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ANALYTICAL STUDIES OF THE INFLUENCE OF THE TECHNOLOGICAL PARAMETERS OF THE PROCESS OF PULLING THE STRIP THROUGH THE BENDING-STRETCHING DEVICE ON THE CHANGE OF THE ENERGY-FORCE PARAMETERS OF THE PROCESS

Abstract. It is impossible to imagine the modern development of technology without the use of metal products, including wire products, which are subject to high requirements in terms of variety and quality, and to the production processes, for example, wire of a fashioned profile, the flexibility of technology, high efficiency and economy, labor safety and automation. One of them is the process of drawing metal in roller dies, which combines the features of two methods of pressure metal processing - rolling and drawing. The main working tool when applying the drawing process in roller dies is a roller die with non-driven working rollers. The main drawback of the roller dies method is the presence of traction force. Stretching stresses in combination with a decrease in the plasticity of the metal during the drawing process can lead to the destruction of the rolled product. This limits the assortment of profiles, the total crimping in one of transition. It is possible to increase the plasticity of metal in two ways - thermal and mechanical. The thermal method, which is widely used in industry, requires significant energy consumption. At the same time, previous studies, which were carried out including in the ISI NASU, showed that it is possible to increase the plasticity of the metal by means of alternating sign deformation of the profiles, using, for example, equipment for straightening profiles or a scale breaker. The purpose of analytical research is to establish the dependence of the influence of the technological parameters of the drawing process in a roller drawing machine combined with the pulling of strips through a device for bending with tension (DBT) on the change of the energy parameters of the process based on the developed mathematical model. Analytical studies of the influence of the technological parameters of the DBT were carried out for the case of deformation of the initial workpiece of round cross-section with a diameter of 5.90 mm from low-carbon steel of the St.08 brand in a double-roll roller die with smooth rolls, combined with DBT in the conditions of the laboratory base of the pressure metal processing department of the Iron and Steel Institute of the Z.I. Nekrasov of NASU. On the basis of the revealed regularities, the dependences of the energy-force parameters of the process of drawing in a roller die, combined with the drawing of strip through the DBT, on the influence of the main technological parameters were obtained. It was established that an increase in the distance between of the axes rollers of the DBT at a constant value of the movement of the axis of the pressure roller of the DBT in the vertical direction leads to a decrease in the angle of coverage of the roller by the strip. It has been established that at a constant distance between the axes of the DBT rollers, when the amount of movement of the axis of the DBT pressure roller increases vertically, on the contrary, the values of the angle of coverage of the roller by the strip increase. It is shown that an increase in the number the rollers of DBR leads to an increase in both the pulling force of the strip and the normal component of the force acting on the trunnion of the rollers of the DBT. It was determined that the most significant influence of the height of the stretched strip and the radius the rollers of the DBT on the pulling force occurs in the range of relations $R/h \leq 10$. It was established that an increase in the total degree of preliminary deformation in the roller die and sign-changing deformation in the DBT of the strip leads to an increase in the value of the pulling force.

Key words: sign-changing deformation with stretching, tape type profiles, mechanical properties, bending and stretching roller device, roller die, pulling force, strip.

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Introduction. It is impossible to imagine the modern development of technology without the use of metal products, including wire products, which are subject to high requirements in terms of variety and quality, and to the production processes, for example, wire of a fashioned profile, the flexibility of technology, high efficiency and economy, labor safety and automation. One of them is the process of drawing metal in roller dies, which combines the features of two methods of pressure metal processing - rolling and drawing. The main working tool when applying the drawing process in roller dies is a roller die with non-driven working rollers [1-4].

The use of drawing in roller dies is effective in the conditions of production of bars and wire of fashioned profile, in draft passes when drawing wire rod, cast and other types of blanks, in the production of

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reinforcing wire and wire made from materials that are difficult to deform.

Compared to cold rolling and flattening, the process of drawing in roller dies has higher technological flexibility, does not require large capital costs for the organization of production. Compared to conventional drawing using monolithic dies, the drawing process in roller dies has the following advantages: lower energy consumption; higher permissible deformation per pass; higher homogeneity of product properties [5-8].

The main drawback of the roller portage method is the presence of pulling force. Stretching stresses in combination with a decrease in the plasticity of the metal during the drawing process can lead to the destruction of the rolled product. This limits the assortment of profiles, the total crimping in one of transition.

It is possible to increase the plasticity of metal in two ways - thermal and mechanical. The thermal method, which is widely used in industry, requires significant energy consumption. At the same time, previous studies, which were carried out including in the ISI NASU, showed that it is possible to increase the plasticity of the metal by means of alternating sign deformation of the profiles, using, for example, equipment for straightening profiles or a scale breaker.

The main technological factors that affect the energy-force parameters of the sign-changing deformation process are rectangular cross-section strip through a device for bending with tension (DBT) according to the "stretching with bending" scheme are: the initial size of the strip (radius for the blank a circular cross-section preparation $R_{bl.}$ or, in our study, it is half the height for the strip $h_{s.}/2$); steel brand; the initial level of the mechanical properties of rolled steel; the value of the angle of coverage of the bending roller; value of the ratio of the radius of the roller $R_{r.}$ to half the height of the strip $h_{s.}/2$ [9].

The magnitude of the counter-tension force in front of the first roller as the main energy-force parameter of the process of changing sign deformation of the strip through the DBT determines (equal to) the force of cold deformation (pulling) of the strip through this device and the power of the drive motor of the traction device, the amount of the maximum possible deformation during the first transition, the stability of the cold deformation process and other parameters. When working with a large back tension, frequent breaks in the rolling stock are possible, which are associated with an increase in the values of stresses that stretch the surface layers of the strip throughout the center of deformation. In turn, the magnitude of the force of pulling the strip through the rollers of the DBT is determined by the radius of the rollers $R_{r.}$, the value of the yield strength of the material of the strip σ_{T0}, by the number of rollers n, half the height of the strip $h_{s.}/2$, value of the distance between the axes of the rollers L_i.

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The main influence on the size of the angle of coverage of the pressure roller by the strip γ gives the radius of the rollers $R_{r.}$, the distance between the axes of the rollers L_i and the amount of movement of the axis of the pressure roller DBT vertically ΔT.

The purpose of analytical research is to establish the dependence of the influence of the technological parameters of the drawing process in a roller drawing machine combined with the pulling of strips through the DBT on the change of the energy-force parameters of the process based on the developed mathematical model.

Materials and Methods. As a mathematical apparatus for conducting analytical studies, we used the developed model for determining the energy-force parameters (EFP) of the drawing process in a roller drawing machine combined with the pulling of strips through the DBT. The main provisions of the mathematical model are outlined in the works [10, 11].

Analytical studies of the influence of the technological parameters of the DBT on the change in the angle of rounding of the roller by the strip (γ,) and the length of contact between the strip and the roller (l, mm) were carried out for the case of deformation of the initial workpiece of round cross-section with a diameter of 5.90 mm from low-carbon steel of the St.08 brand in a double-roll roller die with smooth rolls, combined with DBT in the conditions of the laboratory base of the pressure metal processing department of the Iron and Steel Institute (ISI) of the Z.I. Nekrasov National Academy of Sciences of Ukraine. The radius of the rollers die was R=72.5 mm. Half the height of the strip after the transition from the roller die to the DBT was equal to $h_1/2$=2.60 mm. The scheme of the deformation of the original round workpiece in the smooth rolls of the roller die is shown in fig. 1. DBT parameters: radius of DBT rollers R_r.=18 mm; radius of the trunnion of the DBT rollers R_{tr}.=5 mm; coefficient of friction in DBT f = 0.01.

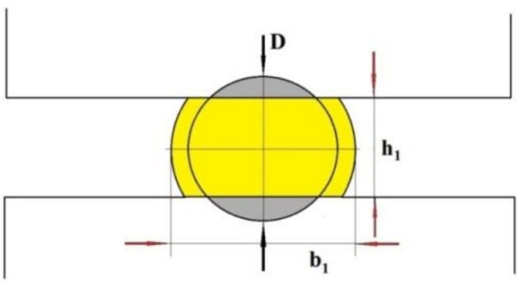

Figure 1 – Scheme of deformation of the original round workpiece in a roller die during analytical studies

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The initial distance between the axes of the L_i DBT rollers was changed every 5 mm from 35 to 70 mm with a constant value of the vertical movement of the axis of the DBT pressure roller ΔT, mm. In the experiments, the amount of movement of the axis of the pressure roller DBT along the vertical ΔT in 1 mm was also changed from 2 to 8 mm with a constant value of the distance between the axes of the rollers L_i, mm.

Results and Discussions. The magnitude of the counter-tension force in front of the first roller as the main energy-force parameters of the process of changing sign deformation of the strip through the Device for Bending with Tension (DBT) determines (equal to) the force of cold deformation (pulling) of the strip through this device and the power of the drive motor of the traction device, the amount of the maximum possible deformation during the first pass, the stability of the cold deformation process and other parameters. When working with a large back tension, frequent breaks in the rolling stock are possible, which are associated with an increase in the values of stresses that stretch the surface layers of the strip throughout the center of deformation. In turn, the magnitude of the pulling force the strip through the rollers of the DBT is determined by the radius of the rollers $R_{r.}$, the value of the yield strength of the material of the blank σ_{T0}, by the number of rollers n, the height of the strip h_s, (in our case, half the height of the strip $h_{s.}/2$) and the value of the distance between the axes of the rollers L_i.

The main influence on the angle of rounding of the pressure roller by the strip γ is provided by the radius of the rollers $R_{r.}$, the distance between the axes of the rollers L_i, and the amount of movement of the axis of the pressure roller DBT vertically ΔT.

The results of calculation of the influence of the technological parameters of the DBT: the distance between the axes of the rollers L_i and the values of the displacement of the axis of the pressure roller of the DBT vertically ΔT on the change in the angle of coverage of the roller by the strip γ and the length of contact between the strip and the roller l_k given in the table 1, 2, respectively, and their summary is presented in fig. 2.

From the analysis of the results of table 1 and 2 and fig. 2 it is established that at a constant value of the distance between the axes of the rollers L_i with an increase in the amount of movement of the axis of the pressure roller DBT vertically ΔT, the values of the angle of rounding of the roller by the strip γ and the length of contact between the strip and the roller l_k increase. It was determined that at a constant amount of movement of the axis of the pressure roller DBT vertically ΔT an increase in the values of the distance between the axes of the rollers L_i, on the contrary, the values of the

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angle of rounding of the roller by the strip γ and the length of contact between the strip and the roller l_k decrease.

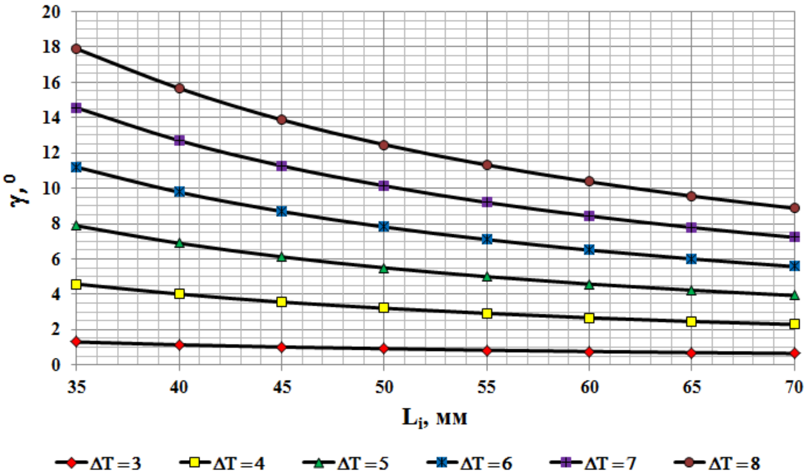

Figure 2 – Influence of parameters L_i and ΔT on the angle of rounding of the roller by the strip: $R_{r.}$ = 18 mm; $R_{tr.}$ = 5.0 mm; $h_{s.}/2$=2.6 mm

Table 1 – The value of the angle of coverage of the roller by the strip γ from the distance between the axes of the rollers L_i and the movement of the axis of the pressure roller DBT vertically ΔT

Indicators of technological parameters						
The distance between the axes of the rollers, L_i, mm	Vertical movement of the DBT pressure roller axis, ΔT, mm					
	ΔT=3	ΔT=4	ΔT=5	ΔT=6	ΔT=7	ΔT=8
	The angle of coverage of the roller by the strip γ, ⁰					
35	1.3	4.58	7.88	11.2	14.56	17.90
40	1.14	4.01	6.89	9.78	12.70	15.66
45	1.01	3.56	6.12	8.69	11.27	13.88
50	0.92	3.21	5.50	7.81	10.14	12.47
55	0.83	2.92	5.00	7.10	9.20	11.32
60	0.76	2.67	4.58	6.50	8.43	10.37
65	0.70	2.46	4.23	6.00	7.78	9.56
70	0.65	2.29	3.93	5.57	7.22	8.87

Table 2 – The value of the contact length of the staff with the roller $l_{k.}$ from the value of the distance between the axes of the rollers L_i and the displacement values of the axis of the pressure roller DBT vertically ΔT

Indicators of technological parameters						
The distance between the axes of the rollers, L_i, mm	Vertical movement of the DBT pressure roller axis, ΔT, mm					
	ΔT=3	ΔT=4	ΔT=5	ΔT=6	ΔT=7	ΔT=8
	The contact length of the staff with the roller $l_{к.}$, mm					
35	1.078	3.94	7.04	10.04	14.03	17.94
40	0.94	3.44	6.15	9.08	12.24	15.63
45	0.83	3.06	5.47	8.07	10.86	13.86
50	0.75	2.75	4.92	7.25	9.76	12.45
55	0.68	2.50	4.47	6.59	8.87	11.30
60	0.63	2.29	4.10	6.04	8.12	10.35
65	0.58	2.12	3.78	5.57	7.49	9.54
70	0.53	1.96	3.51	5.17	6.95	8.86

Knowing the amount of effort that must be applied to the front end of the strip to pull it through the rollers of the DBT allows you to qualitatively take into account the effect of the amount of back tension during the first crimping. The work [12, 13] is known, which describes the method of calculating these forces. However, calculations based on the above formulas showed that for roller DBT with adjustable bending of profiles of circular sections between the rollers, they will be valid only for small elastic deformations with a small curvature of the bend, for example, for straightening long pipes on rollers, when $(\rho+r)/r\geq10^3$, where ρ is the bending radius of the product and r is product radius [5, 14]. Analysis of the formulas and calculation results showed that the formulas in work [12] provide an underestimate of the drawing process force, because they do not take into account the part of the work that is required for additional bending of the metal layer when changing the angle of coverage of the pressure roller by the strip γ and, accordingly, reduce the amount of work that is required for drawing process the strip through the DBT rollers. Therefore, taking into account the results of work [5, 14], the results of the calculation of the value of the normal component force acting on the pin of the roller F_i were additionally analyzed and compared with the calculated value of the drawing process force P_i through the DBT.

Analysis of changes in the pulling force of strip of the $P_{pull.}$ and the normal component of the force F_n acting on the trunnions of the DBT rollers was performed from the number of rollers n involved in the deformation process in the DBT. The number of rollers n, which were involved in the deformation process in the DBT, varied in steps of 1 piece

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from 1 to 7 pieces.

In the table 3 shows the results of these calculations, and fig. 3 shows the dependence of the drawing process force of the strip and the normal component of the force acting on the trunnions of the DBT rollers on the number of rollers that are involved in the deformation process in the DBT.

Table 3 – The value of the pulling force of the strip and the normal component of the force acting on the trunnions of the rollers from the number of rollers of the DBT

Number of rollers, *n*, pieces	The normal component of the force acting on the trunnions of the DBT rollers, $F_{n.}$, N	The force of the pulling the strip through the DBT, $P_{pull.}$, N	$\frac{F_{n.}-P_{pull.}}{F_{n.}} \times 100\%$, %
1	4212	2884	31.5
2	7216	4406	38.9
3	10237	5937	42.0
4	13276	7477	43.7
5	16331	9025	44.7
6	19403	10582	45.5
7	22493	12147	46.0

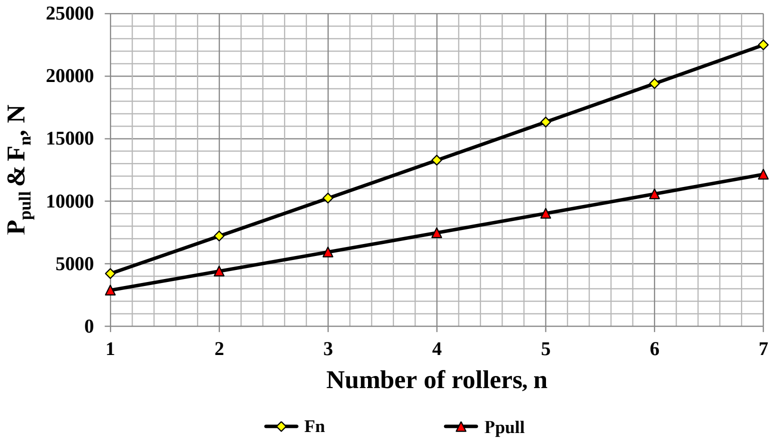

Figure 3 – Dependence of the pulling force and the normal component of the force acting on the trunnion on the number of DBT rollers: σ_{T0} = 572 N/mm^2; $R_{r.}$ = 18 mm; $R_{tr.}$ = 5.0 mm; $h_{s.}/2$=2.6 mm; L_i = 35 mm; Δt = 4.0 mm; f = 0.01

From the data in the table 3 and fig. 3 it is established that with an increase in the number of involved rollers, the DBT leads to an increase in

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both the pulling force the strip and the normal component of the force acting on the trunnion of the rollers of the DBT. At the same time, with an increase in the number of DBT rollers, the value of the normal component of the force $F_{n.}$ increases more intensively than the increase in the values of the pulling force of the $P_{pull.}$ strip, which is illustrated in fig. 3 and the values of table 3 ($\frac{F_{n.}-P_{pull.}}{F_{n.}} \times 100\%$). These dependencies absolutely clearly reflect the logic of the mechanism of the pulling the strip through the DBT.

The normal component of the force acting on the pin of the roller F_i according to the work [4] is 20-40 % greater than of the pulling force P_i through the DBT. Therefore, the radius of the trunnion and roller bearings must be determined taking into account the value of the normal component of the force acting on the trunnion, and not by the magnitude of the pulling force.

The results of calculations of the amount of the pulling force through the DBT from the height of the strip (½ the height of the strip $h_{s.}/2$), which is drawn and the radius of the rollers R_r of the DBT are given in the table 4 and fig. 4.

Table 4 – The value of the pulling force through the DBT depends on the height of the pulling strip and the radius of the rollers of the DBT

R_r, mm	½ the height of the strip, $h_{s.}/2$, mm											
	$h_{s..}/2$ = 2.5 mm			$h_{s.}/2$ = 2 mm			$h_{s.}/2$ = 1.5 mm			$h_{s.}/2$ = 1 mm		
	$P_{draw.}$, N	$\frac{R_{r.}}{h_{s.}/2}$	1	$P_{draw.}$, N	$\frac{R_{r.}}{h_{s.}/2}$	1	$P_{draw.}$, N	$\frac{R_{r.}}{h_{s.}/2}$	1	$P_{draw.}$, N	$\frac{R_{r.}}{h_{s.}/2}$	1
20	9958	8	5.56	5872	10	2.91	3317	13.3	1.26	1965	20	0.38
30	7304	12	3.85	4457	15	2.00	2694	20	0.86	1770	30	0.26
40	5904	16	2.94	3720	20	1.52	2373	26.6	0.65	1671	40	0.20
50	5039	20	2.38	3267	25	1.23	2178	33.3	0.52	1611	50	0.16
60	4452	24	2.00	2960	30	1.03	2046	40	0.44	1571	60	0.13
70	4026	28	1.72	2739	35	0.89	1951	46.6	0.38	1543	70	0.11
80	3704	32	1.52	2572	40	0.78	1879	53.3	0.33	1521	80	0.10

From the analysis of the data in the table 4 it is determined that the value of the pulling force $P_{pull.}$ depends inversely proportionally on the value of the radius of the DBT rollers R_r and directly proportionally on the value of the height of the strip $h_{s.}/2$. With an increase in the radius of the DBT rollers, the value of the pulling force $P_{pull.}$ decreases with a constant value of the height of the strip. At a constant radius of the DBT rollers, the value of the pulling force $P_{pull.}$ decreases with a decrease in the height of the strip. At the same time, if you use a strip of minimum height, for example $h_{s.}/2$=1 mm or $h_{s.}/2$=1.5 mm, then the value of the pulling force depends

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little on the value of the radius of the DBT rollers in comparison with a strip with a height of $h_{s.}/2$ =2 mm or $h_{s.}/2$ =2.5 mm (table 4 and fig. 4). The rate of reduction in the force of pulling strip with a height of $h_{s.}/2$=2 mm or $h_{s.}/2$=2.5 mm due to DBT is much greater than when pulling strip with a height of $h_{s.}/2$=1 mm or $h_{s.}/2$=1.5 mm, which is explained by the influence of the scale factor of the original strip. From the data in the table 4 and the dependencies shown in fig. 4, it is established that the strongest influence of the height of the extending strip and the radius of the rollers on the pulling force is observed in the range of the ratio $R_{r.}/h_{s.}/2 \leq 10$.

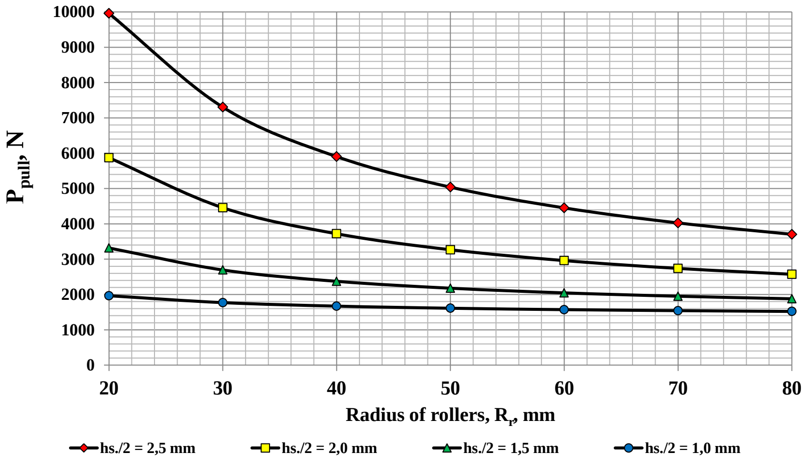

Figure 4 – The influence of the height of the strip and the radius of the rollers on the pulling force through the DBT: σ_{T0}= 572 N/mm^2; $R_{tr.}$ = 5.0 mm; L = 2$R_{r.}$+10 mm; Δt= 4.0 mm; n = 7; f = 0.01

Analysis of the change in the pulling force of the strip through the DBT and the normal component force F_n. acting on the pins of the rollers of the DBT depending on the degree of preliminary deformation in the roller drag and the number of rollers that were involved in the deformation process in the DBT was carried out. In the table 5 shows the results of these calculations, and Fig. 5 shows the dependence of the force of pulling the strip on the degree of preliminary deformation in the roller mill and the number of rollers involved in the deformation process in the DBT.

From the analysis of the data in the table 5 and fig. 5 it is determined that the magnitude of the pulling force of the strip through the DBT $P_{pull.}$ and the normal component of the force acting on the pins of the rollers F_n increases with an increase in the number of rollers n involved in the DBT and with a constant value of the degree of preliminary deformation ε.

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Table 5 – The value of the pulling force of the strip and the normal component of the force acting on the roller trunnions from the number of DBT rollers and the amount of the degree of preliminary deformation in the roller portage

Number of rollers, *n*, pieces	Indicators of technological parameters					
	The degree of preliminary deformation of the strip in of the roller die, %					
	ε = 10 %		*ε* = 20 %		*ε* = 30 %	
	The normal component of the force acting on the trunnions of the DBT rollers, F_n, N	The force on the pulling of the strip through the DBT, $P_{pull.}$, N	The normal component of the force acting on the trunnions of the DBT rollers, F_n, N	The force on the pulling of the strip through the DBT, $P_{pull.}$, N	The normal component of the force acting on the trunnions of the DBT rollers, F_n, N	The force on the pulling of the strip through the DBT, $P_{pull.}$, N
1	4212	2884	5177	3946	1526	5997
2	7216	4406	6990	5143	1692	6850
3	10237	5937	8817	6346	1863	7703
4	13276	7477	10654	7554	2039	8557
5	16331	9025	12501	8767	2218	9411
6	19403	10582	14357	9985	2400	10266
7	22493	12147	16221	11208	2584	11121

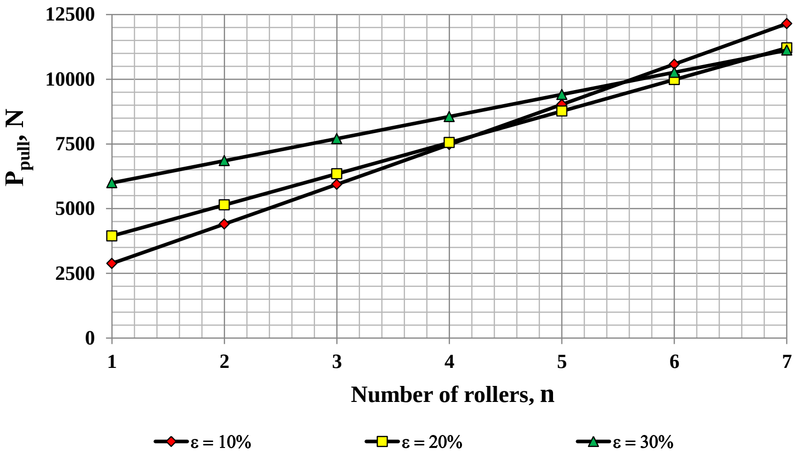

Figure 5 – The influence of preliminary crimping of the strip in the roller die on the force conditions

Conclusions

On the basis of the revealed regularities, the dependences of the energy-force parameters of the process of drawing in a roller die, combined with the pulling of strip through the DBT, on the influence of the main technological parameters were obtained.

In particular, the following new regularities of the combined processes of drawing in roller die and pulling through DBT were obtained:

- an increase in the distance between of the axes rollers of the DBT at a constant value of the movement of the axis of the pressure roller of the DBT in the vertical direction leads to a decrease in the angle of coverage of the roller by the strip;
- it has been established that at a constant distance between the axes of the DBT rollers, when the amount of movement of the axis of the DBT pressure roller increases vertically, on the contrary, the values of the angle of coverage of the roller by the strip increase;
- an increase in the number the rollers of DBR leads to an increase in both the pulling force of the strip and the normal component of the force acting on the trunnion of the rollers of the DBT;
- the value of the pulling force depends inversely proportionally on the value of the radius the rollers of the DBT and directly proportionally on the value of the height of the strip;
- it was determined that the most significant influence of the height of the stretched strip and the radius the rollers of the DBT on the pulling force occurs in the range of relations $R/h \leq 10$;
- an increase in the total degree of preliminary deformation in the roller die and sign-changing deformation in the DBT of the strip leads to an increase in the value of the pulling force.

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АНАЛІТИЧНІ ДОСЛІДЖЕННЯ ВПЛИВУ ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ ПРОЦЕСУ ПРОТЯЖКИ ШТАБИ ЧЕРЕЗ ЗГИНО-РОЗТЯГУВАЛЬНИЙ ПРИСТРІЙ НА ЗМІНУ ЕНЕРГОСИЛОВИХ ПАРАМЕТРІВ ПРОЦЕСУ

Анотація. Сучасний розвиток техніки неможливо представити без використання металовиробів, у тому числі, виробів з дроту, до яких пред'являють високі вимоги по різноманіттю й якості, а до процесів виробництва, наприклад, дроту фасонного перерізу – гнучкості технології, високої ефективності і економічності, безпеки праці і автоматизації. Одним з них є процес волочіння металу у роликових волоках, який поєднав в собі особливості двох методів обробки металів тиском – прокатки і волочіння. Основним робочим інструментом при застосуванні процесу волочіння в роликових волоках є роликова волока з неприводними робочими роликами.

Основний недолік способу волочіння в роликових волоках – наявність тягового зусилля. Розтягуючи напруження у сукупності зі зниженням пластичності металу в процесі волочіння, можуть привести до руйнування прокату. Це обмежує сортамент профілів, сумарне обтиснення за один перехід. Підвищити пластичність металу можливо двома способами – термічним і механічним. Термічний спосіб, якій широко застосовується в промисловості, потребує значних витрат енергії. У той же час попередні дослідження, які були проведені в тому числі в ІЧМ НАНУ, показали, що підвищити пластичність металу можливо способом знакозмінного деформування профілів, застосував для цього, наприклад, обладнання для рихтування профілів або окалинозламувача. Метою аналітичних досліджень є встановлення залежностей впливу технологічних параметрів процесу волочіння в роликовій волоці поєднаного з протягуванням штаби через згино-розтягувальний пристрій (ЗРП) на зміну енергосилових параметрів процесу на основі розробленої математичної моделі. Аналітичні дослідження впливу технологічних параметрів ЗРП проводилися для випадку деформування вихідної заготовки круглого перерізу діаметром 5,90 мм з низьковуглецевої сталі марки Ст.08А в двовалковій роликовій волоці з гладкими валками, поєднаного зі ЗРП в умовах лабораторної бази відділу обробки металів тиском ІЧМ НАНУ. На підставі виявлених закономірностей отримано залежності енергосилових параметрів процесу волочіння в роликовій волоці, поєднаного з протягуванням штаби через ЗРП від впливу основних технологічних параметрів. Встановлено, що збільшення відстані між осями роликів ЗРП при постійній величині переміщення осі натискного ролика ЗРП по вертикалі призводить до зниження величини кута охоплення ролика штабою. Визначено, що при постійному значенні відстані між осями роликів ЗРП при збільшенні величини переміщення осі натискного ролика ЗРП по вертикалі, навпаки, збільшуються значення кута охоплення ролика штабою. Показано, що збільшення кількості роликів ЗРП призводить до збільшення, як сили протягування штаби, так і нормальної складової сили, що діє на цапфи роликів ЗРП. Визначено, що найбільш вагомий вплив висоти штаби, що протягується і радіуса роликів ЗРП на силу протягання відбувається в діапазоні відносини $R/h \leq 10$. Встановлено, що збільшення сумарного ступеня попередньої деформації в роликовій волоці та знакозмінної деформації в ЗРП штаби призводить до підвищення величини сили протягування.

Ключові слова: знакозмінна деформація з розтягуванням, профілі стрічкового типу, механічні властивості, згино-розтягувальний роликовий пристрій, роликова волока, зусилля при протягуванні, штаба.

Посилання для цитування: Аналітичні дослідження впливу технологічних параметрів процесу протяжки штаби через згино-розтягувальний пристрій на зміну енергосилових параметрів процесу / В. Г. Раздобрєєв, К. Ю. Ключніков, Д. Г. Паламар, О. І. Лещенко, О. П. Іванов // *Фундаментальні та прикладні проблеми чорної металургії.* 2024. Вип. 38. С. 455-468. https://doi.org/10.52150/2522-9117-2024-38-455-468

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