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Development of new roll pass designs for ball-rolling rolls with continuously variable parameters

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Abstract. This article outlines modern approaches to the creation of roll passes for helical rolling mills for the production of grinding balls. The key feature is the roll design with continually varying parameters of its elements. Such elements include: flange width varying along the length of the roll; flange height, with a nonlinear function of flange rising; pitch of the helical groove which maintains constancy of the volume of the metal being deformed. Particular attention is paid to a new conceptual pass design for ball-rolling rolls with a variable groove depth, the prospects of which are connected with uniformity of reduction and the production of balls not only with the correct geometry, but also with a more homogeneous structure. The article shows functions of a continuously varying pitch of a helical groove of rolls with a constant and variable flange width, as well as with a variable depth of the groove. A practical test was conducted on ball-rolling rolls for production of balls with a nominal diameter 120 mm with continuously varying pitch. Experience has shown positive results both in reducing loads and in increasing the dimensional accuracy.

1. Introduction

One of the well-known and productive methods for the production of grinding balls is helical rolling [1–2]. The deformation of the metal is carried out on a ball rolling mill in rolls with screw passes.

The workpiece is fed between rolls that rotate in the same direction and are located at certain angles relative to each other. After passing through the roll passes, the workpiece is gradually crimped and takes the form of balls, which are separated from each other by cutting the bridge with the roll flange [1] at the last moment. Pass design of ball-rolling rolls, including the design of profile elements, should allow implementation of an efficient technology and, provide the possibility of manufacturing rolling tools on existing metal-cutting equipment.

Initially, from the 50s of the 20th century, cutting screw passes in rolls of ball-rolling mills caused certain difficulties since they were produced on screw-cutting lathes.

At the tie, manufacturing of roll passes required adjusting of the calculated screw pitch according to the capabilities of the machines available. Usually, the screw parameters were provided by selection of pairs of interchangeable gears and changes could only be discrete. That is, the finished roll had a discretely varying pitch of the helical pass [1–4]. The advantage of such passes is the relative simplicity and accessibility of metal-cutting equipment for the production of rolls. The disadvantages are the uneven reduction during the transition from one step to another, causing peaks in the load on the rolling drive, as well as long manufacturing time of rolls of this type due to the constant set-up of the machine feed change gear train and the need for its precise tuning to the required step.

For the first time, a continuously changing nonlinear parameter in the form of a step was used in practice and described in [5–6]. This cutting method was provided through the use of semi-automatic copy machines. At present, the production of ball-rolling rolls is carried out at 4 or 5 axis machining centers with independent drives, which allow to obtain an open profile of any complexity formed by curves of the 1st and 2nd orders [7] using the 3-D model.

The combination of rational pass design and dynamic rolling mode improvement, as was shown by us in [8], unambiguously lead to an increase in the service life of the rolling tool.

In connection with the above, development of roll design with continuously changing parameters of the profile elements is an urgent task, as this will provide less wear on the working surfaces, reduce dynamic load peaks, uniform reduction will lead to a more homogeneous grain structure and a uniform temperature distribution on the surface of balls subjected to further heat treatment.

2. Variable parameters used in roll passes of ball-rolling rolls

Among all the variable parameters of profile elements of ball-rolling rolls, the main ones can be distinguished: the pitch of the helical line T_i, the height of the flanges H_i, the width of the flanges B_i (Figure 1).

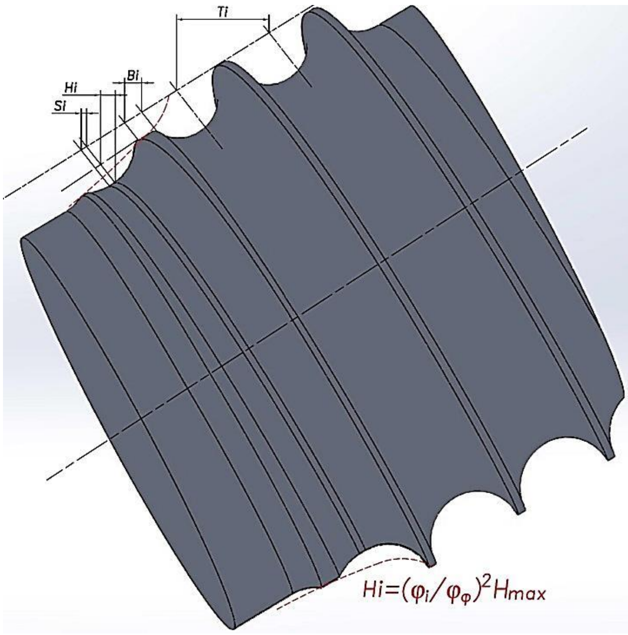

Figure 1. Ball rolling model with parabolic flange rising rule.
T_i – the pitch of the helix;
B_i – the flange width;
H_i – the flange height;
H_{max} – the maximum flange height (at the end of the forming section);
S_i – the magnitude of pass gauge expansion;
φ_i – the position angle along the helical line from the start of the flange;
$\varphi_\text{ф}$ – the angle at which the forming section ends (at which the flange has a maximum height H_{max}).

The influence of the pitch varying on the rolling process and the quality of the products were analyzed in the following works [9–14]. In their works, authors of Lublin University of Technology [15] present the results of experimental studies using rolls with different flange widths. Three possible structural cases were studied where the flange width changes in the direction of the workpiece movement along the rolls: 1 – decreases, 2 – increases 3 –remain approximately constant. In the first case, wear of rolls in the workpiece entry area decreases, in the second case wear decreases at the crossing point of the two rolls, however, in both cases there is a significant difference in reductions at the surface of the ball, which leads to higher wear intensity of the rolls. The third case with approximately the same flange width along the entire length of the roll is recognized as the most acceptable. Judging by the data of [1, 4, 6], the width of the flange depends on the helical groove pitch T_i and the pass gauge spacing S_i (Figure 1). As a result, a design can be considered rational where the flange first slightly thins out, and then increases as the workpiece moves along the rolls, creating favorable conditions for separating the tail from the finished ball.

The rise of flanges is characterized by an increase in their height in the initial, forming, section of the roll. This is necessary to ensure gradual cutting into the workpiece. The function that determines the increase in height - the so-called rule of flange rising the can be linear, parabolic or hyperbolic [7]. At the moment, the linear rule has received the widest application. If a nonlinear rule is applied, the flange width will 'float' unevenly (Figure 1), which will lead to uneven metal adherence to the roll and instability of the rolling process.

3. New pass designs with continuously varying parameter

As noted above, the pitch of the helix must continuously vary to maintain a constant volume of metal between the rolls, which is limited by adjacent flanges, including the volume of metal in the tail. In our previously published works [7, 16], the pitch variance function Δt was derived for rolls with a continuously varying pitch and a constant flange width.

$$\Delta t = T_{mn} - \int_R^0 \frac{\pi b(R^2 - x^2) + x^2(R - \frac{x}{3})}{\pi R^2} dx \tag{1}$$

where b_φ (b) is the flange width (tail length); R is the radius of the sphere of the conditional pass (the depth of the roll groove); T_{mn} is the main pass pitch (set during design taking into account the flange width).

For ball-rolling rolls with a linearly increasing flange width, the pitch variance function of a screw pass has the form equation (2).

$$\Delta t = T_{mn} - \int_R^0 \frac{\pi b_\varphi (1 - x) + x^2(R - \frac{x}{3})}{\pi R^2} dx \tag{2}$$

Application of passes with a continuously varying pitch, calculated according to equations (1 and 2), eliminates jumps in loads during the rolling process.

A roll pass design with a variable depth of the groove has been developed to improve reduction uniformity and temperature distribution, as well as the formation of a more uniform structure of the balls.

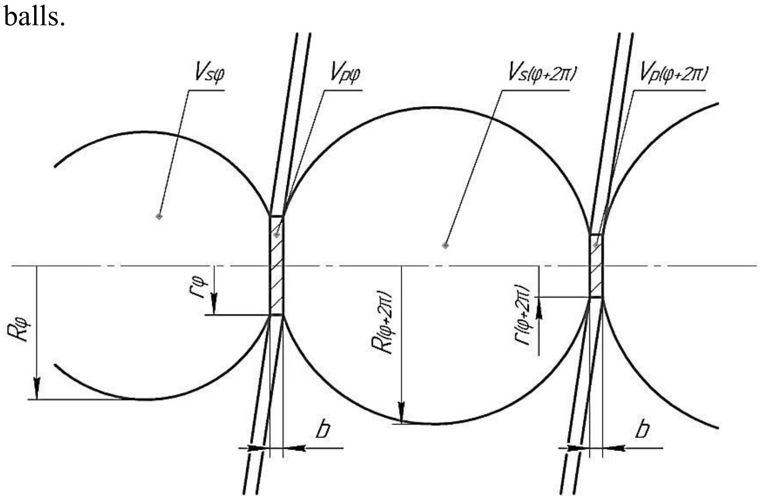

Figure 2. Section of a workpiece during rolling with a variable groove depth.

Given the strength conditions, the width of the flange was set, which is assumed to be constant. According to Figure 2, applying the partition into the basic geometric figures, we find the change in the radius ΔR which forms the ball.

From the conditions of constancy of metal volume passing through a screw pass, we compose equation (3)

$$V_{p\varphi} + V_{s\varphi} - V_{p(\varphi+2\pi)} - V_{s(\varphi+2\pi)} = 0 \tag{3}$$

where $V_{p\varphi}$ is the volume of the truncated tail of the conditional pass, $V_{s\varphi}$ is the volume of the truncated ball of the conditional pass, $V_{p(\varphi + 2\pi)}$ is the volume of the truncated tail in the next turn of the conditional pass, $V_{s(\varphi + 2\pi)}$ is the volume of the truncated ball in the next turn of the conditional pass.

When substituting the values of volumes of simple shapes that make up this system, it turns out:

$$\pi r_{\varphi}^2 b + [\frac{3}{4}\pi R_{\varphi}^3 - r_{\varphi}^2(R_{\varphi} - \frac{r_{\varphi}}{3})] - \pi r_{(\varphi+2\pi)}^2 b - [\frac{3}{4}\pi R_{(\varphi+2\pi)}^3 - r_{(\varphi+2\pi)}^2(R_{(\varphi+2\pi)} - \frac{r_{(\varphi+2\pi)}}{3}) - r_{\varphi}^2(R_{\varphi} - \frac{r_{\varphi}}{3})] = 0 \tag{4}$$

where r_{φ} – is the tail radius of the conditional pass.

To derive the function of groove depth variance, we take $r_{(\varphi + 2\pi)} = 0$, because conditionally, the flange is reduced to contact. By substituting this value in equation (2), we get:

$$\pi r_{\varphi}^2 b + \frac{3}{4}\pi R_{\varphi}^3 - \frac{3}{4}\pi R_{(\varphi+2\pi)}^3 = 0 \tag{5}$$

The change in groove depth along the helical line will be determined by the difference in the grooves of adjacent turns: $\Delta R = R_{(\varphi + 2\pi)} - R_{\varphi}$, substituting this value in equation 5 and transforming, we obtain:

$$\Delta R = \sqrt[3]{\frac{4}{3} r_{\varphi}^2 b + R_{\varphi}^3} - R_{\varphi} \tag{6}$$

Because as the groove depth increases, the radius of the pass grows in all directions, the change in the radius of the pass will be equal to the change in the pitch of the helical line: $\Delta R = \Delta T$.

Given a variable value: $0 < r_{\varphi} < R$, where, r_{φ} is the radius of the previous position, and $R = R_{\varphi}$ is the radius of the workpiece, the pitch variance function will have the form:

$$\Delta t = \int_0^R (\sqrt[3]{\frac{4}{3} x^2 b + R^3} - R) dx \tag{7}$$

Thus, expressions (1), (2), (7) can be used to create models of rolls necessary for their manufacture.

4. Industrial trials of new pass designs

As noted above, the pitch as a production experiment, ball-rolling rolls were calibrated with a continuously varying pitch to obtain balls with a diameter of 120 mm.

The width of the flanges along the entire length of the roll is assumed constant and, based on the strength conditions, was 11 mm, in this regard, the calculation was carried out according to equation (1).

By integrating expression (1), 5 points are defined for tracing a curve to form the helical surface of the roll. The helical line of the roll with a continuously varying pitch is a kind of a second-order spatial curve, therefore, it is determined by its five points, and no four of them should lie on one straight line [17]. Based on these 5 points, a curve is built that is a helix with a continuously varying pitch; on the basis of this curve, a 3-D roll model is built. A set of rolls was made using this model on a 5-axis machining center (Figure 3). Results of test rolling showed that the load when using rolls with a continuously varying pitch during rolling decreased by 25–35%, in contrast to rolls with a discretely varying pitch.

Figure 3. Roll with constant flange width and continuously variable pitch.

Figure 4. Ball produced during the trial rolling.

The dimensions of the ball resulting from new rolls meets the requirements of Russian State Standard GOST 7524–2015 [18], and a significantly lower error is ensured. According to [18], the dimensions should be in the range: 125±5 mm. Actual results were 125±0.4 mm. An insignificant girdle up to 4 mm wide (Figure 4) is not a defect, but is required to prevent overflow of the pass, in the case of rolling a workpiece with a diameter at the upper tolerance limit. The produced batch of balls had no surface imperfections which could be rated as defective according to the standard.

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