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Improvement of energy balance in automotive vehicle, based on combustion engine losses

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ABSTRACT

The paper presents an innovative method to increase the overall efficiency of the internal combustion engine. The presented method is based on the kinetic energy derived from the flow of exhaust gases in the exhaust system of the internal combustion engine. This energy is used to drive a high speed turbogenerator which is integrated with the gained energy system management. Such a system, which uses energy otherwise lost in the engine exhaust system, allows the acquisition of additional electrical energy. As a result, it improves the energy balance of a motor vehicle. This is particularly important in a situation of constantly expanding system of electric receivers in vehicles. The paper presents an analysis of the research results of the system of energy recovery, carried out on turbo supercharged engine with spark ignition. The article also gives the research results on the impact of the proposed system on the environment.

KEYWORDS: recuperation, turbogenerator, exhaust system

1. Introduction

Visible demand growth for electricity on board a vehicle is associated with a continuous increase in the amount of electronic devices installed. They are both part of the equipment increasing the comfort of the vehicle, and also the instruments to ensure active and passive safety of the car. For the sake of environmental standards of today's vehicles, many car companies have introduced electronic systems into the By-Wire technology. An example of such solutions is a commonly used system: Steer by-wire or Brake by-wire. This is illustrated by vehicles with functioning electric refrigerant fluid pumps, electric air conditioning systems, or electronic thermostats actively regulating the temperature of the engine. However, the increase in the number of devices powered by electricity translates into a power source, which directly translates into a degree of thermal unit load. On the market there are already Premium class vehicles, where the demand for electricity amounts to 15 kW. Therefore, there is a need for battery charged from other sources of electricity. Electrical energy in the vehicle is used mostly in systems increasing the driver's comfort and safety, but also in the components responsible for the propulsion system management of the vehicle.

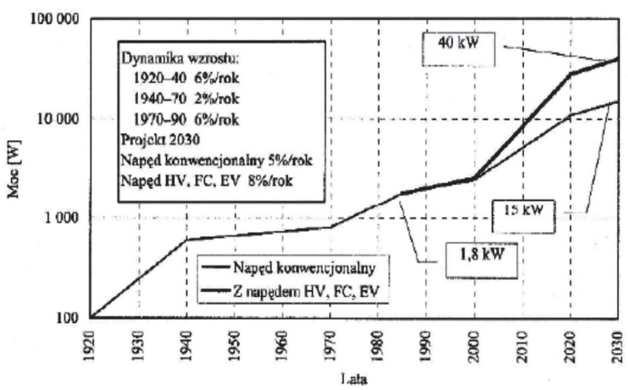

Fig. 1. Dynamics of growth electric power consumption [2] [own study]

Power consumption in the vehicle varies, depending on the function of the electrical devices in the car. The highest energy consumption is visible in the devices boosting driving comfort. Here you can include air conditioning 1000 W, a blower 300 W, electric seat adjustment 400 W, etc. Relatively little amount of power is used by the devices which increase driving safety, including the ABS 50 W, ESP 50 W, the lighting of 150 W (Fig.1). The increase in demand for power on board a modern vehicle, directly contributed to the search by the industry for solutions dealing with recuperation and energy savings. The main area of research is directed at the source of the combustion engine losses, thus the optimization of the cooling system, exhaust system and a reduction in friction losses of engines. The subject literature indicates that there are some solutions that use the exhaust gas stream in the exhaust system as a source of energy. These include the following solutions: Turbocompound, Tigers and ElectricTurbocompound.

2. Recuperation Energy System with Turbogenerator – REST

The presented project of energy recovery system (REST) is based on application of a high speed turbo generator into the exhaust system of the combustion engine (Fig.2). It is the result of an analysis of a continuous growth in energy demand in contemporary vehicles, as well as a disproportionate increase in the improvement of the efficiency of combustion units. The nominal specifications of the generator used in the project are the following: the power of 1 kW, variable three-phase voltage 187V and the maximum speed of 100,000 rpm.

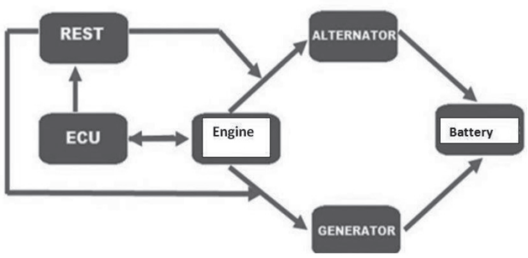

Fig. 2. Block schema of System REST [own study]

Theoretical considerations on the use of the turbogenerator in the process of electric energy recovery from the exhaust system, indicate the possibility of improving the balance of electrical energy on board the vehicle. Therefore, it is proposed for the power supply system with the use of the turbogenerator, to create a system of management and disposal of energy from two sources. These are: a classic alternator and a high speed turbogenerator which is used depending on the load unit, operating conditions, the demand for energy and attention to environmental standards. A control unit connected with the main controller of the drive unit, acquires information of the current power consumption. On this basis, it controls the operation of one or both energy sources adding up their operations. The system is also responsible for storing of the appropriate level of energy, taking into account such variables as the outside temperature affecting the capacity of the battery, the number of switched on receivers and the average speed of the vehicle. Resource management is performed by adjusting the generator load current and switching the excitation current to the alternator. The basis of the REST system is a high speed brushless electric generator with permanent magnets. Due to the number of windings, these machines can be divided into 2-phase and 3-phase. Mechanical parameters do not distinguish them from the brush electrical machines. Their significant advantages include: high durability, possibility of precise speed control, possibility of use in adverse operating conditions (high temperature). The discussed generator consists of a stator, on whose surface drains of the heat removal were milled, and a rotor with a permanent magnet. As a protection against damage to the magnet, the flange of a titanium alloy was applied to the rotor, and its task is to carry the partial stress at high operating speeds. The material for the rotor shaft is made from structural steel S235 JRG2. Taking into account the specific conditions of the generator work, especially in terms of temperature transferred from the exhaust system used to integrate the power source to the turbine, a housing centering the shafts of both elements was created. The housing contains channels which use the flow of air entering the compressor, as a refrigerant for the generator. Small torque of the brushless electric generator enables it to work with a flue gas turbine. The measured torque of the generator at approximately 2 Nm ensures that the flue gas turbine will not be held back by its operation. Three-phase voltage generated by the generator G is sent to the six pulse bridge. Therefore, the PWM system was used on the filter output through capacitor C 470 μF to minimize ripple voltage circuit 0,1μF capacitor filters higher harmonics components of the ripple voltage which may occur during the operation of the system from both the six pulse rectifier, and from the converter system lowering the voltage obtained from the high speed generator. The arrangement of the voltage converter is implemented on a dedicated integrated circuit SG3525 (Fig.3)

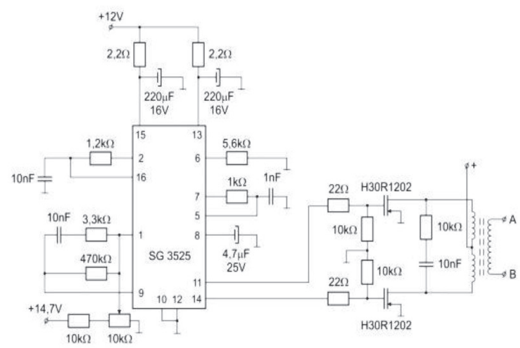

Fig. 3. Voltage converter module based on the system SG3525 [own study]

3. Management module

EvB 5.1 set is a runtime system based on widely available microprocessors ATMega32, the Atmel Company (Fig.4). The board is equipped with a number of peripheral elements whose control terminals are led onto pin header. This allows the user for quick implementation of any project without creating a dedicated board. All headers are labeled, and are located near the peripheral devices, to which they are connected, which allows intuitive connection of elements without the need to read the documentation.

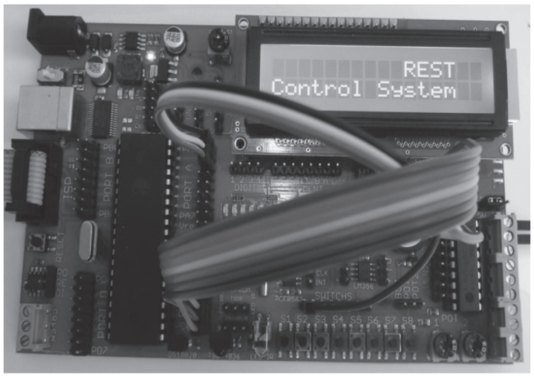

Fig. 4. Controller EVB performing the functions of the REST module [own study]

To create algorithms - commands for the REST system, C++ programming language was used with the help of the Eclipse platform (Fig. 5). Therefore, the platform enriched with plugins is becoming a very popular tool used in the fields of information technology irrespective of whether we work in Java, C ++ and PHP. The integrated development environment built on the Eclipse platform provides opportunities for work and development of applications in a very friendly and user-friendly conditions.

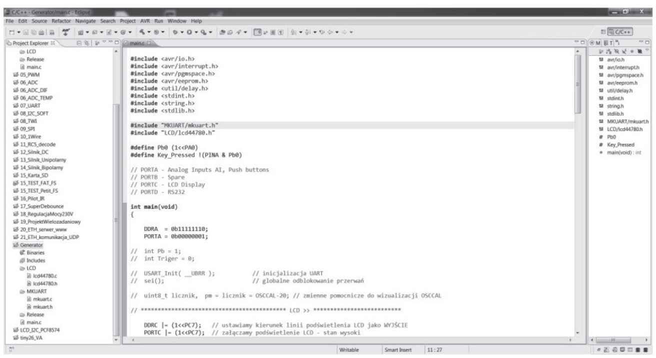

Fig. 5. Window of the Eclipse application [own study]

In the design of the functioning of the system, the following conditions were assumed to enable proper interaction of the turbogenerator with a driving unit:

- the system is activated by rotating values of 1500 rev / min,
- the controller enables loading the generator only in a situation when the engine obtains the operating temperature of 840C,
- REST module constantly monitors the level of demand for energy in the vehicle, among other things by measuring the battery voltage,
- the system takes into account the stabilization period of the generator rotation, and therefore allows generator full load after 2 seconds of stabilized rotation
- the module will not be running in a situation when the engine control unit activates MIL control,
- the controller deactivates the functions of the REST system when the pressure drops in the intake manifold - a leak in the channel boost.

4. Research

The Project is based on four variants of testing energy recovery system. The first is a series of studies on the internal combustion engine without an alternator. This variant is intended to indicate what impact on the engine has its cooperation with the alternator. In this study, the ignition system is powered by the external power source. The second variant of the experiment is a test on the internal combustion engine working with an 700W alternator. This power is defined on the basis of the total load power of electric receivers in the car from which the examined petrol unit comes (Renault Clio III generation 2012). The next variant of the study is an analysis of the parameters of the engine cooperating with the implemented REST system. During the above test the motor and generator parameters were determined accompanying the maximum electric power obtained by the turbo set in specific load values and rotational speed. Knowledge of extreme values of electric power in the individual operating points of the engine, allowed for testing the fourth variant – cooperation of the engine with the alternator and the REST system. The alternator was subsequently charged with powers analogous to those obtained by the turbogenerator at the same measuring points. This study allowed to make a comparison which of the energy sources saves fuel.

5. Results

As part of the metering operations of the turbogenerator, such parameters as current and voltage were recorded in order to calculate the power subsequently. During the study, these parameters were varied in order to determine the generator power for different operating states of the internal combustion engine. This experiment was repeated for each case of the studied rotational speed and for all assumed load points of the engine. The graph shows the power waveforms as a function of torque (Fig.6). For speed of 1500 rev / min (Fig.7), power measurement of the system for all torques was carried out, while, at each measuring point the generator was loaded with three different current values, in which different power values were obtained. Analogously for the moment, the powers were the following 0.6W, 0.9W and 1.3W.

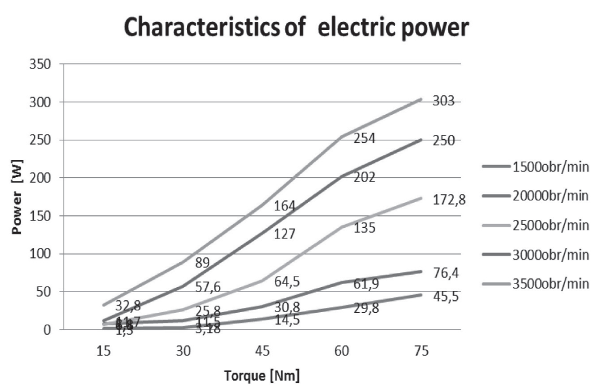

Fig. 6. The graphs of power of the system REST for different rotation speeds of the internal combustion engine [own study]

With a torque 30Nm, the currents transferred to the turbogenerator had a value of 0.115A, 0.13A and 0.045A for the power 4W, 3.18W, and 2.5W. With a torque 45Nm, the obtained voltage is: 45V, 66V, and 79.5V for the power 14.5W, 13.2W, and 7.95W. For the above speed of 1500 rev / min, the highest values of the observed parameters were recorded at the engine load with a torque 75NM. At that point, the following values of power were obtained: 41W, 46.5W and 41.2W, analogously to the current 0.51, 0.4A and 28.3A. For the speed 2000 rpm / min, the highest parameters were recorded at the moment of 75Nm for the 61.7V, 127.3V and 143.2V for power values 70.3W, 76.4W, and 28.6W.

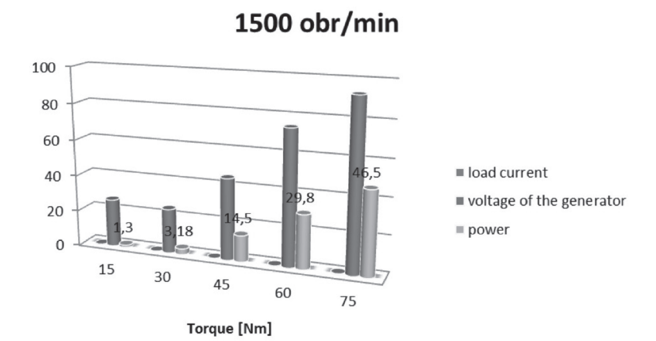

Fig. 7. Parameters of the system REST for the selected loads with the rotation speed 1500 rev / min [own study]

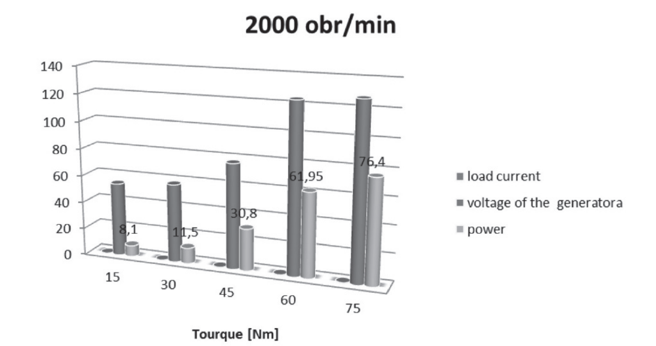

Fig. 8. Parameters of the system REST for the selected loads with the rotation speed 2000 rev / min [own study]

The speed of 2500 rev / min and a engine load of 75Nm were accompanied by the following electrical parameters of the turbogenerator (Fig. 9). The required current 0.73A, 0.5A and 0.2A. Powers obtained with these currents are analogously 53.6W, 57.6W and 29.8W. Another investigated value of rotational speed is 3000 rev / min which is, as in previous studies, the highest power of the system REST which was recorded with a load of the order of 75Nm (Fig.10). The electric power obtained by the generator with such a torque is 223.3W; 250W and 208W for the current 2.9A, 1.79A and 1.2A.

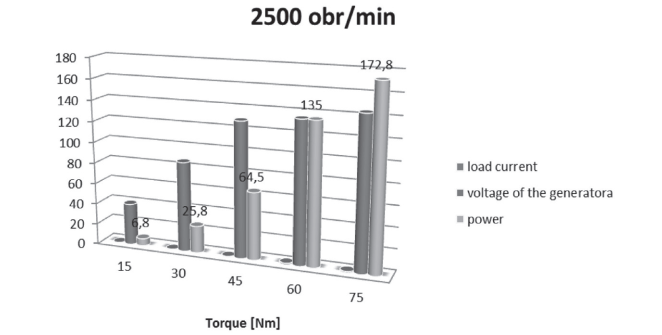

Fig. 9. Parameters of the system REST for the selected loads with the rotation speed 2500 rev / min [own study]

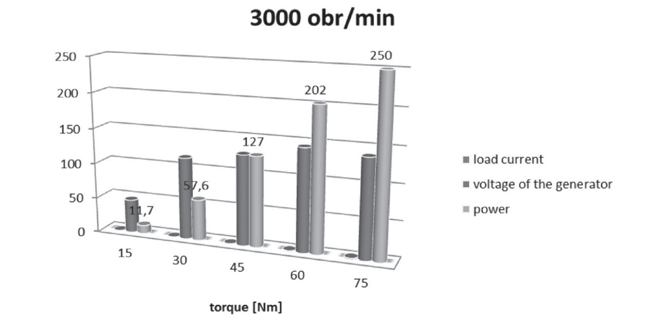

Fig. 10. Parameters of the system REST for the selected loads with the rotation speed 3000 rev / min [own study]

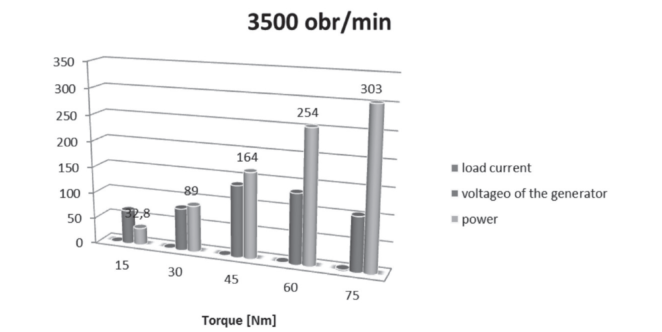

Fig.11 Parameters of the system REST for the selected loads with the rotation speed 3500 rev / min [own study]

The highest electric power gained during the experiment, generated by the system REST, was obtained at a speed of 3500 rev / min, and with a torque 75Nm (Fig11). The generator had values: 104V, 2.9A and power of 303W. In addition, the required current was at 2.1A with 140V and the obtained power was 294W, and also the required current was at 1.6A with 180V and the obtained power was 288W. However, the resulting maximum electrical power is not sufficient enough to replace the traditional alternating current alternator. On the other hand, these studies show that it is possible in certain operating conditions of the engine and the vehicle, disconnect the alternator. This solution also allows to use smaller nominal generator power, which enables the reduction of electricity.

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