Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

STABILIZING PISTON SPEED WITH A LAYER OF CARBON NANOTUBES ON THE LATERAL SURFACE OF THE PISTON

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Abstract

The paper presents the possibility of stabilizing higher harmonics of piston speed generated by torsional vibrations of the shaft. As a result of torsional vibrations, the transient speed of the piston deviates from the values resulting from the known formulae describing geometrical dependences of the piston position versus the angle of rotation of the crankshaft [1]. This phenomenon causes the desired effect of damping torsional vibrations. As it is known, in larger engines of the cylinder diameter exceeding 120mm and the number of in-line cylinders greater than or equal to 6, structural damping is insufficient and it becomes necessary to use torsional vibration dampers. In article [2] attention was drawn to the effect of damping higher harmonics of the moment generated by the engine whose lateral surfaces are coated with layers of nanotubes, which was not however, the main subject of the article. This work presents a preliminary analysis and determinants of the efficiency of vibration damping due to the impact of nanotubes on the reduction of the amplitude of higher harmonics of the moment generated by the engine. In addition, the possible mechanism of the phenomenon of vibration damping by a layer of nanotubes is presented. However, one should emphasize that at this stage the authors do not close the debate concerning the mechanical properties of the structures based on carbon nanotubes (CNTs), but in fact, they open up such a discussion. Besides the confirmed properties of nanotubes, such as extremely high tensile strength of properly structured fiber formed by CNTs, there is very little data concerning the properties of chaotic structures in which nanotubes combine in larger structures adopting any directions. No less important is the base on which nanotubes are grown, and it can be very different. The authors of the paper have presented preliminary results of a positive impact of selected properties of CNTs on the vibrations of the crankshaft.

Keywords: *friction in internal combustion engine, nanotubes layers, crankshaft torsional vibration*

1. Introduction

One of the methods of reducing friction losses in a combustion engine is coating the lateral surfaces of pistons with proper layers with a low coefficient of friction. This method assumes that in a combustion engine the lateral surface of the piston comes into direct contact with the cylinder bearing surface. As it is confirmed by the research and computer simulations, the described situation is a phenomenon of a relatively short duration, usually when the engine is started, following a longer standstill [3]. Consequently, in a properly designed piston-cylinder group, the friction losses depend to a small extent on coating the lateral surfaces of the piston with layers with a low coefficient of friction. The importance of these coatings is exposed in easier engine start, and first of all, in reducing abrasive wear, before a continuous oil film is formed on the cylinder bearing surface. However, it appears that coating the cylinder bearing surface with specific layers may lead to reducing vibrations of the crankshaft, and thus the whole sequence of drive transmission. Fig. 1 presents schematically and disproportionately the combination of the side-surface of a piston coated with a layer of carbon nanotubes with the cylinder bearing surface.

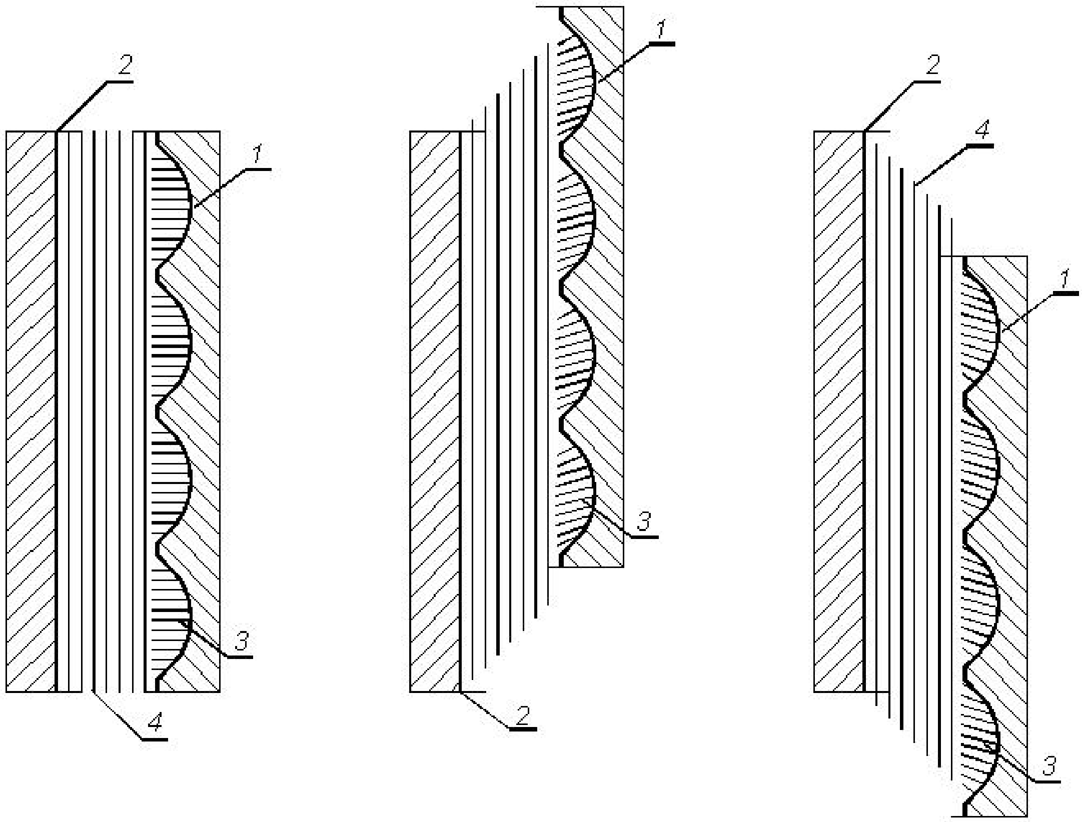


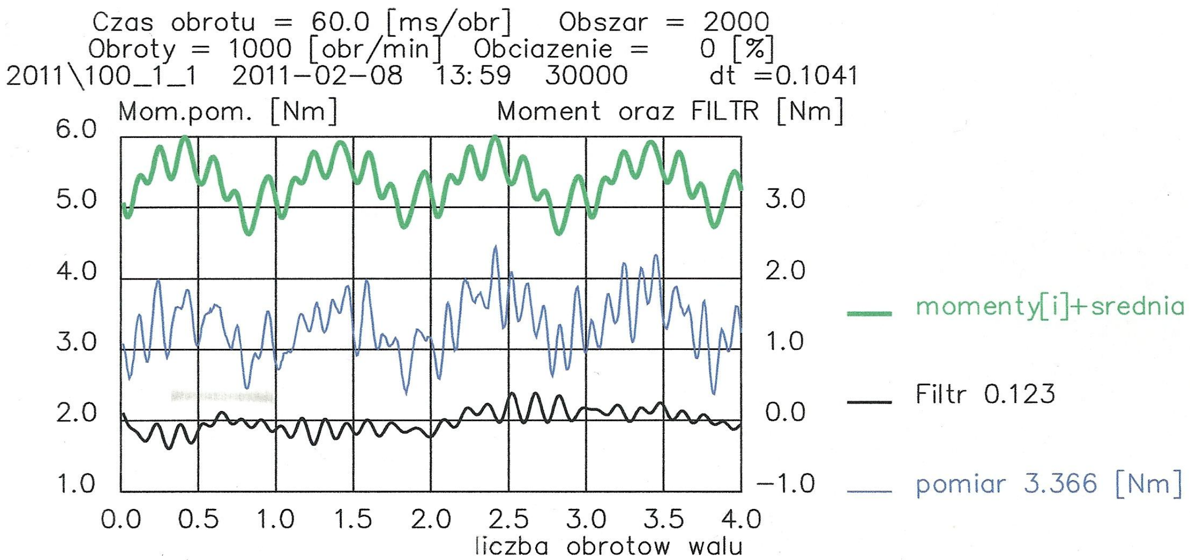
Fig. 1. The combination of the side-surface of a piston coated with a layer of carbon nanotubes with the cylinder bearing surface – description in the text

The structure of the lateral surface of piston 1 was outlined while taking into account only the trace of the curvature of the cutting tool that is left after finishing. Both on the lateral surface of the piston and on cylinder bearing surface 2 there is micro-roughness which is not relevant to the discussed issue, therefore, Fig. 1 pictures the plateau of these surfaces. In the grooves of the side-surface of the piston, there are embedded carbon nanotubes 3, which in fact form a chaotic structure. But in order to orientate the reader which direction the layer of nanotubes is deforming, they were pictured by horizontal lines. The layers of the oil film formed between the surfaces in contact was marked by vertical lines. The position of the piston on the left side in Fig. 1

corresponds to the zero relative velocity of the piston and sleeve. The middle diagram shows laminar motion of the oil film layers when the piston is ascending, and the diagram on the right side describes the piston motion in the opposite direction. As a result of the laminar movement of the oil film layers, within the contact area of a layer of nanotubes, there occurs a tangential force deforming nanotubes located in the grooves of the lateral surface of the piston. The deformation of the nanotube layer may be elastic, elastic-plastic or plastic. The results of the test carried out by the authors of this article confirm that the structure of randomly oriented nanotubes mainly exhibits elastic properties. This means that the energy of deformation of the nanotube layer is absorbed at the very moment when the piston accelerates, and when the piston slows down its speed in relation to the sleeve, the energy is transferred onto the piston and further onto the power receiver. As a result, there occurs suppression of higher harmonics describing the movement of the piston, which is equivalent to damping torsional vibration of the shaft. As it is known, the basic component of damping torsional vibrations in a classic internal combustion engine is generated by the viscous force of the oil film on the cylinder bearing surface. Unfortunately, such damping of torsional vibrations causes large energy losses because the change in the velocity of oil layers which are moved laminarily causes energy absorption, whether the piston accelerates or slows down; therefore, irrespective of the direction of the piston motion as well.

2. The course of engine's moment of resistance to motion

The actual course of the coupling moment of an internal combustion piston engine with a driving machine deviates considerably from the calculation values based on geometrical relationships. The reason lies in numerous phenomena, but the vibrations of the following unit: the engine shaft – the driving machine shaft are the most important. From a very extensive study, we selected the most representative measurement results of the coupling moment of a two-cylinder combustion engine with a driving machine and the obtained results are presented in Fig. 2-4.



KEY: Czas obrotu- revolution time, obszar – area, obroty- revolutions, obciążenie – load,
pomiar – measurement, Moment oraz filtr – torque and filter, liczba obrotów wału – crankshaft revolutions

Fig. 2. The course of the coupling moment of a two-cylinder combustion engine with the machine driving the engine at the angular velocity of 1000 rpm for standard pistons whose lateral surface is not coated with a layer of nanotubes, description in the text

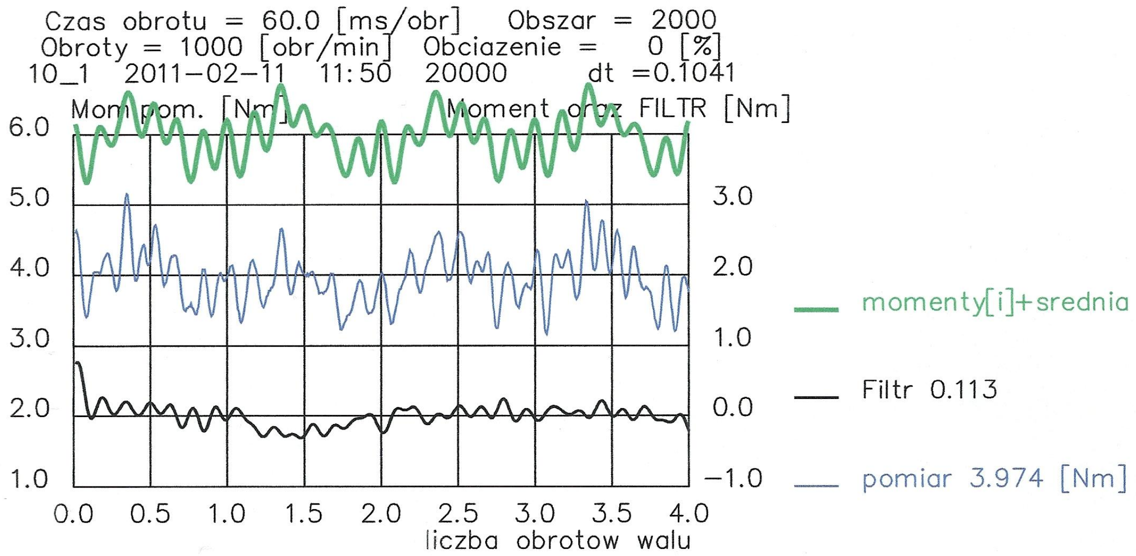


Fig. 3. The course of the coupling moment of a two-cylinder combustion engine with the machine driving the engine at the angular velocity of 1000 rpm after 10-minute grinding-in of nanotubes on the lateral surface of the piston

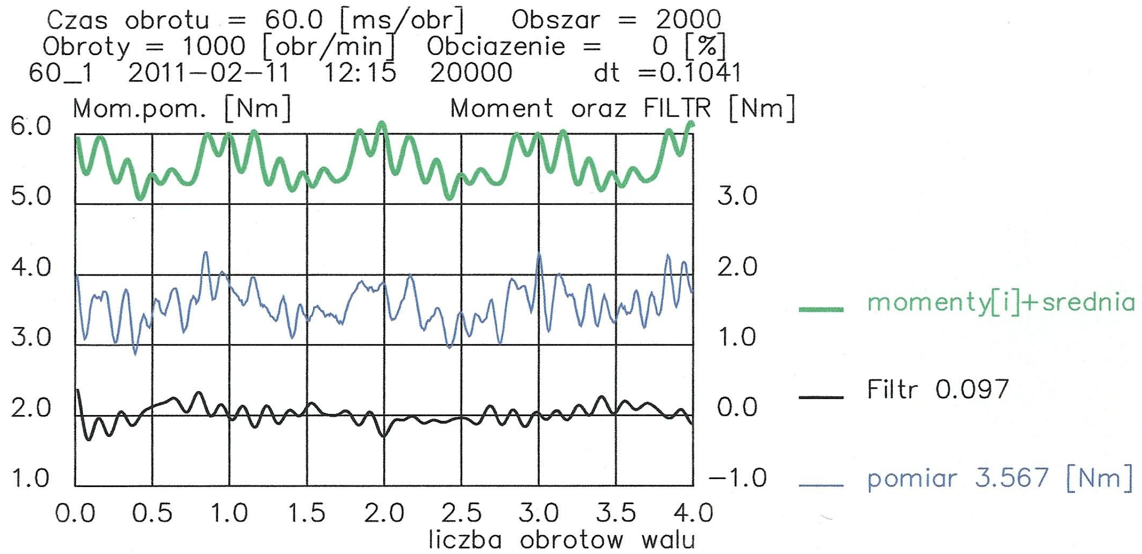


Fig. 4. The course of the coupling moment of a two-cylinder combustion engine with the machine driving the engine at the angular velocity of 1000 rpm after 60-minute grinding-in of nanotubes on the lateral surface of the piston

The following are marked in the drawings:

- the blue line – the course of the measured coupling moment, wherein the scale of the graph is described on the left vertical axis. The mean coupling moment is given on the right side of the drawing, next to the word "pomiar",
- the green line – the course of the processed signal of repeatable moment every two rotations of the crankshaft; the scale of the graph was described on the right vertical axis,
- the black line – the course of the filtered signal causing unrepeatability of the coupling moment at the rhythm of processes taking place in the engine, the scale of the graph was also described on the right vertical axis.

Due to the engine type and its modifications, the course of the coupling moment should in principle be repeatable every single rotation, but because of the difference in distance of two double cranks from the driving machine there must occur certain differences in the generated moment of resistance related to the compression of the agent within cylinder volume. This results from differential susceptibility of drive transmission.

What is important is the answer to the question of the cause of unrepeatability of the measured coupling moment. As one can notice, in the case of full repeatability of the coupling moment the filtered signal shown as the black line in Fig. 2-4 should amount to 0. However, since the filtered signal shows variable values, one should accept a definition of a certain indicator which would be the measure of unrepeatability of the course of the coupling moment. The simplest and, as it seems, the most proper indicator of the unrepeatability of the coupling moment is the sum of deviations from the mean value in relation to the number of included values. In this case, the mean value is 0, and the deviation is always assumed positive. The indicator of unrepeatability of the courses of the coupling moment is to be referred to as α in later parts of the article.

As mentioned above, it is torsional vibrations that are the main cause of unrepeatability of the courses of the coupling moment. The frequency of these vibrations is dependent on the mass moments of inertia of the elements coupled with the shafts and the rigidity of the units connecting the shafts, and not on the angular speed of the set: combustion engine – driving machine. One can, therefore, put forward a hypothesis that the smaller the value of indicator α of unrepeatability of courses, the less the energy of torsional vibrations, and therefore less stress loading the engine's shaft.

In Fig. 2-4 the values of indicators α were marked next to the word „Filtr" on the right side of the graphs. The value of indicator α is given in [Nm]. More details of the process of evaluating the value of the filtered signal are provided presented in literature [2].

In the case of a standard piston engine in which the piston lateral surface is not coated with a layer of nanotubes, the value of indicator α was 0.123 [Nm] – Fig. 2. Coating the lateral surface of the pistons with a 5 μm layer of nanotubes brought about a decrease in the initial value of indicator α to the level of 0.113 Nm – Fig. 3. This value was obtained following a 10-minute running-in of the engine, since the moment when pistons coated with a layer of nanotubes were embedded. The shape and location of the layer of nanotubes is shown in Fig. 5.

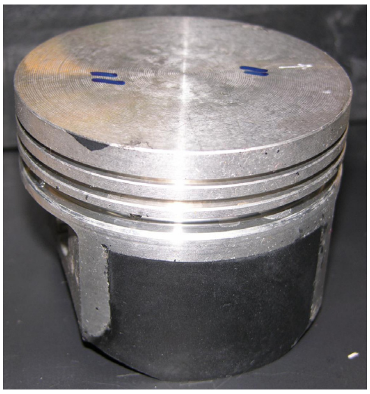


Fig. 5. The piston with a layer of nanotubes applied to the lateral surface prior to testing

Further grinding-in the layer of nanotubes on the lateral surface of the piston during the period of 30 minutes caused a systematic decrease in the average value of the coupling moment, followed by its stabilization. The course of the coupling moment that was obtained after 60 minutes is shown in Fig. 4. The value of indicator α after 60 minutes of movement decreased to 0.097 [Nm] so in relation to the value α for standard pistons, the decrease in free vibrations of the set was reduced by approximately 25%.

Having completed the testing, a disassembly of the engine was performed. Examination of the pistons demonstrated that the layer of nanotubes was worn off to the edges of vertices that were left as a result of machining – Fig. 6.

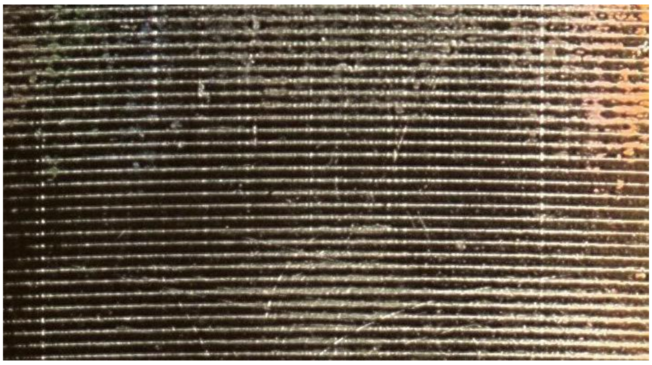


Fig 6. A section of the lateral surface of the piston following a 60min running process

One should emphasize that applying a layer of nanotubes on the surface of an aluminum alloy is a process that is still in its experimental phase, and first attempts to control such a process gave positive results in very few laboratories [4-14]. Fig. 7-8 present the structures of the chosen ways of growing nanotubes on the surface of a carrier.

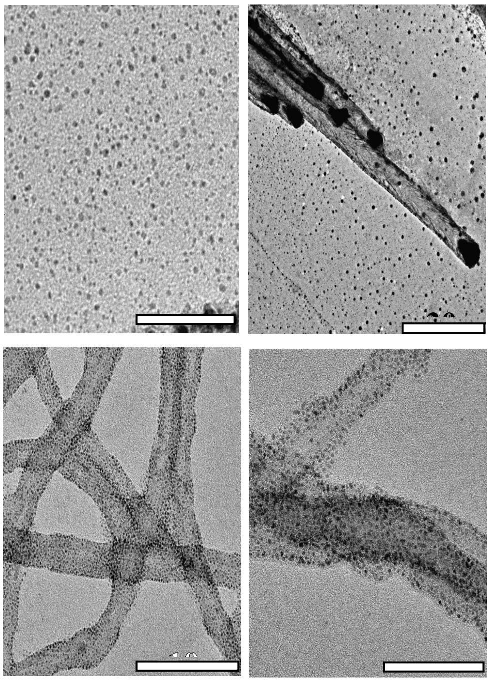


Fig. 7. Pictures from a transmission electron microscope presenting CNTs with the embedded platinum nanoparticles on them

Conducting the process of growth while applying a strong electric field allows for vertical growth of nanotubes, which is very important from the viewpoint of mechanical properties of the applied layers on the side-surfaces of pistons. The vertical growth of CNTs was presented in Fig.ures 8A), B) and C), whereas the anisotropic one in Fig. 8 D).

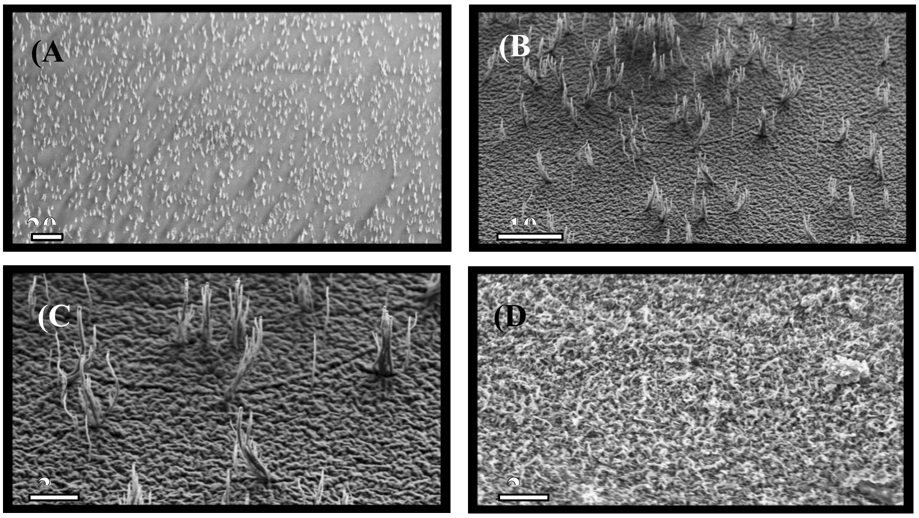


Fig. 8. Pictures from a scanning electron microscope (SEM) showing metal surface coated with CNTs with the embedded platinum nanoparticles on them

Current research focuses on growing more durable layers of CNTs of the desired mechanical properties on the surface of aluminum alloys.

3. Summary

The research presented in the article shows the possibility of using coverings of layers of nanotubes on the lateral surface of the aluminum alloy piston in order to reduce unwanted torsional vibrations in the sequence of drive transmission. Further tests modifying the structures of nanotubes are being carried out in order to reduce frictional resistance and to more effectively reduce the vibrations of the engine shaft. The experiments concerning applying various elements and chemical compounds on CNTs suggest that damping properties of nanotube layers and the frictional forces generated by them on the contacting point of oil film allow for obtaining significantly better performance of piston combustion engines. Frictional losses of pistons on the cylinder bearing surface will, however, depend first of all on the parameters of the oil film that is generated by properly designed lateral surface of the piston. Any layers applied to the lateral surfaces of pistons may reduce friction only in the phase of starting an engine, before oil film is formed on the cylinder bearing surface.

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