Assessment of the state of the geometrical surface texture of seal rings by various measuring methods

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Abstract. The present paper concerns the metrological measurements of the geometric structure of the faces of seal rings made of silicon carbide and carbon-graphite. Three different instruments, i.e. the stylus profilometer, the optical profilometer, and the atomic force microscope, were used to measure the geometric structure of surfaces. In the comparative analysis, an identical area of the ring surface which was mapped by three measuring instruments with different sampling densities resulting from their metrological characteristics was assumed. The measurements made show that for the silicon carbide ring, the surface texture measurements on an atomic force microscope and optical instruments more accurately represent the actual topography than the measurement determined by the stylus profilometer.

1. Introduction
The state of topography of surfaces many sliding connections of the mechanical parts (performing relative motion), determines their tribological and exploitation properties. In the case of mechanisms such as contact seals, sliding bearings or friction clutches, materials properties, technology and surface topography of the contacting surfaces are very important for their durability and reliability. The geometric texture of the surface determines the actual contact surface of co-operating elements and actual contact pressures [1,2]. In the case of face mechanical seals, the condition and microstructure of the surface significantly affect the tightness of the face contact of seal rings and the frictional resistance.

In the literature on face seals, for example [3-5], the theoretical models of the microroughness contact of the surface of seal rings and the estimates of the height of the gap and the flow rate (leakage) on their basis. Properties of materials and surface topography parameters of the co-operating seal rings are required as input parameters in these models. Hence, the reproduction accuracy of real conditions of the contact of seal rings depends on the physical assumptions adopted and the accuracy of input parameters, including surface roughness parameters.

In recent years, modern measuring techniques and specialized computer software have been developed to measure and analyze surface topography. Contact profilometry with a mapping blade, phase shifting interferometry, confocal microscopy, coherent scanning interferometry, focus variation microscopy, scanning tunneling microscopy, and atomic force microscopy, among others, belong to the methods of spatial topography [6]. The choice of the appropriate method for a given measurement task depends on the properties of a measured sample such as the hardness determining the ability to use contact methods or the degree of light absorption by the material of the measured element.
determining the possibility of using optical methods. The state of surface topography characterized by the amplitude of roughness, the distance between the roughnesses and the inclination angle of roughness slopes are another important element that depends on the selection of the method [7].

The proper selection of the method of measuring very smooth surfaces that guarantees reliable results should consider an analysis of potential major sources of errors for each method affecting the measurement results [8].

This paper describes the results of roughness measurements of the faces of seal rings which were obtained from the measurements with three instruments: a stylus profilometer, an optical profilometer, and an atomic force microscope.

In the comparative analysis an identical surface area mapped by three used instruments was assumed, but with different densities of sampling resulting from their metrological characteristics.

In order to compare the measuring instruments used, five amplitude parameters and five surface parameters of the topographies of the faces of two seal rings were adopted.

2. Research object

The object of the study was the topography of faces of seal rings in the mechanical face seal. The figure shows a diagram of the mechanical face seal showing the gap formed by the actual (roughened) sealing surfaces of the two rings.

![Figure 1. Mechanical face seal scheme: 1- rotating ring seal, 2- stationary ring seal](image)

The stationary ring (2) (Figure 1) made of silicon carbide and the rotating ring (1) made of carbon-graphite and flexibly attached were subjected to metrological studies. The material kit of seal rings is a typical set used in modern face seal designs by many manufacturers. It is well known from the use of face seals that carbon-graphite is characterized by good sliding properties, whereas silicon carbide is a hard material resistant to wear and temperature. The hardness of the carbon-graphite ring was about 110 HR and that of the ring made of silicon carbide over 3000 HV. The surfaces of both rings (in the technological process) were ground and then lapped to achieve values of surface roughness Ra between 0.03 and 0.06 μm. The finishing process (preparing faces) of the seal rings provides an isotropic roughness of the surface.

3. Methods of measurement

The topography of the faces of seal rings was measured by the contact method, the non-contact method, and on an atomic force microscope.

A Taylor Hobson Form Talysurf PGI 1230 profilometer was used to make measurements by the contact method. This instrument has an interferometer head with a measuring range of 12.5mm and a resolution of 0.8nm, which makes it possible to perform stereometric measurements of the surface while taking the contour, waveform and roughness of the surface into account. The instrument is equipped with a table to move the measured object in the Y axis with a maximum resolution of 1 μm. In the measurements presented in this paper, a conical measuring tip with the rounding radius of 2 μm and a vertex angle of 60° was used. Before the measurements 1mN pressure force, the traversing speed of the measuring tip v_tr=0.5 mm/s was set on the device. Topographic measurements were made on surfaces of 1mm x 1mm, making 401 linear runs distant 1 μm apart.

Measurements by the non-contact method were performed on a Talysurf CCI instrument using coherent correlation interferometry which combines vertical scanning with optical interferometry. Thanks to this system, it is possible to make an analysis of the geometric surface with the vertical
resolution up to 10µm and the constant in the measuring range of 2.2 mm. A Talysurf CCI has the ability to measure any surface of the reflectance between 0.3% and 100%. The measurement time is from tens of seconds to a few minutes and is dependent on the height of the roughness of the element being measured. The same measurement made on the contact profilometer can take from several dozen minutes to several hours. The x50 lens was used to scan the test surface of 0.33x0.33 mm. Measurements were recorded in the matrix of 1024 x 1024 points.

The third measuring instrument used to measure the surface topography of the examined rings was an AFM Dimension Icon atomic force microscope. The atomic force microscope illuminates the surface of the workpiece with a cantilever whose tip radius is a dozen or so nanometers. The force between the tip (needle) of the probe and the surface of the sample to be measured causes the lever to deflect. The detector measures the inclination of the lever as it moves over the surface of the element. The Dimension Icon atomic force microscope can work in three modes: contact, non-contact and intermittent contact. The measurements were made using an AFM instrument operating in the contact mode with a SCANASYST-AIR measuring probe with a 2nm tip radius. A maximum area of 90µm x 90 µm was used to measure the geometric structure of the surface. Measurement data were recorded in the matrix of 512 x 512 points.

4. Results of measurements and their analysis
Surface roughness measurements were carried out with the three above-described instruments on the faces of both seal rings in the examined face seal. The measuring areas for the measuring instruments used were different, i.e. for the Form Talysurf PGI stylus profilometer – 1mm x 1mm; for the Talysurf CCI optical profilometer – 0.33mm x 0.33mm, and for the AFM Dimension Icon atomic force microscope – 90 µm x 90 µm. Horizontal sampling densities (in x, y plane) used for each instrument are shown in the table below.

| Instrument                                      | Δx (µm) | Δy (µm) |
|------------------------------------------------|---------|---------|
| Dimension Icon atomic force microscope         | 0.18    | 0.18    |
| Talysurf CCI optical profilometer              | 0.33    | 0.33    |
| Form Talysurf PGI 1230 stylus profilometer    | 0.125   | 1.00    |

Measurement data were recorded and then analyzed in a TalyMap Platinium software. An analysis of the measurement results was made for a uniform area of 90µm x 90µm. The surface area assumed for the analysis was determined by the technical feasibility of the measurement on the atomic force microscope. In order to compare and evaluate the values of the parameters obtained in the measurements on three of the above-mentioned instruments, the following geometrical surface texture (GST) parameters were chosen:
- amplitude parameters of the surface:
  - arithmetic mean height of the surface Sa,
  - root mean square height of the surface Sq,
  - maximum peak height of the surface Sp,
  - maximum pit height of the surface Sv,
  - maximum height of the surface Sz
and parameters of the areal material ratio curve - Abbott–Firestone curve:
  - core height Sk,
  - reduced peak height Spk,
  - reduced dale height Svk,
  - areal material ratio of the peak height Smr1,
  - areal material ratio of the dale height Smr2.
In addition, there are isometric images of the surface topography, material ratio curves and selected surface roughness profiles of the face of the stationary and rotary rings. As previously mentioned, an equal area of the surface was assumed to analyze the measurement results and the evaluation of the three measuring instruments. Figure 2 shows the isometric images of the face of the stationary ring (made of carbide) obtained from measurements made with the three instruments.

Figure 2. Isometric images of the topography face of the stationary ring obtained from measurements made with: (a) AFM; (b) PGI; (c) CCI

Exemplary roughness profiles isolated from the measuring surface of the stationary ring and material curves (Abbott-Firestone curve) are shown in Figure 3. The isometric images of the surface topography (Figure 2), material contribution curves, and negative values of the asymmetry coefficient Sk (skewness) indicate that the surface of the ring after the reach process has surface characteristics of the plateau type.
Figure 3. The extracted GST profile and parameters of material ratio curve determined: (a) AFM, (b) PGI, (c) CCI.

Similar measurements of GST were made for the carbon-graphite ring. Images of surface topography, profiles extracted from the analyzed surface and material contribution curves are presented in subsequent Figures 4, 5.

A summary of the amplitude values of the GST parameters obtained from measurements made with three instruments: AFM, PGI, CCI, is presented in the diagrams: for the stationary ring (Figure 6) and for the rotary ring (Figure 7).
Figure 4. Isometric images topography of the face of the rotary ring obtained from the measurement made with the instruments: (a) AFM; (b) PGI; (c) CCI.

Figure 5. The extracted profile and the distribution of heights determined: (a) AFM, (b) PGI, (c) CCI.
Figure 6. Summary of surface amplitude parameters GST for the stationary ring.

In the presented charts (Figures 6, 7), it can be seen that for measurements performed on an AFM, the highest values of all surface amplitude parameters SGP were obtained. In the case of a rotary ring (Figure 7), values for amplitude parameters, i.e. Sa, Sq, Sz, Sv, increase for each instrument in the following order: AFM > PCI > CCI.

Figure 7. Summary of surface amplitude parameters SCP for the rotating ring.
For the stationary ring (Figure 6), the values of the parameters Sa, Sq, Sz, Sv change for each instrument in the following order: AFM> CCI> PGI. The values of Sa, Sq, Sz parameters obtained for the atomic force microscope are nearly twice as high as those for the stylus profilometer.

The measurements made show that for the silicon carbide ring, the SGP measurements made with AFM and CCI instruments more accurately represent the actual topography than the measurement made with the PGI stylus profilometer, which is due to the filtering effect of the roughness by the mapping blade of the profilometer. The microstructure of the superfinished surface of this ring is more homogeneous and has less characteristic pores (Figure 2) than the superfinished surface of the carbon-graphite ring (Figure 4).

5. Conclusions
The following conclusions can be drawn from the analysis of the measurement results obtained from the three different measuring instruments:

1) the isometric images of the surface topography and the material contribution curves indicate that the surfaces of both rings after the reach process have surface characteristics of the plateau type;
2) on the basis of the graphs of structure directionality, it should be noted that the faces of the seal rings have an isotropic, random microroughness structure of 70-80%;
3) the atomic force microscope, due to its metrological characteristics of horizontal sampling density, vertical resolution and the geometry of the mapping probe most accurately reproduces the actual stereometry of the very smooth elements, i.e. faces of the seal rings, which results in the highest values of amplitude parameters derived from this method;
4) differences in the values of geometric surface structure parameters obtained using the three different methods may also be due to the lack of homogeneity of surface topography in individual areas of the seal rings.

6. References

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