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System based on thermal control of the HCCI technology developed for reduction of the vehicle NO_X emissions in order to fulfil the future standard Euro 7

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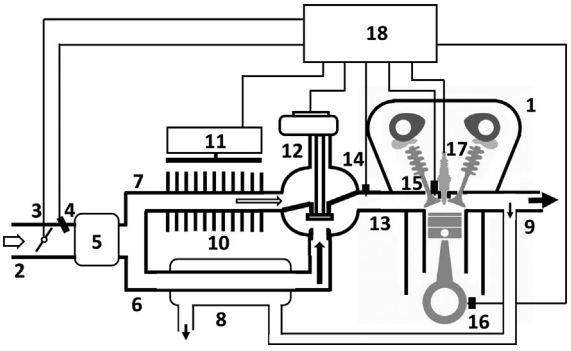
HIGHLIGHTS

- Presentation of new system based on thermal control of the HCCI technology.
- The HCCI technology represents a future trend in modern vehicle engines.
- Application of HCCI technology reduces the vehicle NOx emissions.

GRAPHICAL ABSTRACT

System based on thermal control of the homogenous fuel mixture self-ignition process with compression (1 – combustion engine, 2 - suction pipe, 3 – throttle valve, 4 – fuel injector, 5 – compressor, 6 – heated pipe, 7 – cooled pipe, 8 - heater, 9 – exhaust gas pipe, 10 – cooler, 11 – fan, 12 – mixing valve, 13 – output pipe, 14 – air temperature sensor, 15 – cylinder pressure sensor, 16 – crankshaft speed sensor, 17 – spark ignition, 18 – computer with s ECU).



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ABSTRACT

On the present the environmental protection belongs among the most important worldwide priorities. From this reason there is valid within the framework of the European Union the standard Euro, which is specifically defined in the transport area. Nowadays the actual issue of this standard is signed Euro 6. It is established in order to eliminate most of the undesirable air pollutants. However, there is already prepared a new and even stricter emission standard Euro 7. It is a well-known fact that the actual emission standards are very hard and the automobile factories, together with the engine design concepts are trying to fulfil the new emission standards, mainly the NO_X emission requirements. These circumstances also caused the infamous affair "dieselgate". The new engine concept, which is called HCCI (Homogeneous Charge Compression Ignition), could be a suitable solution of the present NO_X emission problems. Principle of the HCCI technology is based on self-ignition of the homogenous fuel mixture using compression in order to reduce emissions, whereas the NO_X emission level is almost negligible. However, there are also several essential problems connected with the above-mentioned innovative technology, for example a high level of pressures arising during the compression process and intensive heat release. Another serious problem is a complicated control of the self-ignition process. This article presents an original technical solution, which enables to regulate the whole self-ignition process and in this way to ensure a reliable operation of the HCCI engine. We would like to emphasize also a fact that this unique solution was applied for a patent, as well.

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The innovated piston combustion engine was installed in the experimental vehicle designed for participation at the international competition shell eco marathon 2018 in London focused on minimisation of the fuel consumption.

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1. Introduction

The automotive industry is a strategic branch of industry within the EU and international framework. It is permanently facing to the durable challenges that are presented in the form of requirements concerning efficient exploitation of the fuel energy, reduction of the emissions and application of the new technologies. Nowadays there is valid within the European countries the emission standard Euro 6, which should help to eliminate most of the harmful substances that are occurring in the air. The upcoming new emission standard Euro 7 will be even more strict and demanding (Geng et al., 2016; Yamada et al., 2016).

In the 2015 year occurred information about a fact that in some of the motorcars was installed a software, which enabled to hide the over-limit values of the nitrogen oxides during the emission testing process. This affair is called "dieselgate". Officially, all the motorcars fulfil limits defined for production of the nitrogen oxides (NOx). The emission testing process is performed in the laboratory conditions and the above-mentioned "special" software was able to overreach the testing machine. The collusive software cooperated with the engine control unit, identified the measuring process and switched the engine into the operational regime with the reduced emission values (Simmons and Seakins, 2012; Fameli and Assimakopoulos, 2015; Feng et al., 2014).

It is possible to say that the current emission limits are very demanding. From this reason there are occurring serious problems for the automobile factories how to meet the emission standards (Puškár et al., 2015). Technological development of the future and better engines, together with application of the anti-emission actions, requires expensive investments.

However, there is at disposal one possible solution, which consists in application of a new, special technology. This innovative technology is called the "Homogeneous Charge Compression Ignition", i.e. the HCCI technology, which is based on a specific combination of the gasoline engine (using the spark ignition principle) with the diesel engine (utilizing the compression ignition process). Such combination of two quite different ignition methods in one combustion engine offers the best operational characteristics of both ignition systems. There is applied in this case a gasoline as the engine fuel, but the indicated efficiency of such engine is higher, similarly to the diesel engine (Sinay et al., 2014; Balland et al., 2014; Grega et al., 2015; Homisin et al., 2016).

The engine indicated efficiency is a function of the compression ratio and specific heats ratio $\gamma = c_p / c_v$, Fig. 1, where the physical units of the c_p/c_v is $[J \cdot kg^{-1} \cdot K^{-1}]$.

The process of the homogenous charge combustion is running at once within the piston combustion volume. Thanks to this fact the whole charge is combusted almost completely. Efficiency level of the gasoline exploitation is very high thanks to application of the progressive and perspective HCCI technology. Another positive result consists in a substantial reduction of the engine fuel consumption, together with reduction of the exhaust gas emissions and what is important the NO_x emission level is almost zero. On the other hand, it is necessary to say that application of the HCCI technology induces some of fundamental problems, for instance a high level of the pressure values, high thermal loading during the compression process, complicated control of the self-ignition process etc. (Puškár and Bigoš, 2010).

The worldwide reputable automotive companies are dealing with a development of the HCCI technologies. The contemporary problems concerning the diesel engines emphasize an importance of such development strategy, which is based on the HCCI-engines. The innovative HCCI technology, which is integrated together with the modern motor-management components (e.g. with the direct fuel injection, VVT etc), enables to save the fuel and to fulfil the future emission standards (Puškár and Bigoš, 2012; Puškár et al., 2012a). The global efficiency of the piston combustion engine, which is equipped with the HCCI technology, is close to the diesel engine efficiency; however, the HCCI-engine does not require application of an expensive system necessary for elimination of the NO_x emissions. Effectiveness of the HCCI system is based on the fuel combustion at lower temperature levels and on reduction of heat losses, together with the decreased CO_2 emissions (Puškár et al., 2012b; Puškár et al., 2014; Puškár and Bigoš, 2013).

The piston combustion engine equipped with the HCCI technology is determined not only as a driving aggregate for the "classic" motorcars, but this kind of engine can be also used as a driving unit of the electric generators installed in the vehicles with the hybrid drives (Czech, 2013).

2. Working principle of the HCCI technology

A physical and technical principle of the HCCI-engine operation, which is using combustion of the gasoline-air mixture, is well known among the engine designers already during a longer time. This technology offers a possibility to increase the gasoline engine efficiency so that it could be similar to the diesel engine efficiency. The self-ignition process is running at once in the combustion area. The gasoline-air fuel mixture is ignited as a result of the self-ignition process after compression of the charge. In any case, application of the spark plugs remains still necessary, for example in the case of the cold engine start or during a high-load working regime of the engine. If the engine is operating with a low-level loading, so there is activated the controlled homogenous charge compression ignition process. The specific fuel consumption of the combustion engine equipped with the HCCI technology is similar to the specific fuel consumption of the diesel engine, however it is not necessary in this case to apply an expensive system intended for elimination of the NO_x emissions (Puškár and Bigoš, 2013; Rybár and Beer, 2015).

A relation between the in-cylinder pressure and the crank angle for 500 sequential combustion cycles during the HCCI regime illustrates Fig. 2 (Rybár et al., 2016). There is also visible in this figure a transition regime where the fuel mixture is ignited by means of the sparking plug during the stable combustion in the HCCI working mode. A relation

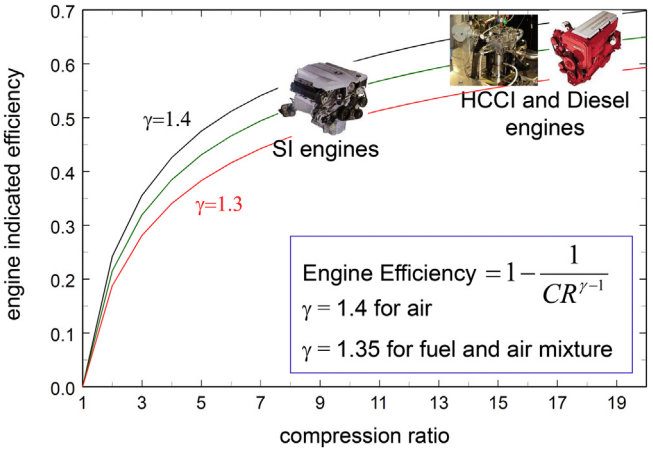

Fig. 1. Indicated efficiency of various engine types.

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