Method of calculating of optimal grading modes with regard to forming of grinding surface roughness

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Abstract. The factor affecting the grinding time and surface quality are considered. The methods of calculating the optimum cutting conditions for the grinding operations are suggested.

1. Introduction
One of the promising directions of development of active control systems is their use in automated systems for surface quality control.
In the grinding process there is a gradual decrease in the size of the grinding wheel and the change in cutting ability. On linear dimensions processing error using active control devices sized circle wear does not affect in many cases. However, the change in cutting ability of the wheel during its resistance causes a change of the cutting forces and hence to the appearance of various power and thermal deformations of the system, thus increasing the roughness of the processed surface [1; 2; 3, 4].
Thus, the calculation of the optimal grinding modes should be based on models that include roughness parameters $RA = f(X)$ (where $X$ – cutting modes).

2. Restrictions selection
Ground surface roughness height is largely determined by the grinding modes. To decrease the roughness is needed to increase grinding speed, radial and tangential innings decrease [5; 6; 7; 8; 9]. Dependence of the parameter $RA$ of the ground surface on the wheel speed $vS$, radial feed $SR$ and tangential feed velocity $vK$ are shown on the fig.1 [10].

Fig.1. Dependence of the roughness parameter $RA$ on grinding modes
Ideally, the high processing speed reduces the manufacturing parts time. However, due to the heating of the surface layer may occur the microhardness structure decrease due to the changes (release) of the metal in the surface layer. Such a reduction of microhardness affects the performance properties of the parts adversely.

Grinding burn marks are also rude defects in the surface layer of the metal. These defects are formed when grinding is performed at unacceptably high cutting modes.

The determination of optimal grinding mode is necessary to ensure high performance, the accuracy and quality of the ground surface at the lowest cost of production.

Since cutting modes is closely correlated with the majority of quality processing indicators, the calculation of grinding modes should be carried out taking into account the conditions for obtaining roughness surface no more than a given.

Formulation of any optimization problem begins by defining a set of independent variables, and typically includes conditions that characterize their acceptable values. Thus, in solving the problem of minimizing processing time $T_{PR}$, is necessary to solve:

$$T_{OPT} \rightarrow \min,$$

under the constraints:

$$R_A \leq R_{AMAX},$$

$$v_{SMAX} \leq v_S \leq v_{SMAX},$$

$$S_{RMIN} \leq S_R \leq S_{RMAX},$$

$$v_{KMIN} \leq v_K \leq v_{KMAX}.$$  \hspace{1cm} (2)

Criterion restrictions are selected from the following considerations:

- Surface roughness parameters are selected according to the requirements of the design documentation (1);

- Rotation speed $v_S$ circle should be the maximum considering the drive possibilities of the machine, but no more than $v_{SMAX}$, in which the heating surface can lead to a reduction of parts surface microhardness (dispensing), as well as the strength of the abrasive tool;

- Radial feed (allowance) $S_R$ should be greater than the depth of the defective metal layer formed on the previous operations and sufficient to correct the residual error of the part shape;
- Tangential flow $v_k$ must be maximum to reduce the processing time, but not more than the value at which there are power and thermal deformation of the items, and as a consequence an roughness increase in parts.

In constructing a mathematical model of a particular grinding process is necessary to know the numerical values of the parameters and the patterns of their changes under varying process conditions. Since the grinding process is characterized by great variability of parameters and processing conditions, the reliable data can only be obtained by experimental study of a particular process.

To improve the quality in the existing technology is necessary to carry out experiments to assess the effect of the various factors on surface roughness and conditions using the experimental design method. As the variable factors are taken tangential velocity value $v_k$, radial feed $S_R$, tangential flow $v_S$. For a given process it is possible to take the additional parameters $X_i$, such as the properties of the abrasive tool, coolants etc. Output parameters are processing time $T_{PR}$ and $R_A$ processed surface roughness.

As an entry-level are selected the technological factors values corresponding to the normal process modes. Variation interval is chosen, on the one hand, several times to be fitted into the range of variation of the variable factor, and on the other hand would allow to ignore the errors of the executive and measurement instruments and mechanisms [11].

On the basis of the experiment a model of surface roughness depending on factors is constructed:

$$R_A = f(v_k, S_R, v_S, X_1, ..., X_m).$$

Substituting into the formula instead of the $R_A$ the maximum allowable roughness inherent in the design documentation and taking into consideration the restrictions (2), we obtain the range of the cutting parameters on the basis of the desired quality parameter.

Taking into consideration the limitations imposed by the machine characteristics (maximum and minimum speed drives, etc.), we obtain the range of the cutting modes parameters change:

$$\begin{align*}
v_{S\text{MIN}} \leq v_S & \leq v_{S\text{MAX}} \\
S_{R\text{MIN}} \leq S_R & \leq S_{R\text{MAX}} \\
v_{K\text{MIN}} \leq v_k & \leq v_{K\text{MAX}}
\end{align*}$$

Here, the index «D» means allowable cutting conditions based on the required surface roughness $R_A$ and based to the restrictions (2).

Minimization problem. Processing time is determined by three factors: the tangential velocity $v_k$, radial feed $S_R$, tangential flow $v_S$.

Using method of mathematical planning of the experiment we will get a model to calculate the processing time depending on the cutting conditions:

$$T_{DSP} = f(v_k, S_R, v_S)$$
Thus, the problem of minimizing the processing time is reduced to solution:

\[ T_{\text{OPT}} = f(v_K, S_R, v_S) \rightarrow \min \]

under the constraints (3).

Most often, the model is described by continuous functions of second or third order \[12\], and therefore can be applied to optimize the gradient method.

\[
\text{gradf}(v_K, S_R, v_S) = \begin{bmatrix}
\frac{\partial f(v_K, S_R, v_S)}{\partial v_K}, & \frac{\partial f(v_K, S_R, v_S)}{\partial S_R}, & \frac{\partial f(v_K, S_R, v_S)}{\partial v_S}
\end{bmatrix}
\]

To find the minimum of the function \( T_{pb} \) vector \( g \) of unit length of search direction is determined:

\[
g = -\frac{\text{gradf}(v_K, S_R, v_S)}{\left| \text{gradf}(v_K, S_R, v_S) \right|}
\]

3. Conclusion. Solution of the problem of minimizing the processing time with the constraints of the desired surface roughness allows you to get the optimum grinding modes, which increases tool life, reduces the processing time and reduces defects output.

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Innovative Mechanical Engineering Technologies, Equipment and Materials-2013 IOP Publishing
IOP Conf. Series: Materials Science and Engineering 69 (2014) 012044 doi:10.1088/1757-899X/69/1/012044
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