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EFFECT OF THE CONDITIONS AND KINEMATICS OF WORKING ON THE DESIGN OF THREAD ROLLING TOOLS

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Abstract: *The article contains issues regarding thread shaping with following methods: tangential, radial, axial and planetary which are all used in technology of thread rolling. The analysis of processing conditions was carried out – technological and rolling kinematics in relation to construction of rolling tools. On above basis the general quidelines and dependences that set basic construction parameters of flat dies were presented.*

Key words: *threads rolling, methods, tooling construction.*

1. INTRODUCTION

The thread rolling process takes advantage of the ability of metals to undergo permanent plastic deformation. Plastic deformation is a permanent change in the shape and dimensions of an object or its fragment, which remains after the external forces have ceased. The process of thread profile formation is determined by the stress and strain state in the zone of contact between the tool and the workpiece and by the magnitude of allowance for embossing the blank, as defined by initial diameter d_w.

The whole thread making cycle requires a certain number of workpiece rotations $n_{o.p}$ to displace some volume of material (embossing) and to produce the final shape and dimension (sizing). Embossing starts from the point of the tool coming into contact with the workpiece surface and ends after it has reached the thread minor diameter. Depending on the number z_R of mating tools, after each workpiece revolution, $1 / z_R$, the partially formed thread profile gets into the zone of, e.g., the second (Fig. 1a), and then the third (Fig. 1b) tool.

The layers shown in Fig. 1 are the feed, $p_{o.p}$, as expressed by the magnitude of gradual tool thread penetration into the material during one turn of the workpiece. Both the number of revolutions and the feed should be adjusted to the physical and mechanical properties of material, and their recommended values for sample types and accuracy classes of threads are given in Table 1.

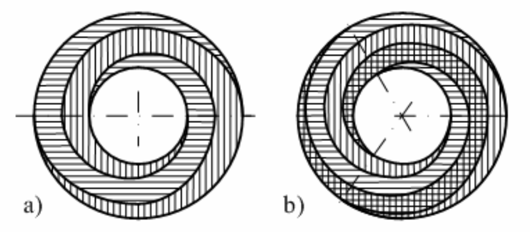

Fig. 1. Thread rolling using two (a) and three (b) tools.

Table 1

Recommended number of workpiece rotations $n_{o.p}$ and feed $p_{o.p}$ in the rolling of threads

Material worked		**Metric**, P [mm]					
		≤ 1			1.25÷1.5		
		4h	6g	6e	4h	6g	6e
		Unified UNF, P [TPI]					
		80÷24			20÷16		
		3A	2A	1A	3A	2A	1A
		Unified G, P [TPI]					
			28			19	
			A	B		A	B
Steel [MPa]	**R_m< 500**	5 0.1	4 0.12	4 0.15	4 0.15	4 0.2	4 0.2
	500÷750	5 0.08	5 0.1	4 0.12	5 0.12	4 0.18	4 0.2
	750÷900	6 0.06	5 0.08	5 0.1	6 0.1	5 0.16	4 0.18
	900÷1200	8 0.04	6 0.06	5 0.08	7 0.08	6 0.12	5 0.15
Aluminium and aluminium alloys		5 0.1	4 0.12	4 0.15	5 0.1	4 0.15	4 0.2
Copper, copper and zinc alloys		5 0.1	4 0.12	4 0.15	5 0.1	4 0.12	4 0.15

The influence shown by the above-mentioned working parameters and threading kinematics on the constructional dimensions of the tools under discussion should be considered with respect to the rolling methods and the types of tools that they use [1].

2. FLAT DIES

Thread rolling using flat dies (Fig. 2) is a universal method enabling threads to be made on standardized parts, including parts hard to be worked with other methods, such as sheet-metal screws or wood screws [2, 3, 4].

The embossing part length l_{we} depends on the assumed feed $p_{o.p}$, which determines the number of revolutions, as calculated from the relationship:

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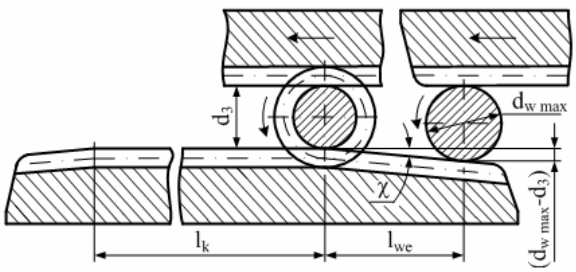

Fig. 2. Schematic of thread rolling with flat dies.

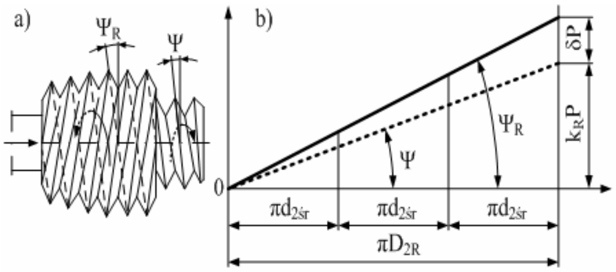

Fig. 3. Schematic of the kinematic system of longitudinal rolling with threaded rolls.

$$n'_{o.p(we)} = \frac{\left(d_{w\max} - d_3\right)}{z_R \cdot p_{o.p}}. \tag{1}$$

The calculated value of $n'_{o.p(we)}$ should be rounded as follows:

- when $0.2<(n'_{o.p(we)} -[A]) < 0.7$ then $n_{o.p(we)} = [A] + 0.5$,
- when $(n'_{o.p(we)} - [A]) \geq 0.7$ to $n_{o.p(we)} = [A] + 1$,
- when $(n'_{o.p(we)} - [A]) \leq 0.2$ then $n_{o.p(we)} = [A]$.

where: [A] – integer part of the value of $n'_{o.p(we)}$

The effective length l_{we} of the fixed die embossing part is:

$$l_{we} = n_{o.p(we)} \cdot \pi d_{2śr} \tag{2}$$

and the sizing part length l_k, while considering the number of revolutions $n_{o.p}$ recommended for the given conditions equals:

$$l_k = \left(n_{o.p} - n_{o.p(we)}\right) \cdot \pi d_{2śr}\,. \tag{3}$$

To release the workpiece after ending of threading, the sizing part of the movable die should be longer by the value of $\pi d_{2śr}$. The angle of relief , χ, for the fixed die embossing part is calculated from the formula:

$$\chi = \arctan\frac{068 \cdot P}{l_{we}}, \tag{4}$$

while satisfying the condition of $\tan\chi < \tan\varsigma < 0.1$ (the angle χ should be less than the angle of friction ς, which ensures that the workpiece is seized by the dies and the slip during rolling is eliminated).

3. THREAD ROLLS

3.1. The longitudinal method

By this method, the workpiece being threaded rotates between rolls with multiple thread with k_R (Fig. 3a), with the axial motion being performed either by the workpiece or by the rolls [5]. For the axial displacement of the workpiece to take place for this rolling case, there must be a difference between the lead angle ψ_R of thread on the rolls and the lead angle ψ of thread on the workpiece, which is shown schematically in Fig. 3b.

In that case, with the constant contact between the tool and the workpiece, upon the full rotation of the roll, a longitudinal workpiece displacement will take place by the quantity of δP, which is the measure of axial feed being equal to:

$$p_w = \pm \pi d_{2śr}\left(\tan\psi_R - \tan\psi\right) \tag{5}$$

and the sign (+ or −) denotes the direction of workpiece movement.

The difference in lead angles can be obtained by selecting the roll diameter for a thread by two type dimensions greater than the one being made, while retaining the same pitch, according to the formulae:

$$D_{2R} = k_R \cdot d_{2obl}\,, \tag{6}$$

$$d_{2obl} = \left(d_{2śr} + 2\right), \tag{7}$$

where: $d_{2śr}$ – diameter of thread being made;
d_{2obl} – diameter assumed for calculation.

The feed is the greater, the greater is the difference between the angles ψ_R and ψ; in practice, it normally equals $(0.15\div0.20)P$.

3.2. The in-depth method

By the in-depth method (Fig. 4), thread is made during the radial feed of cylindrical multiple-thread rolls [6 and 7]. During rolling, there occurs a difference in the turning path of the mating thread diameters between the roll thread and the workpiece thread, which results in a slip.

The maximum magnitude of this slip occurs in the area of contact between the diameters D_R and d_3. When the working is conducted on a fixed workpiece, it will be

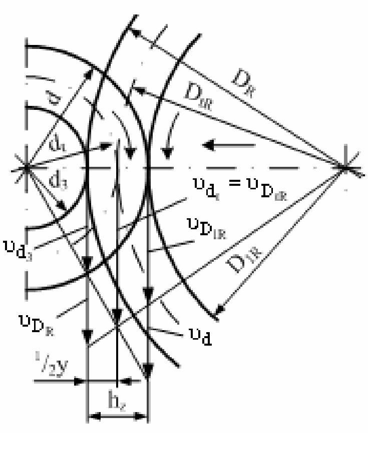

Fig. 4. Schematic of thread rolling by the in-depth method.

necessary to find roll dimensions, at which slip-less turning will take place. These conditions are satisfied by the relationship:

$$D_R = k_R \cdot d_3 + (k_R + 1)\cdot y \cdot h_z\,, \tag{8}$$

where: k_R – multiplicity of thread on the roller,
d_3 – internal diameter thread made,
h_z – height thread roller,

which is determined from the analysis of the distribution of velocity and friction power in the turning plane and the determined rolling roll diameters, where the coefficient y is assumed to be equal to 1.18 for metric threads, and 0.96 for unified threads.

3.3. The tangential method

The dimensions of cylindrical rolls with the tangential feed of the workpiece (Fig. 5) are dictated by the need for chocking (biting) the workpiece to be threaded at the point of starting the thread rolling process [8, 9].

In a system with two rolls of identical diameters, this condition will be met when the angle β is less than the angle of friction of ς = 5º42', in which case:

$$D_{R1} = D_{R2} \geq D_{Rgran} = 202.25\left(0.995 d_{w\max} - d_3\right), \tag{9}$$

with roll thread multiplicity equal to:

$$k_R > k_{Rgran} = \frac{D_{Rgran} - 2h_w}{d_{2śr}}\text{, integer.} \tag{10}$$

During rolling, when $D_{R1} > D_{R2}$, the condition of biting the workpiece by the rolls will be met, if:

$$\cos\beta_1 = \frac{\left[0.5\left(D_{R1} + d_{w\max}\right)\right]^2 + \left[0.5\left(D_{R1} + D_{R2}\right) + d_3\right]^2 - \left[0.5\left(D_{R2} + d_{w\max}\right)\right]^2}{0.5\left(D_{R1} + d_{w\max}\right)\left(D_{R1} + D_{R2} + 2d_3\right)} > 0.995 \tag{11}$$

$$\cos\beta_2 = \frac{\left[0.5\left(D_{R2} + d_{w\max}\right)\right]^2 + \left[0.5\left(D_{R1} + D_{R2}\right) + d_3\right]^2 - \left[0.5\left(D_{R1} + d_{w\max}\right)\right]^2}{0.5\left(D_{R2} + d_{w\max}\right)\left(D_{R1} + D_{R2} + 2d_3\right)} > 0.995 \tag{12}$$

The permissible value of angles determines the need for selecting the appropriate minimal permissible multiplicity k_{R1} and k_{R2} of the roll thread, which, with the diameters D_{R2} = 0.7 D_{R1} and D_{R2} = 0.85 D_{R1} for selected thread dimensions, are given in Table 2.

Another type of rolls used in the tangential method is the rolls with a backed-off working part (Fig. 6), which find application primarily in die holders and die heads,

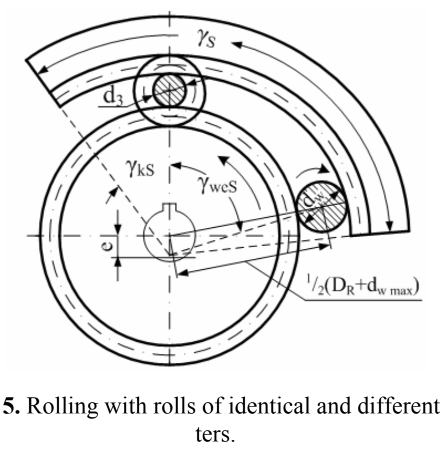

Fig. 5. Rolling with rolls of identical and different diameters.

Table 2

Minimal multiplicities k_{R1} and k_{R2} of the thread of rolls with different diameters

Metric thread	P mm	$\frac{k_{R2}}{k_{R1}} \approx 0.7$			$\frac{k_{R2}}{k_{R1}} \approx 0.85$		
		$\frac{k_{R2}}{k_{R1}}$	cosβ₁	cosβ₂	$\frac{k_{R2}}{k_{R1}}$	cosβ₁	cosβ₂
M5	0.8	30/42	0.9975	0.9952	28/32	0.9964	0.9953
M6	1	32/44	0.9975	0.9953	30/34	0.9964	0.9954
M8	1.25	28/38	0.9973	0.9952	26/30	0.9963	0.9952
M10	1	18/26	0.9977	0.9953	16/18	0.9962	0.9953
M10	1.25	24/34	0.9977	0.9955	22/26	0.9967	0.9955
M10	1.5	28/38	0.9974	0.9954	26/30	0.9965	0.9954
M12	1	14/20	0.9975	0.9952	12/14	0.9961	0.9950
M12	1.25	18/26	0.9976	0.9951	18/20	0.9964	0.9957
M12	1.5	22/32	0.9976	0.9951	22/26	0.9967	0.9955
M12	1.75	28/38	0.9975	0.9955	26/30	0.9966	0.9955
M14	1.5	20/28	0.9976	0.9955	18/22	0.9968	0.9954
M14	2	26/36	0.9975	0.9953	24/28	0.9965	0.9953
M16	1	14/20	0.9981	0.9964	12/14	0.9971	0.9962
M16	1.5	16/22	0.9974	0.9953	16/18	0.9965	0.9957
M16	2	24/34	0.9982	0.9964	22/26	0.9974	0.9964

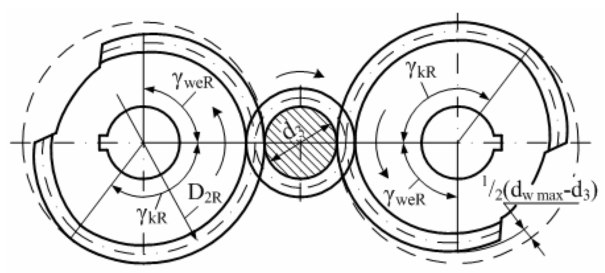

Fig. 6. Thread rolling with relieved rolls.

where the full rolling cycle is made during one their rotation [6 and 10].

The length of the embossing and sizing parts is calculated in a similar manner as for flat dies. and their corresponding central angles are determined from the relationships:

$$\gamma_{weR} = \frac{360^\circ \cdot l_{we(\gamma weR)}}{\pi D_{2R}}\,,$$

$$\gamma_{kR} = \frac{360^{\circ} \cdot 1_{k(\gamma kR)}}{\pi D_{2R}}. \tag{13}$$

Moreover. the following condition must be satisfied:

$$\frac{180^{o}\left(d_{w\max} - d_3\right)}{\pi\gamma_{weR}\left(D_R - d_{w\max} + d_3\right)} \le 0.1\,, \tag{14}$$

for the workpiece to be automatically bitten by the rolls.

4. THE PLANETARY METHOD

Rolling by the planetary method takes place with the eccentric relative position of the roll and the segment (Fig. 7). Thus created working space is characterized by a variable lead of the segment working part profile. which allows gradual formation of the thread on the workpiece [11, 12].

By a detailed analysis of the threading kinematics (Fig. 7), with a variable lead of the segment working part profile (γ_S = 90°, 120° and 150°) created in this system. while allowing for the embossing part (γ_{weS}), the sizing part (γ_{kS}), the thread size (M3÷M6 with P = 0.5÷2 mm). and the eccentric offset e (0.5÷2 mm), the relationship of $k_S = f\left(p_{o.p}, P\right)$ was determined. A sample formula for calculating the multiplicity k_s of the segment with γ_S = 120° has the form of:

- for the rolled thread range of M3÷M6:

$$k_S = \left(2.117P - 0.132\right)\cdot p_{1o.p}{}^{\left(0.95P^4 - 2.203P^3 + 1.52P^2 - 0.1709P - 1.146\right)}; \tag{15}$$

- for M6÷M10:

$$k_S = \left(-3.918P^2 + 10.776P - 4.874\right)\cdot p_{o.p}{}^{\left(10.024P^2 - 0.066P - 1.010\right)}; \tag{16}$$

- for M10÷M16:

$$k_S = \left(2.083P - 0.093\right)\cdot p_{1o.p}{}^{\left(-0.743P^4 + 4.512P^3 - 10.068P^2 + 9.768P - 4.523\right)}. \tag{17}$$

Due to the behaviour of the segment profile lead curve, the value of $p_{o.p}$ taken for the calculation occurs only during the first revolution of the workpiece.

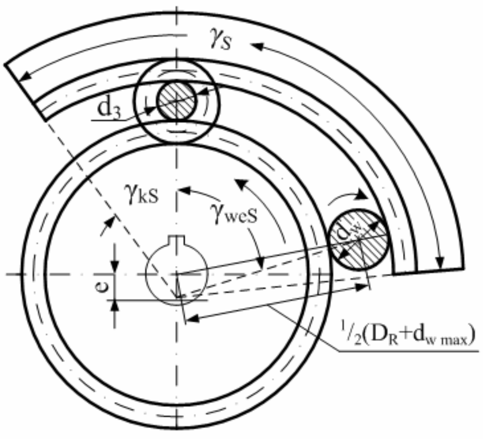

Fig. 7. An eccentric roll-segment system.

5. CONCLUSIONS

In the manufacturing techniques direct relationships occur between the process kinematics in the tool-workpiece system and product quality (regarded as a set of technical. technological and operational characteristics) and the design of tools used in those processes. This relation is of substantial importance in the methods of rolling threads and. in addition. the high diversity of methods used arise the necessity for the comprehensive solution of problems connected with the design of different types of tools intended for making various surfaces and solids of a helical contour.

The working conditions and kinematic relationships occurring during the rolling of thread by different methods determine the basic constructional dimensions of the tools, which ensure the correct thread formation process. This constitutes, at the same time, a starting point enabling the remaining dimensions of mating flat dies rolls. or a roll with a segment to be calculated afterwards according the classical methodology.

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