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POSSIBILITIES OF MEASURING SURFACE ROUGHNESS WITH CONFOCAL LASER SCANNING MICROSCOPE OLS 3000

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ABSTRACT
The contribution presents the results of the evaluation of surface roughness achieved with Confocal Laser Scanning Microscope OLS 3000 compared with parameters acquired with 3D profilometer Talysurf CLI 1000. The potential of the microscope and the differences in measuring surface roughness standards are analysed according to ISO 4288.
Keywords: surface roughness, confocal microscopy, surface roughness parameters

1. INTRODUCTION
Surface texture (roughness) has a decisive impact on the performance features and behaviour of components and together with the surface layer properties is crucial for the useful life and functional reliability. At present, assessment of surface roughness and waviness can be performed using a number of methods. The contribution compares measurement of principal parameters of surface roughness with confocal microscope LEXT and with a classic 3D profilometer.

2. PRINCIPLES OF MEASURING SURFACE ROUGHNESS WITH INDIVIDUAL INSTRUMENTS
2.1. Microscope Olympus LEXT OLS 3000
Confocal laser microscope LEXT OLS 3000 allows for observation of surfaces both in 2D image and in 3D image enhances quality of acquired images and enables to measure lengths, shapes and surface roughness. It allows for 3D observation as well as high precision 3D measurement in real time. Thanks to its outstanding resolution of 0.12 μm and magnification range from 120x to 14 400x, confocal microscope LEXT can operate within the limits of common optical microscopes and scanning electron microscopes.
Surface roughness measurement complements the operation program. Measurement can be performed only for 3D scanned surface using confocal optics, which is a case non-contact surface roughness measurement of components.

2.2. Talysurf CLI 1000
3D surface profiling system Talysurf CLI 1000 is effective for carrying out a fast spatial surface assessment, analyzing surface along three axes, including analyses assessing surface texture both from the section profile (2D) and from the surface (3D).
Basic technical parameters in case of using the inductive gauge: contact measurement, ranging from 0,1 mm to 2.5 mm, excellent resolution – from 2 nm to 40 nm, measurement of internal surfaces and a high precision.

3. CONDITIONS FOR CORRECT MEASUREMENT OF SURFACE ROUGHNESS
The cut-off option is used for roughness measurement and obtaining "correct" measurement results will depend on setting of a number of parameters that can be selected both with the measuring

instrument and in the process of assessment. To set the measuring instrument correctly, the cut-off must be properly chosen.

Cut-off – the limit wavelength represents the length. While the basic length is a physical quantity (length of the inspected surface), the limit wavelength (cut-off) is a software function. There are many guidelines for selecting the limit cut-off wavelength, e.g. in ISO 4288 (see Table. 1). It is recommended to set the profile filter at the value approximately corresponding with the spacing of peaks and valleys multiplied by five.

Table 1. Recommended cut-off values (ISO 4288)

Periodic profiles	Nonperiodic profiles		Cut-off	Principal /Assessed length
RSm [mm]	Rz [μm]	Ra [μm]	Λc [mm]	Λc / L [mm]
>0,04-0,13	>0,1-0,5	**>0,02-0,1**	**0,25**	**0,25/1,25**
>0,13-0,4	>0,5-10	**>0,1-2**	**0,8**	**0,8/4**

The real field of view of LEXT is indicated in Table 2. In comparison with Table 1 it becomes evident that the measured length for surface roughness assessment is applicable only for the surfaces with roughness less than Ra < 0,1 μm and magnification 5x (zoom 1x and 2x) and magnification 10x (zoom 1x). In all other cases the length necessary for proper measurement of surface roughness is less.

If the surface has a value of Ra > 0,1 μm (the standard requires the basic length of 4 mm), then the required length will not be displayed in the field of view of the microscope.

Table 2. Field of view of microscope Lext OLS 3000

Objective magnification	Zoom			
	1x [mm]	2x [mm]	4x [mm]	6x [mm]
5x	**2,56 x 2,56**	**1,28 x 1,28**	0,64 x 0,64	0,427 x 0,427
10x	**1,28 x 1,28**	0,64 x 0,64	0,32 x 0,32	0,213 x 0,213
20x	0,64 x 0,64	0,32 x 0,32	0,16 x 0,16	0,107 x 0,107
100x	0,128 x 0,128	0,064 x 0,064	0,032 x 0,032	0,021 x 0,021

The comparison of Tables 1 and 2 results in the fact that the confocal microscope displays the length (surfaces) which is less than necessary for assessing the surface roughness with values higher than Ra = 0,1 μm.

4. ROUGHNESS MEASUREMENT METHODOLOGY

4.1. Confocal laser microscope LEXT OLS 3000

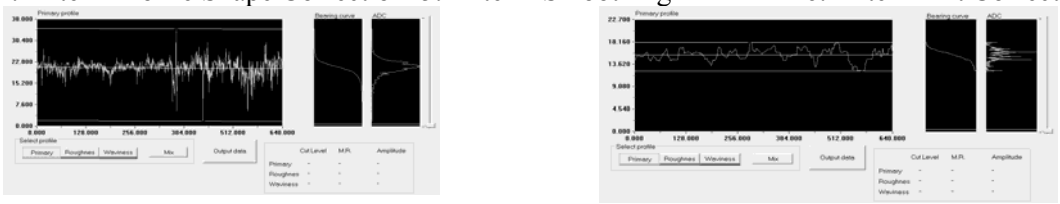
In surface roughness measurement with confocal microscope LEXT OLS 3000 it is desirable to prepare the measured profile so that the profile is leveled with respect to the horizontal plane; for preparation of the measured surface prior to 2D surface texture assessment, two procedures have been chosen, which are linked with various types of surface treatment and profile treatment by means of filters:

Procedure A – a simplified procedure involving a gradual application of three filters (Fig.. 1):

1. Filter - Tilt Correction 2. Filter - Height Noise Removal 3. Filter - Tilt Correction

Procedure B – a procedure involving a gradual application of six filters, which are suitable for a given profile (Fig. 1):

1. Filter - Tilt Correction 2. Filter - Height Noise Removal 3. Filter - Spike Removal
4. Filter - Profile Shape Correction 5. Filter – Smoothing 6. Filter - Tilt Correction



Procedure A *Procedure B*

Figure 1. 2D profiles after application of filters

After this procedure, the software of microscope Lext OLS 3000 used the filter for identifying roughness and waviness deviations. The software offers the following options of filtering: without filter 1/3; 1/5; 1/10; 1/20 and 1/50. Measurements were carried out on two etalons with a big difference in nominal values of surface roughness: lapped surface Ra = 0,05 μm and ground surface

Ra = 0,8 μm. Three different cuts were chosen in the 3 D acquired images: one in the central part and two were symmetrically located on both sides. Then individual filters were applied to the profiles in compliance with the procedure A or B and surface roughness parameters were determined.

4.2. Talysurf CLI 1000

Surface roughness measurement of etalons was made in cut (2D profile) at the length of 4 mm with the step of 0,5 μm by the inductive gauge with the range of 523 μm in Z axis and resolution of 8 nm. Three profiles were measured in the same way as with confocal microscope Lext OLS 3000. Assessment of the obtained data was performed using program Talymap Platinum with cut off = 0,25 mm on the etalon profile with the nominal value of Ra = 0,05 μm and cut off = 0,8 mm on the etalon profile with the nominal value of Ra = 0,8 μm.

5. RESULTS AND THEIR DISCUSSION

Surface roughness was assessed by means of selected height and length parameters of roughness profile (Rx) and waviness profile (Wx):

1. Average arithmetic deviation of the profile Ra, Wa
2. Average quadratic deviation of the profile Rq, Wq
3. Average width of elements of the profile RSm, WSm

Assessment of results in measuring surface roughness with confocal microscope LEXT OLS 3000, their comparison with parameters obtain with 3D profilometer Talysurf CLI 1000 are shown in Tables 3 – 4.

Etalon roughness Ra 0,05 μm - Values of height parameters of surface roughness Ra captured with the confocal microscope using **procedure A** are comparable with the etalon nominal value and measurements performed with the profilometer only in magnification 100x without filtering (values in bold print in the table). When filtered, the parameters have lower values. The same tendency can be observed in parameters Rq and Wa. If lower levels of magnification are used, the values are higher. Length parameters RSm have a comparable value only with magnification 10x and filters 1/5 to 1/20; if the magnification is 5x, the values are up to ten times higher; if the magnification is 20x to 50x, the captured values are considerably lower and amount to 15 to 60 % of the value measured with the inductive profilometer. Comparable results were not obtained for parameter WSm with any magnification or filter – all values are substantially lower.

Table 3. Surface roughness Ra – etalon – lapped surface

Procedure A							
Filter for roughness assessment	Average arithmetic deviation of roughness profile Ra [μm]						
	Magnification					Inductive gauge	Etalon
	5x	10x	20x	50x	100x		
unfiltered	10,656	1,557	0,496	0,204	**0,056**	**0,057**	**0,05**
1/3 ÷ 1/50	8,38÷7,38	1,44÷1,35	0,47÷0,43	0,2÷0,165	0,03÷0,02		
Procedure B							
bez	5,046	0,685	0,222	0,113	**0,045**		
1/3 ÷ 1/10	4,2÷3,9	0,54÷0,51	0,21÷0,21	0,09÷0,07	0,03÷0,02		
1/20	3,796	0,463	0,196	**0,059**	0,016		
1/50	2,608	0,337	0,143	**0,049**	0,009		

When applying **procedure B** the height parameters Ra, Rq, Wa reached on the whole lower values and for the length parameters RSm and WSm the measured values were

Table 4. Parameter RSm; procedure A – etalon – lapped surface

Filter in roughness assessment	Average width of profile elements RSm [mm]					
	Magnification					Inductive gauge
	5x	10x	20x	50x	100x	
without	0,112	0,018	0,009	0,004	0,006	**0,015**
1/5	0,050	**0,016**	0,009	0,004	0,004	
1/20	0,096	**0,015**	0,009	0,003	0,002	
1/50	0,069	**0,014**	0,008	0,003	0,002	

higher. Comparable values of the surface roughness parameter Ra (Table. 3) could be measured only with magnification 50x and filters 1/20 and 1/50. All other height parameters Rq and Wa have a tendency similar to procedure A.
Length parameters RSm have a comparable value only with magnification 20x without filtering; in all other cases the measured parameters have the same tendency as in case of procedure A, but the measured values are lower. No comparable results were obtained for parameter WSm in any measurement – all values obtained from the confocal microscope are considerable lower.
Etalon roughness Ra 0,8 µm - Values of height parameters of surface roughness Ra captured with the confocal microscope using **procedure A** are comparable with the etalon nominal value and measurements performed with the profilometer only in magnification 50x and filter 1/3. The same tendency can be observed in parameter Rq; parameter Wa has identical value only with magnification 100x and filter 1/3, all other parameters are substantially higher. Length parameters RSm have a similar value only if magnification 5x is used and any filer, but they are lower by about 10%. All other results are lower, regardless of magnification or filter. In case of parameter WSm, no comparable results were reached with any magnification or filter.
When applying **procedure B** the height parameters Ra, Rq, Wa reached lower values than in case of procedure A, while the length parameters RSm and WSm exhibited higher measured values. Comparable values of the surface roughness parameter Ra could be measured only with the magnification 20x and filters 1/3 and 1/5. All other values were higher.
Parameter Rq has a similar tendency as parameter Ra. Parameter Wa reaches a comparable value only with magnification 100x and filter 1/3. Other values are higher.
Length parameters RSm have a comparable value only with magnification 20x without filtering; in all other cases the measured values are lower. In case of parameter WSm, no comparable results were reached in any measurement (all measured values are considerably lower).
Generally speaking, the values of length parameters of surface roughness become lower with a higher magnification (5x to 100x), since roughness is assessed for a shorter length, which involves less uneven surface); filters have the same effect (without filter, 1/3 to 1/50), when the peak values are obtained without filtering and the lowest values using filter 1/50; it is in compliance with the principles of surface roughness assessment, as the small filter divides the profile for calculating the parameters into shorter lengths.

6. CONCLUSION

Following conclusions and recommendations can be drawn from the values of surface roughness measured with confocal microscope LEXT OLS 3000:

- surface roughness assessment using height parameters is applicable to the surfaces having roughness Ra < 0,1µm in magnification 100x without filtering,
- surface roughness assessment using length parameters is not suitable owing to a low correspondence,
- lower values of surface roughness are obtained in procedure B than in procedure A – due to smoothing of the profile.

When measuring surface roughness with the confocal microscope it is recommended to compare the measured parameters with the parameters measured on an appropriate etalon of surface roughness, which was manufactured using the same technological process, since a more objective measurement can be obtained. Roughness measurement with the confocal microscope should be considered as complementary to analyses carried out with observation or measuring microscope.
The contribution has been prepared using the results of the research intent UO FVT 0000404 "Research and Development of modern materials and technologies for military equipment applications"as well as SV K216 "Application of materials and technologies in special equipment"and is a component in solving these research issues...

7. REFERENCES

[1] ISO 4288; ISO 8785; ISO 4287 - Geometrical product specifications (GPS)
[2] Manual LEXT OLS 3000
[3] Manual Talysurf CLI 1000