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STRUCTURE ANALYSIS OF THE SURFACE OF PLUNGER AND BARREL ASSEMBLY IN THE INJECTION PUMP PUMPING SECTION

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Abstract

Precision surfaces in a diesel engine's fuel system are used in the two components. First one is the pumping section in the injection pump. The second ones are injectors. In this paper authors present results of the topography measurements of the surface of plunger and barrel assembly in the injection pump pumping section. The measurements were performed using the atomic force microscopy (AFM) NT-206.

The measured surface topographies were shown in the form of two and three-dimensional views of selected areas of the investigated surfaces. There are also presented the profiles of the selected area cross-sections as well as roughness height distribution and cumulative height distribution of roughness. Additionally, the basic parameters describing the surface roughness, such as: a roughness average Ra, a root mean square value Rq of roughness, a skewness Ssk (Rsk) and kurtosis Sku (Rku), are also specified. The samples (plungers and barrels), which have been measured, come from the injection pump pumping section as a new ones and after estimated period of operation time. The lateral precision surfaces have been measured. The atomic force microscope NT-206 allows to perform scanning of the measured surface with maximum are dimensions of 32 μm x 32 μm and maximal roughness height of ± 1 μm. Scanned surfaces was divided into 256x256 measuring points and the measurements were performed in the static (contact) mode. After surface scanning on the atomic force microscope, the data was calculated in the SurfaceXplorer® 1.311 or Gwyddion 2.35 software. In this paper, only selected surfaces from the several dozen performed scans are shown. The obtained results allow to determinate the degree and type of wear of tested surfaces at the micro-level.

Keywords: *atomic force microscope, surface topography, roughness, plunger, barrel, injector pump, pumping section*

1. Introduction

This study concerns analysis of the surface structure of precision assemblies of the fuel system of a diesel engine. Such surfaces can be found in the two locations: firstly in the pumping section of the injection pump, secondly, they are surfaces of injectors [5]. In this paper, the author analyses the topography of the surfaces of plunger-barrel assemblies of the injection pump (pumping section).

A surface quality of precision assemblies in the injection pump has a very large impact on the proper operation of a diesel engine. Both, the plunger and the barrel of the pumping section, are adjusted, so that the gap between the side surface of the plunger and the inner surface of the barrel is approximately 1-3 μm [5]. This clearance provides sufficient lubrication of the side surfaces of the plunger and the barrel while still providing enough sealing to maintain high pressure of diesel fuel. Impurities in the fuel are of the same order of magnitude or greater, as the gap of precision this assembly (from tenths of microns to several microns) [5]. The penetration of the hard particles from the fuel, between the side surface of the plunger and barrel, can cause scratching of such precision assemblies, which generates leakage and pressure drop of injection process. This fact can result in reduced fuel dose, deterioration of spraying quality or even a lack of fuel injection, increased fuel consumption, penetration of fuel into the lubricating oil and deterioration of its performance characteristics.

The aim of this work is to investigate the surface topography of the new and used precision assemblies of pumping section of the injection pump (Fig. 1) and the evaluation of the wear of the these surfaces.

The determination of wear of the surfaces may be made, inter alia, on the basis of several basic parameters of the surface structure [1-9]. In this study, the surface parameters were determined in accordance with the PN-EN ISO 4287/1999 standard. These parameters are: average roughness height Ra, root mean square of roughness height Rq, skewness Ssk (Rsk), kurtosis Sku (Rku). These parameters have been calculated for the selected surfaces and for the profiles at specific cross-sections.

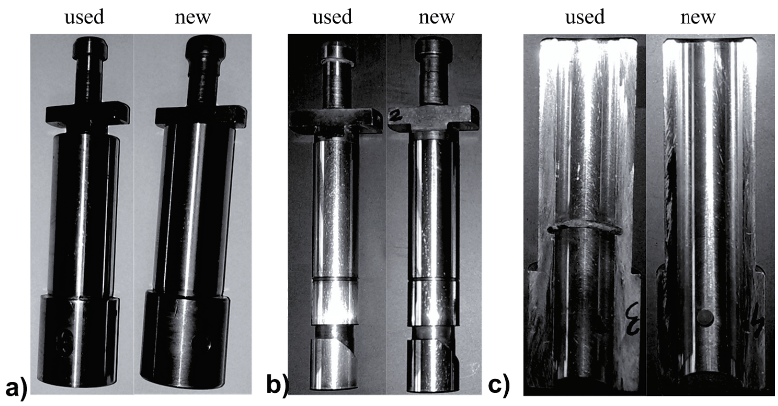

Fig. 1. The investigated plunger-barrel-assemblies; a) view of the assemblies, b) plungers, c) half-cut barrels

2. Investigations of surface structure

The study of surface topography was carried for the new and the used pumping sections of the injection pump (for the surface of plunger and barrel). The used pumping section operated approximately 1,000 hours in Cegielski-Sulzer 3AL25/30 engine. This is the four-stroke, three-cylinder ship engine with a power of 396 kW, which is installed on a laboratory at the Department of Marine Engineering at Gdynia Maritime University. This engine is not intensively operated but it is working often at different simulated malfunctions, also at malfunctions of the injection system.

The measurement of the surface structure at micro-scale was made with the Atomic Force Microscope (AFM) NT-206. This microscope can measure the area with dimensions of 32 μm x 32 μm, while the maximum measurable roughness height is ±1 μm [1]. The scanned area was divided into 256x256 measurement points. The measurements were carried out in the static (contact) mode. In order to investigate a specific area, a sample was cut so, that its height does not exceed 8 mm and the length and width – 1 cm (these are the maximum values given in the AFM manual). Then, a dozen surface scans of each sample were carried out. This paper presents the six images of each surface in the form 2D view (Fig. 2, 4, 6, 8) and one selected surface topography in the 3D view, as well as the cross-section of selected profiles and also the roughness height distribution and the roughness cumulative height distribution (Fig. 3, 5, 7, 9).

Figure 2 shows a 2D view, as in Fig. 3 is shown a 3D view and cross-sectional profile of the plunger surface, which was used in operated pumping section. In addition, Fig. 3 contains graphs showing the roughness height distribution and cumulative height distribution and also the data concerning the roughness parameters. The measured surface of plunger of the non-used pumping section is shown in Fig. 4 and 5 in the same manner.

Figure 6 shows a 2D view, as in Fig. 7 is shown a 3D view and cross-sectional profile of the barrel surface of the operated pumping section. As in the previous figures, there are also graphs showing the roughness height distribution and cumulative height distribution and the roughness parameters (Fig. 7). In the same manner, in Fig. 8 and 9, are shown the results for the surface of non-used barrel of pumping section.

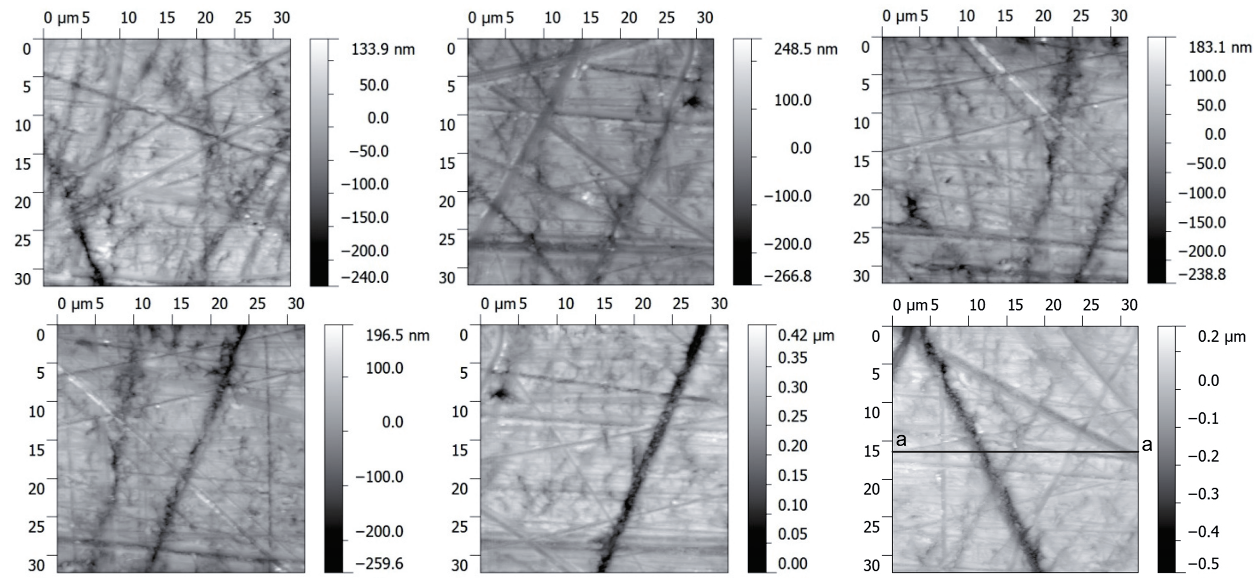

Fig. 2. 2D-view of the plunger surface topography of the operated pumping section of injection pump

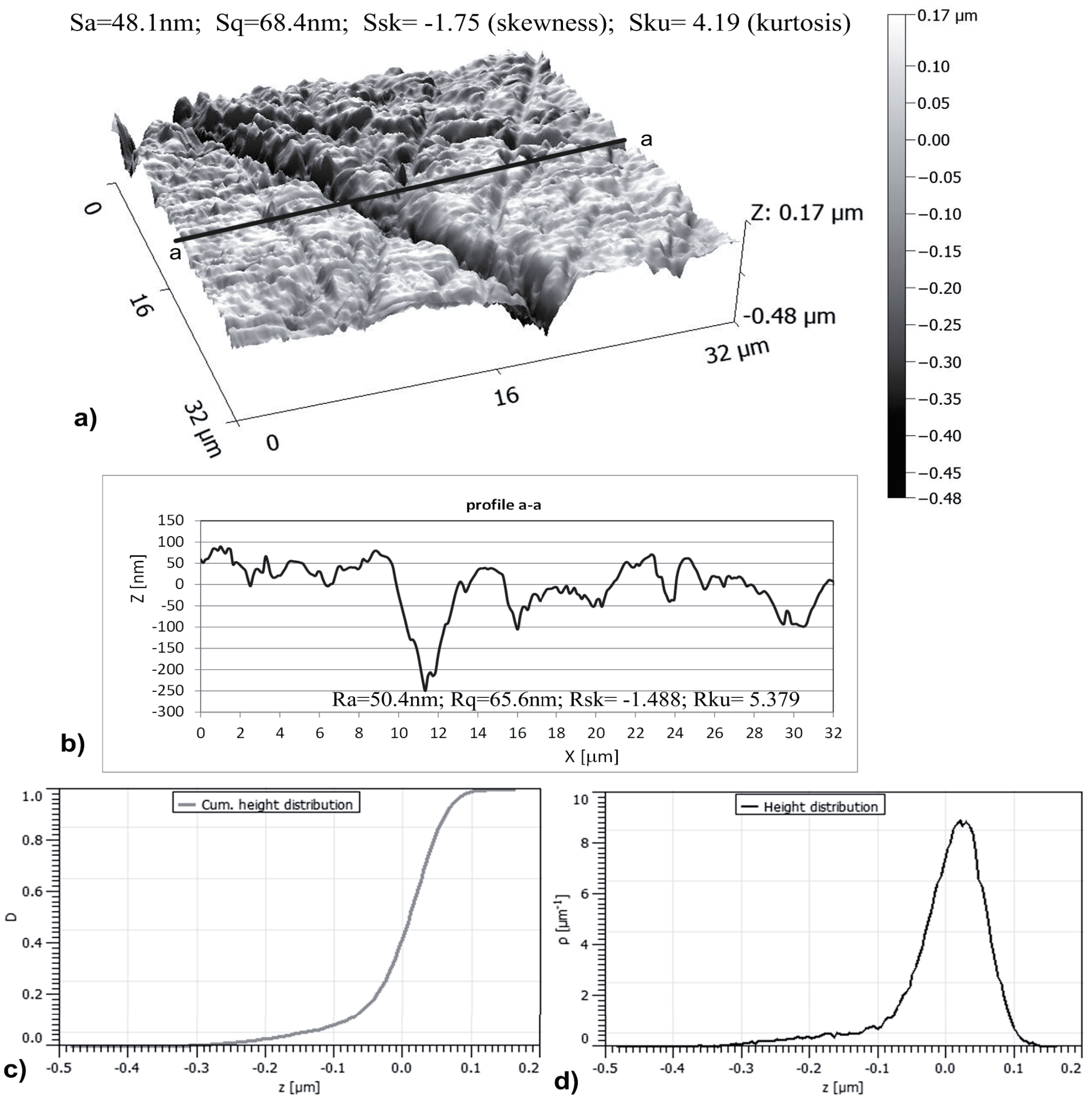

Fig. 3. The surface topography of operated pumping section plunger: a) 3D-view, b) profile of the selected cross-section, c) cumulative roughness height distribution, d) roughness height distribution

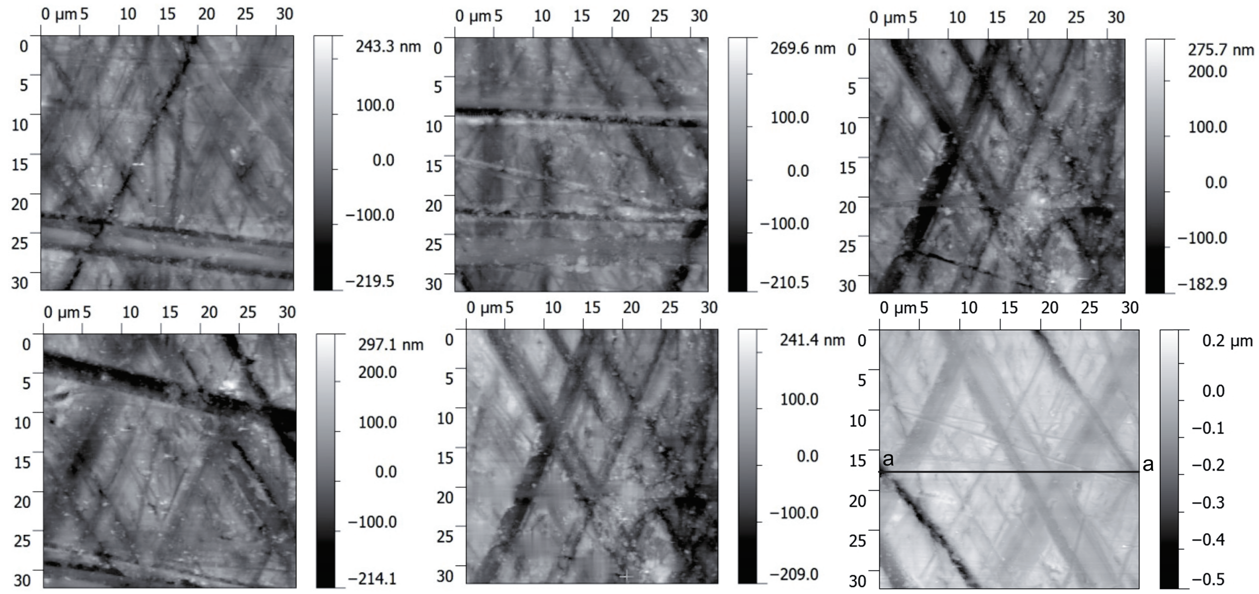

Fig. 4. 2D-view of the plunger surface topography of the non-operated pumping section of injection pump

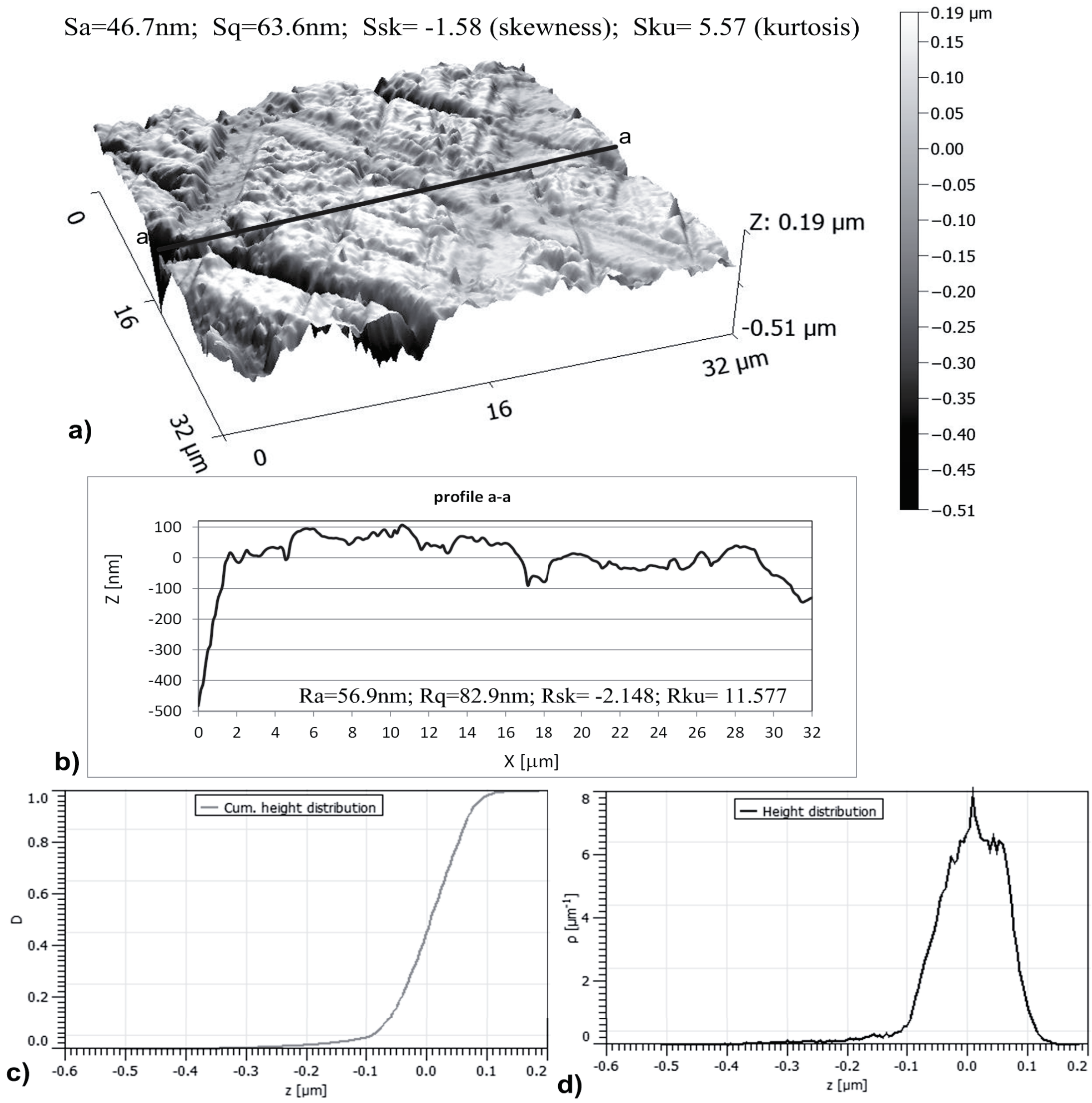

Fig. 5. The surface topography of non-operated pumping section plunger: a) 3D-view, b) profile of the selected cross-section, c) cumulative roughness height distribution, d) roughness height distribution

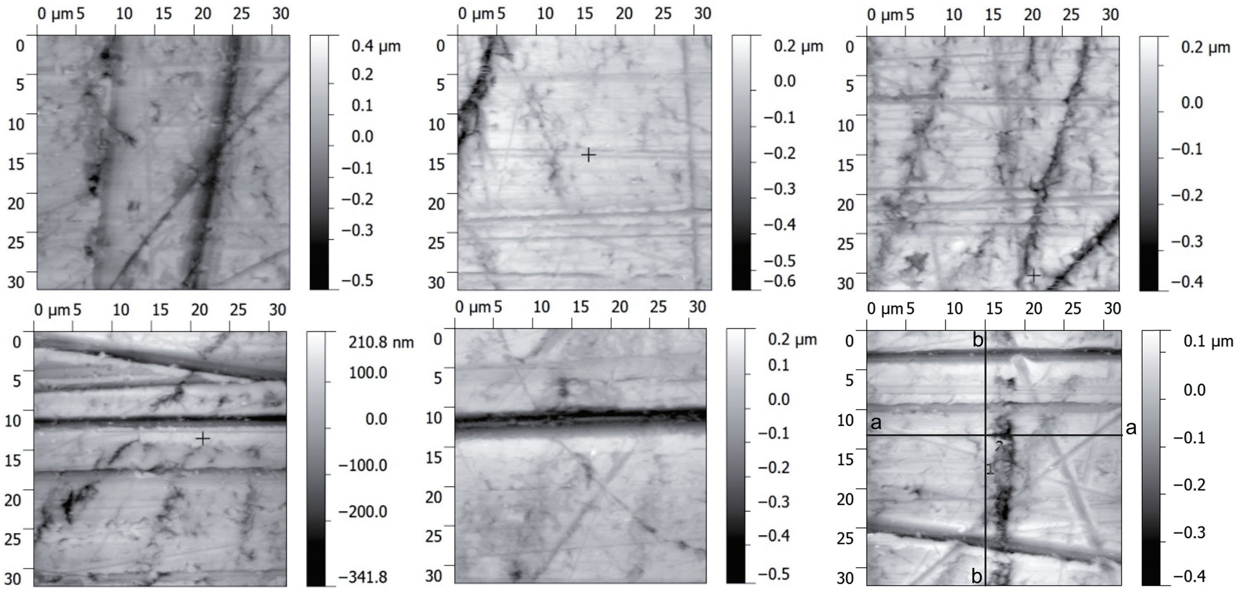

Fig. 6. 2D-view of the barrel surface topography of the operated pumping section of injection pump

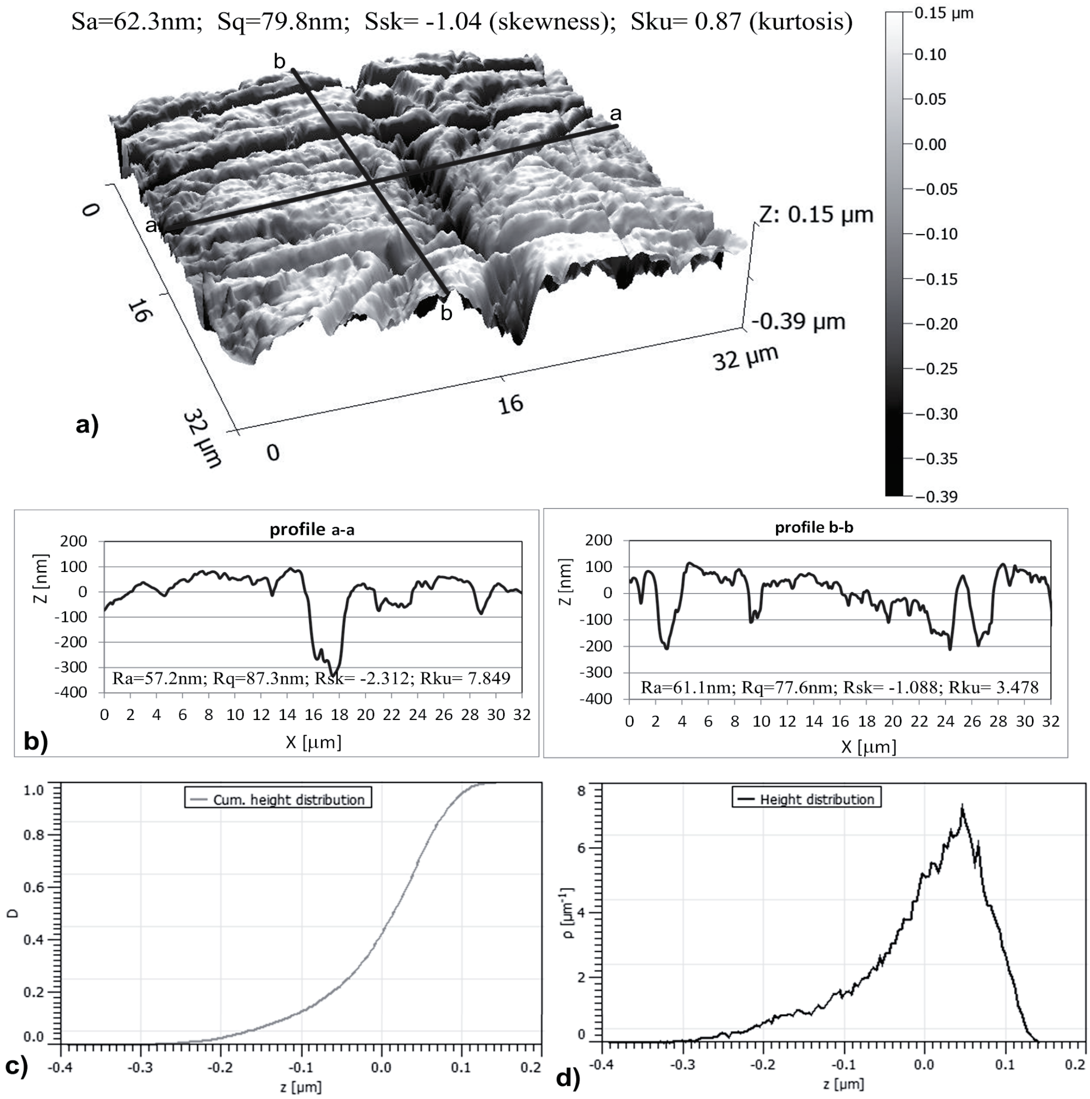

Fig. 7. The surface topography of operated pumping section barrel: a) 3D-view, b) profile of the selected cross-section, c) cumulative roughness height distribution, d) roughness height distribution

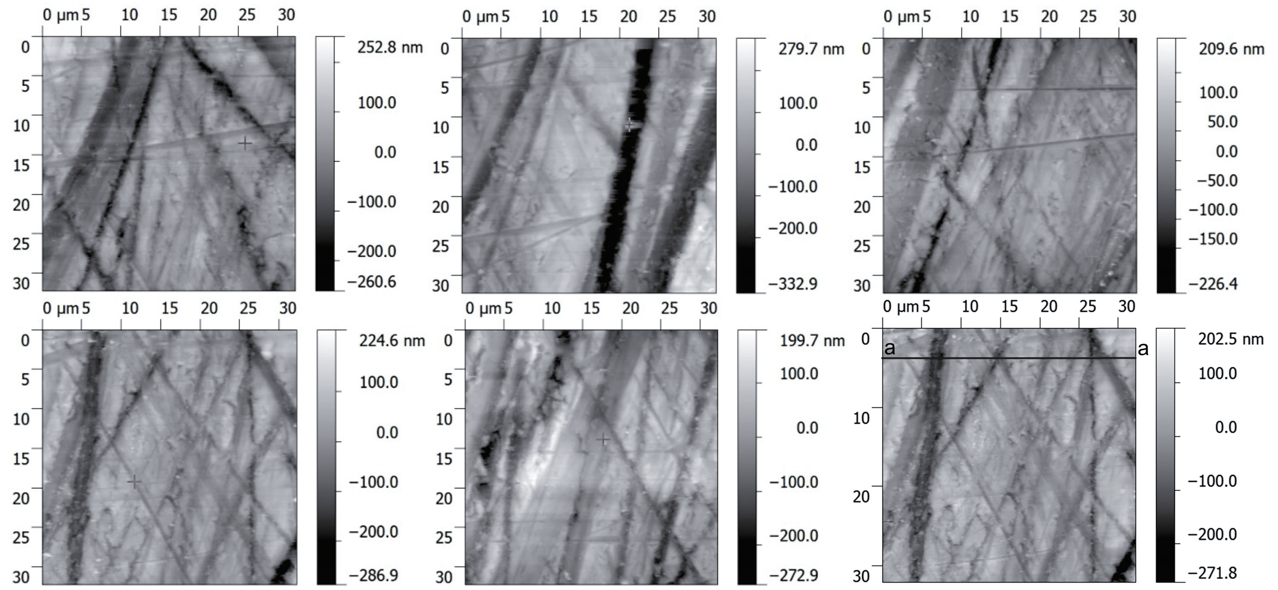

Fig. 8. 2D-view of the barrel surface topography of the non-operated pumping section of injection pump

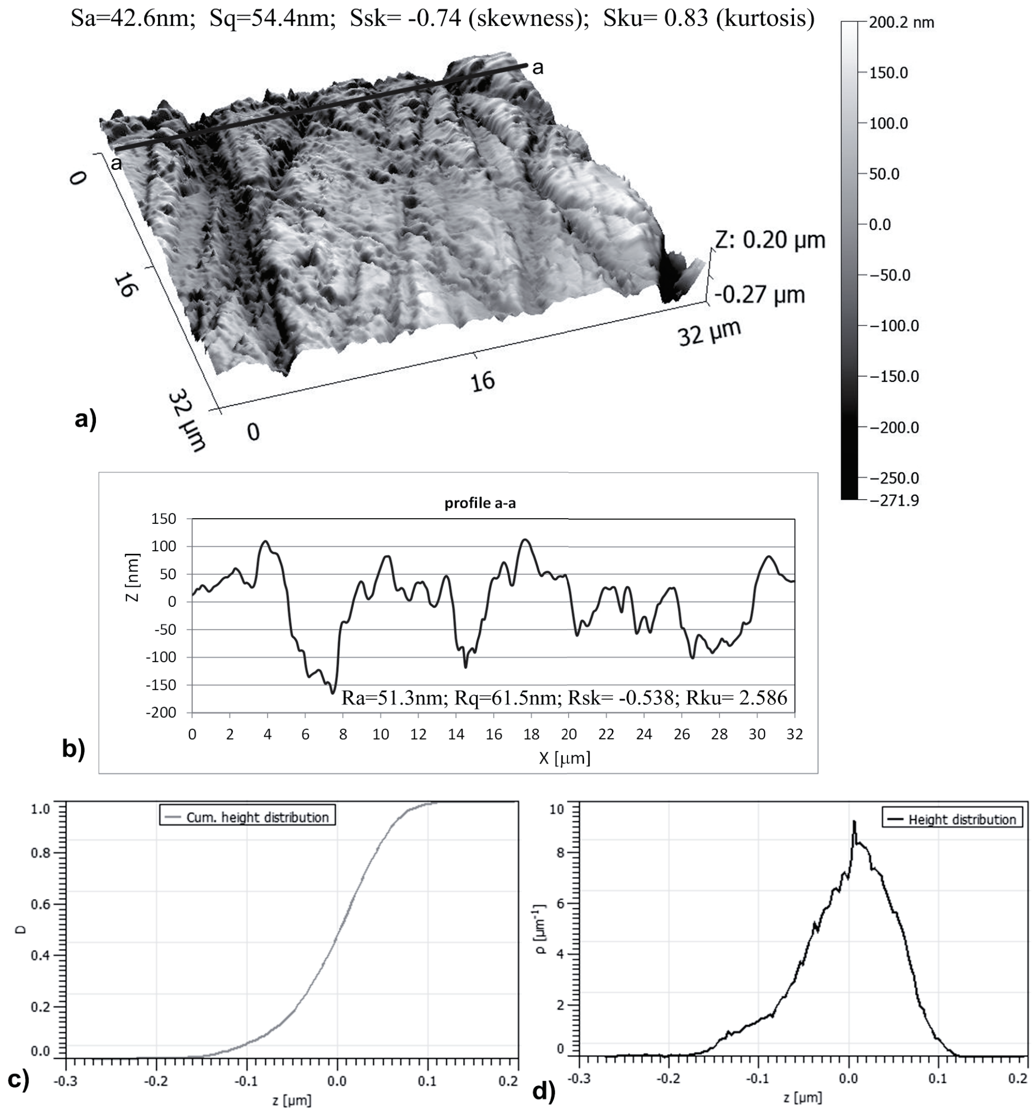

Fig. 9. The surface topography of non-operated pumping section barrel: a) 3D-view, b) profile of the selected cross-section, c) cumulative roughness height distribution, d) roughness height distribution

After surface scanning on the Atomic Force Microscope, the data was investigated in the SurfaceXplorer® 1.311 and Gwyddion 2.35 software. The 3-D views, cross-sectional profiles, cumulative height distributions and height distributions were generated in the Gwyddion 2.35.

The values of roughness parameters Sa and Sq (Ra and Rq for profile) for the investigated plunger and barrel surfaces of non-used pumping section, are in the range from 43 nm to 82 nm (Fig. 5a, 5b, 9a, 9b), while these parameters for the investigated used pumping section are in the range from 48 nm to 87 nm (Fig. 3a, 3b, 7a, 7b). The tested surfaces, especially the new ones, are characterized by the distinct traces of treatment. The surfaces of the used pumping section plunger and barrel have blunted tops of roughness elements and deeper randomly distributed scratches (grooves), resulting from contact with hard contaminants from the fuel. The width of these impurities is of the order 2-3 μm (see Fig. 3b and 7b) and their depth reaches 200-300 nm.

The nature of roughness height distribution and cumulative height distribution curves is similar for the plunger's surfaces of the new and used pumping section of injection pump. The same situation occurs when considering curves representing the roughness height distribution and cumulative height distribution of barrel surfaces of the new and the used pumping section. However, when comparing the nature of curves showing the roughness height distribution of plunger and barrel, there can be observed a distinct difference. In the case of surface topography of the plunger, we have steep curves of height distribution (for the barrel they are flat). This means that, on the surface of the barrel appears more peaks and valleys of varying heights (from -200 nm to +120 nm, see Fig. 7d, 9d). On the surface of the plunger we have a lot peaks and valleys with a height in the range from -90 nm to +100 nm (see Fig. 3d, 5d). Similar conclusions we can learn by analysing the curves describing the cumulative height distribution.

3. Observations and conclusions

In this paper, are shown only selected surface topographies from among dozens of scans performed and analysed with the Atomic Force Microscope.

From the comparison of surface topography of the plunger and barrel of the new and the used pumping section presented in this paper, it is evident that the surfaces of the used section are characterized by deep scratches and surface defects. The width of scratches is of the order 1-3 μm, i.e. the same order as the gap height of plunger-barrel-assembly, which means, that these scratches could have done the hard particles of impurities present in the fuel. Some scratches on the surfaces of new and used pumping section of the injection pump are due to the method of surface treatment (grinding, honing). In Fig. 2, 4, 6, 8 are shown the distinct scratches situated in the two directions. The angle between these directions is about 60°.

The analysis of the surface structure allows determining the degree and type of wear. The tested surfaces, which were used in the operated pumping section, contained deeper scratches, which could cause a decrease in the fuel delivery pressure to injector.

The surfaces of plunger and barrel of new pumping sections and the surfaces of plunger of used pumping sections of injection pumps are referred as the structural and directional surfaces. The surfaces of barrels of used pumping sections of the injection pump can be classified as the surfaces with a random structure.

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