RESEARCH OF SURFACE ROUGHNESS ANISOTROPY

N.Bulaha, J.Rudzitis, J.Lungevics, O.Linins, J.Krizbergs

Institute of Mechanical Engineering,

Riga Technical University,

6 Ezermalas Str., LV-1006, Riga, LATVIA

e-mail: mti@rtu.lv

The authors of the paper have investigated surfaces with irregular roughness for the purpose of determination of roughness spacing parameters perpendicularly to machining traces – RSm_1 and parallel to them – RSm_2 , as well as checking the relationship between the surface anisotropy coefficient c and surface aspect ratio Str from the standard LVS EN ISO 25178-2. Surface roughness measurement experiments with 11 surfaces show that measuring equipment values of mean spacing of profile irregularities in the longitudinal direction are not reliable due to the divergence of surface mean plane and roughness profile mean line. After the additional calculations it was stated that parameter Str can be used for determination of parameter RSm_2 and roughness anisotropy evaluation for grinded, polished, friction surfaces and other surfaces with similar characteristics.

Keywords: *anisotropy coefficient, roughness spacing parameters, surface texture, texture aspect ratio.*

1. INTRODUCTION

Analysis of surface roughness spacing parameters [1] provides that for surfaces with irregular roughness spacing parameters values occasionally are not reliable due to the fact that mean plane of surface roughness and the roughness profile mean line are located at different levels, in particular, it is expressed for mean spacing of profile irregularities in the longitudinal direction. Thereby difficulties with surface anisotropy evaluation are arising.

In order to solve the existing problems, scientists offer using the visual method, which will allow identifying more reliable values of spacing parameters RSm_1 and RSm_2 . In addition, it is reasoned that the surface roughness anisotropy can be described by the surface aspect ratio Str from standard EN ISO 25178-2: 2012 [2], which is essentially equal to the roughness anisotropy coefficient c .

$$Str = c. \quad (1)$$

By contrast, variants of surface roughness anisotropy evaluation offered in [1]

are justified only in theory, which is why it is important to prove them with practical experiments.

2. EXPERIMENTAL PART

To test relation (1) according to which, with specially oriented surface roughness correlation function $\rho(\tau_1, \tau_2)$ [3], texture aspect ratio Str is equal to surface roughness anisotropy coefficient c , the authors of the paper have studied 11 surfaces obtained by different technological methods (see Table 1 and Table 2).

Surface roughness measurement experiment was carried out on the profilograph-profilometer Taylor Hobson Talysurf Intra 50. It is the measuring equipment that provides determination of surface roughness parameters in the 3-D coordinate system. Before the start of the experiment, the 2-D surface roughness measurements were made in order to determine the sample and evaluation length for each sample surface. In addition, a required number of points – 300 points – were chosen, considering the developed methodology mentioned in [4]. After the roughness measurement experiment, the filtering of obtained surface topography was carried out to make surface leveling and separate from it form and waviness occurring at various mechanical machining conditions (part clamping, deflection, thermal processes, vibrations and the cutting-tool path deviation). After surface filtration, the 3D roughness parameters and additional profile parameters, which were extracted from different surface cross sections, were determined. The values provided in Table 1 and Table 2 are mean values obtained from three measurements of surfaces.

Table 1 contains images of each 3D surface roughness $h(x, y)$ and 3D surface roughness autocorrelation function $\rho(\tau_1, \tau_2)$ in order to show the characteristics of the technological process. Parameter Sa is provided as well, but in crosswise direction 1 (crosswise to machining (friction) traces) and in longitudinal direction 2 – parameters Ra_1 , Ra_2 .

Table 1

Comparison between 3D and 2D Height Parameters of Irregular Surface Roughness

Machining	Topography, correlation function	$Sa, \mu m$	$Ra_1, \mu m$	$Ra_2, \mu m$
1. Surface grinding (Rugotest No. 104, surface No.3)		0.048	0.036	0.008

Machining	Topography, correlation function	$Sa, \mu\text{m}$	$Ra_1, \mu\text{m}$	$Ra_2, \mu\text{m}$
2. Surface grinding (Rugotest No.104, surface No.7)		1.410	1.115	0.140
3. Surface grinding (Rugotest No.104, surface No.8)		3.130	2.660	0.229
4. Cylindrical grinding (Rugotest No.105, surface No.1)		0.028	0.018	0.015

Machining	Topography, correlation function	$Sa, \mu\text{m}$	$Ra_1, \mu\text{m}$	$Ra_2, \mu\text{m}$
5. Cylindrical grinding (Rugotest No.105, surface No.4)		0.174	0.143	0.058
6. Cylindrical grinding (Rugotest No.105, surface No.8)		3.500	3.487	0.715
7. Surface after the sliding experiment		0.077	0.071	0.025

Machining	Topography, correlation function	$Sa, \mu\text{m}$	$Ra_1, \mu\text{m}$	$Ra_2, \mu\text{m}$
8. Surface after finishing the sliding friction		0.674	0.517	0.061
9. Lapping		0.133	0.102	0.081
10. Nano-coating		0.612	0.082	0.085
11. Polishing (bobsled runner)		0.127	0.107	0.022

Table 2 comprises mean spacing of profile elements RSm_1 and RSm_2 , and surface anisotropy characteristics Str and c . Furthermore, mean spacing of profile irregularities RSm_2 was acquired using 2 methods: using measuring equipment Taylor Hobson Intra 50 (RSm_2 – mean spacing of profile irregularities in longitudinal direction measured with the measuring equipment) and using visual determination method ($[RSm_2]_{viz}$ – mean spacing of profile irregularities in longitudinal direction determined by visual inspection). It should be noted that based on evaluation given by 5 specialists the visual method allows one to determine RSm values with a 10 % margin of error. The error is not small; however, it produces better results than using an incorrect value of mean spacing of profile irregularities.

Table 2

Analysis of irregular surface roughness spacing parameters

No.	Machining	RSm_1 , mm	RSm_2 , mm	$[RSm_2]_{viz}$, mm	Str	c
1.	Surface grinding (Rugotest 104, surface No.3)	0.088	0.131	0.400	0.144	0.150
2.	Surface grinding (Rugotest 104, surface No.7)	0.140	0.348	4.200	0.031	0.033
3.	Surface grinding (Rugotest No.104, surface No.8)	0.095	0.087	3.200	0.024	0.029
4.	Cylindrical grinding (Rugotest No.105, surface No.1)	0.073	0.051	1.430	0.055	0.051
5.	Cylindrical grinding (Rugotest No.105, surface No.4)	0.059	0.101	1.250	0.047	0.047
6.	Cylindrical grinding (Rugotest No.105, surface No.8)	0.080	0.141	1.200	0.063	0.066
7.	Surface after the sliding experiment	0.029	0.031	1.750	0.013	0.016
8.	Finishing	0.100	0.160	3.200	0.029	0.031
9.	Lapping	0.049	0.044	0.157	0.333	0.312
10.	Nano-coating	0.016*	0.011	0.025	0.612	0.640
11.	Polishing (bobsled runner)	0.030	0.032	1.430	0.018	0.021

*Determined by visual inspection

In Table 1, values of profile parameters Ra_1 and Ra_2 were compared with Sa values for each machining type. If these parameters are close in their numerical value (more precisely – have the same order of magnitude), it means that the mean lines of the corresponding profiles are positioned close to the mean plane of roughness, spacing parameters of these profiles can be considered probable for the mean plane level and, therefore, they characterise 3D roughness surface. If that is not the case, RSm_1 and RSm_2 values are determined visually.

In crosswise direction, there is only one surface (nano-coated) with values of parameter Ra_1 significantly different from value of parameter Sa . In this case,

parameter RSm_1 cannot be considered as belonging to the level of the mean plane and cannot be used for calculation of anisotropy coefficient c . RSm_1 value of this surface was determined visually.

As for the other surfaces, RSm_1 values obtained with the measuring equipment were eligible for usage in calculating c according to formula (1).

Parameter RSm_2 used in formula (1) is determined in a similar manner. If $Ra_2 \approx Sa$, parameter RSm_2 obtained with the measuring equipment can be used to calculate anisotropy coefficient c , if $Ra_2 \ll Sa$, this means spacing of profile irregularities is determined visually and is written as $[RSm_2]_{viz}$. As shown in Table 2, all 11 surfaces required $[RSm_2]_{viz}$ value to be determined.

When the values of mean spacing of profile elements are obtained, anisotropy coefficient c is calculated according to formula [1]:

$$c = \frac{RSm_1}{RSm_2}. \quad (2)$$

The calculated c values are compared to values of 3D surface texture aspect ratio Str (see Fig. 1).

Fig. 1. Relationship between parameters c and Str (with $\pm$ marked visual detection error range of parameter c): a – the whole surface, b – surfaces with increased anisotropy.

Data provided in Fig.1 reflect formula (1) reasonably accurately. It is clearly seen in surfaces with anisotropy coefficient $c < 0.1$ (surfaces with increased anisotropy). Autocorrelation function of these surfaces is notably oriented along crosswise and longitudinal profiles.

3. EVALUATION METHODOLOGY FOR ANISOTROPY

Surface roughness anisotropy can be evaluated following the steps listed below:

1. Create 3D surface roughness topography.
2. Determine surface texture parameters Sa and Str .
3. Chose surface sections that are perpendicular and parallel to the traces of surface machining.
4. Determine height parameters Ra_1 and Ra_2 for surface roughness profiles and spacing parameters RSm_1 and RSm_2 .
5. Compare mean values of Ra_1 and Ra_2 of the profiles with surface texture parameter Sa .
 - 5.1. If values of both parameters are close to or almost the same as Sa values, it can be considered that the mean lines of all profiles are located at the mean plane level and, thus, it can be assumed that RSm_1 and RSm_2 values characterise the surface.
 - 5.2. If parameter Ra_1 is close to Sa in value while parameter Ra_2 significantly differs, mean spacing of profile elements RSm_2 is determined using surface texture aspect ratio by formula: $RSm_2 = RSm_1 / Str$.
 - 5.3. If neither of the parameters (Ra_1 and Ra_2) is close to Sa value, anisotropy is evaluated using the visual method and formula (1): $c = RSm_1 / Rsm_2$.

4. CONCLUSIONS

Within the present research, the analysis of roughness anisotropy for 11 surfaces with irregular character has been made. Firstly, anisotropy coefficient c has been calculated by measuring mean spacing of profile irregularities for surface roughness using measuring equipment Taylor Hobson Talysurf Intra 50 and, in addition, using the visual method, when a mean line of a profile and mean plane of a surface are at different levels. Then the calculated values of anisotropy coefficient c have been compared to the values of surface texture aspect ratio Str . During the research, it has been established that surface texture parameter Str can be applied to surface roughness anisotropy analysis and calculations of mean spacing of profile irregularities. In the research, the methodology for surface roughness anisotropy determination has been proposed.

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VIRSMAS RAUPJUMA ANIZOTROPIJAS IZPĒTE

J.Rudzitis, N.Bulaha, J.Lungevičs, O.Liniņš, J. Krizbergs

Kopsavilkums

Dotajā rakstā tika veikti virsmu ar neregulāru raupjumu pētījumi, ar mērķi noteikt raupjuma soļa parametrus perpendikulāri apstrādes pēdām RSm_1 un paralēlī tām – RSm_2 , kā arī pārbaudīt sakarību starp virsmas anizotropijas koeficientu c un virsmas tekstūras indeksu Str no LVS EN ISO 25178-2. Virsmas raupjuma mērīšanas eksperimenti ar 11 virsmām rāda, ka mēraparāta soļa vērtības virsmas garenvirzienā nav ticamas, sakarā ar virsmas vidējās plaknes un profila viduslīnijas nesakrišanu. Veicot papildus aprēķinus tika secināts, ka parametru Str var pielietot raupjuma anizotropijas novērtēšanai, piemēram, slīpētām, pulētām, berzes virsmām un citām virsmām ar līdzīgām īpašībām.

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