MACHINE SCIENCE

ISSN: 2227-6912
E-ISSN: 2790-0479

2024, № 2 Pages 59-64

IMPROVING SURFACE QUALITY IN FLAT GRINDING OPERATIONS USING MODERN TECHNOLOGICAL METHODS

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https://doi.org/10.61413/XTTO3306

Abstract: The article analyzes general aspects of the flat grinding process, analyzes the main features, provides a technological solution to the issues of surface and surface layer formation, dimensional and shape accuracy. The main input parameters affecting quality are machine parameters, processing methods, grinding wheel and abrasive grain characteristics, cutting mode elements, etc. The degree of influence of factors, as well as strength and hardness indicators obtained from the physical and mechanical properties of the part material, in general, is analyzed and the pattern of quality formation is determined. Similarities and differences in operations performed on the side and periphery of the grinding wheel during flat grinding, as well as functional dependencies of productivity and quality indicators are determined. It is determined that to select optimal processing modes for flat grinding operations, it is considered necessary to control process parameters, use machines controlled by a modern digital program, and modernize other process equipment in terms of increasing quality. In the article, the general aspects of the flat grinding process are analyzed, the main features are analyzed, the technological solution of the issues of surface and surface layer quality formation, size and shape accuracy is given.

Keywords: *grinding, abrasive grain, hardness, roughness. dimensional accuracy, productivity*

Introduction.

In all areas of modern machine engineering, there is a high demand for parts with precise accuracy and quality. Achieving this quality requires the application of advanced technological processes, which is of particular importance. In this regard, abrasive machining operations, as a finishing process, ensure the required quality of machine parts. High-quality indicators not only involve improving the design, metallurgical, and metrological parameters, but also depend on the proper implementation of technological processes themselves. It should be noted that the demands of time are constantly increasing, and manufacturers are required to adopt more advanced machining methods, achieve high productivity, and ensure the profitability and competitiveness of enterprises, as well as meet environmental, occupational safety, and other conditions.

For many machine engineering companies, the grinding operation is considered the final finishing process. Through the application of this operation, high-precision machine parts with circular, flat, and complex surfaces are processed, and both dimensional and shape accuracy, as well as surface layer quality, can be brought to the required level.

Recently, more attention is being given to the grinding operation, and its technological capabilities are continuously being improved. The main aspect of this process is the possibility of automating and mechanizing these operations. In most manufacturing industries, especially in precision machining, the quality application of functional connections on planar surfaces, in line with the demands of time, is being increasingly utilized [1, 2]. However, there are still several shortcomings in the grinding process, which is used to obtain precision planar surfaces with high accuracy, both in terms of micro-geometrical parameters and the high physical-mechanical properties of the surface and its layers. These shortcomings include problems related to the delivery of coolant-lubricant fluids to the contact zone, the uneven effect of abrasive particles on the surface, the generation of high heat during cutting, the removal of chips from the cutting zone, the clogging of the grinding wheel, etc. These undesirable factors remain unresolved aspects of the process. The listed issues negatively affect both the enhancement of the micro-geometrical parameters of the surfaces and the improvement of their physical-mechanical properties [3, 4, 5]. The complete elimination or significant reduction of these problems requires substantial scientific and research efforts.

The flat grinding process can be performed along the wheel's side and peripheral surface, each method having its own distinct advantages and disadvantages. Peripheral grinding is of higher quality compared to side grinding but is somewhat less productive. Depending on the geometric dimensions of the machine part, its configuration, the accuracy and quality requirements for the main working surface, as well as the type of machine and its technological capabilities, the operation can be performed either on the side or the peripheral surface.

Side grinding is applied for processing harder materials, while peripheral grinding is more suitable for processing softer parts. In general, it can be stated that the highest precision and surface quality are achieved in peripheral grinding [6, 7, 8]. The figure illustrates the impact scheme of the grinding wheel on the workpiece surface during a peripheral grinding operation. As shown in the diagram, abrasive particles have various physical interaction possibilities with the surface, and these interactions continuously change throughout the machining process.

The technological capabilities of modern CNC grinding machines have been significantly expanded, and the main kinematic parameters that define the fundamental motion scheme of flat grinding are as follows: the primary motion (rotation of the grinding wheel around its axis), the main feed motion (longitudinal movement of the grinding head), vertical feed motion or cutting depth (motion perpendicular to the grinding wheel surface), and lateral feed motion (movement of the grinding wheel parallel to the processed surface).

In addition to the machine specifications, the grinding wheels must also meet various requirements, such as high hardness, heat resistance, wear (fragmentation) resistance, impact resistance, multi-purpose use, and others [9, 10]. The abrasive materials used can be natural (quartz, corundum, etc.) or synthetic (electro corundum, boron carbide, nitrides, silicon carbide, etc.), and they are selected based on the machining method and the type of workpiece material.

As seen, the formation of the geometric parameters of the high-precision surfaces of the parts has a complex structure and must be carried out throughout the entire technological process. Compared to side grinding, peripheral grinding has a smaller contact area between the grinding wheel and the workpiece, which helps prevent excessive heat generation. Although the lower heat may complicate chip removal, it is considered a positive factor in terms of maintaining dimensional accuracy and machine settings.

Formulation of the problem. One of the key issues in ensuring quality in grinding is related to the process of grinding wheel conditioning. In this regard, modern, computer-controlled machines play a prominent role. The abrasive particles on the cutting surface of the grinding wheel have arbitrary shapes and placements, which, by creating different cutting angles, generate micro-cutting effects. In this context, each abrasive particle penetrates the surface to different depths; larger particles experience higher loads, while smaller particles are less loaded [11, 12]. As a result, microscopic observations of the chips show that their size and shape vary. Some abrasive particles are unable to perform cutting; instead, they only cause plastic deformation of the surface, while very small particles do not make contact at all. Figure 1 illustrates the chip formation scheme during peripheral flat grinding [13, 14, 15]. As shown in the diagram, the thickness of the contact layer and the length of the contact result in the formation of chips in a "comma" shape.

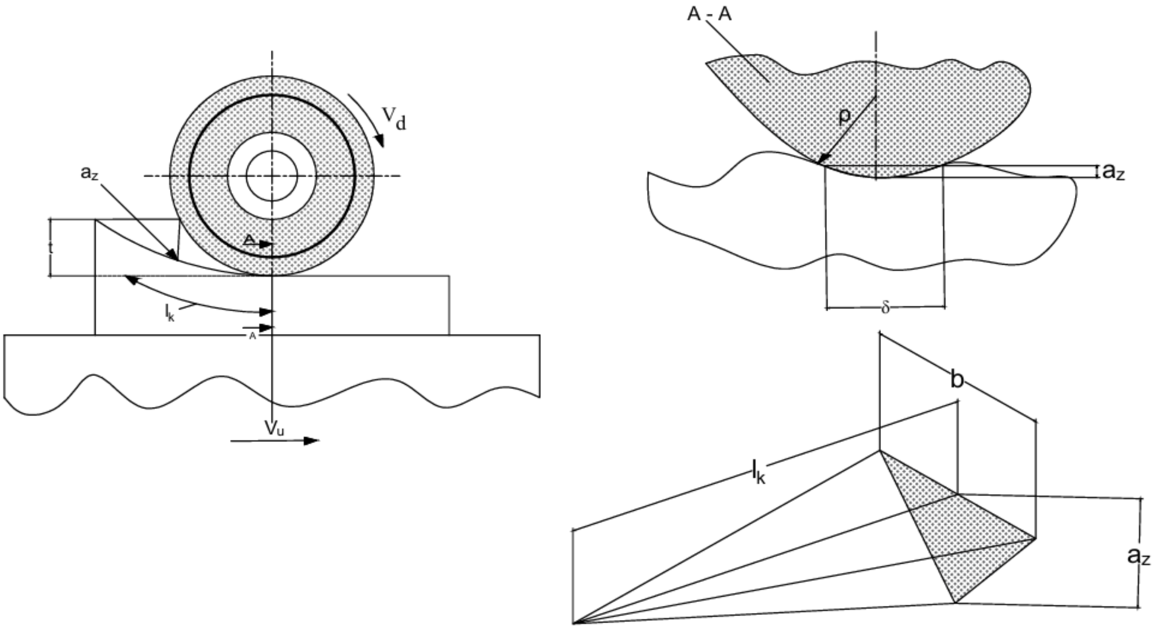


Figure 1. Chip formation scheme in peripheral flat grinding.

In flat grinding, the length of the contact between the workpiece and the abrasive wheel, denoted as l_k, is determined by the following expression:

$$l_k = \sqrt{Da_x} \tag{1}$$

Here, D is the external diameter of the grinding wheel (in mm), and a_z is the thickness of the cut layer (in mm).

If we simplify the "comma" shaped chip by approximating it as a pyramid with a triangular base, where the height is equal to the contact length lk, then the volume of the chip can be considered as the volume of the pyramid.

$$\omega y' = \frac{1}{3} a_z^2 \sqrt{2\rho D} \tag{2}$$

Here, ρ is the radius of the abrasive particle's apex (in mm).

The volume of the chip obtained from this expression can be used to determine the volume of material removed from the metal surface per minute, denoted as Q. This volume is related to the number of active abrasive particles (N_m) passing through the grinding zone and participating in chip removal during that time period. Thus, the material removal rate per minute is given by the ratio of the chip volume to the number of active abrasive particles involved in the cutting process.

$$\omega y' = \frac{Q}{N_m} \tag{3}$$

The minute material removal rate (Q) can be expressed in terms of the specific minute material removal rate (Q_{yd}), and the number of abrasive particles' apexes in a unit surface area of the circle

(N_z) as follows:

$$\omega y' = \frac{Q_{yd} H}{6 \cdot 10^4 N_g H V_d} = \frac{Q_{yd}}{6 \cdot 10^4 N_g V_d} \tag{4}$$

Here, V_d is the rotation speed of the wheel, in mm/min, and Hd is the width of the grinding wheel, in mm.

Assuming $\omega y = \omega y'$ (i.e., the angular velocity of the grinding wheel is constant), the final expression for the cutting thickness a_z (assuming it's small) would be as follows:

$$a_z = 33\sqrt{\frac{Q_{yd}}{N_z V_d}} \cdot \sqrt[4]{\frac{1}{D\rho}} \tag{5}$$

Here:

Q_{yd} is the specific minute material removal rate (in mm^3/mm),

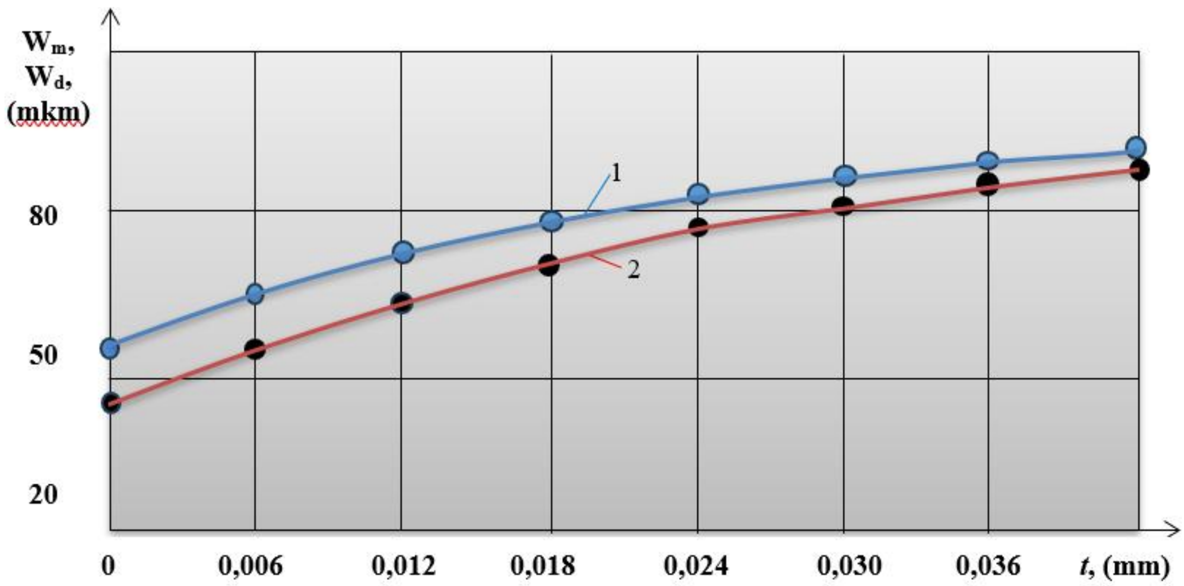
N_z is the number of active cutting tips of the abrasive particles per 1 mm^3 of the working surface of the wheel (in count),

D is the diameter of the wheel (in mm),

ρ is the radius of the abrasive particle's apex (in micrometers).

The graph shows the distribution of nonlinearity and non-flatness parameters formed during the processing of 33CrMoV12-9 steel using a CNC surface grinding machine model SGS-1632 AHD on a PP-250x20x76 machine with a typical 25A25PJM17K5P grinding wheel.

In surface grinding, the processing accuracy is characterized by the indicators of non-linearity (W_m) and non-parallelism (W_d). The theoretical and experimental results showing the dependency of non-linearity and non-parallelism (W_m, W_d) on the cutting depth (t) are presented in Figure 2.



Figur 2. Graph of dependence of nonlinearity-1 and nonflatness-2 (W_m, W_d) on the cutting depth (t);

As with all mechanical machining processes, the cutting force in planar grinding depends on the physical and mechanical properties of the workpiece, primarily its hardness, the cutting parameters (such as cutting depth and feed rate), and other factors. As the cutting depth and feed rate increase, the cutting force also increases. However, when the cutting speed increases, the cutting force decreases because the thickness of the material being cut by each individual abrasive particle decreases. Additionally, the type of grinding wheel and its technological characteristics have a significant impact on the cutting force.

The productivity of the operation Q (mm³/min) characterizes the working capacity of the grinding wheel. In the peripheral surface grinding process, the non-parallelism of the surface is influenced by the cutting regime elements. The empirical model for this dependency is as follows:

$$W_m = 144,32 t^{0,65} V_1^{0,39} S_w^{0,51} \quad (6)$$

For the SGS-1632 AHD model CNC flat surface grinding machine, using 33CrMoV12-9 steel (Annealed HB Max.229) as per UNI EN ISO 4957:2002 standards (ISO 4957, developed by ISO/TC 17, Steel, Subcommittee SC 4), the following cutting conditions are applied during the machining of the workpieces:

- cutting depth - t=(0.006÷0.042) mm;
- longitudinal feed – V_l=(6÷18) m/min;
- lateral feed – S_w=(1.45÷6.25) mm/d.w.

The empirical model for the formation of surface non-parallelism in the peripheral flat surface grinding process, based on the cutting regime elements, has been derived from studies on grinding with a PP250x20x76-form grinding wheel of type 25A25PSM17K5P and grinding a 33CrMoV12-9 steel plate and the research has shown that the primary factor affecting non-parallelism is the value of the cutting depth.

$$W_d = 141,41 t^{0,59} V_1^{0,41} S_w^{0,48} \quad (7)$$

It should be noted that the choice of grinding wheel characteristics is of particular importance:

- although a soft wheel has high cutting properties, the intensity of eating is also high;

- a solid wheel is poorly eaten, but quickly becomes dull and loses the ability to cut;

- for a hard tool, it is more advisable to use diamond and elbor wheels than electrocorundum-silicon carbide wheels.

Results and Conclusions. Based on numerous theoretical and experimental studies, it can be concluded that the surface quality in the planar grinding process depends on many factors that are functionally interconnected. There are various approaches to quality control, among which the most important are the application of modern technological methods and the use of next-generation technological equipment. To achieve a surface topography that is as close as possible to a plane after flat grinding, the elastic displacements of the system in both the width and length directions of the machining should be kept stable. Geometric shape errors typically manifest significantly in transverse cuts, especially at the zones where the grinding wheel makes contact with and exits the workpiece. The variation in the contact area at the entry and exit zones of the contact creates elastic displacements, resulting in non-linearity and non-planarity in the surface profile.

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Received: 06.09.2024
Accepted: 22.11.2024