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Особливості холодної періодичної прокатки при виробництві довгомірних конічних трубчатих виробів

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Features of cold periodic rolling in the production of long conical tubular products

Анотація. *Істотна економія металу досягається при використанні в металоконструкціях трубчастих виробів змінного перерізу. Особливі технічні ефекти досягається у трубопроводах з змінною швидкістю потоку середовища. Процес ХПТ з зміною протяжності зони деформації в результаті варіювання довжини ходу робочої кліті забезпечує вирішення таких задач. Розглянуто особливості: формоутворення трубчастих виробів змінного перерізу; калібрування інструменту; визначення законів зміни довжини ходу робочої кліті. Розглянуто питання вдосконалення механізмів та вузлів цих станів.*
Ключові слова: *трубчасті вироби, зона деформації, робоча кліть, калібр, приводний механізм, миттєвий осередок деформації.*

Abstract. *Significant metal savings are achieved when using tubular products of variable cross-section in metal structures. Special technical effects are achieved in pipelines with variable medium flow rates. The HPT process with a change in the length of the deformation zone as a result of varying the stroke length of the working stand provides solutions to the following problems. The following features are considered: – shaping of tubular products of variable cross-section; – tool calibration; – determination of the laws of changing the stroke length of the working stand. The issue of improving the mechanisms and components of these machines is considered.*
Keywords: *tubular products, deformation zone, working stand, caliber, drive mechanism, instantaneous deformation zone*

In cherished memory of our teachers,
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and Doctor of Technical Sciences,
Professor Arkadii Semenovych Tkachenko

Tubular products of variable cross-section, which, being equally strong for a certain type of load, allow achieving significant metal savings when used as load-bearing elements of various metal structures. In some cases, they ensure the achievement of a certain technical effect - for example, in pipelines with a medium flow rate that varies along its length (automotive, aircraft manufacturing, power units of various fields of application and in a number of other areas of use).

A promising method for obtaining such products is the technological process [1], which consists in continuously changing the length of the deformation zone. The nature of the change and the limit values of the wall thickness of the finished pipe are completely determined by the calibration of the rolling tool, i.e. the nature of the change and the limit values of the gap between the crest of the gauge stream and the forming mandrel (for example, if they are parallel, then the finished pipe has a constant wall thickness). This method has maximum technological capabilities, since a whole range of products can be manufactured on one set of rolling tools. The method was developed at VNITI, where specialized cold rolling mills for conical pipes KhPTK-40 and KhPTK-75 with an adjustable mechanical drive of the working stand were first developed and manufactured [2]. The kinematic features of rolling long conical pipes on KhPTK mills are explained in Fig. 1.

The radius of the inner surface of the product is determined by the dimensions of the mandrel and its location in the deformation zone. Fig. 1, *a* show the initial (front) position of the gauges, from which the process of rolling a pipe of given dimensions and shape begins. In the position of the gauges II (Fig. 1, *b*), which corresponds to the opening of the feed and rotation throat (the rearmost position of the stand), the pipe blank is fed by the amount $\boldsymbol{m}$ and rotated. During the movement of the stand forward, the deformation of the fed metal occurs. Section 1 moves forward by the amount of linear displacement. During the first rolling cycle, the length of the stand stroke changes by the amount Δx_1 and the cross section 2 of the finished product is formed. The radius of this cross section R_2 is equal to the radius of the caliber stream in section 2. Section 1-2 of the finished pipe consists of part of the working cone and part of the instantaneous deformation center and has a length

$$l_{1-2} = m\mu_x^{(1)}, \quad (1)$$

where m- the value of a single feed of the workpiece;

$\mu_x^{(1)}$ – the extraction coefficient on the first double run of the stand.

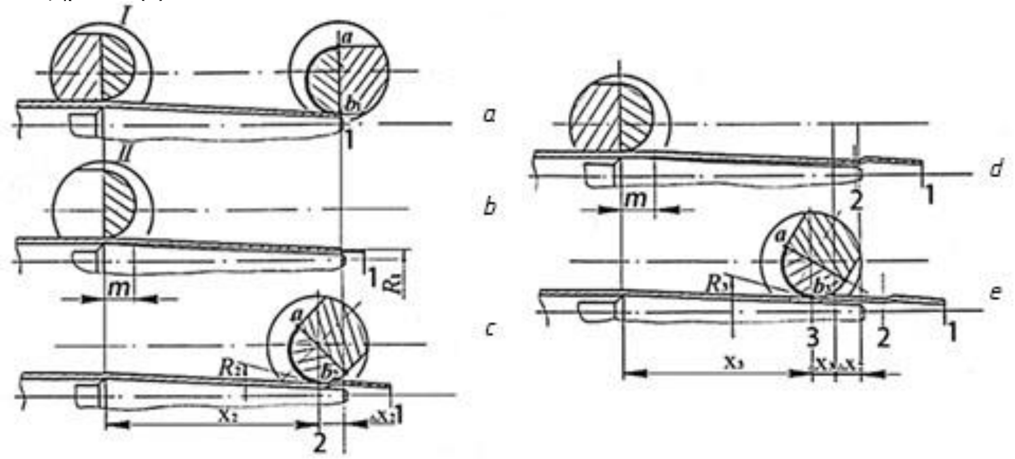

Fig. 1. Scheme of cold rolling of long tapered pipes on periodic rolling mills with changing the length of the stand stroke

The radius of the inner surface of section 2 is determined by the corresponding size of the mandrel. The third and subsequent sections are formed in a similar way (Fig. 1, *d* and 1, *e*) of the product. Thus, a variable cross-section pipe rolled on a HPTC mill can be represented as a sequence of elementary sections, each of which is formed in one double pass. The absence of a calibration section on the stream is due to the mobility of the front edge of the working cone. Therefore, each elementary section of the finished product is geometrically a combination of the corresponding part of the working cone, formed during the previous double pass, and an element of the instantaneous deformation center of the pipe blank, "frozen" in the extreme front position of the working stand (Fig. 1, *c*). Since during the return stroke of the stand, the section of the instantaneous deformation center, enclosed between the center line and its rear edge, is rolled out, the elementary section formed includes only the front zone of the deformation center. This zone is located between the center line of the working rolls and the front edge, which is determined by the dependencies known from the theory of cold rolling of pipes.

The geometric parameters of the instantaneous deformation center, and therefore the shape of the outer surface of the product, are largely determined by the conditions of the technological process. In [2], the dependences for establishing the limiting value of the single feed value, based on the given waviness of the outer surface, were first obtained. These studies were developed in a number of works related to the issues of determining the quality parameters of the outer surface and managing them; the mechanism of formation of irregularities such as "convexity" and "concaveness" on the pipe surfaces, which are formed as a result of ovalization of the rolled section in the outlets of the caliber stream and from the wave of metal during deformation of the workpiece by the bottom of the caliber stream, was considered. Some recommendations were developed that allow reducing these irregularities or reducing the level of their influence on the quality of the finished product. In [2, 4, 5], it was shown that the length and taper of each $i$elementary section, along with the feed value and calibration, are determined by changing the length of the working stand stroke Δx_i. The shape of the rolled pipe, as a sequence of elementary sections, is determined by the sequence of values Δx_i, i.e. the law of change of the length of the working stand stroke, which can be established either as a function of the serial number of the double stroke $\Delta x_i(i)$, or as a function of the length of the stroke $\Delta x(x_i)$. Despite the fundamental value of this parameter, there is no information about the method of its determination. Thus, in the work [2] there is only the total number of double strokes, during which a given product should be formed. For this, the length of the workpiece is determined L_3 from the condition of equality of the volumes of the finished conical pipe and the workpiece

$$L_3 = \frac{L_{\text{тр}}}{3({R_3}^2 - {r_3}^2)}\left[(R^2 + R_1^2 + RR_1) - (r^2 + r_1^2 + rr_1)\right], \quad (2)$$

where R_3 and r_3 are the outer and inner radii of the workpiece;

$R$and R_1 – the maximum and minimum radii of the outer surface of the finished conical pipe;

r and r_1 – the same inner surface of the conical pipe;

$L_{\text{тр}}$ – product length.

Based on the found length of the workpiece and the adopted value of the single feed, the following is determined: the number of N double passes of the stand, during which the given product is formed $N = \frac{L_3}{m}$ and some averaged value Δx_Φ changes in the length of the working stand stroke; $\Delta x_\Phi = \frac{x_m}{N}$ – the maximum length of the working stand stroke, on which the front section of the finished conical pipe is formed. It should be noted here that this approach to determining the parameter N is valid only in the case when it is known a priori that the drive mechanism works out the required law of changing the working stand stroke and as a result, a product of the specified dimensions is formed from the cylindrical workpiece. All the aspects described lead to the fact that the adjustment of the HPTC state for rolling each product is practically carried out experimentally after a series of trial rolling's of a batch of adjustment pipes.

In works [4, 5], attempts were made to somewhat refine the known sequence of calculating the initial parameters for the simplest linear-conical calibration of a rolling tool. However, the question of finding the necessary law of change in the length of the working stand stroke $\Delta x(x_i)$ remained unresolved. The drive mechanisms used on the KhPTK-40 and KhPTK-75 mills (the technical characteristics of which are given in Table 1) (Fig. 2.) represent a spatial system of power levers driven by crank wheels 4, lower connecting rods 5 and rockers 6, which transmit oscillatory motion to the two-armed levers 7 relative to the sliding hinge support 10. This motion, using connecting rods 8 connected to the upper hinges of the levers, is converted into a reciprocating movement of the working stand 9, the length of which depends on the position of the support 10 installed on the movable carriage 11. The carriage 11 is moved along the fixed inclined guides 13 by a screw mechanism 12. Stable positioning of the rear position of the stand is ensured by the corresponding inclination of the guide 13.

Types of products produced on HPTK mills. These mills can roll pipes of variable cross-section, representing a working cone (or their combination); various types of stepped pipes; cylindrical with variable wall thickness (if there is a mechanism for moving the mandrel); various profile products with a curvilinear generator. The main types of products of variable cross-section obtained on cold rolling mills of conical pipes are presented in Fig. 3.

Features of tool calibration of HPTK mills. The main difference in the kinematics of the technological process being analyzed is the programmatic change in the stroke length of the working rolls (cells), i.e. the length of the workpiece deformation zone, which causes a change in the draw ratio and all energy-power and geometric parameters during the rolling cycle of the finished product.

Table 1. Technical characteristics of the KhPTK-40 and KhPTK-75 mills

Indicators	Unit of measurement	Condition of HPTK-40	Condition of KhPTK-75
Workpiece dimensions: - outer diameter - maximum length - wall thickness	 mm m mm	 35– 46 5 1 , 35– 4.5	 20– 100 10 1 –15
Dimensions of finished pipes: - outer diameter - maximum length - wall thickness	 mm m mm	 18– 32 15 0.4– 4.5	 10– 120 20 0.8– 15
Rolling speed	dv . h. /min.	33/44/67	6 –50 (reg .)
Intensity of change in the length of the cage stroke	mm	0.05– 2.5	0.05– 2.0
Roller barrel diameter	mm	300	434
Cage stroke length	mm	50– 800	150– 1100
Crank radius	mm	300	480
Innings	mm	2.5– 15	2 –30
Main engine power	kW	28/35/40	110

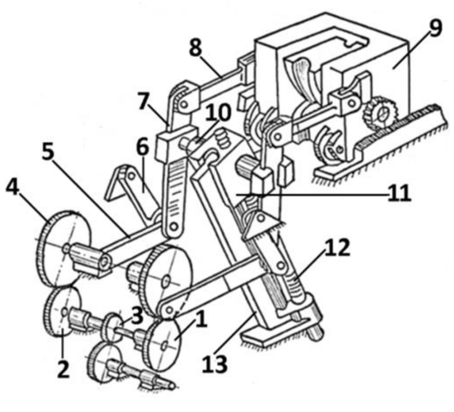

Fig. 2. Scheme of the lever drive mechanism of the KhPTK mill [3]

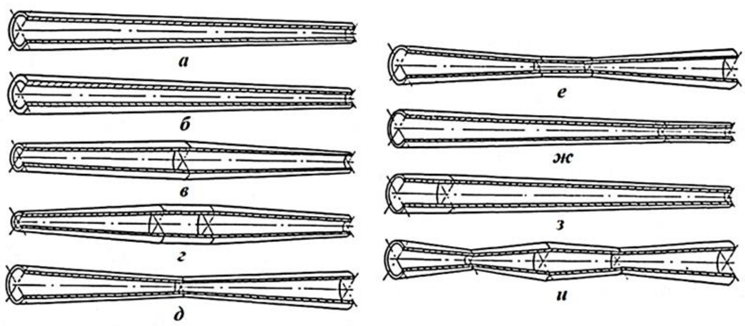

Fig. 3. Main types of variable cross-section products produced on KhPTK mills

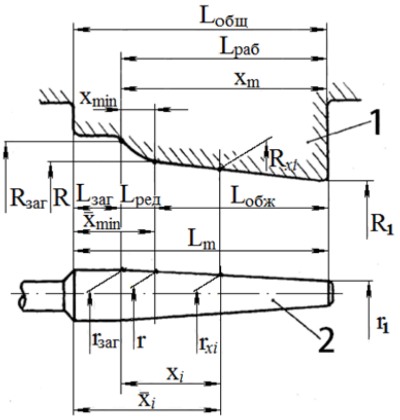

Fig. 4. Scheme of calibration of rolling tools of KhPTK mills:
1 - scan of the crest of the caliber stream; 2 - mandrel

Due to the lack of mathematical models describing the relationship between the mechanical characteristics of the HPTC mill equipment with the conditions of the technological process and the profile of the product being formed, the tool calibration was established based on the condition of obtaining a given product geometry. Thus, for HPTC mills with lever drive mechanisms, the best correspondence of technological and mechanical parameters occurs when using linear-conical calibration of the stream and mandrel. Calibers of HPTC mills (Fig. 4) along the sweep length $\mathrm{L}_{общ}$ have 3 sections: feed and rotation throat $\mathrm{L}_{заг}$ (in the rearmost position of the cage), reduction sections $\mathrm{L}_{ред}$ and crimping $\mathrm{L}_{обж}$. To ensure the production of pipes with the maximum difference in diameters, the length of the reduction section is taken as minimum based on the radii of the outer $\mathrm{R}_{заг}$ and inner $\mathrm{r}_{заг}$ workpiece surfaces. Reduction areas $\mathrm{L}_{ред}$ and crimping $\mathrm{L}_{обж}$ together constitute the working part of the gauge $L_{раб}$, and at their common boundary the radii of the gauges R and the mandrels r are equal to the maximum radii of the product being formed. At the end of the compression zone the radii R_1 and r_1 are equal to the maximum radii of the product. On the calibration constructed in this way, the product is rolled by changing the length of the working stand stroke $\bar{\mathrm{x}}_i$ from maximum value $L_m = L_{заг}$ to minimum $\mathrm{x}_{min} = L_{заг} + L_{ред}$. Actual value of stroke length $\bar{\mathrm{x}}_i$ should be used in the construction and synthesis of parameters of adjustable drive mechanisms. However, when considering the mechanism of product shaping and creating models that describe the interdependence of technological and mechanical characteristics of the process, it is more convenient to use the conditional stroke length x_i, which is counted not from the rear edge of the feed and rotation throat (as for $\bar{\mathrm{x}}_i$), but from the beginning of the reduction section. From Fig. 4 it is seen that $\bar{\mathrm{x}}_i = \mathrm{x}_i + L_{заг}$. The conditional stroke length x_i changes from the maximum value $\mathrm{x}_m = L_{раб}$ to the minimum $\mathrm{x}_{min} = L_{ред}$.

Forming of pipes of variable cross-section on HPTC mills. Long pipes of variable cross-section, formed on HPTC mills, depending on the course of the technological process, can be conditionally divided into two types - with direct and reverse taper . Rolling of pipes with direct taper is carried out by reducing the length of the working stand stroke during the cycle from the maximum value at which the cross-section of the smallest dimensions is formed to the minimum value at which the maximum cross-section of the finished product is formed. Rolling of pipes with reverse taper is carried out by changing the length of the working stand stroke, which is continuously increasing.

When the working cone is formed, the minimum cross-section **a** of the finished pipe is formed with the radii of the outer and inner surfaces, respectively, R_1 and r_1 (Fig. 5, I). The formation of the first elementary section on the first double stroke of the working stand occurs in the following way. When the gauges move from the extreme front position to the extreme rear, metal is compressed, caused by elastic deformation of the working stand, rolling tool and material rolled during the previous forward stroke. As a result of the drawing, a linear displacement of the cross section **a** occurs by the value $\Delta l^{a}_{обр}$ (Fig. 5, II). In the extreme rear position of the working stand, the workpiece is rotated and fed by a given value m (Fig. 5, III). The volume of metal fed into the deformation zone is compressed during the forward stroke of the working stand, which leads to a linear displacement of the cross section relative to the front edge of the stand stroke by the value

$$\Delta\, l^{(1)}_{пр} = km\mu^{(1)}_{x}, \qquad (3)$$

where $\mu^{(1)}_{x}$ is the current value of the extraction coefficient (with the length of the stand stroke x_i);

k – empirical coefficient that establishes the ratio between the value of linear displacement during the reverse stroke of the cage to the full value of linear displacement during a double stroke.

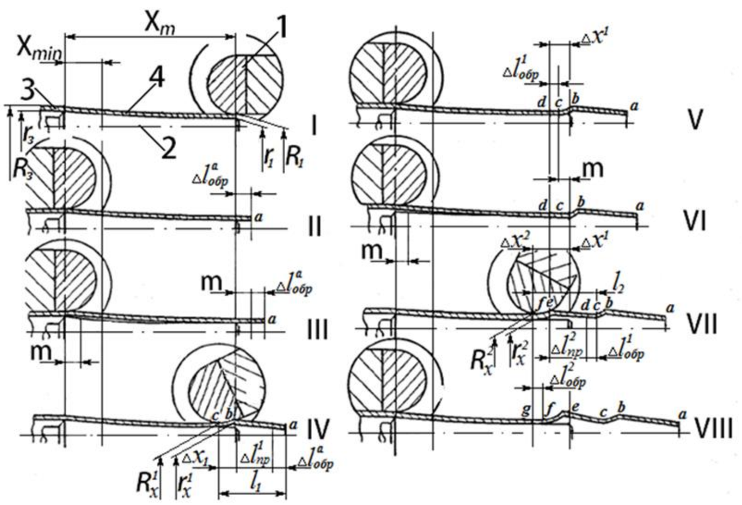

Fig. 5. Scheme of the technological process of forming a pipe of variable cross-section

Change in the length of the cage stroke during the first stroke on Δx_1 leads to the fact that the gauges do not "finish" to their previous position by the same amount Δx_1. The intersection ***c*** (Fig. 5, IV) lies in the plane passing through the line of the centers of the working rolls, is the rear boundary of the formed first elementary section of the product. The radii of the outer $R^{(1)}_{x}$ and the inner $r^{(1)}_{x}$ surfaces of this cross-section depend on the profile of the gauges and mandrel, as well as the position of the center line, i.e. the magnitude of the change in the stroke length of the working stand Δx_1. The length of l_1 the formed section (i.e. the distance between sections ***a*** and ***c*** of the longitudinal axis of the pipe) can be determined as follows

$$l_1 = \Delta\, l^{(0)}_{звр} + \Delta\, l^{(1)}_{пр} + \Delta x_1. \qquad (4)$$

Conicity of the outer surfaceγ_X this elementary plot

$$\gamma^{(1)}_{X} = \frac{\Delta R^{(1)}_{x}}{l_1} = \frac{\Delta R^{(1)}_{x}}{\Delta l^{(0)}_{звр} + \Delta l^{(1)}_{пр} + \Delta x_1}; \qquad (5)$$

where $\Delta R^{(1)}_{x}$ – change in the radius of the stream of calibers on the site $(x_m;\ x_m - \Delta x_1)$;

$\Delta R^{(1)}_{x} = R_1 - R^{(1)}_{x}$.

This value is determined both by the change in the stroke length Δx_1 and by the calibration of the rolling tool, i.e. by the dependence $R(x_i)$. The current value of the stroke length of the working stand $x_i$is considered to be the stroke length at which i the –th deformation cycle from the beginning of rolling a given product began. The stroke length at the end i of the –th cycle and the beginning of the (i+1) th is equal to $x_{i+1} = x_i - \Delta x_i$. Accordingly, the radius of the outer surface of the front section of the formed i–the front section is equal to $R_{xi} = R(x_i)$, and the rear section is equal to $R_{xi+1} = R(x_{i+1}) = R(x_i - \Delta x_i)$. The radii of the inner surface $r_{xi} = r(x_i)$ and $r_{xi+1} = r(x_{i+1})$.

When the gauges are returned to the rearmost position, the formation of the second conical section begins due to the metal being drawn out by an amount $\Delta l^{(1)}_{обр}$ (Fig. 5, V). Feeding the workpiece (Fig. 5, VI) and further compression leads to the formation of a second section with length l_2, which is determined similarly to (4)

$$l_2 = \Delta\, l^{(1)}_{звр} + \Delta\, l^{(2)}_{пр} + \Delta x_2. \qquad (6)$$

where Δx_2 is the change in the length of the second stroke of the working stand.

Conicity of the outer surface of the second section

$$\gamma^{(2)}_{x} = \frac{\Delta R^{(2)}_{x}}{l_2} = \frac{\Delta R^{(2)}_{x}}{\Delta l^{(1)}_{звр} + \Delta l^{(2)}_{пр} + \Delta x_2}; \qquad (7)$$

where $\Delta R^{(2)}_{x}$ changing the radius of the stream R_x on the site $(x_m - \Delta x_1; x_m - \Delta x_2 - \Delta x_1)$.

Thus, the length i of the –th elementary section of the finished product is equal to the sum of the values of the linear displacement of the pipe during i the –th forward stroke of the stand, the linear displacement of the previous reverse stroke, and the value of the stroke change Δx_i:

$$l_i = \Delta\, l^{(i)}_{пр} + \Delta l^{(i-1)}_{звр} + \Delta x_i. \qquad (8)$$

The magnitude of the linear displacement during the reverse stroke of the tool is 30-40% of the total displacement during a double stroke [6], i.e., when rolling cylindrical pipes, the coefficient $k$in expression (3) is 0.7-0.6. Significant compression of the metal during the reverse stroke is due not only to the elastic aftereffect of the working stand, rolling tool and metal, but is largely a consequence of the rolling of the so-called "whiskers" that fill the caliber releases during the forward stroke, after the workpiece is rotated in the extreme front position of the stand. A distinctive feature of the technological process under consideration is the absence of rotation of the workpiece in the front position of the stand, as a result of which the compression of the "whiskers" is not carried out. This significantly reduces the value of $\Delta l_{обр}^{(i)}$. In addition, the magnitude of the compression during the reverse stroke is significantly affected by the direction and magnitude of the displacement of the working section during the rolling process. Therefore, to ensure the stability of the process and increase the accuracy of finished products of variable cross-section, they are rolled piece by piece with the workpiece rigidly fixed in the chuck. As a result of experimental studies conducted on the KhPTK-75 mill, it was established that the value of the coefficient $k$when rolling conical pipes should be taken equal to 0.7-0.8, i.e. the length of the section of the finished pipe being formed is largely determined by the magnitude of the linear displacement during the forward stroke of the stand. To simplify the considered mechanism of shape formation, it is assumed that the length l_i is equal to the sum of the total magnitude of the linear displacement Δl_i on i the –th double stroke $\Delta l_i = \Delta l_{пр}^{(i)} + \Delta l_{звр}^{(i)}$and the magnitude of the change in the length of this stroke Δx_i.

$$l_i = \Delta\, l_{пр}^{(i)} + \Delta l_{звр}^{(i)} + \Delta x_i = \Delta l_i + \Delta x_i. \qquad (9)$$

Expressing Δl_i in terms of the current value of the extraction coefficient at the end of the double stroke of the stand under consideration and the single feed, we obtain

$$l_i = m\mu_x + \Delta x_i. \qquad (10)$$

It is customary to consider elementary sections as conical, and the geometric dimensions of the front and rear ends of each of them are determined by the geometric dimensions of the rolling tool (gauges - for the outer surface and mandrels - for the inner surface).

Iterative model of shaping of long conical pipes using linear-conical calibration. To find the required law of change of the length of the cage stroke, $\Delta x_i(x_i)$ a discrete approach was used, in which the pipe of variable cross-section is represented as a sequence of elementary conical sections of length l_i. As a result of a decrease (increase) in the length of the cage stroke by Δx_i there is a change in the radius of the formed outer surface by a value ΔR_i that is determined by the averaged taper of the stream of calibers a_i in the stream section$(x_i; x_i - \Delta x_i)$

$$\Delta R_i = a_i \Delta x_i. \qquad (11)$$

Thus, the taper γ_i of the outer surface of the formed on i the -th from the beginning of rolling a double pass of the elementary section is equal to

$$\gamma_i = \frac{\Delta R_i}{\Delta l_i} = \frac{\Delta R_i}{m\mu(x_i) + \Delta x_i}. \qquad (12)$$

Here $\mu(x_i)$ is the maximum value of the exhaust during the double stroke of the considered stand.

A conical pipe consisting of elementary sections of constant taper can be formed only with an appropriate choice of the law of change of magnitude Δx_i and calibration of the rolling tool. Therefore, one of the most important tasks is to develop a method for determining the tuning characteristics of the drive mechanism for rolling conical pipes of given parameters.

Determination of the law of change in the length of the working frame stroke. Forming a pipe length$L_{тр}$ and with radii of the outer surface R and R_1 and the inner - $r$and r_1 is carried out in calibers with radii $R_к$ and $R_{к1}$ (the development of the crest of the stream is a straight line) on a conical mandrel with radii $r_к$ and $r_{к1}$. The maximum length of the stand stroke on which the front end of the pipe is formed $(R_1 x\, r_1)$ is equal to x_m. If the dimensions $R_к$; $r_к$ and R; r($R_к > R$and $r_к > r$) differ, rolling can be carried out to some minimum x_{min} value of the length of the cage stroke. It is obvious that at $R_к = R$ and $r_к = r$ $X_{min} = 0$. The generatrix of the outer surface of the conical tube in the Z0Y coordinate system (Fig. 6) is described by the equation

$$y(z) = K_н z + R_1, \qquad (13)$$

where $K_н = \frac{R - R_1}{L_{тр}}$ – the taper of the outer surface of the pipe being processed.

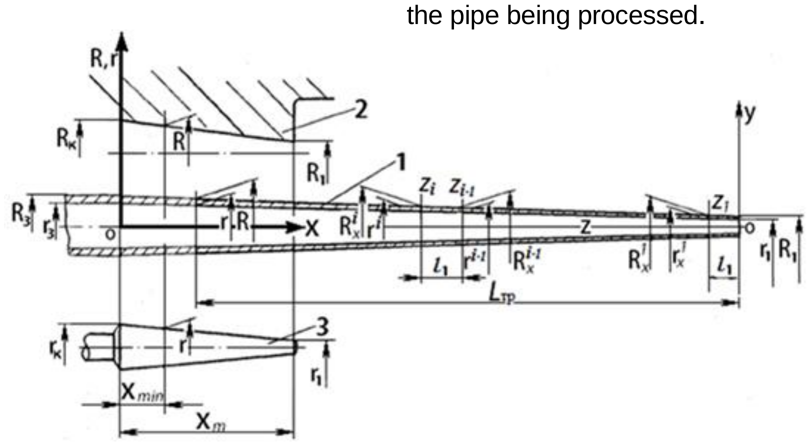

Fig. 6. Scheme of forming a conical pipe of given dimensions: 1 – tubular product being formed; 2 – reaming of the crest of the stream of calibers; 3 – mandrel

Since $y = R_{xi}$, then the equation of the generator can be represented in the form

$$R_{xi} = K_н z_i + R_i. \quad (14)$$

The rolling process of a conical pipe begins after rolling the working cone, when the pipe cross-section of the minimum radius of the outer surface is formed R_1. During the first double pass, the first elementary section of the finished pipe is formed with a length of Δl_1, a maximum radius R_{x1} and a minimum of R_1. In this case, the pipe cross-section with a radius R_{x1} has the coordinate $z_1 = \Delta l_1$. The value Δl_1 is determined by the dependence (9) for the first double pass of the stand, therefore

$$z_1 = \Delta l_1 + \Delta x_1. \quad (15)$$

Coordinate z_2 for a section having an outer surface radius R_{x2} and formed during the second double pass of the cage, will be equal to

$$z_2 = \Delta l_2 + \Delta x_2 + z_1 = \Delta l_1 + \Delta l_2 + \Delta x_1 + \Delta x_2, \quad (16)$$

where Δl_2 is the linear displacement of the pipe during the second double pass.

Thus, the coordinate $z_i$of the cross-section with radius R_{xi}, formed on $i$the -th double-pass stand from the beginning of rolling, is equal to

$$z_i = \sum_{n=1}^{i} \Delta l_n + \sum_{n=1}^{i} \Delta x_n. \quad (17)$$

The second sum of expression (17) is the difference between the maximum stroke length of the working cage x_m its current value x_i. So

$$z_i = \sum_{n=1}^{i} \Delta l_n + x_m - x_i. \quad (18)$$

Taking this into account, expression (14) will take the form

$$R_{xi} = K_н\left(\sum_{n=1}^{i} \Delta l_n + x_m - x_i\right) + R_i. \quad (19)$$

As is known $\Delta l_i = m\mu_x$, based on the assumptions made above, the current value of the extraction coefficient is equal to

$$\mu_x = \frac{R_з^2 - r_з^2}{R_{xi}^2 - r_{xi}^2}. \quad (20)$$

Let's express the radii R_{xi} and r_{xi} due to the taper of the caliber stream $a(x_i)$ and the mandrel $b(x_i)$ in general terms

$$R_{xi} = R_К + \int_0^{xi} a(x_i)dx;\ r_{xi} = r_К + \int_0^{xi} b(x_i)dx. \quad (21)$$

For simplicity, we assume that $R_К = R$ and $r_К = r$.

The equation of the generator of the outer surface of the pipe (19) can be as follows

$$R + a x_i = K_н\left(m\sum_{n=1}^{i} \frac{A}{Bx_i^2 + 2Cx_i + D} + x_m - x_i\right) + R_1, \quad (22)$$

where i=1,2,3 ... N.

Equation (22) contains the required value of the length of the working stand stroke x_i for i the double stroke from the beginning of rolling, as well as the total number of double stand strokes N. required to form a given product. After a series of transformations (22) leads to a cubic equation for the desired value x_i.

$$-B(K_н + a)x_i^3 + (BQ_i - 2C(K_н + a))x_i^2 +$$
$$(2CQ_i - D(K_н + a))x_i + (AK_н m + DQ_i) = 0, \quad (23)$$

Here $Q_i = K_н(x_m + mS_{i-1}) + R_1 - R$.

According to the dependence (23) for determining the magnitude of the cage stroke it is necessary to find the numerical value of the sum S_{i-1}. It can be calculated only if the length of the previous double cage stroke is known x_{i-1}. Thus, the calculation of the magnitudes x_i can be carried out only by successively increasing the index from i=1 when $S_0 = 0$, $z_0 = 0$, $x_0 = x_m$ and to the value i = N , which is determined from the condition $Z_N = L_{тр}$ or

$$x_m - x_N + m\left(\frac{A}{Bx_N^2 + 2Cx_N + D} + S_{N-1}\right) = L_{тр}. \quad (24)$$

As an example in Fig. 7. The graph of the change in the length of the working stand stroke $x_i$required for rolling a conical pipe 40x4 – 20x1.0 with a length of 2000 mm at a feed of 3 mm is given. Curve 2 indicates the necessary law of the change in the stand stroke for forming a pipe 40x4–20x1.0 with a length of 1070 mm. According to the coordinates $y = R_{xi}$ and, z_i the calculated profiles were constructed, which completely coincided with the specified ones (Fig. 8 shows the construction of the profile of a pipe 40x4 – 20x1.0 with a length of 1070 mm).

When rolling tapered tubes, for which it is necessary to implement a final section of constant wall thickness equal to the thickness$t_з$ the wall of the workpiece, the equation of the generator during rolling within the reduction zone has the form

$$-2\ a t_{заг}(K_н + a){x_i}^2 + \{t_{заг}(2R - t_{заг})(K_н t_{заг} - a) + 2a[K_н(X_m + mS_{i-1}) + R_1 - R]\}x_i + t_{заг}(2R - t_{заг})[K_н(X_m + mS_i) + R_1 - R] + mK_н A = 0. \quad (25)$$

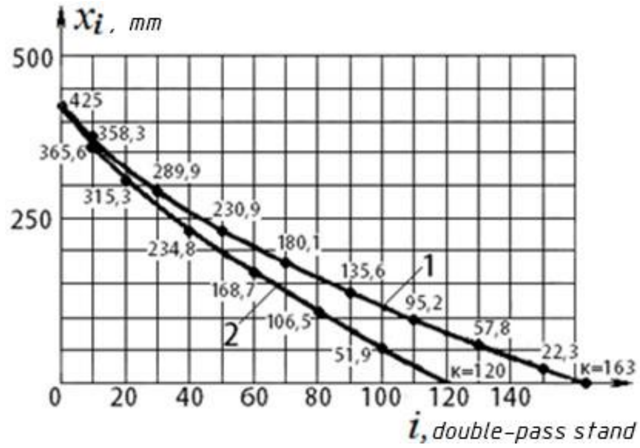

Fig. 7. Change in the length of the working stand stroke when rolling a tapered pipe 40x4 – 20x1.0 with a length of 2000 mm (1) and 1070 mm (2)

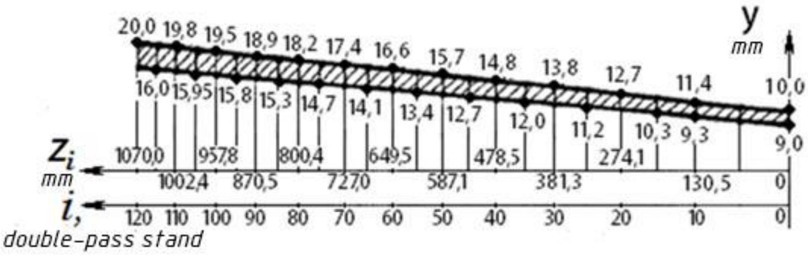

Fig. 8. Construction of a pipe profile 40x4 – 20x1.0 with a length of 1070 mm according to coordinates R_{xi} and z_i

Here the amount S_{i-1} is determined by the following relationship

$$S_{i-1} = S_0 + \frac{A}{t_{\text{зar}}((2R_1 - t_{\text{зar}}) + 2a t_{\text{зar}} X_{i-1})} + S_{i-2}; \quad (26)$$
$$S_i = S_0 = \frac{A}{\mathrm{B}x_i^2 + 2Cx_i + \mathrm{D}} + S_{i-1},$$

where i = 1,2,3,...,1,...,N.

Equations (23) and (25) allow us to determine the law of change in the length of the working stand stroke x_i(i), necessary for forming pipes with given geometric parameters on a working tool with linear-conical calibration. To verify the results of these developments, experimental studies were conducted on the KhPTK-75 mill, which confirmed the validity of the developed model.

***Determination of drive mechanism adjustment parameters*.** On HPTC mills with a lever drive mechanism, the change in the length of the stand stroke is carried out by changing the ratio of the lengths of the arms of the oscillating levers, connected at the lower ends to the leading crank-rocker mechanism and auxiliary levers, and at the upper ends by means of connecting rods with the working stand. The movement of the central hinges of the levers is carried out by a carriage driven along inclined guides. The current value of the length of the stand stroke depends on the distance H_i between the current position of the carriage and the initial one. To find this dependence, the position of the lever AB, which corresponds to the extreme variable (front) position of the working stand (Fig. 9), was considered.

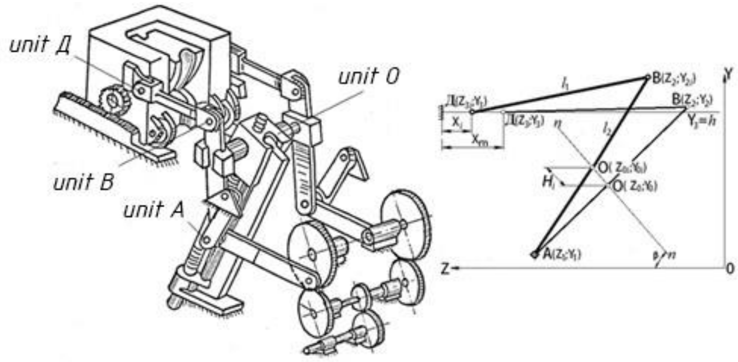

Fig. 9. Before determining the carriage position as a function of the cage stroke length

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In this case, the center 0 of the double- arm lever joint occupies its lowest position on the line *n – n*, which makes an angle β with the horizontal and has coordinates z_0 and y_0.

Let's define the coordinates z_{2i} and y_{2i} of the hinge B of a double-arm lever occupying an arbitrary position. It is known that

$$\frac{y_{2i}-y_1}{y_{0i}-y_1}=\frac{z_{2i}-z_1}{z_{0i}-z_1}, \quad (27)$$

$$l_2=\sqrt{(z_1-z_2)^2+(y_{2i}-y_1)^2}, \quad (28)$$

where l_2 – length of the double-arm lever;

z_1 and y_1- coordinates of hinge A.

A joint consideration of (27) and (28) leads to the expressions

$$z_{2i}=z_1-\frac{l_2}{\sqrt{1+q_i^2}};\ y_{2i}=y_1-\frac{l_2 q_i}{\sqrt{1+q_i^2}}. \quad (29)$$

Here $q_i=\frac{y_{0i}-y_1}{z_{0i}-z_1}$ is a dimensionless parameter that characterizes the magnitude of the displacement of the center 0 along the guide line *nn*.

Point D lies on the line $y_3=h$ at a distance l_1 from the center of the hinge B (l_1 - the length of the upper connecting rod of the drive mechanism), therefore the coordinate of z_{3i} the point Д$_3$ is found from the equation

$$(z_{3i}-z_{2i})^2+(h-y_{2i})^2={l_1}^2, \quad (30)$$

substituting into (30) the values of the coordinates y_{2i} and z_{2i} dependencies (30), we obtain

$$\left(z_{3i}-z_1+\frac{l_2}{\sqrt{1+q_i^2}}\right)^2={l_1}^2-\left(h-y_1+\frac{l_2 q_i}{\sqrt{1+q_i^2}}\right)^2. \quad (31)$$

After transformations, we arrive at an equation containing the unknown quantity q_i

$$q_i^2\left(F^2-4{l_2}^2(h-y_1)^2\right)-8q_i{l_2}^2(z_{3i}-z_1)(h-y_1)+F^2-4{l_2}^2(z_{3i}-z_1)^2=0, \quad (32)$$

where $F=(z_{3i}-z_1)^2-{l_1}^2+(h-y_3)^2+{l_2}^2$,

The coordinate of z_{3i} point D in the Z0Y system (Fig. 9) can be represented in the following form:

$$z_{3i}=\mathrm{x}_m+\lambda_0-\mathrm{x}_i. \quad (33)$$

where λ_0 is a constant value that depends on the choice of the coordinate system and the parameters of the drive mechanism

$$\lambda_0=\sqrt{{l_1}^2-\left(h-y_1+\frac{l_2 q_0}{\sqrt{1+q_i^2}}\right)^2}+z_1-\frac{l_2}{\sqrt{1+q_i^2}}.$$

The found solution of equation (32) corresponds to the desired position of the swing center O_i, at which the stroke length of the working cage is equal to x_i.

Let us define the relationship between the parameter q_i and the movement of the carriage H_i from its lowest position. Let us represent the coordinates of the center of swing z_{0i} and y_{0i} in the following form:

$$z_{0i}=z_0+H_i cos\beta;\ y_{0i}=y_0+H_i sin\beta. \quad (34)$$

Then

$$q_i=\frac{y_0+H_i sin\beta-y_1}{z_0+H_i cos\beta-z_1}. \quad (35)$$

After some transformations we have

$$H_i=\frac{(y_0-y_1)-q_i(z_0-z_1)}{q_i cos\beta-sin\beta}. \quad (36)$$

Thus, solving equation (32) for a series of numerical values x_i (in ascending order of index i from 1 to N) the corresponding values of the dimensionless parameter are determined q_i, and depending on (36) the carriage movement H_i necessary for rolling a conical pipe of given parameters is determined.

As an example, Fig. 10 shows a graph of the change in the length of the working stand stroke required for forming a conical pipe 56x4 – 38x1 with a length of 3000 mm on the KhPTK-40 mill at a feed of 4 mm with a working part length of x_m=425 mm. Fig. 11 shows the law of carriage motion (curve 1).

To roll a tapered pipe with a straight generatrix, it is necessary to perform uneven movement of the carriage along the guides. This necessitates the installation of mechanisms with an adjustable gear ratio, which significantly complicates the design of the mill and reduces its reliability.

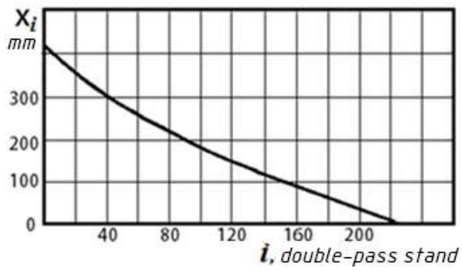

Fig. 10. Change in the length of the stand stroke when rolling a pipe 56x4 – 38x1 with a length of 3000 mm

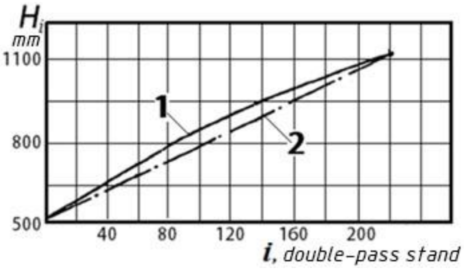

Fig. 11. Moving the carriage H_i when rolling a pipe 56x4 – 38x1 with a length of 3000 mm: 1 – theoretically; 2 – experimentally

Example of calculation of setting the drive mechanism of the KhPTK-75 mill for rolling current collector rods of ZIU-9 trolleybuses (pipe 51x3.5 - 25x3.2; length 4475 mm; material steel 30 KhGSA).

Billet dimensions . Since the finished pipe has a significant difference in diameters, the diameter and wall thickness of the billet are taken equal to the corresponding dimensions of the maximum cross-section of the pipe being rolled.

Calibration of work rolls. Linear-conical calibration is used, R_k=25.5 mm, R_1=12.5 mm, x_m=609 mm (length of the working part of the calibers-half disks of the KhPTK-75 mill). The dependence $R(x)$has the form

$$R(x) = 25{,}5\text{-}\frac{25{,}5\text{-}12{,}5}{609}x = 25{,}5 - 2{,}135 \cdot 10^{-2}x, \text{ mm}$$

The profile of the product being formed. The pipe has a conical shape. The radius of the outer surface is described by the relationship

$$Y(z) = 25{,}5\text{-}\frac{25{,}5\text{-}12{,}5}{4475}z = 25{,}5 - 2{,}905 \cdot 10^{-3}z, \text{ mm}$$

Changing the wall thickness of the finished product. The current collector rod tube has a wall thickness that varies linearly from t=3.5 to t=3.2 mm, so

$$t(z) = 3{,}2 + \frac{3{,}5\text{-}3{,}2}{4475}z = 3{,}2 + 6{,}7 \cdot 10^{-5}z, \text{ mm}$$

The size of a single feed of the pipe billet is taken equal to m=5 mm.

***The dependence* z(x) *is established from the condition* $\boldsymbol{R(x) = Y(z)}$.** For the pipe being formed and the calibers used

$$25{,}5\text{-}2{,}135 \cdot 10^{-2}x = 25{,}5\text{-}2{,}905 \cdot 10^{-3}z,$$

$$z = 7{,}3480x \text{ mm}.$$

Mandrel profile

$$R(x) = \frac{x}{609}(3{,}5\text{-}3{,}2\text{-}25{,}5 + 12{,}5) + 25{,}5\text{-}3{,}5,$$

$$R(x) = 22\text{-}2{,}0854 \cdot 10^{-2}x, \text{ mm}.$$

Calculation of the function of changing the stroke length of the working stand. The results of calculating the installation parameters of the drive mechanism of the KhPTK-75 mill for rolling a tapered pipe 51x3.5 - 25x3.2, 4475 mm long are given in Table 2, where it is indicated:

x– current value of the length of the i-th double run of the stand – x_i, mm;

dx– change in stroke length – Δx_imm;

z– coordinate $z_i$mm;

Rx– outer surface of the current pipe cross-section – R_x, mm;

q– parameter value q_i for the calculated value Δx_i;

H– carriage movement from its lowest position – H_i, mm.

The parameter $q_i$was calculated for the lever drive system of the KhPTK-75 mill. Its numerical values are given in Table 2.

The gear ratio of the kinematic gearbox $U_p$is determined based on the condition of its stepwise regulation (the number of steps is assumed to be k= 5).

From *N* = 580 double moves of the stand, the values i=1; N/k; $2N/k$; $3N/k$; ...; *N are selected* , namely i=l, 116, 232, 348, 464, 579. These double move numbers correspond to the coordinates of the carriage position H_1 = 387,8; H_{348} = 867,6; H_{116} = 552,0; H_{464} = 1033,2; H_{232} = 709,1; H_{579} = 1209,0.

The gear ratios of the regulating stages of the kinematic gearbox are equal (the pitch of the carriage movement screw t=10 mm):

$$U_1 = \frac{580}{552{,}0-387{,}8} \cdot \frac{10}{5} = 7{,}06; \qquad U_4 = \frac{580}{867{,}6-709{,}1} \cdot \frac{10}{5} = 7{,}32;$$

$$U_2 = \frac{580}{709{,}1-552{,}0} \cdot \frac{10}{5} = 7{,}38; \qquad U_5 = \frac{580}{1209{,}0-1033{,}2} \cdot \frac{10}{5} = 6{,}60.$$

$$U_3 = \frac{580}{867{,}6-709{,}1} \cdot \frac{10}{5} = 7{,}32.$$

The research results presented above were also used in the development of methods for calculating technological parameters for adjusting the HPTC mills in the manufacture of: tubular products of variable cross-section for special power plants ordered by the enterprise NPO "TECHNOMASH" (pipe 7x0.3–3x0.3, length 3000 mm); special tubular products of variable cross-section for shipbuilding enterprises.

Improvement of mechanisms and units of the HPTC mill. ***A significant simplification of the stereometry*** of the drive mechanism of the HPTC mill while simultaneously reducing material consumption, increasing maneuverability, reliability and durability can be achieved by using mechanisms with higher kinematic pairs in the line of moving the stand with stable positioning of its position during the feeding and turning operations, in particular internal gear wheels with a gear ratio of 2 and worm gears.

Table 2. Results of calculation of installation parameters of the drive mechanism of the KhPTK-75 mill for rolling a tapered pipe 51 x3.5 - 25x3.2, length 4475 mm

i	x, mm	dx, mm	z, mm	Rx, mm	q, mm	H, mm
1	607.38	1.62	11.91	12.5	–,43E+01	387.8
20	577.46	1.54	231.78	13.2	–,46E+01	416.2
40	547.57	1.46	451.41	13.8	–,49E+01	445.5
60	51909	1.39	660.69	14.4	–,53E+01	474.1
80	491.83	1.34	861.01	15.0	–,57E+01	502.2
100	465.63	1.29	1053.48	15.6	–,61E+01	530.0
120	440.39	1.24	1238.99	16.1	–,66E+01	557.5
140	415.99	1.20	1418.27	16.6	–,72E+01	584.8
160	392.35	1.16	1591.95	17.1	–,78E+01	611.9
180	369.41	1.13	1760.54	17.6	–,85E+01	639.0
200	347.10	1.10	1924.50	18.1	–,93E+01	666.0
220	325.36	1.07	2084.20	18.6	–,10E+02	692.9
240	304.16	1.05	2239.97	19.0	–,11E+02	719.9
260	283.46	1.02	2392.12	19.4	–,13E+02	747.0
280	263.21	1.00	2540.90	19.9	–,15E+02	774.2
300	243.39	0.98	2686.53	20.3	–,17E+02	801.5
320	223.97	0.96	2829.23	20.7	–,20E+02	828.9
340	204.93	0.94	2969.17	21.1	–,24E+02	856.5
360	186.24	0.93	3106.52	21.5	–,30E+02	884.3
380	167.88	0.91	3241.43	21.9	–,40E+02	912.4
400	149.83	0.90	3374.04	22.3	–,61E+02	940.7
420	132.08	0.88	3504.47	22.7	–,12E+03	969.3
440	114.61	0.87	3632.82	23.1	–,20E+04	998.1
460	97.41	0.85	3759.21	23.4	0.14E+03	1027.3
480	80.47	0.84	3883.73	23.8	0.67E+02	1056.9
500	63.76	0.83	4006.47	24.1	044E+02	1086.8
520	47.29	0.32	4127.51	24.5	0.33E+02	1117.1
540	31.04	0.81	4246.92	24.8	0.27E+02	1147.8
560	15.00	0.80	4364.78	25.2	0.22E+02	1179.0
Tubing has been formed at N=579 double steeps .						

* Every twentieth value of all parameters is printed

The cold rolling mill for long pipes of variable cross-section [7] (Fig. 12) includes a stand 1 with work rolls, a mechanism 2 for its reciprocating movement, a rotary -feed device 3 with a screw mechanism 4 for moving the workpiece chuck 5, on the nut of which a gear wheel 6 is fixedly fixed, which receives rotation, for example, from a Maltese mechanism. The work rolls can rotate by means of a kinematic connection of rails with a worm cut 7 and gear wheels 8 fixed on their necks. The mechanism for reciprocating movement of the stand includes two carriers 10 driven by the engine 9, each of which has a gear crank wheel 11 with a crank pin 12. On it, with the possibility of rotation, a slider 13 is located, installed in a vertical groove of the stand frame. The gear crank wheel is in internal engagement with a double-crown gear wheel 14, which has twice the number of teeth and the outer ring of which is connected by means of a wheel 15 to a shaft 16 passing through a stationary rack with a worm gear and an adjustable gear clutch 17 connected to it. The other end of the shaft is connected through a gearbox 18 to a gear wheel 6 and, by means of an additional shaft 19 and a gearbox 20, to a screw 21 of the mechanism for moving the mandrel 22. The rotation of the carrier 10 by means of the motor 9 leads to a reciprocating movement of the cage by an amount that depends on the angle of rotation of the double-crown gear wheel 14 from the initial position, at which the trajectory of the movement of the crank finger is placed horizontally. When the double- crown gear wheel 14 rotates, the trajectory of the crank pin movement is rotated, which, if there is a kinematic connection between it and the cage using the slider 13, causes a change in the length of the cage stroke. Its minimum value, equal to zero, occurs when the double-crown gear wheel 14 is rotated by an angle of 90° (while the crank pin 13 moves vertically). During the open state of the feed throat and the rotation of the workpiece, the rotary -feed device 3 is triggered. The rotation of the nut is transmitted to the double-crown gear wheel by means of the gear wheel 6 fixed on it, the transmission shafts 16, the gearbox 18 and the gear wheel 15. The extreme rear position of the gauges is fixed by constantly rotating them to this position through a worm gear, which includes stationary rails 7, which receive rotation from shafts 16, and gear wheels 8. To maintain the constant mutual arrangement of the gauges and the mandrel, the mandrel rod is synchronously moved by a screw mechanism, which receives rotation from shaft 16 through an additional shaft 19. The magnitude of the change in the stroke length of the working stand is set by the gear ratio of the gearbox 18. The presence of adjustable gear couplings 17 allows you to adjust the extreme fixed position of the gauges. The proposed kinematic connection of the rotary -feed mechanism and the mechanism of reciprocating movement of the stand allows you to improve the quality of the products being rolled and the reliability of the mill as a result of the fact that the change in the stroke length of the stand is carried out with the feed and rotation throat open. The presented layout provides a significant reduction in overall dimensions and metal consumption of the mill as a whole.

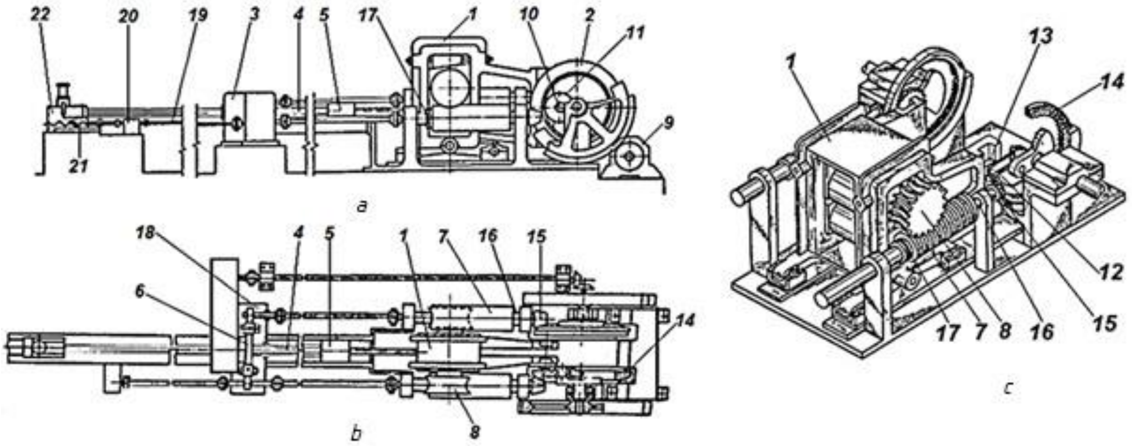

Fig. 12. Cold rolling condition of long pipes of variable cross-section: a – general view; b – top view; c – mechanism of reciprocating movement of the stand

Optimization of the design of the working frame elements. The design of the working frame of the HPTK mill, its rigidity and other operating parameters largely determine the quality of the products of variable cross-section that are manufactured. The traditional frame (Fig. 13, *a*) has a massive base, which contributes to increasing the stability of its reciprocating motion and reducing wear of the supporting surfaces.

The inflows 7 are designed to connect the stand with the drive mechanism, and the inflows 8 with the balancing device. It is equipped with a pressure device 2, which is installed between the upper roll cushion 3 and the frame 1. The device includes punches 4, shear elements placed in the wedge-matrixes 5, which are simultaneously wedges that provide changes in the positions of the upper roll cushions 3. The wedges 5 move along the inclined planes of the upper roll cushions in directions parallel to the rolling axis. The wedges are fixed by screws 6 mounted in the racks of the side frames of the frame 1. As a result of wear of the working rolls and bearings, as well as plastic deformation of the elements of the devices 2, the inter-roll gap increases, which causes additional movement of the wedges 5, which causes a shift in the zones of interaction of the pressure devices with the roll cushions. The latter complicates the process of regulating the solution between the rolls, as a result of which the specified parameters of the deformation cell change [8]. The formation of the stereometry of the instantaneous deformation cell (MOD) is influenced to varying degrees by such indicators of the moving stand assemblies as the mutual orientation of the roll axes and the rolling axis. Calculation schemes that determine the consumer characteristics of the finished product are erroneously built on the assumption that the half-sections of the MOD, moving along the mandrel axis, are located in a plane perpendicular to the rolling axis; are symmetrical; and under the action of rolling forces move in the vertical direction. Due to the differences in the rigid characteristics and wear characteristics of the parts and assemblies that close the power flows in the left and right windows of the frame, the wedges 5 will occupy different positions along the rolling axis, which will lead to skewing and crossing of the roll axes. Thus, when loading the stand of the KhPT-32 mill of the EZTM design with a rolling force of 0.5 MN, the upper roll cushions, depending on the position of the wedges, change their position in the stand windows, causing a skew of its axis, which is characterized by a difference in the position of the centers of symmetry of the bearing supports of up to 17 μm (Fig. 13, *b*).

Distinctive design features of the rational working frame of the KhPTK mill. When creating the design of the working frame, attention was paid to establishing a rational shape of its bed, the possibility of reducing weight while simultaneously increasing the bearing capacity and rigidity of the structure, the possibility of choosing the optimal scheme of the pressure device, and others.

The rational working cage (Fig. 14) consists of an oval-shaped frame 1, in the windows of which a pressure device 2 is mounted, working rolls (upper 3 and lower 4), which are mounted on bearings in the pillows 5 of the upper roll and pillows 6 of the lower one. Oval-shaped frames with internal windows are made in the form of internal 7 and external 8 shells.

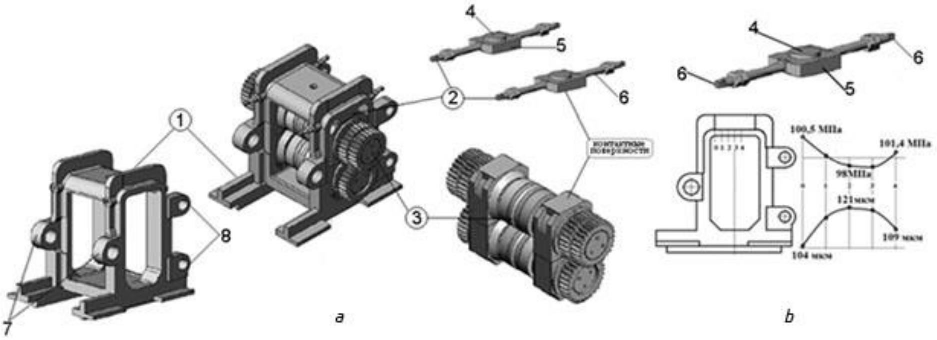

Fig. 13. Working stand of the HPT mill of the EZTM design

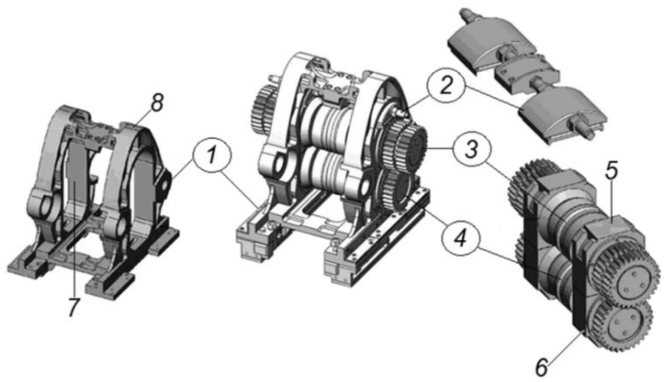

Fig. 14. Rational working stand of the KhPTK mill [9]

Design features of the optimal pressure device. One of the shortcomings of the existing stands of the HPTK mill is that they do not allow the selection of axial gaps in the roll supports, which appears due to wear of the bearings, due to which the relative axial displacement of the roll streams occurs and the shapes of the deformation centers are distorted. This leads to biting of the pipe metal and the appearance of errors in their shapes. In addition, the design of the stands does not allow compensating for errors in processing and assembly of parts, which leads to the appearance of additional loads. Effective management of the rolling process and the exclusion of the appearance of non-technological loads in the elements of the working stand caused by inaccuracy in the manufacture and assembly of parts allows the use of a pressure device of optimal design. Fig. 15 shows the kinematic and structural diagrams of such a pressure device, which contains wedge and screw mechanisms for moving the bearing assemblies of the upper roll. In the structural diagram, the movable MOD is represented by a kinematic pair of the fourth kind.

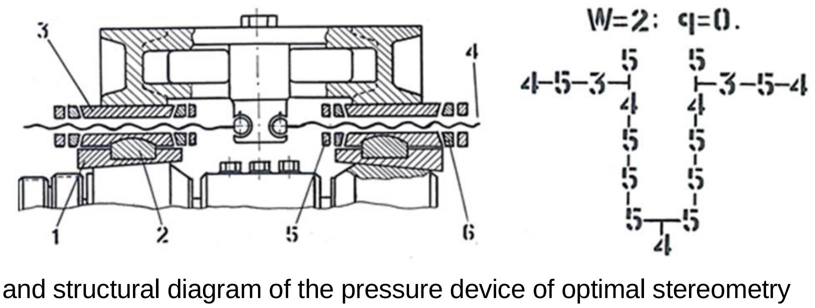

Fig. 15. Kinematic and structural diagram of the pressure device of optimal stereometry

The wedge mechanisms contain wedges 1, moving in a plane perpendicular to the rolling axis, in opposite sides of the roll axis along the inclined contact surfaces of the pillows of the bearing assemblies of the upper roll. Two pairs of compensating inserts with cylindrical surfaces, the axes of one of which 2, installed on the wedges 1, are parallel to the longitudinal axis of the frame, and the axes of the other 3, in contact with the frame, are parallel to the roll axis. Screws 4, fixed in the frame by kinematic pairs of the fourth kind, which provides rotational movements in the spherical holes of the frame and eliminates rotation of the screws relative to their own longitudinal axes, nuts 5 and spherical washers. The optimal scheme of the pressure device is built using structural synthesis methods [10], which satisfies the conditions of unconstrained assembly and indifference to deformations of the base parts, and this allows for effective rolling of long conical pipes, eliminating the manifestation of non-technological loads in the elements of the working stand; simplifying the adjustment process; increasing the reliability and durability of the stands.

Conclusions. The main difference of the technological process under consideration is the need for a programmatic change in the stroke length of the working rolls (cell), i.e. the values of the displacements of the MOD of the pipe billet, which necessitates the need for discrete changes in the draw coefficients and all energy-power and geometric parameters during the rolling cycle of a long product with variable cross-sectional parameters. Based on the conditions for obtaining the specified geometry, the features of the functioning of the HPTC mill with a drive lever mechanism in relation to the technological and mechanical parameters of the process implementation are revealed. The development of an iterative model of the formation of tubular products of variable cross-section, the lengths of which are many times greater than the sweeps of the caliber stream, is presented, the results of which were used in the development of methods for calculating the technological parameters of the HPTC mill settings in the conditions of pilot production of the State Enterprise "Research and Design and Technological Institute of the Pipe Industry named after Ya.Yu. Osada".

Design solutions for further improvement of equipment elements are considered. In the state of the HPTC [7], the drive of the variable-size stand stroke is carried out by the simplest epicyclic internal gear transmission with two degrees of freedom, and the positioning of the stand elements to perform the feed-turn operation before the start of the next rolling cycle is implemented by a worm gear, which allows improving the stereometry of the unit for the manufacture of long tubular products with variable cross-sectional parameters with a simultaneous reduction in material consumption.

The presented studies on the behavior of MOD elements allowed us to develop design solutions that improve the quality characteristics of the manufacturing process of tubular products with variable cross-sectional parameters, the length of which is many times greater than the sweep of the caliber stream.

Бібліографічний опис

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