Correlation Method Based on Processing of Surface Images of Machine Components

A. D. Abramov, A. I. Nikonov, S. P. Orlov
Samara State Technical University
e-mail: esib@samgtu.ru

***Abstract*— The method of image processing of machine parts surfaces by optoelectronic and computer means is considered as an integral part of the technological process of manufacturing machine components with precision surfaces. The method is based on the correlation processing of the image of the investigated surfaces and makes it possible to estimate the microrelief parameters in the production conditions in real time. The results of determining the surface microrelief parameters for blades of gas turbine engines are given.**

Keywords*— *technology; processing method; measurement; microrelief; image; autocorrelation; quasioptimal; algorithm

I. Introduction

High technologies of the XXI century combine various scientific and technological directions in the field of mechanical engineering, including the development of modern instrumentation for measuring both the parameters of the process itself and the quality of products. Numerous studies have established a significant effect of microrelief (roughness) of surfaces various parts of machines and mechanisms for their reliability and durability [1–3]. Accordingly, the development and implementation of effective means of monitoring roughness parameters directly in production conditions can significantly improve the reliability and durability of the products. At present, optical instruments for the evaluation of microrelief parameters are widely used in engineering [4–5]. However, these means, as a rule, can be used only in laboratory conditions and for selective control.

In work [5] the optoelectronic method of definition of parameters of the microrelief, based on computer processings of the image of an investigated surface is considered. Thus multiplicate character of an additional error of the measurement arising under action of function of influence $f_{вл}(\Delta\Phi, \Delta\alpha)$, where $\Delta\Phi$ and $\Delta\alpha$ are deviations of capacity of a light stream and angle of its falling on an investigated microrelief from rating values has been established. The method is based on a comparative correlation processing of the halftone image of the microrelief and a special set of halftone images of the reference microrelief with known roughness parameters. Image processing was performed using the expression known for calculating the two-dimensional correlation function [6]

$$r_{xu}(k_1,k_2) = \frac{\sum_{n_1=0}^{N_1-1}\sum_{n_2=0}^{N_2-1}\left(u-m_u\right)\left(x(n_1-k_1,n_2-k_2)-m_x\right)}{\sigma_1\sigma_2}, \quad (1)$$

where $u = u(n_1, n_2)$ is the fragment of the image (standard) that is located inside the search area $x(n_1,n_2)$, that is, the image of the examined microrelief of the pixel format $K_1 \times K_2$, and σ_1, σ_2 are the mean square deviations of the magnitudes $u(n_1,n_2)$ and $x(n_1,n_2)$ from their mathematical expectations m_u and m_x respectively.

The microrelief parameter – the average arithmetic deviation of the profile from the midline Ra, was determined with a given probability from the experimental dependence $Ra = f(U_{CP})$, where U_{CP} is the random mean value of the variable component of the autocorrelation function.

II. Problem Statement Recearch

The use of expression (1) requires a considerable amount of computational operations, which significantly reduces the capabilities of the method for the operational control of the microrelief parameters. For example, the image processing time of the examined microrelief of 320 × 240 pixels is 447484 ms for a PC with a processor Intel(R) Core(TM)2CPU 4300 @ 1.80GHz.

It is necessary to create a method for studying the microrelief of complex surfaces of machine parts in production conditions on the basis of optimal algorithms that will significantly increase the speed of the optoelectronic method of estimating the microrelief parameters.

III. Statement of the Substance of the Problem Solution

To solve this problem, we considered quasi-optimal correlation algorithms that have found wide application in the correlation extreme navigation systems of unmanned aerial vehicles [7–10].

The algorithm was tested with criterial function that uses binary images

978-1-5386-5824-6/18/$31.00 ©2018 IEEE

$$r_{x,y}(k_1,k_2)=\frac{1}{N}\sum_{i=0}^{2^{n-1}}F_{ii}(\Delta), \qquad (2)$$

where $F_{ii}(\Delta)$ is double the criterial function acquires a single value when the i pixel coincides in the reference image – the EI and the fragment of the binary current image – the microrelief TI, N – the number of compared elements in the EI and the microrelief fragment, $r_{x,y}(k_1,k_2)$ is the correlation coefficient representing the normalized sum of the coincident pixels in the TI and EI.

The scheme for the formation and movement of the selected EI microrelief is shown in Fig. 1.

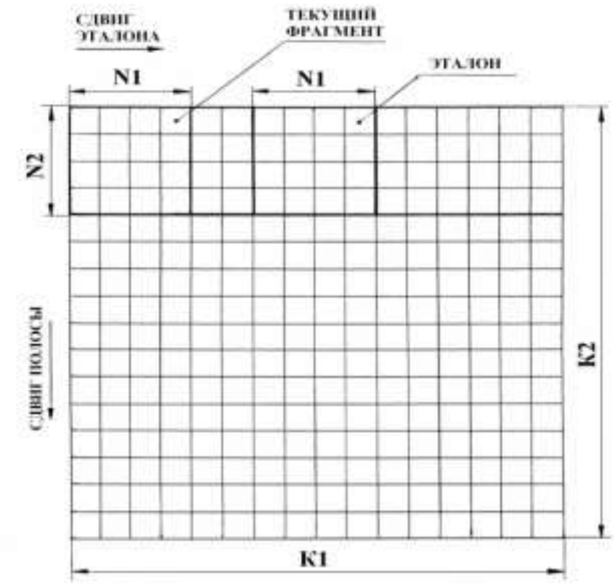

Fig. 1. Scheme of formation and movement of the standard

In the image from the first line, a strip with a width of N_2 pixels is allocated, and a standard of $N_1 \times N_2$ pixel size is set in the center of this strip. Then the standard, starting with the leftmost position, moves along the selected strip in steps of 1 pixel. At each combination of the standard and the TI fragment $r_{x,y}(k_1,k_2)$ is calculated by formula (2).

Having finished calculation $r_{x,y}(k_1,k_2)$ in the first strip, we specify a following strip of the same format, but displaced downwards on one pixel. In this strip on the center sets a new standard with the same dimensions and performed the same calculation at etc. Since the standard is formed in the image of the microrelief, the coefficients $r_{x,y}(k_1,k_2)$ are the autocorrelation coefficients. After processing the entire image, we get a two-dimensional autocorrelation function. Thus negative effect of function of influence on an assessment of parameters of a microrelief is compensated also

$$\Delta B = B_T \ f_{вл}(\Delta\Phi,\Delta\alpha) - B_Э \ f_{вл}(\Delta\Phi,\Delta\alpha) = f_{вл}(\Delta\Phi,\Delta\alpha)\cdot 0 \ \text{ if } B_T = B_Э .$$

Besides only in this point the sum of the pixels which have concurrently on value of standard $B_Э$ and fragment TI – B_T, according to (2) also is increased.

IV. Complex of Equipment for Research

For carrying out of researches about a condition of a microrelief of a surface (roughness) of mechanical products the digital measuring microscope of set Smart Visionc has been used. The microscope was completed with a personal computer and a videocamera DIGITAL CAMERA Computar ZC-F11CH3. By the method of grinding and polishing, images of standard surfaces with different roughnesses were made. The parameters of roughness according to [11] were determined by the model SJ-201P, sample No.1 had $Ra = 0{,}13$ μm, sample No.2— $Ra = 0{,}084$ μm, sample No.3 — $Ra = 0{,}048$ μm and the sample No.4— $Ra = 0{,}025$ μm. The format of the examined surface microrelief image was $K_1 \times K_2$ =320×240 pixels which conformed to an analyzed microrelief in the size of 3×2,5 mm. Appropriating algorithms and programs have been developed for processing half-tone pictures of investigated microreliefs.. The brightness range of the video signal in the resulting image was 0 to 255 relative units. Binarization of the halftone image was carried out according to the adaptive method [5]. The surface image was divided into square fragments (windows 16×16 pixels) and in each window the average level of brightness of the video signal $B_T(x,y)$ was calculated. As a result of comparison of each pixel of a window $B_i(x,y)$ with threshold value $B_T(x,y)$ new significance by a rule was attached to it: $B_i(x,y)$ = 0FFH, if $B_i(x,y) \geq B_T(x,y)$ and $B_i(x,y)$ = 00H, if $B_i(x,y) < B_T(x,y)$. Binary images of the investigated surfaces are shown in Fig. 2.

It can be seen from Fig. 2 that the microrelief changes with change Ra. The oriented texture for the sample with $Ra = 0{,}13$ μm is transformed into a texture that has a random pattern of alternating small light and dark spots for the sample with $Ra = 0{,}025$ μm, that due to the changing relationship between regular and random component in mechanical processing surface.

For binary images, the autocorrelation function was calculated by the algorithm (2). The calculation time in this case was 480 ms, which is several orders of magnitude shorter than the time (447484 ms) required when using (1).

The analysis of the received two-dimensional autocorrelation functions has shown, that on average accidental amplitude U_{CP} researched microreliefs essentially differ from each other.

Least squares for a dependency $Ra = f(U_{CP})$ was defined as analytical expression

$$Ra = 0{,}0065 \times Ucp - 0{,}02 \ \mu m, \qquad (3)$$

and, for a confidential interval I_β, where gets U_{CP}, expression I_β looks like

$$I_\beta = (3,4U_{CP}^2 + 14,4U_{CP} + 1)\times 10^{-3} \qquad (4)$$

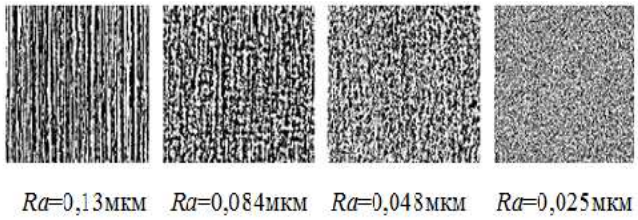

Fig. 2. Binary images of investigated samples

The standard deviation of the estimate in the determination U_{CP} was determined by the formula [12]

$$\sigma_T = \frac{\sigma}{\sqrt{n}}.$$

30 images were examined on the surface of each of the above-mentioned samples. Setting the well-known probability of recognition of the roughness of the investigated microrelief P = 0.99, and also t_β = 2.576, we obtain the mean square deviations, confidence intervals and amplitudes of the variable component for the corresponding autocorrelation function (see the data in Table 1).

TABLE I. PARAMETERS OF AUTOCORRELATION FUNCTION

Specifying parameters	**Parameter values**			
Ra , µm	0,130	0,084	0,048	0,025
σ_T , µm	0,240	0,218	0,182	0,055
I_β	0,92	0,63	0,44	0,37
U_{CP}	49,58… …50,92	40,27… …41,53	33,46… …34,34	25,73… …26,27

The algorithm and method for determining the roughness of the microrelief on the basis U_{CP} were used to investigate the roughness of the polished surfaces of the pen of the blades of the 1st stage of a gas turbine engine.

The processing of the experimental results showed that the average value of the variable component of the correlation function, computed from 30 images, was U_{CP} = 22,1 rel. units. The use of expression (4) yielded I_β = 0,21 rel. units., then $U_{CP\,\min}$ =21,89 rel. units., and $U_{CP\,\max}$ = 22,32 rel. units. Expression (3) for the area of the back surface of the blade feather gave the following results of Ra = 0,21 µm, $Ra_{\min}$ = 0,14 µm and $Ra_{\max}$ = 0,27 µm, which is in complete agreement with the values Ra , measured by the profilograph.

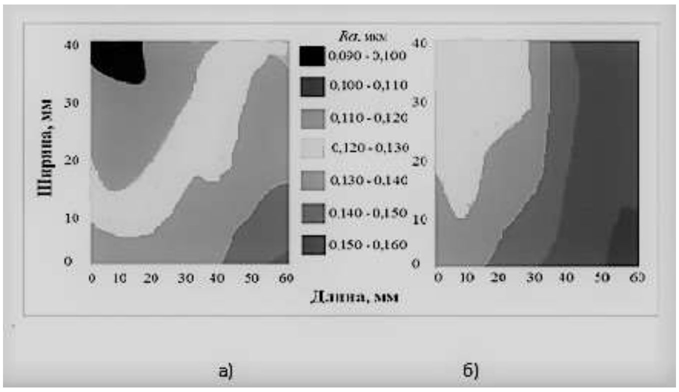

Fig. 3. Fields of surface roughness 1 blades after turbine stage 1 transition a-trough, b-backrest

Next, a sequential opto-electron scan of the entire surface of the back and trough of the blade was performed, a calculation for each section and construction of the roughness fields presented at Fig. 3.

V. DISCUSSION OF RESULTS IN SCIENTIFIC AND APPLIED ASPECTS

The use of a quasioptimal algorithm makes it possible to significantly reduce the time for determining the parameters of the microrelief by the optic-electron method and, consequently, to monitor them directly in the production environment.

The resulting roughness fields make it possible to determine the most dangerous parts of the surface where unacceptable values of stress concentrators are formed and, consequently, apply appropriate measures to reduce the stress state of the surface layer, which will increase the reliability and durability of industrial products during their operation. The patent of the Russian Federation [13] has been received for the considered method.

REFERENCES

[1] Petreshin D.I., Suslov A.G., Fedonin O.N. Control of quality parameters of the surface layer of machine parts under conditions of uncertainty. *Progressivnye tekhnologii i sistemy mashinostroyeniya*. 2016, no. 4(55), pp. 57-61. (In Russian).

[2] Suslov A.G. Automated provision of a complex quality parameter of the surface layer Cx at machining. *Naukoyemkiye tekhnologii v mashinostroyenii*. 2011, no. 2, pp. 34-39. (In Russian).

[3] Ivanov A.Yu., Leonov D.B. Technological methods of ensuring .the quality of products. *Nauchno-tekhnichesky vestnik Sankt-Peterburgskogo gosudarstvennogo universiteta informatsionnykh tekhnology, mekhaniki i optiki*. 2011, i.75, no. 5, pp 111-114. (In Russian).

[4] Makeev A.V. On optical methods for monitoring the surface roughness. *Interekspo Geo-Sibir*. 2016. Vol. 5, no. 1, pp.147-151. (In Russian).

[5] Abramov A.D., Nikonov A.I. The analysis and correlation method of elimination errors of optiko-electronic determination of microrelief parameters. *Vestnik kompyuternykh i informatsionnykh tekhnology*. 2016, no. 1, pp 3– 9. (In Russian) .

[6] Pratt W.K. Correlation Techniques of Image Registration, *IEEE Trans. Aerospace and Electronic Systems.* 1974 AES-10, 3, pp 353-358.

[7] Naumov A.I, Kichigin E.K., Safonov I.A. On-board complex of high-precision navigation with correlation-extreme navigation system and digital terrain map. *Vestnik Voronezhskogo gosudarstvennogo*

tekhnicheskogo universiteta. 2013, vol. 5, no. 6-1, pp. 51-55. (In Russian).

[8] Mikryukov A.N. Use of changes in the graphic field in problems of correlation-extreme navigation. *Pribory i sistemy. Upravleniye, kontrol, diagnostika*. 2010, no. 3, pp. 65-69. (In Russian).

[9] Pluzhnikov A.N., Potapov N.N. Correlation-extreme processing of navigation information. Digital algorithms and hardware implementation. *Datchiki i sistemy*. 2013, no. 11(174), pp 22-27. (In Russian).

[10] Belov R.V., Ogorodnikov K.O. Realization of the modified algorithm of recurrent-searching estimation of the correlation-extreme navigation system by terrain relief. *Upravleniye bolshimi sistemami*. 2017, vol. 68, pp. 162-176. (In Russian).

[11] State Standard 8.009-84. State system for ensuring the uniformity of measurements. Standardized metrological characteristics of measuring instruments. Moscow, Standartinform Publ. 2006. 27 p. (In Russian)..

[12] Wentzel E.S. Probability theory. 11th ed. Moscow. KNORUS Publ. 2010. 664 p. (In Russian).

[13] Abramov A.D., Nikonov A.I., Nosov N.V. *Sposob kontrolya sherokhovatosti poverkhnosti*. Patent RF, no. 2413179, 2010. 11p.