RESEARCHES OF INFLUENCE KIND OF PISTON ON SOME PARAMETERS OF THE S12-U WOLA DIESEL ENGINE

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Abstract

Increased weight and greater requirements, regarding manoeuvring opportunities need extension of the power of combustion engines determining their powertrain units. In case of the family „W" engines, following developmental versions came into existence as a result of the modernization of the earlier version, among others thru the optimization of the combustion process, applying of the supercharging, as well as strengthening of the internal construction, which made it possible to carry greater thermal and mechanical loads. The subjects of the study were pistons made from composite materials of the small hysteresis of the alloy mounted on the S12-U combustion engine. In the novel construction of the piston, the outline of the overcoat was modified, the shape of the combustion chamber, the hole for the piston pin, grooves for the piston rings and shape of internal surfaces remained unchanged. A characteristic feature of the novel piston is the smaller hysteresis of the coefficient of thermal expansion composite alloy, α, of which the pistons were made, whereas a so-called hysteresis is the difference of the coefficient α, which occurs during warming and piston cooling, and takes place during working of the piston in the combustion engine. The smaller hysteresis of the coefficient α makes the decreasing clearances between piston and cylinder possible, what has a beneficial influence on work parameters of the combustion engine, especially under conditions of partial loading of the engine. Basic parameters of the engine for the maximum torque characteristics and load characteristics are the object of the paper.

Keywords*: diesel engine, engine testing, engine piston, composite alloys, emissions, fuel consumption*

1. Introduction

The requirements, which the contemporary military heavy vehicles have to fulfil, first of all the tanks, cause their mass to undergo major increase. A basic factor is the strengthening of the resistance on the enemy fire, which is the improvement of armour plating. Second major factor increasing the chances of survival on the contemporary battlefield is manoeuvring properties.

The two above-mentioned factors: increased weight and greater requirements, regarding manoeuvring opportunities, force the necessity to increase the power of combustion engines, which are their powertrain units. In case of the family „W" engines, following developmental versions came into being as a result of the modernization of the earlier version, among others thru optimization of the combustion process, the use of the supercharging, as well as strengthening of the internal design, which let to carry greater thermal and mechanical loads.

The most loaded mechanically and terminally elements of combustion engines are pistons. The requirements they need to fulfil concern high strength properties in high temperatures and functional, mainly relying on minimizing the difference in the thermal expansion during warming and cooling, which increases the resistance of the construction piston on fatigue damages, both mechanical and thermal, and increases the resistance pistons on thermal shocks.

2. Object and research purpose

Subject of the study were mounted pistons made from composite materials with the small hysteresis on the engine S12-U, shown in Fig. 1. This is the twelve-cylindrical compression-ignition engine, with direct-injection, cooled with liquid, re-charged mechanically, multifuel, of the 38.88 dm^3 stroke capacity and the maximum power 625 kW at the rotational speed of 2000 rpm. The engine S12-U is a powertrain unit of the tank PT-91 and caterpillar heavy vehicles.

Fig. 1. View of the S12-U research engine

Researches were carried out with regard to two piston versions:

1. The standard piston 3304-05-24.01 BX, in the version presently produced. This piston is made from the drop forging of PA12 material, which surface is phosphatising, the skirt is graphitic, the nominal diameter is ø149.515 mm.
2. Novel piston 1304-05-1 was made of the cast from composite material, which surface is phosphatising, the skirt is graphitic, and the nominal diameter is ø149.610 mm.

In the novel design of the piston the shape of skirt was modified; the shape of the combustion chamber , combustion chamber, hole of piston pin, grooves for piston rings and internal surfaces remained the same.

A characteristic feature of the novel piston was the smaller hysteresis of the coefficient of thermal expansion of composite alloy, α, from which pistons were made, whereat a so called hysteresis is the difference of the coefficient α, which occurs during warming, and cooling of the piston and takes place during work in the combustion engine [1, 2, 5, 9, 10]. The smaller hysteresis of the coefficient α lets on decreasing clearances between piston and cylinder, which has favourable influence on work parameters of the engine, especially under conditions of partial engine loads. Characteristics of the standard piston, in reference to the coefficient α, are presented in Fig. 2, and novel piston – in Fig. 3. The difference of the coefficient α for the standard piston for the temperature 297K is 2.65 x E-6/K, at the practically zero-difference of this coefficient α for the temperature 497K for novel piston, and the same value of the coefficient and for the temperature 497K during warming and cooling of the piston [11-14].

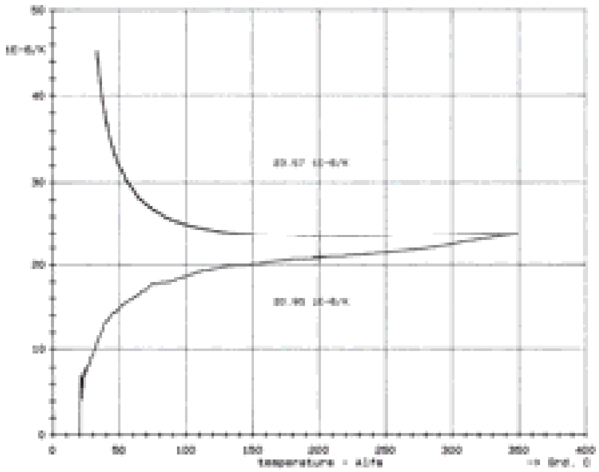

Fig. 2. The course of the coefficient of thermal expansion in the function of the temperature during warming and cooling for standard piston material

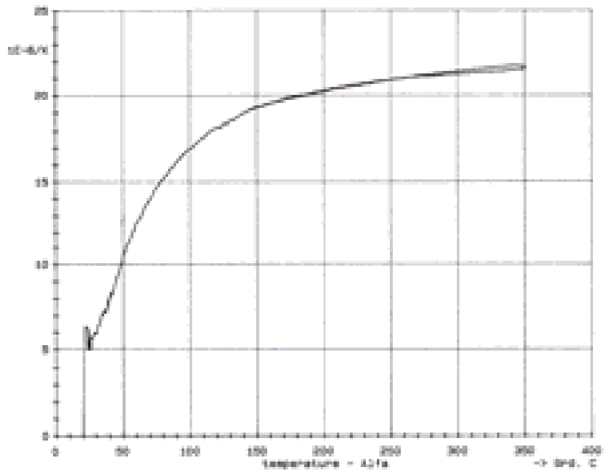

Fig. 3. The course of the coefficient of thermal expansion in the function of the temperature during warming and cooling for novel piston material

The purpose of research was the identification of parameters of the engine with pistons, made of the novel material and of the new technology, taking into account the influence of the novel solution on main parameters of the engine [3, 4, 6-8]. Within the framework of carried out research, the comparison of parameters of the engine with standard and novel pistons was accomplished thru:
– combustion process in the cylinder,
– brake specific fuel consumption,
– blow-through values to the crank case,
– content of harmful compounds in exhaust gases

3. Research stand

Researches were realised on the engine test bench of WOLA Factory in Warsaw in cooperation with Institute of Aviation. The general view of the research stand is introduced in Fig. 4.

Requirements and conditions concerning the measuring stand were the following:
– On the research stand, the engine was elastically connected with the dynamometric brake;
– The engine was equipped with exhaust manifolds. The system of transferring the exhaust gases was closed, with the maximum backpressure, which was equal to 5 kPa. On the research stand, the engine worked without the air filter (see Fig. 5).

The research stand was equipped with instruments and measuring equipments, enabling the direct measurement of the following parameters: torque measured at the use of the water cooling brake dynamometer SCHENCK (see Fig. 6), fuel consumption, rotational engine speed, temperature of water, oil on intake and the exhaust from the engine, oil pressure, ambient air temperature, barometer pressure, temperature of the fuel before the dosing pump, pressure of the fuel out of the dosing pump, blow-through to the crank case value (see Fig. 7), specific weight of the fuel and lube oil, overpressure of the supercharging of the compressor, the temperature of exhaust gases at the outlet from the head.

Fig. 4. Research stand

Fig. 5. Combustion engine on research stand

Fig. 6. SCHENCK brake

The measurement of the maximum pressure in combustion chamber (pz) was done by means of the piezoelectric, water-cooled sensor, from which the signal was registered on the oscilloscope. The exhaust gas analysis was carried out by means of the exhaust emission analyzer Motorscan Leader 800, shown in Fig. 8.

Fig. 7. The equipment of the research stand to measurement of blowthrough to the crank case

Fig. 8. The equipment of the research stand – exhaust emission analyzer

4. Methodology of research

Dynamometer brake tests of the engine were carried out on the research stand „PZL -WOLA" in two stages:

- Stage I – test of the engine with standard pistons 3304-05-24.01BX, which result is the point of reference to the results obtained in the second stage,
- Stage II – test of the engine with novel pistons 1304-05-1.

In order to reduce to the minimum the influence of factors not connected with the studied pistons on the work parameters, the researches were performed on the same copy of the S12-U engine, without the change of the regulation and without the exchange of accessories elements of the engine. For each stage of the research, an engine with novel set of the pistons was ready, as well as parts directly connected with it, i.e. piston rings and cylinder liners. Assuming that all remaining engine parts were the same, or originated from the current fully repeatable production line (cylinder liners and piston rings), it is possible to assume that the observed parameters change of the engine work is influenced only by the change of the piston from the standard piston to the novel one.

Researches were performed with the use of the basic fuel to supply the engine, i.e. the diesel oil city SUPER and multiseasonal CF-4 SAE 20W/50 lubrication oil.

Each stage of the research consisted of two fundamental phases:

Phase I – overlapping with the program of standard industrial tests of the engine S12-U, making preparation of the engine to the fundamental part of the test, which was carried out according to the following program:

- engine running-in during 150 min,
- the regular test during 90 min,
- the approval test during 30 min.

Phase II - the fundamental part of the research, during which the parameters of the work of engine were measured and underwent estimation and comparison. Phase II was performed according to the following program:

Accomplishment of the maximum torque characteristics within the range of the rotational engine speed from 1200 to 2000 rpm. Measurements were performed for rotational engine speeds of 2000, 1950, 1900, 1800, 1700, 1600, 1500, 1400, 1300, 1200 rpm. During testing for maximum torque characteristics, the following parameters of the work of the engine were registered:

- the standard set of parameters registered by the measuring equipment of the research stand SCHENCK dynamometer,
- the maximum pressure of the combustion pz, measured in one of the cylinders, measurements were performed for every range of rotational engine speed,
- the content of harmful substances in exhaust gases HC, CO, CO_2 and soot; measurements were performed for every range of rotational engine speed,
- accomplishment of load characteristics within the range of the rotational engine speed, from 1200 to 2000 rpm; measurements were performed at rotational engine speeds of 2000, 1950, 1900, 1800, 1700, 1600, 1500, 1400, 1300, 1200 and for the engine power from value of the maximum torque characteristics, for given values of rotational engine speeds, with interval of 100 kW.

During the testing of load characteristics, the following engine parameters were registered:

- the standard set of parameters registered by the equipment of the research stand SCHENCK, the maximum pressure of the combustion pz, measured in one of the cylinders; (measurements were performed for every rotational engine speed range and load),
- the content of harmful compounds in exhaust gases HC, CO, CO2 and soot, measurements were performed for every rotational speed range and load.

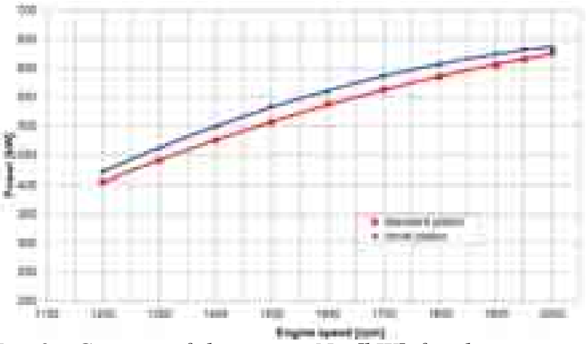

Fig. 9. Courses of the power Ne [kW] for the maximum torque characteristics

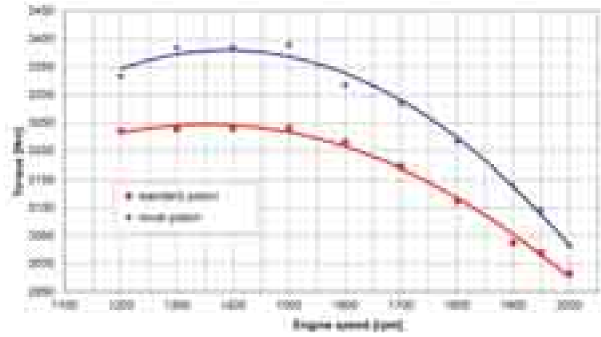

Fig. 10. Courses of maximum torque M [Nm] versus engine rotational speed

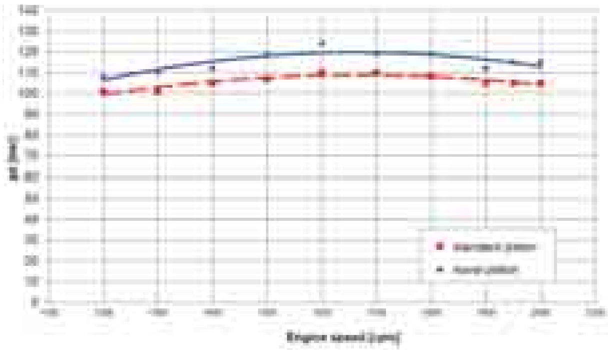

Fig. 11. Courses of combustion pressure pz [bar] characteristics for the maximum torque characteristics

5. Test results

Novel pistons were made from material characterised with high strength parameters and the small hysteresis of the coefficient of thermal expansion α. These parameters were obtained as a result of adding into base alloy the novel alloy, such chemical elements, as chromium, molybdenum, wolfram, and increased content of copper and nickel, and thru applying the full heat-treatment, assuming the solutioning and ageing, whereat the ageing was realized in two stages. Researches carried out on the S12-U engine showed that novel pistons had worked properly in the engine.

Applied novel pistons made from composite material and according to the 1304-05-1 design, as a result of decreasing the working clearance in the cylinder, assured the improvement of many essential parameters of the engine work, among others:

– small extension of the power Ne (approx. 1.5%) was obtained, the courses of the maximum torque characteristics represents Fig. 9,
– increase of the torque M (approx. 4%) was obtained, the courses of the maximum torque characteristics represents Fig. 10,
– increase of the maximum pressure combustion (pz), the courses of the maximum torque characteristics represents Fig. 11,
– decrease of the brake specific fuel consumption BSFC (approx. 4%), the courses of the maximum torque characteristics represents Fig. 12,
– decrease of fuel consumption Gh, the courses of the maximum torque characteristics represents Fig. 13,
– decrease of the harmful exhaust gases components' emission level − hydrocarbons HC (approx. 24%), the courses for the maximum torque characteristics represents Fig. 14,
– decrease of the emission level of harmful components of combustion gas – carbon monoxide CO (approx. 10-20%), the courses for characteristics of maximum torque characteristics is represented on Fig. 15,
– decrease of the emission level of harmful components in exhaust gases - hydrocarbons HC (approx. 24%), the courses for load characteristics, for rotational speeds 1200, 1400, 1600, 1800 and 2000 rpm is introduced on Fig. 16-20,

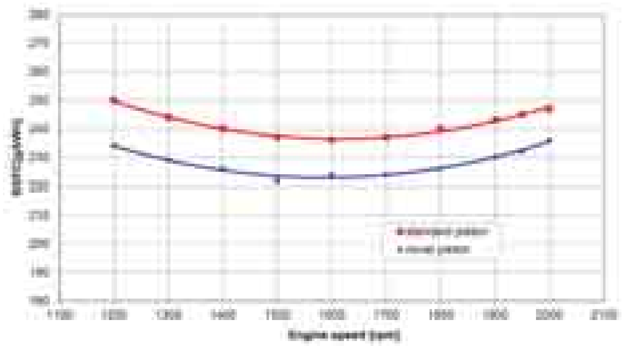

Fig. 12. The courses of the brake specific fuel consumption BSFC for the maximum torque characteristics

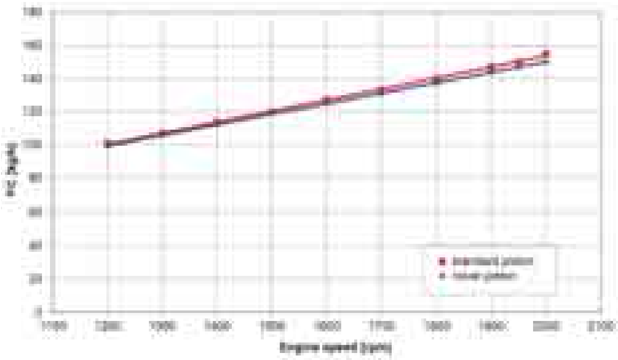

Fig. 13. The courses of fuel consumption Gh[kg/h] for maximum torque characteristics

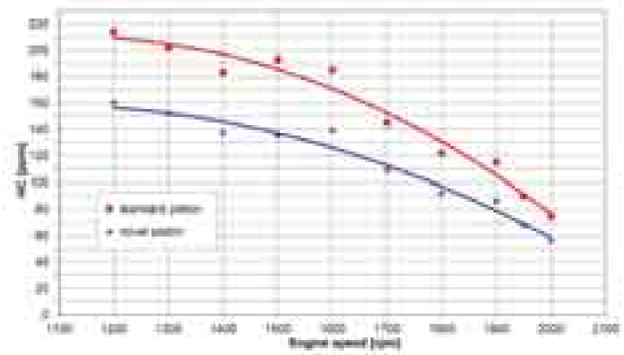

Fig. 14. The courses of the concentration of the hydrocarbons (HC) for the maximum torque characteristics

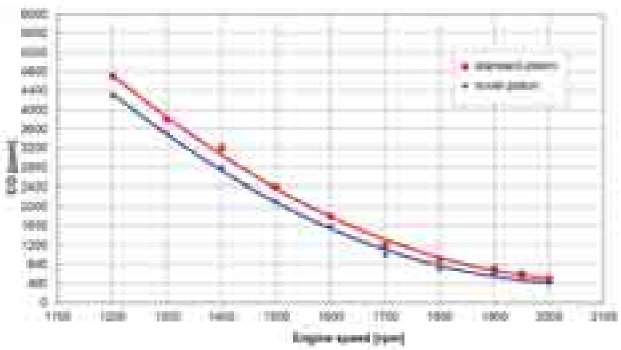

Fig. 15. The courses of the concentration of the carbon monoxide (CO) for the maximum torque characteristics

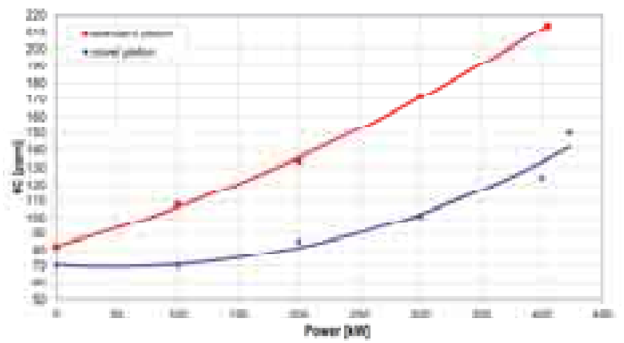

Fig. 16. Courses of the concentration of hydrocarbons (HC) for the part load characteristics 1200 rpm

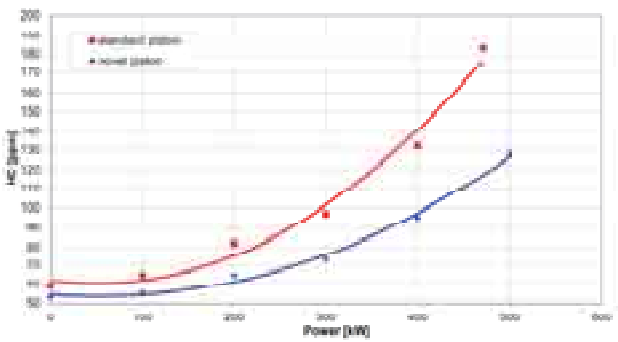

Fig. 17. Courses of the concentration of hydrocarbons (HC) for the part load characteristics 1400 rpm

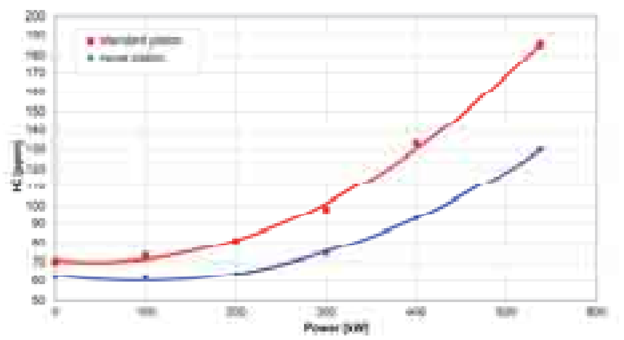

Fig. 18. Courses of the concentration of hydrocarbons (HC) for the part load characteristics 1600 rpm

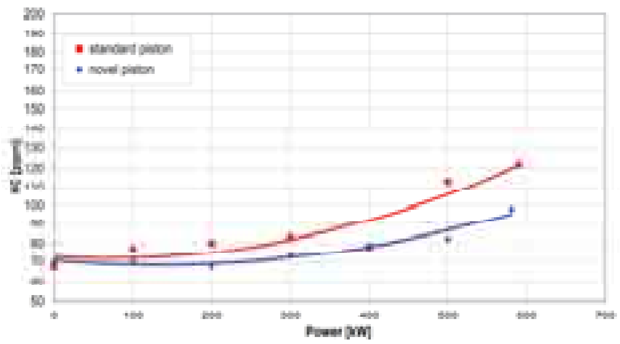

Fig. 19. Courses of the concentration of hydrocarbons (HC) for the part load characteristics 1800 rpm

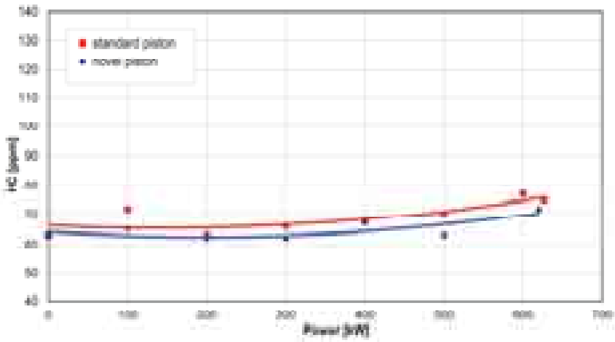

Fig. 20. Courses of the concentration of hydrocarbons (HC) for the part load characteristics 2000 rpm

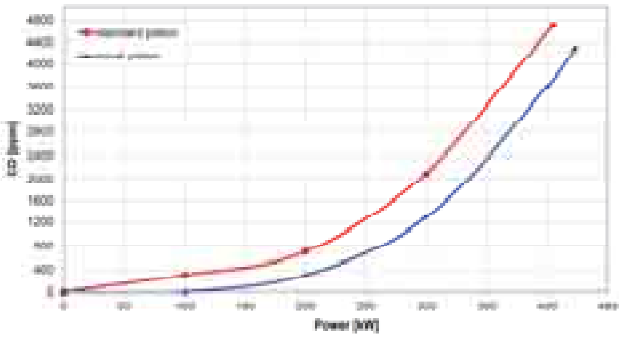

Fig. 21. Courses of the concentration of the carbon monoxide (CO) for the part load characteristics 1200 rpm

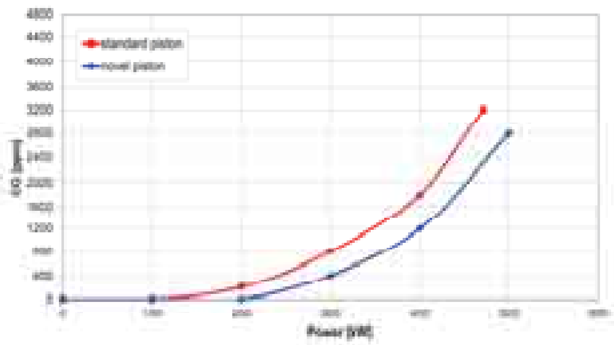

Fig. 22. Courses of the concentration of the carbon monoxide (CO) for the part load characteristics 1400 rpm

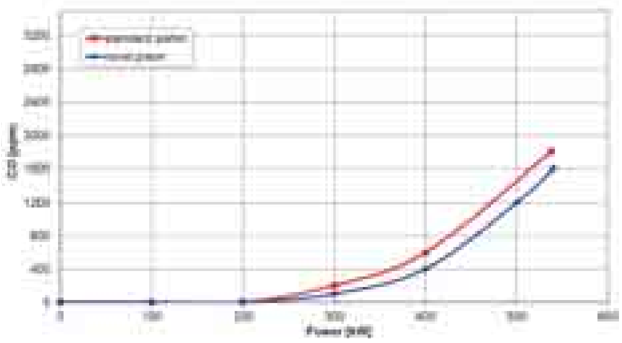

Fig. 23. Courses of the concentration of the carbon monoxide (CO) for the part load characteristics 1600 rpm

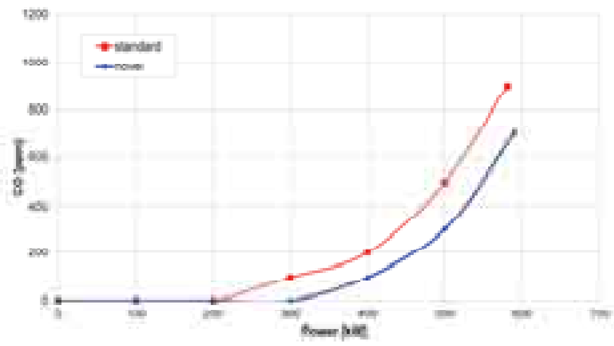

Fig. 24. Courses of the concentration of the carbon monoxide (CO) for the part load characteristics 1800 rpm

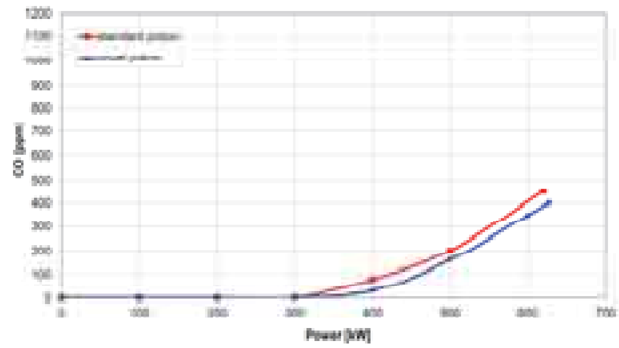

Fig. 25. Courses of the concentration of the carbon monoxide (CO) for the part load characteristics 2000 rpm

– decrease of the emission level of harmful components of exhaust gases - the carbon monoxide CO (approx. 10-20%), relative to the engine rotational speed, the course for load characteristics for engine rotational speeds 1200, 1400, 1600, 1800 and 2000 rpm is presented in Fig. 21-25,
– substantial differences in the emission level of the carbon dioxide and particulate matters did not become essential during research.

6. Conclusions

Novel material for pistons is characterised with, first of all, small hysteresis of the coefficient of thermal expansion α, unique strength properties and the large resistance on seizing.

Changes of the coefficient of thermal expansion in reference to standard piston-silumins applied on pistons can be meaningful during warming and cooling, as well as during the following cycles of warming and piston cooling.

The developed novel material is characterised with very high strength properties, both in the normal temperature, and in the full range of values of the operating temperature of pistons, up to 350^{o}C.

Characteristics of novel piston-silumins give opportunities to minimize the clearances and obtain proper work in the full range of engine rotational speeds and loads.

Researches proved the influence of the dimension-hysteresis of material of the piston on essential parameters of the work of the compression-ignition engine.

Novel pistons give the opportunity to decrease the working clearances of the piston in the cylinder, especially at partial engine load, and to improve many essential parameters of the engine work, among others:
– decrease of the oil consumption, approx. 17%,
– the slight increase of the power (approx. 1.5%), the torque (approx. 4%) and pressure of the combustion (pz),
– the decrease of the brake specific fuel consumption (approx. 4%),
– the decrease of the emission level of harmful components of exhaust gases, mainly hydrocarbons (approx. 24%) and the carbon monoxide (approx. 10-20% depending on the rotational engine speed),
– essential decrease of blow-throughs to the crankcase (approx. 35-45%).

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