



An investigation of the grinding wheel wear with the use of root-mean-square value of acoustic emission

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This paper presents the results of an investigation of the grinding wheel wear in a peripheral surface grinding process. During this investigation varying geometrical parameters of an active grinding wheel surface have been measured and the components of the grinding force and acoustic emission signal have been recorded. On the basis of these output quantities an analysis has been conducted of an acoustic emission descriptor's practicability, i.e. a root-mean-square (RMS) value, to characterize the cutting abilities of a grinding wheel in the time progress of its work. This article also presents a new energy coefficient, which determines the rate of grinding wheel wear in the form of a RMS value of acoustic emission signal falling on a contact surface of a grinding wheel. Moreover, the article presents some examples of a correlation between the root-mean-square value of acoustic emission signal and the surface roughness of a workpiece, which shows that the parameters of acoustic emission signal can be a useful tool to monitor the surface roughness during the grinding process.

Keywords: grinding process, grinding wheel wear, tool life, acoustic emission, root-mean-square

1. Introduction

The results of an abrasive machining process, which ensures the expected quality of the workpiece, depend on three elements: the kind of stock (material), grinding conditions and the geometrical state of the active flank of the grinding wheel (AFGW). On the assumption that in the manufacturing cycle only one material is being processed and that the parameters are constant, the only variable in the whole process is the geometry of grinding wheel surface, which is determined by the wear and glazing of the grinding wheel in the function of time.

Among the methods allowing wear evaluation, there are direct and indirect methods which describe the changes on the wheel surface in the grinding process. In industrial applications, where a great capacity and efficiency of manufacturing processes are required, the most widely applied are non-destructive methods, which additionally do not need to hold up the machining. That group includes indirect methods, which are based on an observation and analysis of effects which accompany the grinding process and which are greatly dependent on the properties of the grinding wheel tested.

Recently, an acoustic emission (AE) has been the method most commonly applied, but still in the phase of research. We are hopeful that this method will be useful for monitoring the adaptation grinding machining methods. Of the methods applied so far, this is the one which gives the most essential information about the phenomena occurring in the grinding zone. An AE contains in a global manner the phenomena occurring both in the tool and the workpiece. Especially, an AE signal provides information about the size and nature of deformations being the result of machining conditions and the grinding wheel wear.

The main purpose of this paper is to evaluate the grinding wheel wear and to determine the tool life based on the changes of geometric parameters, which describe the state of AFGW, and the output quantities of the grinding process: F_c (tangent force), F_n (normal force) and U_{RMS} (root-mean-square value).

2. Research methods

Experiments were carried out with a universal surface grinder OC3, model 3711. An aloxite grinding wheel designated by producer as T1 250×32×98 99A60J7V was used. The grinding process took place at a constant flow rate of cooling-lubrication fluid $Q_c = 3$ [dm³/min]. The samples were made from tool steel (NC10 60±2HRC) and machined at the following parameters:

- grinding wheel peripheral speed $v_s = 27.5$ [m/sec];
- tangential table feed speed $v_{ft} = \{4; 14; 24\}$ [m/min];
- axial table feed $f_a = 0.3$ [mm/stroke];
- working engagement $a_e = 0.03$ [mm].

The grinding wheel was dressed with the use of M1010 single point dresser with a 1.23 carat diamond tip and a vertical angle of 93–110° under constant conditions in 3 passes:

- grinding wheel peripheral speed $v_s = 18$ [m/sec];
- axial dresser feed speed $v_{fd} = 230$ [mm/min];
- dresser engagement $a_d = 0.05$ [mm].

Output parameters of the process were recorded with the use of the Kistler equipment. Grinding forces were measured with a 9251A dynamometer, and the acoustic emission signal, with a 8152A2 sensor. Signals 1 or 2 seconds long of the frequency of 25 kHz per channel were recorded in files for statistical data handling.

The surface roughness of workpieces was described by an arithmetic mean roughness value (R_a) of a profile with the use of a ME 10 surface analyzer.

The measurement of the edge wear of the grinding wheel was carried out by means of an axial profile mapping on a razor blade, which was placed along the grinding wheel axis and fixed in a holder on the magnetic chuck of the grinding machine. The edge wear of the grinding wheel was determined by means of the active grinding wheel length (B_{kr}), with the use of Measuring Processor MZ-3541 (a distance measuring computer system).

3. Analysis of results

The most synthetic measure allowing the grinding wheel cutting abilities to be evaluated is the ratio of cutting abilities of an active grinding wheel surface (K_{AFGW}) related to the geometric features of AFGW. In the numerator of the expression representing K_{AFGW} , there are the values directly related to the area of the machined layer cut, and in the denominator, the values connected with the characteristics of the AFGW wear:

$$K_{AFGW} = \frac{w_i \cdot a_{zsr} \cdot l_w}{l_s \cdot B_{kr}}, \quad (1)$$

where:

l_s – mean abraded length of abrasive grain vertex profile,

w_i – mean amount of abrasive grain vertices,

l_w – mean distance between abrasive grain vertices,

a_{zsr} – elementary cutting depth per one abrasive grain (i.e., an abrasive grain load in the grinding zone).

The changes of this ratio, determined on the basis of measurements in the function of the grinding wheel working time, are presented in Figure 1.

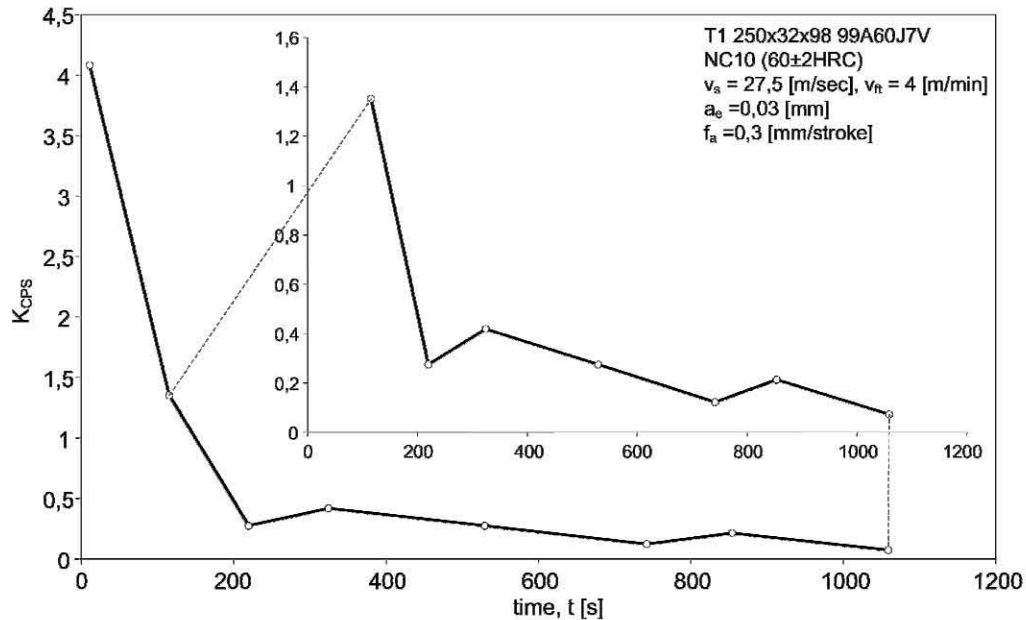


Fig. 1. The changes of the ratio of cutting abilities (K_{AFGW}) depending on the working time of the grinding wheel

Under given machining conditions, K_{AFGW} ratio represents a visible loss of cutting abilities of the grinding wheel after 1058 [sec] (about 17 [min]) of working time.

The analysis of the relationship between geometric parameters of AFGW, included in K_{AFGW} ratio, and the output quantities of the process in each case showed that the acoustic emission was characterized by a better correlation coefficient than any force component.

Figure 2 depicts the relationships between the output quantities (F_c , F_n , U_{RMS}) and the active grinding wheel length (B_{kr}) for one example of machining parameters.

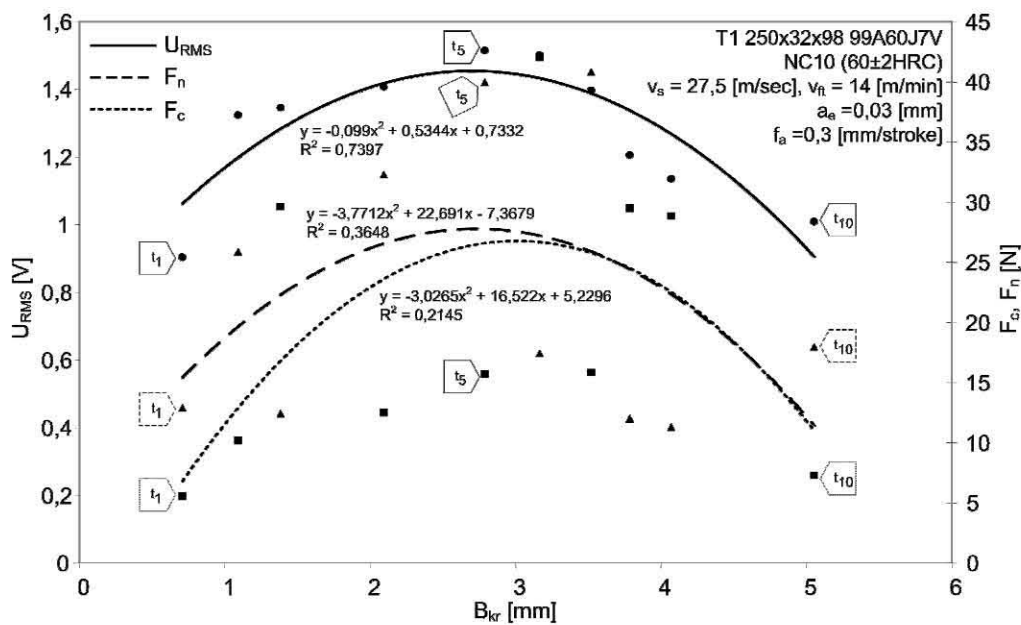


Fig. 2. The changes of the output process signals (F_c , F_n and U_{RMS}) depending on the active grinding wheel length (B_{kr})

In this case, the function $U_{RMS} = f(B_{kr})$, expressed in the form of quadratic polynomial below, has been distinguished from two other by the highest correlation coefficient: $R^2 = 0.74$ (the correlation coefficient has been determined in MS Excel program and presents the concentration ratio of the experimental data to the assigned curve):

$$U_{RMS} = -0.099 \cdot (B_{kr})^2 + 0.5344 \cdot (B_{kr}) + 0.7332. \quad (2)$$

The correlation between the components of the grinding force (F_c , F_n) and the changes of the analyzed geometrical parameters of an active grinding wheel surface is low.

Similar results have been obtained for the remaining parameters, which describe the geometry of the active grinding wheel surface, and are given in K_{AFGW} ratio. But for an increase of tangential table feed speed (v_{ft}), due to an escalation of the changes in the grinding zone, the correlations described become lower.

The relationships obtained between the tangent force (F_c), normal force (F_n), root-mean-square value (U_{RMS}) and the ratio of the cutting abilities of active grinding wheel surface (K_{AFGW}) are presented in Figure 3.

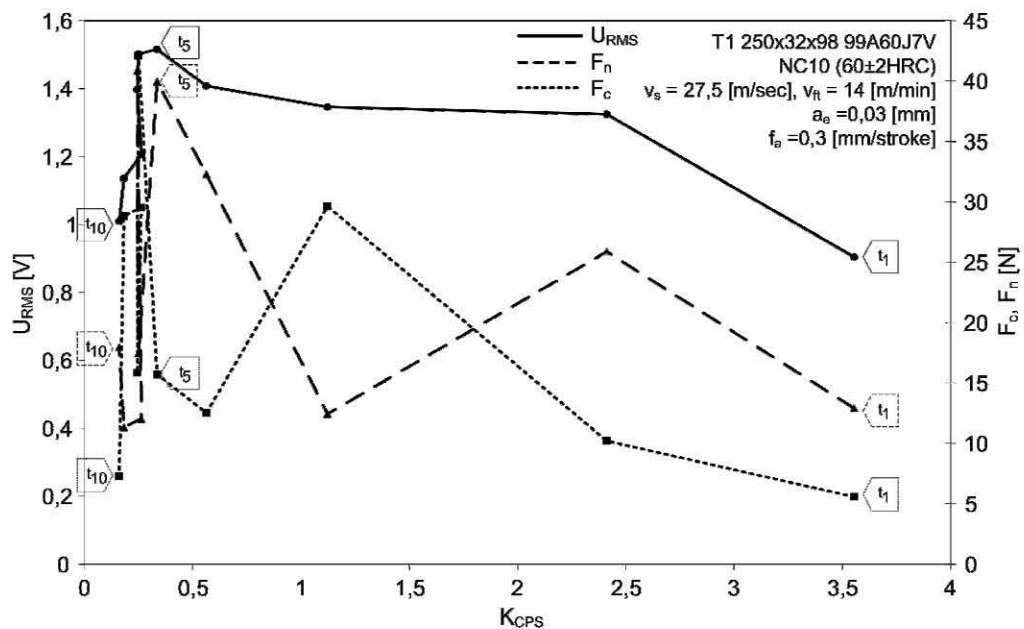


Fig. 3. The relationships between the output process values (F_c , F_n , U_{RMS}) and the ratio of the cutting abilities of active grinding wheel surface (K_{AFGW})

Along with the time of the grinding wheel work, its cutting ability diminishes to a certain value of the coefficient K_{AFGW} ($K_{AFGW} = 0.3355$; $t_5 = 190.97$ [sec]). In the period of the grinding wheel work (in the example analyzed), both components of the grinding force and the RMS increase. This increase in the values of the components of the grinding force and RMS was caused by an increasing quantity of grains in the grinding zone (as a result of B_{kr} increase – the contact length).

After the boundary value of the coefficient K_{AFGW} has been exceeded, the values of U_{RMS} , F_n and F_c signals are reduced considerably, since in this period of grinding wheel work ($t > t_5 = 190.97$ [sec]), the grain vertices begin to show an abrasive wear of the larger part, and the elementary cutting depth for one abrasive grain (a_{zst}) becomes shallower. For this reason, the coefficient K_{AFGW} has a small value and changes in a very narrow range (0.3355–0.1611) with a tendency to decrease.

The consequence of this is a significant decrease in the AE signal and in the values of the grinding force components. The changes of the AFGW geometry, caused by its wear, have a direct influence on the size of the mechanical and thermal loads of workpieces in the grinding zone.

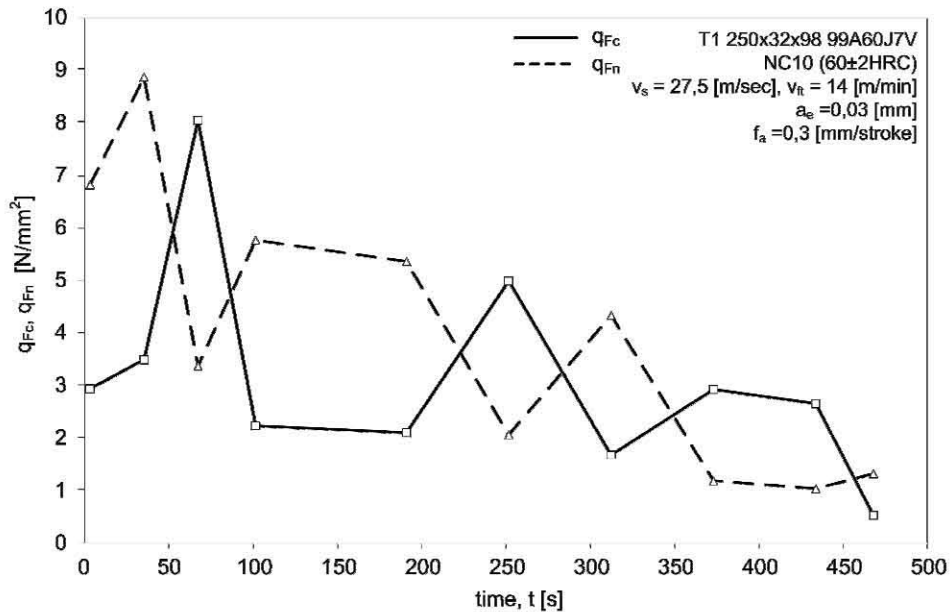


Fig. 4. The changes of grinding force components for the elementary surface in the grinding zone, depending on the working time of the grinding wheel

The loss of the cutting ability of the grinding wheel in the case analyzed occurred as a consequence of a considerable reduction of the elementary cutting depth for one abrasive grain in the grinding zone, due to the width enlargement of the contact zone (B_{kr}) and an increase in the quantity of active grains. The relationships between the values of the components of the grinding force per an elementary surface of the grinding zone (Figure 4) have a visibly diminishing tendency. These quantities are given below as the coefficients of an elementary loading of the grinding zone with the contiguous and normal grinding force.

Besides, a new energetic coefficient has been proposed. It describes the cutting ability of the grinding wheel by the root-mean-square value of the acoustic emission signal (U_{RMS}) per an elementary surface of the grinding wheel contact with the workpiece ($B_{kr} \cdot L_{\psi}$):

$$q_{Fc} = \frac{F_c}{B_{kr} \cdot L_{\psi}}, \quad (3)$$

$$q_{Fn} = \frac{F_n}{B_{kr} \cdot L_{\psi}}, \quad (4)$$

$$q_{RMS} = \frac{U_{RMS}}{B_{kr} \cdot L_{\psi}}, \quad (5)$$

$$L_{\psi} = \sqrt{d_s \cdot a_e}, \quad (6)$$

where:

L_{ψ} – the length of grinding zone contact with workpiece,

d_s – the external diameter of grinding wheel,

a_e – working engagement of grinding wheel.

The nature of the changes of the coefficient q_{RMS} in the function of working time of the grinding wheel in the case selected is presented in Figure 5.

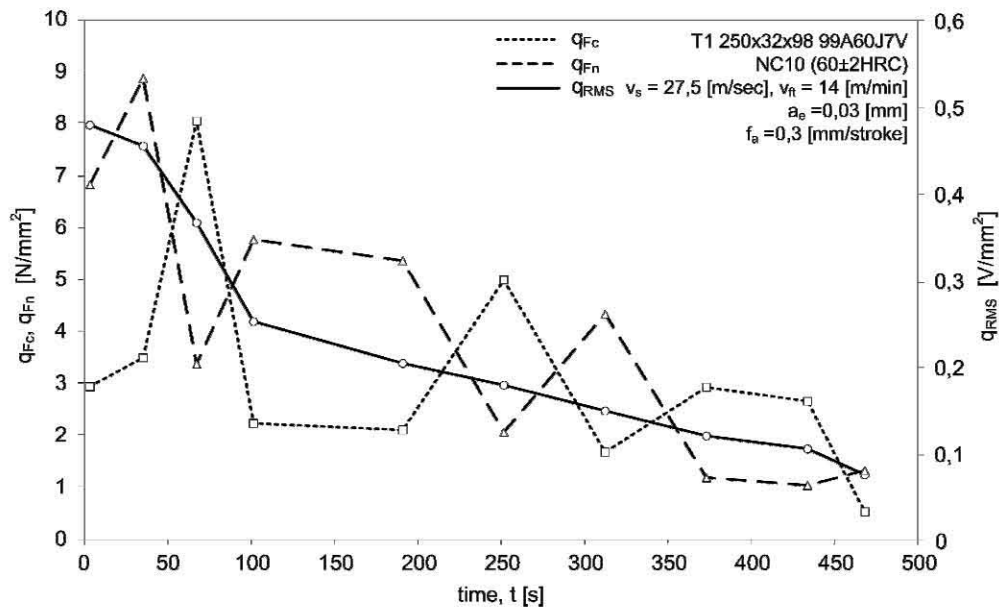


Fig. 5. Changes of q_{RMS} values depending on the grinding wheel working time

The lowest values of the coefficients q_{Fc} and q_{RMS} were measured after the time t of the grinding wheel work equal to 468 [sec] (ca. 8 [min]). In this case, the working conditions of the abrasive grain in the grinding zone were not suitable for initiating a self-sharpening process and for appearing new microvertices on active grinding wheel surface.

There was only an abrasive wear of grain vertices, and the final effect of this was grinding burn on the machined surface and the changes in the surface microhardness. The grinding wheel lost its cutting ability.

Based on the above, the changes of q_{Fc} and q_{RMS} coefficient allow the cutting ability of the grinding wheel to be unambiguously determined; besides, they can be more useful parameters than other parameters. These coefficients can be used as the criterion of the grinding wheel durability.

The correlations between the changes of q_{Fn} , q_{Fc} and q_{RMS} coefficients and the ratio of cutting ability of active grinding wheel surface (K_{AFGW}) are presented in Figure 6.

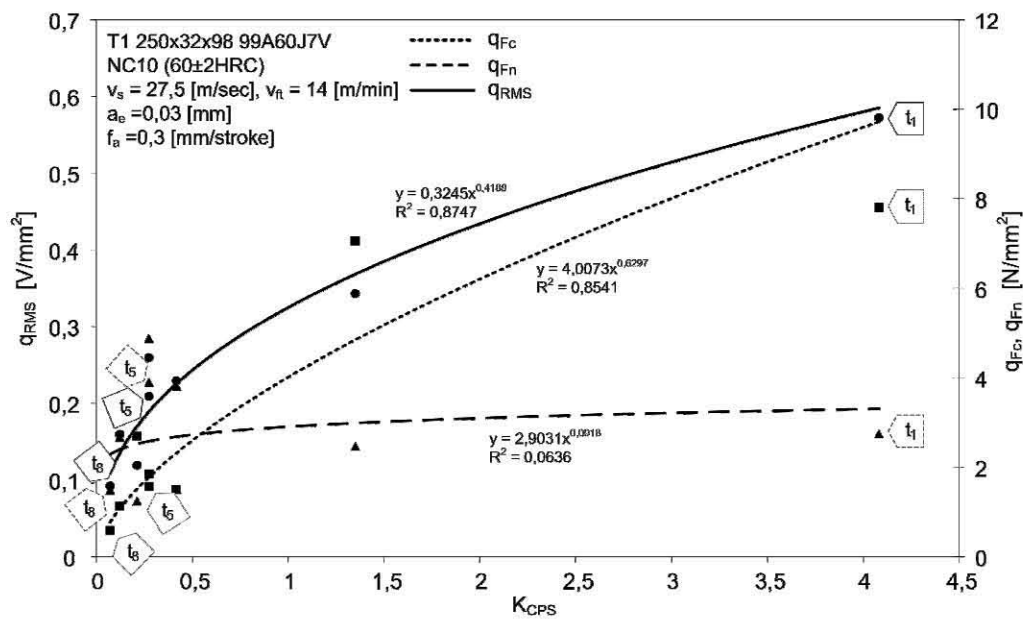


Fig. 6. The correlations between the changes of q_{Fn} , q_{Fc} and q_{RMS} coefficients and the ratio of the cutting ability of active grinding wheel surface (K_{AFGW})

Under conditions of our investigations the dependence q_{RMS} had the highest correlation ($R^2 = 0.8747$). It was approximated by the following function:

$$q_{RMS} = 0.3245 \cdot (K_{AFGW})^{0.4189}. \quad (7)$$

Based on the wear evaluation, as Kannatey-Asibu and Domfeld [2] proposed, in the present investigations the parameters of beta distribution were used to analyze the root-mean-square values of acoustic emission, on the assumption that this signal shows a beta distribution.

$$r = \frac{\overline{U}_{\text{RMS}}}{W_{\text{RMS}}} (\overline{U}_{\text{RMS}} - (\overline{U}_{\text{RMS}})^2 - W_{\text{RMS}}), \quad (8)$$

$$s = \frac{1 - \overline{U}_{\text{RMS}}}{W_{\text{RMS}}} (\overline{U}_{\text{RMS}} - (\overline{U}_{\text{RMS}})^2 - W_{\text{RMS}}), \quad (9)$$

$$\text{kurtosis} = 6 \cdot \frac{(r-s)^2 \cdot (r+s+1) - r \cdot s \cdot (r+s+2)}{r \cdot s \cdot (r+s+2) \cdot (r+s+3)}, \quad (10)$$

where:

W_{RMS} is a variance of the signal U_{RMS} ,

r, s are the beta-distribution parameters.

The kurtosis is a normalized fourth-order centre moment, which appears to be a useful measure.

It became evident that the changes of kurtosis for the RMS value of acoustic emission (U_{RMS}) are dependent on the grinding wheel wear, and this relation increases together with wear stages (Figure 7).

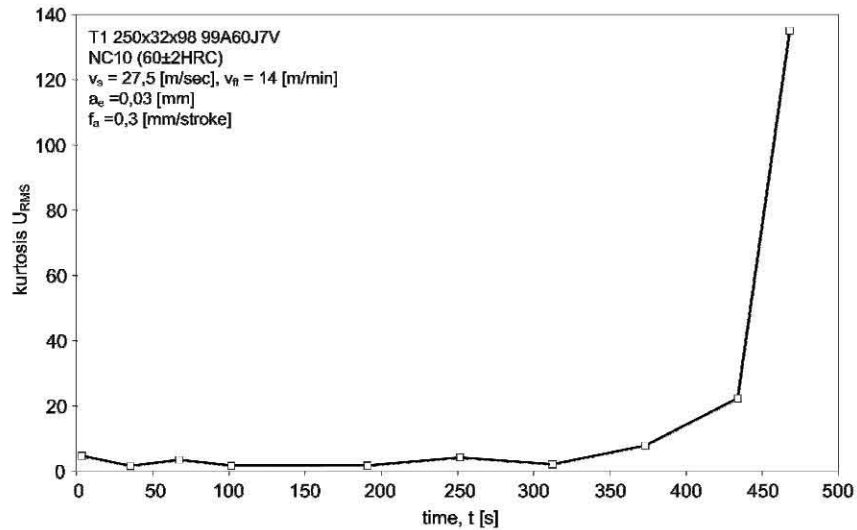


Fig. 7. Loss of the cutting abilities expressed by the kurtosis of U_{RMS}

The nature of the kurtosis changes of the signal U_{RMS} shows an abrupt increase of its value when the process is stopped because of the grinding burns appearing on the machined surface. This testifies to substantial changes in the CPS geometry, a loss of its cutting ability and a considerable thermal influence of the grinding wheel on the machined surface, which results in grinding burns.

So, the kurtosis parameter can play a major role in revealing the changes in the process producing the surface (e.g., tool wear).

The changes in the AFGW geometry, caused by its waste, have a decisive effect upon the results of the grinding process estimated in this article based on the measurements of the roughness of the grinding surface (R_a).

The reduction of an average height of abrasive grain vertices, the appearance of microvertices on grains and the reduction of an average elementary cutting depth for one abrasive grain (a_{zsr}), and indirectly the smaller cutting abilities of the grinding wheel, are due to a decrease in the grinding surface roughness.

The changes in the surface roughness of grinding workpiece in the function of grinding force components and in the function of root-mean-square are presented in Figure 8.

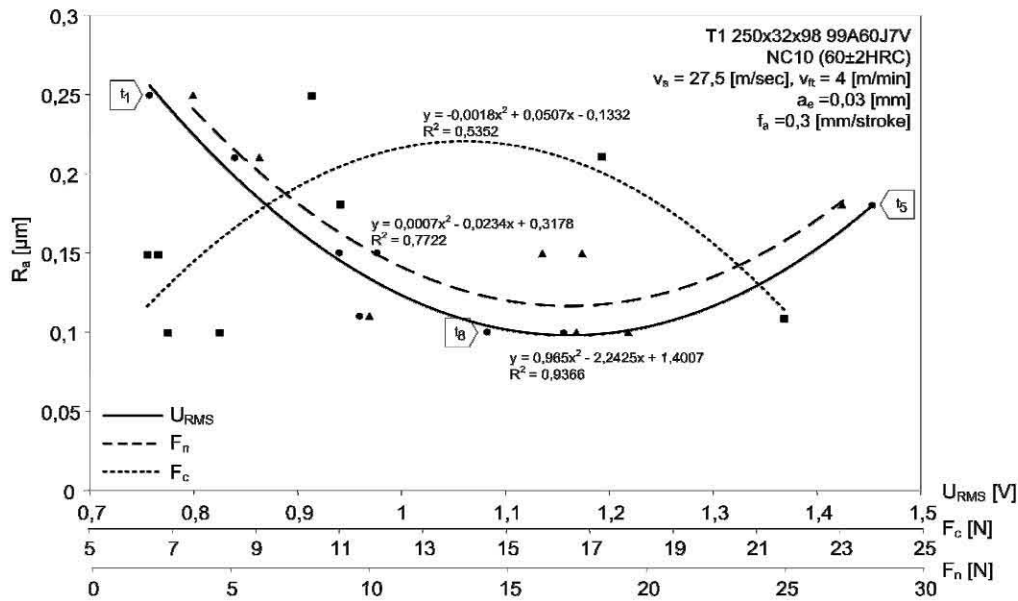


Fig. 8. The correlation between the roughness of the machined surface (R_a) and the registered output quantities (F_c , F_n , U_{RMS})

The highest correlation, under the working conditions studied, was for $R_a = f(U_{RMS})$ expressed by the function with the correlation coefficient $R^2 = 0.9366$:

$$R_a = 0.965 \cdot (U_{RMS})^2 - 2.2425 \cdot (U_{RMS}) + 1.4007. \quad (11)$$

Together with the tangential table feed speed increase (v_{ft}), the correlation coefficient of function $R_a = f(U_{RMS})$ became smaller, which was the result of more significant dynamic changes in the grinding zone along with a load increase of grinding grains.

4. Summary

The investigations into the changes of geometrical parameters of the active grinding wheel surface (AFGW) and the output quantities of the grinding process (F_c , F_n and U_{RMS}) show clearly that due to the complexity of the grinding wheel wear process, in evaluation of the grinding wheel durability, the most useful are geometrical parameters of AFGW defined by the coefficient of cutting ability (K_{AFGW}) and energetic quantities defined by the coefficients q_{RMS} , q_{F_c} representing an elementary load of the grinding zone.

The best correlation shows the RMS value of the acoustic emission, which is the measure of the energy emitted by the material as a result of deformations occurring in it. Apart from this, the signal received from the whole machined material volume captures the total influence of the results of the wear of abrasive grains and AFGW, which have a direct influence upon the size of deformations in the workpiece.

That is why the coefficient q_{RMS} shows a very high correlation with the ratio of the cutting abilities of active grinding wheel surface (K_{AFGW}) related to geometric results of AFGW wear and a kinematic nature of grain working conditions.

Therefore, the root-mean-square of the acoustic emission may be sufficient to evaluate the cutting ability of the grinding wheel without measurements of geometrical changes of the AFGW and without breaks in the process. The results of the investigations show that the kurtosis of U_{RMS} allows us to evaluate the wear progress, or to notice the destructive wear, or to detect grinding burns on the machined surface.

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Badanie zużycia ściernicy z wykorzystaniem wartości skutecznej sygnału emisji akustycznej

Przedstawiono wyniki badań nad zużyciem ściernicy elektrokorundowej w procesie obwodowego szlifowania płaszczyzn. Mierzono zmieniające się parametry geometryczne czynnej powierzchni ściernicy (CPS), rejestrowano wartości składowych siły szlifowania oraz sygnał emisji akustycznej. Na podstawie tych wielkości wyjściowych procesu przeanalizowano przydatność deskryptora emisji akustycznej (EA), jakim jest wartość skuteczna (RMS), w scharakteryzowaniu zdolności skrawnych ściernicy w miarę czasu jej pracy. Zaprezentowano także nowy współczynnik energetyczny, określający stopień zużycia ściernicy, w postaci wartości skutecznej sygnału emisji akustycznej przypadającej na powierzchnię kontaktu ściernicy. Ponadto przedstawiono przykłady korelacji wartości skutecznej sygnału emisji akustycznej z chropowatością powierzchni szlifowanego przedmiotu, które wskazują na możliwość wykorzystania sygnału EA i jej wartości skutecznej (RMS) do monitorowania chropowatości powierzchni szlifowanej.