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Losses of IC engine – a chance for electrical energy recuperation

Straty silnika spalinowego – możliwości odzyskiwania energii elektrycznej

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Key words: turbogenerator, engine losses, exhaust system

Abstract

The paper presents an analysis of the energy balance and selected processes accompanying the IC engine working from the point of view of improving its efficiency. The article presents an analysis of the losses accompanying the work of the IC engine of the latest generations, as well as discusses efficiency of the systems improving performance of the above mentioned units. The systems described and suggested solutions are based on utilization of the IC engine losses as the source of their functioning. Besides, the structures of electrical energy management on board of a modern automobile are outlined and the concept of the distribution and supervision of electrical energy originating from the turbogenerator located in the exhaust system of the piston engine is proposed. Finally, an innovative solution is put forward of how to solve the problem of eclectic energy distribution and management of the system based on the use of kinetic energy of the exhaust gas passing through the IC engine exhaust system.

Słowa kluczowe: turbogenerator, straty silnika spalinowego, układ wydechowy

Abstrakt

W artykule przeanalizowano bilans energetyczny oraz wybrane procesy towarzyszące pracy silnika spalinowego pod kątem poprawy jego sprawności. Zaprezentowano analizę strat towarzyszących pracy silnika spalinowego najnowszych generacji, rozważając zarazem skuteczność systemów podnoszących sprawność powyższych jednostek. Opisane systemy oraz propozycje rozwiązań oparte są na wykorzystaniu strat silnika spalinowego jako źródła ich funkcjonowania. Przedstawiono też struktury zarządzania energią elektryczną na pokładzie współczesnego pojazdu samochodowego oraz koncepcję dyspozycji i nadzoru energii elektrycznej pochodzącej z turbogeneratora zlokalizowanego w układzie wydechowym silnika tłokowego. W materiale zaproponowano innowacyjne rozwiązanie dystrybucji i zarządzania energią eklektyczną systemu opartego na wykorzystaniu energii kinetycznej przepływu spalin w układzie wydechowym silnika spalinowego.

Introduction

The engine is a power energy device used to convert some type of energy into mechanical work. The principle of the IC engine operation consists in converting chemical energy of the fuel into mechanical work following a defined convention. The heat generated in the process of the fuel combustion is the result of the huge pressure increase in the cylinder. The expanding exhaust gases move the piston which by means of the connecting rod enforces the rotation of the engine's craftshank. These activities are performed by pistons in a continuous way. Regardless of the fact whether we deal with a self-ignition unit or spark ignition unit, the similarity in engines' functioning is determined by their efficiency at similar levels. It is necessary to take into account also the latest structures used in motor industry, such as direct petrol injection (Fig. 1) and work on the stratified mixture for units of spark ignition and the 3rd generation common rail system using the 2000 bar pressure on the rail and five sequences of injection per one stroke of the compression ignition engine.

Fig. 1. View of the combustion chamber in the EcoBoost engine [1]
Rys. 1. Widok komory silnika EcoBoost [1]

Using the cooling system, exhaust system and similar materials for making the units in both machines shows the structure of losses accompanying their work. External heat balance is based on measurements of mechanical energy and energy taken outside by the cooling liquid and exhaust gases. The external balance equation takes the following form:

$$Q = Q_e + Q_{ch} + Q_w + Q_n + Q_r \qquad (1)$$

where:

- Q – total amount of heat input to the engine within one second in J/h;
- Q_e – useful heat, i.e. the amount of heat converted into useful work within one second, J/h;
- Q_{ch} – cooling loss, i.e. the amount of heat rejected from the combustion gases within one second, J/h;
- Q_w – exhaust loss, i.e. the amount of heat rejected to the coolant within one second in J/h;
- Q_n – incomplete losses, J/h;
- Q_r – the balance residue / remainder in J/h.

Tigers

Turbo-generator Integrated Gas Energy Recovery System is a concept which was developed in 2005 by a consortium of Visteon UK and the University of Sheffield. The main idea here is to obtain electrical energy taking advantage of one of the greatest IC engine losses, i.e. exhaust gases. Kinetic energy of exhaust gases passing through the combustion system is used to power a turbogenerator installed in the IC engine exhaust system. The high-speed generator is to aid the work of the alternator and improve the energy balance of the existing energy supply system (Fig. 2). A correctly constructed exhaust system enables optimum use of the exhaust gas energy to power the IC turbine.

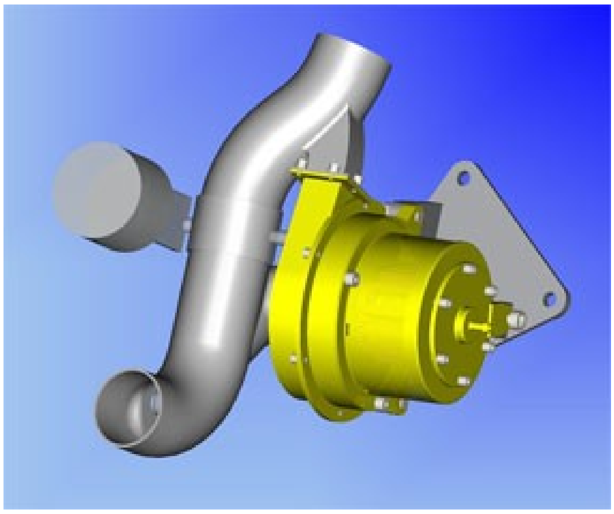

Fig. 2. TIGERS system [2]
Rys. 2. System Tigers [2]

According to the constructors, the turbogenerator co-operating with the spark-ignition engine having the capacity of 2000 dm^3 can generate the max. energy of 6 kW. With the long-term perspective in mind, one can put forward a thesis about replacing the hitherto source of electrical energy in the automobile with the turbogenerator. The Visteon company has also prepared a design of the energy supply system based on the TIGERS device for the voltage of 340 V. Such a solution could be used in hybrid vehicles as an element improving the electrical energy balance and co-operating with the equipment recuperating energy from kinetic power. The structural problems related to the use of the tubogenerator in the exhaust system are those of cooling and lubricating the rotating element.

Turbocompound

The idea of recuperating energy from exhaust gases has been known since the Second World War when it was patented by the US. Once it was used in ships and today in SCANIA automobiles. The classical turbocompound system consists of a turbine and compressor. At low rotational speeds of the engine's craftshank the pressure of exhaust gases is not high enough to overcome the resistance of the turbo-compressor unit, which definitely worsens the exchange of charges and increases fuel consumption. In order to avoid this unfavorable phenomenon, the exhaust system is equipped with a valve, which in these adverse conditions does not deliver exhaust gases to the turbine, but directly to the dampers and the environment. At higher rotational speeds of the engine, when the exhaust gas parameters are adequate, everything proceeds in a traditional way, i.e. exhaust gases are delivered to the turbine (Fig. 3).

Fig. 3. Turbocompound system architecture [3]
Rys. 3. Budowa układu Turbocompound [3]

The turbine is mounted in the exhaust system behind the traditional turbo-compressor. The turbine, via transmission gears and hydrokinetic clutch, transmits the torque to the craftshank. Transmitting energy via the clutch is necessary in order to compensate for the difference in rotational speeds between the flywheel and the turbine which may reach even 55 thousand RPM. The use of the above described system translates into relative benefits which are illustrated by a comparison of two units from the Scania "stable". A 12-litre, six--cylinder engine of Scania DT-12 equipped with Turbocompound is characterized by the power of 470 hp and torque of 2200 Nm, and its parameters are close to those of the 16-litre, 8-cylinder engine. For the sake of comparison, the basic version of the DT-12 unit – DC-12 – generates 420 hp and 2000 Nm. An evolution of the compound design is a device patented by the Caterpillar company which developed a prototype electrical turbo-aid system known as ETC (Electrical Turbocompound Caterpillar). The device consists of a compressor, turbine and high-speed electric current generator.

Such a combination of elements eliminates mechanical connection with the engine's craftshank. The use of the generator allows us to improve efficiency of the turbocompressor in the range of low rotational speeds. The moment the exhaust gas pressure is too low, the generator works as an electric engine powering a compressor. This is the way to eliminate the "turbo hole" effect and the engine develops power more smoothly. At high rotational speeds of the craftshank, the power surplus generated by the turbine is used for the electric power production by the generator.

BMW turbosteamer

Is a highly complicated and costly system based on the steam engine principle and intended to boost efficiency of a classical combustion unit. The system consists of three fluid circuits, two heat exchangers and an expansion unit. The BMW engineers claim that the above system can recover as much as 80% of the heat energy, so far irretrievably lost in the exhaust system. To this end they used a water-filled system in which water, thanks to heat exchangers, is heated to 550ºC. Then the generated steam is converted into mechanical energy transferred to the crankshaft. The second circuit is a low-temperature one in which ethanol – the base medium – absorbing heat from the cooling system and the end of the engine's exhaust system works at average temperature of 150ºC. The energy obtained in this way, like in the case of the first circuit, is transferred to the crankshaft of the IC engine (Fig. 4).

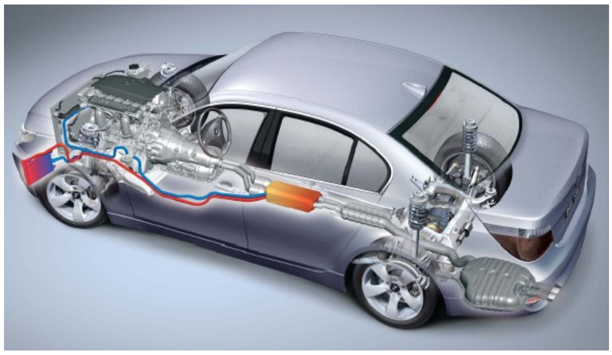

Fig. 4. BMW Turbosteamer system architecture [4]
Rys. 4. Budowa system BMW Turbosteamer [4]

Turbogenerator

Extensive research carried out in the engine test house at the Faculty of Mechanics of Opole University of Technology indicates that despite its small capacity, the IC engine can generate sufficient exhaust gas pressure to power the turbogenerator. Analysis of the fuel consumption, engine torque, unit power and indicated pressure in the system consisting of a thermal engine with and without a turbogenerator show unambiguously that the unit's efficiency increases. Knowing the source of the major loss in efficiency of an IC engine, most designs aiming at energy recuperation are based on the use of the exhaust system. This assumption was also adopted by Sławomir Dziubański, Ph.D., Eng.

who implemented an experimental application project of a high speed turbogenerator for the IC engine exhaust system. The nominal parameters of the generator used for this project are: power of 1 kW, voltage of 187 V three-phase alternative current and maximum speed of up to 100 000 RPM.

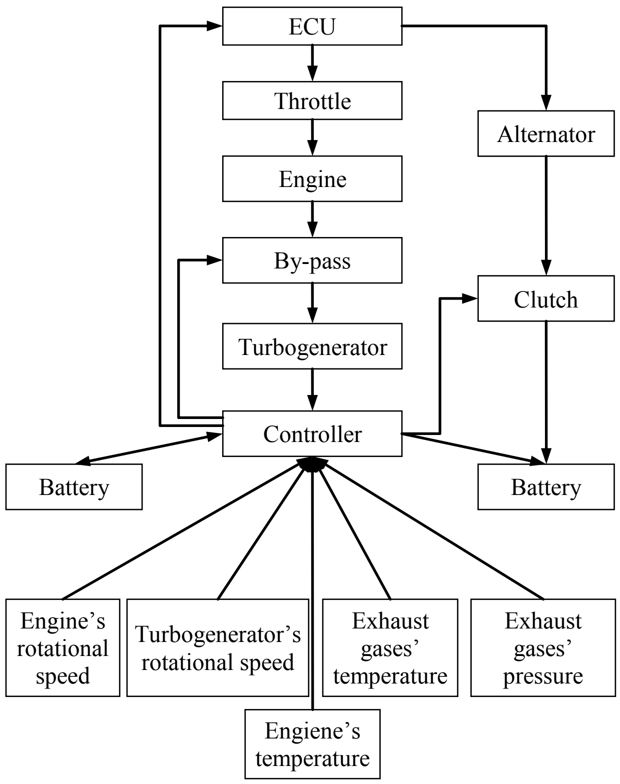

Fig. 5. Turbogenerator test stand
Rys. 5. Stanowisko badawcze turbogeneratora

Figure 5 depicts the values of the IC unit. The results obtained in the course of the research into the turbogenerator and defining the range of the electrical energy which can be obtained in the recuperation process show that it is possible to considerably improve the electrical energy balance on board of a vehicle. For this reason it is recommended that the electrical energy supply system with the use of a turbogenerator should possess the management and distribution systems for energy from both sources depending on the extent to which the unit is loaded, operation conditions, demand for energy and care about ecological standards.

The control module's (Fig. 6) task would be to provide data about the current demand for energy, to control work of one of the energy sources or to sum them up and to plan storage of suitable energy levels depending on the battery size – all these by means of the CAN data bus. Energy source management would be accomplished by a by-pass valve for the turbogenerator and a switch for the alternator actuation. It is also suggested that the second, small auxiliary battery should be used whose task would be to absorb energy from the turbogenerator performing also a safety function in case of energy deficit.

Conclusions

Analysis of current advancement of research in the field of systems boosting efficiency of thermal units indicates validity of conducting research into

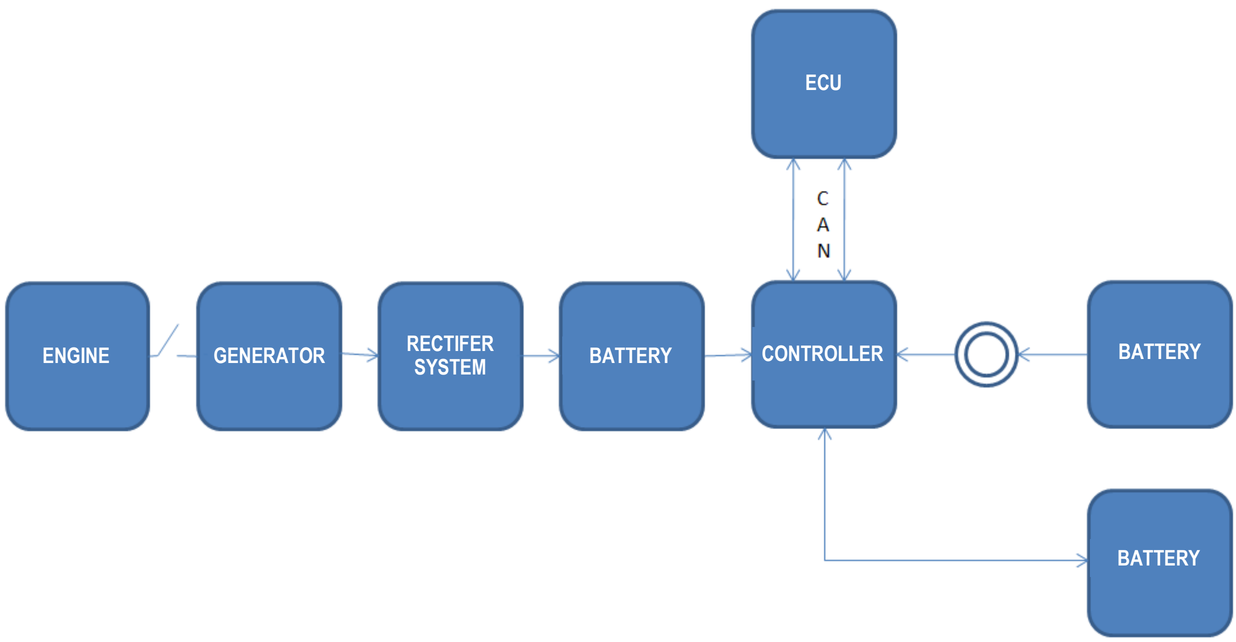

Fig. 6. Block diagram of energy management concept
Rys. 6. Schemat blokowy projektu zarządzania energią

electrical energy recuperation. For structural and economical reasons, it seems justified to focus the research on the development of the high-speed turbogenerator utilizing kinetic energy of the exhaust gas flow.

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