Automated Control System Qualities of Roller Bearings in Butt End Grinding Operations

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Abstract. An automated system for controlling the quality of the surface layer during grinding has been developed, which makes it possible to carry out highly productive and defect-free processing of flat surfaces of structural steels by energy parameter, cutting power in particular. The proposed system makes it possible to avoid scorch marks, reduce the hardness of the material surface due to uneven workpiece allowance and high temperatures in the cutting zone, and stabilize roughness. The operation of the adaptive system is based on temperature monitoring of the surface layer, which is determined by the operating parameters of the machining process (workpiece feed rate, allowance size, and cutting ability of the abrasive tool). An algorithm for the operation of an automated quality control system for the machining of roller bearing rings in centerless face grinding operations has been developed, which takes into account the unevenness of the machining allowance and allows for automatic dressing of grinding wheels as they become blunt. The use of the automated system made it possible to stabilize the parameters of the surface layer of the ends of bearing rings in terms of roughness at the level of 0.4–0.6 µm and hardness of 60–62 HRC, to avoid scorch marks and product defects, and to improve the efficiency of the process of machining flat surfaces in the machine-building industry.

Keywords: bearing · grinding · quality · control · temperature · power · automation · algorithm · system

1 Introduction

Currently, the problem of simultaneously ensuring high quality and productivity of abrasive machining of bearing steels 50100, 52100, which are characterized by high hardness (55–65 HPC) and prone to the appearance of thermal defects, is relevant. The disadvantages of traditional grinding methods when machining such materials are the difficulty of obtaining surfaces of the required accuracy in geometric and quality in physical and mechanical characteristics [1]. The roughness of the ends of the bearing rings should not exceed 1.25 µm [2], the occurrence of burn-ins of the surface layers, a decrease in hardness and the appearance of microcracks are not allowed. The processing of the ends of the roller bearing rings is accompanied by increased thermal stress of the process,

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which is due to the continuity of the cutting process, a significant contact area of the tool surface with the workpiece surface and is the cause of the appearance of burn-ins, bond destruction and increased wear of the abrasive wheel.

This causes significant difficulties in their processing both from the point of view of ensuring stable quality and achieving high process productivity due to the low dimensional stability of the cutting tool, the increase in the number of its edits and operation at low operating parameters. Reducing product defects at high process productivity and intensification of operating parameters in machining operations, which is especially evident in abrasive machining of flat surfaces, is an urgent task, since scorching and a decrease in the hardness of the surface layer of iron-carbon alloys constitute a significant percentage, which requires taking action to eliminate them. The aim of the work is to develop an automated quality control system that reduces the thermal stress of the cutting process and minimizes defects in the face grinding of bearing rings.

2 Literature Review

Managing the quality of the surface layer of machine parts during grinding remains an urgent problem of modern production. Currently, there are no grinding methods that ensure the complete absence of thermal defects on the surface during the grinding process. Increasing the requirements for the quality of the surface layer of products requires the creation of new, more progressive methods of finishing and methods of their control, which ensures the obtaining of specified quality parameters with high process productivity. The complexity of the grinding process and the phenomena associated with it necessitates a deep theoretical and experimental study of the physical essence of the phenomena occurring during abrasive processing of materials. Owing to the works of famous scientists, including Yakimov O., Lebedev V., Marchuk V., Larshin V., Novikov F. and others, the scientific foundations of the grinding process have been created, technological methods of abrasive processing have been developed, which are widely and successfully used in various branches of mechanical engineering. These works and the experience of enterprises have shown the wide possibilities of grinding processes for ensuring high quality of machine parts during processing. In works [3–5], studies were conducted on the thermal stress of the grinding process and ways to reduce the cutting temperature, in particular by using intermittent grinding.

In the works [6, 7] it is proposed to ensure high quality of the surface layer due to optimal parameters of the intermittent abrasive tool, which provides temperature reduction, high cutting ability and stability due to self-sharpening. However, many time-varying factors, such as unevenness of the allowance value, uneven wear and change in the wheel profile, cause an unpredictable change in the components of the cutting forces, which in turn leads to instability of the grinding process. In the work [8] the issue of optimizing the dressing of the abrasive tool is considered by identifying and eliminating idle strokes of the tool, which makes it possible to reduce the number of dressings of the wheel. However, this method does not allow to assess the level of blunting of the abrasive during the cutting process. Ensuring high productivity and quality of parts during abrasive processing is possible by controlling the disturbing factors of the process, the main of which is the unevenness of the workpiece allowance. When grinding on double-sided face grinding machines, it is possible to stabilize the quality of the surface layer of the end surfaces of cylindrical parts, roller bearing rings, in particular, by maintaining the grinding power spent on cutting at a constant level. It is possible to implement such a grinding method when using grinding wheels with an intermittent working surface, which retain high cutting ability for a long time, and using automatic control systems. Thus, in particular, in the work [9], the issues of building a grinding system using online sensors are considered. However, for the effective functioning of the automated system, it is necessary to develop an algorithm for the operation of the ACS taking into account the peculiarities of the butt end grinding process.

3 Research Methodology

Currently, double-sided face grinding machines of the type 3344AE are used to process the end surfaces of roller bearing rings, which provide high productivity and sufficient dimensional accuracy. However, there is an unresolved problem of ensuring the specified physical and mechanical properties of the surface layer of the rings, which is manifested in reduced microhardness and the appearance of burn-ins. The quality of the surface layer of parts can be stabilized by maintaining the power consumed during cutting at a constant level. It is possible to implement such a grinding method when using grinding wheels with an intermittent working surface, which operate in self-sharpening mode and using an adaptive control system (ACS).

The use of an adaptive control system in face grinding operations is an indispensable condition for ensuring high productivity and a given quality, which are interconnected and limit-setting. Having considered the technological factors influencing the operational accuracy and thermal stress of the process of flat grinding of the end surfaces of roller bearing rings, it was established that the main disturbance is the machining allowance, which is formed in the blanking turning operations and fluctuates within 0.3 ± 0.05 mm and is poorly predictable. Considering the fact that there is a significant number of parts in the processing zone (8–15 rings, depending on the size of the roller bearing), even a slight change in the allowance will lead to a significant change in the thermal stress of the cutting process. Therefore, the use of intermittent grinding using an ACS will prevent the appearance of defective parts by controlling the specified temperature regime of the surface layer of the part, wear of abrasives.

The principle of operation of the automatic control system is that an electrical signal proportional to the grinding power is supplied from the electric motors of the grinding wheel drive to the electronic unit, which compares the controlled value and controls the actuator. An increase in the grinding power beyond the permissible set value causes the activation of the automatic control system actuator, which reduces the feed rate of the part into the processing zone, thereby reducing the thermal stress of the cutting process. When the cutting power decreases below the maximum permissible value, the automatic control system will increase the feed rate of the part, thereby ensuring that the grinding power is maintained at a given level.

For a mathematical description of the operation of the ACS in centerless face grinding operations, let us consider the scheme of forces arising during the cutting process (Fig. 1).

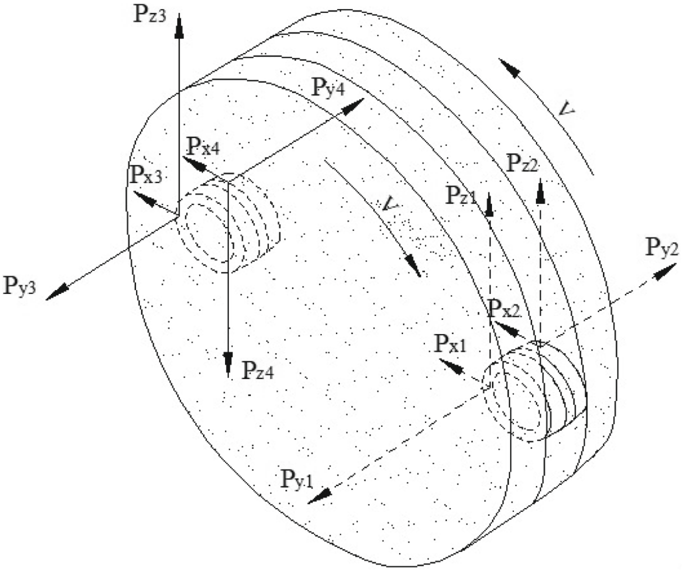

Fig. 1. Scheme of forces arising in the grinding process on a double-sided face grinding machine 3344AE: Px1, Py1, Pz1 – for the left grinding wheel and Px2, Py2, Pz2 – for the right one, where Px1 and Px2 are axial forces acting in the grinding plane in the feed direction; Py1 and Py2 are normal forces acting in the plane perpendicular to the grinding plane; Pz1 and Pz2 are tangential components of forces acting in the grinding plane perpendicular to the feed direction.

The power P spent on cutting consists of the powers spent on grinding the side surfaces of the right P1 and left P2 ends of the roller bearing ring:

$$P = P_1 + P_2 \tag{1}$$

$$P_1 = F_{z1} \cdot V \tag{2}$$

$$P_2 = F_{z2} \cdot V \tag{3}$$

where: F_{z1}, F_{z2} – tangential components of the cutting force of the right and left ends of the roller bearing ring; V – cutting speed.

The difference in the tangential components of the cutting forces determines the difference in power between the left and right grinding wheels:

$$\Delta P = P_1 - P_2 = V \cdot (F_{z1} - F_{z2}) \tag{4}$$

A feature of grinding roller bearing rings is that the area of the side surfaces of the right and left ends of the bearing ring have different values, so the tangential components of the cutting forces will differ by the proportionality coefficient k, which makes it possible to control the most loaded end from the point of view of thermal force influence.

The tangential components of the cutting forces are equal to:

$$F_{z1} = k_1 \cdot F_{y1} \tag{5}$$

$$F_{z2} = k_2 \cdot F_{y2} \tag{6}$$

where: F_{y1}; F_{y2} – normal components of the cutting force of the right and left ends of the ring; k_1, k_2 – proportionality coefficients.

The maximum temperature value in the surface layer of the part at a depth from the surface can be determined by the formula [10]:

$$T_{\delta.\max} = T_{0.\max}\left(1 - 0.5\sqrt{\frac{V}{ah}} \cdot \delta\right). \tag{7}$$

where: $T_{\delta.\max}$ – maximum temperature value in the surface layer of the part at a distance δ from the surface; $T_{0.\max}$ – maximum contact temperature on the treated surface; V – speed of movement of the heat source (parts); α – thermal conductivity coefficient; h – half-width of the heat source in the direction of the velocity vector; δ – distance from the surface of the part.

The maximum temperature on the surface of the part can be determined by the following formula [10]:

$$T_{0.\max} = \frac{1.47P}{\lambda S} \cdot \sqrt{\frac{V}{ah}}, \tag{8}$$

where: λ – thermal conductivity coefficient of the part material; S – the area of the end of the ring.

Substituting (8) into (7) we obtain:

$$T_{\delta.\max} = \frac{1,47P}{\lambda S} \cdot \sqrt{\frac{V}{ah}} \cdot \left(1 - 0.5\sqrt{\frac{V}{ah}} \cdot \delta\right). \tag{9}$$

Then the permissible cutting power when grinding roller bearing rings on automatic face grinding machines can be found by the formula:

$$[P] = \frac{T_{\delta.\max} \cdot \lambda \cdot S}{0.75 \cdot \left(\sqrt[2]{\frac{ah}{V}} - \delta\right)}. \tag{10}$$

The scheme of the adaptive surface layer quality control system during flat face grinding is shown in Fig. 2.

The adaptive control system operates according to the algorithm shown in Fig. 3. The conditions block sets the values of the permissible level of cutting power and the minimum feed rate of the part. The specified power values are compared with the actual value, which is taken from the electric drive motor by the ACPM-50/100/150 active power sensor. The value of the electrical signal, which is proportional to the grinding power, enters the control unit. Maintaining the grinding power at the specified level is ensured by adjusting the speed of the electric drive of the workpiece feed mechanism using the CFM310S frequency converter according to the algorithm in Fig. 3.

The proposed ACS, in addition to maintaining a given temperature range of the surface layer during the processing process, allows for dressing of grinding wheels as

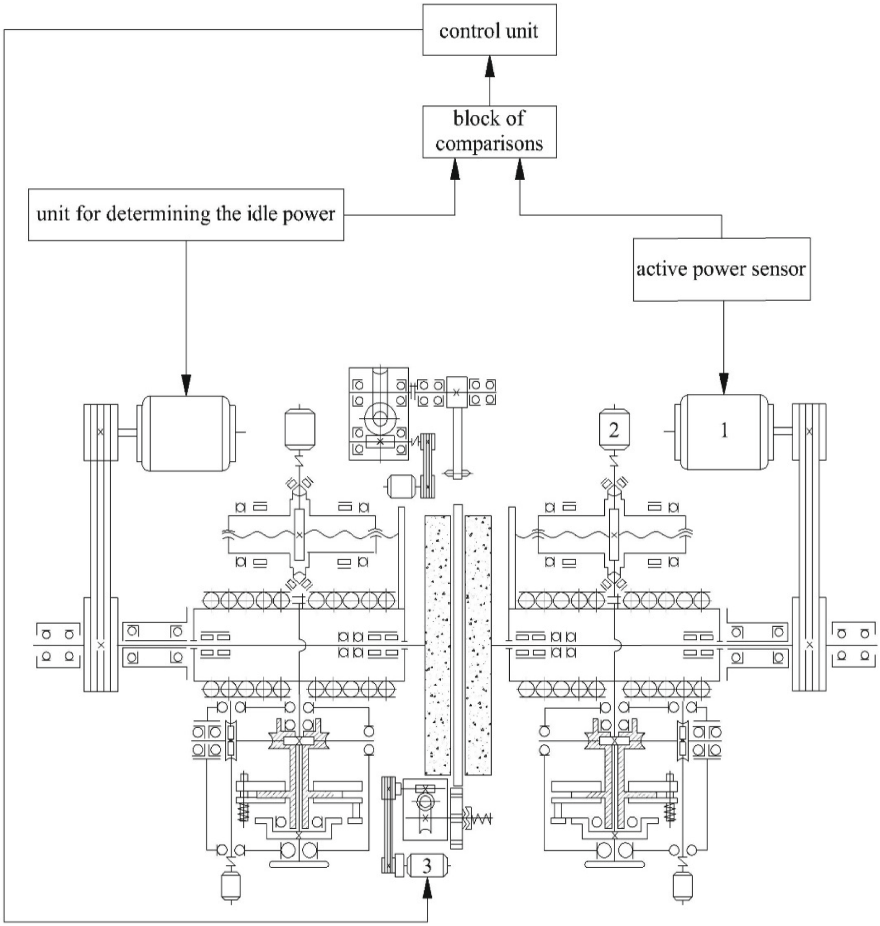

Fig. 2. Block diagram of the adaptive quality control system for grinding: 1 – electric motor of the grinding wheel drive mechanism; 2 – electric motor of the grinding wheel feed mechanism; 3 – electric motor of the parts feed mechanism drive.

they wear out. To do this, it is necessary to first set the minimum speed of feeding the part into the cutting zone and compare the actual and set values of its speed. The condition $\upsilon_d < \upsilon_{dmin}$ *at* $P > [P]$ will reflect the process of dulling and salting of the grinding wheel. In this case, a dressing command is given. It should be noted that the efficiency of the proposed ACS largely depends on how rationally the value of the parameter υ_{dmin} is selected, since an overestimation of this parameter will lead to an increase in the number of dressings of the grinding wheel, and an underestimation will lead to an increase in the time for processing a batch of parts.

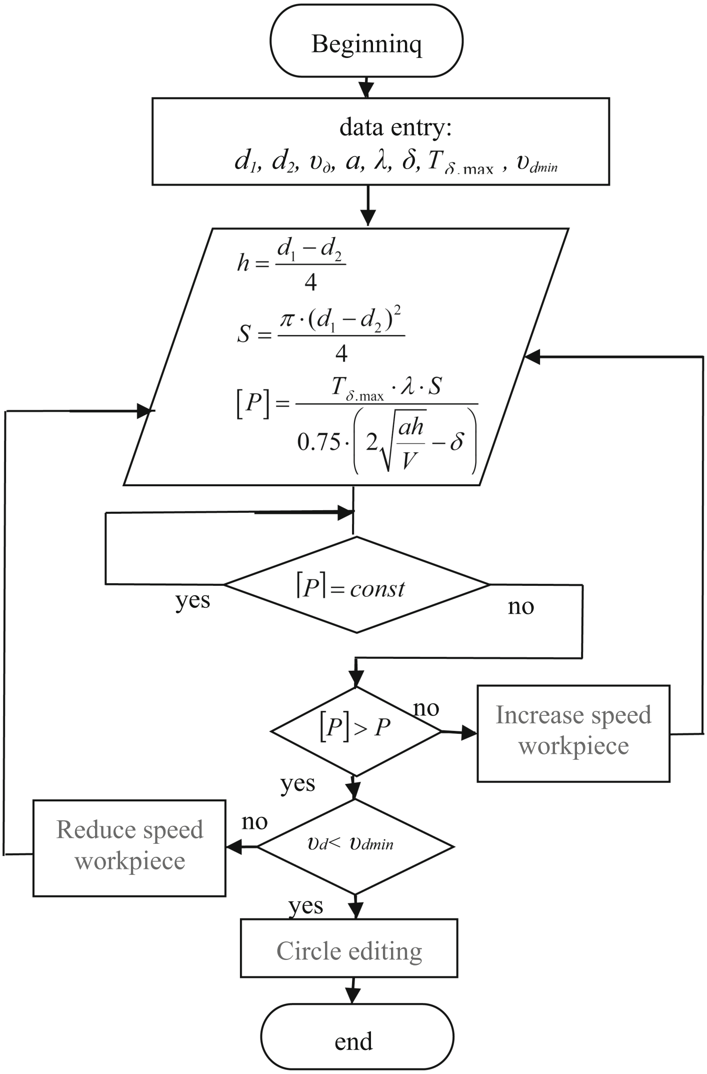

Fig. 3. Algorithm of ACS operation.

4 Results and Discussion

Studies of the dependence of the parameters of the processed surfaces on the processing modes, the design and characteristics of the cutting tool, and the method of supplying the coolant to the cutting zone were carried out on an experimental stand (Fig. 4) based on a double-sided face grinding machine model 3344AE.

This approach, on the one hand, ensured the conduct of research in a wide range of changes in technological parameters, and on the other hand, direct comparison of individual studies with real conditions of processing research on double-sided face grinding

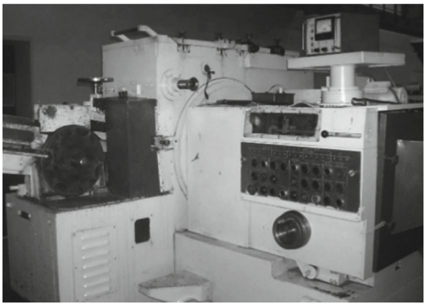

Fig. 4. General view of the experimental stand based on the 3344AE face grinding machine.

machines, which allowed obtaining results with a sufficient level of reliability. The stand is additionally equipped with a wattmeter for measuring the power consumed in the cutting process with the upper measurement limit of 40 kW. Oscillograms of cutting powers with and without the use of the ACS are shown in Figs. 5, 6.

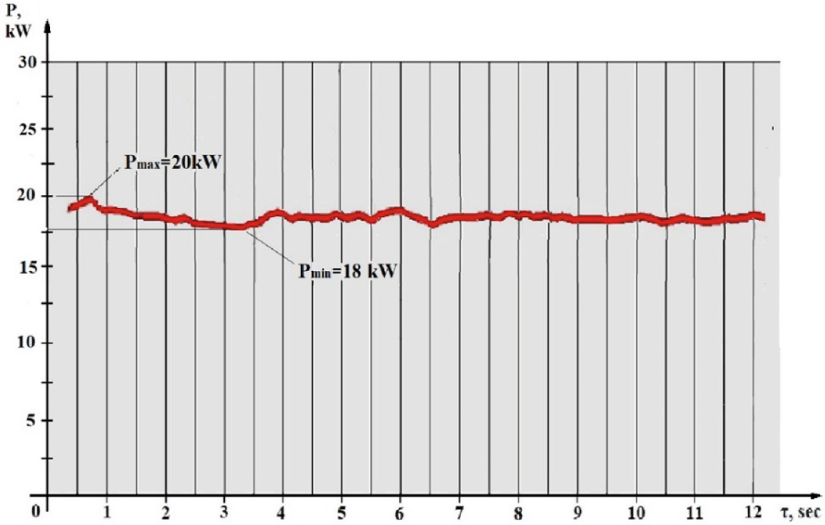

Fig. 5. Oscillogram of cutting power on the 3344AE automatic face grinding machine of the 6-7313A.02 ring without the use of an automatic control system (Vabrasive circle = 30 m/s; υworkpiece = 5 m/min; t = 0.1 ± 0.05 mm; steel 52100).

The power and thermal stress of the process of grinding the ends of roller bearing rings on the 3344AE double-sided face grinding machine largely depend on two quantities, one of which is scholastic in nature and is poorly predictable. These include the machining allowance formed during the preparation turning operations and the feed rate of the part, which determine the volume of material removed by the abrasive per unit of time. Therefore, the proposed ACS, in addition to maintaining a given temperature range of the surface layer during the machining process, allows for the correction of grinding wheels

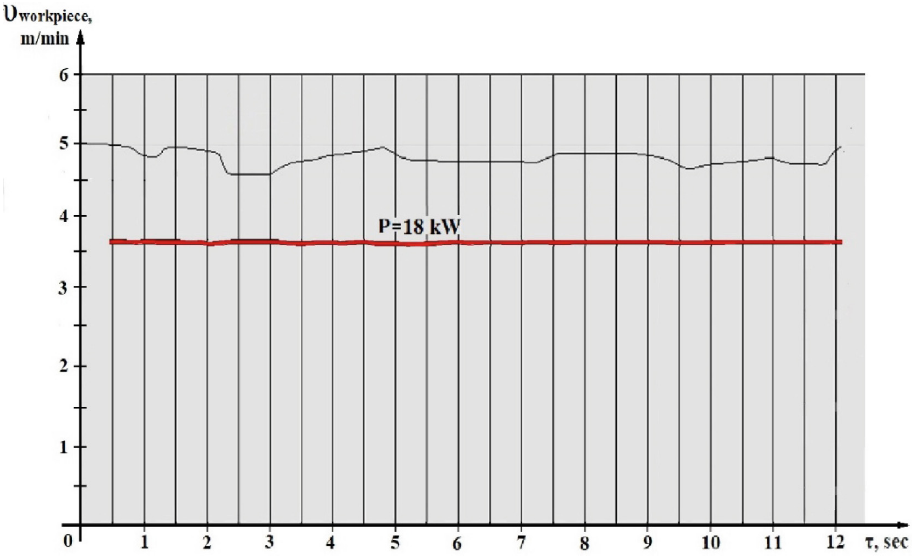

Fig. 6. Oscillogram of cutting power on the face grinding machine 3344AE of the ring 6-7313A.02 using the automatic control system (Vabrasive circle = 30 m/s; t = 0.1 ± 0.05mm; steel 52100).

as they wear out. To do this, it is necessary to first set the minimum speed of moving the part into the cutting zone and compare the actual and set values of the speed of movement of the part. It is not difficult to predict that the condition *υworkpiece < υworkpiecemin at P > [P]* will reflect the process of blunting and salting of the grinding wheel. In this case, a command is given for correction. It should be noted that the efficiency of the proposed ACS largely depends on how rationally the parameter value *υworkpiecemin* is selected, since its overestimation will lead to an increase in the number of grinding wheel adjustments, and its underestimation will lead to an increase in the time for processing a batch of parts.

5 Conclusions

An engineering methodology has been developed for highly productive and defect-free machining of the end surfaces of bearing rings and ensuring automatic control of the wheels as they wear out by maintaining the power consumed for cutting at a constant level.

The use of an adaptive control system made it possible to stabilize the quality parameters of the end surfaces of bearing rings (end roughness at the level of 0.4–0.6 μm, surface layer hardness at the level of 60–62 HRC) with high productivity of the machining process and to avoid the appearance of defective parts. The error of the obtained experimental data does not exceed 1.5%.

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