Possibilities of applying motif group parameters for description roughness of turned surfaces

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Abstract. This article explores the methodology of assessing the applicability of roughness parameters from the motif group to the evaluation of one–way and periodic geometrical surface structures. The results of surface roughness measurements of aluminum samples turned with variable kinematic parameters were presented. Usability of using surface motifs in combination with selected parameters described in ISO standards for assessment of geometrical structures characteristic for longitudinal turning was shown.

Keywords: aluminum alloys, surface geometrical structure, roughness parameters

1 Introduction

In modern manufacturing techniques the main goal is to achieve good, repeatable quality of products. One of the main problems associated with this is the quality of the surface layer of machined object. It combines whole of issues related to methods of surface manufacturing fulfilling specific operation requirements.

Characterizing surface roughness is currently taking a lot of significance in many areas related to the construction, technology and operation of machines and devices. Currently applied methodology of surface roughness analysis was developed around 1970. Since then, over the years, nearly 300 different roughness and waviness parameters were offered to the users [1]. In 90s of the last century, trend for creating new roughness parameters was called "rash of parameters" or "parametric fever"[2]. A large number of defined and possible to use roughness and waviness parameters makes it impossible to give the value to all of them. On the other hand, the complexity of the geometric structure of the surface means that use the one, selected parameter does not give full knowledge about its condition and even more about its operational capabilities [3]. Therefore a few, suitably selected parameters should be used to description of the usable surface state. Because there are no standards or procedures that would inform when and in what cases given parameters should be used, the selection should be representative to given application. For each element to be manufactured, it is necessary to decide which features of the of the geometric structure of the surface are relevant and which roughness parameters correspond to them.

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In industry, the *Ra* parameter is most commonly used parameter. It is given very often in connection with the description of surface machining method by which it can be obtained. If production conditions are stabilized this type of evaluation makes it possible to maintain constant, within defined limits, surface roughness characteristics. It is due to quite strong statistical associations between parameters describing different profile features for surfaces machined in similar conditions. In case of the parts operating under specific conditions and determining the functional characteristics of the entire product e.g. the surface of the exhaust fins of internal combustion engines, two or more roughness parameters are used to assess the surface [4].

Another important aspect increasing the possibilities of describing surface geometrical conditions are differences in the standards regarding surface roughness used in individual countries. Universal globalization however means that many standards have been unified and the most universal are being pursued. Differences, however, remain. An example here can be the so - called French methods for roughness calculating. They were created for the French automotive industry at the beginning of 80s of the last century. In Poland they are called *motif method.*

1.1 Motifs method

This method relies on division primary profile into so – called motifs. According to the norm motif is concluded between the highest points of two locals not necessarily neighboring peaks of the profile (fig.1) Motif is characterized by:

- its length *AR* or *AW* measured parallel to direction of primary profile ,
- its two depths H_j i H_{j+1} measured perpendicularly to direction of primary profile,
- its characteristic depth *T*, which is the lower depth of this two ($T = \min(H_j, H_{j+1})$.

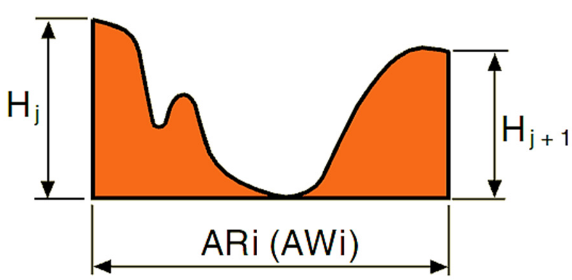

Fig. 1. Roughness motif

Fragments received this way are next joined according to specific rules among which following conditions are distinguished: envelope, length, magnification and equality [5,6].

Envelope condition – concerns peaks which are higher than neighboring ones. Joint peak of two neighboring motifs must be smaller or equal from one of adjacent peak.

Length condition – concerns limitation of length of one motif to the limit value A (conventional boundary between roughness and waviness) or limit value B (conventional boundary between waviness and shape deviations). Sum of the length of two adjacent motifs $AR_i + AR_{i+1}$ have to be smaller or equal to A for roughness and $AW_i + AW_{i+1} < B$ for waviness.

Magnification condition – concerns suppression of the smallest peaks however the greatest possible motifs are sought - after. This condition prevents combining of two motifs when its characteristic depth *T* is smaller than depth of one of the two initial motifs. The effect of this is suppression of the smaller peak lying between large ones. Motifs can be combined only if the characteristic depth T of the created motif is greater or equal to both depths characteristic for component motifs.

Equality condition – prevents combination of motifs with similar depths that occur for example with periodic profiles. Prevents suppression of motifs which depth is similar to depth of adjacent one. The combination of the motifs in this calculation method should be used until all possible further combinations are exhausted. Motifs can be combined only when one of the depths is smaller or equal to 60% of the characteristic depth T of the tested connected motif.

Knowing the conditions for combining motifs it is possible to proceed of calculating parameters from motif group. In this work four of them were designated (fig. 2):
Pt – sum of the height of the highest profile peak Zp and depth of the lowest valley Zv profile inside evaluation length ln
R – arithmetic mean of the depth value H_j of roughness motifs inside evaluation length which value is calculated from the formula 1:

$$R = \frac{1}{m}\sum_{j=1}^{m} H_j \quad (1)$$

Rx – the largest depth H_j from all the roughness motifs inside the evaluation length.
AR – the arithmetic mean of the length value AR_i of roughness motifs inside evaluation length

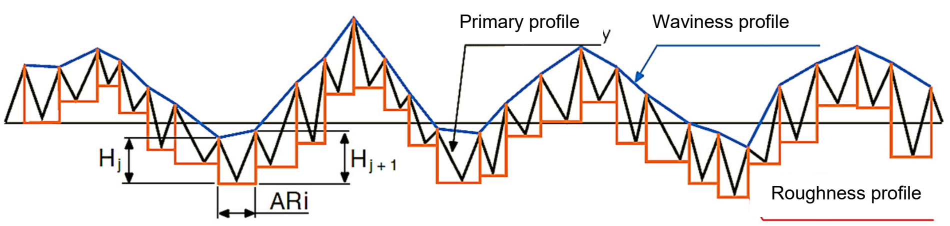

Fig. 2. Graphic description of parameters *R*, *Rx*, *AR*

The undoubted advantages of the motif method are: no need to apply filtration, a small number of parameters and mapping of each local peak on the elevation at omitting those which are in profile valleys and which are not participating in contact of two surfaces cooperating with each other.

2 Research methodology

A shaft of aluminum alloy 7075 was tested. As a machining method turning was chosen. Research was carried out on a CNC TUR 560 MN numerical lathe. For tests turning inserts TCGX16T304-Al H10 were used with uncoated cemented carbide and they were mounted in a holder marked STGCR 2020K16. The following cutting parameters were used: v_c = 105; 210 ; 420 ; 530 and 660 m.min^{-1}; f = 0.08; 0.19; 0.37 mm.rev^{-1}. Depth of cut was a_p =0.5 mm.

Roughness measurements were conducted using Form Talysurf 120L tester (fig. 3) applying following settings: Gaussian digital filter, λc = 0.8 mm, λs = 0.0025 mm, bandwidth: 300:1. During calculating motif parameters following settings were used: shape: straight line LS, filter R & W, A = 0.25 mm, B = 1.4 mm, λs = 0.0025 mm. For analysis of usefulness of motif method for description of examined surfaces, five amplitude parameters, apart from already described parameters from motif group, were chosen: *Ra, Rz, Rp, Rv, Rq,* two statistical: *Rku, Rsk* and spatial: *RSm, RS*, as well as hybrid: *RΔa i RΔq*.

Fig. 3. Measuring stand –Form Talysurf-120L tester, Taylor Hobson Limited company

Two indicators were used for assess suitability of individual roughness parameters. First of them is the correlation coefficient ρ, which defines the level of linear relation between two variables. It is a quotient of covariance and the product of standard deviations of this variables what was shown on equation 2:

$$\rho_{XY} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} \tag{2}$$

It is considered that when the correlation coefficient is equal 0 linear correlation does not exist but a curvilinear correlation may occur. The closer values to the number 1 or -1 will achieve correlation coefficient – the greater linear correlation will be. Above 0.9 and below -0.9 it is considered that very strong linear correlation occurs.

However, one should be aware of the fact of frequent over - interpretation connected with drawing conclusions only on the basis of the value of the correlation coefficient. Therefore to assess the suitability of use of roughness parameters from individual groups second indicator which defines significance level of change of characteristic profile feature was proposed [7,8]. It was marked with a symbol *t*. It is expressed in the percent and described with equation:

$$t = \frac{R_{max} - R_{min}}{R_{śr}} * 100\% \tag{3}$$

where:

- R_{max} – maximum value of tested roughness parameter,
- R_{min} – minimum value of tested roughness parameter,
- $R_{śr}$ – average value of tested roughness parameter,

3 Tests results

Making qualification of suitability of a given roughness parameter for description of roughness changes, the closeness of the correlation coefficient ρ to one was assumed and whether the level of significance of the change of tested parameter *t* is greater than 30%. Tables 1-4 presents surface roughness tests results along with calculated values of suitability indicators of the calculated parameters.

Table 1. Influence of the feed *f* on values of selected amplitude roughness parameters 2D

Machining parameters		Roughness parameters							
		AMPLITUDE					**MOTIF**		
v_c [m.min^{-1}]	f [mm.rev^{-1}]	*Ra*	*Rz*	*Rp*	*Rv*	*Rq*	*Pt*	*R*	*Rx*
105	0.08	0.53	2.989	1.569	1.42	0.64	3.863	1.95	3.21
	0.19	1.183	5.896	3.298	2.598	1.407	6.82	4.796	6.276
	0.37	4.946	19.235	12.414	6.820	5.667	21.976	9.436	21.076
210	0.08	0.551	3.353	1.862	1.490	0.674	4.141	2.236	3.846
	0.19	1.167	5.688	3.412	2.275	1.376	7.134	5.254	6.839
	0.37	4.981	18.966	12.243	6.723	5.694	21.972	9.851	21.583
420	0.08	0.521	3.399	2.030	1.368	0.643	5.473	2.169	4.41
	0.19	0.559	3.564	2.112	1.451	0.713	6.897	2.113	5.813
	0.37	4.917	19.256	12.599	6.657	5.639	21.345	9.773	21.043
530	0.08	0.545	3.09	1.747	1.352	0.661	4.113	2.213	3.796
	0.19	1.194	5.937	3.514	2.423	1.431	6.966	5.22	6.54
	0.37	4.936	19.479	12.72	6.759	5.664	21.94	9.663	21.643
660	0.08	0.610	3.396	1.846	1.550	0.741	4.283	2.17	3.836
	0.19	1.198	5.986	3.593	2.392	1.439	7.233	5.23	6.796
	0.37	4.906	19.461	12.809	6.651	5.637	22.143	9.076	21.463
ρ		0.96	0.96	0.96	0.97	0.96	0.97	0.98	0.97
t [%]		201%	172%	184%	153%	197%	158%	138%	166%

Analyzing presented tests results and roughness measurements it can be stated that according to theory along with increasing of feed all basic amplitude roughness parameters, both classic ones and those of group of motifs also increased. Level of correlation coefficient in each case was greater than 0.96 and indicator *t* oscillated between 138–201%, which clearly indicates good description of the relevance of changes in the profile by these parameters.

Statistical parameters such as skewness *Rsk* and kurtosis *Rku*, showed insufficiently high linear correlation with feed. In their case indicator *t* assumed values greater than limit of 30%, however they were smaller than in case of the amplitude parameters.

Along with increasing feed, change of spatial parameters *RSm* and *RS* was also observed. This indicates a change in the distance between successive profile peaks as well as about increasing width of profile valleys. Linear correlation coefficient assumed for them values greater than 0,95 whereas indicator *t* higher than 154%.

Table 2. Influence of the feed *f* on values of selected spatial, statistical and hybrid roughness parameters 2D

Machining parameters		Roughness parameters						
		STATISTICAL		**SPATIAL**		**MOTIF**	**HYBRID**	
v_c [m.min^{-1}]	f [mm.rev^{-1}]	*Rku*	*Rsk*	*RSm*	*RS*	*AR*	*RΔa*	*RΔq*
105	0.08	2.313	0.075	60.686	16.93	85.133	5.83	7.33
	0.19	2.232	0.290	180.23	36.983	176.133	5.426	7.106
	0.37	2.07	0.655	364.516	192.89	171.533	7.116	8.81
210	0.08	2.766	0.205	67.726	17.5	88.8	6.053	7.69
	0.19	2.360	0.429	187.21	36.03	183	5.526	7.35
	0.37	2.033	0.6407	373.146	200.44	179.3	7.153	8.86
420	0.08	3.467	0.563	71.733	17.91	90.9	5.756	7.533
	0.19	9.734	0.993	79.78	18.206	87.8	5.943	7.676
	0.37	2.085	0.663	373.496	209.873	178	7.243	9.01
530	0.08	2.504	0.346	58.103	16.603	85.57	6.366	7.99
	0.19	2.398	0.415	179.62	36.656	183.47	5.69	7.686
	0.37	2.09	0.661	365.643	292.283	175.83	7.203	9.003
660	0.08	2.384	0.174	64.95	17.413	86.36	6.213	7.823
	0.19	2.439	0.469	177.073	39.133	182.45	5.586	7.663
	0.37	2.117	0.6811	372.566	245.6	163.07	7.173	9.003
ρ		-0.83	0.81	0.99	0.95	0.77	0.78	0.87
t [%]		45%	102%	154%	226%	67%	25%	18%

Remaining parameters including the only spatial parameter from the motif group and hybrid parameters *RΔa* and *RΔq* due to low level of calculated significance indicators were considered to be slightly dependent on the feed value. By analyzing tests results configured by constant feed and variable cutting speed (Table 3 and 4) it can be seen that no parameter has shown sufficient correlation with cutting speed v_c. For none of the parameters correlation coefficient above 0,9 was not obtained. The highest value was obtained for *RΔq* parameter and it was at 0.86. For all parameters apart hybrid, values of indicator *t* higher than 30% were obtained however when linear correlation coefficients were too low. It can be concluded that influence of the cutting speed on surfaces features cannot be described by these parameters.

Table 3. Influence of the cutting speed v_c on the values of selected amplitude roughness parameters 2D

Roughness parameters		Roughness parameters							
		AMPLITUDE					**MOTIF**		
v_c [m.min^{-1}]	f [mm.rev^{-1}]	*Ra*	*Rz*	*Rp*	*Rv*	*Rq*	*Pt*	*R*	*Rx*
0.08	105	0.53	2.989	1.569	1.42	0.642	3.863	1.95	3.21
	210	0.551	3.353	1.862	1.494	0.674	4.14	2.23	3.84
	420	0.521	3.399	2.030	1.368	0.643	5.47	2.16	4.41
	530	0.545	3.099	1.747	1.352	0.661	4.113	2.213	3.796
	660	0.610	3.396	1.846	1.552	0.741	4.283	2.17	3.836

0,19	105	1.183	5.89	3.298	2.598	1.407	6.82	4.796	6.276
	210	1.167	5.688	3.412	2.276	1.376	7.13	5.25	6.83
	420	0.559	3.564	2.112	1.459	0.713	6.89	2.116	5.813
	530	1.194	5.937	3.514	2.421	1.431	6.966	5.2	6.5
	660	1.198	5.986	3.593	2.397	1.439	7.233	5.23	6.796
0,37	105	4.946	19.235	12.414	6.829	5.667	21.976	9.436	21.076
	210	4.981	18.966	12.243	6.723	5.694	21.97	9.85	21.58
	420	4.917	19.256	12.599	6.654	5.639	21.34	9.77	21.043
	530	4.936	19.479	12.72	6.751	5.664	21.94	9.663	21.643
	660	4.906	19.461	12.809	6.659	5.637	22.143	9.076	21.463
ρ		-0.05	0.4	0.48	-0.23	-0.02	0.29	0.04	035
t [%]		81%	65%	85%	73%	75%	54%	107%	56%

Additionally correlation between classical parameters and those from motif group was checked. Such dependence or independence of parameters is very important and plays (or may play) decisive role in selection of identification method and describing geometrical surfaces features. In a situation when two parameters are strongly dependent from each other they can be treated as a complement of main indicator used for description a given feature of parameter. As the main indicator ideal for describing given feature such parameter should be chosen that is absolutely independent of others because only in such case its values can be determined in unequivocally and objective way.

Table 5 shows linear correlation coefficient between classical amplitude parameters, hybrid ones and from motif group. Table 6 shows correlation between spatial parameters and parameter AR from motif group.

Analyzing data given in tables it can be stated that close dependence and correlation is between parameters *Pt, Rx* and *R* from the motif group of parameters and amplitude parameters at the lack of close connection with statistical and hybrid parameters.

Table 4. Influence of cutting speed v_c on selected values of spatial, statistical and hybrid roughness parameters 2D

Cutting speed		Roughness parameters						
		STATISTICAL		**SPATIAL**		**MOTIF**	**HYBRID**	
v_c [m.min^{-1}]	f [mm.rev^{-1}]	*Rku*	*Rsk*	*RSm*	*RS*	*AR*	*RΔa*	*RΔq*
0.08	105	2.313	0.075	60.686	16.93	85.133	5.83	7.33
	210	2.766	0.205	67.726	17.5	88.8	6.053	7.69
	420	3.467	0.563	71.733	17.91	90.9	5.756	7.533
	530	2.504	0.346	58.103	16.603	85.57	6.366	7.99
	660	2.384	0.174	64.95	17.413	86.3	6.213	7.823
0.19	105	2.232	0.29	180.23	36.983	176.133	5.426	7.106
	210	2.36	0.429	187.21	36.03	183	5.526	7.353
	420	9.734	0.993	79.78	18.206	87.8	5.943	7.676
	530	2.398	0.415	179.62	36.656	183.4	5.69	7.686
	660	2.439	0.469	177.073	39.133	182.4	5.586	7.663

0.37	105	2.07	0.655	364.516	192.89	171.533	7.116	8.81
	210	2.033	0.64	373.146	200.44	179.3	7.153	8.86
	420	2.085	0.663	373.496	209.873	178	7.243	9.01
	530	2.09	0.661	365.643	292.28	175.83	7.203	9.003
	660	2.117	0.681	372.566	245.6	163.07	7.173	9.003
ρ		0.32	0.49	0.05	0.27	-0.18	0.56	0.86
t [%]		251%	332%	95%	201%	93%	25%	23%

Table 5. Matrix of correlation coefficients for amplitude, hybrid and motif roughness parameters

	Ra	*Rz*	*Rp*	*Rv*	*Rq*	*Rku*	*Rsk*	*RΔa*	*RΔq*
Ra	1								
Rz	0.9995	1							
Rp	0.9991	0.9998	1						
Rv	0.9987	0.9990	0.9978	1					
Rq	1.0000	0.9996	0.9993	0.9989	1				
Rku	-0.3367	-0.3307	-0.3223	-0.3475	-0.3343	1			
Rsk	0.5267	0.5373	0.5462	0.5182	0.5296	0.5309	1		
RΔa	0.8932	0.8854	0.8900	0.8746	0.8920	-0.2324	0.4603	1	
RΔq	0.9269	0.9237	0.9288	0.9119	0.9266	-0.2399	0.5424	0.9775	1
Pt	0.9957	0.9964	0.9970	0.9937	0.9960	-0.2584	0.5990	0.8864	0.9250
R	0.9657	0.9687	0.9657	0.9736	0.9664	-0.3971	0.5010	0.7653	0.8367
Rx	0.9974	0.9979	0.9984	0.9956	0.9977	-0.2780	0.5830	0.8884	0.9275

Some observed relations are obvious. For example relation *Pt-Rz* results from their definition – *Pt* refers to the primary profile, and *Rz* refers to roughness profile. In 2D system their dependence is defined as $Pt = 1.27Rz$. Equally high correlation occurs between parameters *Rx* and *Rz*. Their dependence was calculated as $Rx = 1.17Rz$.

The only spatial parameter from motif group showed independence from classical parameters. Correlation between *AR*, spatial and hybrid parameters is less than 0.78.

Table 6. Matrix of correlation coefficients for spatial roughness parameters and from motif group

	RSm	*RS*	*RΔa*	*RΔq*
RSm	1			
RS	0.937385076	1		
RΔa	0.774039748	0.891210473	1	
RΔq	0.841180807	0.925931889	0.977547659	1
AR	0.8500291	0.570359323	0.248876757	0.384685697

4 Summary

- For evaluation of usefulness of individual roughness parameters for description geometric changes of surface layer and geometric state of the surface not only correlation coefficient *ρ* should be taken into account but also *t* indicator determining the level of significance of change in characteristic profile feature. Applying of two indicators will allow for more complete assessment of parameters usefulness.
- Use of the parameters from the group of motifs for description of the surface with oriented periodic character is possible and may complement description of this type of surfaces carried out with using parameters described in ISO standards.
- For amplitude parameters best describing surface characterized by features resulting from variable feed during machining include: *Ra*, *Rz*, *Rp*, *Rv*, *Rq* and motif parameters: *Pt*, *Rx*, *R*.
- Spatial parameters that describes in best way surface characterized by features resulting from variable feed may be *RSm and RS. The* only *motif* parameter from that group: *AR* despite the value of indicator *t* equal 67%, due to low correlation does not describe all changes of surface geometrical features.
- Due to the close dependence (regardless of turning parameters) of *Pt* and *Rz* parameters as well as *Rx* and *Rz* it seems unreasonable using all three of them simultaneously.
- Hybrid parameters: *RΔa* and *RΔq* and statistical: *Rku* and *Rsk* do not show sufficiently strong relations with feed and cutting speed, therefore it is not advisable to describe the state of geometric structure of surface by themselves.

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