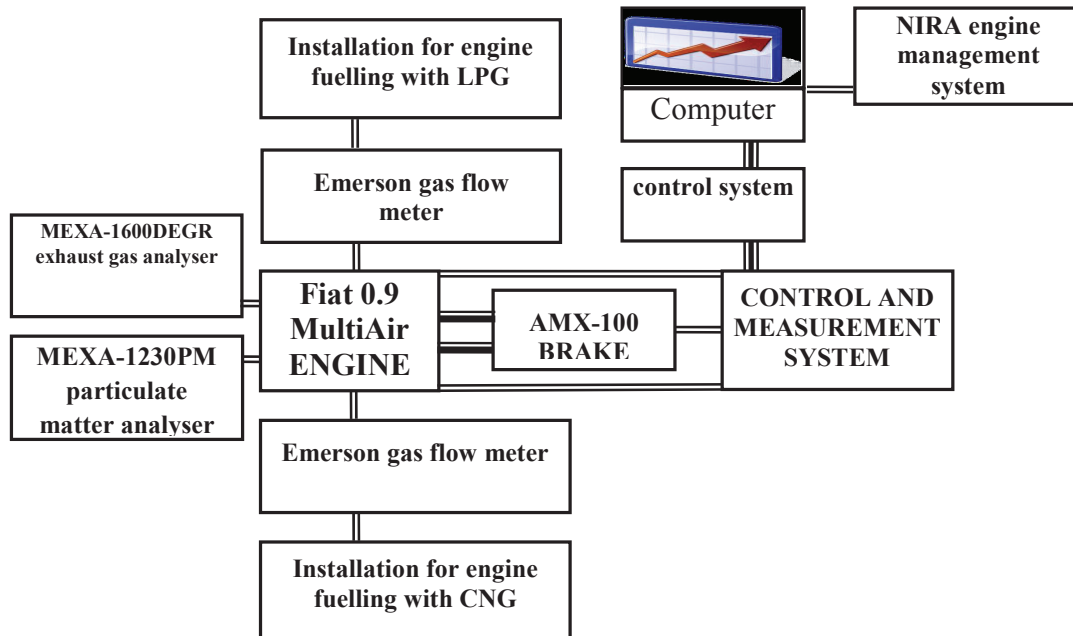

Fig. 1. Block diagram of the research stand

5. Conversion of Fiat 0.9 MultAir engine to fuelling with LPG and CNG

Fiat 0.9 MultiAir engine is equipped with the propane-butane mixture (LPG) and compressed natural gas (CNG) fuel system. The converted LPG fuel system for Fiat 0.9 MultiAir engine is the sequential gas injection system, which assures proper operation of the engine running on gas under all conditions. The installation for engine fuelling with LPG contains a portable gas tank with 60 l capacity. The tank is connected to the single-stage reducer-evaporator with an integrated gas

electro-valve. From the reducer-evaporator, LPG at required pressure is delivered to a full-flow filter of the volatile phase, and then to the injector assembly, in which the gas temperature sensor is located. STELLA I-Plus injectors, controlled electronically, feed the gas, via calibrated nozzles, gas conduits and nipples to the engine intake system, before the inlet valves. The injectors used maintain uniform rate of delivery on all sections while in service. They have invariable work characteristics when in service. They are insensitive to gas impurities and they operate within a wide range of working pressures, thus assuring a stable operation of the system. In the gas installation, a gas injection pressure sensor is located after injectors. It is connected to the engine intake system, and LPG pressure reducer and CNG pressure reducer. One controller, Elisa Stelle by Elpigaz Company, controls the operations of both the LPG fuel system and the CNG fuel system. The installation for the engine fuelling with CNG consists of four gas tanks that have the total capacity of 240 l. After the tanks, a pressure reducer is located, which reduces the gas pressure from 200 bars to approx. 25 bars, so that it is possible to take gas consumption measurements. That is done by Emerson flow meter, located next to the reducer. The flow measurements are based on the Coriolis effect. After the gas flow meter, another reducer is found. Both installations are jointed after the reducers, from which point the gaseous fuel is fed to the injector assembly via one conduit. The injectors inject either LPG or CNG into the intake manifold, depending on which fuel system is currently operating. The use of the same injectors and one control unit for fuelling with gaseous fuels lowers the costs and simplifies the design. The block diagram of the LPG and CNG converted fuel systems for Fiat 0.9 MultiAir engine fuelling with gaseous fuels at the engine test bed are presented in Fig. 2.
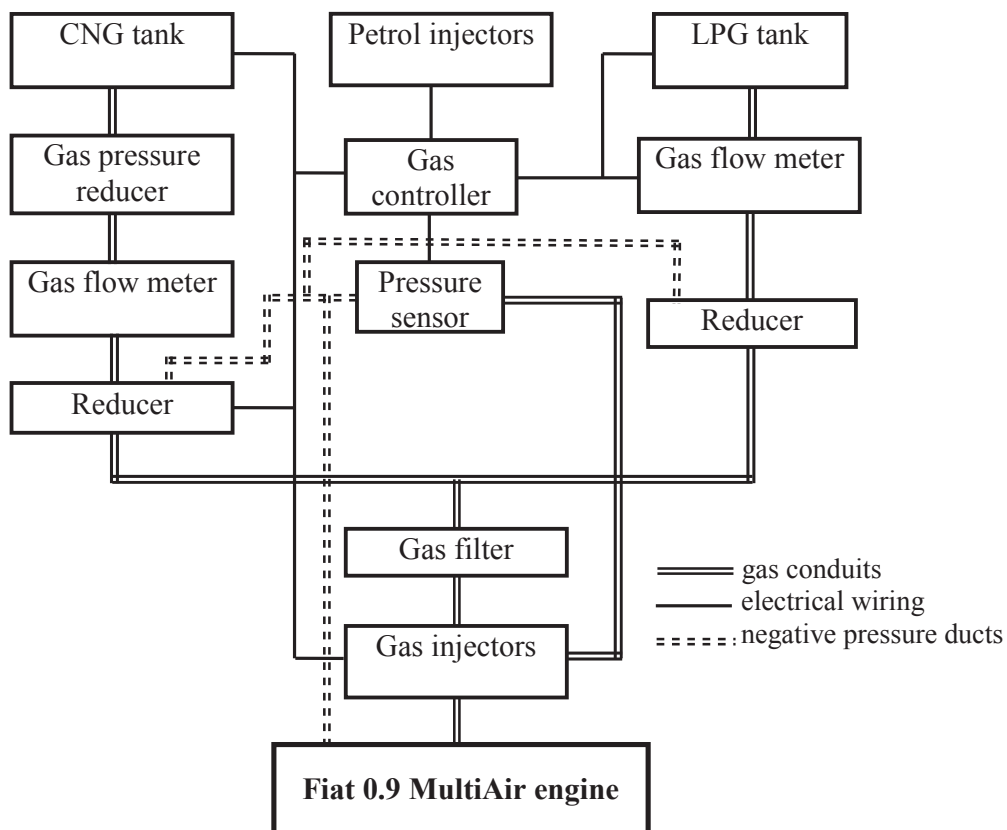

Fig. 2. Block diagram of the installation for Fiat 0.9 MultiAir engine fuelling with LPG and CNG

In modern engines with multi-point petrol injection, the amount of the fuel delivered to the cylinder depends the conditions of the engine work. They are monitored by many different sensors transmitting signals to the unit that controls the engine work. The signals substantially affect the pattern of the process of fuel-air mixture preparation and combustion. Due to the information

provided by the sensors, and on the basis of the self-contained map, the petrol injection control unit determines the petrol injector opening time separately for each cylinder. That assures a delivery of an appropriate amount of petrol per the engine working cycle. In the sequential injection, petrol is delivered to each cylinder at different time, but always at the same phase of the engine working cycle. The unit that controls the LPG and CNG fuel system in Fiat 0.9 MultiAir engine, installed at the engine test bed, controls the opening time of gas injectors on the basis of signals transmitted by the engine control unit to petrol injectors. The opening time for gas injectors is determined separately for individual cylinders. The time is corrected depending on the injected gas temperature and pressure measured on the gas line. Such a solution allows simplifying electrical connections and obtaining low exhaust emissions. It also assures effective indicators of the gas-fuelled engine work that are comparable with those for the engine running on petrol. When the engine is fuelled with gas, a disconnecting bundle linked to the unit that controls the LPG and CNG fuel system disconnects petrol injectors.

6. Summary

In recent years, the main development trends in piston IC engines reflect efforts to reduce the exhaust gas toxic emissions, and to lower fuel consumption. In the design of engines and their systems, limits as regards specific power ratio have already been achieved. That refers to both parameters of the working processes and their control. Standards on exhaust toxicity are already very tight; in the future, they might be even more rigorous. As regards spark ignition engines, compliance with the standards could be achieved by high pressure direct petrol injection, including layered mixtures and modern ignition systems, a higher degree of compression, the use of alternative fuels and devices for the exhaust gas neutralisation such as catalytic reactors installed in the exhaust systems.

One of the ways to reduce exhaust toxic emissions is the engine fuelling with gaseous fuels, including LPG, CNG and LNG natural gas, biogas and others. Those fuels have advantageous properties that can be utilised especially for spark ignition engine fuelling, which was discussed in the present study. The engine test bed presented in the paper, consisting of eddy current brake, Fiat 0.9 MultiAir spark ignition engine equipped with three fuel systems for petrol, LPG and compressed natural gas CNG, also has an external unit for the engine work control.

The gaseous fuels and petrol used for fuelling the engine at the test stand have different physical and chemical properties. The engine design was optimised for fuelling it with petrol. To effectively utilise the properties of LPG and CNG gaseous fuels for engine fuelling, it is necessary to select appropriate engine regulation parameters, e.g. the ignition advance angle or the degree of supercharging. The design of the stand makes it possible to optimise engine fuelling with LPG and CNG, which is intended because of economical, energy and environmental concerns.

One of the trends in engine development is to assure engine multi-fuelling. At the stand, Fiat 0.9 MultiAir engine can be alternatively fuelled with three fuels, namely petrol, LPG or CNG. Such a solution can be transferred to an engine actually installed in a vehicle so that it could run alternatively on the fuels mentioned above, depending on the fuel price and availability. The engine appropriate work control could be chosen depending on the fuel used.

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