INVESTIGATION OF FORCE PARAMETERS DURING ROLLING IN RELIEF ROLLS

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ABSTRACT

The paper presents the results of theoretical studies of the force parameters of thick-sheet blanks rolling in relief rolls. Empirical dependences were obtained to determine the average rolling pressure and force. When studying the pressure, the approach of replacing the deformation scheme with a flat analog was used. In the analysis of the force, the finite element method was used to determine the geometric parameters of the deformation zone. Verification of the obtained dependencies was carried out by comparison with the results of computer simulation. Comparative analysis showed high convergence of the calculation and simulation results, as well as the possibility of applying the formulas obtained not only for symmetrical rolling or for speed asymmetry, but also in the case of rolling in relief rolls of different diameters.

Keywords: asymmetric rolling, simulation, FEM, equation, pressure, force.

INTRODUCTION

The creation of new deformation technologies that makes it possible to obtain workpieces with improved mechanical properties remains one of the urgent tasks of metal forming. At the same time, it should be taken into account the fact that before conducting laboratory and industrial tests of a new deformation scheme, it must be comprehensively studied theoretically. At this stage, it is usually carried out to identify patterns of changes in energy-power characteristics from various geometric and technological parameters of the process. The obtained dependences, after checking for adequacy, allow to determine the most optimal parameters of the investigated deformation process. This approach has proven itself well in the study of combined processes [1, 2].

The purpose of this work is to determine the dependencies for finding the average pressure and deformation force during rolling in relief rolls. Due to the fact that the shape of the deformation zone during deformation in these rolls is quite complex, to solve the problem it was decided to apply the approach applied to deformation zones with a complex spatial shape [3]. The essence of this approach is to present the original spatial shape of the deformation zone with the closest

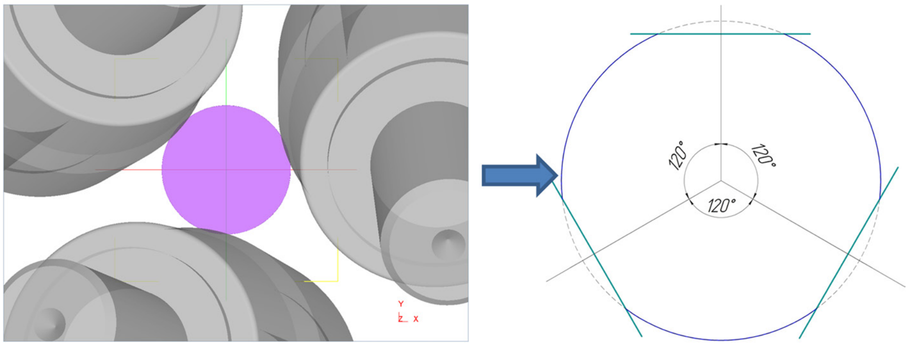

Fig. 1. Replacement flat diagram of the deformation zone during screw rolling.

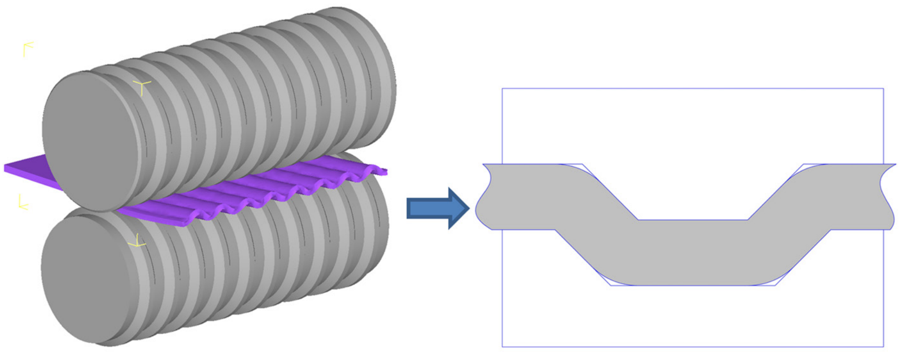

Fig. 2. Replacement flat diagram of the deformation zone during rolling in relief rolls.

flat scheme in appearance. For example, the scheme of screw rolling can be easily represented as a upsetting of a round billet with three strikers (Fig. 1).

For the rolling scheme in relief rolls, the closest scheme will be deformation in trapezoidal strikers (Fig. 2). Taking into account the presence of an approximation factor when replacing deformation schemes, after obtaining empirical dependencies it is necessary to check the adequacy of the obtained pressure and force values, which will be carried out using computer simulation.

EXPERIMENTAL

Fig. 3 shows a diagram of the introduction of a trapezoidal protrusion into the workpiece. At the same time, 2 deformation zones can be distinguished on the workpiece (highlighted in gray): zone 1 - the compression zone of the workpiece with a horizontal section of the protrusion; zone 2 - the compression zone of the workpiece with an inclined section of the protrusion [4].

The total work of the introduction of a trapezoidal protrusion into the workpiece can be found by the formula using the principle of work balance:

$$A_{SUM} = A_1 + A_2 + A_{SHEAR} \quad (1)$$

where A_1 - work for metal compression in the first zone; A_2 - work for metal deformation in the second zone; A_{SHEAR} - the work required to metal shear along the interface of zones 1 and 2.

A_1 work can be determined by the formula of E.P. Unksov for the strip upsetting [5]:

$$A_1 = \beta\left(\sigma_Y + \frac{g\tau}{3h_2}\right)gu_y \quad (2)$$

where g - length of the small base of the ledge; h_2 - the height of the workpiece after compression in zone 1; u_y - compression value in zone 1; σ_Y - yield strength of the material, MPa; β - coefficient of broadening during upsetting (usually in the range of 1.07 - 1.1, however, for the considered rolling scheme in relief rolls, β = 1 should be taken, since the thickness of the workpiece will not change in the deformation zone, i.e. plastic bending and

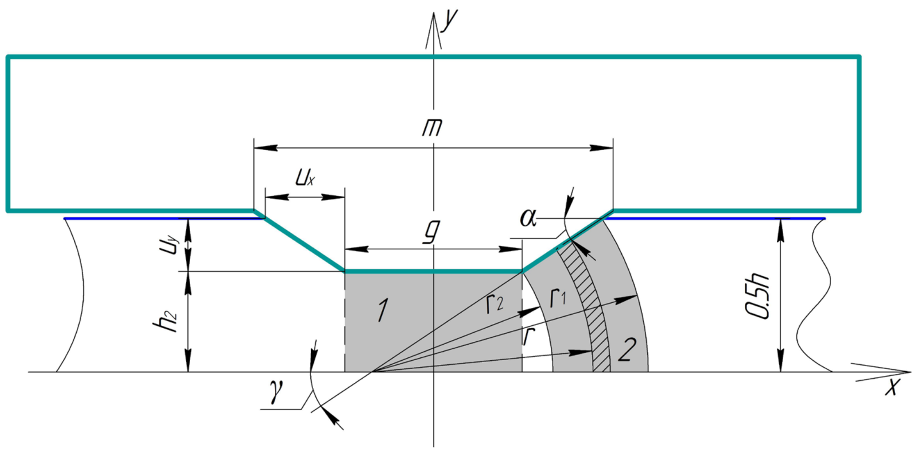

Fig. 3. The introduction of a trapezoidal protrusion into the workpiece.

shear will occur); $\tau = \mu\sigma_Y$, where μ - friction coefficient at the contact of tool and workpiece.

Work in the second zone is also determined by the work balance method:

$$A_2 = A_D + A_F \tag{3}$$

where A_D - deformation work; A_F - friction forces work.

The deformation work value is determined by the formula:

$$A_D = -\sigma_Y \frac{2}{\sqrt{3}} u_x r_2 \frac{\pi\gamma}{180} \ln\frac{r_1}{r_2} \tag{4}$$

where u_x - horizontal projection of the inclined section of the protrusion that is embedded in the workpiece.

The friction forces work is determined by the formula:

$$A_F = -\tau u_x r_2 \ln\frac{r_1}{r_2} \tag{5}$$

To determine the total work in the second zone, it is necessary to substitute equations (4) and (5) into equation (3), taking into account the following assumptions:

$$\frac{r_1}{r_2} = \frac{0{,}5h}{0{,}5h - u_y} = \frac{h}{h_2} \tag{6}$$

$$r_2 = \frac{0{,}5h - u_y}{\sin\gamma} = \frac{h_2}{\sin\gamma} \tag{7}$$

$$\ln\frac{h}{h_2} \approx \frac{\Delta h}{h} = \frac{u_y}{h} \tag{8}$$

As a result, the equation for determining the total work in the second zone will have the form:

$$A_2 = -\frac{h_2}{\sin\gamma}\frac{u_x u_y}{h}\left(\sigma_Y \frac{2}{\sqrt{3}}\frac{\pi\gamma}{180} + \tau\right) \tag{9}$$

The value of work for the metal shear along the interface of zones 1 and 2 can be found by substituting the displacement of points on this surface from u_y to 0 and taking the average displacement in this area as a value of $0{,}5u_y\sin\alpha$. As a result, this component can be found by the formula:

$$A_{SHEAR} = 0{,}5h\sigma_Y u_y \sin\alpha \tag{10}$$

After substituting expressions (2), (9), (10) in formula (1), the total work of the introduction of a trapezoidal protrusion into the workpiece has the form:

$$A_{SUM} = -\frac{h_2}{\sin\gamma}\frac{u_x u_y}{h}\left(\sigma_Y \frac{2}{\sqrt{3}}\frac{\pi\gamma}{180} + \tau\right) + \\ + \beta\left(\sigma_Y + \frac{g\tau}{3h_2}\right) g u_y + 0{,}5h\sigma_Y u_y \sin\alpha \tag{11}$$

After dividing both parts of the formula by the u_y and the contact surface area, a formula for determining the average pressure is obtained:

$$p_{AV} = -\frac{h_2}{g\sin\gamma}\frac{u_x}{h}\left(\sigma_Y \frac{2}{\sqrt{3}}\frac{\pi\gamma}{180} + \tau\right) + \\ + \beta\left(\sigma_Y + \frac{g\tau}{3h_2}\right) + \frac{1}{g} 0{,}5h\sigma_Y \sin\alpha \tag{12}$$

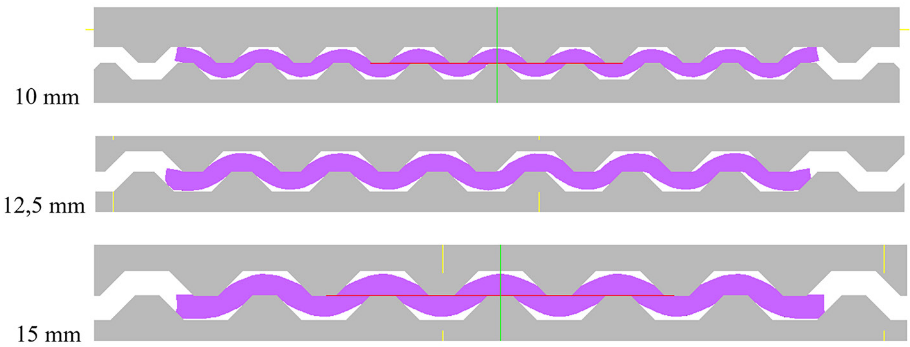

Fig. 4. Workpiece profiles at the moment of exit from the deformation zone of relief rolls.

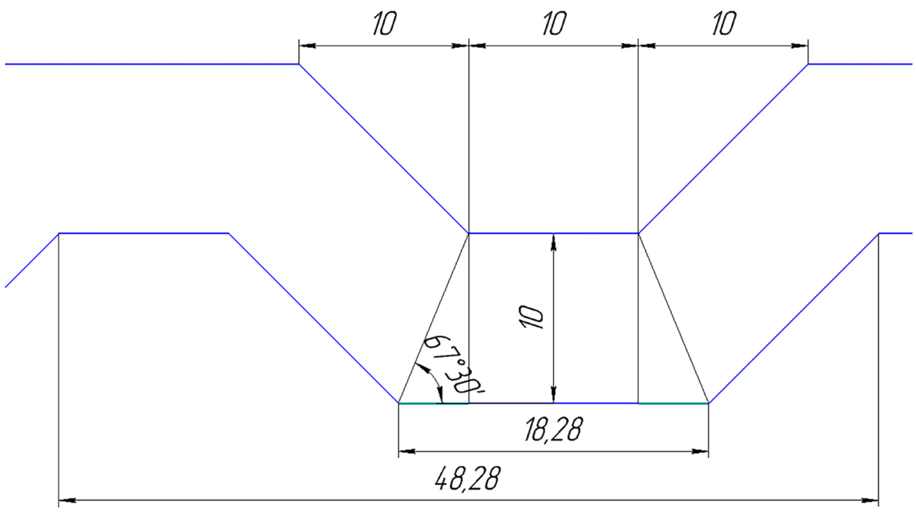

Fig. 5. Configuration of the unit width of the profile.

To determine the rolling force, a classical formula is used in which the average pressure is multiplied by the contact surface area. The value of this area is usually represented by multiplying the average contact surface width by the deformation zone length. However, when considering the deformation scheme, the determination of these geometric parameters is difficult due to the fact that after being captured by relief rolls, the metal changes the cross-section shape in accordance with the rolls configuration, while the gap profile between the rolls is never completely filled. As a result, the contact surface width will always be less than the rolled workpiece width. Analytically, it is impossible to predict the approximate contact surface width, therefore to solve this problem, it was decided to use the approach proposed by A.A. Bogatov when determining the deformation parameters in forging strikers with a complex contact surface [6, 7].

The essence of this method is the initial modeling of the process by the finite element method. Then the necessary parameters are measured in the obtained models, on the basis of which correction coefficients are introduced into the classical formulas.

Fig. 4 shows the workpiece profiles of various thicknesses at the time of the exit from the deformation zone of relief rolls of the various configurations. In all considered models, the initial workpiece width was 400 mm.

From the shape of the workpiece profiles in Fig. 4, it can be seen that in all cases the workpiece is completely in contact with both the horizontal section of the protrusion and approximately the half of inclined section length. At the same time, the task is to find the number of contact steps for a given width and thickness of the workpiece.

To determine the number of contact steps for each roll, it is necessary to consider the unit width of the profile (Fig. 5). The value of this parameter will consist of the length of lower protrusion base (equal to triple the length of the protrusion width) and the depression width, which is found by the formula:

$$b = g + 2\left(\frac{h}{tg67{,}5}\right) \quad (13)$$

The initial workpiece width should be divided by the value of the unit width of the roll profile. The resulting value, rounded to an integer, will represent the number of contact steps for one of the rolls, for the other roll the number of contact steps will be less by 1.

Thus, the following values of contact steps were obtained with a workpiece width of 400 mm: for a thickness of 10 mm - 8 and 7; for a thickness of 12.5 mm - 7 and 6; for a thickness of 15 mm - 6 and 5. Comparison of the obtained values with the data of Fig. 4 showed complete convergence.

For the variant when the workpiece end is on a horizontal protrusion (case for 10 mm), due to the bending action both ends are partially in contact with both rolls, as a result of which contact with the horizontal section of the protrusion will be incomplete. The effect of contact at the workpiece ends in this case can be ignored, since such a double contact is identical for both rolls.

For the variant when the workpiece end is located on an inclined section of the protrusion (cases 12.5 and 15 mm), the side face of the workpiece is partially in contact with one of the rolls, whereas on the opposite roll at the last contact stage there is no contact on the inclined section. In this case, the influence of the contact of the ends of the workpiece can also be considered mutually exclusive.

As a result, the total contact surface width can be determined by the following formula:

$$B_{CONTACT} = \frac{Bg\left(1+\sqrt{2}\right)}{(4g + 2\left[\frac{h}{tg67{,}5}\right])} \quad (13)$$

To find the value of the deformation zone length, the classical formula is usually used:

$$l_d = \sqrt{R \cdot \Delta h} \quad (14)$$

Here, with a known radius of the rolls on the rolling mill, it is only necessary to find the amount of change in the workpiece height. Theoretically, its maximum possible value will be equal to double thickness of the workpiece. However, it can be seen from Fig. 4 that in all cases the total amplitude of the ridges is approximately 1.8 of the workpiece thickness. Therefore, the formula for determining the deformation zone length during rolling in relief rolls can be presented in the following form:

$$l_d = \sqrt{0{,}8hR} \quad (15)$$

RESULTS AND DISCUSSION

To check the adequacy of the pressure values obtained by calculating the formula (12), three different variants of M1 copper alloy blanks were calculated. The workpiece thickness was chosen as a variable parameter: 10 mm, 12.5 mm and 15 mm. The initial data for the calculation are presented in Table 1. Taking into account the fact that when rolling in relief rolls due to plastic bending and shear, the height of the workpiece changes by a double amplitude, it can be assumed that $h = 2h_2$. To determine the parameter τ, the value of the coefficient of friction was assumed to be 0.7, which corresponds to a roughened surface with a notch without the use of lubrication [8]. To find the u_x parameter, the following expression is used:

$$u_x = h_2 tg\left(90 - \alpha\right) \quad (16)$$

As a result, an average pressure value of 136.8 MPa was obtained for all thicknesses. This is a consequence of the fact that in the studied configuration of relief rolls,

Table 1. Initial data for calculating the average pressure.

Thickness, mm	h, mm	h_2, mm	g, mm	$\gamma=\alpha$, deg	σ_Y, MPa	$\tau = \mu\sigma_Y$, MPa	u_x, mm
10	20	10	10	45	120	84	10
12.5	25	12.5	12.5	45	120	84	12.5
15	30	15	15	45	120	84	15

the values of the gap between the rolls and the protrusion width are equal. As a result, the unit width of the gap between the rolls (the distance between two identical points along the width of the roll) for all thicknesses will be the same in shape and size ratios, differing only in scaling, which depends on the workpiece thickness.

When simulation with the specified parameters, the following results were obtained (Fig. 6).

Table 2 shows the values of the average pressure obtained by formula (12) and during computer simulation. Comparison of the results showed high convergence, which indicates adequate calculation results.

Fig. 7 shows a graph of the force when rolling a workpiece with a thickness of 10 mm and a width of 400 mm.

When calculating the force by multiplying the average pressure (12), the contact surface width (13) and the length of the deformation zone (15), a force value of 654048.3 N was obtained. Table 3 shows the summary values of the forces obtained during calculation and simulation. In all cases, the comparison of the results gives a fairly low error. At the same time, in all cases, the simulation force is slightly greater than the calculated one, which is associated with the value of the yield strength - one value is used in calculations, and in simulation it constantly changes according to the hardening curves of the material.

The considered technique is applicable not only in the case of symmetrical rolling or with speed asymmetry, but also in the case of rolling in relief rolls of different

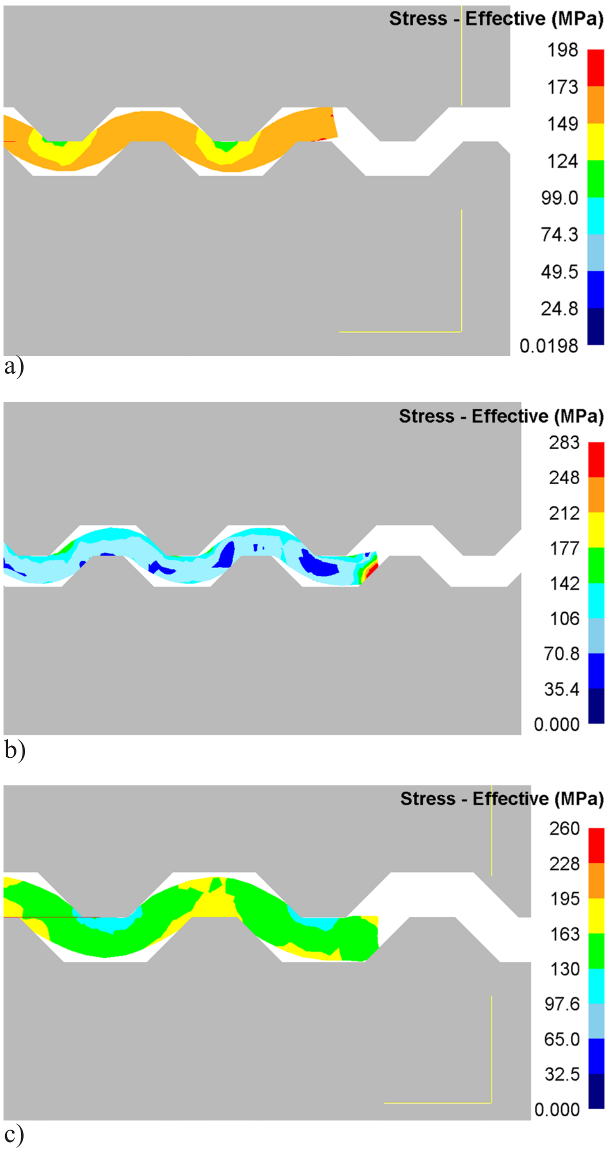

Fig. 6. Average pressure during simulation rolling of workpieces of various thicknesses in relief rolls: a) - 10 mm; b) - 12.5 mm; c) - 15 mm.

Table 2. Values of the average pressure during rolling in relief rolls.

Workpiece thickness, mm	Average pressure at calculation, MPa	Average pressure during simulation, MPa
10	136,8	140-147
12,5	136,8	135-142
15	136,8	130-138

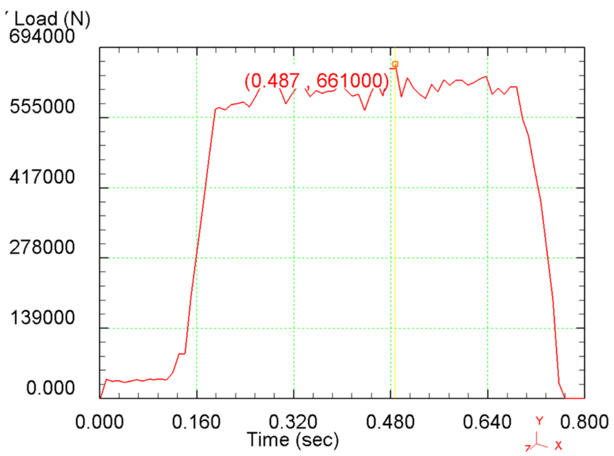

Fig. 7. Force graph when rolling a workpiece with a thickness of 10 mm and a width of 400 mm in relief rolls.

Table 3. Values of rolling forces in relief rolls.

Workpiece thickness, mm	Rolling force during calculation, N	Rolling force during simulation, N
10	654048,3	661000
12,5	783480,2	789000
15	858259,6	863000

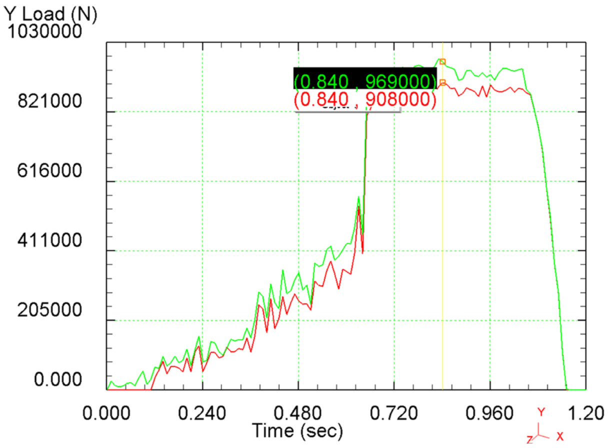

Fig. 8. Graph of rolling forces in relief rolls with geometric asymmetry.

diameters. In this case, the key parameter will be the deformation zone length, which depends on the roll radius. For testing, a rolling model of a workpiece with a thickness of 12.5 mm, a width of 400 mm in relief rolls with diameters of 200 and 300 mm (an asymmetry coefficient of 1.5) was constructed. The force graph on the rolls is shown in Fig. 8.

Based on the data obtained, the magnitude of the force on a roll with a diameter of 200 mm was 908000 N, and on a roll with a diameter of 300 mm - 969000 N. When calculated according to the considered method, the magnitude of the force on a roll with a diameter of 200 mm was 914060.2 N, and on a roll with a diameter of 300 mm - 959563.4 N.

CONCLUSIONS

The paper presents the results of theoretical studies of the force parameters of rolling thick-sheet blanks in relief rolls. Empirical dependences were obtained to determine the average rolling pressure and force. When studying the pressure, an approach was used to replace the deformation scheme with a flat analog - a broaching in trapezoidal forging strikers. To derive the average pressure equation, the work balance method was used. In the force analysis, the finite element method to determine the geometric parameters of the deformation zone was used, followed by the introduction of correction coefficients into known formulas from the rolling theory. Verification of the obtained dependencies was carried out by comparing with the results of computer simulation for three thicknesses of M1 copper alloy blanks: 10 mm, 12.5 mm and 15 mm with a width of 400 mm blanks. Comparative analysis showed high convergence of the results of calculation and simulation, as well as the possibility of applying the formulas obtained not only for symmetrical rolling or for speed asymmetry, but also in the case of rolling in relief rolls of different diameters.

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