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KINETIC SIMULATION OF ROD ROLLING IN A WIRE BLOCK

Rolling of round billet in the system of calibers "oval-round" in wire blocks is the main method of modern production of wire rod. However, due to the lack of much experimental data in the corresponding development of the theory of high-speed rolling, simulation is relevant. To build a kinetic model of the high-speed rolling process, the calculation algorithms are taken into account the longitudinal stability of the process. The adequacy of the model is assessed by the results of the calculation of the calibration of the rolls for the stands of the wire block when rolling the wire rod with a diameter of 5.5 mm, which correspond to the proprietary materials of the design documentation.
Keywords: *high-speed rolling; kinetic model of wire rod rolling; longitudinal stability of rolling; calibration of rolls.*

Прокатка круглої заготовки в системі калібрів «овал-круг» у дротяних блоках є основним методом сучасного виробництва катанки. Однак у зв'язку з відсутністю багатьох експериментальних даних при відповідному розвитку теорії високошвидкісного прокатування актуальне імітаційне моделювання. Для побудови кінетичної моделі процесу високошвидкісного прокатування до алгоритмів розрахунків додається врахування поздовжньої сталості процесу. Адекватність моделі оцінюється за результатами розрахунку калібровкі валків для клітей дротяного блоку при прокатуванні катанки діаметром 5,5 мм, які відповідають фірмовим проектним матеріалам.
Ключові слова: *високошвидкісне прокатування; кінетична модель прокатування катанки; поздовжня сталість прокатки; калібровка валків.*

Problem's Formulation

In modern wire rod manufacturing with the use of wire blocks, it is important to avoid an unstable process, which is expressed in slips of workpiece in the rolls, leads to equipment failures and reduced productivity of the technological process. When improving the technological process, system analysis involves the study of material flows from the source material to the final product. Analysis of the production of small-grade rolled metal allows us to present the process of forming and transportation of metal as a set of operations to which the material of the initial workpiece in the process of its transformation into marketable products. We obtain a scheme in the form of a linear flow process for technological specialization of both its stages and individual operations. By stages, the technological process of production the products is one-line. Moreover, in the analysis of the operative process during the steps also has a pronounced single-line flow character. However, even for such a simple scheme in the design and control should use a scientific approach based on mathematical modeling and simulation.

Analysis of recent research and publications

According to the tasks of rolling production technology, plastic deformations of the processed material are first subject to modeling. Known methods for calculating the modes of reduction and calibration of rolls in the rolling of profile products, including the production of wire rod, set out in the fundamental works [2—5]. In modern rolling mills during the production of round profiles use a system of oval-round gauges [2, 3, 6, 7]. This system allows for a smooth transition from one cross-sectional shape to another in the rolling. When calculating the modes of reduction and calibration the rolls of the wire block, fundamental difficulties are caused by the exact determination of the ratio between longitudinal and transverse deformation, as well as the choice of the friction coefficient, especially in high-speed stands, since experimental and calculated analytical data in the literature are absent. The systems approach focuses on the simulation of high-speed working processes, taking into account their various aspects.

Formulation of the study purpose

First of all, the aim of this work is to develop a kinetic model of wire rod rolling in a wire block, which, along with the law of constancy of seconds volumes (process kinematics), would take into account the equilibrium conditions of metal in the rolls with the presence of forward and rear tension rolling on all stands of the wire block (dynamics of process).

Presenting main material

Modern mathematical models in rolling production can be divided into three classes. The first includes descriptive models: regression and other empirically established quantitative dependencies that do not claim to reveal the mechanism of the process being analyzed. They are usually used to describe separated dependencies and are included as fragments in simulation models. These include most of the calculation formulas for determining the extension.

The second – qualitative models, which are built to determine the dynamic mechanism of the studied process, are able to reproduce the dynamic effects observed in the behavior of systems, such as changes in stress in the deformation center. To do this, you can use the solution of the boundary value problem with the equation of T. Karman or energy methods. Usually these models are subjected to quantitative research using analytical and computer methods.

The third class – simulation models of specific technological systems that take into account all available information about the object of production. The purpose of building such models is a detailed prediction of the behavior of complex systems or solving the optimization problem of their operation. Calculations of longitudinal stability in rolling the profiles should be included in the methods of technological calculations.

The kinetic model is applicable to the analysis of the rolling process the wire rod with a diameter of 5.5 mm in the wire block of the mill 400/200 of PJSC "DMC". Taking into account the thermal expansion and half the minus tolerance in terms of the corresponding strip, the final transverse dimensions of the strip after rolling in the tenth stand will be $h_{1\,(10)} \times b_{1\,(10)} = 4.87 \times 4.87$ mm. Let us set the lead value $S_{(10)} = 0.05$. Taking into account the real linear speed of the rolls $v_{в(10)} = 98$ m/s, we determine the speed of the wire rod exit from the last stand

$$v_{1\,(10)} = (1 + S_{(10)})\, v_{в\,(10)} = 1.05 \cdot 98 = 102.9 \text{ m/s}.$$

As a result, the second volume of metal will be

$$V_{sec} = 4.87 \cdot 4.87 \cdot 102.9 = 2440.5 \text{ mm}^2 \cdot \text{m/s}.$$

Further, proceeding from the law of constancy of second volumes, we determine the kinematic value of the angle of the neutral section

$$\gamma_{p10} = \sqrt{\frac{S_{(10)} \cdot h_{10}}{R_{10}}}\,,$$

where R_{10} is the rolling radius the rolls in stand 10.

After substitution of values (R_{10} = 104, 36 mm)

$$\gamma_{p10} = \sqrt{\frac{0{,}05 \cdot 4{,}87}{104{,}36}} = 0{,}048\,.$$

We numerically solve the differential equation of T. Karman [8] with the known parameters R_{10}, h_y, f_y ($f_y = 0.26$ is the friction coefficient obtained from the conditions of longitudinal stability of the strip in rolls [9]) taking into account the front and rear tensions.

Assume

$$q_{010} = \frac{\sigma_{010}}{2k_{cp10}} = 0.05\,; \quad q_{110} = \frac{\sigma_{110}}{2k_{cp10}} = 0.0\,,$$

where q_{110} and q_{010} are front and rear tensions in 10 stand, $2k_{cp10}$ is the average deformation resistance.

With the specified parameters, we find such an angle of rolling α_{y10}, at which the angle γ_{10}, obtained from the equilibrium conditions by the results of solving the Karman equation, would be equal to the neutral angle γ_{p10}. The solution results in the form of graphs are shown in Fig. 1 for the case of α_{y10} = 0.145 at absolute reduction Δh_{10} = 2.2 mm. Then the initial thickness $h_{0\,10}$ = 7.07 mm. To determine the initial width of the profile in the tenth pass $b_{0\,10}$, it is necessary to determine the final dimensions of the roll in the 8th pass. To do this, asking ourselves $S_8 = 0.05$, we will find the final speed of the strip in this pass.

Taking into account that v_{B8}= 63.21 m / s, we have

$$v_{18} = 1.05 \cdot 63.21 = 66.37 \text{ m/s.}$$

Then

$$h_{18} = b_{18} = \sqrt{\frac{V_{\sec}}{v_{18}}} = \sqrt{\frac{2440.8}{66.37}} = 6.06 \text{ mm.}$$

Hence it follows that $h_{09} = b_{09} = 6.06$ mm. Determine the kinematic and geometric parameters in the 9th pass. As before, we set advancing $S_8 = 0{,}06$ and take into account value v_{B8}= 79.6 m/s. We find $v_{19} = 1.06 \cdot 79.6 = 84.38$ m/s.

Considering that $b_{19} = h_{010}$= 7.07 mm, we find the final metal thickness in the ninth pass:

$$h_{19} = \frac{V_{\sec}}{v_{19} \cdot b_{19}} = \frac{2440.8}{7.07 \cdot 84.38} = 4.09 \text{ mm.}$$

$$\Delta h_9 = 6.06 - 4.09 = 1.97 \text{ mm}; \alpha_{y9} = \sqrt{\frac{1.97}{104.7}} = 0.137; \; R_9 = 104.6 \text{ mm.}$$

Let us determine $\gamma_{p9} = \sqrt{\frac{0.06 \cdot 4.09}{104.7}} = 0.0483$, for $q_{09} = 0{,}06$ and $q_{19} = 0{,}055$ by the indicated calibration parameters $\gamma_9 = \gamma_{p9}$, i.e. the equilibrium conditions of the metal in the ninth stand are consistent with the law of constancy of second volumes. In this case, the broadening of the metal in this passage is equal to $\Delta b_9 = 7.07 - 6.06 = 1.01$ mm.

Considering that $b_{010} = h_{19}$= 4.09 mm, we get the broadening of the roll in the tenth pass $\Delta b_{10} = 4.87 - 4.09 = 0.78$ mm. According to the results of calculations, the deformation modes and kinematic parameters in stands 9 and 10 are determined.

We continue calculating the parameters in the eighth stand. Find the neutral angle

$$\gamma_{p8} = \sqrt{\frac{0.05 \cdot 6.06}{103.88}} = 0.054.$$

Numerical solution of the differential equation of equilibrium at h_{18}= 6.06 mm; $f_y = 0.26$; $R_8 = 103.88$ mm; $q_{18} = 0{,}06$ and $q_{19} = 0{,}055$; $\alpha_8 = 0.191$ gives $\gamma_8 = \gamma_{p8} = 0.054$. Next, we determine $\Delta h_8 = 103.88 \cdot 0.191^2 = 3.8$ mm and $h_{08} = 6.06 + 3.8 = 9.86$ mm. The value $b_{0\,8}$ is calculated in the same way as for stand 10. The final dimensions of the roll in the sixth stand are preliminarily determined, which corresponds to the initial dimensions $h_{0\,7}$ and $b_{0\,7}$. We use $b_{17} = h_{08}$= 9.86 mm. Then, acting in the same way as in the 9th passage, we find $h_{1\,7}$, Δh_7, α_{y7} and Δb_7. Geometric and kinematic parameters for rolling in 4, 5 and 6 stands are calculated by the same way. Further, in accordance with the algorithm, calculations continue until the first pass. For the convenience of analysis, the data and results of calculations of technological parameters during rolling the corresponding strip are summarized in tabl. 1.

b_1, mm	4,87
R	104,4
h_1	4,87
f	0,26
α	0,145
$q_0/2k$	0,05
$q_1/2k$	0
$R_{ном}$	104,4
$Q^*_{ср\ пр}$	-0,0139
$p_{ср}$	1,27652
$M_{пр}$	0,064
$T_{оп}$	0,0168
$T_{от}$	0,0467
γ	0,048

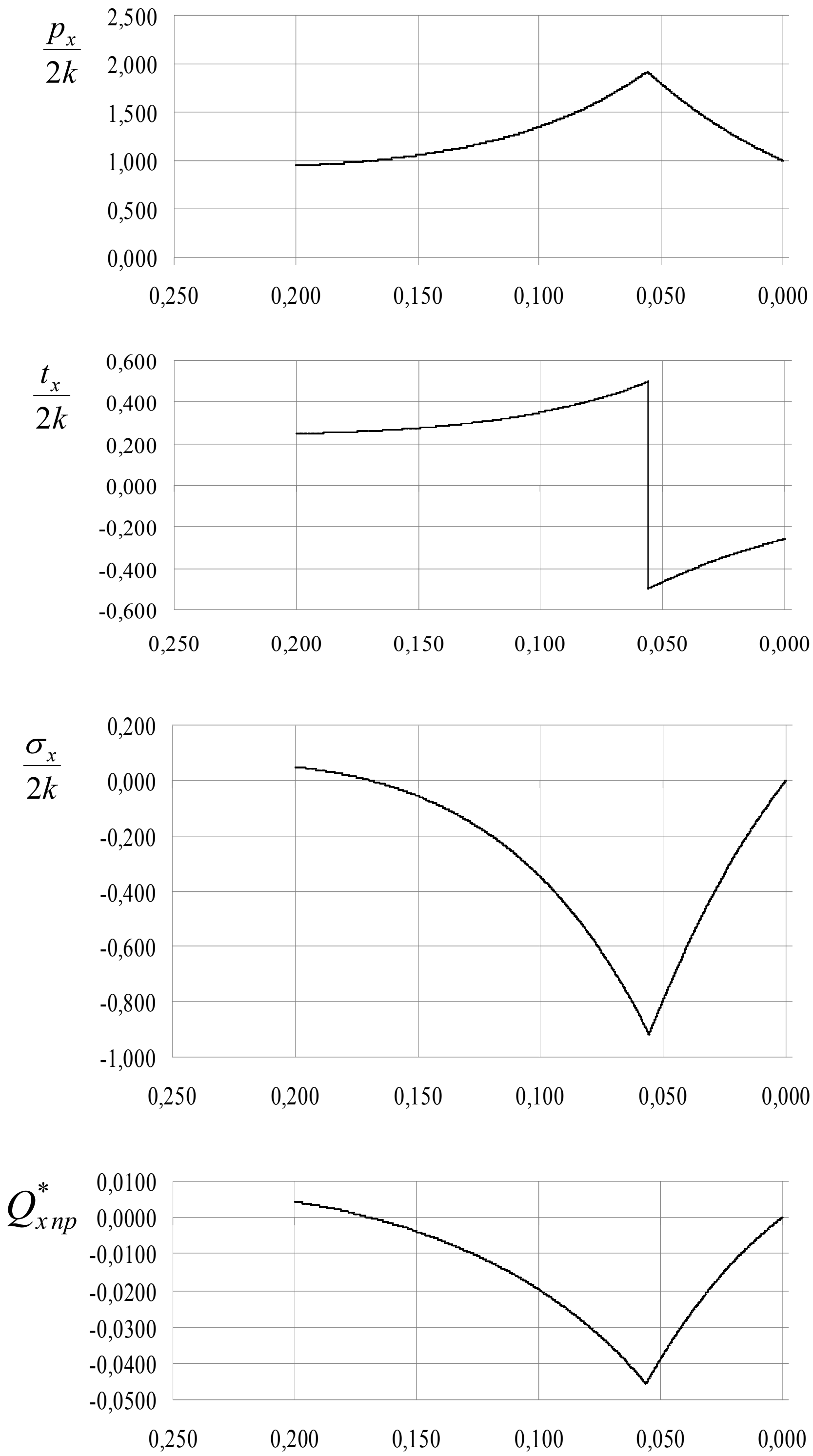

Fig. 1. Distribution of the stresses and current longitudinal force in the deformation zone of the tenth stand

Table 1. Geometric, kinematic and force parameters of rolling the corresponding strip

NR	h_0	h_1	Δh	b_0	b_1	Δb	R_k	q_0
1	15.33	8.99	6.34	15.33	18.9	3.57	102.6	0
2	18.9	11.9	7.03	8.99	11.9	2.88	101.7	0.06
3	11.87	6.9	4.97	11.87	16.7	4.83	103.3	0.07
4	16.65	9.58	6.96	6.9	9.58	2.68	103.3	0.05
5	9.58	5.6	3.98	9.58	13.0	3.42	104.0	0.06
6	12.99	7.62	5.37	5.6	7.62	2.02	103.3	0.05
7	7.62	4.59	3.03	7.62	9.86	2.24	104.4	0.06
8	9.86	6.06	3.8	4.59	6.06	1.47	103.9	0.06
9	6.06	4.09	1.97	6.06	7.07	1.01	104.7	0.06
10	7.07	4.87	2.2	4.09	4.87	0.78	104.4	0.05

Table 1 continuation

NR	q_1	α	v_r	v_1	S	γ_p	$Q^*_{\text{cp np}}$
1	0.06	0.249	13.68	14.36	0.05	0.068	-0.0145
2	0.07	0.263	16.82	17.32	0.03	0.061	-0.0036
3	0.05	0.219	20.37	21.29	0.05	0.057	-0.0096
4	0.06	0.26	25.08	26.08	0.04	0.061	-0.0065
5	0.05	0.196	31.63	33.53	0.05	0.057	-0.0127
6	0.06	0.228	40.02	42.02	0.05	0.061	-0.0106
7	0.06	0.17	49.87	53.36	0.07	0.055	-0.0138
8	0.06	0.193	63.25	66.37	0.05	0.059	-0.0124
9	0.05	0.136	79.6	84.39	0.06	0.048	-0.0127
10	0	0.145	98.0	102.9	0.05	0.048	-0.0139

Taking into account that the condition $\gamma = 0$ does not always accurately reflect the limiting conditions of rolling [10, 11], the paper analyzes the internal longitudinal forces in the deformation zones of all stands of the block. To characterize these current forces, their average resultant $Q^*_{cp\,np}$ [8, 9, 12] is used. If this force is directed opposite to the direction of movement the metal (is negative), then the process is carried out steadily without signs of slipping. When $Q^*_{cp\,np} > 0$, the rolling process is impossible. Table 1 shows the calculated values of the force $Q^*_{cp\,np}$ and shows that under the given conditions of friction, the values of the angles of capture, specific tensions, as well as with the obtained dimensions h_{0i}; b_{0i}; h_{1i}; b_{1i} the process of metal deformation along the mill line should be performed steadily without complications.

At the same time, it should be noted that in the first four passes the longitudinal stability of the rolling piece is somewhat worse than in the other stands of the block. The minimum modulus value of the dimensionless force $Q^*_{\text{cp np}}$ is observed in the deformation zone of the second stand. Obviously, this is due to a significant angle of capture, as well as a significant rear specific tension of the rolling specimen.

According to the conditions for recalculating the dimensions of the corresponding strip and the real rolling specimen [13], the dimensions of the profile were determined when rolling in each stand of the block and roll grooves in the round-oval-round scheme, which are presenting in tabl. 2.

Table 2. Transverse dimensions of the specimens in a wire block

Stand's number	Corresponding strip				Real profile dimensions			
	F_0	F_1	h_0/b_0	h_1/b_1	h_0	b_0	h_1	b_1
1	235	170	1	0.476	17.3	17.3	9.24	19.41
2	170	140.9	2.025	1	19.41	9.24	13.4	13.4
3	140.9	115	1	0.478	13.4	13.4	7.75	18.9
4	115	91.78	2.091	1	18.9	7.75	10.81	10.81
5	91.78	72.74	1	0.431	10.81	10.81	6.32	14.66
6	72.74	58.06	2.32	1	14.66	6.32	8.6	8.6
7	58.06	45.26	1	0.466	8.6	8.6	4.88	10.47
8	45.26	36.72	2.148	1	10.47	4.88	6.84	6.84
9	36.72	28.92	1	0.579	6.84	6.84	4.62	7.98
10	28.92	23.717	1.729	1	7.98	4.62	5.5	5.5

Comparing the results of the calculations performed with the data from the calibration table for the rolls of the wire block when rolling wire rod with a diameter of 5.5 mm, drawn up in accordance with the proprietary design documentation, we can conclude that they do not differ significantly and complement each other.

Conclusions

A kinetic model has been developed for rolling wire rod in the stands of a wire block by the gauges' system the oval-round, taking into account the law of constancy the seconds volumes, the equilibrium of specimen in rolls in the presence of tension in the metal, as well as the fulfillment of the condition for the longitudinal stability of the process. Using this model, the calculation of the calibration of the wire block the 400/200 mill for rolling wire rod with a diameter of 5.5 mm was carried out, the results obtained correspond to the proprietary materials of the design documentation.

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КІНЕТИЧНЕ МОДЕЛЮВАННЯ ПРОКАТУВАННЯ КАТАНКИ У ДРОТОВОМУ БЛОЦІ

Максименко О.П., Нікулін О.В., Самохвал В.М., Приймак А.Б.

Реферат

Високошвидкісна прокатка є основним способом виготовлення катанки на сучасних металургійних підприємствах. По стадіях процес виробництва дрібносортного прокату є однолінійним. Однак і для такої технологічної схеми при проектуванні та для керування треба користуватися науковим підходом на основі математичного моделювання. Системний підхід орієнтує на імітаційне моделювання високошвидкісних процесів обробки, враховуючі їх різні аспекти. Прокатка круглої заготовки в системі калібрів «овал-круг» у дротяних блоках найбільш поширена у виробництві катанки. Однак у зв'язку з відсутністю багатьох експериментальних даних при відповідному розвитку теорії високошвидкісного прокатування актуальне математичне моделювання. Для побудови кінетичної моделі процесу високошвидкісного прокатування до алгоритмів розрахунків додається врахування поздовжньої сталості процесу. Наведені розрахункові значення поздовжньої результуючої сили за заданих умов тертя, значеннях кутів захвату, питомих натягів, а також при отриманих розмірах показують, що процес деформації металу по всій лінії стану має здійснюватися стійко без ускладнень. Разом про те, слід зазначити, що у перших чотирьох проходах поздовжня стійкість розкочування трохи гірше, ніж у інших клітинах блоку. Очевидно, це пов'язано із значним кутом захоплення, а також суттєвим заднім питомим натягом прокатування. Адекватність моделі оцінюється за результатами розрахунку калібровкі валків для клітей дротяного блоку при прокатуванні катанки діаметром 5,5 мм, які відповідають фірмовим проектним матеріалам.

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