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Technical and economic grounds for the process of manufacturing of screw working bodies of apparatus for preparation of fodder mixtures

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Abstract. A toolkit for the implementation of a new technological process for manufacturing a set of screw sections for the screw working body of the extruder has been developed and tested. The process of pulse amplification of operating device screw surface of extruder with deforming punches has been described. The regression equation of the cutting power of external radial grooves is obtained, depending on the change in the size of the feeder of the cutter, the cutting speed and the radius of the groove. The results of studies of strengthening the surfaces of screw working bodies with the obtaining of regression equations that can be used to determine the dependence of the hardnessthe impact strength on the punches, torque and the maximum power.

Keywords: auger with screw, punch, torque, power.

INTRODUCTION

The designs of screw working bodies of extruders are widely used in agricultural production in the production of fodder mixtures. However, in the process of prolonged operation of the extruder, the screw working surface of the working body of the extruder is subject to considerable load and intense deterioration. Therefore, auger working extruder bodies are much more in need of repair or replacement compared to other parts and mechanisms of extruders. Therefore, there is a significant need in the development of the process of manufacturing the screw working body of the extruder, which would provide significantly higher parameters that would enhance the reliability and durability of its screw working body.

Questions of the technological feasibility of screw constructions, the development and research of various methods of their manufacture were engaged by Hevko,. Pylypets (2002), Rohatynskyi (2014, 2017), Vasylkiv (2015), Drahan (2007), Diachun (2008) and many others (1998, 2000, 2006). However, a number of issues relating to the study of technology for manufacturing and strengthening their screw working surfaces in order to increase the durability of these parts need further study.

The purpose of the work is technical and economic grounds of the process of manufacturing screw working bodies of extruders for the production of fodder mixtures.

MATERIALS AND METHODS

For today, in agricultural production, in the manufacture of fodder mixtures, installations and lines that are widely used for mixing and feeding agricultural materials and extruders are widely used (Figure 1). The construction of the screw working element of the extruder (Figure 1) includes a shaft, on which the outer diameter is rigidly with the possibility of axial displacement, separate sections of screws are installed (Figure 2), in which the outer diameter is cut into 3 ... 4 turns of various steps. Moreover, screws are installed in the form of a continuous screw line. We will give a brief description of the design of the screw working element of the extruder: the total length of the shaft L = 160 mm; working length l = 80 mm; external diameter of screw D = 60 mm; inner diameter of the screw d = 50 mm; step p variable (from 5 to 20 mm); shear thickness h of 3 to 5 mm; screw material - Steel 45.

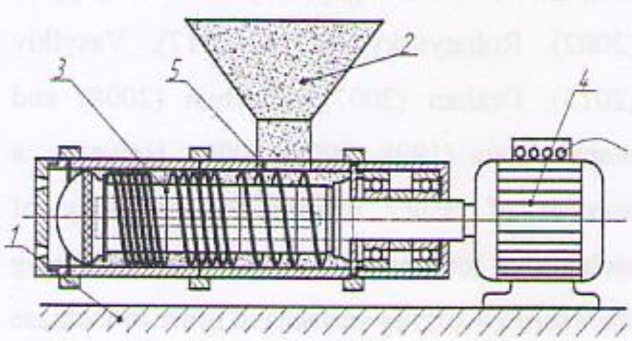


Figure 1. Constructive scheme of the extruder: 1 – table; 2 – bunker; 3, 5 – sections of screw extruder; 4 – engine

Figure. 2. Separate sections of screw extruder

In the process of operation, the screw working surface of the extruder is subject to considerable load and intense deterioration. Therefore, it was necessary to develop the technological process of manufacturing the screw working body of the extruder, which would provide increased reliability and durability of the screw working body. For this purpose, a more efficient technological process was developed and tested.

The developed technological process involves cutting the groove using a special device (Figure 3), which ensures that the groove is sliced simultaneously with many cutters (8) instead of one. This ensures a significant saving of time and electricity during cutting (8 times), improving the quality of the process by reducing the value of the work piece deformation and the higher rigidity of the tool-manufacturing system, as well as the partial compensation of the cutting forces of the oppositely arranged cutters.

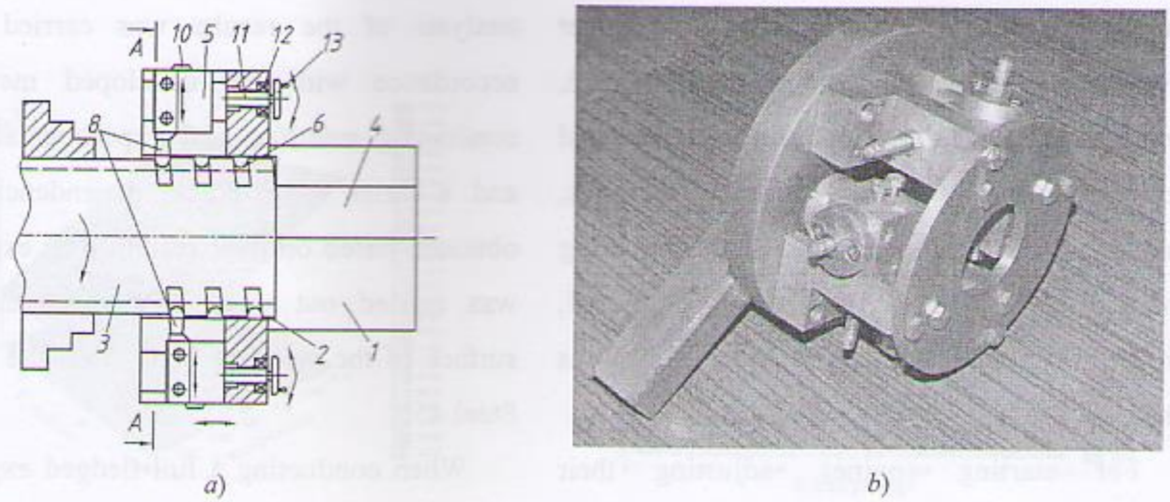


Figure 3. The device for cutting the screw groove of the working body of the extruder: *a*) a structural scheme for cutting grooves; 1 – clamping chuck; 2, 3 – workpiece; 3, 1 – rest of the machine; 4 – holder of the device; 5 – cutting tools; 6, 8 – cutters; 7, 6 – screw groove workpieces; *b*) general view

Also, the developed technological process instead of the quenching operation includes a reinforcement operation, which is executed by a specially designed lining tool to strengthen the working screw surface of the screw extruder (1991, 2004, 2009, 2010, 2011, 2016) (Figure 4).

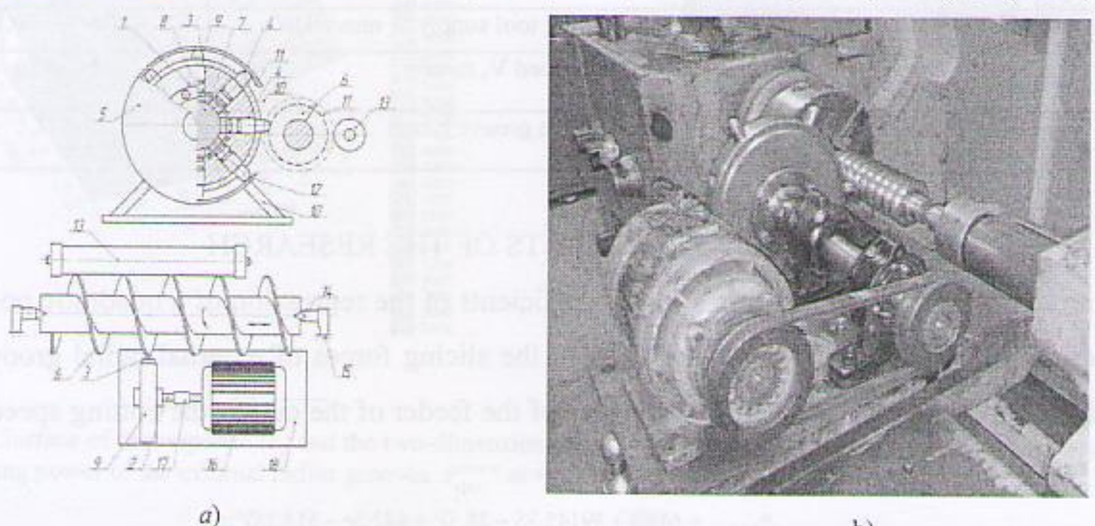


Figure 4. The process of strengthening the surface of the screw working body using a lining tool: a) a design diagram; b) general view; 1 18 – a table of a circular tool; 2 16 – electric motor; 3 0 – clamping chuck; 4 15 – the center of the tailstock; 5 6 – screw surface of the working body; 6 5 9 – lining tool; 7 4 - deforming punches

Strengthening the screw surface of the working body involves fixing it in the chuck and the center of the tailstock lathe. The table of a lining tool is fixed in the tool rest of this machine. The deforming punches of the lining tool are spring-loaded with the springs of compression, and in the middle of the grooves of deforming punches, the lubricant under pressure is put. A disk with deforming punches rotates at a speed of 1000 and more rpm, which ensures the strengthening of the screw surface of the working body throughout its length. The duration of the hardening time is from 20 to 80 s per screw, depending on the number of strikes during that time. Effective duration (at a higher frequency of striking loads) is 20 s per turn, which is calculated in terms of one conditioned screw section of the extruder for 80 seconds, and the entire set of screws for one working extruder body is 320 s. To drive the lining tool, an electric motor with a power of 0.9 kW is used.

For starting engines, adjusting their rotational speed, and removing experimental data during experiments, a frequency converter that was driven from a personal computer using the PowerSuite v.2.5.0 software was used. The analysis of the results was carried out in accordance with the developed method of conducting multifactorial experimental studies and a series of graphical dependencies were obtained based on their results. The experiment was carried out when processing the screw surface of the working body from the material Steel 45.

When conducting a full-fledged experiment PFE 3^3 with the cutting of the screw groove, the change in the cutting effort was made from the size of the feeder of the cutter, the cutting speed and the groove radius (Table 1).

Table 1. Characteristics of factors and the values of their levels

Coded designation factor	Name of the factor	The value of factor levels
x_1	The size of the cutting tool supply S, mm/aisle	0,04-0,07-0,1
x_2	Cutting speed V, m/min	10-20-30
x_3	Radius of the groove r, mm	3-5-7

THE MAIN RESULTS OF THE RESEARCH

As a result of the experiment, unknown coefficients of the regression of a quadratic polynomial were determined and the regression equation of the slicing forces of external radial grooves were determined depending on the change in the size of the feeder of the cutter, the cutting speed and the groove radius:

$$P_{z(S,V,r)} = 616{,}8 + 39145{,}3S - 28{,}5V + 442{,}5r - 513{,}3SV + \\ + 8633{,}3Sr - 5{,}74Vr - 69133{,}3S^2 + 1{,}28V^2 - 23{,}6r^2. \quad (1)$$

The analysis of the regression equation (1) showed that the main factors that influence the increase of the power of cutting external radial grooves are: factors x_1, x_3, $(S,\ r)$, and combinations of these factors. The factor x_3 (V) leads to a decrease in the power of cutting grooves. In general, to reduce the force of cutting external screw grooves, it is necessary to reduce the feed of the cutter to the passage and the radius of the groove, as well as to increase the cutting speed.

According to the obtained regression equations, the surface of the response and their two-dimensional cross section of the power of cutting external radial grooves from the change of two factors for $x_3 = const$ (Figure 5 - Figure 7) are constructed.

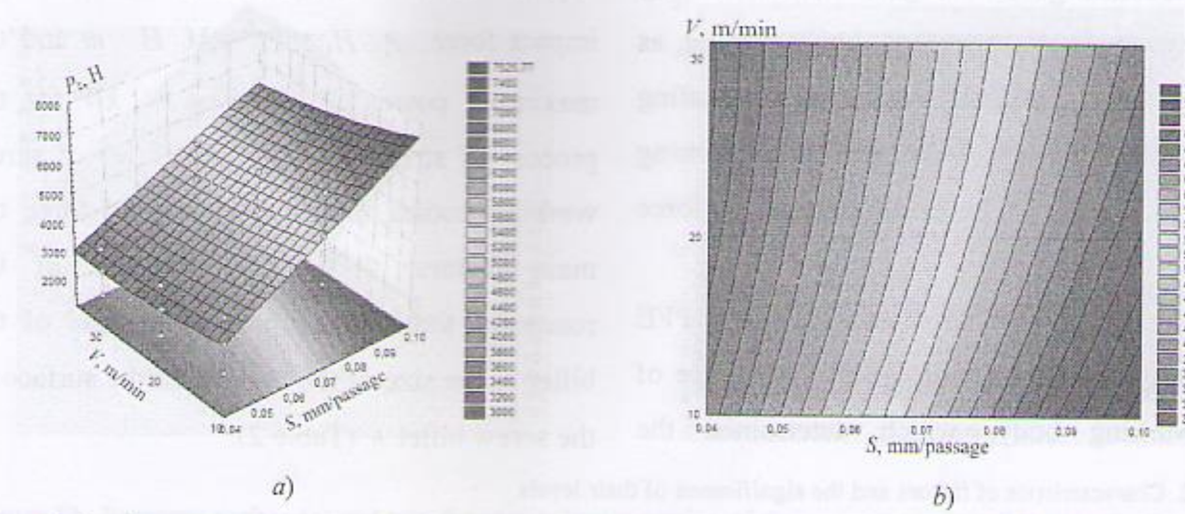


Figure 5. Surface response (a) and two-dimensional cross-section of the response surface (b) the dependence of the cutting force of the external radius grooves $P_{z(S,V)}^{Rz\,ar45}$ at = r = 5 mm

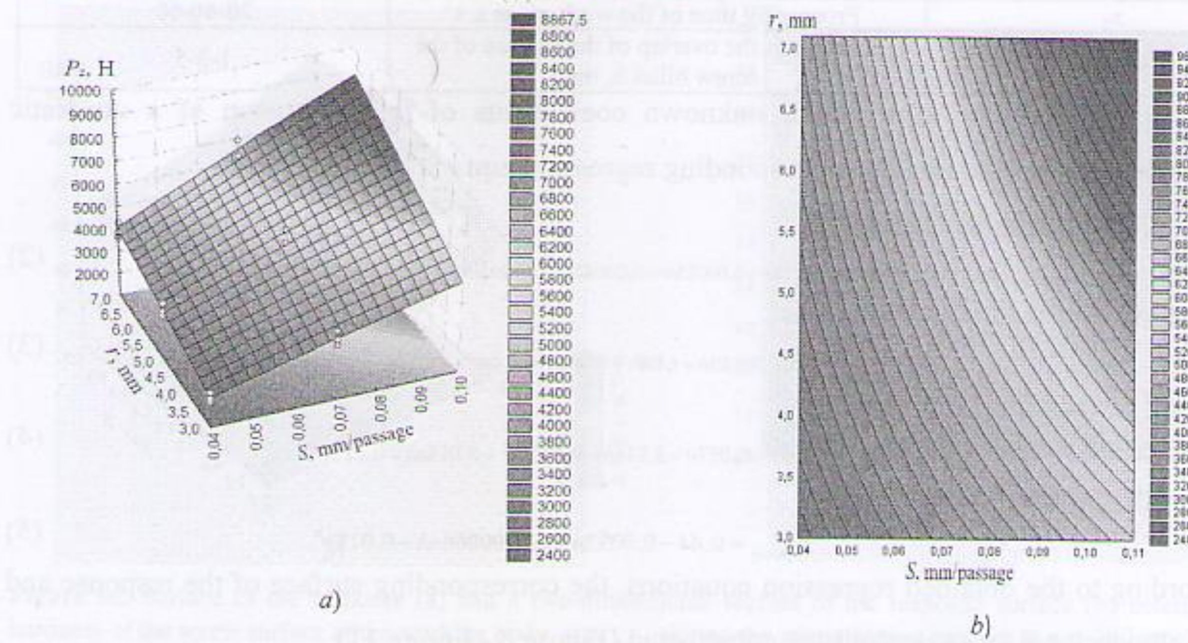


Figure 6. Surface of the response (a) and the two-dimensional cross section of the response surface (b) the dependence of the cutting power of the external radius grooves $P_{z(S,r)}^{Rz\,ar45}$ at = V = 20 m / min.

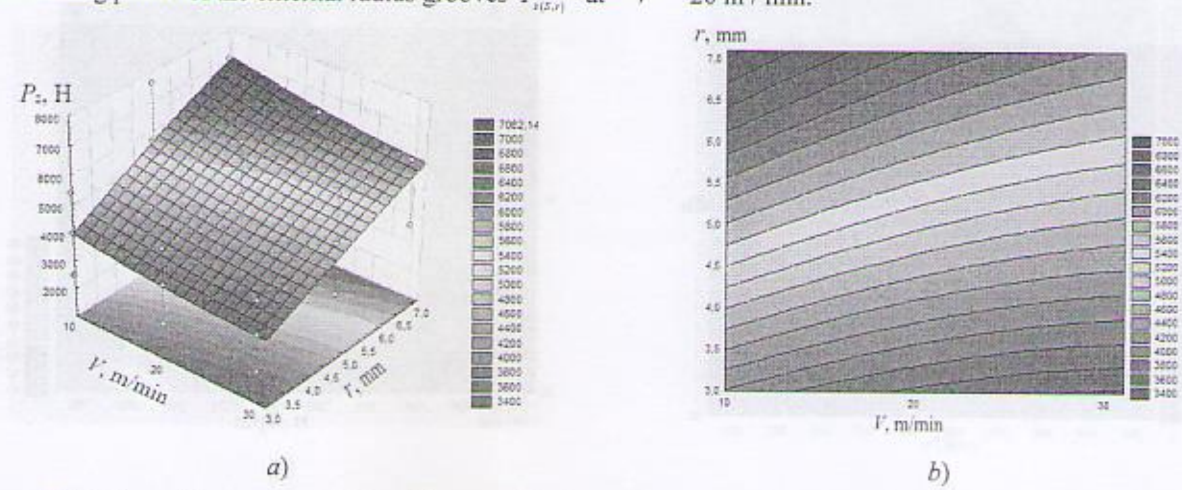


Figure 7. Surface of the response (a) and the two-dimensional cross-section of the response surface (b) dependence of the power of the external radial grooves $P_{z(V,r)}^{Rz\,ar45}$ at S= 0.07 mm/passage

From Figure 5 - Figure 7 it can be seen that with the increase in feed during cutting, as well as the radius of the groove, the cutting effort increases, and with increasing cutting speed it decreases. The maximum cutting force is 8867 N.

Also, a full-featured experiment of PFE 3^3 was made to strengthen the screw surface of the working body, which determined the dependence of the hardness of the HRC, the impact force, P_*, H, torque M, $H \cdot m$ and the maximum power consumption N, kW for the process of strengthening the surfaces of screw working bodies from the change of three the main factors: the rotational speed of the rotational tool n, the processing time of the billet t, the size of the overlap of the surface of the screw billet h (Table 2).

Table 2. Characteristics of factors and the significance of their levels

Coded desig nation factor	Name of the factor	The value of factor levels
x_1	Rotational speed of lining tool n, rpm	190-290-390
x_2	Processing time of the work piece t, s	20-40-60
x_3	The value of the overlap of the surface of the screw billet h, mm	1-3-5

As a result of the experiment, unknown coefficients of the regression of a quadratic polynomial are determined and the corresponding regression equations are derived:

– HRC hardness determination:

$$HRC_{(n,t,h)} = 33,28 + 0,24n - 0,17t + 2,12h + 0,00025nt - 0,00042nh + 0,0042th + 0,0000055n^2 + 0,0018t^2 - 0,24h^2 \quad (2)$$

– to determine the force of impact:

$$P_{*(n,t,h)} = -1256,1 + 48,02t + 580,03h + 1,63th + 0,004n^2 - 0,44t^2 - 71,44h^2 \quad (3)$$

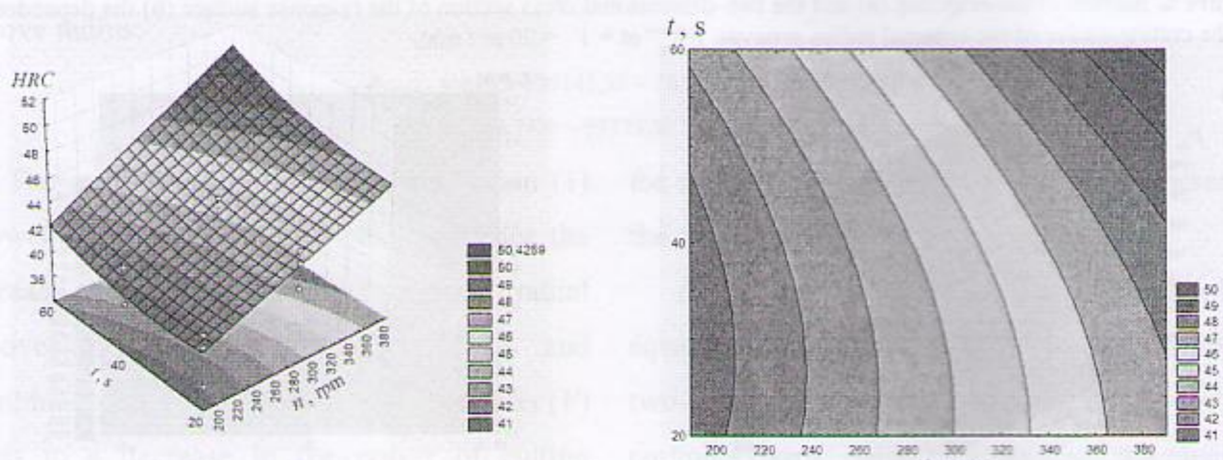
– for determining the torque:

$$M_{(n,t,h)} = 12,57 - 0,057n - 3,334h + 0,0001n^2 + 0,015nh + 0,211h^2 \quad (4)$$

– with maximum power output:

$$N_{(n,t,h)} = 0,44 - 0,0033n + 0,0000066nh - 0,018h^2 \quad (5)$$

According to the obtained regression equations, the corresponding surface of the response and their two-dimensional cross sections are constructed (Figure 8 - Figure 11).



a) b)

Figure 8a. Surface of the response (a) and a two-dimensional cross-section of the response surface (b) determination of the hardness of the screw surface of the working body $HRC_{(n,t)}$ during the strengthening process at $h = 3mm$

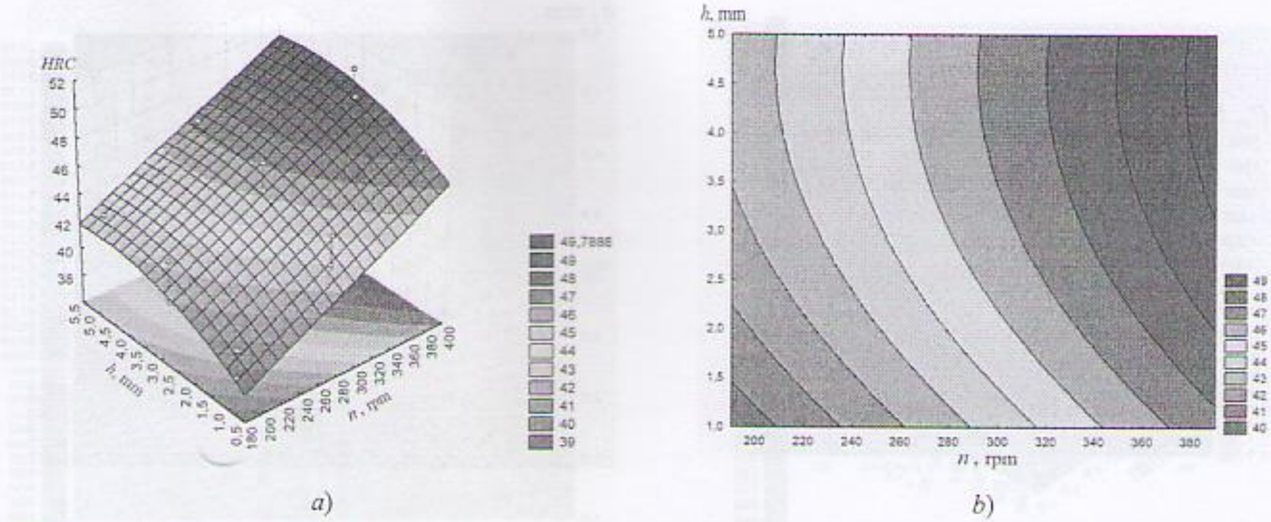


Figure 8b. Response surface (a) and two-dimensional cross-section of the response surface (b) determination of the hardness of the screw surface of the working body $HRC_{(n,h)}$ during the strengthening process at *t = 40c*

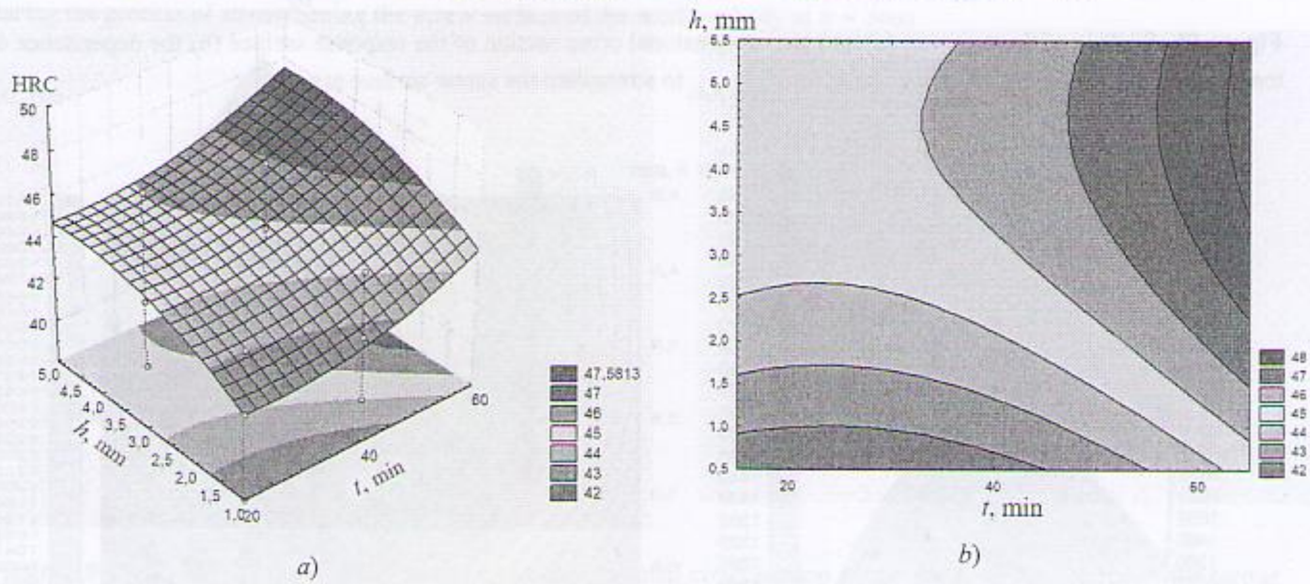


Figure 8c. Surface of the response (a) and a two-dimensional section of the response surface (b) determining the hardness of the screw surface of the working body $HRC_{(t,h)}$ during the strengthening process at *n = 290 rpm.*

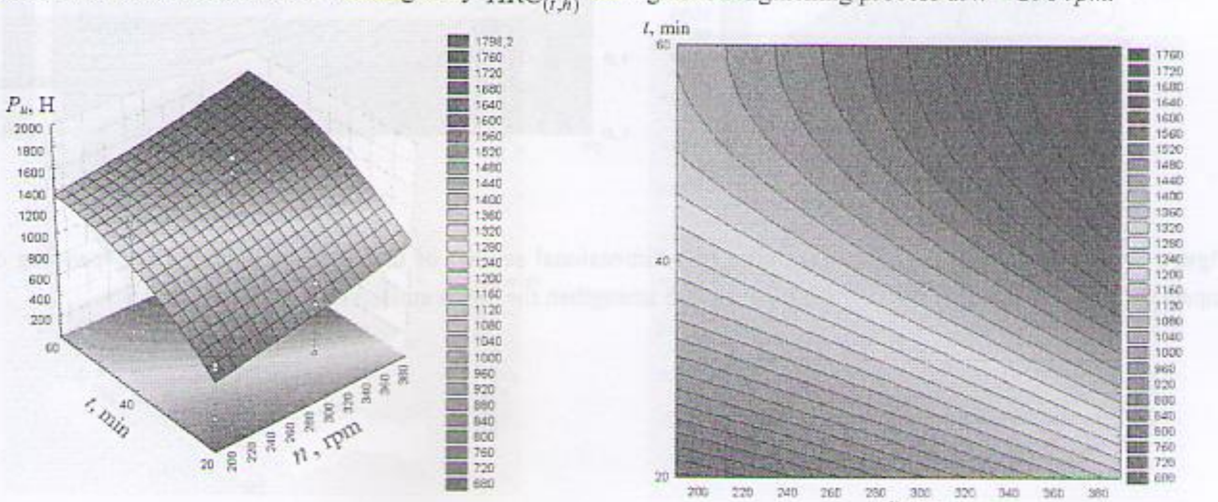


Figure 9a. Surface of the response (a) and two-dimensional section of the response surface (b) depending on the force of impact of the stroke of the lining tool $P_{u(n,t)}$ to strengthen the screw surface at *h = 3 mm*

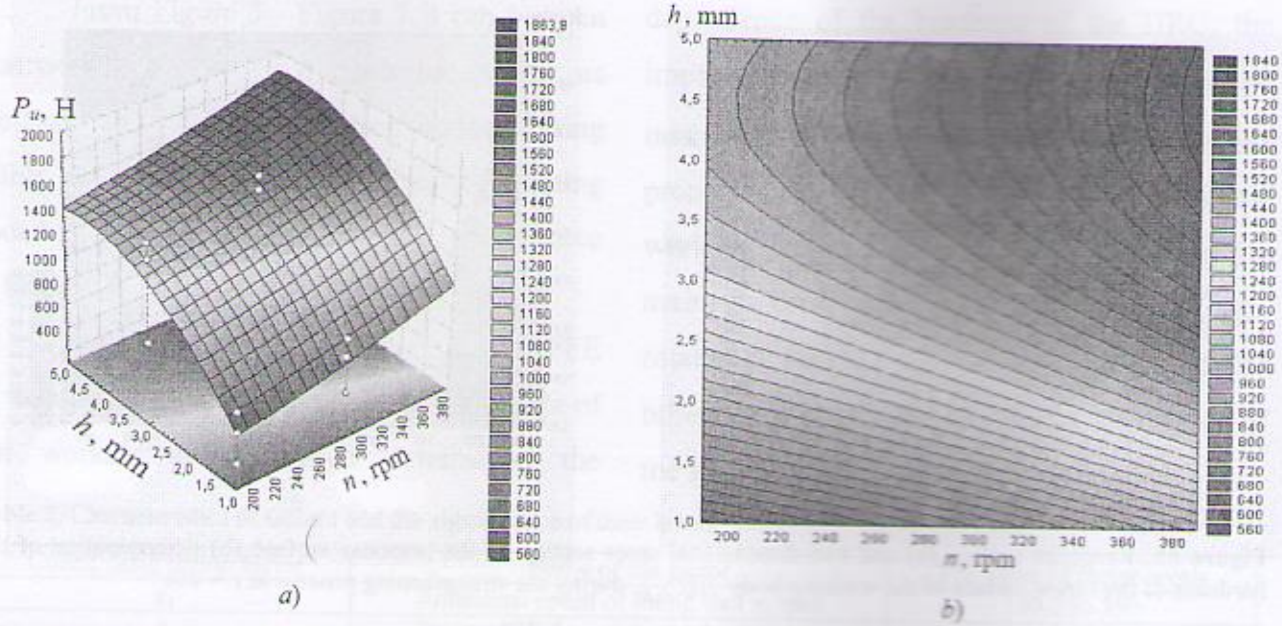


Figure 9b. Surface of the response (a) and two-dimensional cross section of the response surface (b) the dependence of the impact force of the stroke of the lining tool $P_{u(n,h)}$ to strengthen the screw surface at $t = 40\ s$

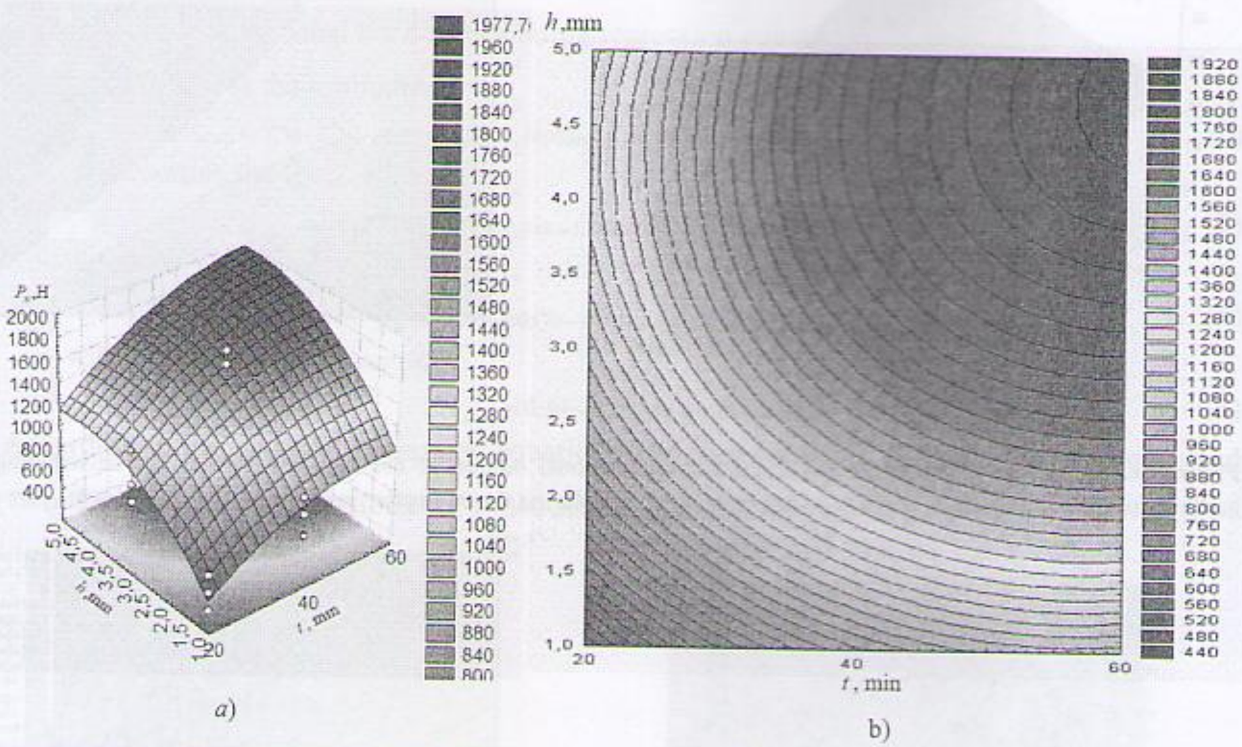
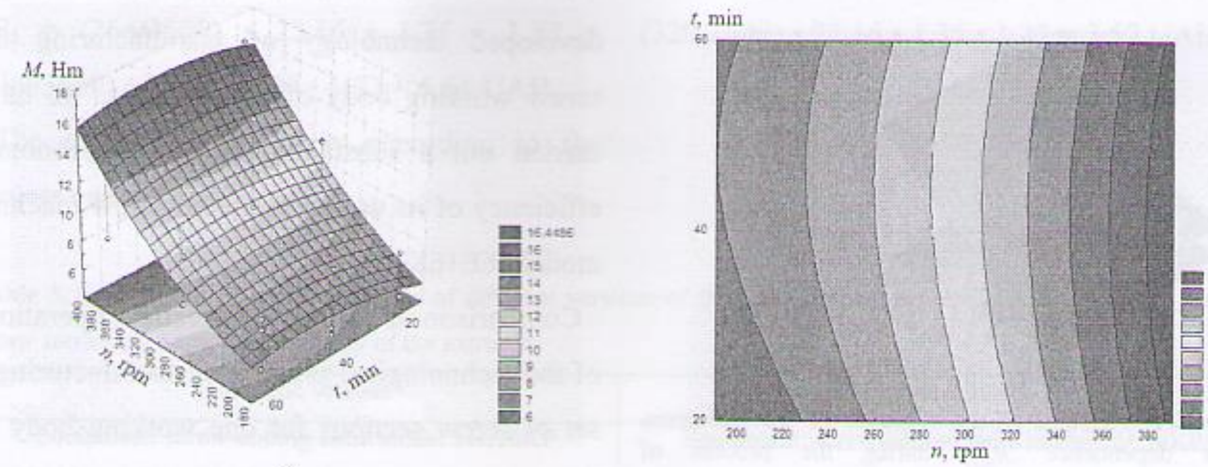
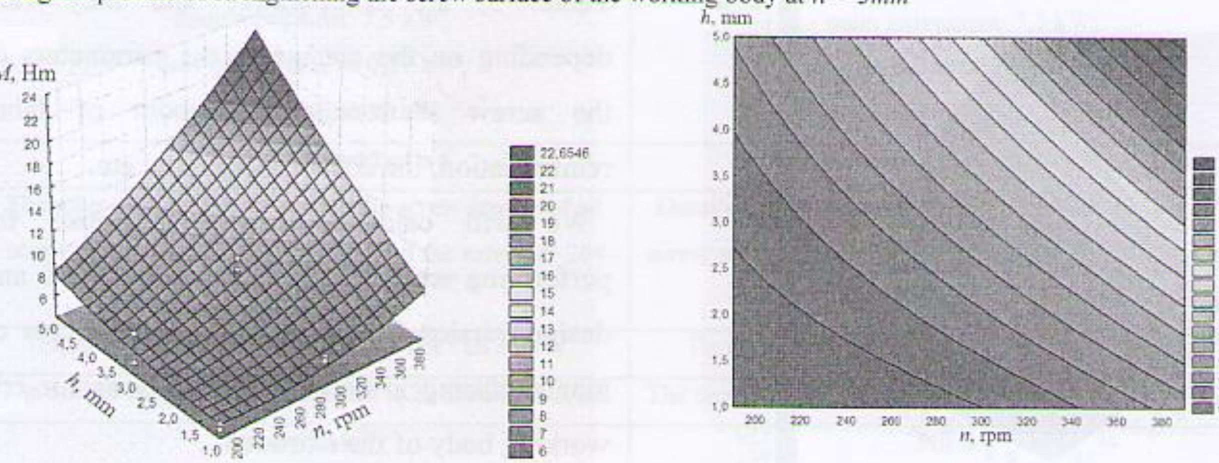


Figure 9c. Surface of the response (a) and a two-dimensional section of the response surface (b) depending on the impact force of the bump of the lining tool $P_{u(n,h)}$ to strengthen the screw surface at $n = 290\ rpm$.



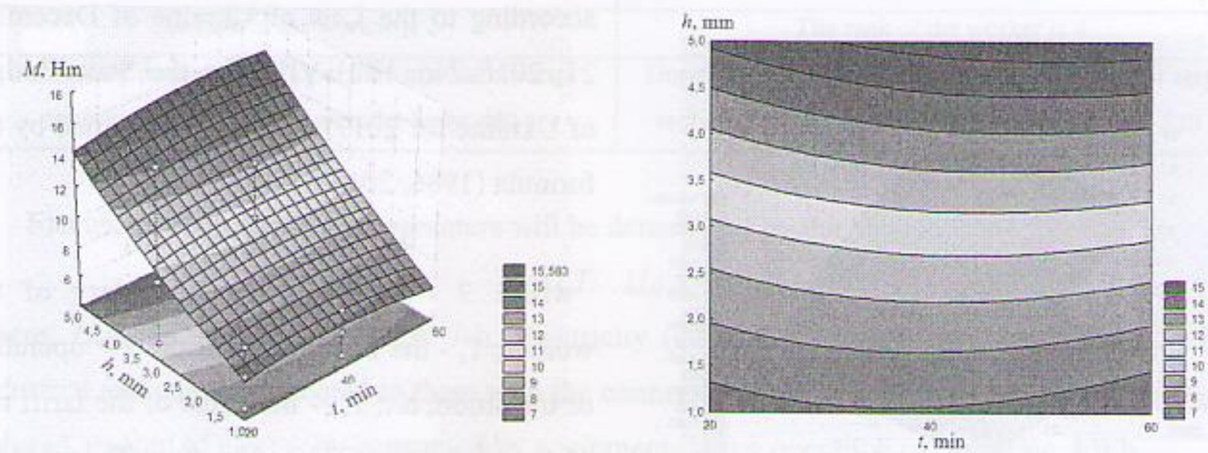
a) b)

Figure 10a. Surface of response (a) and two-dimensional section of the response surface (b) of torque $M_{(n,t)}$ depending during the process of strengthening the screw surface of the working body at $h = 3mm$



a) b)

Figure 10b. Surface of the response (a) and a two-dimensional cross section of the response surface (b) of the torque $M_{(n,h)}$ depending during the process of strengthening the screw surface of the working body at $t = 40c$



a) b)

Figure 10c. Surface of response (a) and two-dimensional section of the response surface (b) of the torque $M_{(t,h)}$ depending during the process of strengthening the screw surface of the working body at $n = 290$ *rpm.*

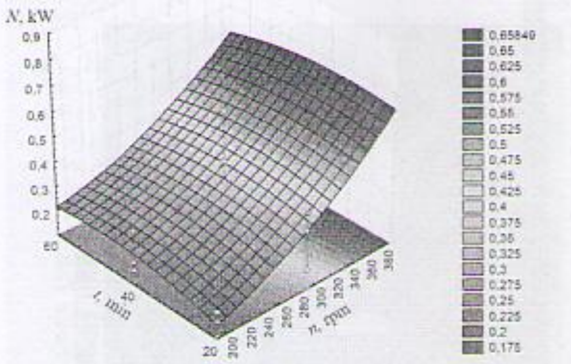


Figure 11a. Surface of the response of the maximum power dependence $N_{(n,t)}$ during the process of strengthening the screw surface of the working body at *h = 3 mm*

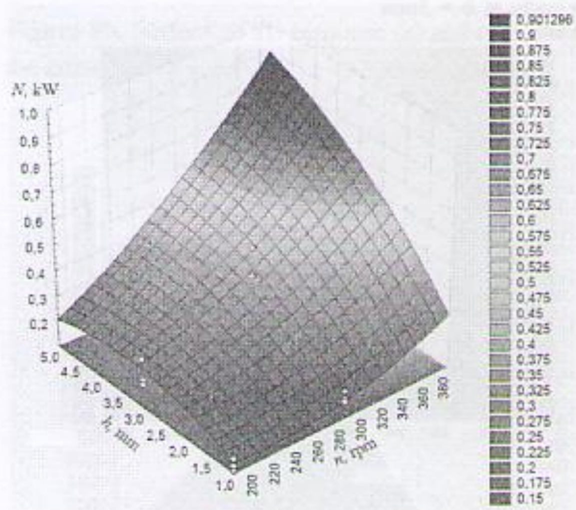


Figure 11b. Surface of the response of the maximum power dependence $N_{(n,h)}$ during the process of strengthening the screw surface of the working body at *t = 40 c*

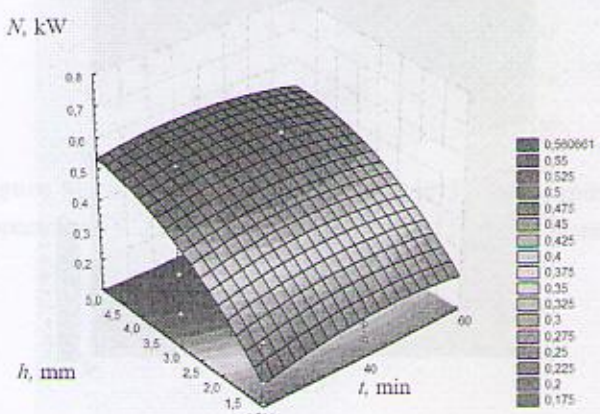


Figure 11c. Surface of the response of maximum power $N_{(t,h)}$ during the process of strengthening the screw surface of the working body at *n = 290 rpm.*

In order to confirm the effectiveness of the developed technology of manufacturing the screw working body of the extruder, we have carried out a substantiation of the economic efficiency of its use on the lathe-screw machine model 16E16KP.

Comparison of variants of excellent operations of the technological process of manufacturing a set of screw sections for one working body of the extruder according to certain criteria is presented in the Table. 3. The data presented in Table. 3, are comparative and may vary depending on the change in the parameters of the screw sections, the amount of labor remuneration, the cost of electricity, etc.

We will calculate certain expenses for performing separate operations in the basic and design version of the technological process of manufacturing a set of screw sections for one working body of the extruder.

The cost of wages of the worker engaged in the implementation of operations, taking into account the single social contribution (0,22 according to the Law of Ukraine of December 21, 2016, No. 1801-VIII "On the State Budget of Ukraine for 2017") will be determined by the formula (1986, 2015):

$$3 = \Sigma T_i \cdot T_{cl} \cdot K_i \cdot K_н,$$

where *3* - expenses for the salary of the worker; T_i - the complexity of the 1st operation or transition, h .; T_{cl} - the value of the tariff rate of the 1st level (3723 / (21 • 8) = 22.16 UAH / hour); K_i - tariff rate of the 1st category; $K_н$ - coefficient, taking into account the single social contribution (1.22).

The cost of wages in the basic version will be: $З_b$ = (264/3600) • 22.16 • 1.35 • 1.22 + (480/3600) • 22.16 • 1.09 • 1.22 = 6.61 UAH.

The cost of basic salary according to the project variant will be:

$З_n$ = (33/3600) • 22.16 • 1.35 • 1.22 + (320/3600) • 22.16 • 1.35 • 1.22 = 3.57 UAH.

Table 3. Comparison of separate criteria of different versions of the technological process of manufacturing a set of screw sections for one working body of the extruder

The basic version	Project version
Equipment: screw-cutting lathe model 16E16KP	Equipment: screw-cutting lathe model 16E16KP
The cost of second hand equipment is 82 thousand UAH.	The cost of second hand equipment is 82 thousand UAH.
Power: -main movement: 7,5 kW; -flow of movement: 0,37 kW; - cooling pump: 0,12 kW.	Power: - main movement: 7,5 kW; - flow of movement: 0,37 kW; - cooling pump: 0,12 kW.
The rank of the worker is 4	The rank of the worker is 4
Duration of operation of cutting the screw groove of all screw sections of the working body of the extruder: 264 s.	Duration of operation of cutting the screw groove of all screw sections of the working body of the extruder: 33 s.
Equipment: thermo oven CHO 6x4x4 \ 10 35 kW.	Equipment: screw-cutting lathe model 16E16KP.
The cost of second hand equipment is 20 thousand UAH.	The cost of second hand equipment is 83 thousand UAH.
Power: 35 kW.	Power: - main movement: 7,5 kW; - flow of movement: 0,37 kW; - cooling pump: 0,12 kW; - movement of the rolling tool: 0.9 kW.
The rank of the worker is 2	The rank of the worker is 4
Duration of the quenching operation of a set of screw sections for one working extruder body: 480 s.	Duration of operation of strengthening the set of screw sections for one working body of the extruder: 320 s.

Electricity costs for these parameters will be determined by the formula (1986, 2015):

$$E = \Sigma T_i \cdot Ц_{el.en} \cdot B_{kW\,h},$$

where: $Ц_{el.en}$ is the price of 1 kW / h. Electricity (Class II - 1.96 UAH from 12.01. 2017 for industrial and consumers equal to them with the connected capacity of 750 kVA and more); $B_{kW\,h}$ - reduced amount of electricity consumed by equipment during operation or transition, kWh.

Electricity costs in the basic version will be:

E_b = (264/3600) · 1,96 · (7,5+0,37+0,12) + (480/3600) · 1,96 · 35 = 10,64 UAH.

The cost of electricity in the project version will be:

E_n = (33/3600) · 1,96 · (7,5+0,37+0,12) + (320/3600) · 1,96 · (7,5+0,37+0,12+0,9) = 1,69 UAH.

The cost of depreciation of equipment (when used in one shift), when processing the unit of production, we determine from the dependence (1986, 2015):

$$A = B_o \cdot K_a \cdot \Sigma T_i / T_d,$$

where: B_o – the cost of equipment used in the process, UAH; K_a - depreciation coefficient, 0,2; T_d – actual equipment running time during the year, 2070 hours.

The cost of depreciation of equipment (when used in one shift), in the basic version will be:

$$A_b = ((264/3600) / 2070) \cdot 82000 \cdot 0{,}2 + ((480/3600) / 2070) \cdot 20000 \cdot 0{,}2 = 0{,}84 \text{ UAH}.$$

The cost of depreciation of equipment (when used in one shift), according to the project version, will be:

$$A_n = (((33 + 320) / 3600) / 2070) \cdot 82000 \cdot 0{,}2 = 0{,}78 \text{ UAH}.$$

Having made the appropriate calculations for the elements of individual expenses for the implementation of the basic and design versions of the technological process of manufacturing a set of screw sections for one working body of the extruder, their results are reflected in Table 4.

Table 4. Calculation of the elements of individual expenses for the implementation of the technological process of manufacturing a set of screw sections for one working body of the extruder

Elements of cost	Basic version	Project version
Salary costs	6,61	3,57
Electricity costs	10,64	1,69
Costs of depreciation of equipment	0,84	0,78
Total cost	18,09	6,04

Annual economic effect when replacing the basic version of the technological process of manufacturing a set of screw sections for one working body of the extruder for the project:

$$E_p = (3600 \cdot 2070 / (264 + 480)) \cdot (18{,}09 - 6{,}04) = 120694{,}37 \text{ UAH}.$$

CONCLUSIONS

1. A new, more effective compared to the basic technological process of manufacturing a set of screw sections for the screw working body of the extruder has been developed.
2. A methodology was developed and a full-featured experiment of PFE type 3^3 with the cutting of the groove was performed to determine the change in the cutting effort from the size of the feeder of the cutter, the cutting speed and the radius of the groove. Also, a methodology was developed and a full-featured experiment PFE 3^3 was performed to strengthen the screw surface of the working body, which determined the dependence of the hardness of the HRC, the impact force, H, torque M, $H \cdot m$, and the maximum power consumption N, kW for the process of strengthening the surfaces of screw working bodies from the change of

three main factors: the rotational speed of the lining tool n, the processing time of the work piece t, the magnitude of the overlap of the surface of the screw billet h.

3. The regression equation of the cutting power of external radial grooves is obtained, depending on the change in the size of the feeder of the cutter, the cutting speed and the radius of the groove. It has been established that with the increase in feed during cutting, as well as the radius of the groove, the cutting effort increases, and with increasing cutting speed decreases. The maximum cutting force of 8867 N during simultaneous cutting of grooves with cutters is achieved with a maximum feed of 0.1 mm / passage, a radius of 7 mm grooves and a minimum cutting speed of 10 m / min.
4. The results of studies of strengthening the surfaces of screw working bodies with the obtaining of regression equations that can be used to determine the dependence of the hardness of the HRC of the treated surface, the impact strength of P_u, H on the punches, torque M, H · m and the maximum power N, kW on the device are presented for the shock strengthening in the process of working surfaces of screw working bodies from the change of three main factors: the speed of rotation of the lining tool, the processing time of the billet and the size of the surface of the screw billet for steel material 45.
5. Costs for the implementation of a new technological process of manufacturing a set of screw sections for one working body of the extruder will be 3 times smaller, compared with the basic technological process. Annual economic effect when replacing the basic variant of the technological process of manufacturing a set of screw sections for one working body of the extruder on the design will amount to 120694.37 UAH.

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