A Device for Measuring the Wear of Replaceable Rotary Tool Inserts of Milling Drums of Road Milling Machines

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Abstract. In the article, based on studies of the wear of the cutting surfaces of the incisor inserts of road cutters, an original device is proposed that allows measuring all wear elements of the cutting inserts of road cutters, including the kinematic profile of the wear site proposed for the first time. Experimental studies of prototypes of assemblies with elastic elements embedded in them have been carried out and a decrease in noise content in the general flow of measuring information has been achieved due to the simplicity of the design and the absence of destabilizing complex-profile and kinematically dependent mechanisms and assemblies in it. For the first time, the proposed solutions made it possible to increase the efficiency of road milling machines (RMM), including expanding their operational, technological, economic, and design and mechanical capabilities.

Keywords: measurement, tool inserts, wear elements, kinematic profile, wear site, road milling machines.

Introduction

The operation of milling drums of road milling machines is accompanied by intensive wear of replaceable rotary tool inserts. At the same time, depending on the operating conditions, the size of the wear pads, as well as the shape of the worn surface, vary greatly. In these conditions, the development of a device for mobile measurement of all wear elements of replaceable rotary cutter rates of milling drums of road milling machines is relevant. Improving the efficiency of road milling machines by considering them as an object of management and creating automatic milling process control systems based on standard components of road milling machines.

1. Methodology

It is established that from the moment of embedding a round replaceable tool insert into the surface to be processed and until they come out of contact with this surface, chips with a thickening at the end are formed, the size of which depends on the speed and depth of milling. Figure 1 shows a prefabricated cutter with a round shank used in milling drums.
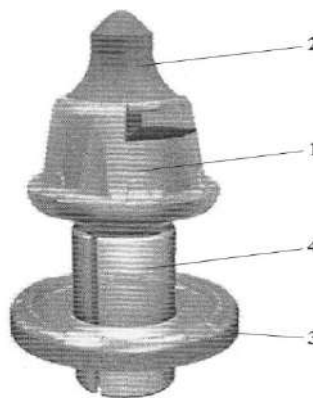

Fig.1. - A prefabricated cutter with a round shank

The body 1 (Figure 1) of the cutter consists of a head and a cylindrical shank. A replaceable carbide tip 2 is attached to the head using high-temperature solder. With the help of a wear washer 3 and a clamping sleeve fitting the shank 4, the assembly structure of the tool insert in the tool holder is based with the possibility of periodically turning it at an angle of 10° (per revolution of the rotating milling drum). This rotation is performed in the absence of chip removal by this cutting plate [1]. The rotation of the tool insert is facilitated by low-amplitude "swinging" of the shank with a sleeve inside the washer and minor dynamic vibrations of the tool holder body. All this creates a precessional movement of the tool insert inside the base hole of the tool holder, provides conditions for uniform wear of the cutting and contacting surfaces of prefabricated tool inserts. With uniform (along the arc of the circle) wear of the cutting part of the head of the tool insert, the effect of self-sharpening of the cutting parts occurs, which increases the service life of the tool insert as a whole.

Tip 2 is made of tungsten-cobalt hard alloys for example, (VK6 with 94% tungsten carbide and 6% cobalt) cap-shaped (three versions), or cylindrical shape [1] Tungsten carbide (WC) with a hardness of 9 according to the Mohs school is close to the hardness of diamond (hardness 10), while cobalt, as a more viscous malleable material, provides cementing properties to this two-component alloy [2].

For tangential rotating cutting inserts with metal-ceramic tungsten-cobalt alloys, the cutting angle is reduced compared to radial ones, which leads to a 20-25% reduction in cutting force and a reduction in the energy intensity of the process.

Research [3] based on statistical processing of 1470 pieces of worn cutting inserts on Wirtgen W500 and Wirtgen DC200 milling drums has established that 63% of assembled cutting inserts are subject to uniform wear; 19% are subject to intense wear of the cutter body (when using them as scoring tool holders (item 2 in Figure 1.2), or when working in a viscous environment, for example, in viscous asphalt); 13% are subject to uneven wear due to jamming in the tool holder and 5% of cutting inserts fail due to chipping and destruction of carbide tips (item 2 in Figure 1).

The operation of milling drums with prefabricated rotary cutting inserts is characterized by [3, 4]: frequency of operation of the cutting inserts, variable area of the removed layer with one cutting insert, a variable (changing) number of cutting inserts in operation, which causes variations in the forces, moments and cutting power required for milling.

The total path length in the asphalt concrete pavement of one cutting insert is determined as [5]:

$$L = \frac{S}{6} \cdot arc\,cos\left(1 - \frac{P}{R}\right) \tag{1}$$

where L – is the path length of the cutting insert 3 per one revolution of the milling drum 2 from point «b» to point «a», passed in asphalt concrete pavement 1, Figure 1.6;

S – the area of the worn-out coating;
P – depth of cut (depth of cut) of the cutting insert;
R – milling drum radius;
α – the angle between the points of contact of the cutting insert with the asphalt concrete pavement;
ω and **v** – respectively, the angular velocity and the speed of relative movement (feed) of the milling drum.
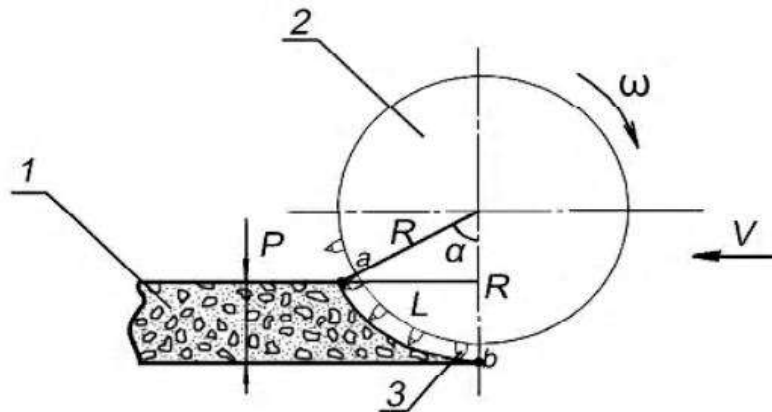

Fig. 2. - Path length of the cutting insert in an asphalt concrete road surface

To ensure the performance of incisal inserts, dry or wet cooling is used [7].
In the first case, the road milling machine (milling drum) is removed from contact with the asphalt concrete surface and rotated idle for 1-2 minutes. The wet method uses a forced supply of coolant under pressure from nozzles to the surface of the milling drum.

Periodic preventive control of cutters for rotation around their axis (usually manually) also creates conditions for uniform wear over the entire surface (the circumference of the contact surface).

The wear of rotary cutting inserts is negatively affected by various factors [1, 7]:

A. Operational:
1 – physical and mechanical characteristics of the treated surface (its hardness, composition and type of the treated layer, temperature).
2 – presence of coolant in the cutting zone.
3 – type and characteristics of road milling machines.

B. Technological:
1 – milling modes (milling depth, milling drum rotation speed);
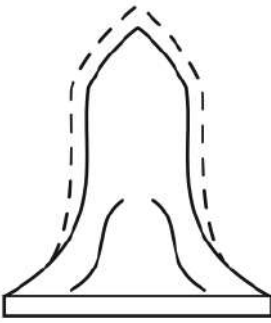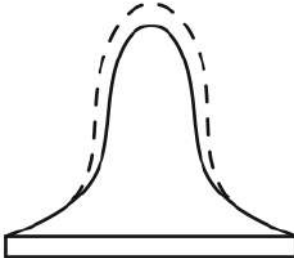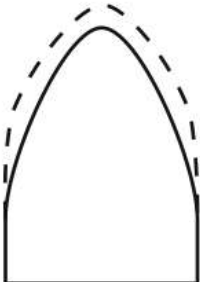2 – adjustment parameters (angles of attack, rotation and tilt in the milling drum coordinate system [1].

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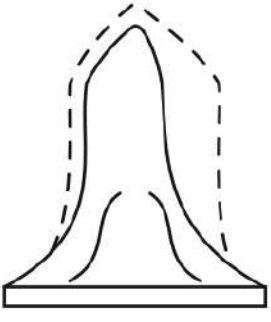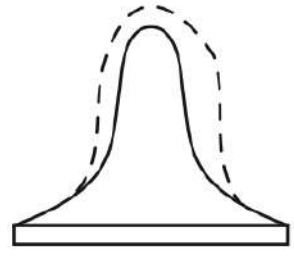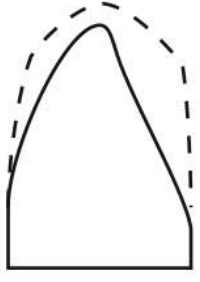
C. Design:
1 – shape of the carbide tips used;
2 – type of solder;
3 – location of the cutting inserts on the milling drum;
4 – step of arrangement of cutting inserts on the drum;
5 – inclination and pitch of the spirals of the locations of the cutting inserts on the drum;
6 – presence of chip ejectors and their angle of inclination relative to the spiral direction of the location of the cutting inserts on the drum.

Table 1 shows the shapes of worn surfaces of different types of tips, where:

1) A1-A4 – correctly worn cutting inserts. Such wear occurs when the milling technological regimes are observed, periodic preventive inspections of the milling drum are carried out, and the cutting inserts are rotated.
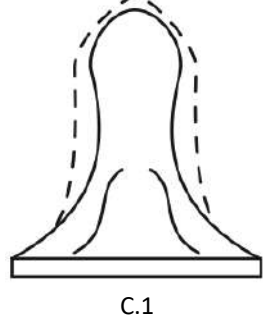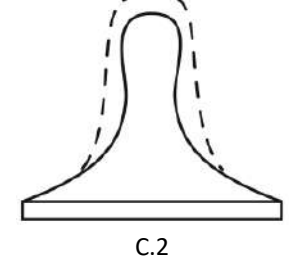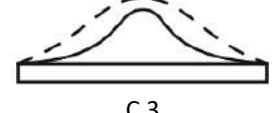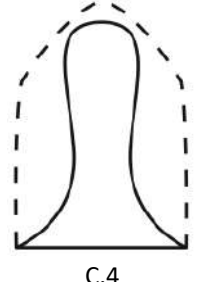
2) B1-B4 – incorrect operation of the cutting insert, when milling was carried out while the cutting insert was blocked (jammed) in the tool holder.

3) C1-C4 – incorrect operation of the cutting insert, when milling was carried out with free rotation (with a gap) movement of the cutting inserts in the tool holder.

Table 1. Shape of worn surfaces of different types of tips

Cap-shaped in a massive design	Long cap-shaped	Cap-shaped flat design	Cylindrical
A.1	A.2	A.3	A.4
B.1	B.2	B.3	B.3
C.1	C.2	C.3	C.4

In Table 1, the dotted line shows the shape of the unworn (initial) surfaces of different types of tips.

There are other forms of worn surfaces of the tips of cutting inserts (for example, wear of only the upper end part, which occurs during radial indentation in the direction of the machined surface during fluctuations in the milling depth) and others.

2. Results and discussion

To study the nature of wear of rotary, replaceable cutting inserts, the author was the first to develop a stationary device for measuring the wear of these inserts [8], Figure 3.
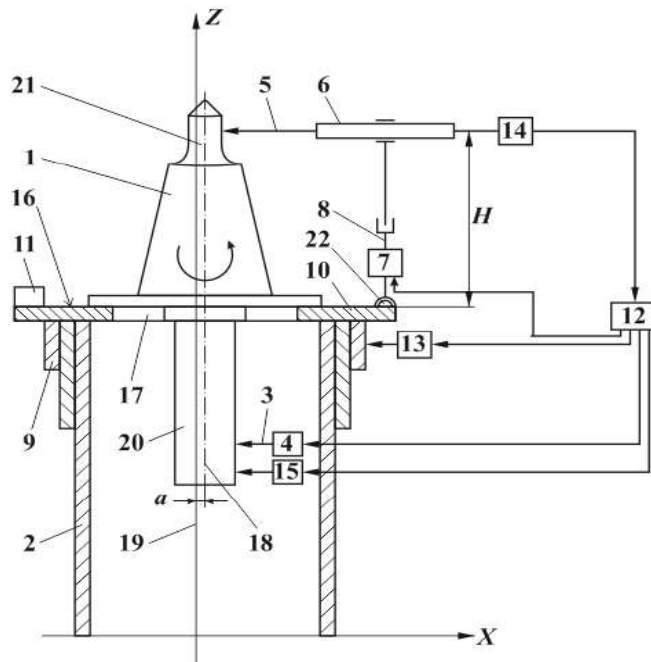
Fig. 3. - Device for measuring wear of replaceable rotary cutter inserts of milling drums

A device for measuring the wear of replaceable rotary cutting inserts 1 of milling drums contains a housing 2, a rotation drive of the cutting insert and a measuring transducer for determining the position and condition of the cutting edges of the cutting inserts.

In accordance with the proposed technical solution, the rotation drive is made prefabricated and consists of a three-detector (three-contact) clamping device with three circumferentially located cams 3 with autonomous drives 4 of their radial adjustment movements.

The measuring transducer of the position and condition of the cutting edges of the cutting inserts is made as a prefabricated device and consists of a contact tip 5 and a wide-range linear measuring transducer 6 interacting with it, for example, a linear inductosyn. The measuring transducer itself is installed on a stand 8 telescopically extendable from the drive 7 of vertical movements in such a way that the measuring transducer has the possibility of both installation radial movement and further precision measurement of deviations from roundness with fixed radial (along the X axis) and vertical (along the Z axis) positions of the measuring transducer.

The rack 8 of the measuring transducer is attached to the edge of a rotating disk 10 resting on the sleeve 9, which is additionally equipped with a counterweight 11 located opposite the rack 9.

The device additionally includes a microprocessor control device 12 and a rotation drive 13 of the sleeve 9 with the disk 10, while the output of the measuring transducer 6 is connected through the amplification-converter unit 14 to the input of the microprocessor control device 12, the output of which is connected to the input of the rotation drive 15 of the cutting insert 1, the inputs of the autonomous drives 4 of the radial adjustment movements of the cams 3, the input of the drive 7 of the vertical movements of the rack 8 and the input of the rotation drive 13 of the sleeve with the disk. In block 14 it is possible to visually control the amount of movement of the tip 5 per revolution of the cutting insert.

The device is used as follows.

The replaceable rotary cutting insert 1 to be measured is installed with its flat supporting surface of the head on the base surface 16 of the rotary disk 10, while the shank of the cutting insert 1 passes through the hole 17 in the disk, and its lower console part is at the level of the cams 3 and the rotation drive 15. Cams 3 synchronously moving towards the center are in contact with the cylindrical surface of the shank 20 of the cutting insert.

At the first stage, the axis 18 of the shank 20 of the cutting insert is aligned with the axis 19 of the rotary disk 10 (the algorithm for determining the center of the hole by three points of contact located at 120° intervals is not disclosed in the materials of this application). The existing mismatch in the position of the axes 18 and 19 is compensated by the drives of 4 radial adjustment movements of the cams 3 (the drives are built into each cam, are autonomously controlled and move independently of each other in the radial direction until the axes 18 and 19 are aligned, while the design of the drives in the materials of this application not disclosed). In Figure 1, the mismatch is indicated as "a".

After combining the axes 18 and 19, upon command from the microprocessor control device 12, the rotation drive 13 of the sleeve with the disk is activated, making one full revolution. In this case, the contact tip 5 comes into contact with the working (worn) surface of the carbide tip 21, and the linear inductosyn 6 records the actual radial movement of the tip 5 per revolution of the cutting insert. A circular diagram of the cross-section of the tip 21 at height "H" is reproduced.

Upon command from the microprocessor control device 12, the drive 7 periodically moves the measuring transducer in the vertical direction, reproducing the cross section at an intermediate local level. The totality of such circular patterns (processed in device 12) gives a real picture of the wear of the working surfaces (carbide tip 21 of the cutting insert).

Experience in operating milling drums with replaceable cutting inserts has shown that the nature of wear of the carbide tip 21 can be anything - from uniformly symmetrically correctly worn - to a one-sided worn position of the working edges of the tip, for example, when the cutting insert is blocked (jammed) in the tool holder, or when it is freely -rotational (with clearance) movement of the cutting inserts in the tool holder

Real objective data on tip wear allows us to develop recommendations for their restoration, for example, by surfacing.

The device is effective in operation, allows you to identify the degree of wear and the possibility of restoring each incisal insert. The procedure for diagnosing and measuring the wear of one replaceable cutting insert takes up to 3 minutes.

The rack 8 has the possibility of installation and/or adjustment angular movement within ±20° relative to the vertical position, for which a part-rotary spherical hinge 22 is introduced into the design of the device. Such actions are necessary for monitoring complex-profile cutting inserts, for example, cap-shaped ones in a flat design

Previously, the main design features of prefabricated cutters with round shanks were noted and the main factors influencing their wear were identified and technical means for measuring the wear of the cutting surface of cutter inserts of road milling machines were disclosed.

Let us highlight individual elements of wear of the cutting surfaces of cutting inserts: dimensional U1, height of the wear area U2 and kinematic profile of the wear area U3. In Figure 4, the positions indicate: 1 – the original unworn profile of the cutting surface of the cutting insert; 2 – kinematic profile of the wear area on the cutting surface of the cutting insert.

The kinematic profile of the wear area was proposed by the authors for the first time and was constructed based on the average of thirty repeated measurements on each of the measured sections Hi (using the drive 7 of the vertical movements of the rack 8, the pitch of the measured sections ΔH was set to 2.35 mm). For comparative analysis, the original unworn profile of the cutting surface of the cutting insert was also recorded (curve 1, Figure 4).
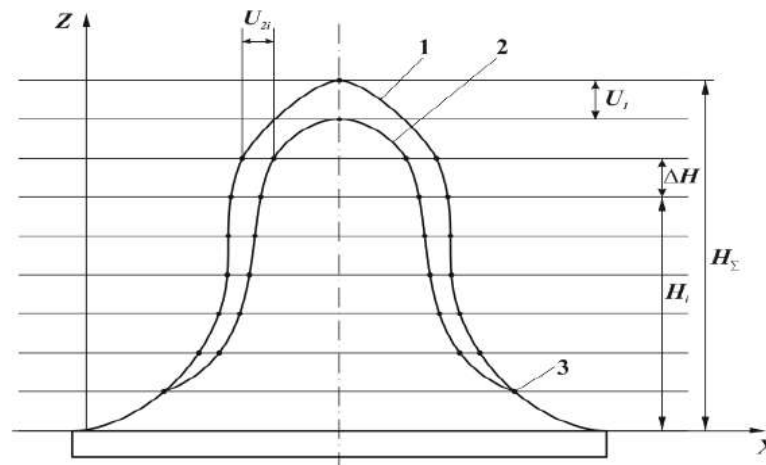

Fig. 4. - Profiles of cutting surfaces of cutting inserts

When the contact tip 5 (Figure 3) goes beyond the wear area, the readings of the measuring transducer 6 coincide (for the original (new) and used (worn) cutting inserts - point 3, Figure 4. Having fixed the boundary point of transition from the worn to the original (unworn) surfaces of the cutting surface of the cutting insert, all wear elements of the cutting inserts were found – U1, U2 and U3.

The result of measuring an individual wear element is taken to be the average of thirty repeated measurements [9], which previously included corrections to compensate for systematic errors:

$$\tilde{A} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

where x_i – the i-th measurement result;

n – number of repeated measurements (n=30).

The measurement error is assessed by indicating the confidence interval corresponding to a certain confidence probability value [10].

Confidence limits of random error are established for measurement results belonging to a normal distribution. In this case, to test the main hypothesis (belonging to a normal distribution), we use a composite criterion, according

to which [7] they determine that the relation $\tilde{d}$ at a significance level of 2% belongs to the interval $\left[d_{1-q_{1/2}}, d_{q_{1/2}}\right]$ and checking whether differences are exceeded $(x_i - \tilde{A})$ values $Z_{P/2} \cdot S$, where

$d_{1-q_{1/2}}$ и $d_{q_{1/2}}$ – quantiles of distribution [9, table 1];

$Z_{P/2}$ – upper quantile of the distribution of the normalized Laplace function corresponding to the probability P/2 [11, tables П-2];

S – estimate of standard deviation.

$\tilde{d}$ and S were calculated using the formulas:

$$\tilde{d} = \frac{\sum_{i=1}^{n}|x_i - A|}{n \cdot S^*}, \tag{3}$$

$$S^* = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \tilde{A})^2}{n}}, \tag{4}$$

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \tilde{A})^2}{n-1}}, \tag{5}$$

where S* is a biased estimate of the standard deviation.

Received values:

$$S^* = \sqrt{\frac{39,1}{30}} = 1,14 \text{ мкм}, \ S = \sqrt{\frac{39,1}{29}} = 1,16 \text{ мкм}, \ d = \frac{27,8}{30 \cdot 1,14} = 0,8129, \tag{6}$$

$$Z_{P/2} \cdot S = 2,33 \cdot 1,16 = 2,7 \text{ мкм}$$

confirm compliance with two conditions of the composite criterion:

$$0,7110 < 0,8129 < 0,8827$$

and that none of the differences $(x_i - \tilde{A})$ exceeds 2,7 мкм.

The above confirms that the distribution of the measurement results of the wear elements of the cutting surface of the cutting inserts corresponds to the normal distribution law.

Confidence limits ±ε of the random error of the measurement result are determined by the formula: ε = t•S, where t is the Student coefficient.

Since the proportion of systematic errors in the total measurement error of wear elements (dimensional wear) of the cutting surface of cutting inserts is small, in accordance with [10], the measurement accuracy can be expressed as:

$U1$ = 5,9 мкм, Δ from –2,4 мкм to +2,4 мкм, at P = 0,95.

The measurement accuracy of U_2 is determined by the measurement discreteness and the size of the measurement interval of the transducer 6, as well as the positioning accuracy of the rack 8.

When measuring U_2 we can distinguish:

1 – methodological error (error in fixing the moment of transition from worn to unworn cutting surface of the cutting insert Δ_1);

2 – instrumental errors (2-1 – manufacturing error of hemispherical surfaces of the part-turn hinge 22 interacting with each other – Δ_2; 2-2 – manufacturing error of guides for linear movements of tip 5 along the X axis and post 8 along the Z axis – Δ_3; 2-3 – manufacturing error of synchronously moved cams 3, including their radial displacement drive – Δ_4).

3 – counting errors (subject to visual reading in block 14), including the error due to parallax – Δ_5.

According to the patterns of occurrence, these errors are divided into systematic (Δ_2, Δ_3 and Δ_4) and random (Δ_1, Δ_5).

After certification of the device, systematic errors identified a priori were excluded.

Total measurement error $\boldsymbol{U_2}$: $\Delta_{\sum U_2} \in \Delta_1, \Delta_5$.

It has been experimentally established that the standard deviation of the total measurement error U_2 ($\sigma_{\sum U_2}$) does not exceed 2.9 μm.

The accuracy of measuring the kinematic profile of the wear area is influenced by the same factors as the accuracy of measuring U_2. It has been established that the variation of standard deviations based on the results of repeated measurements of cutter wear (at different levels of position of the rack 8) is insignificant, and the standard deviation of the total error in measuring the kinematic profile $\sigma_{\sum КП}$ does not exceed 3.5 μm.

For a comparative analysis of the device we developed with known similar ones, we used a criterion that directly reflects their main purpose - obtaining measurement information. Thus, from the point of view of information theory [11], the measurement accuracy is determined by the value (magnitude) of the entropy measurement error, calculated by the formula [8]:

$$\Delta = K \cdot \sigma = \frac{d}{2} \cdot \frac{n}{10^{\frac{1}{n} \sum_{\sigma=1}^{m} n_i \cdot \ln n_i}}, \tag{7}$$

where K – is the entropy coefficient depending on the type of error distribution law;
σ – root mean square value of measurement error deviation, μm;
d – width of the local interval of the distribution histogram, μm;
n – number of measurements;
n_i – number of measurements in the i-th column;
m – number of columns of the distribution histogram.

For the developed device, the value of the entropy measurement error was:

$$\Delta = \frac{30}{2 \cdot 10^{\frac{1}{30} \sum (2 \cdot 1,4313 + 5,9157 + 7,2248 + 8,5878)}} = \frac{15}{10^{0,819}} = \frac{15}{6,7} = 2,24 \text{ мкм}$$

$$K = \frac{\Delta}{\sigma_{30}} = \frac{2,24}{1,16} = 1,93$$

Conclusions

Based on the research carried out on the wear of the cutting surfaces of cutter inserts in road milling machines, the following conclusions can be drawn:

1) measurement of selected wear elements of the cutting surfaces of cutting inserts can be carried out with sufficient accuracy to solve practical problems;

2) the accuracy of measuring wear elements of the cutting surfaces of cutting inserts using the developed device, determined by the value of the entropy measurement error, is higher than the accuracy of measuring the same wear elements using known devices;

3) reduction of noise content in the general flow of measurement information was achieved due to the simplicity of the design and the absence of destabilizing complex-profile and kinematically dependent mechanisms and assemblies;

4) according to the results of the study, all certified cutting inserts are classified as suitable, repairable and not subject to restoration with the consumption of a minimum amount of additional material to create a restored wear-resistant coating using technological methods of surfacing on repairable cutting inserts.

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