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THE DESIGN OF PIPE THREAD ROLLING ROLLERS

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Subject review
The analysis of the allowance distribution in pipe thread rolling with rollers of the identical thread crest rounding radius has been presented. Theoretical relationships and methodology for computing the embossing thread diameter with the assumed distribution of the embossing allowance as measured by the displaced material volume have been elaborated. Examples illustrated elaborated relationships have been given.

Keywords: *allowance distribution, rolling rollers, thread*

Oblikovanje valjaka za valjanje cijevnog navoja

Pregledni članak
Prezentirana je analiza distribucije tolerancije kod valjanja cijevnog navoja s valjcima identičnog polumjera zaobljenja vrha navoja. Razrađeni su teorijski odnosi i metodologija za računanje promjera utiskivanja navoja s pretpostavljenom distribucijom tolerancije utiskivanja koje je mjereno pomoću istisnutog volumena materijala. Dani su ilustrirani primjeri razrađenih odnosa.

Ključne riječi: *distribucija tolerancija, navoj, valjci za valjanje*

1 Introduction

Execution of high-plastic steel thread and threads made of some non-ferrous metals and their alloys is a complex technological task. High ductility and elasticity is the distinctive feature of the mentioned group of materials. Difficulties in rolling thread made of these materials with cutting method may have effect in built-up edge which causes the increase of cutting torque and generates additional heat. Altogether it brings about the quicker wear of tool cutting wedges. Furthermore the quality of thread, its geometry and precision do not comply with legal standards. Plastic cold thread shaping in metal greatly eliminates the above difficulties. For external thread rolling method is applied and for internal thread embossing method is applied.

Plastic shaped threads increase mechanical and physical features and higher dimensional accuracy. Basically the tools used for that technology have higher attrition resistance which results in much longer durability in comparison with cutting method tools. Moreover the possibility of use faster thread rolling speed has direct influence on process efficiency. In spite of well-developed thread rolling machine and technology instrumentation production the professional literature concerning improvements of tools construction requires extension.

Long-term studies over thread shaping process include notably analysis of rolling process [1, 2, 3, 4, 6, 7, 10] which is the basis for new construction researches concerning thread working part that forms the crest [5, 8, 9, 10]. The significant part in those tools development has been taken by companies: FETTE, Wagner and Reed Rico [11, 12, 13, 14] that have been producing threading heads which are used for rolling with axial, radial or tangential method.

Optimization in manufacturing process for improving the exploitation properties is a wide subject of interest whose proper application allows obtaining high-quality product.

The research results shown in the monograph [10] enabled the development of the profile of working portion of roller for rolling metric and inch thread: Unified National Coarse and Unified National Fine.

The previously not applied new method of roller construction guarantees even distribution of the embossing allowance along the embossing part which results in increase of working life of such tools.

The present paper deals with the construction optimization of rollers for pipe parallel G type threads rolling. Within mentioned range the theoretical relations and methodology of roller construction dimensions calculation was determined for rollers with annular profile that are used in angular threading heads; self-opening with rollers mounted on eccentric shafts both fixed and rotating.

2 The design of the embossing portion

One of the types of external thread rolling tools are annular-profile rollers. Fig. 1 shows four design solutions with a conical embossing portion. In the first design option with a variable thread crest radius (Fig. 1a), the distribution of the allowance, as measured by the displaced material volume, is considered as favourable to the thread forming process [7].

The arrangement of thread crests along the element of the cone makes this design easy to execution in engineering respect. On the other hand, the large radius of the first thread may make the start of thread crest sinking into the material difficult; therefore, this type of solution is recommended for rolling coarse and medium-fine threads with pitches of $P < 1,5$ mm.

When using the second design (Fig. 1b), the material is displaced as a result of interaction between thread crests and thread flanks. In this case, an uneven distribution of the embossing allowance occurs, which increases 2,2 times with four and 3,5 times with six embossing threads, as compared to the first thread [10]. In the next two design options with the identical thread crest radius (Figs. 1c and 1d), although they differ in construction, the process and successive phases of thread crest forming are identical.

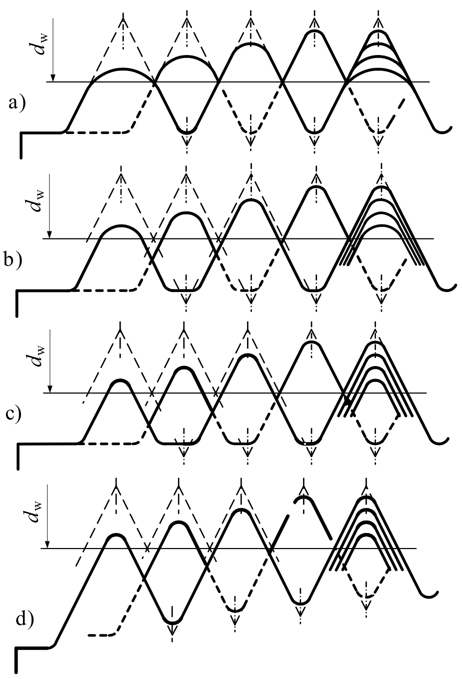


Figure 1 The axial profiles of the embossing portion of rollers: with varying (a, b) and identical (c, d) thread crest radii

Compared to the former options (Figs. 1a and 1b), there is also a greater disproportion between the volumes of displaced material per successive threads. Based on the investigation carried out so far for the aforementioned designs, a theoretical background has been developed, which enables the optimization of the axial profile of the embossing portion of rollers designed for rolling coarse and fine metric threads and UNC and UNF unified threads [5].

As a supplement concerning pipe threads, the present article contains the analysis of volume variations during rolling using rollers with an embossing portion axial profile of identical thread crest radii, r_w (Fig. 2). Also in this case, the material is displaced as a result of interaction between the crest and the flanks of successive threads.

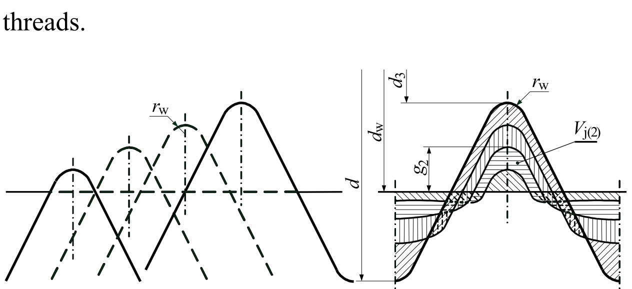


Figure 2 The axial profile of the embossing portion with a fixed thread crest radius

The analysis of the magnitude and distribution of the displaced material volume was made for a set of unified pipe threads from $R^1/_{16}$ to $G1^1/_4$. The article constitutes a supplement for the complete coverage of the area encompassed by the software application assisting the design of tools to be used in external thread rolling engineering [10].

3 Analysis of the displaced material volume

For computing the volume of displaced material, relationships [5, 10] were used, which considered the tool embossing portion design, as shown in Fig. 1c and Fig. 1d, and the dimensions of the thread to be rolled. The total material volume, V_j, embossed by successive threads (except for the first thread) is composed of two parts: the V_g part displaced from the starting material region, and the V_w part being already displaced, situated below the surface of the cylinder of diameter d_w. Example results of computation of these volumes for G5/8 thread made using rollers with 4, 6 and 9 embossing threads, respectively, are shown in Fig. 3.

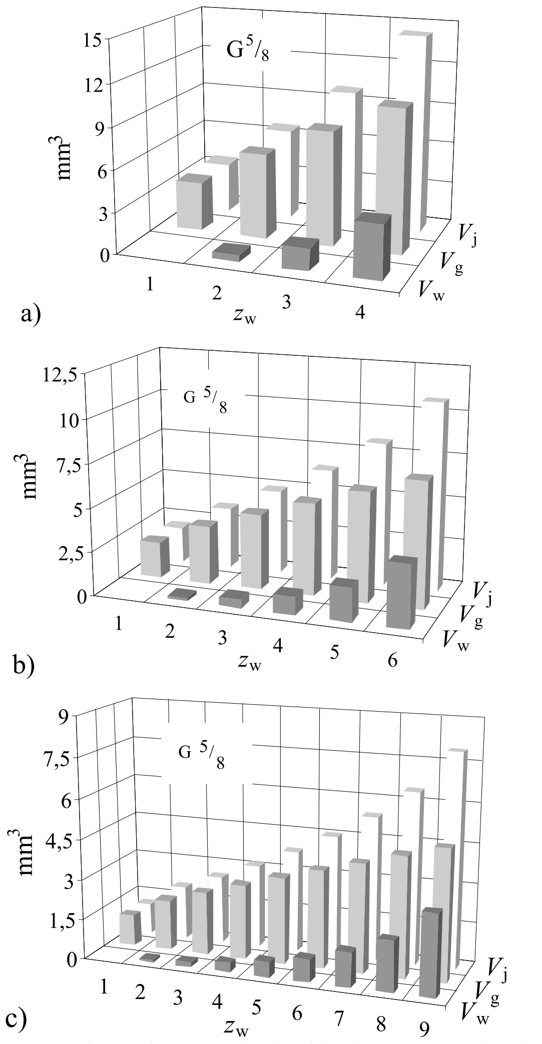


Figure 3 Volume of material displaced by the embossing threads

The results indicate that, similarly as for the other type dimensions, the sum of volumes V_w, i.e. parts of the material displaced from the thread crest formed by the preceding thread (re-displaced), constitutes (21 ÷ 23) % with six and (29 ÷ 32) % with nine embossing threads relative to the volume V_g, and, respectively, (17 ÷ 22) %, (20 ÷ 22) % and (22 ÷ 24) % relative to the total volume V_j that is embossed during rolling of the thread under analysis. This part of the deformed material has not been previously allowed for; however, it is of major importance in analysis involved in the optimization of the embossing portion axial profile.

Fig. 4 represents the results of computation of the total displaced material volume per the successive 4, 6 or 9 embossing threads, depending on the design.

The volume increase factors for successive threads, as compared to the first thread, are as follows:

- with 4 threads: 1; 1,8; 2,8; 4,0
- with 6 threads: 1; 1,7; 2,3; 3,1; 4,0; 5,2
- with 9 threads: 1; 1,7; 2,2; 2,7; 3,3; 4,0; 4,6; 5,6; 7,0.

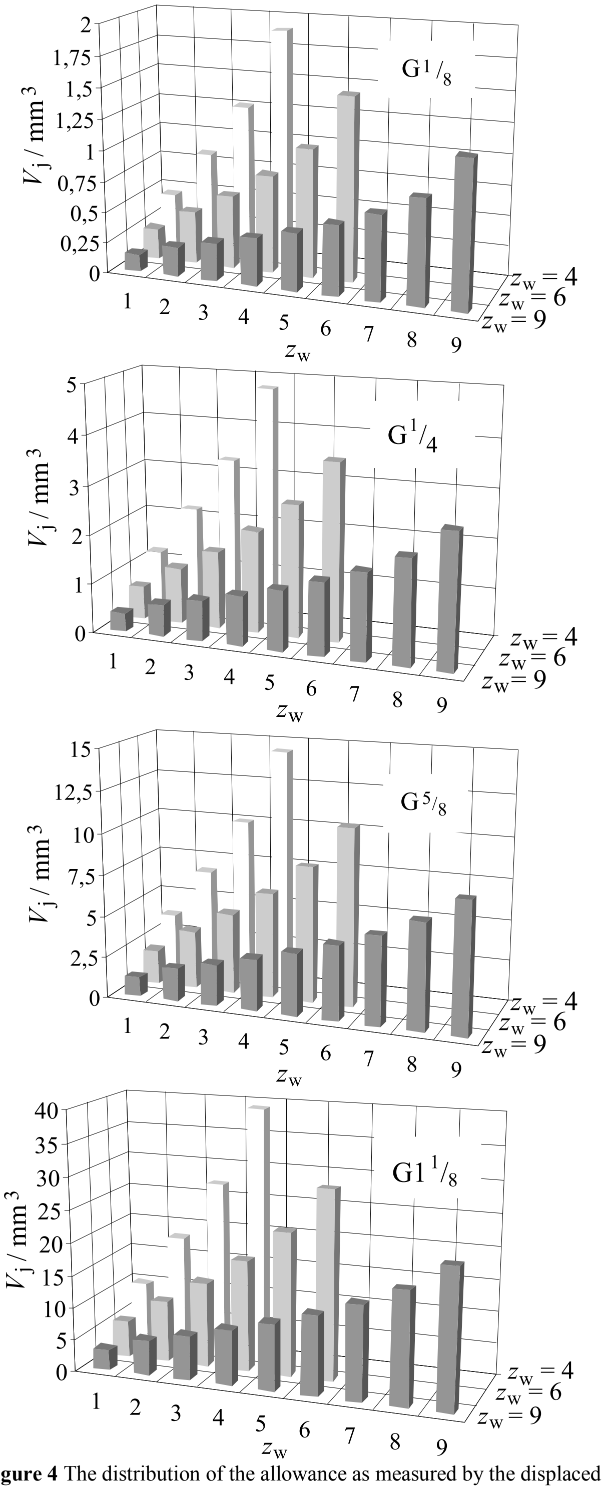


Figure 4 The distribution of the allowance as measured by the displaced material volume, depending on the number of embossing threads

The above indicates that with the conical profile of the embossing portion, the distribution of the material allowance for thread profile formation in rolling of unified pipe threads is uneven. Despite the similar distribution pattern as for metric threads, the allowance magnitudes are different due to the profile angle (55°), which has significance in the subsequent procedure to optimize the design under examination.

4 Optimization of the embossing portion design

The occurring uneven distribution of allowances implies that it is necessary to determine the relationship between the sinking of thread "*g*" into the material being worked and the material volume being displaced by this thread.

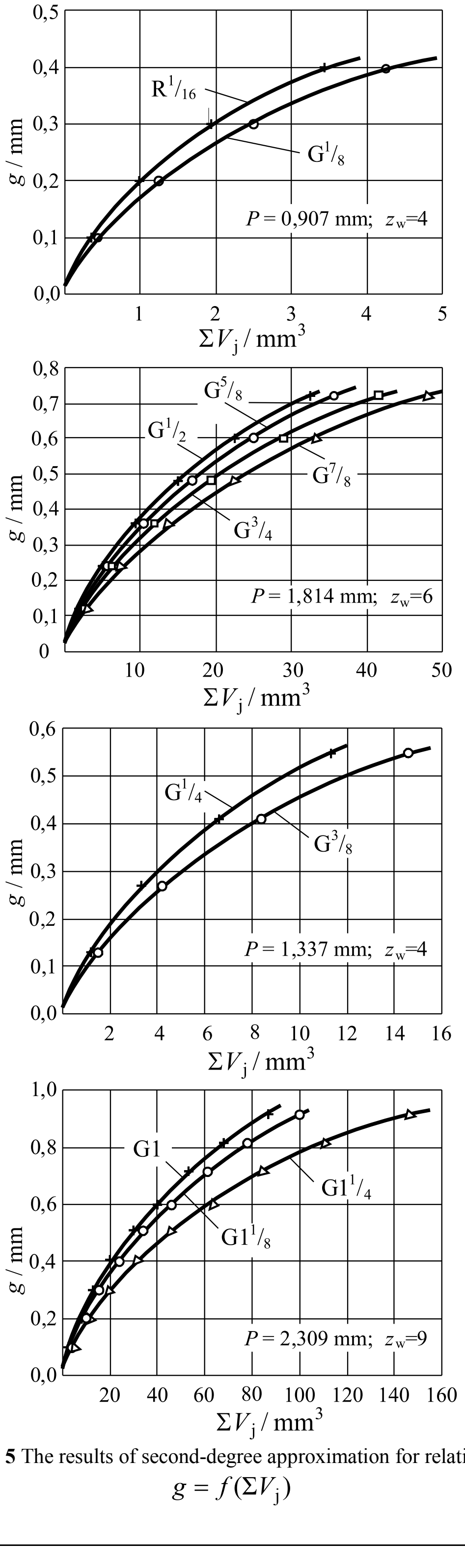


Figure 5 The results of second-degree approximation for relationship $g = f(\Sigma V_j)$

To this end, using the V_j unit volume computation results for the pipe thread set under examination, a theoretical relationship between the thread sinking and the displaced material volume has been determined in the form of the following function:

$$g = a(\Sigma V_j)^2 + b(\Sigma V_j) + c. \tag{1}$$

The value of ΣV_j is taken as the sum of volumes, e.g. for $g_3 = \Sigma V_{j(1-3)} = V_{j1} + V_{j2} + V_{j3}$. The obtained relationships $g = f(\Sigma V_j)$ for selected threads with an identical pitch are represented in Fig. 5.

For the set of threads with P = 2,309 mm (11 turns/inch) and z_w =9, Eq. (1) has the following form:

thread G1:

$$g = -0{,}00009 \cdot (\Sigma V_j)^2 + 0{,}01786 \cdot (\Sigma V_j) + 0{,}05222,$$

thread G1$^1/_8$:

$$g = -0{,}00007 \cdot (\Sigma V_j)^2 + 0{,}01556 \cdot (\Sigma V_j) + 0{,}05227,$$

thread G1$^1/_4$:

$$g = -0{,}00005 \cdot (\Sigma V_j)^2 + 0{,}01326 \cdot (\Sigma V_j) + 0{,}05230.$$

Then, to reduce the number of equations, which is of major importance when creating the software, the relationships $g = f(\Sigma V_j, d_{max})$ covering the sets of threads with an identical pitch were determined. For this purpose, the polynomial coefficients of function $g = f(\Sigma V_j)$ were approximated to determine the relationship between the "g" thread sinking and the displaced material volume ΣV_j and the thread diameter d_{max}. For the examined pipe thread range of R$^1/_{16}$ ÷ G1$^1/_4$, the following equations have been obtained:

4 embossing threads

R$^1/_{16}$; G $^1/_8$; *P* = 0,907

$$\begin{aligned} g &= (0{,}0009036 d_{max}^2 - 0{,}0102629 d_{max} - 0{,}0023959)(\Sigma V_j)^2 + \\ &+ (-0{,}004891 d_{max}^2 + 0{,}062944 d_{max} + 0{,}0146045)(\Sigma V_j) + 0{,}01563. \end{aligned} \tag{2}$$

G $^1/_4$; G $^3/_8$; *P* = 1,337

$$\begin{aligned} g &= (0{,}0000376 d_{max}^2 - 0{,}0007429 d_{max} - 0{,}0001012)(\Sigma V_j)^2 + \\ &+ (-0{,}0007001 d_{max}^2 + 0{,}0154822 d_{max} + 0{,}0021091)(\Sigma V_j) + 0{,}020715. \end{aligned} \tag{3}$$

G $^1/_2$; G $^5/_8$; G $^3/_4$; G $^7/_8$; *P* = 1,814

$$\begin{aligned} g &= (-0{,}0000022 d_{max}^2 + 0{,}0001426 d_{max} - 0{,}0025977)(\Sigma V_j)^2 + \\ &+ (0{,}00006 d_{max}^2 - 0{,}00426 d_{max} + 0{,}10399)(\Sigma V_j) + 0{,}026533. \end{aligned} \tag{4}$$

G 1; G 1 $^1/_8$; G 1 $^1/_4$; *P* = 2,309

$$\begin{aligned} g &= (0{,}0000001 d_{max}^2 - 0{,}0000019 d_{max} - 0{,}000176)(\Sigma V_j)^2 + \\ &+ (-0{,}0000239 d_{max}^2 + 0{,}0011636 d_{max} + 0{,}0070753)(\Sigma V_j) + 0{,}03674. \end{aligned} \tag{5}$$

6 embossing threads

R$^1/_{16}$; G $^1/_8$; *P* = 0,907

$$\begin{aligned} g &= (0{,}0008183 d_{max}^2 - 0{,}0093282 d_{max} - 0{,}0021776)(\Sigma V_j)^2 + \\ &+ (-0{,}0046249 d_{max}^2 + 0{,}0591835 d_{max} + 0{,}0138087)(\Sigma V_j) + 0{,}02089. \end{aligned} \tag{6}$$

G ¼; G $^3/_8$; *P* = 1,337

$$\begin{aligned} g &= (0{,}00003461 d_{max}^2 - 0{,}0006838 d_{max} - 0{,}0000932)(\Sigma V_j)^2 + \\ &+ (-0{,}0006651 d_{max}^2 + 0{,}0147071 d_{max} + 0{,}0020035)(\Sigma V_j) + 0{,}0276. \end{aligned} \tag{7}$$

G $^1/_2$; G $^5/_8$; G $^3/_4$; G $^7/_8$; *P* = 1,814

$$\begin{aligned} g &= (-0{,}0000017 d_{max}^2 + 0{,}0001201 d_{max} - 0{,}0022615)(\Sigma V_j)^2 + \\ &+ (0{,}0000541 d_{max}^2 - 0{,}0040687 d_{max} + 0{,}0991576)(\Sigma V_j) + 0{,}035348. \end{aligned} \tag{8}$$

G 1; G 1 $^1/_8$; G 1 $^1/_4$; *P* = 2,309

$$\begin{aligned} g &= (0{,}0000001 d_{max}^2 - 0{,}0000019 d_{max} + 0{,}000166)(\Sigma V_j)^2 + \\ &+ (-0{,}0000274 d_{max}^2 + 0{,}0014425 d_{max} + 0{,}0008058)(\Sigma V_j) + 0{,}04904. \end{aligned} \tag{9}$$

9 embossing threads

R$^1/_{16}$; G $^1/_8$; *P* = 0,907

$$\begin{aligned} g &= (0{,}0007733 d_{max}^2 - 0{,}0066176 d_{max} - 0{,}0020584)(\Sigma V_j)^2 + \\ &+ (-0{,}0044525 d_{max}^2 + 0{,}056987 d_{max} + 0{,}0132962)(\Sigma V_j) + 0{,}02447. \end{aligned} \tag{10}$$

G $^1/_4$; G $^3/_8$; *P* = 1,337

$$\begin{aligned} g &= (0{,}0000331 d_{max}^2 - 0{,}0006541 d_{max} - 0{,}0000891)(\Sigma V_j)^2 + \\ &+ (-0{,}0006437 d_{max}^2 + 0{,}0142338 d_{max} + 0{,}001939)(\Sigma V_j) + 0{,}03214. \end{aligned} \tag{11}$$

G $^1/_2$; G $^5/_8$; G $^3/_4$; G $^7/_8$; *P* = 1,814

$$\begin{aligned} g &= (-0{,}000002 d_{max}^2 + 0{,}0001322 d_{max} - 0{,}0023825)(\Sigma V_j)^2 + \\ &+ (0{,}0000523 d_{max}^2 - 0{,}0039374 d_{max} + 0{,}096014)(\Sigma V_j) + 0{,}04109. \end{aligned} \tag{12}$$

G 1; G 1 $^1/_8$; G 1 $^1/_4$; *P* = 2,309

$$\begin{aligned} g &= (-0{,}00000037 d_{max}^2 + 0{,}00002176 d_{max} - 0{,}0002285)(\Sigma V_j)^2 + \\ &+ (-0{,}0000277 d_{max}^2 + 0{,}0014789 d_{max} + 0{,}0006432)(\Sigma V_j) + 0{,}05688. \end{aligned} \tag{13}$$

The dimensions of embossing threads (their successive diameters and crest rounding radii) depend on the "g" sinking values that define the position of the crests of individual embossing threads (thus the dimensions of diameters D_{zw}) and are directly related to the head diameter D_c and the minor diameter D_{1R}, the pitch diameter D_{2R}, and the major diameter D_R on the sizing portion of the rolling roller. On the other hand, the successive tool tip penetrations are influenced by:

- the number of mating rolling rollers, which is normally 2 on thread-rolling machines and 3 in threading heads;
- the number of effective embossing threads; and
- the distribution of the allowance, measured as the displaced material volume, on individual threads.

Considering the above, each of the rollers will have a specific number of effective embossing threads; e.g. with z_{we} = 6 and the number of rollers z_R = 3, there will be two threads on each of the rollers. It is also advisable that the first roller should have a thread of diameter D_{zw0} that will not take part in the working, but only bring the roller in to the surface being threaded. To assure the uniform loading of individual rollers and reduce the wear of the last embossing threads, while considering the gradual increase in the strain hardening of the deformed material top layer and having in mind easier starting of the threading process, the following assurance distribution has been assumed:

- with 4 effective embossing threads: 15, 30, 35 and 20 %V_c,
- with 6 effective embossing threads: 10, 15, 20, 20, 20 and 15 %V_c,

- with 9 effective embossing threads: 5, 10, 15, 15, 15, 15, 10, 10 and 5 $\%V_c$.

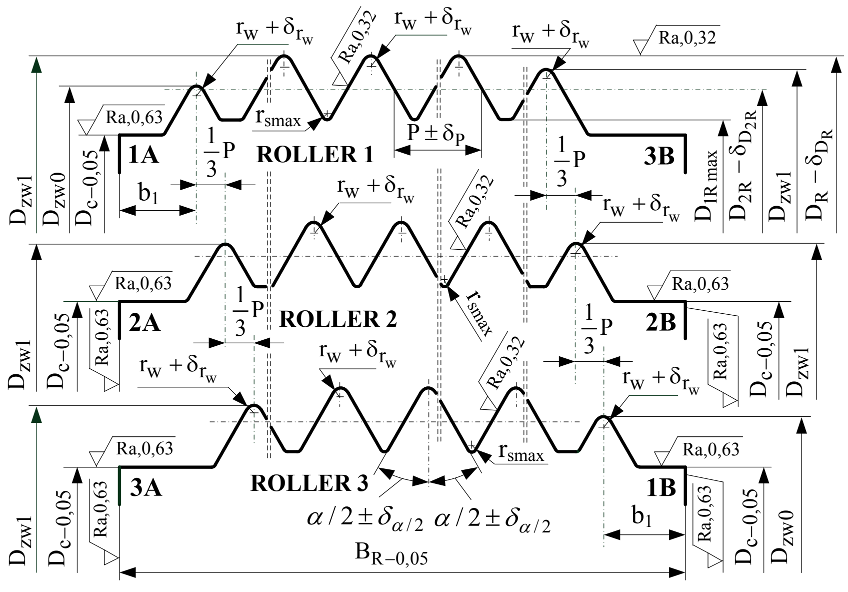
Using the proper formula for the selected thread, the values of g can be calculated for successive embossing threads by substituting the respective sums of the values of $\%V_c$ for ΣV according to the assumed allowance distribution. Next, knowing the g values and the outer roller diameter, the diameters and crest radii of individual embossing threads are calculated from the formulas given in Tab. 1. The method of determining these dimensions is shown on two examples.

The first example relates to the fixed self-opening threading head with three rollers mounted on eccentric shafts, applicable for e.g. rolling of G3/8 thread. In the case of this thread, the deformed material volume with 6 embossing threads is V_c=15,22 mm^3. Taking the above-proposed allowance distribution being equal to 10, 15, 20, 20, 20 and 15 $\%V_c$, the values of successive embossing threads sinking from g_1 to g_6 are: 0,11; 0,23; 0,36; 0,46; 0,52 and 0,54 mm. For further calculations, it will be necessary to determine the roller outer diameter D_R. In this respect, with a view to the head design, the following condition must be met:

$$D_R \le 6{,}464 d_3 - 7{,}646 c_1.$$

Table 1 Formulas for calculation of diameter D_{ZW} and radius r_{ZW} of rolling roller threads

Roller no.		z_{we}			Roller no.		z_{we}		
		4	6	9			4	6	9
ROLLER 1	D_{zw0}	$D_R - (d_{w\,max} - d_3)$			ROLLER 1	D_{zw0}	$D_R - (d_{w\,max} - d_3)$		
	D_{zw1}	$D_{zw0} + 2g_3$				D_{zw1}	$D_{zw0} + 2g_2$		
	D_{zw2}	-	D_R	$D_{zw0} + 2g_6$		D_{zw2}	D_R	$D_{zw0} + 2g_4$	
	D_{zw3}	-	-	D_R		D_{zw3}	-	D_R	$D_{zw0} + 2g_6$
ROLLER 2	D_{zw1}	$D_{zw0} + 2g_1$				D_{zw4}	-	-	$D_{zw0} + 2g_8$
	D_{zw2}	D_R	$D_{zw0} + 2g_4$		ROLLER 2	D_{zw1}	$D_{zw0} + 2g_1$		
	D_{zw3}	-	-	$D_{zw0} + 2g_7$		D_{zw2}	$D_{zw0} + 2g_3$		
ROLLER 3	D_{zw1}	$D_{zw0} + 2g_2$				D_{zw3}	-	$D_{zw0} + 2g_5$	
	D_{zw2}	-	$D_{zw0} + 2g_5$			D_{zw4}	-	-	$D_{zw0} + 2g_7$
	D_{zw3}	-	-	$D_{zw0} + 2g_8$		D_{zw5}	-	-	D_R



Values of calculated embossing portion thread diameters				Other roller working part dimensions / mm				
Roller no. and side	D_{zw0}	D_{zw1}	D_{zw2}	D_R	δ_{D_R}	D_{2R}	$\delta_{D_{2R}}$	$D_{1R\max}$
				70,00	0,09	69,05	0,02	68,13
	mm			D_C	P	δ_P	r_w	δ_{r_w}
1A, 3B	68,90	69,62	70,00	67,80	1,337	0,010	0,13	0,02
2A, 2B	-	69,12	69,82	$r_{s\max}$	$\alpha_R/2$	$\delta_{\alpha_R/2}$	b_1	-
3A, 1B	-	69,36	69,94	0,015	27,5°	25	1,07	-

Figure 6 The shape and dimensions of the working portion of rollers for rolling G$^3/_8$thread with a threading head

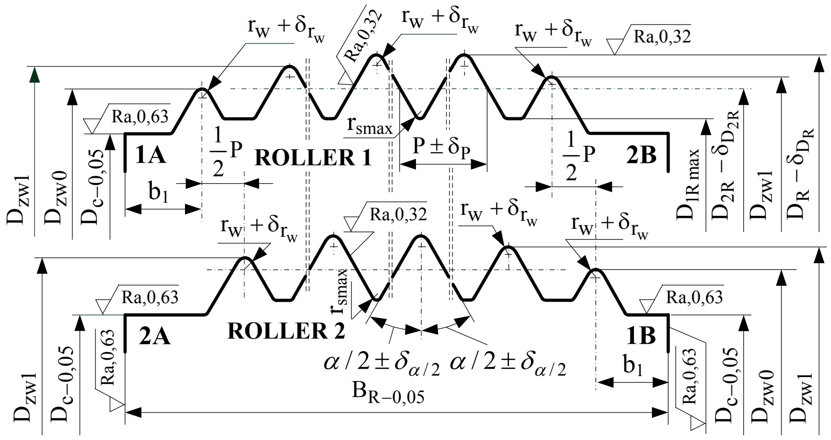
For the thread taken, while assuming the inter-roller distance as c_1 = 3 mm, $D_R \le$ 72,18 mm is obtained, from which D_R = 70 mm has been taken. The calculation results for embossing thread diameters D_{zw} and radii r_{zw}

are illustrated in Fig. 6. Each of the rollers has a double embossing portion; therefore, after one embossing portion side has been worn, the other is used. For the thread taken, assuming the inter-roller distance as c_1 = 3 mm, D_R ≤ 72,18 mm is obtained, and D_R = 70 mm has been taken. The calculation results for embossing thread diameters D_{zw} and radii r_{zw} are illustrated in Fig. 6.

Each of the rollers has a double embossing portion; therefore, after one embossing portion side has been worn, the other is used.

The second example concerns rolling of G1$^1/_8$ thread on a double-roller thread-rolling machine. It was assumed that the thread would be formed by 9 embossing threads with equal allowance distribution to each of the rollers, namely 10, 15, 15 and 10 % V_c to the first roller and 5, 15, 15, 10 and 5 %V_c to the second roller. The displaced material volume in rolling G1$^1/_8$ thread is V_c = 100,18 mm^3, and successive thread sinking values "g", as calculated from formula (12), are: 0,13; 0,26; 0,44; 0,59; 0,71; 0,81; 0,85; 0,88 and 0,90.

For this example, the roller diameter must satisfy the condition: $D_R \le L_{0max} - (d_{max} + h_z)$. Considering the assumed distance between rolling machine spindle axes of L_{0max} = 180 mm and the roller thread profile height of h_z for thread G1$^1/_8$ on the sizing portion, D_R ≤ 153,35 mm is obtained and D_R = 140 mm has been taken.



<table>
<tr><th colspan="7">Values of calculated embossing portion thread diameters</th></tr>
<tr><td rowspan="2">Roller no. and side</td><td>D_{zw0}</td><td>D_{zw1}</td><td>D_{zw2}</td><td>D_{zw3}</td><td>D_{zw4}</td><td>D_{zw5}</td></tr>
<tr><td colspan="6">mm</td></tr>
<tr><td>1A, 2B</td><td>178,17</td><td>178,69</td><td>179,35</td><td>178,80</td><td>179,93</td><td>-</td></tr>
<tr><td>2A, 1B</td><td>-</td><td>178,43</td><td>179,05</td><td>179,60</td><td>179,87</td><td>180,00</td></tr>
<tr><th colspan="7">Other roller working part dimensions / mm</th></tr>
<tr><td>D_R</td><td>δ_{D_R}</td><td>D_{2R}</td><td>$\delta_{D_{2R}}$</td><td>D_{1Rmax}</td><td>D_C</td><td>P</td></tr>
<tr><td>180,00</td><td>0,13</td><td>178,38</td><td>0,03</td><td>176,82</td><td>176,30</td><td>2,309</td></tr>
<tr><td>δ_P</td><td>r_w</td><td>δ_{r_w}</td><td>$r_{s\,max}$</td><td>$\alpha_R/2$</td><td>$\delta_{\alpha_R/2}$</td><td>b_1</td></tr>
<tr><td>0,015</td><td>0,24</td><td>0,04</td><td>0,28</td><td>27,5°</td><td>20</td><td>1,85</td></tr>
</table>

Figure 7 The shape and dimensions of the working portion of roller for rolling of G1 thread on a double-roller rolling machine

The values of the diameters of individual embossing threads and their crest radii are shown in Fig. 7.

5 Conclusions

The determined relationships between thread sinking and the displaced material volume and thread diameter, covering the sets of identical-pitch threads, are of key importance in the development of software assisting the design of rolling rollers. The methodology of g value calculation makes it possible to set a design for the assumed embossing allowance distribution and to determine the diameters of individual embossing threads that perform the work proper in forming the crest of the thread being rolled.

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