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# Method of Galculating Metal Pressure on Rolls During Cross-Heligal Rolling

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**Abstract.**

The method for determining the metal pressure on the rolls in transverse rolling cone of the deformation zone during cross-helical rolling is considered. The method is based on the provision according to which the deformation process in the transverse rolling cone of the deformation zone of the piercing mill can be imagined as the process of rolling a strip on a sheet rolling mill, when the strip is delivered to the rolls at a certain angle. In this case, this process can be considered as a process of rolling strip on a continuous mill. The method involves dividing the transverse rolling cone of the deformation zone into separate ring elements, determining geometric, deformation, kinematic and force parameters for each ring element, and then finding the metal pressure force on the rolls in the rolling zone of the deformation zone of the cross-helical rolling mill by summing the forces acting on the ring elements. The graphs are given that were obtained using the Excel program and reflect the dependence of the specific pressure in the rolling zone on the geometric and deformation parameters of the piercing process.

**Keywords:** cross-helical rolling; deformation metal pressure; roll.

## Introduction

Determination of the specific pressures between metal and rolls in the process of piercing of round tube work is a difficult task. In the theory of tube rolling, there are various methods for calculating specific pressures that provide satisfactory results [1-4]. At the contemporary stage, the most accurate is considered to be A.I. Tselikov's formula [5] derived using the method of characteristics. According to this formula, the average specific pressure between the metal and the rolls in the piercing sector of deformation zone is equal to:

$$p_1 = 2k(1,25\ln\frac{2r}{b} + 1,25\frac{b}{2r} - 0,25),$$

where $k$ is the resistance to plastic deformation of the metal for a tense situation "pure shear"; it can be determined by from the image $2k = 1,15\sigma_{\text{act}}$; here $\sigma_{\text{act}}$ is actual resistance to plastic deformation of metal; $r-$ radius of the tube work in the center of deformation zone; $b-$ the width of the deformation zone in the same section.

The above formula is used when $1 \le \frac{2r}{b} \le 8,5$ and when $\frac{2r}{b} \triangleright 8,5$ the average specific pressure can be calculated by the Prandtl formula $p_1 = 2k(1+\frac{\pi}{2}),$ which is also derived by the method of characteristics for inserting a punch into a plastic body. Using the same formula, we can calculate the average specific pressure in the transverse rolling cone..

## Main Part

We have developed the method of calculating the average specific pressure in a transverse rolling cone. The method is based on the provision according to which the deformation process in the transverse rolling cone of the deformation center of the bending station can be imagined as the process of rolling a strip on a sheet-fed stand, when the strip is delivered to the rolls at a certain angle. If we select a ring element on the deformable product at the beginning of the stretching zone and consider its deformation in the rolling cone, we will get that this process is continuous and will be completed in several cycles. In such a case, this process can be considered as a rolling process on a continuous mill.

The deformation zone should be divided into ring elements according to the principle of Emelianenko-Tselikov, according to which the reduction of the spindle wall in any section of the transverse rolling cone is determined by the difference in wall thickness in this section and in the section at a distance from it, when the volume of the metal between these sections is equal to the volume of the supplied metal in the rolls 1/n per revolution (n is the number of rolls in a given working stand [6].

The scheme of the division of the transverse rolling cone is given in fig. 1.

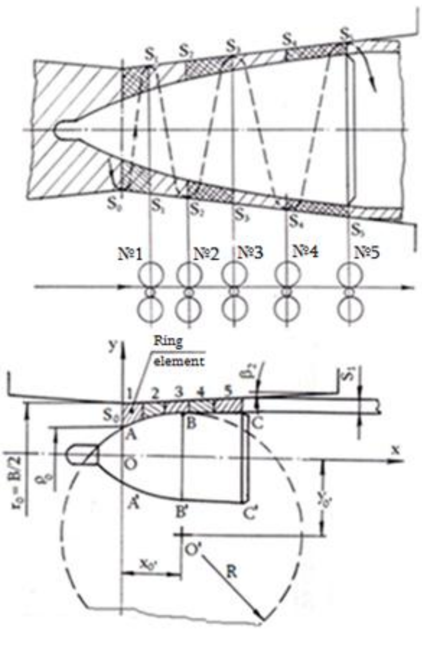


**Fig. 1. Scheme of the division of the transverse rolling cone**

A rectangular coordinate system xOy is also marked on this drawing, the center of which is placed in the center of the deformation zone. In this coordinate system, the geometrical parameters of all the ring elements of the deformation zone are determined by using the equations of the profile of the roll barrel and the mandrel.

First of all, we calculate the delivery volume using the formula:

$$\Delta V = Fu_x \Delta t, \qquad (1)$$

where $F$ is the cross-sectional area of the product; $u_x -$ axial velocity of workpiece: $u_x = u_{x0}\dfrac{F_0}{F}$;

$u_{x0} -$ the axial velocity of the workpiece at the center of the deformation, which is equal to: $u_{x0} = v_0 Sin\alpha\eta_0$, here $v_0 -$ the circular speed of the roll in the center of deformation zone; $\alpha -$ the delivery angle; $\eta_0 -$ coefficient of axial slip between metal and rolls, $\eta_0 = 03{,}5 \div 0{,}68$ [7]; $F_0 -$ cross-sectional area of the product in the center of deformation zone; $\Delta t -$ 1/n-turn time of roll.

After that, using the equations of the roll barrel generatrix line and the mandrel's profile, we will determine the radiuses of the workpiece - we will find the outer radius according to the roll barrel scraper equations, and the inner radius - with the ruler profile equation.

The equation of the roll barrel generatrix line represents a line in the xOy system, the angular coefficient of which is equal to the tangent of the angle of inclination of this line to the x axis [8], i.e. $y' = a_1 x + b_1$, where $a_1$ is the angular coefficient of the roll barrel generatrix line: $a_1 = tg\beta_2$; $\beta_2 -$ the angle of the rolling cone; $b_1 = \dfrac{B}{2} -$ half of the distance between the rolls in the center of deformation zone.

The mandrel's profile is the interface of the circumference of the spherical area ($R_{sph}$) and the line of the rolling zone (see Fig. 1.). In order to simplify the calculation, we can replace the actual profile of the mandrel with a square parabola (Fig. 2), whose equation is written as follows:

$$y''^2 = c\ (x+k) \text{ or } y'' = \sqrt{c(x+k)} \qquad (2)$$

The coefficient c is determined from this equation after inserting the coordinates of any characteristic point, for example "D": $x_D = l - k$; $y_D = \delta/2$, here $l$ is the length of the ruler; $k -$ pulling out the nose of the mandrel from the center of the deformation zone; $\delta -$ diameter of the mandrel.

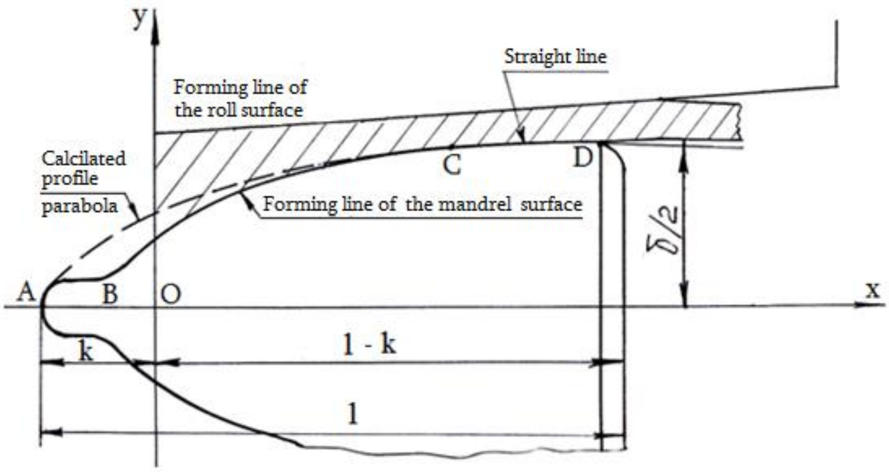


Fig. 2. The calculated profile of the mandrel

Then $c=\dfrac{\delta^2}{4l}$ and the equation of the mandrel profile will be:

$$y''=\sqrt{\frac{\delta^2}{4l}(x+k)} \qquad (3)$$

Based on the delivered volume, we calculate the width of the ring elements:

$$\Delta l=\frac{\Delta V}{\pi[y'^2(x)-y''^2(x)]} \qquad (4)$$

From the scheme in Fig. 3, we get the width of the first ring element:

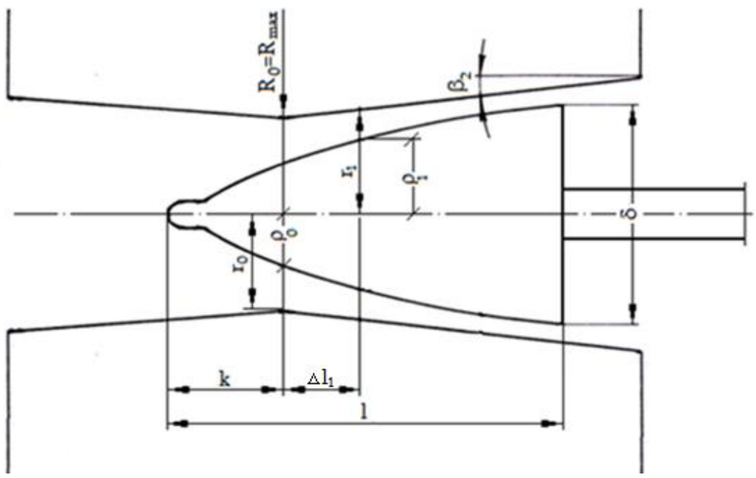


**Fig. 3. The scheme of determining the width of the ring element**

$$\Delta l_1=\frac{\Delta V}{\pi[y'^2(x_0)-y''^2(x_0)]};\quad here\ \mathrm{x}_0=0 \qquad (4a)$$

Following in the $x=x_1=\Delta l_1$ cross-section, we calculate the geometrical, deformation, kinematic and force parameters for the first ring element of the deformation zone:

1) Ordinates of the roll and mandrel profile points in $x=x_1=\Delta l_1$ cross section:

$$y'(x_1)=a_1x_1+b;$$

$$y''(x_1)=\sqrt{c(x_1+k)} \qquad (5)$$

2) The initial and final wall thickness of the ring element:

$$S_0=y'(0)-y''(0);$$

$$S_1=y'(x_1)-y''(x_1) \qquad (6)$$

3) Reduction of wall thickness: $\Delta S=S_0-S_1$.

4) Average wall thickness: $\bar{S}=0,5(S_0+S_1)$.

5) Relative deformation of the wall: $\varepsilon_S=\Delta S/S_0$.

6) The radius of the roll in the given section equal to:

$$R_{\min}=\frac{A}{2}-y'(x_1), \qquad (7)$$

where A is distance between the axes of the rolls.

7) We calculate the width of the deformation center by the formula:


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$$b = \sqrt{\frac{2R_{\min} \cdot y'(x_1)}{R_{\min} + y'(x_1)} \cdot \Delta S} \qquad (8)$$

8) Contact area: $\Delta F = b\Delta l_1$.

9) The circular speed of the workpiece: $u_y = v_0 Cos\alpha \cdot \eta_y$, where $v_0$ is the circular speed of rolls; $\alpha -$ delivery angle; $\eta_y -$ coefficient of tangential slip between the metal and the rolls, $\eta_y = 0,85 \div 1,05$ [7].

10) stress state coefficient $n'_\sigma = 1 + 0,25b/\bar{S}$.

11) The coefficient of influence of the width of the ring element on the pressure; when $\Delta l \lhd 5b$ this coefficient calculated by the formula:

$$n_B = (1 + \frac{3\Delta l - b}{3\Delta l}\frac{b}{4\bar{S}}) : (1 + \frac{b}{4\bar{S}}) \qquad (9)$$

12) Actual resistance to plastic deformation of metal calculated by the formula:

$$\sigma_{\text{act}} = \frac{133\varepsilon^{0,252}({ds}/{dt})^{0,143}}{e^{0,0025\,t}}, \qquad (10)$$

where ${ds}/{dt}$ is rate of deformation, ${ds}/{dt} = \frac{\Delta S \cdot u_y}{\bar{S}b}$; e - the base of the natural logarithm, e = 2,72; t – metal temperature, t = 800-1200$^0$C.

13)Average specific pressure calculated by the formula:

$$\bar{p} = n'_\sigma n_b \sigma_{\text{act}} \qquad (11)$$

14) The metal pressure on the roll for considered ring element is determined by the formula:

$$\Delta P_1 = \bar{p} \cdot \Delta F \qquad (12)$$

We will calculate the height of the second ring element $\Delta l_2 = \frac{V_0}{\pi[y'^2(x_1) - y''^2(x_1)]}$ and

for the value $x = x_2 = \Delta l_1 + \Delta l_2$ of the argument, we repeat all the above calculations from 1 to 14 inclusive.

As a result, we get the metal pressure on the roll, which acts within the second ring element.

We continue the calculation until the argument reaches or exceeds the value:

$$x = \Delta l_1 + \Delta l_2 + \Delta l_3 + ..... = x_{\max}, \qquad (13)$$

here $x_{\max} = \frac{d_1 - B}{2tg\beta_2}$; $d_1$ is the diameter of the pipe; $B -$ the distance between the rolls; $\beta_2 -$ the angle of the launch cone. In the first case, the calculations end, in the second case, they continue on the value $x = x_{\max}$ of the argument.

In the end, we get the metal pressure on the rolls for all the ring elements, by adding them together we will have the full value of the metal pressure for the transverse rolling cone of the deformation zone:

$$P_2 = \Delta P_1 + \Delta P_2 + \Delta P_3 + ...... \qquad (14)$$

A specific numerical example performed by the authors using the method presented above according to the following initial data:

- tube dxS = 89x12; workpiece $d_0$ = 90; sleeve $d_1xS_1$ = 95x16;
- diameter of the roll D = 700 mm;
- angle of the launch cone of the roll $\beta_2 = 4,5^0$; $tg\beta_2 = tg4,5^0 = 0,08$;
- delivery angle α=6$^0$; $Sin\alpha = Sin6^0 = 0,1045$; $Cos\alpha = Cos6^0 = 0,9945$;
- Rotational frequency of roll n = 100 RPM;
- diameter of the mandrel $\delta = 58$; length $l = 116$;
- minimal distance between rolls $B = 80$;
- Pulling the mandrel from the center of the deformation zone $k = 26$ mm;
- tube material – steel 45.

The scheme of the deformation zone is given in Fig. 4.

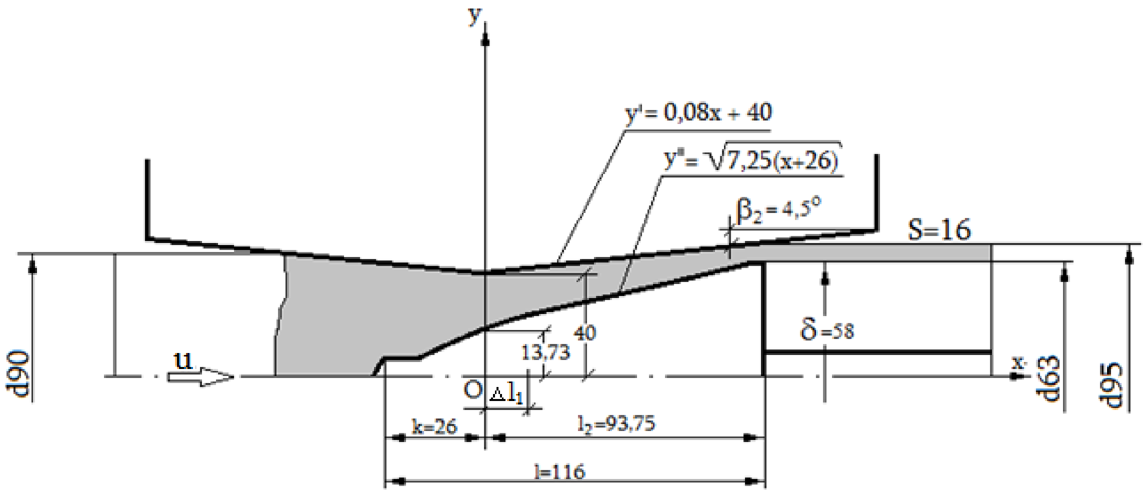


Fig. 4. Scheme of the deformation zone

According to the report in the Excel program, the force acting in the transverse rolling cone of the deformation zone of the cross-screw rolling mill is P = 19175,95 kg or 19.2 T, which corresponds to the experimental value reported in the technical literature [8].

As a result of theoretical research using the Excel program, graphs (fig. 5) were obtained that reflect the relationship between specific pressure and geometric and deformation parameters.

Analysis of the first graph (see 5a) shows that the increase of the deformation rate from 5 $sec^{-1}$ to 23 $sec^{-1}$ leads to increasing specific pressure from 15 $kg/mm^2$ to 21 $kg/mm^2$, i.e. the ratio of growth this parameters is 0,33 $kg.sec/mm^2$.

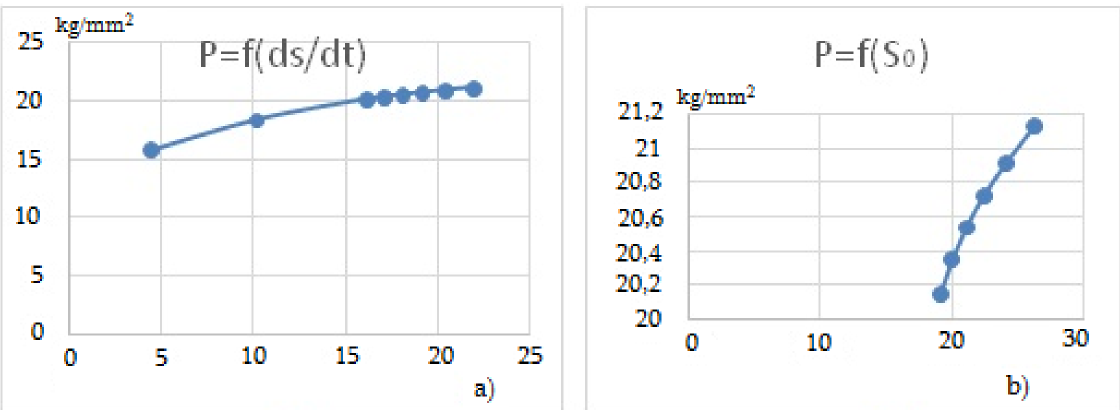


Fig. 5. Relationship between specific pressure and deformation rate and wall thickness of tube

As it should from the second graph (5b) the thickness of the pipe wall increases from 19 mm to 27 mm, but specific pressure increases from 20,1 $kg/mm^2$ to 21,2 $kg/mm^2$ that is the ratio of growth this parameters is equal to 0,14 kg/mm. That is almost two times less than in the first case, i.e. the deformation rate


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has a greater effect on the specific pressure than the thickness of the tube wall.

## Conclusion

Proposed method for determining the metal pressure on the rolls during cross-helical rolling involves dividing the rolling zone of the deformation zone into separate ring elements, fin ding the metal pressure force on each separate ring elements and summing the forces acting on the ring elements.

2. Numerical calculations of forces acting in the transverse rolling cone of the deformation zone of the cross-screw rolling mill have shown that obtained values of forces corresponds to the experimental values reported in the technical literature.

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