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NEW CONSIDERATIONS OF EVALUATING THE ANISOTROPY OF MACHINED SURFACES

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Abstract

New proposed indices to evaluate surface texture anisotropy together with others used in view of literature are examined here. The surfaces studied are a highly anisotropic and an isotropic and evidently may be characterized alternatively according to the desired tribological function or machining process control.

Keywords*: surface topography, anisotropy, roughness, waviness, statistical systems, machining.*

1. INTRODUCTION

Manufacturing processes, material removal and forming, performed in industrial practice lead to a wide variety of surface textures, which can be divided into isotropic or anisotropic. A texture is characterized as isotropic, if its topographic properties are statistically independent from the measuring direction over the surface.

Most of the machined surfaces are topographically anisotropic; they possess a "lay", an orientation of the surface pattern with respect to the axis of the relevant machining method [1-3]. In this regard, machining processes with tools of defined geometry like turning, shaping and milling usually generate severe anisotropic patterns, whilst others like EDM create isotropic texture. The directional properties affect the tribological function of the surface (frictional behaviour, wear, lubricant retention etc.)[4]. Considering the existence of isotropy or anisotropy on a surface and these magnitudes several criteria have been manifested in literature. Most of them are based on an "anisotropy index", a ratio combining topographic parameters, usually along two directions on the surface. Values of these indices near unity characterize a surface as isotropic, whereas lower or higher values will correspond to anisotropy.

Some of the existing methods for evaluating surface texture anisotropy in view of literature are:

a) The ratio γ of the auto correlation lengths of two representative profiles along the principal axes of the surface. These auto correlation lengths $\lambda 0.5$ correspond to the abcissae of the corresponding auto correlation functions at 50% of their initial values. If Rxx(0) and Ryy(0) are the values of the auto correlation functions in the directions xx and yy accordingly, the ratio $\gamma = \frac{\lambda_{0.5yy}}{\lambda_{0.5xx}}$ is called the anisotropy index. The range of values for γ theoretically is from 0 to ∞. Full isotropy is denoted by γ=1.

b) The ratio of the minimum and maximum RMS slope values over the profile $\gamma = \frac{\Delta_{qyy}}{\Delta_{qxx}}$ is another proposed anisotropy index.

c) By a similar concept, another ratio called long crestedness $\Lambda = \frac{2\sqrt{m_{20}m_{02} - m_{11}^2}}{m_{20} + m_{02}}$ was proposed after a more detailed analysis considering seven independent combinations of moments of the surface power spectral density function [5,6]. For an isotropic surface γ=1, whereas γ=0 characterizes the extreme case of anisotropy with infinitely long crests.

d) Application of fractal geometry analysis considering the basic parameters namely, fractal dimension and topothesy and the manner they vary in different directions. Both are found to be sensitive to the directions of anisotropy [5-7].

e) Applying the Hurst orientation transform to machined surfaces [12], a texture aspect parameter Str was introduced to identify the isotropy or anisotropy. It is defined as the ratio between the axes of an ellipse fitted to a "rose plot" of Hurst coefficients; $S_{tr} \geq 0.5$ indicates isotropy, while $S_{tr} \leq 0.5$ denotes anisotropy.

Anisotropy up to now is ascribed only to surface roughness, whilst textures incorporate another morphological component corresponding to long wavelengths, surface waviness. Although waviness is usually omitted in the analysis and surface control, may significantly affect surface functioning [8]. For an integrated description of surface texture a new set of parameters for the unfiltered or raw profile has been introduced. Those Pa, Pt, Ptp etc. parameters also adopted in the ISO 4287-1997 standard are defined in a similar manner to the roughness parameters. By the same concept we must distinguish between the Abbott curve (bearing curve) representing the raw profile and the other for roughness obtained by appropriate filtering. Related comparisons are made among these measures of anisotropy along with different indices proposed for special cases of machined surfaces or an integrated texture approach.

The new suggestions are as follows:

- The waviness component of the surface texture has to be considered in critical and high precision applications, as well as in highly anisotropic textures, where the waviness shows the same directional variations as roughness (not necessarily with the same trend) and an integral texture anisotropy index could be proposed.
- Abbott curves would offer a measure of anisotropy via corresponding parameters, standardized (ISO 13565-2:1996) or not [10].
- Multi- parameter statistical systems like Fisher-Pearson to describe the profile parameters distribution over the surface, would provide a correct evaluation of anisotropy.

In the present study these methods are applied in two extremely different surface textures, one processed by Electro-Discharge Machining (EDM), which is isotropic and the other face milled (strongly anisotropic).

2. RESULTS

2.1 Presentation of results

For the milled specimen face milling was performed on a CNC milling machine with an one tooth cutter, feed fz=0.14mm/rev and cutting speed v=200m/min. These conditions prevent built-up edge formation and the resulting profile is typical for milling.

The Electro-Discharge machined specimen was processed on an EDM machine tool at a working voltage 30V with pulse current ie=5A and pulse-on time tp=500μs. Ten surface texture measurements of both specimens were carried out on a stylus profilometer Talysurf 3+ with a cut-off length of 0.8mm and the selected parameters were determined through the software Talyprof.

The milled surface is highly anisotropic possessing an annular lay and different topographic components along two crossed directions, as illustrated in Fig.1; very high waviness is located in the tangential direction, as well as the profile is purely periodic in the radial direction, as expected.

On the contrary, the EDM'ed surface patterns are quite similar measured along two mutually perpendicular directions, as they exhibit a multi- directional lay (Fig. 2); both profiles are random in shape.

The machined specimens are tested against the aforementioned criteria, as shown in Table 1.

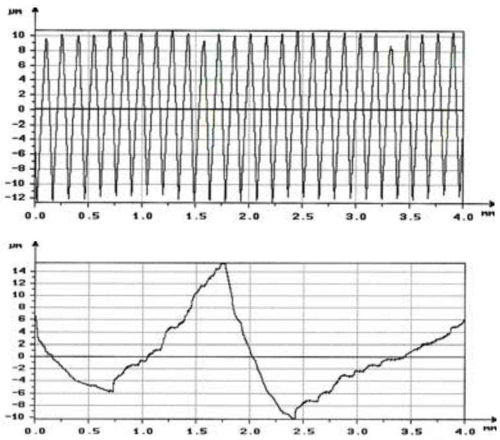

Fig. 1: *Profiles of the face milled surface in radial and tangential directions, respectively*

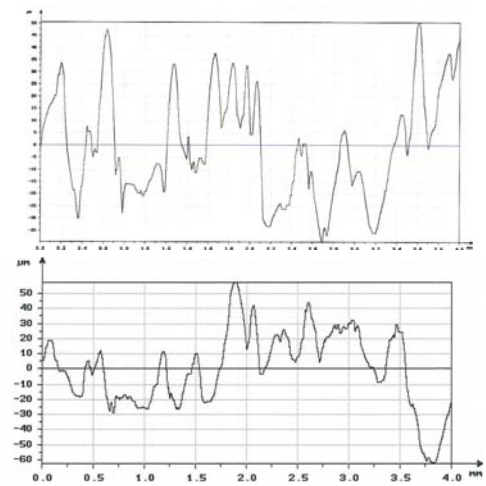

Fig. 2: *Profiles of the EDM’ed surface along two mutually perpendicular directions*

2.2 Discussion

The auto correlation length ratio $\lambda_{0.5}$ expresses explicitly the state of anisotropy. The **Rq** ratio expresses anisotropy in a clear quantitative manner. Mapping of both specimens surfaces according to **Rq** in different directions is presented in Figs 3 and 4. The asperities mean slope ratio **RDelQ** is also distinctive as the **Rq** ratio. Fractal dimension D reflects the “complexity” of surface profiles and as the anisotropic crossed patterns have unsimilar structures, they exhibit different values but this distinction is not much pronounced in the relevant **D** ratio value. The corresponding ratios for the Abbott curve parameters can describe more properly the raw profile components and to characterize correctly the roughness anisotropy, especially via the **Rk** ratio. It must be noted here that the ratios **Rtp** at 10 per cent and 40 per cent evaluate the existing anisotropy in a different way, which must be taken into account functionally and in this regard the latter can characterize more properly the anisotropy after the running-in stage.

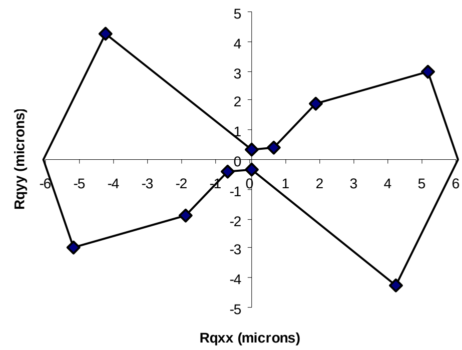

Fig. 3: *Rq anisotropy map for the face milled surface*

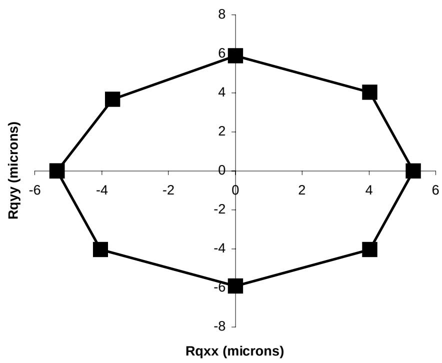

Fig. 4: *Rq anisotropy map for the EDM’ed surface*

Table 1. Anisotropy evaluation ratios using various methods

	anisotropic	Isotropic
D	0.71	0.94
$\boldsymbol{\lambda_{0.5}}$	0.07	0.65
$\mathbf{R_q}$	7.33	1.26
$\mathbf{W_q}$	0.04	0.72
$\mathbf{P_q}$	1.19	0.97
$\mathbf{P_{tp\ (10\%)}}$	0.19	1.77
$\mathbf{R_{tp\ (10\%)}}$	0.35	1.16
$\mathbf{P_{tp\ (40\%)}}$	0.56	1.51
$\mathbf{R_{tp\ (40\%)}}$	1.86	1.25
$\mathbf{R_{DelQ}}$	5.15	1.02
$\mathbf{R_k}$	7.95	1.60
F-P k	-0.002	0.25

(The bold symbols stand for ratios of the relevant magnitudes measured along two mutually perpendicular directions on the surface)

The morphological differences can be described better through statistical models of the profile height distribution and the Fisher-Pearson system can be as such. The **k** coefficient ratio shows the highest distinction between the isotropic and the anisotropic surfaces. The **Pq** ratio characterizes both surfaces as isotropic and constitutes the integrated approach regarding the process and the machine tool set-up. The waviness ratio **Wq** can stand as a criterion for isotropy but can be misleading for generally describing anisotropy.

3. CONCLUSIONS

- Regarding as a criterion the higher difference in the various "anisotropy index" values taken for anisotropic and isotropic surfaces accordingly, the R_q, R_k, and R_{DelQ} are more descriptive.
- The Abbott curve parameters and the Pearson coefficients can satisfactorily evaluate anisotropy with the advantage of their statistical character.
- The use of the waviness and raw profile ratios must be held with great care, as they can be descriptive especially when low roughness is accompanied by high waviness but on the other hand they could be misleading if the profile shape is of interest or for routine industrial inspection.
- The integrated surface texture anisotropy has to be considered in critical functional applications and consequently waviness cannot be neglected.

Several other machined surfaces must be examined under these aspects and the findings may contribute to an introduction of new criteria in relation to function and probably the desired engineering surface typology.

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