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**COMPUTER IMPLEMENTATION OF THE INDIRECT METHOD FOR ESTIMATING OF THE PREDICTED MICROROUGHNESSES**

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**КОМП'ЮТЕРНА РЕАЛІЗАЦІЯ НЕПРЯМОГО МЕТОДУ ОЦІНЮВАННЯ МІКРОНЕРІВНОСТЕЙ, ЩО ПРОГНОЗУЮТЬСЯ**

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**КОМПЬЮТЕРНАЯ РЕАЛИЗАЦИЯ КОСВЕННОГО МЕТОДА ОЦЕНИВАНИЯ ПРОГНОЗИРУЕМЫХ МИКРОНЕРОВНОСТЕЙ**

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*It is offered the computer implementation of the method for indirect estimation of the microroughnesses according to the measurement deviations of the rotational speed of the grinding wheel. It is developed the mathematical model of the process of diamond grinding and it is formulated requirements for measurement accuracy on the basis of the analysis of its output signal. It is developed the information technology of the separation of the constituents into the deviation signal. It is offered the method and device for compensation of the kinematic error of the primary converter.*

**Keywords:** *method of measuring, deviations, mathematical model, kinematic error.*

*Запропоновано комп'ютерну реалізацію метода для непрямого оцінювання мікронерівностей за даними вимірювань девіацій швидкості обертання шліфувального круга. Розроблено математичну модель процесу алмазного шліфування та на основі аналізу її вихідного сигналу сформульовано вимоги за похибкою вимірювань. Розроблено інформаційну технологію поділу внесків подач до сигналу девіацій. Запропоновано метод та пристрій для компенсації кінематичної похибки первинного перетворювача.*

**Ключові слова:** метод вимірювань, девіації, математична модель, кінематична похибка.

*Предложена компьютерная реализация метода для косвенного оценивания микронеровностей по данным измерений девиаций скорости вращения шлифовального круга. Разработана математическая модель процесса алмазного шлифования и на основе анализа ее выходного сигнала сформулированы требования по точности измерений. Разработана информационная технология раздела вкладов подач в сигнал девиаций. Предложен метод и устройство для компенсации кинематической погрешности первичного преобразователя.*

**Ключевые слова:** метод измерений, девиации, математическая модель, кинематическая ошибка.

**Preface.** It is offered the indirect method of estimating of the predicted microroughnesses of the machined surface of workpieces with diamond grinding on the deviation signal of the rotational speed wheel. Standard levels of deviations are set on the base of the possible «qualitetov» of the purity workpieces surface and are entered into the databank of the computer system in the form of regulations. In this case deviations are the source of the indirect information about microroughnesses, and the signal which contains the information about the deflection of the predicted «qualitetov» purity from the adjusted value using the processing program of the batch workpieces. The implementation of the proposed ideas allows building a computer system in order to receive the predicted quality of the machined surface of workpieces without direct changes of its microroughnesses.

**The aim and task of the research work is.** The object of the article is the computer implementation of the indirect method for estimating of the predicted microroughnesses. The progress of this object is provided by solving of such problems:

- to establish requirements for metrological characteristics of the measuring device based on the output analysis of a mathematical model of the process of diamond grinding;

- to realize the using of the information measuring device and analyze its efficiency;

- to develop the information technology of the instantaneous speed signal processing of the wheel rotation.

The hardware and software estimation of the predicted microroughnesses is a logical connection of rotation detector, measuring converter, microcontroller device. The output signals are the given values of the transverse and longitudinal feed of the grinding wheel.

### The simulation process of diamond grinding.

The requirements for metrological characteristics of the measuring converter are formulated by analyzing the output signal of a mathematical model of the process of diamond grinding. The diamond tool feeds were used in its development as input signals. The output signal of the model is the cutting force of the workpieces material. The expression for the transfer function that links the transverse feed with the radial component of the cutting force was obtained considering the dynamics of the cutting process of the workpieces material, the elastic deformation of the kinematic scheme of the grinding machine and the diamond tool linear wear [1, 2]

$$W_1(p) = \frac{K_1(1 - e^{-pt_1})}{1 + K_1(1 - e^{-pt_1}) \left[ pK_2 \left( \frac{p^2}{\Omega^2} + \frac{2\beta_1 p}{\Omega} + 1 \right) + \frac{K_3}{p\tau} (1 - e^{-p\tau}) \right]}, \quad (1)$$

where  $K_1$  – the transfer coefficient of the cutting process of the workpieces material on the coordinate  $S_1$ ,  $\beta_1$  – the damping

coefficient,  $K_2$  – the state stiffness of the machine design,  $K_3$  – the grinding wheel wear coefficient,  $\tau$  – time rotation of the wheel,  $t_1$  –

the front or back wheel move time,  $\Omega$  – the resonant frequency of the grinding machine design.

The expression for the transfer function that links the transverse feed with the tangential component of the cutting force was obtained

$$W_2(p) = \frac{K_5 K_4 (1 - e^{-pt_1})}{p [K_5 + K_4 (1 - e^{-pt_1})]}, \quad (2)$$

where  $K_4$  – the transfer coefficient of the cutting process of the workpieces material on the coordinate  $S_2$ ,  $K_5$  – the state stiffness of the machine design.

considering the dynamics of the cutting process of the workpieces material, the elastic deformation of the kinematic scheme of the grinding machine and the diamond tool linear wear [1, 3]

The input signal considering the front and back grinding wheel move was depicted by such expression (similar presentation for longitudinal feed) [4]

$$S_1(t) = \begin{cases} 0, & \text{if } -\pi < \Omega t < -\pi + \alpha, -\alpha < \Omega t < \alpha, \pi - \alpha < \Omega t < \pi, \\ S_1, & \text{if } \alpha < \Omega t < \pi - \alpha, \\ -S_1, & \text{if } -\pi + \alpha < \Omega t < -\alpha, \alpha > 0, 0 < \alpha < 0.5\pi. \end{cases} \quad (3)$$

The radial and tangential components of the cutting force of the workpieces material are orthogonal in their effect on the grinding wheel. The following equation for their summation was

$$F(p) = \sqrt{W_1^2(p)S_1^2(p) + W_2^2(p)S_2^2(p)}. \quad (4)$$

The cutting force of the workpieces material is a source of rotary oscillations. The shaft with the grinding wheel was given in the form of the mechanical system with one degree

obtained on the basis of the linearity of the Laplace transform and the complementary theorem of addition [4]

of freedom. The movement of the wheel is described by the second order differential equation [5]

$$J\varphi''(t) + \beta_2\varphi'(t) + \gamma_1\varphi(t) = RF(t), \quad (5)$$

where  $J$  – the inertia moment of the circle,  $\beta_2$  – the damping coefficient,  $\gamma_1$  – the stiffness of the shaft,  $R$  – the wheel radius.

workpieces material was obtained after the procedure of normalization and transformations [6]

The transfer function that links deviations and the cutting process of the

$$W_3(p) = \frac{Rt_1\gamma_1 p}{Jt_1 p^2 + \beta_2 t_1 p + \gamma_1}. \quad (6)$$

The block diagram of the diamond grinding process was made by the expressions (1), (2), (4) and (6) (Fig. 1). The deviation schedule of the grinding wheel rotation speed within its one turn was prepared as a result of simulation (Fig. 2). It was set that the amplitude

of deviations didn't exceed 0.05 signal amplitude of the instantaneous speed. So the procedure of the signal deviations measurements requires the development of high-precision methods and suitable technical means.

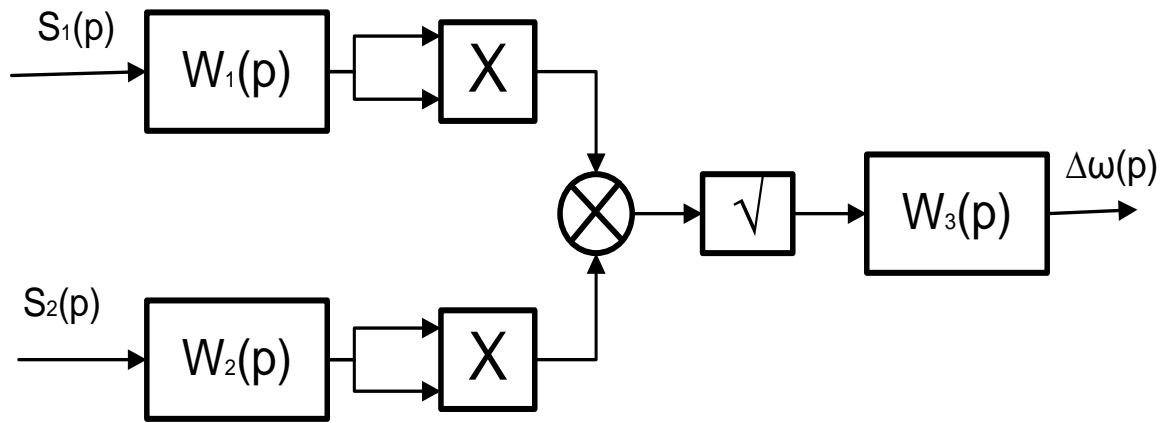


Fig. 1 Block diagram of the diamond grinding process

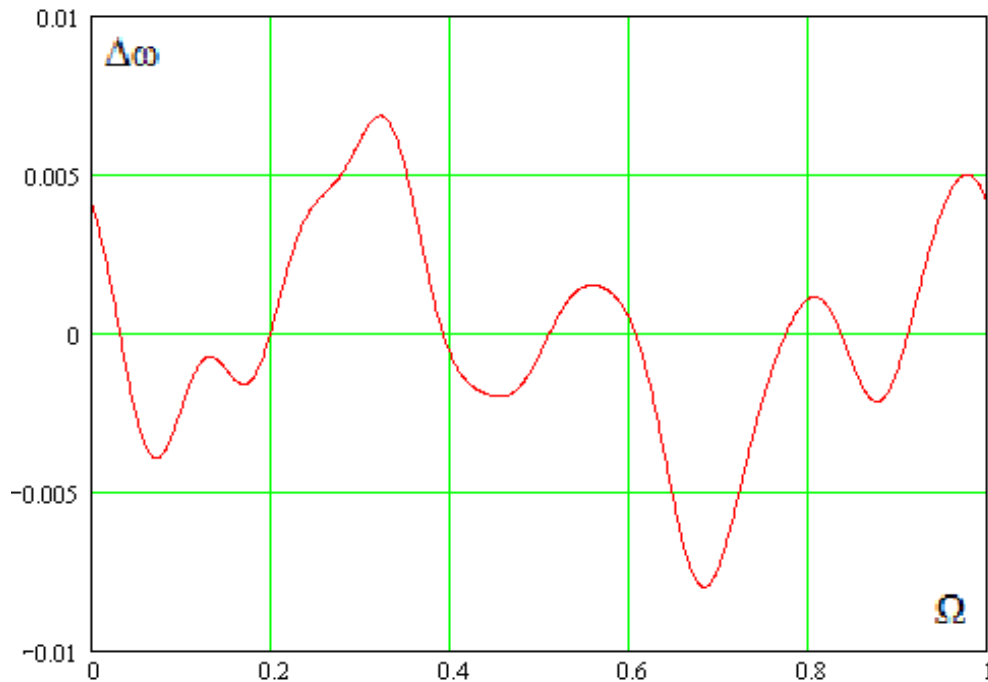


Fig. 2 Output signal of the model of the diamond grinding process

#### Measuring converter.

Its development was started from the analysis of components of the sensor error:

- the error recovery of the analog signal from discrete samples which is determined for its frequency representation in this way [7]

$$\delta_1 = \frac{t_0}{8} \sqrt{0.1 \sum_{i=1}^{10} \Omega_i^4} 100\%, \quad (7)$$

where  $t_0$  – a set of discretization;  $\Omega_i$  – harmonic of frequency representation of the deviation signal;

- the cinematic error of the primary converter which is defined by the example of research tolerances for the manufacturing

production of gear wheels of different classes of accuracy [8] and it is given in Table 1. This expression is used to evaluate the kinematic error

$$\delta_2 = \frac{\Delta m}{m} 100\%, \quad (8)$$

where  $\Delta m$  – the tolerance for the kinematic error of the gear wheel,  $m$  – module;

-

the dynamic error of the primary

converter.

Table 1 – Numerical data of the kinematic error

Accuracy class of gears	4	5	6	7	8
$\delta_2, \%$	0	1	2	2	4
	.80	.25	.00	.75	.00
Error of deviation measurements, %	1	2	4	5	8
	6.0	5.0	0.0	5.0	0.0

Data of Table 1 permit to make a conclusion: the problem of the precision measuring deviations is to develop technical means for reducing the magnitude of the kinematic error in manufacturing of the primary converter. One of the possible ways to solve this problem is to perform certifications of the primary converter. The results of it are corrections which the measuring converter takes into account to determine the deviation signal. The synchronization device that has the appropriate primary converter is also a part of the measuring converter.

To compensate the kinematic error the author proposes a method of multichannel measurements of time intervals that are formed

by one mark of the primary converter and match to the requirements for a full rotation of its shaft. Using the method of measuring the instantaneous speed the kinematic error of the primary converter has no effect on the duration of the intervals formed by time. Data of Table 1 and this conclusion prove the correctness of the proposed method.

The dynamic error of the primary converter is the time shift of discrete samples of time realization of deviations which appear as a result of the kinematic deviation. It was conducted the estimation of the dynamic error of shifts in time of the discrete samples of signal deviations. The absolute value of the dynamic error is defined as follows [9]

$$\Delta_1 = \frac{1}{z} \sum_{i=0}^{z-1} [\Delta\omega(i\Delta t + \sigma) - \Delta\omega(i\Delta t)], \quad (9)$$

where  $z$  – the number of marks of the primary converter,  $\sigma$  – the mean square deviation of temporary displacement of discrete samples is defined on the basis of the

manufacturing tolerances of the primary converter.

The sum is replaced by the integral up to the magnitude of the second order minority concerning the dynamic error of the primary converter [9]

$$\Delta_1 = \frac{1}{\Delta t} \int_0^{\Delta t} [\Delta\omega(\Omega t + \Omega\sigma) - \Delta\omega(\Omega t)] dt. \quad (10)$$

For a harmonic signal this expression after mathematical transformation is in the form of

$$\Delta_{1,i} = \frac{2A_i}{\pi} \sin(\varphi_i - 0.5i\Omega\sigma) \sin(i\Omega\sigma). \quad (11)$$

The relative error of the harmonic signal was obtained in the expression

$$\delta_i = \frac{2}{\pi} \sin(\varphi_i - 0.5i\Omega\sigma) \sin(i\Omega\sigma). \quad (12)$$

The dynamic error of the primary converter is determined taking into account the contributions of the harmonic components to the deviation signal [10]

$$\delta_3 = \sqrt{\frac{\sum_{i=1}^{10} (A_i \delta_i)^2}{\sum_{i=1}^{10} A_i^2}}. \quad (13)$$

The results of calculations of the dynamic error of the primary converter are given in Table

2.

Table 2 – Numeral data of the dynamic error

Accuracy class of the primary converter					
Error of deviation measurement, %	.10	.80	.40	.90	4.10

The gist of the method, proposed by the author for the hardware compensation of the kinematic error of the primary converter, consists in the following [11]. The output signal of the primary converter using the counter and decoder is converted into some impulse sequences, which correspond to the moments of passing near the sensing element of the converter of one mark and which are applied to the input channel for the measurement of time intervals. The number of these channels as a part of this device is determined by the number of marks of the primary converter. Hardware implementation of channels for the measurement was made on the basis of the time discretization method. The elimination of the mutual overlapping of the output signal channels when they are combined in the measurement information signal for the digital processing device is performed using counters. The volume of the latter and the frequency of a

generator are selected so that the counter overflow can be performed for a time slightly less than the average period of pulse pattern. So the calibrated time interval is excluded from the measurement information of each channel. The combination of the output signals of channels into the signal of the measurement information is performed using the logical scheme OR.

The original device for measuring instantaneous speed of the grinding wheel rotation was designed using this method (Fig. 3). It is considered [12]. Fig. 4 illustrates : PC – primary converter; D – decoder; G – generator; N – the number of channels for measurement; AND1,..., AND4 – logic circuitry;  $N_x$  – output code; OR1, OR2 – logic circuitry; C1,..., C4 – pulse counter; PSh – pulse shaping; T1,..., T3 – trigger; DL – delay line. The device for measurement has two channels, which measure the duration of the pulses of the direct and inverse outputs T1.

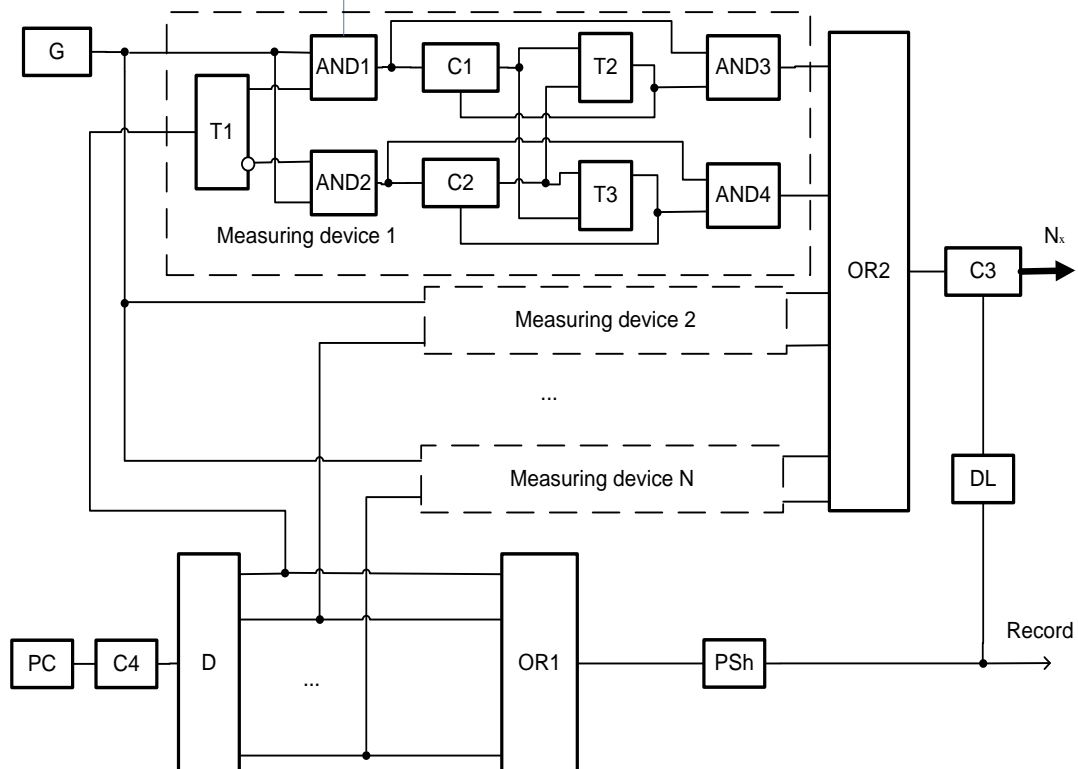


Fig. 3 Compensation device of the kinematic error

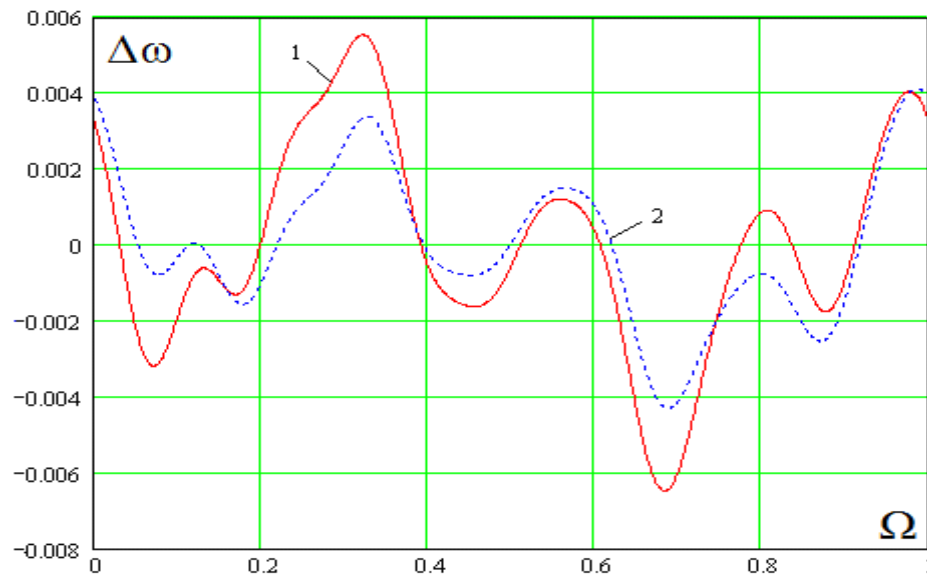


Fig. 4 Graphs of the constituents of the deviation signal:  
1 – transverse feed, 2 – longitudinal feed

The measurement information signal for the device is formed by the scheme OR2. The counter C3 converts this signal into a digital code. The block PSh generates a recording signal code in the register device 5 and using the block D converts the counter C3 to the zero state.

**Information technology of deviation signal processing.** The separation of the constituents of the deviation signal was

$$\gamma_1 = \frac{\Delta\omega_1}{\Delta\omega} = 0.81 \quad \text{and} \quad \gamma_2 = \frac{\Delta\omega_2}{\Delta\omega} = 0.586.$$

Algorithm of the digital processing device of the signal speed was developed based on the tolerance control:

- to present temporal implementation of the deviation signal after the normalization of its parameters by a limited Fourier series;
- to determine the acting value of the deviation signal;
- to get normalized values of feeds by multiplying weight coefficient;
- to analyze the data bank of standard levels of deviation amplitudes and if necessary to form signals of feed adjustment.

**Conclusion.** It is offered the computer implementation of the indirect method for estimating of the predicted microroughnesses of the machined surface of workpieces. It was

developed on the basis of their frequency representation. Graphs of the constituents of the deviation signal were prepared as a result of simulation (Fig.4). These graphs were prepared during the analysis of the mathematical model of the diamond grinding process using such constituents of the deviation signal :  $S_1(t) = 0$ ,  $S_2(t) = 0$ . It was determined the weight coefficients of the separation of the constituents of the deviation signal

improved the mathematical model of the process of diamond grinding, which is characterized by two coordinates, the use of feed diamond tool as input signals and deviations as the output signal. For the first time it was developed the method and the information technology of the separation of the constituents of the grinding wheel of the deviation signal on the basis of their frequency representations. First it is offered the method of measuring instantaneous speed of grinding wheel rotation which is characterized by using the hardware compensation of the kinematic error of the primary converter. It was designed the measuring design and the technology of the instantaneous speed signal.

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