Regularities of motion and accuracy of double-sided processing of cylindrical rollers

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Abstract. The influence of machine setting parameters on the behavior of the cylindrical roller during the processing of its ends is investigated. The regularities of motion and accuracy of double-sided processing of rollers have been established. A system of indicators is proposed that relates the characteristics of rotation to the accuracy of processing. The optimum shape of the roller rotation frequency curve is established, which ensures the highest processing accuracy for these grinding conditions. Practical recommendations for the choice of technological parameters are given.

1. Introduction

A specific feature of the processing of cylindrical rollers with circular feed is the possibility and necessity of their rotation. The kinematics of the relative movement of the grinding wheel and blank largely determines the formation of macro – and microgeometry of the surface during grinding and is the subject of separate studies [1–3].

The main nominal kinematic parameters for double-disc grinding are the angular speed and directions of rotation of each grinding wheel, the direction of the trajectory and the feed rate of the blanks, the angular speed of rotation of the blank.

The favorable role of rotation or turns of the blank around its axis in reducing the errors of the treated surfaces and improving their quality

Researchers point to the favorable role of rotation or rotations of the blank around its axis in reducing the errors of the treated surfaces and improving their quality [4, 5].

It is known, that the processing of free workpieces on double-disc grinders with circular feed must be accompanied by their rotation [3, 5]. Rotation of blanks allows to intensify the process of grinding, to reduce the number of passes necessary for final processing.

At the same time, it can be assumed, that rotation of such blanks as bearing rollers leads to a transformation of the initial deviation from the perpendicularity of the end face into its convexity, the hereditary effect of which on the accuracy of the subsequent centreless grinding operation is much less. The convexity of the end is also more favorable from the point of view of the influence on the working capacity of the roller in the bearing.

In [5], for the first time, we show the curve of the dependence of the rotation frequency of the roller on its coordinate in the grinding zone, at which high precision is provided. The relationship of this curve to the so-called equivalent frictional transmission curve is found. In an imaginary friction transmission the driving link has a radius $R_i$ equal to the current distance between the roller and grinding wheel axes minus the radius of the roller, the driven link has the radius of the roller minus the chamfer $r$, and the movement is transmitted without slipping.

The fact that it is possible to obtain high precision machining on machines with forced rotation, as well as the revealed interrelation of the nature of the rotation of the blank with accuracy is the basis for carrying out in this work a detailed study of the problems, associated with the rotation of blanks during their form shaping.

2. Experimental research of real kinematics of the grinding process

2.1. Description of means and methods of measurement
In the recorded following kinematic, force and geometric characteristics of the grinding process of the rollers: the dependence of the rotational speed of the workpiece from its current position, measured along the trajectory of movement (hereinafter - rotation characteristic (RC); length of the roller moving with rotation in the grinding zone, normal and the tangential cutting forces, the errors of the machined ends by the parameters of the end runout and the deviation from the flatness. To be able to compare the duration roller rotation and removal of the allowance, the dependence of the removed allowance on the current coordinate of the workpiece in the grinding zone was periodically recorded using a special technique [6].

Registration of the rotation frequency of the roller with its translational circular motion between the grinding wheels in the processing area was carried out using a fiber optic sensor. This method makes it possible to make measurements in a hard-to-reach zone of the machine between two rotating grinding wheels while moving the measurement object, makes it possible to investigate the behavior of the rollers relatively small, not sensitive to the lubricating-cooling technological environment, is contact-free, without intervention in the technological process.

We analyzed and proved the possibility of using an original design with two standard fiber bundles (Figure 1), while one of them (11) is illuminating, the other (12) – the receiving channel, when measuring the rotation frequency of a roller of a fiber optic sensor. The luminous flux from the emitter 2, which is a lamp with a spot filament, is supplied by a lighting channel 11 to the cylindrical surface of the roller 1, on which a "black" spot is applied with concentrated nitric acid. The difference in the reflection coefficients from the "black" and the original surface leads to the fact that the rotation of the roller in the basilar sleeve 9 with the radial hole causes modulation of the light flux entering the receiving channel 12. In the photoelectric multiplier 6, the light flux is converted into an electrical signal and, after additional amplification in the operational amplifier 5, is fed to an oscilloscope or processor 4. Figure 1 also denoted: 3, 7 – power supplies of the illuminator and the photoelectric multiplier; 8 – a detachable body with curved grooves under the light guides; 10 – disk separator.

![Figure 1. Scheme of registering the rotation frequency of the roller by a fiber-optic sensor](image)

Preparation of the roller for measuring the speed of rotation consists in applying a stain on its cylindrical surface with nitric acid, the size of which should not exceed the width of the groove in the basing sleeve to exclude the effect of the etched surface on the friction conditions of the roller on the sleeve.

The optics of the sensors should ensure maximum use of the light flux of the emitter. The power of the reflected light stream and the current at the input of the photoelectric multiplier depend on the gap between the end of the light guides and the reflecting surface, so the preparation of the sensors for work involves determining the optimum gap-the alignment of the optical system. The obtained value of the optimal gap for the sensor used in the work – 2.2 – 2.9 mm provides the convenience of placing the light guides relative to the surface of the roller.
The correctness of the procedure for recording the rotation frequency was verified by registering the revolutions of a high-speed electrospindle (from 100 to 1000 s\(^{-1}\)) with a spot on the end section simultaneously with their registration with the built-in electronic frequency counter. The discrepancy did not exceed 5%.

The technique for registering grinding forces is discussed in detail in [6, 7].

2.2. Types and characteristics of rotation

The analysis of the obtained experimental data has shown, that, depending on the settings and grinding conditions, the character of roller rotation changes.

All the RC can be systematized according to four main indicators.

1. Type of RC.
2. All RC can be attributed to three main types (Figure 2).

![Figure 2. CR types (a) and grinding forces, stock allowance (b)](image)

Type I (curve 1) – acceleration of the roller at the entrance to the grinding zone to the circumferential speed equal to the speed of the circle at the periphery and its braking to a complete stop in the first half of the zone.

Type 2 (curve 2) – acceleration of the roller to the circumferential speed equal to the wheel speed at the entrance of the grinding zone, drop speed to zero in the first half area, feed movement without rotation, the second acceleration roller after passing the center to a maximum value \(f_m\) followed braking to zero in the second half of the zone.
Type 3 (curve 3) – acceleration, by analogy with the first two types of RC, continuous rotation of the first half area with a frequency close to the frequency \( f_i \) of the driven member of the equivalent friction transfer (at a frequency of rotation of the grinding wheel \( f_w \))

\[
f_i = \frac{f_w R_i}{r},
\]

(1)
a steep slope at the moment, when the end of the roller touches the edge of the grinding wheel hole, and the subsequent rise of the RC curve in the central region of the zone to the level \( f_m \), then the roller stops to stop completely.

The type of RC is the main feature, on which you can systematize the whole variety of RC.

2. The length of the rotation zone with its continuity – \( L_R \) (Figure 2 (a)).

3. Maximum roller rotation frequency after passing the center of the grinding zone – \( f_m \) (Figure 2 (a)).

4. The total length of the sections on which the roller rotates with the stock removal – \( L_{BP} \).

Obviously, the most important, from the point of view of forming accuracy of processing, is the behavior of the roller in the stock removal zone. This feature of the systematization of RC links RC with the stock removal process. The patterns of removal of the allowance in double-disc grinding are considered by the author in the works [6, 7, 8].

\( L_{BP} \) is determined by simultaneous recording of RC and grinding forces. The duration of the force action determines the length of the allowance removal section \( L_P \) (Figure 2 (b)). \( L_{BP} \) is defined as the sum of the lengths of roller rotation segments within the \( L_P \).

Since the coordinate of the end of stock removal is variable quantity, it is more convenient to operate with the relative characteristic \( L_{BP0} = L_{BP}/L_P \), which indicates the part of the allowance removal zone on which the roller rotates.

3. RC indicators and processing accuracy

An investigation of the relationship between RC indicators and the processing accuracy was carried out on machines of two sizes when processing rollers of three sizes (14x14 mm, 15x15 mm, 32x52 mm). For the limiting accuracy indicator, the end runout \( \Delta \) (μm) was adopted.

In Figure 3 shows the graphs of the dependence of the accuracy of the processed ends on the RC types.

It should be noted, that each type of RC corresponds to its range and the average value of the processing error, as well as its own range of values of the parameter \( L_{BP0} \). With RC of the third type, the average error values of the processed ends are approximately 2 times lower than in the RC of the second type and 4 times lower than in the RC of the first type.

The second most important influence on the accuracy of processing is the relative indicator of the total length of the sections on which the roller rotates with the stock removal \( L_{BP0} \).

The relationship between \( L_{BP0} \) and end run-out \( \Delta \) has an exponential character (Figure 4) – with an increase in \( L_{BP0} \), the value of the end error decreases, and the scattering also decreases.

The dependence of the runout \( \Delta \) (μm) of the roller 14x14 mm on the \( L_R \) (mm) indicator can be represented as a regression equation (variation interval \( L_R = 160 - 240 \) mm)

\[
\Delta = 6.57 - 0.019 \cdot L_R.
\]

(2)

It follows that an increase in the length of the section of the grinding zone \( L_R \), at which the roller rotates continuously, from 160 to 240 mm, leads to an increase in the average processing accuracy by a factor of 1.8.

Influence on the accuracy of the fourth indicator – the maximum speed of the roller after passing through the center of the grinding zone – \( f_m \) is explained through its connection with the \( L_R \) indicator. With the increase in the peak speed of the roller during its second acceleration, the length of its continuous rotation zone also increases.
4. The causes of different ends errors generation with different RC indicators value

Consider the causes for the formation of different error of the ends at different indicators of RC rollers.

With RC of the first type (they correspond to small values of $L_{BP0}$) the rotation stops in the first half of the grinding zone during the intensive removal of the allowance. In this case, any deviations from the perpendicularity of the roller axis to the working faces of the grinding wheels (caused by geometrical inaccuracy in the manufacture and assembly of the machine or accidental misalignment of the roller in the bushing), as well as the intrinsic curvature of the cutting surface of the wheel, causes the error of machining in the form of end runout.

At RC of the second type (they correspond to the average values of $L_{BP0}$), the rotation restart and partially corrects the deviation from the perpendicularity of the surfaces of the ends of the roller of its axis. But, as a rule, in the zone of the second rotation, after passing through the center of the grinding zone, a small allowance of 1-6 μm is removed, which is smaller in absolute value at the present moment of error in the end, and therefore no complete correction of the error occurs.

With RC of the third type and the values of $L_{BP0}$ close to 1, the favorable role of roller rotation around its axis during the form shaping process is fully revealed.

The reasons for the influence of the $L_R$ parameter on the end runout in RC of the third type and $L_R > L_P$ should be looked for in that, when the roller enters the diffuser part of the grinding zone and the stock removal is nominally completed, it is possible to periodically contact the roller with the ends of the grinding wheels, for example, due to their axial runout. This may entail local microremoval on separate parts of the end of the roller and the formation of an additional error in the form of a runout, if the roller does not rotate at this stage. Therefore, the greater the part of the working zone, the grinding of the roller is accompanied by rotation, the less is the probability of the formation of this error.

The condition for minimizing end run-out

$$L_R > L_Z,$$  \hfill (3)

where $L_Z$ – length of circular trajectory of the roller in the grinding zone.

An increase in the parameter $f_m$ under the same conditions of roller braking entails a corresponding increase in $L_R$, so that the effect of $f_m$ on the run-out of the treated ends is similar to effect of the $L_R$ on the run-out (2).

As a result of the analysis of the correlation of RC indicators with the processing accuracy it is possible to describe the form RC, at which the processing accuracy is highest for given grinding conditions. The RC of the optimal shape is RC of the third type with continuous rotation at the stock
removal area \( (L_{1/V_0} = 1) \), with parameter \( L_R > L_z \) (3), with the dip of the curve symmetrical with respect to the center of the zone and the maximum value of \( f_m \).

Such a shape of the RC curve should serve as a reference for setting up double-disc grinding machines in order to obtain the highest precision for the given grinding conditions for machining accuracy in the face runout parameter.

The optimal form of RC is achieved by a rational choice of such technological parameters as the setting angles of inclination of grinding wheels in the horizontal and vertical planes, the removed allowance and the speed of blanks feed.

5. Effect of technological parameters on RC indicators

To realize the optimal RC, the influence of the parameters of the angular setting of the grinding wheels in the horizontal \( \gamma \) and vertical \( \alpha \) planes, the allowance \( t \), and the speed of supply of the parts \( V \) to the RC indicators were studied.

Below are typical RCs showing the effect of the process setup parameters and processing conditions (Figure 5).

At \( \gamma = 0 \), irrespective of the values of other technological factors, only the RC of the first type (curves 1 and 2 in Figure 5 (a)) takes place and rarely the second type.

With an angular setting of the grinding wheels only in the horizontal plane \( (\gamma > 0) \) at \( \alpha = 0 \) (curves 1 and 2 in Figure 5 (b)), RC of the third type stably realize, their characteristic feature is the asymmetry of the falling and rising branches of the curve RC with respect to center of the zone. The curve 3 of the rotation frequency of the equivalent frictional transmission (1) also is shown.
The effect of the angular setting of the grinding wheels in the vertical plane $\alpha$ and the stock allowance $t$ on RC at $\gamma=5 \cdot 10^{-4}$ rad is shown in Fig. 5 (c). For $\alpha=0.5 \cdot 10^{-4}$ rad, regardless of the allowance values $t=0.06$ mm (curve 1), $t=0.10$ mm (curve 2), $t=0.15$ mm (curve 3), an increase $f_m$ and the symmetry of the central part of the curve. Thus, when the grinding wheel is installed, when they receive angular setting both horizontally and vertically, the maximum values of $f_m$ and the symmetry of RC in the center of the grinding zone are observed. The size of the allowsance does not significantly affect the RC, with its increase, RC in the first half of the grinding zone approaches the curve 4 of the rotation frequency of the equivalent frictional transmission.

With an increase in the feed rate $V$, the roller deceleration curve after the second acceleration becomes more flat, and accordingly, the $L_R$ value increases (Figure 5 (d)).

Thus, for the implementation of RC optimal shape when choosing the technological parameters should be guided by the following recommendations: the creation of a confusable technological space from the input rollers in the grinding zone ($\gamma>0$); the ratio between the angular displacements $\alpha/\gamma \sim 0.1$; the increased values of the feed rate $V$ and allowance $t$.

6. Conclusions

As a result of an experimental study of the process of double-disc grinding of cylindrical rollers machined in the nests of a disc-separator with a circular feed, the regularities of their rotational motion are revealed, and the relationship of the rotation characteristics to the processing accuracy is established.

1. The systematization of rotation characteristics of rollers is performed, their indicators, which connect the rotation characteristics with the accuracy of processing, are proposed.

2. The relationship between the parameters of the rotation characteristics and the accuracy of the machined ends is determined in terms of the end runout parameter. The optimal form of the roller rotation frequency curve, which ensures the highest accuracy for these grinding conditions, is established.

3. The influence of the main technological parameters is determined - angular displacements of grinding wheels in the horizontal and vertical planes, the feed rate and the allowable allowance for the parameters of the roller speed curve.

4. The research results have found practical application. They are the basis for developing recommendations for the choice of setting parameters and modes, based on the criterion for the implementation of stable rotation of the blank in the grinding zone, in order to improve the accuracy of processing.

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