Image Analysis to Optimize Calculations of Grinding Modes

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Abstract. Modeling helps to investigate and analyze the interrelationships of grinding parameters as a single system. The article describes a computer model of the surface layer of a grinding wheel, taking into account the cutting modes and characteristics of the circle. The subsystem of the surface layer of the grinding wheel is the most important subsystem of grinding, since it connects the main characteristics of the circle with the cutting modes and with the parameters of the workpiece. The output characteristics of the model are the parameters of the working layer with a height of several micrometers, in which micro-cutting occurs. It is impossible (or very difficult) to obtain them by conducting full-scale experiments, since the processes are instantaneous, and the cutting elements have micro-dimensions. This problem was solved by creating a simulation stochastic model based on the geometric representation of the surface layer, which clearly displays the result. The analysis of the image of this model allowed us to numerically describe the output parameters of cutting. The article offers a faster algorithm for analyzing the image of the simulation model of the surface layer. It is carried out over a matrix containing numerical information about the projection of the surface layer, the main parameters of each single slice are calculated, and only after that the result is displayed on the graphic screen. To simulate a single grinding mode, it is necessary to repeat the process of “image creation - image analysis– output of results” hundreds of times until a stable state is reached. The use of the algorithm in an automated system will allow you to create a system for automatically searching for optimal grinding modes, as well as to derive analytical dependencies of cutting modes on input parameters, for example, on the parameters of the circle and the workpiece.

1. Introduction. Problems of the mode-tool equipment of the grinding operation
An example of how image analysis is necessary to study the relationship of parameters is the modeling of a grinding operation.
In practice, there is a situation when the parameters of the grinding wheel are known, it is necessary to realize its potential cutting ability, assign the maximum possible cutting modes. This will increase the efficiency of the grinding operation [3].

It is known that the grinding process is influenced not only by the modes, but also by the characteristics of the processed material and the grain material, bundles, processing scheme, geometric dimensions of the tool, etc. [3,4]. In addition, grinding differs from other metal-cutting operations mainly by the unstable geometry of the cutting edges [4]. Cutting here occurs due to mass micro-cutting-scratching with the tops of the grains [2]. Since the geometry of the grains and their location in the surface layer are random, the cutting forces of each grain are random, the number of ligament bridges holding the grains is random, the strength of the grains is random. It is difficult to create a single analytical model of the grinding process due to the large number of parameters. The most difficult issue is to determine the number of cutting grains, as well as their geometric parameters that affect the cutting performance. Conducting field experiments is difficult due to the small grain sizes, high temperatures in the cutting zone and the transience of the process. Therefore, previously [4] grinding modes were assigned based on average values, without taking into account the best options. Computer modeling makes it possible to apply a probabilistic and statistical approach, link all the main parameters of the system, take into account complex and diverse processes that occur during grinding, and take into account their impact on the performance of the operation [1]. To date, several such models have been proposed [5-20]. They differ in the degree of elaboration of each relationship, contain a different description of the parameters.

Scientists of Kurgan University [1,2] have previously proposed the creation of a simulation model of the interaction of the grinding wheel with the cutting surface to find the optimal mode-tool equipment for the grinding operation. A graphic image was created in the model, on which the projections of the vertices of the abrasive grains of the grinding wheel were drawn in turn in an orderly manner, rotated at an angle that takes into account the cutting modes [1]. The calculation of the cutting forces, the forces of grain retention by the bundle, the strength of the grains allowed us to take into account the fact that when cutting, the most protruding grains are removed, the cut area of which is large, thereby previously invisible new grains open and enter the cutting process. After scanning, the visible information was processed: the affiliation of each color pixel of the image to the grain was analyzed, its number was determined, as well as all output parameters: the number of cutting grains, the cut area, the length of the working edges, the average and maximum depth of the cut, the overlap coefficient, the size of each wear site and the total wear area, the cutting force on each grain and the total force, etc. However, the bottleneck of this model was low performance. Reading graphic information from redrawn screens showing step-by-step changes slowed down the entire automated system and made it difficult to conduct a large number of experiments. The main imperfection is in the slow graphical analysis of information, which is especially noticeable when sequentially building-redrawing to calculate a stable state. To obtain the results, it is necessary to repeat the scanning of the graphic image until the number of cutting grains is stabilized. In research work, such states must be obtained hundreds of times before the desired combination is determined.

2. Architecture of the simulation model of the surface layer: general information

At the first stage of modeling, a structural and functional model of the object is developed, then it is supplemented with logical and mathematical connections. The object of modeling in this case is the model of the grinding operation as a large technical system. For the main characteristics of the most significant subsystems, the following were selected: for an abrasive tool – the grain size and their brand, which characterizes the strength of the grains, the strength of grain retention by a bundle, the volume fractions of grains, bundles, pores in the circle; cutting modes – the speed of the circle and parts, feed, cutting depth; The cutting process is the cutting force on a single grain, the total area of grain wear on a single surface [3].

An important element is the shape and size of the cutting grain. It was previously established that for practical calculations, it is possible to take the projection of the grain shape in the form of an
ellipse, the average diameter \( dz \) of which depends on the grain size [1]. Based on the method of obtaining grains, the size of the grain diameter obeys the normal law, the spread of which can be determined according to GOST R 52381-2005. The model uses a generally accepted formula for obtaining a normal distribution from a uniform one, with coefficients selected for the distribution:

\[
\sum_{k=0}^{11} \text{rnd}(dz) = \frac{Kiz \cdot dz \cdot kiz}{0.1} + 1
\] (1)

The second parameter of the ellipse is the length \( lz \). The ratio of the two length to the diameter of the grain is usually called the isometry coefficient of the \( Kiz \) grain, it characterizes the material of the grains. It was previously shown that its maximum value can be assumed to be 1.5 [1]. However, we should take into account the fact that the grains can be randomly located in a circle (Figure 1), so in the model, we will set a random length value for each grain:

\[
Kiz := 1.5
\]

\[
kiz := 1 + \text{rnd}(Kiz - 1)
\]

\[
lz := dz \cdot kiz
\]

Figure 1. The random shape of the grains of the grinding wheel forms a random slice.

It is generally accepted that the length of the cut with one grain per revolution of the circle is equal to the length of the arc of contact \( Lk \) of the abrasive wheel with the workpiece (Figure 2) and is determined by the expression [3]:

\[
Lk := (Dekv \cdot t)^{0.5}
\]

(4)

where \( t \) is the grinding depth, mm; \( Dekv := Dkr \cdot \frac{d_{det}}{Dkr + d_{det}} \) - the equivalent diameter of the circle and the part; the sign "+" - for the round outer, "-" - for the inner, \( d = \infty \) - for flat grinding; \( Dkr, d_{det} \) - the diameter of the circle and the part, respectively.

The next important parameter is the angle of "attack", which connects the parameters of the cutting mode and the characteristics of the circle [4]:

\[
w := 2 \frac{vd}{vkr} \left( \frac{t}{Dekv} \right)^{0.5}
\]

(5)
The order of creating a model can be described as follows. A window of a given width (a few mm is enough for studying) of infinite length is set. It generates from 2000 to 5000 coordinates of the centers of abrasive grains, taking into account the average grain density in a circle of 6.06 pcs/mm² for an average $dz = 0.4$ mm. The grains have a normally distributed value of the diameter and the isometry coefficient, as well as a random offset from each other by a distance between the centers of at least $dz$. Each grain is described as a projection of the vertex of an ellipsoid on a vertical plane and is written to a matrix of 1 and 0, where 1 is the image. A common matrix is created, taking into account the location of the top point of the grain in the coordinate system, the matrix of each grain-ellipse is transferred to it, filling in the grain number pixel by pixel where 1 is written. Each subsequent grain puts its number on top of the previous ones. This means that if the grain covers a certain area with its shadow (projection), then its number is written in each pixel on this area. This results in a common matrix of all grain projections.

The created array of grain vertices is rotated by the angle of "attack" $w$, taking into account the influence of cutting modes (5). Visible grains – active, cutting. Invisible grains do not leave a trace on the treated surface. The resulting digital matrix of projections of the maximum cross-sections of active grains is drawn on the screen (Figure 3).

In the matrix, the current characteristics of the working layer at the length of the contact arc are calculated using simple arithmetic operations: the number of visible (cutting) grains, the percentage of...
visible grains, the average and maximum cut areas, the average and maximum cut height, the average width, the average length of the cutting edges. To calculate the average and maximum length of the wear site, a certain level is set, according to which all grains are cut, grain wear is simulated. To avoid cauterization on the treated surface, a restriction is introduced: the total wear surface area cannot exceed 4% of the total area under study [4].

3. Results of the study
The new model also differs in the multicolored vertex projections. Each grain number (on the length of the contact arc) in the model is assigned its own number and color. Experiments have shown that the matrix size of 800 x 400 pixels describes the working layer quite well. The matrix is processed by grain numbers. Figure 4 shows a screen with sharp grains at the run-in stage. Figure 5 illustrates the working layer with worn grains.

Figure 4. The result of the model operation at the run-in stage, sharp grains.

Figure 5. The result of the model taking into account the wear of the grains.

Figure 6 shows the results of the study showing the dependence of the $S_{average}$ cut area(a), the number of $N_{visible}$ cutting grains collected along the length of the contact arc, (b) and the grain overlap coefficient on the angle of "attack" $K_{overlap} = N_{visible} / N$. It can be seen that all dependencies can be described by a linear law.
The analysis of experimental data shows that with an increase in the ratio of the speed of the part to the speed of the circle, the cut area increases, the grain overlap coefficient decreases, i.e. more efficient cutting is achieved, although the number of cutting grains itself decreases. This means that for each specific grinding operation (certain conditions), it is possible to find the maximum possible cutting modes in which the grinding wheel will more fully reveal its cutting potential.

To this model, you can add any model for calculating cutting forces, holding forces, and the strength of each cutting grain, since it is universal. Longer experimental studies will allow you to create analytical dependencies.

4. Conclusion
The relevance of the study is due to the complexity of describing the working layer of the grinding process. In this regard, this article is aimed at creating a single simulation model. The capabilities of modern computers made it possible to create a computer model of the grinding process and analyze the image of the working layer. It is based on theoretical foundations, so it will allow you to show reliable results. With the help of the obtained model, it is possible to determine the optimal modes for specific conditions of the grinding operation and automate the process of their appointment.

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**Acoustic Emission Signal and Grinding Wheel Wear**

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