Base error for centerless grinding of spherical rolling elements

O P Reshetnikova, B M Iznairov, A N Vasin, N V Belousova and A V Panfilova

Yuri Gagarin State Technical University of Saratov, 410054, Saratov, Politehnicheskaya street, 77, Russia

E-mail: olgareshetnikova1@yandex.ru

Abstract. The article considers a method for centerless grinding of spherical blanks. The scheme is implemented due to the presence of a trapezoidal helical groove on the driving wheel. The schematic diagram of the proposed method largely corresponds to the traditional centerless grinding scheme, which allows the use of machine tools available in production. It is shown that in the case of centerless grinding of balls, there is an error of basing on the operational size, namely, the diameter of the spherical surface. The adjustment size is mathematically determined when performing the technological operation of centerless grinding of balls, as well as the error of the adjustment size.

1. Introduction

In mechanical engineering, parts with a spherical shape are often used [1, 2-5]. Difficulties in production are balls used in friction units, such as ball screws and bearings. Production of balls is associated with the need to use complex technologies [3, 4, 5] and expensive equipment. The accuracy of parts is constantly increasing, so in production it is necessary to ensure high accuracy of spherical surfaces, which requires a special approach to the finishing methods of their processing [1, 2, 4, 5, 6, 7]. Today, the production of ceramic balls for bearings is widespread [3, 8, 9, 10, 11]. However, the published research works do not provide data on the possibility of using these technologies for steel billets. The main methods of final processing of balls are: processing with cast-iron disks of a special section with V-shaped grooves [2, 12, 13, 14] and methods of centerless grinding of balls [4, 6, 15, 16]. Methods of processing with magnetic fluid [17] and using ultrasound [3, 8, 9] are less common. However, the processing cycle is quite long and unfavorable for the environment [8, 9].

In the conditions of mass production the most acceptable methods of processing balls are the methods of centerless grinding [4, 6, 15, 16, 20], since this does not require the use of complex special technological equipment and it is possible to quickly reconfigure and automate the equipment already available at the enterprise.

Currently, a large number of different methods and devices are offered for processing balls in mass production. For example, a method for centerless balls grinding on a pass with their angular rotation [22], in which the balls are placed in a technological device on a beveled support knife and moved by means of a screw groove of the driving wheel with a screw groove along the forming grinding wheel, which is made with discharge ring grooves on the working surface. This method and device can improve performance by providing processing of the surface of the balls in one pass, but has the following disadvantages: low quality of the ball processed surface, which limits its use only by pre-grinding; sharp entry of the ball (according to the normal), after passing the annular discharge groove, into the zone of
action of the annular grinding section, which leads to chipping the edges of the grooves, and requires frequent dressing of the grinding wheel.

There is a method of centerless grinding of balls into a passage with their angular turn [23], in which the balls are placed in a technological device on a beveled supporting knife and moved by means of a helical groove of the drive wheel along the generatrix of the grinding wheel, which is made with discharge screw grooves on the working surface. This method has a significant drawback - an extremely difficult implementation, because the threaded groove on the driving circle can be performed only on specialized equipment having such technical ability. In machines of a centerless grinding group, this is not possible. After the drive circle with the helical groove made on it is installed on a centerless grinding machine, a runout will appear at the helical groove relative to the axis of the spindle. To eliminate the runout, it is necessary to edit the lateral surfaces of the helical groove “in place” on a centerless grinding machine, but this group of machines does not have such an opportunity. Therefore, the shape accuracy of the processed balls will be low, i.e. This method can only be used for roughing.

The development and research of methods for the final processing of balls was carried out by many scientists [15, 16, 18, 19, 20, 21]. Creating new methods of final processing of balls that allow predicting the necessary accuracy of the spherical surface is the main task of various studies of ball processing, it is the basis and prerequisite for further study.

2. The proposed method for centerless grinding of balls

2.1. Research task
The task of the proposed technical solution follows from the shortcomings of existing methods of processing balls and is aimed at eliminating these shortcomings, namely, to improve the accuracy and quality of the processed spherical surface without reducing productivity and increasing the complexity of its processing.

2.2. Description of the ball processing method
The task is solved as follows.

On the driving wheel, screw discharge grooves of a trapezoidal profile are made instead of V-shaped screw ones. In this case, the rectilinear groove forming the bottom is positioned parallel to the axis of the driving wheel.

Figure 1 shows the main view, the diagram of the working area of the device and the section A–A of the device main view.

The essence of the method is as follows. The workpiece 6 is positioned between the grinding 1 and the driving 3 abrasive wheels, the axes of which are parallel. Wheels are of unidirectional rotation with speeds of \( \omega_{gw} \) и \( \omega_{dw} \). As a support for the workpiece, a knife 5 is used, which is a single-beveled wedge with a slope towards the driving wheel, which provides the necessary contact with the latter before the start of processing due to the component of gravity. This allows to transfer the rotation of the workpiece from the driving wheel.

The working area is formed by a set of grooves made as follows: one in the form of a helical line 2 with a rectangular profile on the periphery of the grinding wheel, the second 4 in the form of a trapezoid on the periphery of the driving wheel.

The schematic diagram of this method largely corresponds to the traditional centerless grinding scheme, which allows the use of machine tools available in production.

A significant difference between the proposed device and its analogues is in changing the design of the driving wheel. Performing a screw groove of a trapezoidal profile on the driving wheel allows you to edit the bearing part of the driving wheel directly on the centerless grinding machine and thus eliminate the runout of the driving wheel. No additional thread-cutting device is required to implement edits of the driving wheel, which greatly simplifies and reduces the cost of this operation.
At the same time, the error of basing the spherical blank is significantly reduced, since it is not installed in the prismatic groove of the driving wheel, but on its rectilinear bottom, which leads to an increase in accuracy and a decrease in the size heterogeneity of the processed balls.

3. Determination of the base error for centerless grinding of balls

3.1. Assumptions
In order to consider the process of forming the accuracy of the balls size, we make the following assumptions:

- The surfaces of the faces of the groove made on the driving wheel are absolutely smooth and do not contain roughness or shape errors.

![Figure 1](image)

**Figure 1.** Schema of centerless grinding of a spherical workpiece with a trapezoidal profile of the driving wheel groove.
• The profile of the groove is assumed to be asymmetric, trapezoidal.
• The grinding wheel does not distort the picture of kinematic connections by its force action.
• There is no slippage between the driving wheel and the workpiece.
• The supporting surface of the knife is absolutely parallel to the axis of the driving wheel and has no roughness and shape errors.

3.2. Consideration of the ball basing scheme during processing and determination of the base error

Figure 2 schematically shows the ball blank in the grinding zone in the nominal position and in the position after the removal of the allowance. When exceeding the level at its center on a common plane \( O_{gw} - O_{dw} \) containing the axis of the driving and grinding wheels in the initial position \( h \) and in the end position \( h_1 \).

![Figure 2](image)

**Figure 2.** Scheme of the ball location in the processing zone based on the surface to be machined, provided the cut-in feed grinding wheel: 1 – grinding wheel, 2 – driving wheel, 3 – processing ball blank, 4 – machined ball, 5 – supporting knife.

From the point of view of determining the basing scheme, the mentioned method of processing balls is absolutely not ordinary. It is known that in centerless grinding, the workpieces are based on the surface to be processed: in this case, on the spherical surface, first of the original workpiece. Then, during processing, the technological base is not just immediately cut off, but is constantly updated.

The measuring base for forming the size of the ball is the center of the sphere. It is obvious that the technological and design (measurement) bases are not only not combined in fact, but could not be combined in principle. In addition, the center of the sphere is continuously shifted during processing. These circumstances inevitably cause an error based on the operating size (the diameter of the spherical surface).

It is characteristic that the adjustment size for this processing scheme is not the diameter of the sphere, but the size of the chord \( K - K_1 \), that connects the contact points of the treated surface and the surface
of the driving and grinding wheels. At the end of processing, this chord takes position $K' - K_1$. Therefore, the actual size to be performed is not the diameter of the sphere, but the value of this chord. And the base error will be the projection value of the displacement of the measuring base (the center of the sphere) on the direction of the specified chord.

At the initial moment of processing as presented in figure 2 the center of the ball is located above the axis of the centers of the grinding and driving wheels by the value $h$. When removing the full value of the allowance to the side $Z$, the measuring base of the adjustment size (the contact point $K_1$ of the processed ball with the driving wheel) is lowered together with the ball by the value $OO_1$ until the latter contacts the supporting knife. Moreover, due to the beveled supporting plane of the knife, the ball could additionally shift in the direction of the driving wheel to the point located to the right of the point $O_1$.

However, since the center of the ball with the support knife is initially located above the line of the centers of the grinding and driving wheels, it, under the influence of the driving wheel, "returns" to a certain value in the direction of the grinding wheel. In this case, the final value of the total displacement of the measuring base from point $K_1$ to point $K'$ and its projection on the direction of the adjustment value $K' - K_1$ is formed, which is the error of basing the ball on its diameter size. Further calculations show that the "return" value can be neglected because it is a second-order quantity of smallness.

Now we determine the value of the base error. The value of the adjustment size, which assumes indirectly obtaining the size of the ball $d$ as a result of processing, (the chord $KK_1$) can be determined as follows:

$$KK_1 = 2 \cdot \sqrt{\frac{d^2}{4} - h^2} \cdot \frac{D_B^2}{(D_B + D_{dw})^2}$$

where $D_B$ is the diameter of the ball work piece,
$d$ is the diameter of the produced ball,
$D_{dw}$ is the diameter of the driving wheel.

Similarly, we define the value of the chord $K'K'_{1}$:

$$K'K'_{1} = 2 \cdot \sqrt{\frac{d^2}{4} - \left(\frac{h - D_B - d}{2}\right) \cdot (1 + \sin(\alpha))} \cdot \frac{1}{(d + D_{dw})^2}$$

where $\alpha$ is the bevel angle of the support knife.

Let us denote $h_1$ the value of excess of the center of the processed ball over the plane in which the axes of the driving and grinding wheels are located after the end of processing:

$$h_1 = \left(\frac{h - D_B - d}{2}\right) \cdot (1 + \sin(\alpha))$$
The difference between expressions (1) and (2) is the base error on the adjustment size $\xi$:

$$\xi = 2 \cdot \sqrt{\frac{d^2}{4} - h^2} \cdot \frac{1}{(d + D_{dw})^2} - 2 \cdot \sqrt{\frac{d^2}{4} - h^2} \cdot \frac{D_{B}^2}{(D_{B} + D_{dw})^2}$$

As a result of the adjustment size having an error, the operating size (ball diameter) will also have an error. However, calculations show that these sizes differ by a second-order value of smallness, so the difference between (2) and (1) can be taken as the error value of the operational size, i.e. the value described by the expression (4).

3.3 Example

Let $D_{dw} = 300$ mm; $D_{B} = 26,4$ mm; $d = 25,4$; $h = 10$ mm; $\alpha = 30^\circ$.

Then the calculation on the formulas (1) and (2) gives the result: $KK_1 = 25,343$ mm; $K'K_1' = 25,399$ mm. The error of the adjustment size is $\xi = 0,057$ mm.

4. Conclusion

A method of centerless grinding of balls is proposed, characterized by the presence of screw discharge grooves of a trapezoidal profile on the driving wheel.

It is shown that the use of a trapezoidal groove on the driving wheel allows increasing the accuracy and quality of the processed spherical surface without reducing productivity and increasing the complexity of its processing.

Performing a trapezoidal screw groove on the driving wheel allows to edit the bearing part of the driving wheel directly on the centerless grinding machine and thus eliminate the runout of the driving wheel.

No additional threading device is required to implement the guide wheel edits, which greatly simplifies and reduces the cost of this operation.

The base error is determined that occurs in the process of centerless grinding of balls.

Traditional machine adjustment for the centerless grinding of balls gives a large error in obtaining the exact size of the balls.

A scheme for setting up the machine is proposed, which leads to an increase in accuracy and a decrease in the size of the processed balls.

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