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Coating the bearing surface of a piston with a layer of nanotubes as a means of reducing friction

Abstract: Striving to improve the overall efficiency of combustion engines under real operating conditions of vehicles is effectively implemented by downsizing and turbo-charging. Engine turbo-charging leads to an increase in mechanical loads, in the piston-cylinder group in particular. In order to take full advantage of the opportunity to improve the efficiency of the engines built according to the concept of downsizing, it is appropriate to optimize the piston-cylinder cooperation, especially in terms of friction losses.

This paper examines the possibility of replacing conventional layers covering the bearing surface of the piston with layers formed by nanomaterials. The obtained images of layers of carbon nanotubes (CNTs) on the surface of experimental pistons are presented by means of a scanning electron microscope (SEM). The pistons were embedded in an engine and tested for friction losses.

Key words: *piston skirt, friction losses, nanotubes*

Pokrycie powierzchni nośnej tłoka warstwą nanorurek węglowych jako sposób ograniczenia tarcia

Streszczenie: Dążenie do poprawy sprawności ogólnej silników spalinowych w rzeczywistych warunkach eksploatacji pojazdów jest skutecznie realizowane przez downsizing i doładowanie silników. Doładowanie silników prowadzi do wzrostu obciążeń mechanicznych, szczególnie w grupie tłokowo-cylindrowej. Dla pełnego wykorzystania możliwości poprawy sprawności silników zbudowanych według koncepcji downsizingu celowa jest optymalizacja współpracy tłoka z cylindrem, szczególnie w aspekcie strat tarcia.

W artykule przeanalizowano możliwość zastąpienia konwencjonalnych warstw pokrywających powierzchnię nośną tłoka przez warstwy utworzone z nanomateriałów. Przedstawiono uzyskane za pomocą elektronowego mikroskopu skaningowego zdjęcia warstw nanorurek węglowych na powierzchni eksperymentalnych tłoków. Tłoki te zostały zamontowane w silniku i poddane badaniom strat tarcia, wyniki badań przedstawiono i omówiono w artykule.

Słowa kluczowe: *powierzchnia nośna tłoka, straty tarcia, nanorurki*

1. The origin of the concept of covering a piston with a layer of CNTs[1]

A piston combustion engine used as a power source of motor vehicles is subject to modifications forced by external factors; at present it is the ecological aspect that plays the key role here. One of the most important expectations is the reduction of carbon dioxide emission, which translates into a pursuit of reducing fuel consumption under real operating conditions. The increasing demands which are relative to combustion engines stimulate the development of new technologies; in view of the last ten years or more, the key role has been played by the development of engine turbo-charging systems. Turbo-charging, originally understood as the way to increase the power of a piston combustion engine, is currently used to decrease fuel consumption, in accordance with the concept of the so-called downsizing [2]. This concept has become a widely applicable standard in the construction of combustion engines to drive passenger cars. Fig 1 presents a graph showing the course of chosen parameters describing engine work and car speed recorded during a road test of maximum acceleration. The test was performed for the VW Golf TSI engine of BMY code. It is one of the first engines consistently designed according to the concept of downsizing, with speed range turbo-charging and of the engine cubic capacity equaling

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approximately 1.4 dm^3, and a maximum power of 103 kW. Although downsizing is a concept justified by environmental reasons, its realization in the presented example gives a car of very good performance, which is an important additional advantage. An engine with the mean usable pressure considerably exceeding the value of 2 MPa enables achieving environmental benefits in the form of low fuel consumption, and at the same time secures car acceleration satisfying the users' expectations. Such an engine concept however, is inevitably related to a significant mechanical load on the components of the piston-shaft mechanism. Turbo-charge pressure in excess of 2at obtained already at very low rotational speeds and work at the combustion knock limit contribute to the formation of very large values of maximum pressure in the cylinder. Large gaseous forces lead to loading the bearing surface of a piston with a normal force of a much higher value than in the previously produced engines. In the case of self-ignition engines, the construction of the piston is in fact perceived as the key element blocking a further progress of the concept of downsizing and increasing the mean usable pressure of subsequent generations of engines. This situation paves the way for searching new technologies and their applications in the construction of pistons for the future combustion engines. The authors consider it appropriate to test the usefulness of CNTs as a layer coating the bearing surface of a piston [4].

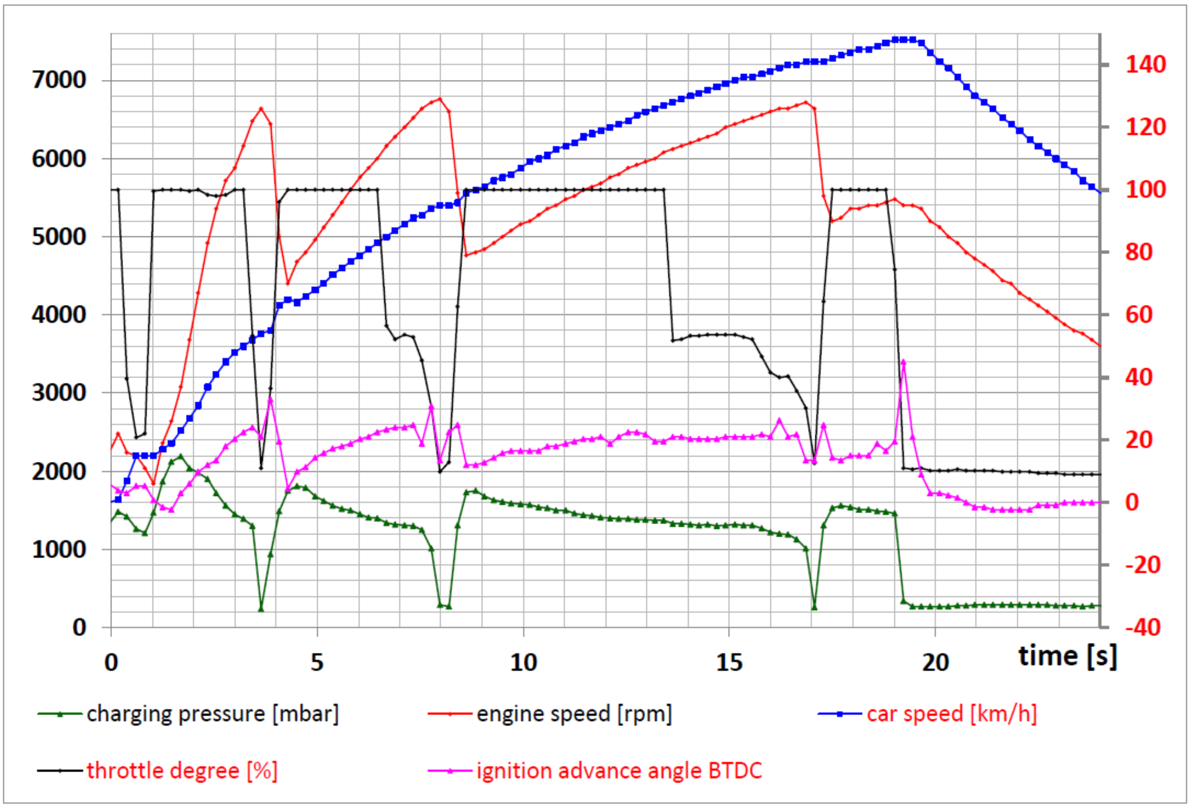

Fig. 1. Maximum acceleration road test for VW Golf TSI automobile, chosen parameters describing engine work

2. Carbon nanotubes

Nanotechnology is commonly considered as a one of the key technologies of the 21st century and its special role results from some exceptional – mechanical, electric, thermal, and optical properties of nanomaterials – completely different from the properties of the conventional construction materials. Carbon nanomaterials form crystal lattices with an extremely limited concentration of defects. The crystal structure gives them very high values of hardness and mechanical strength, which are at least by one order of magnitude higher than those in the case of steel, at very high elasticity values. The organized crystal structure created by carbon atoms arranged in a plane forming a side cylinder surface is a form of fullerenes called a nanotube.

Nanomaterials are characterized by certain especially advantageous mechanical properties unattainable for other materials, however, their scale of applications in the motor industry is limited by their high price, availability in industrial amounts and instability of properties of the individual lots of products.

However, paradoxically, based on the above it should not be concluded that the motor industry is characterized by a certain conservatism which provides an artificial barrier for modern technologies and solutions. Though such a barrier really exists, however, it results from the specificity of a final product, which – due to that improvement process lasting for more than one hundred years – is difficult to be improved in a simple way, and due to a large series production where each modification must be well ransomed by a large investment. At the same time it is worth notifying that a large series production of cars does not only create a certain barrier for the application of new materials, but it is also a driving force which gives bonuses to more effective solutions which are cheaper than the previous ones being used so far. [1]

3. Prototype pistons coated with a layer of carbon nanotubes (CNTs)

For experimental reasons, standard pistons of FIAT 170A.046 engine were coated with a layer of nanotubes within the area of piston bearing surface. Indeed, the technology of applying CNTs accepted in the first experiment enabled performing preliminary tests on pistons mounted in the engine, yet, it did not give fully satisfactory results. The applied layer of nanotubes was characterized by insufficient adhesion to the base material of the piston, which led to cracking and peeling. It was possible to carry out an engine test lasting several tens of minutes, however, in an industrial application such low durability is certainly unacceptable. Images of the surface layer of nanotubes taken by a transmission electron microscope (TEM) are presented in Fig 3.

Fig. 2. View of the piston with an applied layer of nanotubes prior to engine test.

The image depicted on the left-hand side of Fig 3 at relatively low magnification, shows the effect of peeling nanotubes. The surface in the top right corner is the base material of the piston with a visible trace of typical machining. The remaining part of the image is the cracked surface of nanotubes. An image being an enlargement of the part of this surface is presented on the right-hand side of Fig 3. Due to the very large magnification of TEM one can visualize the structure of the nanotube layer, but in the obtained image it was possible to determine approximate diameters of individual carbon nanotubes.

4. Testing prototype pistons

Experimental pistons with a layer of nanotubes were mounted in the engine of the test station, which enabled isolating friction losses generated in the piston-shaft mechanism.

The model station was built of a complete FIAT 170A.046 engine block along with a crankshaft, a connecting rod, pistons and an engine head. The model combustion engine is driven by an external electric motor with a possibility of regulating and stabilizing the rotational speed. There is a torque meter placed on the shaft which links the model engine to the electric motor driving it. The torque meter allows for recording the torque at a high resolution as a function of crankshaft rotation angle**.** In the built-in engine, the timing gear system was disconnected leaving the valves in the closed position. The oil pump and the coolant pump are driven externally by independent electric motors. Their work does not affect the recorded torque. Fuel is not supplied to the engine cylinders and the combustion process cannot be carried out. The view of the station is shown in Fig 4, and its detailed description is presented in the doctoral thesis [5], and selected important information in inter alia [3].

Coating the bearing surface of the piston with a layer of nanotubes modifies the piston-cylinder cooperation conditions, but besides the expected decrease in friction losses one can also notice damping vibrations and lower engine noise. A preliminary discussion of the above-mentioned phenomena was included in the earlier article [4], and at the same time there is no doubt that the subject issues require in-depth research. Fig 5 shows the torque driving the engine with the embedded prototype pistons in a time function. The measurements were performed for the first start of the engine with the new pistons, the engine was driven at a steady rotational speed equaling 1,000 rpm. Before the measurements were taken, the oil temperature had been stabilized. It stood at 80°C and did not change throughout the whole duration of the 30-minute test.

The shown time course of the torque indicates instability of the processes occurring in the engine during the first minutes after engine start. The decreasing value of the torque in the second part of the test is the evidence of a decrease in friction losses and suggests seemingly negative impact on the friction losses by coating the piston with a layer of nanotubes. In fact, the decreasing friction losses result from a reduction in the thickness of the layer of nanotubes, and thus from an increase in the clearance of the piston in the cylinder.

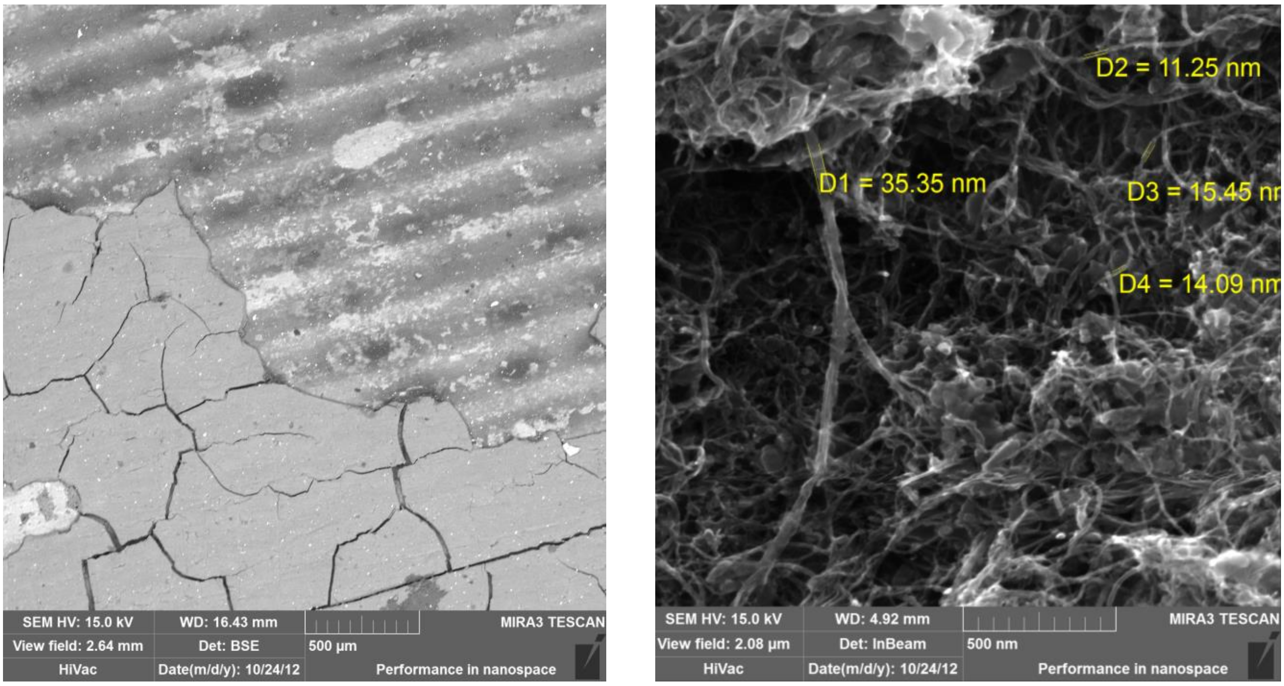

Fig. 3. The surface of nanotubes, an image of TEM (the image on the right-hand side is 1,000 larger than the one on the left-hand side

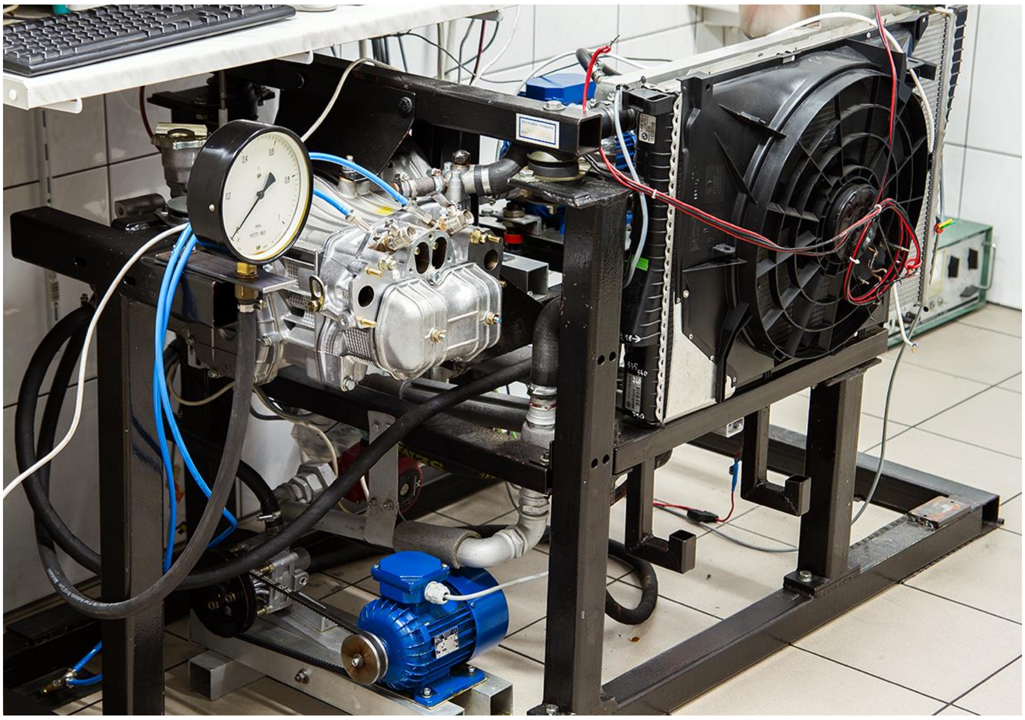

Fig 4. A model test station for examining friction losses in the piston-shaft mechanism.

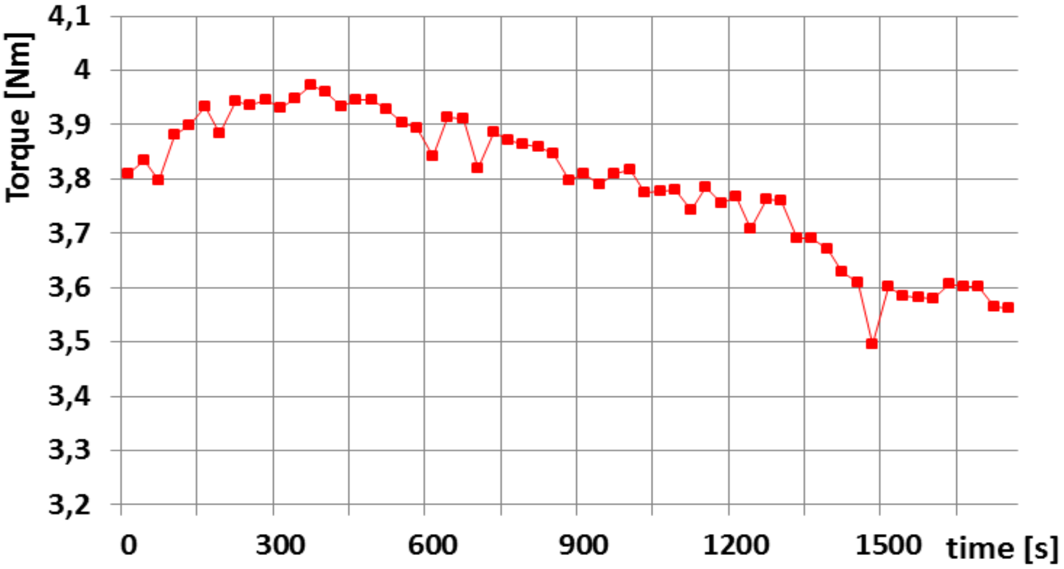

Fig. 5. The course of the torque driving the model station after the first start with the embedded new pistons coated with a layer of carbon nanotubes

Bibliography/*Literatura*

[1] Ciałkowski M, Giersig M., Iskra A., Kałużny J., Babiak M. Selected Possible Applications of Nanomaterials in Automotive Industry, Explodiesel 2009

[2] Golloch R. Downsizing bei Verbrennungsmotoren: Ein wirkungsvolles Konzept zur Kraftstoffverbrauchssenkung, Springer Verlag, 2001

[3] Iskra A., Kałużny J., Babiak M, The influence of oil and coolant temperature on friction losses of the internal combustion engine

[4] Iskra A., Kałużny J., Babiak M, Giersig M, Kempa K., Comparing the Resistance to Motion of Piston Coated with Layer of Nanotubes with Standard Piston, Kones 2012

[5] Kałużny J. Wpływ kształtu powierzchni bocznej tłoka na parametry filmu olejowego pokrywającego gładź cylindra, Praca doktorska, Poznań 2004

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