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OPTIMIZATION OF ROUGHNESS PARAMETERS AND THE DEGREE OF HARDNESS AFTER ROLLING WITH ROLLS WITH THE STABILIZATION OF WORKING EFFORT

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Summary: Surface plastic deformation (SPD) by rolling with rolls or coining by strikers is used to harden the surface layer of metal parts of critical use. Finish SPD is applied to improve the presentation and to increase the wear resistance of the surface layer, and hardening is used to increase the wear resistance of parts.

Modern equipment for hardening surface layers which mostly defines the performance characteristics of the machine parts includes a number of methods: heat treatment, hardening with the HFP, laser processing, etc. Rolling with rolls is widely used for hardening the surface layers of the machine parts.

Spherical or toroidal rolls are mostly used in the technological process of rolling, and the surface becomes wavy with the step other than the feed rate, when the roll is pressed at a high angle.

A lot of researchers believe that the major reason for waviness appearing is the presence of runout roller resulting in a variable rolling feed rate. To avoid the appearing of waviness in finish rolling it is advisable to take the indentation angle valued 2 - 3^0, which limits the roughness of the rolled surface measured 40 $<R_z<$ 80 mcm, and to decrease the waviness it is advisable to use the rolls with a precise profile and to re-grind them as often as possible.At the reinforcement rolling the thin surface layer is whittled away and this decreases greatly the efficiency of the reinforcement.

The constituents of the effort P of the rolling of shafts made of steel 40 (200 HB) with a diameter of 100-200mm on a lathewith a toroidal roll using a device for stabilization ofthe working effort were measured withtheuniversalUDMdynamometer. Thewayofrollingthepartswithrollswiththestabilizationoftheworkingeffortallows to get a reinforced layer of various thickness with a fairly high and homogeneous hardness and increased wear resistance.

Key word: rolling, a roll, average angle of indentation, hardness, response surface, surface roughness.

FORMULATION OF THE PROBLEM

An effort, transmission, roller diameter are the major components of rolling. The transmission of rolling in multiseries and mass production is determined experimentally by a trial lot of details [5-18].It is necessary to optimize the parameters influencing thewear resistance of bodies of rotation after rolling them with rolls in order to reduce the cost of the experiment.

It is necessary to develop modes for rolling the bodies of rotation with rolls to prevent waviness on the workpiece surface.

THE ANALYZES OF THE LATEST RESEARCHES AND PUBLICATIONS

Yu. G. Proskuryakov, L. M. Shkolnik[20]suggested a method for calculating the effort of rolling shafts and holes with Ball and roller with rectilinear generatrix based on the experiments. The effort is defined depending on geometrical sizes of the roll and the detail, the modulus of elasticity of the material being rolled and maximum contact pressure during rolling.

V. M. Braslavskiy[1-7]also developed a technique for selecting the rolling modes and introduced a hardness coefficient.

The works[19, 23, 25, 26, 27] present a technology of rolling the details with rolls with a little effort.

SETTING THE GOAL

To find theoptimal modes of rollingwhich ensure the details' maximum wear resistance after processing with the help of multifactorial experiment.

In order to determine an objective assessment of the device's functioning we solved the following tasks:
- the main factors that have the greatest impact on the quality of the process were identified;
- the possibilities of changing the parameters of the identified main factors are determined through appropriate adjustments.

BASICMATERIALPRESENTATION

Determination of factors influencing the course of the technological process was carried out by the method of peer review ("psychological experiment"),[21, 22, 24, 28] the following analyzes of the factor ranging diagrams. The major factors influencing the course of the technological process are presented in table 1.

Table 1. The main factors influencing the process

№	Factors	Code marks	Rang eofv ariati on	Factor levels		
				Top+1	Basic 0	Bottom -1
1	Roll diameter, *mm*	X_1	10	60	50	40
2	Rolling effort, кН	X_2	1,12	2,99	1,87	0,75
3	Roller feed, *S mm/rot*	X_3	0,02	0,09	0,07	0,05
4	Initial surface roughness R_a,*mcm*	X_4	0,1	0,40	0,30	0,20
5	Number of the roller passes	X_5	1	3	2	1
6	Average angle of indentation *φ*, gr.	X_6	1	5	4	3
7	Detail diameter , *mm*	X_7	10	60	50	40
8	Radius of the roller profiler_p, *mm*	X_8	1	6	5	4

For each factor, we find the sum of the ranks $\sum_{j=1}^{m} a_{ij}$,

where: *m*– number of specialists interviewed;

a_{ji}–rankoffactor*I* appropriated by the researcher*j* .

Next, we determine the deviations*Δ*of the sum of the ranks from the average sum of ranks for each of the factors

$$\Delta_i = \sum_{j=1}^{m} a_{ij} - \frac{1}{k}\sum_{i=1}^{k}\sum_{j=1}^{m} a_{ij} \quad (1)$$

where: Δ_i- the deviations od the sum of the ranks of factor *i*from the average sum of ranks;

k–the number of factors;

$\frac{1}{k}\sum_{i=1}^{k}\sum_{j=1}^{m} a_{ij}$ - the average sum of ranks.

We estimate the degree of consistency of experts' interviewed opinions.To do this, we use the concordance coefficient, which is determined by formula

$$W = \frac{12S}{m^2\left(k^3 - k\right)} \quad (2)$$

where: $S = \sum_{i=1}^{k} \Delta_i^2$

In this case, the concordance coefficient will be$W$ = 0,93

Itwasestimated, thatat$k$>7 value$m\left(k-1\right)W$ obeys the χ^2–distribution with the number of degrees of freedom$f = k-1$

The significance of the concordance coefficient$W$is established using the Pearson criterion.

Having convinced of the consistency of specialists' opinions, it is possible to construct a diagram of ranks (fig.1).

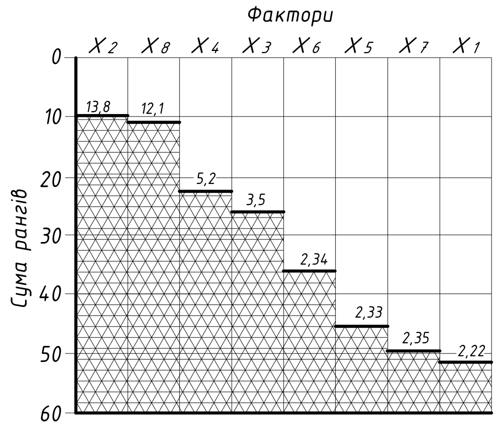

Fig. 1.A diagram of ranks X_1 - the roller diameter; X_2 - the rolling effort; X_3– roller feed; X_4 - the initial surface roughness; X_5 - number of roller passes; X_6 - the average angle of indentation; X_7 - the diameter of the details; X_8 - the radius of the roller profile.

By using the obtained diagram, the significance of the factors was evaluated. To determine the factors that do not affect the technological process, the Student's test was used.

Comparingtheirvalueswithtabularvaluesforthesignificancelevel 0,05 atthenumberofdegreesoffreedom$f$ = 7, itwasestimatedthatfactorsX_1, X_5, X_6, X_7 X_1, X_5, X_6, X_7can be excluded from the following research, and it can be stated that the hypothesis about the significance of the above factors is not accepted. Really, the roller diameter (X_1) doesn't influence the technological process, as the roll has the profile radius in contact with the detail. The number of the roller passes (X_5) slightly influences the quality of the process, and the average angle of indentation (X_6) cannot be changed in the process of experimental research.Similarly, the detail diameter (X7) practically does not affect the technological process.

The analysis of the expert evaluation and their statistical processing made it possible to conclude that the following four factors have the greatest effect on the course and quality of the technological process: rolling effort X_2; roller feedX_3;initial surface roughnessX_4; radius of the roller profileX_8.

In order to reduce the volume of experimental studies and to reduce the number of readjustments of the device, as well as to obtain objectively necessary information on the dependence of the degree of cold hardening and surface roughness on the one-time variation of several kinematic regimes, we used a threelevel D-optimal second-order planning for four independent factors.

After statistic processing of the experimental data of the process of rolling the details with rolls, mathematical models of cold hardening(*CH*) and surface roughness (SR) were obtained with the help of PC. They describe the technological process of rolling with rolls with stabilization of working effort [3]:

$$CH = 18,93207 - 2,99185X_1 + 1,252594X_2 - 0,06056X_3 - 0,04519X_4 + +0,558542X_{12} - 0,06812X_{13} + 0,114792X_{14} - 0,10562X_{23} + 0,135625X_{24} - -0,17104X_{34} + 0,474089X_1^2 + 0,527422X_2^2 + 1,555756X_3^2 - 1,07924X_4^2. \quad (3)$$

$$SR = 0,165438 - 0,01254X_1 + 0,012037X_2 + 0,002352X_3 - 0,00019X_4 + +0,001188X_{12} + 0,002646X_{13} + 0,001646X_{14} + 0,002521X_{23} + 0,000354X_{24} -0,00027X_{34} + 0,00865X_1^2 + 0,00815X_2^2 - 0,01185X_3^2 - 0,01652X_4^2. \quad (4)$$

After statistic processing the analyzes the obtained regression equations were carried out with encoded values of the factors. Investigation of optimization criteria depending on changes in independent factors was carried out using the two-dimensional cross-section method.

The analyzes of mathematical models were carried out for rolling the detail by a roller. In accordance with the experimental design, an assessment was made of the dependence of the technological process performance indicators of the on the rolling effort, *кН* (X_1), radius of the roller profile,*mm* (X_2),initial surface roughness,*mm* (X_3), and roller feed *mm/rot* (X_4), which have the greatest effect on the quality of the technological process. The repetition of the experiments on each of the optimization criteria was three times.

For each row of the plan the average value of CH and SR were calculated. In turn, two factors were equated to zero, leaving the other two unequal to zero.The regression equations for the degree of cold hardening and the surface roughness of the steel experimental sample with possible combinations of factors were obtained.

The combination of such factors of the technological process, as the radius of the roller profile, (X_2), and initial surface roughness, (X_3) at $X_1 = 0$ (the rolling effort = 1,87*кН*) and $X_4 = 0$ (the roller feed = 0,07 *об/мм*) allowed to get the regression equation in the form:

$$CH = 18,93207 + 1,252594X_2 - 0,06056X_3 - 0,10562X_{23} + +0,527422X_2^2 + 1,555756X_3^2 \quad ; (5)$$

$$ШП = 0,165438 + 0,012037X_2 + 0,002352X_3 + +0,002521X_{23} + 0,00815X_2^2 - 0,01185X_3^2 \cdot \quad (6)$$

We take partial derivatives with respect to X2 and X3 and obtain the system of equations for each of the optimization criteria:

$$\begin{cases} \dfrac{\partial CH}{\partial X_2} = -0,10562 \cdot X_3 + 1,054844 \cdot X_2 + 0,25259 = 0 \\ \dfrac{\partial CH}{\partial X_3} = 3,111512 \cdot X_3 - 0,10562 \cdot X_2 - 0,0606 = 0 \end{cases} ; \quad (7)$$

$$\begin{cases} \dfrac{\partial ЗШ}{\partial X_2} = 0,002521 \cdot X_3 + 0,0163 \cdot X_2 + 0,01204 = 0 \\ \dfrac{\partial ЗШ}{\partial X_3} = -0,0237 \cdot X_3 + 0,002521 \cdot X_2 + 0,00235 = 0 \end{cases} . \quad (8)$$

After solving the system of equations for each of the mathematical models, the coordinates of the response surface centers were determined for both optimization criteria and the value of the objective function in the found center of Y_S.

The angle of rotation of the axes in the center of coordinates of the mathematical model in the canonical form was determined by the formula:

$$artg2\alpha = \frac{B_{23}}{B_{22} - B_{33}} \cdot \quad (9)$$

The calculated coordinates of the centers of the response surfaces:

Вычисленные координаты центров поверхностей отклика:

for the degree of cold hardeningX_2 = - 1,1896, X_3 = - 0,0209164, α = 2,93213777 °, Y_S = 18,18768;

for the surface roughnessX_2 = - 0,7416, X_3 = 0,02035403, α'= 3,59212185 °, Y_S = 0,16100.

The coefficients of the regression equations in the canonical form were determined from the characteristic equations for each of the optimization criteria:

$$f(\lambda) = \begin{vmatrix} B_{22} - \lambda & B_{23}/2 \\ B_{32}/2 & B_{33} - \lambda \end{vmatrix} = 0, \quad (10)$$

after which the equation was reduced to the form:

$$\lambda^2 - I \cdot \lambda + D = 0 . \quad (11)$$

The roots of this equation are the coefficients of the mathematical model in canonical form. After the calculations, the regression equations in canonical form will have the form:

$$CH - 18,18768 = 1,55846 \cdot X_2^2 + 0,524717 \cdot X_3^2 ; \quad (12)$$

$$SR - 0,16100 = 0,00823 \cdot X_2^2 - 0,011929 \cdot X_3^2 \cdot \quad (13)$$

The results obtained by combining the factors X2 and X3 are shown in Fig. 2.If we consider the constructed graphs, we can conclude that the zone of optimal alignment of factors is limited by the curves of *CH* and *SR* at the pointsA, B, C, D andE, F, G, H.In this case, the surface roughness in both zones is within0,15 *mcm*<*SR*< 0,16 *mcm*, the degree of work hardening 20,5 *%*<*CH*< 21 *%*.

With these indicators of optimization criteria, the radius of the roller profile is limited to 4,62…4,89 *mm*, and also the initial surface roughness has two diapasons 0,23…0,28 *mm* and 0,33…0,38 *mm*.

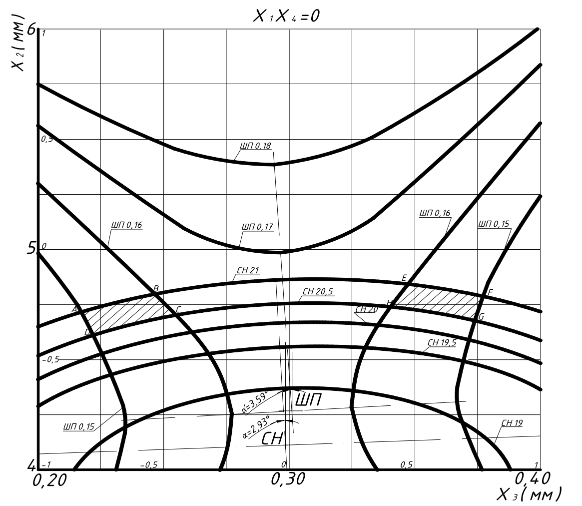

Fig. 2. The two-dimensional surfaces at the intersection of the response factors combining with X_2 and X_3 if $X_1 = 0$ and $X_4 = 0$

Successively changing the combination of factors, two-dimensional intersections of response surfaces are obtained with all possible combinations of factors.

So, when combining the factors of the rolling effort (X_1) and the radius of the roller profile (X_2) at X_3=0 (the initial surface roughness equals 0,30*мм*) и X_4 = 0 (the roller feed equals 0,07 *мм/об*) regression equations were obtained in the form:

$$CH = 18{,}93207 - 2{,}99185\,X_1 + 1{,}252594\,X_2 + ; \quad (14)$$
$$+ 0{,}558542\,X_{12} + 0{,}474089\,X_1^2 + 0{,}527422\,X_2^2$$

$$ШП = 0{,}165438 - 0{,}01254\,X_1 + 0{,}012037\,X_2 + . \quad (15)$$
$$+ 0{,}001188\,X_{12} + 0{,}00865\,X_1^2 + 0{,}00815\,X_2^2$$

The coordinates of the centers of the response surfaces are calculated:

For wear of a bronze sample X_1= 5,6023, X_2 = – 4,1539, α = – 42,2728°, Y_S= 7,9499;

For the surface roughness X_1= 0,7795, X_2= – 0,7953, α' = 33,5875°, Y_S= 0,15576.

Fig. 3 shows the graph constructed for equations (14) and (15).

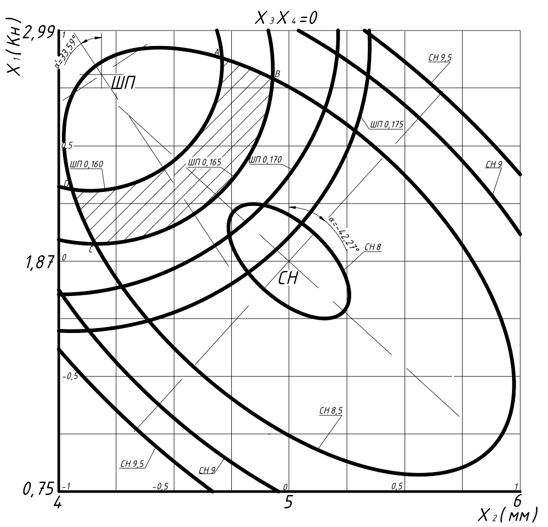

Fig. 3. The two-dimensional response surface section when combining factors when X_1 and X_2 if X_3=0 and X_4= 0

If we consider the constructed graphs, we can conclude that the zone of the optimal combination of factors is limited by the curves *CH* и *SR* at the points A, B, C, D. In these conditions the surface roughness is within 0,16 *mm*<*SR*<0,165 *mm*, the degree of work hardening makes 8,5%.

With these indicators of optimization criteria, the rolling efforts are within 2...2,4 *кН*, and the profile radius of the roller is 4,1...4,8 *mm*. At combining the factors, the initial surface roughness (X_3) and roller feed (X_4) at X_1 = 0 (rolling effort equals 1,87 *кН*) and X_2 = 0 (the radius of the roller profile equals 5 *mm*.) The regression equations were obtained:

$$CH = 18{,}93207 - 0{,}06056\,X_3 - 0{,}04519\,X_4 - ; \quad (16)$$
$$- 0{,}17104\,X_{34} + 1{,}555756\,X_3^2 - 1{,}07924\,X_4^2$$

$$ШП = 0{,}165438 + 0{,}002352X_3 - 0{,}00019X_4 - . \quad (17)$$
$$- 0{,}00027X_{34} - 0{,}01185X_3^2 - 0{,}01652X_4^2$$

The coordinates of the centers of the response surfaces were calculated:

For the degree of work hardening X_3 = 0,02, X_4 = - 0,022, α = 1,86 °, Y_S = 18,93;

For the surface roughness X_3 = 0,099, X_4 = - 0,0065, α'= 1,65 °, Y_S = 0,17.

Fig. 4 shows the graph constructed for equations (16) and (17).

If we consider the constructed graphs, we can conclude that the zone of the optimal combination of factors is limited by the curves *CH* and *SR* at the points A, B, C, D. In these conditions the surface roughness is within 0,14 *mm*<*SR*<0,13 *mm*, the degree of work hardening makes is within 21%<*SR*<20%.

With these indicators of optimization criteria, the initial surface roughness is within 0,37...0,40 mm, and the roller feed is 0,053...0,059 *mm/rot*.

When combining the forces of the rolling efforts (X_1) and the roller feed (X_4) at X_2 = 0 (the radius of the roller profile equals 5 *mm*.) и X_3 = 0 (initial surface roughness is 0,30 *mm*.).

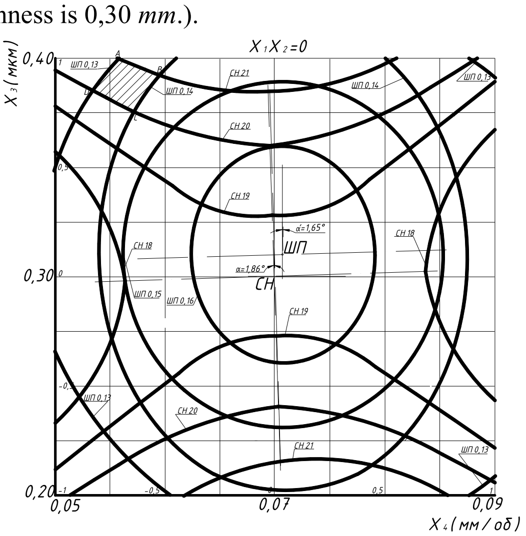

Fig. 4 Two-dimensional response surfaces crossing the combination X_3 and X_4 factors in the X_1= 0 and X_2 = 0

The regression equations were obtained:

$$CH = 18{,}93207 - 2{,}99185X_1 - 0{,}04519X_4 + \\ + 0{,}114792X_{14} + 0{,}474089X_1^2 - 1{,}07924X_4^2; \quad (18)$$

$$ШП = 0{,}165438 - 0{,}01254X_1 - 0{,}00019X_4 + \\ + 0{,}001646X_{14} + 0{,}00865X_1^2 - 0{,}01652X_4^2. \quad (19)$$

The coordinates of the centers of the response surfaces were calculated:

For the degree of work hardening X_1 = 3,14, X_4 = 0,15, α = 2,11°, Y_S = 14,23;

For the surface roughness X_1 = 0,72, X_4 = 0,030, α'= 1,87 °, Y_S = 0,16.

Fig. 5 shows the graph constructed for equations (18) and (19).

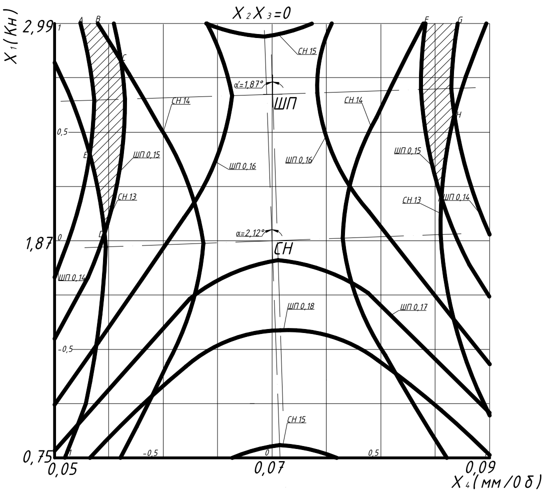

Fig. 5 Two-dimensional response surface section with a combination of factors X_1 and X_4 if X_2 = 0 and X_3= 0

When combining the factors of the rolling effort (X_2) anf the roller feed (X_4) at X_1 = 0 (the rolling effort equals 1,87 *кН*) and X_3 = 0 (initial surface roughness equals 0,30 *mm*.) The regression equations were obtained in such forms:

$$CH = 18{,}93207 + 1{,}252594X_2 - 0{,}04519X_4 + \\ + 0{,}135625X_{24} + 0{,}527422X_2^2 - 1{,}07924X_4^2; \quad (19)$$

$$ШП = 0{,}165438 + 0{,}012037X_2 - 0{,}00019X_4 + \\ 0{,}000354X_{24} + 0{,}00815X_2^2 - 0{,}01652X_4^2. \quad (20)$$

The coordinates of the centers of the response surfaces were calculated:

For the degree of work hardening X_2 = -1,18, X_4 = -0,095, α=2,41°, Y_S = 18,20;

For the surface roughness X_2 = - 0,74, X_4 = -0,0085, α'= 0,41°, Y_S = 0,16.

Fig.6 shows the graph constructed for equations (19) and (20).

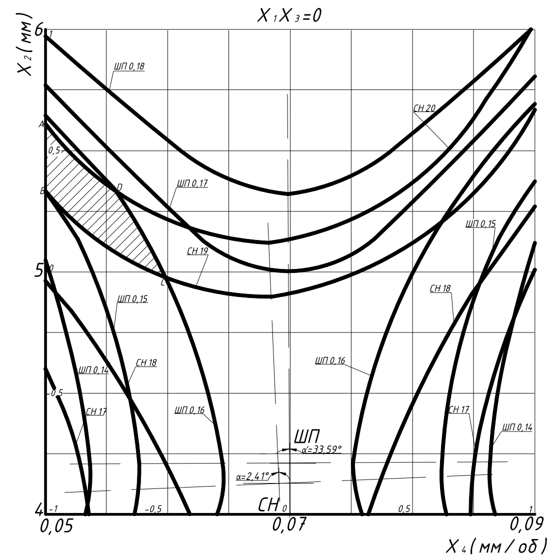

Fig. 6 Two-dimensional cross-section of response surfaces with a combination of factors X_2 and X_4 at the X_1= 0 and $X3$ = 0

If we consider the constructed graphs, we can conclude that the zone of optimal alignment of factors is limited by curves *CH* and *RS* at the points A, B, C, D. In these conditions the surface roughness is within 0,16 *mm*, and the degree of work hardening makes is within 19*%*<*CH*<20*%*.

With these parameters of optimization criteria, the radius of the profile of the roller fluctuates within 5,3...5,5 *mm*, and the roller feed will be equal 0,05...0,061 *mm/rot*.

When combining the factors of the rolling efforts (X_1) and initial surface roughness (X_3) at X_2 = 0 (the radius of the roller profile equals 5 *мм*.) and X_4 = 0 (the roller feed equals 0,07 *mm/rot*.) The regression equations were obtained in such forms:

$$CH = 18{,}93207 - 2{,}99185X_1 - 0{,}06056X_3 - \\ - 0{,}06812X_{13} + 0{,}474089X_1^2 + 1{,}555756X_3^2; \quad (21)$$

$$ШП = 0{,}165438 - 0{,}01254X_1 + 0{,}002352X_3 + \\ + 0{,}002646X_{13} + 0{,}00865X_1^2 - 0{,}01185X_3^2. \quad (22)$$

The coordinates of the centers of the response surfaces were calculated:

For the degree of work hardening X_1 = 3,16, X_3 = 0,089, α=1,80°, Y_S = 14,20;

For the surface roughness X_1 = 0,70, X_3=0,18, α'= 3,68°, Y_S = 0,16.

Fig. 6 shows the graph constructed for equations (21) and (22).

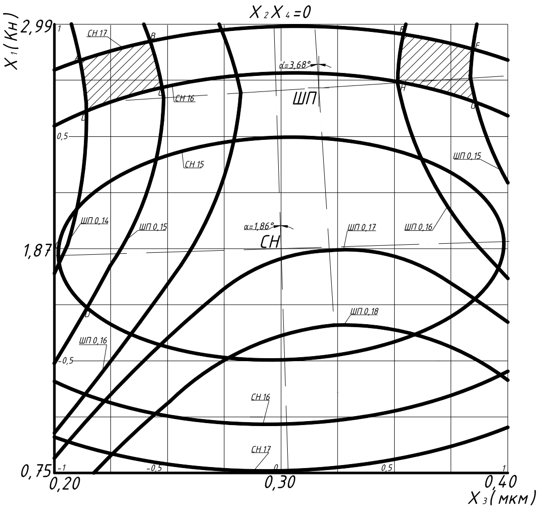

Fig. 7 Two-dimensional cross-section of response surfaces with a combination of factors$X_1$and X_3 with X_2 = 0 and X_4 = 0

If we consider the constructed graphs, we can conclude that the zone of optimal alignment of factors is limited by curves CH and RS at the points A, B, C, D and E, F, G, H. In these conditions the surface roughness is within0,15*mm*<*SR*<0,14*mm*, and thedegree of work hardeningmakes is within17%<*SR*<16%.

With these indicators of the optimization criteria, the rolling effort fluctuates within2,6...2,89 *кН*, and the initial roughness is 0,21...0,24 *mmи* 0,35...0,38 *mm*.

CONCLUSION

With the help of experiment planning during the optimization of the technological process of rolling of the bodies of rotationwith rolls with stabilization of the rolling efforts, the following optimum processing regimes were obtained: The optimal rolling effort at a clean mode is 0,75 *кН*, at a hardening mode is 3 *кН*, the radius of the roller profile is 6 *mm*, the roller feed is 0,07 *rot/min,* the initial surface roughness is 0,18...0,15*mm*.

BIBLIOGRAPHIC LIST

1. **Braslavskiy V.M. 1975.** Tehnologiyaobkatkikrupnyihdetaleyrolikami 2-e izd. M.: Mashinostroenie, 160.
2. **Butakov B.I. 1984.** Usovershenstvovanieprotsessachistovogoobkatyivaniyadetaleyrolikami. Vestnikmashinostroeniya. # 7. 50 – 53.
3. **BabeyYu.I., Butakov B.I., Syisoev V.G. 1995.** Poverhnostnoeuprochneniemetallov. K.: Naukovadumka, 256.
4. **Azarevich G.M., BershteynG.Sh. 1963.** Chistovayaobrabotkatsilindricheskihpoverhnosteyplasticheskimdeformirovaniem. M.: ONTI NII Traktorselhozmasha, 43.
5. **Braslavskiy V.M., Topyichkanov V.V. 1989.** Obkatkadetaleyrolikamikaksredstvopovyisheniyaiznosostoykosti. Pr-vokrupnyihmashin, NIITYaZhMAShUralmashztszodaVyip. XIX. 136 – 144.
6. **Braslavskiy V.M. 1975.** Tehnologiyaobkatkikrupnyihdetaleyrolikami. M.: Mashinostroenie, 160.
7. **Braslavskiy V.M., Butakov B.I., ShilkovYu.Ya. 1985.** Povyishenieiznosostoykostivintovyihparobkatyivaniem rolikamiTehnologiya, organizatsiya i mehanizatsiyamehanosborochnogoproizvodstva. M.: NIIformTYaZhMASh. 15 - 17.
8. **Butakov B.I. 1984.** Usovershenstvovanieprotsessachistovogoobkatyivaniya detaleyrolikamiVestn. mashinostroeniya. # 7. 50 - 53.
9. **Ivanov V.V. 1980.** Iznosostoykoststalnyihdetaley, uprochnennyihobkatkoyrolikom. Tr. TsNIITMASha, kn. 2.M. 67 - 75.
10. **Kascheev V.N. 1985.** Predvaritelnyiynaklep i abrazivnoerazrusheniemetallicheskoypoverhnosti. Selhozmashina. # 1. 20 - 26.
11. **Kragelskiy I.V., Dobyichin M.N., Kombalov V.S. 1985.** Osnovyiraschetovnatrenie i iznos. M.: Mashinostroenie, 526.
12. **Kudryavtsev I.V., Grudskaya R.E. 1984.** Novyiesposobyipoverhnostnogoplasticheskogodeformirovaniya. Mashinostroitel, # 7. 28 - 29.
13. **Markov A .I. 1980.** Ultrazvukovayaobrabotkamaterialov. M.: Mashinostroenie, 238.
14. **FridmanYa.B. 1987.** Mehanicheskiesvoystvametallov. M.: Oborongiz, 556.
15. **Odintsov L. G. 1981.** Finishnayaobrabotkadetaleyalmaznyimvyiglazhivaniem i vibrovyiglazhivaniem. M.: Mashinostroenie, 160.
16. **Papshev D.D. 1983.** Otdelochno-uprochnyayuschayaobrabotkapoverhnostnyimplasticheskimdeformirovaniem. M.: Mashinostroenie, 152.
17. **Ryizhov E.V., Suslov A.G., Fedorov V.P. 1979.** Tehnologicheskoeobespechenieekspluatatsionnyihsvoystvdetaleymashin. M.: Mashinostroenie, 176.
18. **Stepnov M.N. 1980.** Statisticheskayaobrabotkarezultatovmehanicheskihispyitaniy. M.: Mashinostroenie, 232.
19. **Hruschov M.M., Babichev M.A. 1984.** EksperimentalnyieosnovyiteoriiabrazivnogoiznashivaniyaVesti, mashinostroeniya. # 6. 56 - 62.
20. **Shkolnik L.M., Shahov V.I. 1964.** Tehnologiya i prisposobleniyadlyauprochneniya i otdelkidetaleynakatyivaniem. M.: Mashinostroenie. 184.
21. **Popov A. 2010.** Novaya teoriyakontaktnoyprochnostiuprugoszhatyihtel / Motrol, Motoryzacja I energetykarolnictwa. Lublin. Tom12A. 223 – 232.
22. **Holoptsev A. W. 2011.** Osobennostiprimeneniyamnozhestvenno-regresionnyihmodeleydinamikiaktivnosti Sr-90 v tashlyikskomvodohranilischnomvodoemeYuzhnoukrainskoy AES prieeprognozirovanii / Zhebet L.S. // Motrol, Motoryzacja I energetykarolnictwa. Lublin. Tom13. 137 – 149.
23. **Popov A. 2015**. Analizharakteristikkontaktapoverhnostey s pervonachalnyimlineynyim i tochechnyimkasaniem

/ Motrol, Motoryzacja I energetykarolnictwa. Lublin. VOL 17, No.2. 9 – 16.

24. **Aulin V. 2015.** issledovanieizmeneniyamoschnostidizelyaavtomobiley, rabotayuschih v nestatsionarnyihusloviyah / Motrol, Motoryzacja I energetykarolnictwa. Lublin. VOL 17, No.2. 103 – 108**.**
25. **Butakov B. 2013** Volnistostpoverhnostipriobkatyivaniitelvrascheniya rolikami / Motrol, Motoryzacja I energetykarolnictwa. Lublin. – Vol15, No2. 15 – 22.
26. **Butakov B. 2012** Issledovaniyatochnostivalovobkatannyihustroystvom so stabilizatsieyrabochegousiliyaobkatyivaniya / Motrol, Motoryzacja I energetykarolnictwa. Lublin. – Tom14A. 15 – 22.
27. **Butakov B.I., Artyuh V. A. 2013** Opredelenieoptimalnogousiliyaobkatyivaniyavalovrolikami. Sankt – Peterburg, Ch. 2. 58-64.
28. **Pastushenko S. I., Gorbenko O. A., Ogiyenko M.M.** Prognozuvannyatavy`probuvannyatexniky` i texnologijdlyasil`s`kogospodars`kogovy`robny`cztva :zb. nauk. pracz`UkrNDI. – Doslidny`cz`ke, 2008. – Vy`p. 11 (25). – S. 349–356.

OPTIMIZATION OF ROUGHNESS PARAMETERS AND THE DEGREE OF HARDNESS AFTER ROLLING WITH ROLLS WITH THE STABILIZATION OF WORKING EFFORT

Summary: Surface plastic deformation (SPD) by rolling with rolls or coining by strikers is used to harden the surface layer of metal parts of critical use. Finish SPD is applied to improve the presentation and to increase the wear resistance of the surface layer, and hardening is used to increase the wear resistance of parts.

Modern equipment for hardening surface layers which mostly defines the performance characteristics of the machine parts includes a number of methods: heat treatment, hardening with the HFP, laser processing, etc. Rolling with rolls is widely used for hardening the surface layers of the machine parts.

Spherical or toroidal rolls are mostly used in the technological process of rolling, and the surface becomes wavy with the step other than the feed rate, when the roll is pressed at a high angle.

A lot of researchers believe that the major reason for waviness appearing is the presence of runout roller resulting in a variable rolling feed rate. To avoid the appearing of waviness in finish rolling it is advisable to take the indentation angle valued 2 - 3^0, which limits the roughness of the rolled surface measured 40 $<R_z<$ 80 mcm, and to decrease the waviness it is advisable to use the rolls with a precise profile and to re-grind them as often as possible. At the reinforcement rolling the thin surface layer is whittled away and this decreases greatly the efficiency of the reinforcement.

The constituents of the effort P of the rolling of shafts made of steel 40 (200 HB) with a diameter of 100-200mm on a lathe with a toroidal roll using a device for stabilization of the working effort were measured withtheuniversalUDMdynamometer. Thewayofrollingthepartswithrollswiththestabilizationoftheworkingeffortallows to get a reinforced layer of various thickness with a fairly high and homogeneous hardness and increased wear resistance.

Key words: rolling, a roll, average angle of indentation, hardness, response surface, surface roughness.