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Удосконалення методики розрахунку таблиць прокатки для безперервних безоправкових станів гарячої прокатки труб

Shifrin E.I., Gulyaev Y.G.

Improvement of the method for calculating rolling tables for continuous mandrel-free hot pipe rolling mills

Анотація. *Від того, яким чином при розрахунках параметрів налаштування і калібровок валків калібрувальних і редукційних станів гарячої безоправкової прокатки труб, у певній мірі залежить їх точність по товщині стінки і діаметру. До значущих факторів, які мають значний вплив на процес формозмінення труб при поздовжній прокатці в калібрах безперервного безоправкового стана відносяться способи обробки калібрів валків (індивідуальна обробка кожного валка окремо або обробка калібрів у зборі). Розроблено нову методику розрахунку таблиць прокатки труб у даних станах, яка враховує технологію нарізання калібрів прокатних валків. Доведено, що використання удосконаленої методики розрахунку таблиць прокатки на калібрувальних і редукційних станах різної конструкції дозволяє виготовляти гарячекатані труби з суттєвим підвищенням точності геометричних розмірів і зниженням витрат металу.*
Ключові слова: *калібровка валків, редукційний стан, калібрувальний стан поздовжня безоправкова прокатка, таблиця прокатки.*

Abstract. *The way in which the setup parameters and fork calibrations of calibration and reduction mills for hot mandrelless pipe rolling are calculated depends to a certain extent on their accuracy in terms of wall thickness and diameter. Significant factors that have a significant impact on the process of pipe forming during longitudinal rolling in the gauges of a continuous mandrelless mill include the methods of processing roll gauges (individual processing of each roll separately or processing of gauges as a whole). A new methodology has been developed for calculating pipe rolling tables in these mills, which takes into account the technology of cutting roll gauges. It is proved that the use of an improved methodology for calculating rolling tables on calibration and reduction mills of various design allows the production of hot rolled pipes with a significant increase in the accuracy of geometric dimensions and a reduction in metal consumption.*
Keywords: *roll calibration, reduction mill, calibration mill, longitudinal mandrelless rolling, rolling table.*

Dedicated to Professor, Doctor of Technical Sciences GENADIY IVANOVYCH GULYAEV - an outstanding Ukrainian scientist, one of the founders of the theory of pipe reduction

State of the problem. The main issue of the technology of rolling pipes on continuous mandrel -free longitudinal rolling mills (as well as on other pipe rolling mills) is the possibility of manufacturing pipes on these mills with high accuracy of wall thickness and diameter, which largely depend on how the main technological parameters of the forming process are set. This also includes the method of calculating rolling tables.

To date, the following calculation scheme for tables of continuous, burr-free calibration (reduction) of pipes is most often used.

The mode of distribution of partial deformations $\varepsilon_i$across the cages is set.

The ovality value of the calibers is set λ_i. In assigning the values, λ_i the accumulated empirical experience of operating a specific pipe rolling unit is used, or calculation methods are used. In determining the value λ_i by calculation, the formula of G.I. Gulyaev is most often used [1]

$$\lambda_i = \left(\frac{1}{1-\varepsilon_i}\right)^{q_i}, \qquad (1)$$

where q_i is an empirical coefficient that depends on the number of rolls in the stand and the steel grade of the deformed pipe.

Further, using the assumption that the average diameter of the caliber D_i is equal to the sum of its height h_i and width b_i [5]

$$D_i = b_i + h_i, \qquad (2)$$

or the method proposed in [1], calculate the height h_i and width b_i of each gauge, as well as the values of the quantities that determine the dimensions of the gauge (radius R_i and eccentricity e_i for each of the gauges that are cut individually; cutter diameter D_{fi} and cutter offset F_i for each of the gauges that are cut in an assembly).

The disadvantage of this method of calculating rolling tables is that the value of the broadening index δb_i (which largely determines the level of transverse wall difference of finished pipes) of the continuous state is not an independent variable in each stand, and its value is determined by the initially selected mode of distribution of partial deformations ε_i and the ovality of the calibers λ_i.

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At the same time, it was established that, given the initially given law of distribution of partial deformations ε_i across the stands of a continuous mill, the use of assumption (2) gives a significant error in determining the geometric parameters of the gauges, because the ovality of the gauges λ_i also significantly depends on the technology of cutting them on the rolls [6].

Improved method for calculating rolling tables for continuous, straight-run hot-rolling pipe mills.

Based on the shortcomings that were identified when using the current methods for calculating rolling tables for hot-rolled pipes on continuous longitudinal rolling mills, two practical conclusions were made regarding the development of a new, different from the above, concept of building rolling tables for coreless deformation of pipes.

Firstly, when developing tables for specific pipe sizes, it is advisable to initially specify the values of the expansion indices δb_i in continuous state cages, and the ovality of the calibers λ_i is determined as a function of the values of partial deformations ε_i and δb_i.

Secondly, the ovality value λ_i must be determined depending on the technology of caliber manufacturing. This approach to compiling tables of continuous mandrel-free pipe rolling is protected by patents of Ukraine [2, 3].

According to the proposed methodology, the calculation of the parameters for the calibration of rolls of a continuous longitudinal rolling mill for coreless rolling (calibration or reduction) of the outer diameter of a rough pipe blank D_0 to the value D_t is carried out in the following sequence.

Calculate the total absolute deformation of the reduction along the outer diameter $\Delta D_\Sigma = D_0 - D_t$.

The number of mill stands required to perform the deformation $\Delta D_\Sigma$is determined N.

Assigning the values of the diameters of the workpiece D_i after rolling in each stand of the mill, the total absolute deformation is distributed ΔD_Σbetween the stands $N$and the partial deformations are calculated $\varepsilon_i = 1 - \frac{D_i}{D_j}$.

Specify discrete values of the broadening δb_i in the cages of the state.

Depending on the technology used to manufacture the gauges, the ovality of the gauges is determined λ_i, which provides reduction with partial deformation ε_i by widening δb_i in every cage of the state.

Depending on the gauge manufacturing technology used, the height h_i and width b_i of each gauge are calculated, as well as the gauge dimensions (radius R_i and eccentricity e_i- for each gauge that is cut individually; cutter diameter D_{fi} and cutter offset F_i - for each gauge that is cut in an assembly).

Calculations and industrial experiments. As an example, Table 1 shows the calculated parameters for rolling a D_t =168.3 mm pipe from a D_0 =182 mm billet (rolling temperature ot =740 oC) in a 5-stand calibration mill with two-roll stands, the roll calibers of which are individually cut.

Table 1 - Forming parameters when using the known (formula 1) and new improved (proposed) [3] method of calculating rolling tables of the calibration mill

Parameters	Cage number,i				
	1	2	3	4	5
Known method					
q_i	1.5	1.5	1.5	1.5	1.5
ε_i	0.02	0.03	0.01	0.0086	0
D_i, mm	178.36	173.01	171.28	169.8	169.8
λ_i	1.0307	1.0467	1.0152	1.0131	1.0000
δb_i	-0.032	0.19	0.362	0.019	
Proposed method					
δb_i, mm	0.2	0.2	0.2	0.2	
ε_i	0.02	0.03	0.01	0.0086	0
D_i, mm	178.36	173.01	171.28	169.8	169.8
λ_i	1.0438	1.0480	1.0019	1.0178	1.0000

As follows from the above data, when calculating the rolling parameters according to formula (1) for the value of the indicator 1.5 recommended in [1, Table 13] $q_i =$ (which, according to the authors, should ensure rolling with a broadening index δb_{Zi} =0.2) the values of the broadening indices are δb_i =–0.032÷0.362 and differ significantly from the value δb_{Zi} (the ratio $\frac{\delta b_i}{\delta b_{Zi}}$ varies within – 0.16…1.81). This fact is explained by the fact that when using the known method, the value δb_i is dependent on the selected values of partial deformations ε_i and the calculated values λ_i. In the case of using the proposed method (according to the method [2]), the value of the broadening index δb_i is initially set (in the example under consideration, δb_i =0.2), and the calculated values of the ovality of the gauges λ_i ensure rolling according to the initially assigned values $\varepsilon_i$and δb_i.

Industrial testing of the proposed method for calculating rolling tables (roll calibration) was performed for mills with long-roll stands and calibers cut in assembly, carried out in the conditions of a 24-stand reduction mill TPA 140, a 22-stand reduction mill TPA 30-102 and a 5-stand calibration mill TPA 350 "Interpipe Niko Tube ".

Analysis of rolling parameters when using existing roll calibrations showed that the broadening indicators δb_i in the first five stands of the reduction mill in the

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rolling process, they have values within δb_i =30.2÷66.2%, and in the following stands (except for the last two) δb_i =9.4÷18.4% (Fig. 1).

Considering that the 22-stand reduction mill TPA 30-102 produces both relatively thin-walled ($\frac{S_t}{D_t}$ <0.1) and relatively thick-walled ($\frac{S_t}{D_t}$ >0.1) pipes, two modes of distribution of broadening indices across the stands of the reduction mill were proposed, the parameters of which are shown in Fig. 1.

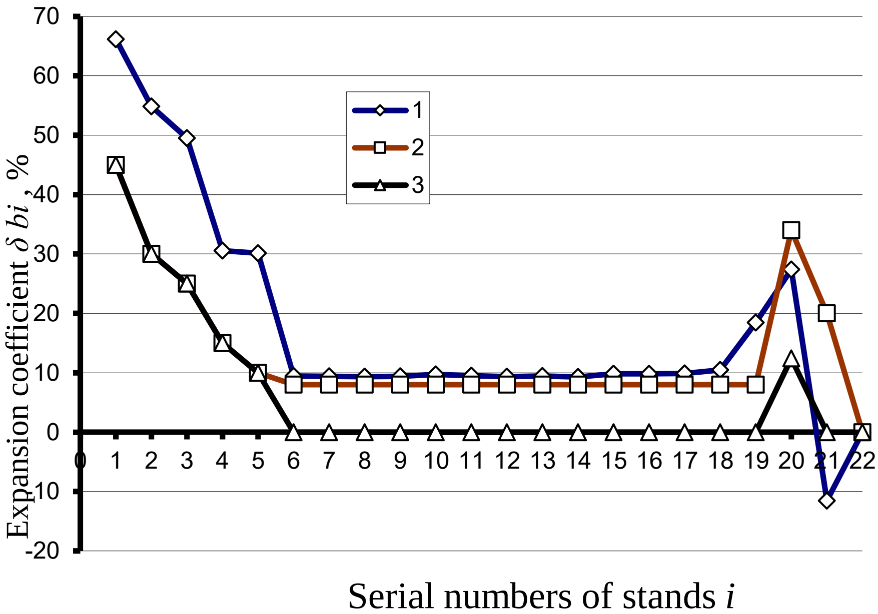


Fig. 1. Shop basic (1) and proposed (2, 3) modes of distribution of expansion indicators δb_i across the stands of the TPA 30-102 reduction mill when rolling along the "basic" route $D_0 \rightarrow D_t$ =117 →42 mm: 2 - $\frac{S_t}{D_t}$ ≤0.1; 3 - $\frac{S_t}{D_t}$ >0.1

As an example, Table 2 shows a comparison of pipe accuracy parameters when rolling pipes on a reduction mill along the route $D_0 x S_0 \rightarrow D_t x S_t$= 117.0x3.50 →48.3x3.25 mm (German standard DIN 2440) using shop rolling tables and rolling tables calculated according to the proposed method [2].

Considering that on TPA 140 of JSC "Interpipe Niko Tube " only relatively thin-walled pipes ($\frac{S_t}{D_t}$ <0.1) are produced, it was decided to use one "base" calibration on the reduction mill, unlike TPA 30-102, where two "base" calibrations were introduced (see Fig. 1). For the proposed base calibration, the mode of distribution of expansion indicators was chosen δb_i on the stands of the mill, in which the value δb_i in the stands of the middle group lies within the range of δb_i=6.8…15.4% (as opposed to δb_i =10.8…19.7% for shop calibration of rolls [6, 7]. At the same time, based on the fact that preliminary ovalization of billets has a positive effect on reducing the transverse wall difference of pipes, such an arrangement of stands was proposed that provides additional ovalization (without deformation in diameter) in the stands of the main group of the reduction mill [4].

Table 2 - Comparison of accuracy parameters of pipes 48.3 x 3.25 mm according to DIN 2440 [9]

<table>
<tr><td rowspan="3">Methodology for calculating rolling parameters</td><td rowspan="3">Relative heterogeneity *</td><td rowspan="3">Ovality*</td><td colspan="4">Pipe wall thickness</td><td colspan="4">Outer diameter of the pipe</td></tr>
<tr><td rowspan="2">Nominal value</td><td rowspan="2">Actual average value</td><td colspan="2">Permissible range of values</td><td rowspan="2">Nominal value</td><td rowspan="2">Actual Average Value</td><td colspan="2">Permissible range values</td></tr>
<tr><td>according to standard</td><td>fact</td><td>According to standard</td><td>fact</td></tr>
<tr><td></td><td>%</td><td>%</td><td>mm</td><td>mm</td><td>mm</td><td>mm</td><td>mm</td><td>mm</td><td>mm</td><td>mm</td></tr>
<tr><td>Workshop</td><td>7.9÷19.8</td><td>0.06÷0.52</td><td rowspan="2">3.25</td><td>3.37</td><td rowspan="2">1.19</td><td>1.05</td><td rowspan="2">48.3</td><td>48.21</td><td rowspan="2">0.9</td><td>0.42</td></tr>
<tr><td>Proposed</td><td>5.0÷14.3</td><td>0.04÷0.29</td><td>3.29</td><td>0.75</td><td>48.26</td><td>0.25</td></tr>
</table>

Notes: the table is based on the results of measurements of 30 pipes (for each position); *without the end sections of the pipe

As mentioned above, the industrial testing of the proposed modes of distribution of partial deformations and the new method of calculating the parameters of roll calibration for a 5-stand calibration mill with two-roll stands and individually cut calibers was carried out under the conditions of TPA 350.

According to the shop rolling table, it was assumed to use oval roll calibration in the first four stands, and round calibration with rounded outlets in the last stand (outlet angle $\alpha_B = \frac{\pi}{6}$rad.). The distribution of partial deformations $\varepsilon_i$across the mill stands is set in accordance with the "falling" mode ($\varepsilon_1 > \varepsilon_2 > \varepsilon_3 > \varepsilon_4 > \varepsilon_5$), and in the last stand of the mill, the partial deformation along the diameter is 0.10…1.37% [8]. For the calculation of new rolling tables and roll ε_5 =calibration parameters, it was proposed:

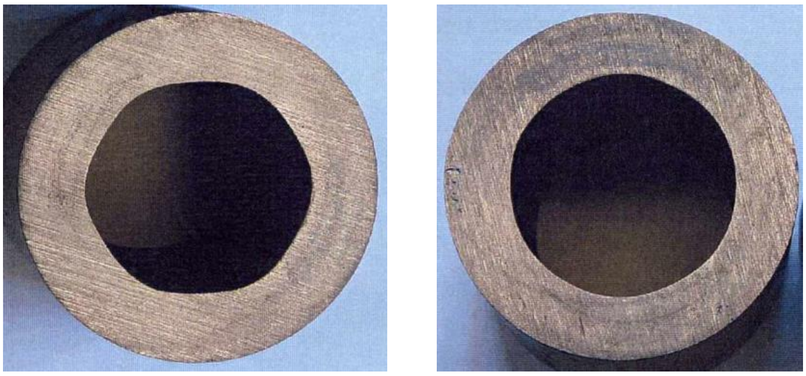
change the mode of distribution of partial deformations and choose ε_i from the condition of minimizing the calculated values of the given relative transverse heterogeneity B_t;

to reduce the ovality of finished pipes, use round roll calibration (λ_5 =0) in the last stand of the mill.

Discussion of the results. From the given data it follows that in terms of relative transverse wall unevenness and ovality, pipes that were rolled using the proposed roll calibration are more accurate than pipes rolled using shop calibration. In the given example (Table 2), the actual range of wall thickness values (absolute transverse wall unevenness ($\Delta S_t = Stmin_{tmax}$) for pipes rolled using the proposed calibration is approximately 25% less than for pipes rolled using the shop calibration of rolls (0.75 mm versus 1.05 mm, respectively); the value of M_{B_t} the mathematical expectation (average value) of the value of the relative transverse wall difference B_t pipes rolled using the proposed calibration are 1.46 times less than those rolled using the shop calibration of rolls ($M^{//}_{B_t}$ =9.6% mm versus $M^{/}_{B_t}$ =14.1%, respectively).

Summarizing the results of comparing the accuracy indicators of pipes of different sizes rolled on reduction and calibration mills using the proposed and shop calibrations of rolls, we can conclude that when using the proposed calibrations, a decrease in the relative transverse wall difference of pipes is observed B_t (the recorded values of the relative decrease M_{B_t} in the value range from 1.12 to 2.45).

It is especially worth noting the high efficiency of using the proposed method for calculating rolling tables (roll calibration parameters) of thick-walled pipes. For example, in the case of manufacturing pipes with dimensions of 57x11÷12 mm from billets of 117x9÷12 mm using the proposed rolling table, their absolute transverse wall difference is approximately 2.0÷2.5 times lower (0.8-1.0 mm versus 1.8-2.4 mm) than that of pipes rolled according to the shop rolling table (Fig. 2) [6].



a b

Fig. 2. Cross-sections of pipes D_tx S_t= 57x11 mm, rolled using the shop rolling table (a) and using the proposed rolling table (b)

The results of industrial tests became the basis for the introduction into production of new roll calibrations, the parameters of which were calculated using the proposed method.

Industrial testing of the proposed roll calibrations of the 24-cage and 22-cage reduction mills TPA 140 and TPA 30-102 of JSC "Interpipe Niko Tube " showed that the accuracy of pipes manufactured using them, in terms of relative transverse thickness variation and ovality, exceeds the accuracy of pipes manufactured using shop roll calibrations. For example, the values of relative reduction recorded during comparative experiments M_{B_t}range from $\overline{M}_{B_t}$ =1.10 to 1.45). This fact served as the basis for the industrial implementation of calibrations calculated using the proposed method in the conditions of the reduction mill TPA 140.

During rolling on a 5-stand calibration mill TPA 350 of JSC "Interpipe Niko Tube" of a pilot-industrial batch of casing pipes according to the API Spec. 5CT standard with a nominal size of 244.48x11.99 mm (blank 255x12 mm, material - steel 32G2, batch volume 1415.4 t), a decrease in the actual metal consumption coefficient by 3.4% was recorded in relation to the value that occurs in the production of pipes of the same assortment using the shop rolling table [10, 11].

The positive test results became the basis for the industrial implementation of the proposed rolling tables and roll calibrations for the entire range of pipes produced on the TPA 350.

Conclusions

A new method for calculating hot-rolled pipe rolling tables on continuous longitudinal rolling mills of various designs has been developed, which takes into account the peculiarities of the technology of cutting calibers on rolls, where the initially specified process parameter is the law of expansion distribution δb_i on the mill stands.

The proposed method for calculating rolling tables was tested in industrial conditions and implemented on the entire range of rolled pipes in the conditions of the TPA 30-102 reduction mill, the TPA 140 reduction mill and the TPA 350 calibration mill of JSC "Interpipe Niko Tube".

When using rolling tables calculated using the proposed method, the relative transverse wall difference of pipes decreases (depending on the standard sizes of rolled pipes) by 1.12…2.45 times for TPA 30-102 and by 1.10…1.45 times for TPA 140; the relative decrease in the metal consumption coefficient for TVA 350 is 3.4%.

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