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ROLLING OF ROTATIONALLY SHAPED SURFACES WITH TANGENTIAL FEEDING OF BLANKS. KINEMATICS AND OUTPUT – PART 1

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ABSTRACT

In this paper the diameters of the rollers that provide reliable rolling of rotationally shaped surfaces with tangential feeding of blanks are determined. The equations for determining the current values of the outer and centroid diameters of rolled rotationally shaped surfaces have been worked out. A method for determining the current values of the speed of shifting of the processed blank and the output of rolling of rotational-shaped surfaces with tangential feeding have been worked out too. It is determined that the alteration of those diameters depending on the radial insertion of the device is done according to a cubic formula. Also it is determined that the speed of shifting and the output depend mostly on the value of the diameter of the driving roller and on the correlation between the diameters of the driven and driving rollers.

1. INTRODUCTION

To realize different non-collapsible wooden element joints, special construction nails are used (fig.1), providing high strength indexes of joining.

Fig.1. Types of special construction nails.

The moulding of profile surfaces of such items is realized through drawing a blank with a specified diameter on special machines, moulding of the head, whetting and rolling on rolling machines, using most frequently tools with flat dies or a roller and sectors (fig.2).

This technology for moulding of profile surfaces provides high accuracy of profile parameters; high output – up to 600 nails rolled with flat chasers and up to 2000 –with roller-sector and high durability- up to 1,2 – 1,4 mln items rolled with one tool set.

With both technologies the resource of moulding tools depends on the durability of tool equipment, since its restoration is limited.

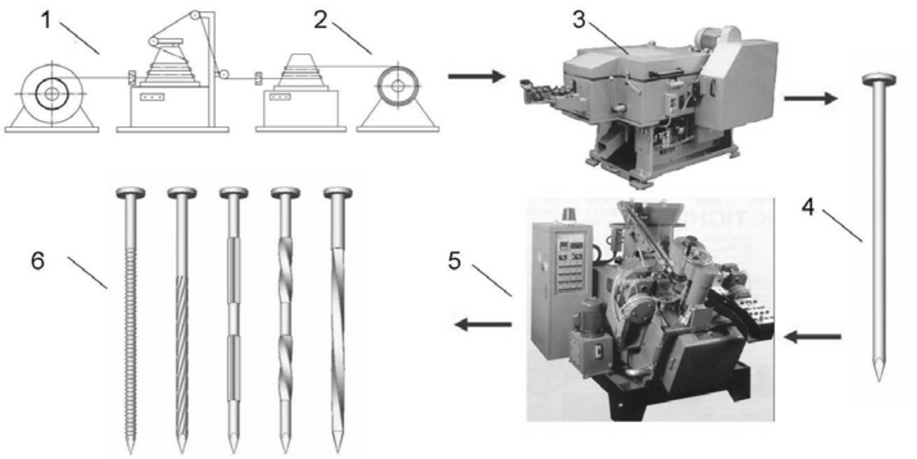

Fig.2. Diagram of the production of profile nails [9].

1 – unwinding device; 2 – drawer; 3 – automatic press Wafios; 4 – smooth nail; 5 – rolling machine sector - roller; 6 – nails with various profile surfaces.

The analysis on the methods of rolling of parts with different helical profile surfaces has shown that the method of rolling with two rollers and a tangential feeding of the blank gives high output too (fig.3). Designed for rolling of small diameter threads [4, 6] and small diameter and module gears [2, 3, 5], this method can be applied for rolling of rotationally shaped surfaces of nails, since the tool equipment used – two rollers – has a construction allowing restoration after wear. This rolling method is not known to have been applied for moulding of rotational profile nail surfaces. No research has been done on the rolling of such surfaces, and there is no data on the conditions required for reliable rolling, nor on the output of this process or its power characteristics.

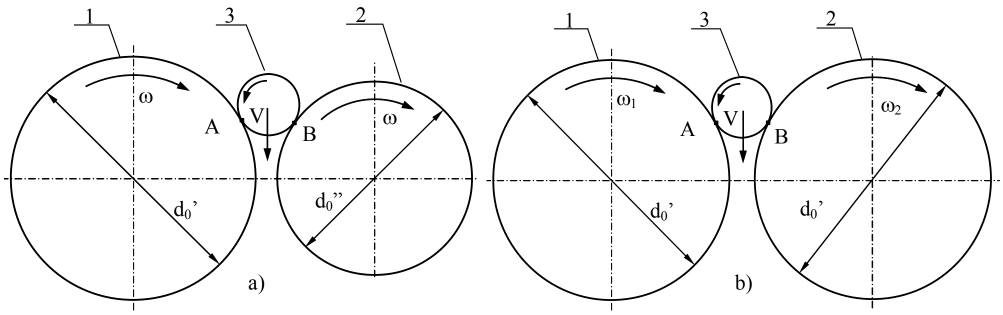

Fig.3. Diagrams of rolling with tangential feeding of the blank realized through rollers with different (a) and equal (b) diameters.

Stated below you will find the major results from the theoretical and experimental research held in the tool-making laboratory of Rousse University. These results provide conditions for design of highly productive and effective machines for rolling of rotational profile nail surfaces.

2. SCHEME OF ROLLING AND CONDITIONS FOR THE REALISATION OF THE PROCESS

The scheme for rolling through tangential feeding are two (fig.3) [1].
On the first scheme (fig.3a) the rollers 1 and 2 have different diameters ($d_0^{'}>d_0^{''}$) and rotate with equal angular speeds ω in the same direction. On the second scheme the rollers have equal diameters d_0 (fig.3b), but they rotate with different angular speeds ($\omega_1>\omega_2$) in one and the same direction. On both schemes rolling is carried out owing to the wedging of the blank between the rollers.

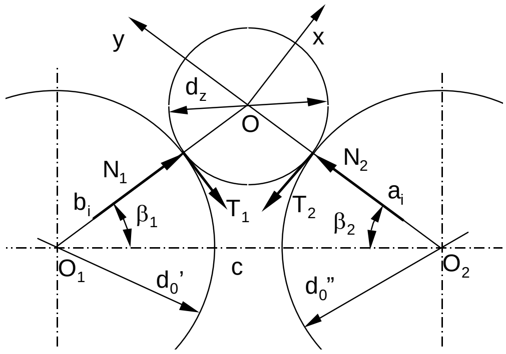

Fig.4. Diagram of forces originating at the process of rolling.

The reliable blank wedging between the rollers depends on the correlation of the diameters of the rollers and the blank, and on the friction in the points of contact. Based on the analysis of the forces of normal pressure N_1 and N_2, originating at the points of contact, and the friction forces T_1 and T_2 (fig.4), considering the indications on fig. 4, the following inequality for determining the diameter of the driving roller has been drawn on the condition of blank equilibrium:

$$d_0^{'\,2}.k.\mu^2 + d_0^{'}(1+k)(\mu^2 d_1 - d_z + d_1) - d_z^2 + d_1^2(1+\mu^2) \geq 0. \qquad (1)$$

Using inequality (1) and the values of the parameters shown in Table 1, graphs have been built, which illustrate the changing of the driving roller diameter d_0 depending on the blank diameter d_z (fig.5), and on the friction quotient μ (fig.6) for different values of the correlation k of the roller diameters ($k=d_0^{''}/d_0^{'}$) when operating by the diagram from fig. 3,a, or ($k=\omega_2/\omega_1$) when operating by the scheme from fig.3,b. Correlation (1) and all other similar correlations cited further refer to both rolling schemes.

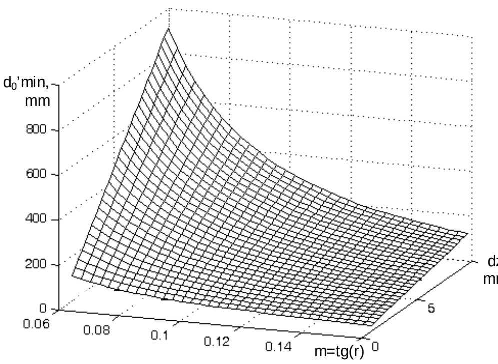

Fig.5. Influence of d_z and μ on the critical values the of $d_0^{'}$.

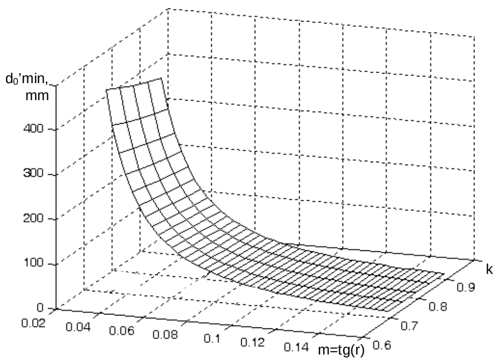

Fig.6. Influence of μ and κ on the critical values of $d_0^{'}$.

The analysis of the results from the operation under the scheme fig. 3,a shows that for the realization of a reliable rolling process it is necessary to have rollers with diameters bigger than those defined by inequality (1).

3. OUTPUT OF THE ROLLING PROCESS

The output of rolling is an essential parameter, determining the applicability of the method. To determine it we need to know:

- The law of changing the outer blank diameter in the process of rolling;
- The changing of the centroid diameters at the time of rolling;
- The speed of movement of the blank during rolling;
- The path of the blank between the rollers.

3.1. DETERMINING THE LAW OF CHANGING OF THE OUTER DIAMETER

During the rolling process, when the tool is inserted into the blank, the outer blank diameter d_i increases, and in the final moment of rolling it reaches a diameter *d.* This diameter d_i is determined by the condition of keeping the volume of the material before and after deformation and on the premises that it is non-shrinkable and flows out only radially.

Table 1. Parameters of the axial profile

d, mm	P,mm	d_1 , mm	α_1	α_2	r, mm
1.64	0.6	1.18	65°	15°	0,05

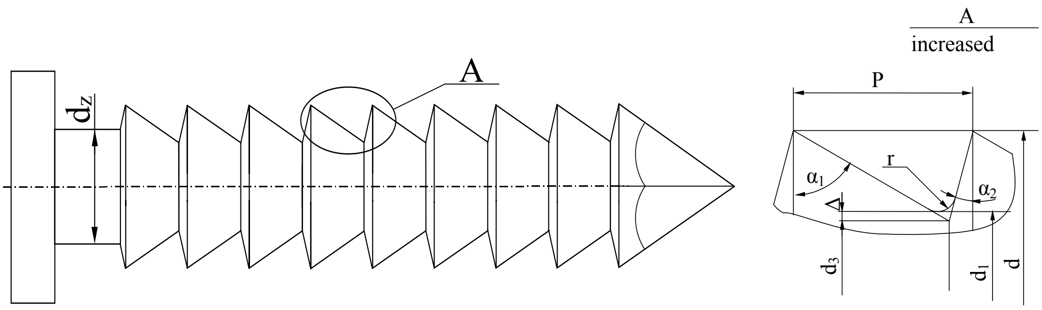

Fig.7. General view and axial profile of rotationally shaped surface.

Using the symbols and parameters of the rotational surface profile with length equal to step *P* (fig.7 and fig.8), the symbols on fig.8 and the blank diameters d_z , as well as the insertion of the tool to d_{1i}, the following equation for determining the current outer diameter d_i of the nail rolled has been worked out:

$$2d_i^3 - 3(d - d_1 - d_{3i})d_i^2 + d_z^3 + \Big[\frac{\pi}{12} f(d_{x1i}^2 + d_{x2i}^2 + d_{x1i}d_{x2i}) -$$

$$-\frac{\pi}{12} x_1(d_{x1i}^2 + d_{3i}^2 + d_{x1i}d_{3i}) - \frac{\pi}{12}(f - x_1)(d_{x2i}^2 + d_{3i}^2 + d_{x2i}d_{3i}) - , \qquad (2)$$

$$-2\pi R_i S\Big]\frac{24}{\pi[tg(\alpha_1) + tg(\alpha_2)]} = 0$$

where S ,mm^2– area of the segment of the longitudinal cross section at the tip of the tool.

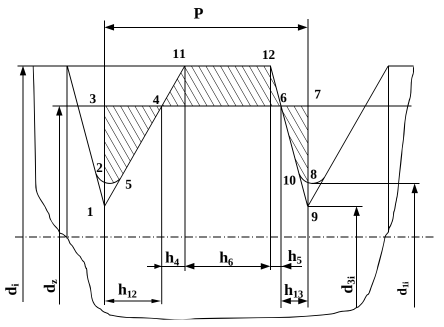

Fig.8. *Diagram for determining the increase of* d_i.

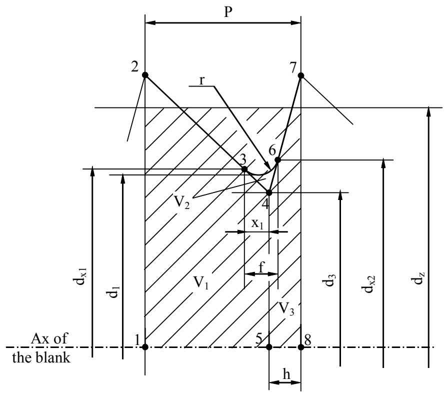

Fig.9. Diagram for determining blank diameters.

One of the real roots of this cubic equation is the value of the current outer part diameter, moulded through a definite radial insertion to diameter d_1. It is determined through a multiple use algorithm of the programming language MATLAB. For the example from Table 1 the changing of the current outer diameter, depending on the insertion of the tool, is shown on fig.12.

3.2. DETERMINING THE CENTROID DIAMETERS OF THE ROLLERS AND THE BLANK

During the process of rolling the blank fed between the rollers rotates, sways and moves downwards. The rollers are inserted and gradually mould the profile of the part. The analysis of the rotation speeds in any contact points of the blank in any moment of insertion shows that the speeds are equal only at one contact point (point *W*) (fig.10). The diameters of the rollers and the blank going through this point are called centroid and are indicated as d_{wi} and d_{wi0}.

During the process of rolling the rollers turn over the blank along the centroid diameters without skidding. There is skidding in any other contact point. The centroid diameters can be determined through the work of the friction forces on the contact surfaces in unit time. This is, in essence, the power of the friction forces. For the processed rotational surface with

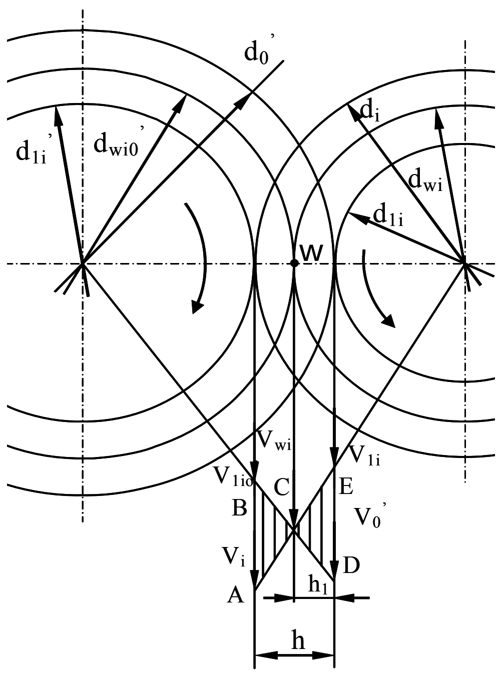

Fig.10. Diagram of speeds and contact points of rolling.

length equal to the step *P*, using the symbols from fig.10 and fig.11, on condition that the radius of rounding at the tip of the profile *r* of the rollers is replaced by the chamfer *f*, and taking into consideration the fact that the friction is in different directions, we write for the power of friction forces the following equation [7]

$$N_{T_1} + N_{T_4} = N_{T_3} + N_{T_2} + N_{T_f} \ ,$$

where in each section with a length l_1, l_2, l_3 and l_4 the powers of the friction forces are of the kind:

$$\begin{aligned} N_{T_1} &= \mu l_1 \delta q \left(V_i - V_{1io}^{'}\right) \\ N_{T_2} &= \mu l_2 \delta q \left(V_0^{'} - V_{1i}\right) \\ N_{T_3} &= \mu l_3 \delta q \left(V_0^{'} - V_{1i}\right), \\ N_{T_4} &= \mu l_4 \delta q \left(V_i - V_{1io}^{'}\right) \\ N_{T_f} &= \mu f \delta q \left(V_0^{'} - V_{1i}\right) \end{aligned} \qquad (4)$$

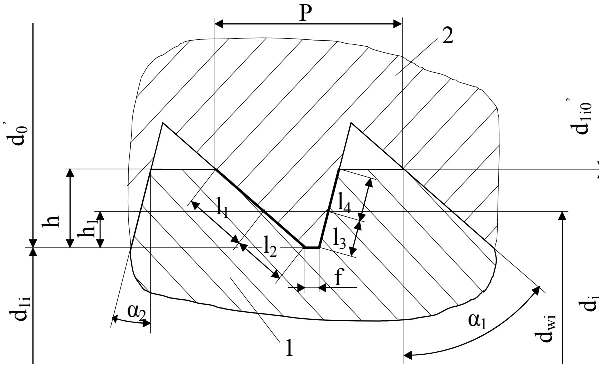

Fig.11. Diagram of the profile of rolling in the i-th moment of insertion.

1. Blank; 2. Driving roller.

where N_{T1}, N_{T2}, N_{T3}, N_{T4}, N_{Tf} ,W – capacity of friction forces at the respective sites; μ – friction quotient; V_i, V_{1i}, V_{1i0}’, V_{i0}’ ,m/s – peripheral speed of the respective diameters of blank and driving roller.

After substitution and modification the distance h_1 and the current centroid diameters of the blank and the driving and driven rollers are determined (6) .

$$h_1 = \frac{h^2[\cos(\alpha_1) + \cos(\alpha_2)]}{2\{h[\cos(\alpha_1) + \cos(\alpha_2)] + f\cos(\alpha_1)\cos(\alpha_2)\}}, \qquad (5)$$

$$\begin{aligned} d_{wi} &= d_{1i} + 2h_1 \\ d_{wi0}^{'} &= d_0^{'} - 2h_1 \\ d_{wio}^{''} &= d_0^{''} - 2h_1 \end{aligned} \qquad (6)$$

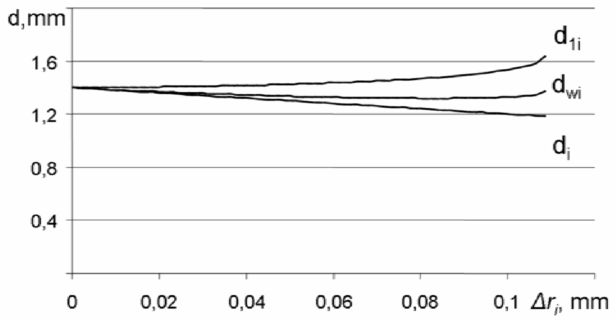

Fig.12. Changing of d_i, d_{1i} *and* d_{wi} *depending on insertion* Δr_i *in the rolling process with* dz = *1.4 mm and* P = *0.6mm.*

Using equations (2), (5) and (6) the graphs on fig.12 are drawn, showing the change of the values of d_{1i} and d_{wi} during the process of rolling, depending on the radial insertion of the rollers Δr_i.

3.3. DETERMINING THE SPEED OF MOVEMENT OF THE BLANK BETWEEN THE ROLLERS

To determine the average speed of movement of the blank between the rollers it is necessary to consider the value and the direction of the speed vector any time the blank center moves.

This vector of speed at any moment lies on the tangent to the trajectory of movement in the specified point (fig.13).

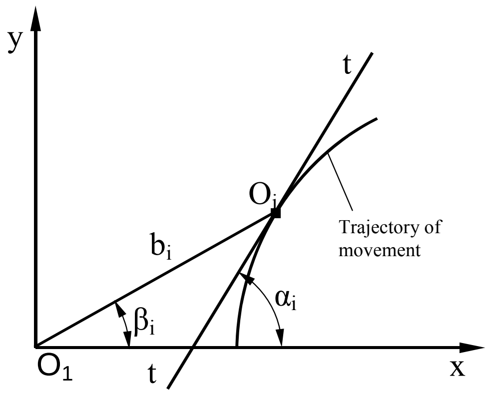

Fig.13. Trajectory of movement of the processed blank center.

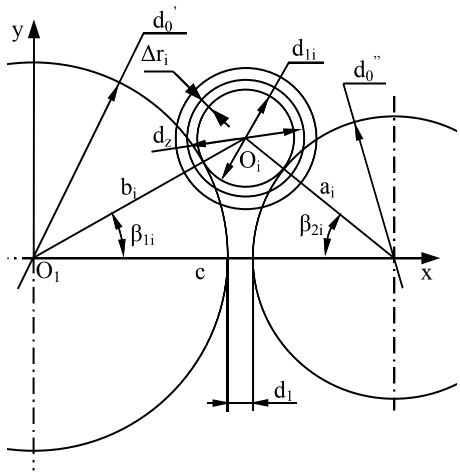

Fig.14. Diagram for determining the parameters influencing the trajectory of movement of the blank center.

Using the equations for determining the centroid diameters and the symbols from fig.14 we show the trajectory of movement of the blank center.

If the axis O_1x coincides with the distance between the roller axes, and pointO_1 coincides with the rotational axis of the driving roller (fig.14), the direction of the blank center speed in point *O*, from the trajectory of movement, is determined through the angular coefficient of the tangent *t-t* (fig.13) according to the equation

$$y' = tg(\alpha_i), \tag{7}$$

where tg(α_i) – Angular quotient of the tangent to the trajectory of the processed blank center.

After considering the symbols shown on fig.13, 14 and carrying out the necessary transformations appears as follows

$$y' = \frac{-\sin(\beta_{1i}) - \dfrac{\cos(\beta_{1i1})}{\sqrt{(2b_i c)^2 - \left(b_i^2 + c^2 - a_i^2\right)^2}}\left[c^2 - (a_i - b_i)^2\right]}{-\cos(\beta_{1i}) + \dfrac{\sin(\beta_{1i})}{\sqrt{(2b_i c)^2 - b_i\left(b_i^2 + c^2 - a_i^2\right)^2}}\left[c^2 - (a_i - b_i)^2\right]} \tag{8}$$

where a_i; b_i ,mm – transitory center distance between the driving and driven roller and the blank respectively; c ,mm – center distance of the rollers.

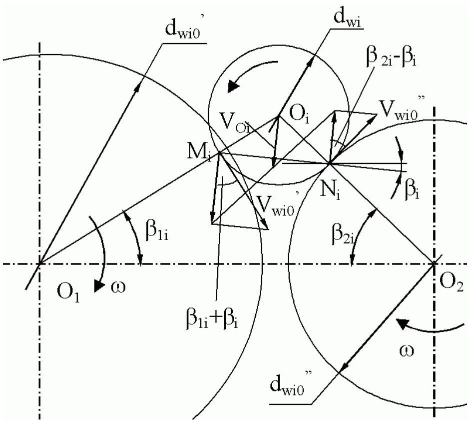

Fig.15 Diagram for determining the speed V_{0i} *of the blank.*

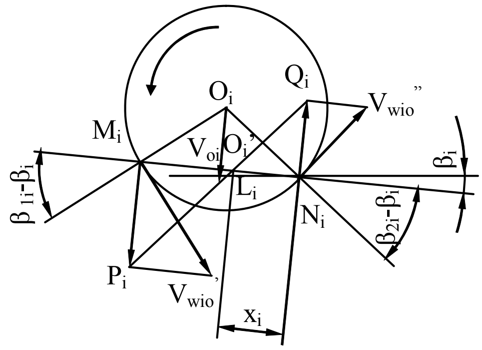

Fig16. Diagram of speeds determining the blank movement.

Generally the value of the speed V_{0i} (fig.15) of movement of the blank center depends on the values of the peripheral speeds of the driving roller $V_{wio}^{'}$ and the driven one $V_{wio}^{''}$, with respective diameters $d_{wi0}^{'}$, and $d_{wi0}^{''}$ (6). Based on the symbols on fig. 16 for the equation for determining the value of the blank center speed of movement V_{0i} at any given moment the following equation has been worked out

$$V_{oi} = \frac{O_i^{'}N_i - x_i}{x_i} V_{wi0}^{''} \cos(\beta_{2i} - \beta\ i) , \qquad (9)$$

where from (fig.16)

$$x_i = \frac{M_i N_i . V_{wio}^{'} \cos(\beta_{2i} - \beta_i)}{V_{wio}^{'} \cos(\beta_{2i} - \beta_i) + V_{wio}^{''} \cos(\beta_{1i} + \beta_i)}$$

After discretization of the trajectory, which the blank center follows in some sections so that every point coincides with Δr_i and assuming with sufficient accuracy that the discrete section of the trajectory is a straight line, the value of the average speed of movement V_{0avi} for the *i*-th section of the trajectory of blank center movement (fig.17) can be determined following the equation:

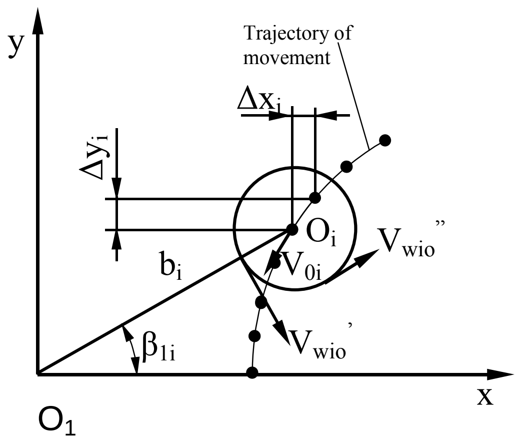

fig.17 Discretization of the trajectory of speed of the blank center during rolling.

$$V_{oavi}=(V_{oi}+V_{o(i+1)})/2. \qquad (10)$$

The time Δt_i necessary for the blank center to move from the i-th to the $(i+1)$-th point is determined by the equation:

$$\Delta t_i = \frac{\sqrt{\Delta x_1^2 + \Delta y_i^2}}{V_{ocpi}}, \tag{11}$$

and the total time Δt and the average speed of movement of the blank V_{0av} – by the equations:

$$\Delta t = \sum_{i=1}^{n-1} \Delta t_i \ , \ V_{ocp} = \frac{\left(\sum_{i=1}^{n} V_{occp}\right)}{n} \tag{12}$$

Then the output per minute A of this method of rolling with rotational frequency of the driving roller $1\ min^{-1}$ is

$$A=60/\Delta t\ . \tag{13}$$

At any moment of movement the blank has rotated

$$n_i = \frac{(V_{wi0}^{'} + V_{wi0}^{''})\Delta t_i}{\pi\left[\dfrac{d_{wi} + d_{w(i+1)}}{2}\right]}\ . \tag{14}$$

and during the period of rolling the rotations n are

$$n = \sum_{i=1}^{n-1} n_i\ . \tag{15}$$

Using an algorithm developed in the program mean of the Excel electronic tables and the above equations, graphs have been drawn, showing the dependence of the output per minute A, the average speed of movement of the blank center V_{0av} and the total number of rotations n of the blank during the process of rolling (fig.18, fig.19, fig.20) on the coefficient k , the diameter d_0' and the diameter dz=1.4mm.

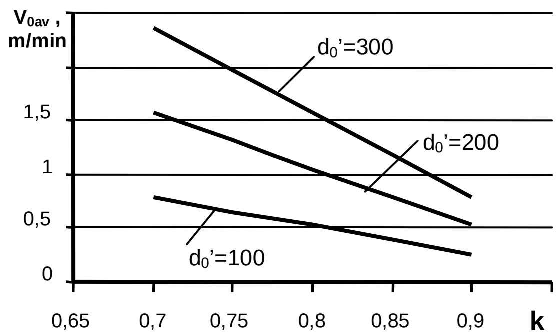

Fig.19. Average speed of movement of the blank center with rotational frequency of the driving roller 1 min^{-1}

Considering that the rolling will be realizes with rotational frequency of the driving roller 90-120 *min*$^{-1}$, the rolling output can reach up to 1800-2400 items per minute, provided there are no other restrictions. In order to mould a quality profile surface, it is recommendable the total number of rotations *n* to be no less than 3,5 – 4. It can be seen from fig.20 that this condition has been met.

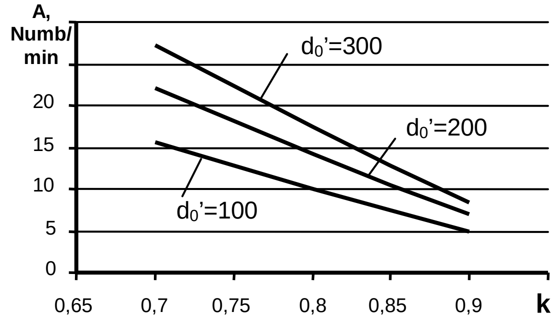

Fig.18. Output of process with rotational frequency of the driving roller 1 min^{-1}

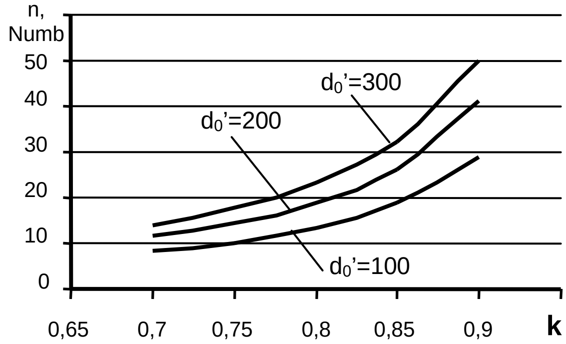

Fig.20. Number of rotations n *of the blank during rolling for one full rotation of the driving roller*

4. CONCLUSIONS

The theoretical analysis of the method of rolling of rotationally shaped surfaces with radial feeding of the blanks shows:

1. The process of rolling of rotationally shaped surfaces is feasible for blank diameters no bigger than 6 mm;
2. In order for profile rotational parts with bigger diameters to be rolled, the roller diameters should be over 300 mm, which makes the equipment needed for the process too expensive;
3. For friction coefficients within the range of 0,06÷0,12 the correlation between the diameters of the driving roller and the driven one does not have a significant influence on the wedging conditions;

4. The growth of the current value of the outer diameter di of the rotationally shaped surface during rolling depends on the insertion of the rollers Δri and is described by a cubic equation;
5. The values of the current outer diameter di of the rotationally shaped surface does not depend on the outer diameters of the rollers $d_0{}'$ and $d_0{}''$;
6. The changing of the current value of the centroid diameter dwi of the rotationally shaped surface during rolling does not depend on the diameters of the rollers d0' and d0";
7. The output of the process of rolling depends significantly on the correlation k of the roller diameters. The influence of the value of the driving roller diameter d0' on the output with a constant value of k is insignificant;
8. The change of the value of the average speed V0av of movement of the blank center depends both on the value of the coefficient k, and on the value of the driving roller diameter d0'. With the decrease of the coefficient k and the increase of d0' the average speed V0av changes substantially;
9. The number of rotations n of the blank depends on the coefficient k and the driving roller diameter d0' .

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VALJANJE ROTACIONO PROFILISANIH POVRŠINA SA TANGENCIJALNIM DOTUROM PRIPREMKA – DEO 1 –

Veliko Ivanov, Aleksandar Ivanov

REZIME

U ovom radu obrađena je problematika izrade elemenata za spajanje (specijalnih eksera) u obradi drveta. Ti elementi poseduju različite profile. Dobijanje tih profila detaljno je opisano u radu, sa posebnim akcentom na fazi valjanja sa ravnim pločama. Prikazanom tehnologijom može se postići veoma efikasna proizvodnja datih spojnih elemenata. Sam proces se odvija u sledećim koracima: žica se odvija sa koturova i nakon ispravljanja dolazi na automatsku mašinu tipa Wafios za izradu klasičnih eksera sa cilindričnim telom. Nakon toga takav proizvod se upućuje na specijalnu mašinu gde se primenom valjanja na cilindričnom telu eksera izrađuju različiti profili (sl. 2).
Analiza je pokazala da izrada tankih elementa sa različitim helikoidnim profilima spoljne površine pomoću metode valjanja daje dobre rezultate.

U procesu valjanja analiziranih profila neophodno je odrediti:

- *zakon promene spoljnog prečnika pripremka u procesu valjanja*
- *promena centralnog prečnika za vreme valjanja*
- *brzinu kretanja obratka za vreme valjanja*
- *putanju obratka između alata (valjaka)*

Istraživanja su rezultirala zaključcima od kojih se navode sledeći:

- *proces valjanja rotacionih profilisani površina izvodljiv je za obratke do prečnika od 6 mm*
- *za valjanje većih prečnika alati (valjci) bi morali da imaju prečnike veće od 300 mm, što takva postrojenja čini neekonomičnim*
- *broj obrtaja obratka "n" zavisi od koeficijenta "K" i prečnika pogonskog valjka "d_o"*
- *rezultat procesa valjanja (broj komada u jedinici vremena) u velikoj meri zavisi od korelacije "K" prečnika valjaka (* $K = d_0'' / d_0'$ *)*
- *vrednost trenutnog prečnika obratka ne zavisi od spoljnjeg prečnika valjaka* d_0' *i* d_0''.

Broj komada koji se na ovaj način može izraditi iznosi 1800 – 2400 u minuti.