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CONSIDERATION REGARDING THE INFLUENCE OF THE PROCESS FACTORS ON THE GEOMETRICAL PRECISION OF SOME COMPLEX PROFILES MANUFACTURED BY COLD ROLLING

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ABSTRACT

Industrial practice emphasizes the wide use of manufacturing by volumetric cold forming of some profiles on parts used within machine building industry; this is justified by certain advantages offered by these rooling processes.
The aim of this paper is to enrich the contributions in this field, by presenting some of the researches made by the authors regarding the geometrical precision of the helical profile (worm) generated by a roll tool and some grooves with involute profile generated by a rack bar tool. We have taken into consideration the following main processing factors: the geometry of the tool and the active precision of the profile, the kind of material and the shape of the blank, the values of the mode of operation parameters, the geometric precision of the roller. The research results allow establishing the workability function connected with the dimensional precision of the generated profiles and offer important information's concerning the development of the straining process.

KEYWORDS: cold rolling, complex profiles, geometrical precision.

1. INTRODUCTION

Teeth processing by plastic deformation through cold volume (PDCV) have several advantages comparing with the cutting process: high productivity, saving material, eliminating the finishing stages of rectification (deficient in time and cost of processing), higher mechanical properties in superficial layer. In this paper there are presented some results of research conducted by the team of authors in connection with the geometric precision of the profiles processed, involute profile of groove and worm type.

The researches realized represent the starting point of the project "Analytical and numerical modelling of the processes of cold plastic processing of complex profiles", project type PCE financed by CNCSIS and actually in progress.

The studies done in this field indicate that the main factors influencing the precision of the profile generated by cold rolling are:

- tool dimensions and the precision of its active profile;
- geometric accuracy and kinematics of the rolling machine;
- the dimension of the workpiece;
- the parameters of the rolling process.

Among the mentioned factors, the first has the largest influence for the processing by copying, and the first two factors in the case of rolling processing.

Since the beginning of the processing by PDCV, for generating involute profile there were used tools with a specific geometry; but, for rolling the threads and worm, some time it was considered that the surface realized on the rolled part is exactly the negative of the generative tool. In reality, the side surface of the helicoids profile generated by cold rolling differs from the tool side surfaces. For example, for the thread rolling with the roll tool with helicoids surface with linear profile in axle section, the surfaces of the generated thread flank have deviations from linearity in axial section, and it increases with decreasing the ratio of the roll diameter and of the part diameter, with decreasing the angle of the thread profile and with increase the ratio of thread pitch and thread diameter.

The dimension of the blank and its tolerance have a significant influence on the dimensional accuracy of the rolling part. Among the rolling parameters, the advance is the one with the greatest influence on the accuracy of the generated profile. Most of the research works performed in this field show that running with minimum sizes of advance lead to small deviations from the prescribed geometry profile.

As order size, the dimensional precision of the profiles processed by DPVR is located in 6-7 precision rank for the threads, in 7-8 precision rank for worm gears and cylindrical teeth and in 6-8 precision rank for grooves. The main profile size deviations that appear are the roundness deviation and cylindrical deviation, which have values below 0.05 mm.

2. RESEARCH METHODOLOGY

Geometric characteristics of the processed profile are presented in Fig. 1 for the Archimedean worm (ZA 1x1, 25x14, STAS 6461-81) and in Figure 2 for the involute groove type SAE (ANSI B 92.1-1970 Add. 92.1b B / ANSI B 92.2M-1980).

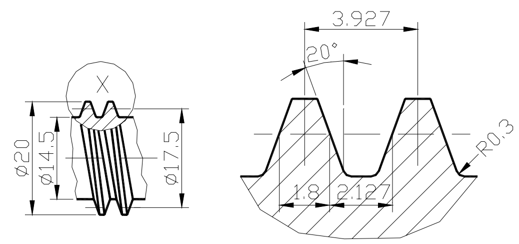

Fig. 1. The shape and nominal dimensions prescribed for the Archimedean worm

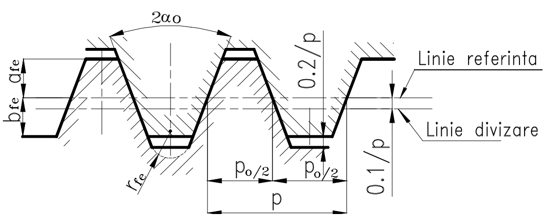

Fig. 2. The geometrical elements and the reference rack for the SAE involute grooves

speed v and radial feed w_r. The technological elements that have made the experimental investigation are:

- the machine-tool: threads machine with two rolls, UPW 25.1;
- the tools: rolls with effective average dimensions presented in Table 2, made of ledeburitic steel 210Cr120 heat-treated to 60 HRC;
- the blanks: the shape is presented in Fig. 6 and the characteristics in Table 3.

The involute groove were processed with rack tool by rolling method, which is based on rolling without slipping of a line on a circle; the line is the rack-tool and the circle is the of wheel-workpiece. To balance the radial component of the forces there are used two rolling tools, diametrically opposed.

Axial module		m	1,25
Amount of threads		z	1
Tooth inclination direction		-	right
Diameter coefficient		q	14
Tooth profile	Pressure angle	α_{0n}	20°
	Axial coefficient of the tooth head high	f_{0a}	1
	Axial coefficient of the tooth leg high	f_{0p}	1,2
Axial pitch		p	3,927
Tooth blank on the division diameter		s_g	2,127
Angle of the reference helix on d_d		θ_0	4°5'8''
Division diameter		d_d	17,5
Exterior diameter		d	20
Interior diameter		d_i	14,5

Module		m	0,7938/1,058
Amount of teeth		z	20/24/28
Tooth profile	Pressure angle	α_0	30°/37,5°/45°
	High of the reference head	a_{fe}	$a_{fe} = 0,5/p$
	High of the reference leg	b_{fe}	$b_{fe} = 0,8/p$ pt. α_0=30°, $b_{fe} = 0,65/p$ pt. α_0=37,5°, $b_{fe} = 0,5 / p$ pt. α_0 = 45°
Reference pitch		p_0	πm
Thickness of the reference tooth		s_0	$p/2$

Table 1. The main mechanical properties of the processed steels.

Material	HB [kg / mm^2]	$Rp_{0,2}$ [N /mm^2]	R_m [N /mm^2]	A_5 [%]	Blank
OLC15	124	287	437	35	Cold pinched+rematured
17MoCr11	175	400	574	29	Hot rolled
OLC35	208	624	712	11	Hot rolled

The processed materials were three types of standard steels: OLC15, 17MoCr11 and OLC 35. Their main mechanical properties are presented in Table 1.

The helical surface (worm) was processing by the method in-feed method, Fig. 3. The two rolls are involved simultaneously with the same speed, the advance movement being made by a single tool, in the next cycle: fast advance, technological advance, profile calibration, rapid withdrawal.

The technological process parameters are: processing force F, depth of deformation h, the rolling

Processing scheme is shown in Fig. 4. The workpiece 5 placed between tailstock centres. The rack tools 4 and 9 are attached to the sleds 2 and 7, triggered by hydraulic cylinders 1 and 6.

The parameters of the working process are: depth deformation h, the running speed v, the deformation force F. The parts of the technological system that have made the experimental investigation are:

- the groove rolling machine, type ROTO-FLO 3225;

- the rack tool made of RP5, heat-treated to 62-64 HRC (Figure 5), with the geometrical characteristics shown in Table 2;
- the workpieces: the shape is presented in Figure 6 and the characteristics in Table 3.

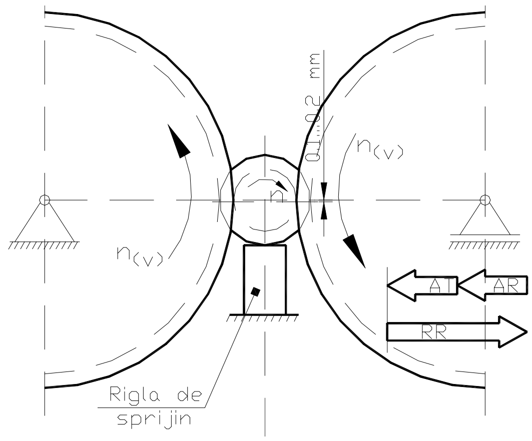

Fig. 3. Worm rolling by in-feed method

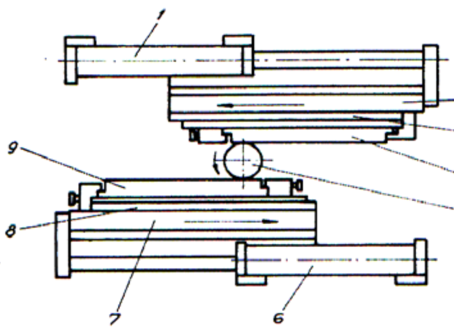

Fig. 4. Groove rolling using rack tools

During processing the worm, the dimension of the workpiece was calculated applying the law of volume constancy, taking into account the specific parameters of the helicoid profile [3]. Starting from the theoretical value of the workpiece size, d_0 = 17.294 mm, we have established three levels of variation for the workpiece dimension (d_{0min}, d_{0med} and d_{0max}, the average value being the theoretically calculated one), the same for the three materials processed.

Table 2. Geometrical characteristics of the rolling tools.

Average effective dimensions of the roll tools								
Exterior diameter d [mm]	Interior diameter d_3 [mm]	Amount of threads	Profile height h [mm]	Size of the profile winding head a [mm]	Profile gap size b [mm]	Lead p [mm]	Profile's semiangle	
							α_{stg}	α_{dr}
176,6	171,08	10	2,76	1,08	0,87	3,94	20°	19°40’
Geometrical and constructive elements of the rack tool								
m [mm]	p [mm]	z_p	α [°]	z_c	z_i	h [mm]	Δa [mm]	β
0,7938	2,4663	213	30	23	11	0,64	0,21	0°4′11″
1,058	3,316	143	37,5	34	6	0,82	0,24	0°6′
1,058	3,3324	143	45	33	6	0,62	0,128	0°4′30″

Table 3. The effective dimensions and the roughness of the workpieces used.

Radial rolling				
l [mm]	l_0 [mm]	d_0[mm]	R_a [μm]	Surface processing method
35 ± 0,1	20 ± 0,05	According with the experimental plan	0,8 – 1,6	turning + grinding
Rolling with rack tool				
94 ± 0,1	10 ± 0,05 20 ± 0,05 40 ± 0,05	According with the experimental plan	0,8 – 1,6	turning + grinding

The research carried out aimed to establish the influence of certain independent process parameters on the dimensional accuracy of the profiles manufactured.

For each type of material and diameter of the workpiece, there have processed in the same conditions three workpiece and there were measured the main characteristics of the geometric profile, Table 4.

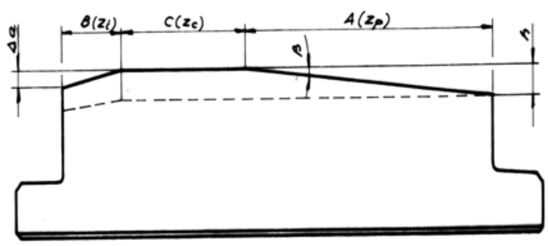

Fig. 5. The rack tool

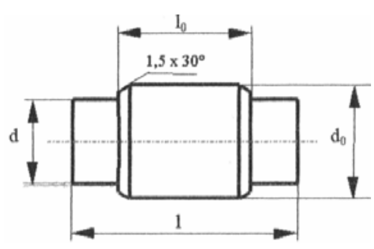

Fig. 6. The workpiece shape

During processing in involute groove, the experiments shown that for a semi-adjustable rack and for a certain adjustment of rack - workpiece, the value of the diameter over the roller varies from sample to sample and is different from the default value, according to the control norm of the achieved groove. This is explained by the technological system deformation, due to the forces of deformation and rigidity of the rolling machine. The variation of the diameter over the roller ***dDR*** is the difference between the effective value obtained by rolling and the default value established by the control norm, considering that this value is dependent on process parameter and is a dimensional accuracy parameter of the manufactured profile. As independent variables of the process is considered: the groove module ***m***, the number of teeth made ***z***, the pressure angle ***α***, the rolled area length ***l***, and the height ***h*** of the tooth made. The experimental plan is presented in Table 5.

dimensions, due to the existence of an axial flow of the material (because of the helical arrangement of the profile);

- the profile size dispersions of the parts made of workpiece with the same dimensions depend on the characteristics of the processed material: they are larger in the case of OLC15 steel and better for the OLC35 steel; this fact puts in evidence a better stability of the process for processing the steels with higher hardness and relative low elongation.

For the involute groove, knowing the rigidity characteristic of the rolling machine (experimentally determined) it was determined a general machinability function for processing precision. The final form of this function for the three materials is presented in Table 7.

Table 4. The experimental plan for processing the helicoid surface.

Input variables				Output variables
d_0[mm]	*Material*	*F_{10} [kN]*	*v [m/min]*	*Geometrical characteristics of the profile*
17,24 / 17,30 / 17,36 $^{0}_{-0,002}$	OLC15	28	13,98	- diameters d, d_d, d_i
	17MoCr11	39		- profile pitch p
	OLC35	56		- profile angles of the tooth, α_s and α_d

Table 5. The experimental plan for involute surface processing.

Material	17MoCr11	OLC35	OLC15
Rack tool	m = 0,7938/1,045 mm; z = 20/24/28 teth; α = 30/37,5/45 °		
Rolling length	l = 10/20/40 mm		
Deformation depth	h = (1…1,3) m, depending on the gear geometry		

3. RESULTS AND DISCUSSION

The analysis of the effective geometric characteristics of the rolling helicoid area, presented in Table 6, allows the following conclusions:

- the profile of the roll tool is not copied as it is, resulting in significant deviations of the flank angles. They are more important for the steel with lower hardness and higher elongation (OLC15) than for the steel with higher hardness and lower elongation (OLC35). However, the differences between the flank angles (α_s and α_d) appeared due to the copy of the tool profile. The deviation of the profile pitch may be related to inaccurate adjustment of the roll tool (their axial positioning).

- the division diameter (d_d) and outside diameter (d) reach to values close to those prescribed to the profile only under certain conditions, Fig.7, which depend on the rolled material and the workpiece diameter:

- for OLC15 steel it is necessary a workpiece with a greater diameter than the average one;

- for OLC35 steel, the workpiece with average diameter ensure at the limit these

It could be noted that the groove module does not affect the dimension variation over rolls; this is explained by the closed values between the module could vary. To highlight the weighting of the other variables in the machinability function, it takes into account that, for a certain adjustment of workpiece-rack tool, the number of teeth z and the pressure angle α are provided by the construction of the tool. So, it was obtained a particular machinability function connected with the accuracy of processing, which depends on the rolling length ***l*** and the height of the manufactured tooth ***h*** (expression of the deformation depth). For the maximum values of the variables ***m***, ***z*** and ***α***, the expression of machinability function is presented in Table 8.

It could be observed that for all processed materials, the biggest influence on the variation rate of dimensions over the rolls has the rolling length and then the deformation depth. For example, an increase of the running length from 10 mm to 40 mm causes an increase of diameter variation over the rolls with 125 ... 150% for the three materials. At the same time, a better geometric precision is obtained in the processing of the carburizing steels (OLC 15 and 17MoCr11), in comparison with the OLC 35 steel, which diameter variation over the rolls is on average 150% higher than the other two materials. An explanation is that the rolling of materials with high hardness and low degrees of deformation determine deviations from the involute shape and from the symmetry of teeth flanks, that have the effect of increasing the thickness of the rolled tooth, leading to increased diameter over rolls.

4. CONCLUSIONS

The researches conducted has highlighted the fact that dimensional precision of the rolling profiles depends on the workpiece size, precision of the roll tools, the characteristics of the processed material and the processing scheme.

Table 6. Effective geometrical characteristics of the rolling helical surface.

Material	d_0	**d**	Δd	$\mathbf{d_d}$	Δd_d	$\mathbf{d_i}$	Δd_i	**p**	Δp	α_s	$\Delta\alpha_s$	α_d	$\Delta\alpha_d$
OLC15	17,24	**19.57**	0.06	**17.4**	0.03	**14.49**	0.01	**3.97**	0.02	**19.52**	0.2	**19.41**	0.77
	17,30	**19.74**	0.05	**17.46**	0.02	**14.49**	0.02	**3.96**	0.02	**20.1**	0.18	**20.35**	0.55
	17,36	**19.96**	0.02	**17.48**	0.02	**14.50**	0.01	**3.95**	0.01	**20.07**	0.12	**20.15**	0.17
17MoCr11	17,24	**19.63**	0.04	**17.48**	0.02	**14.48**	0.02	**3.95**	0.02	**19.46**	0.17	**20.01**	0.4
	17,30	**19.8**	0.04	**17.49**	0.01	**14.48**	0.01	**3.95**	0.01	**19.34**	0.12	**19.65**	0.2
	17,36	**19.96**	0.02	**17.49**	0.01	**14.49**	0.01	**3.95**	0.01	**19.28**	0.1	**19.47**	0.15
OLC35	17,24	**19.82**	0.03	**17.49**	0.01	**14.48**	0.01	**3.96**	0.01	**19.32**	0.08	**19.64**	0.13
	17,30	**19.95**	0.03	**17.5**	0.01	**14.48**	0.01	**3.94**	0.01	**19.49**	0.08	**19.81**	0.1
	17,36	**20.05**	0.02	**17.51**	0.01	**14.51**	0.01	**3.93**	0.01	**19.67**	0.07	**20.17**	0.08

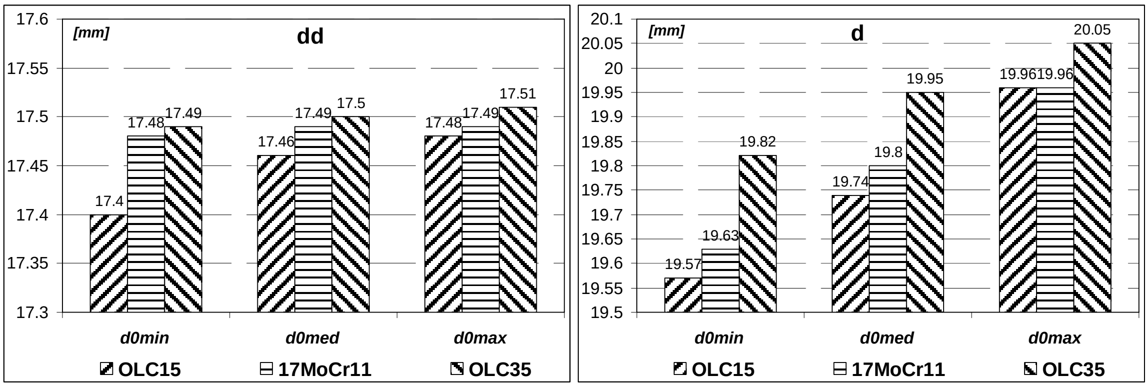

Fig. 7. The dependency between the division and exterior diameters, the type of the processed material and the workpiece diameter for the worms rolled.

Table 7. Machinability function connected with the processing precision.

Material	**Machinability function**
OLC15	$dDr = 0{,}0028\, z^{0{,}179}\ \alpha^{\ 0{,}179}\ l^{0{,}609}\ h^{0{,}333}$
17MoCr11	$dDr = 0{,}0117\, z^{0{,}013}\ \alpha^{\ 0{,}346}\ l^{0.588}\ h^{0{,}065}$
OLC 35	$dDr = 0{,}0031\, z^{0{,}012}\ \alpha^{\ 0{,}546}\ l^{0{,}662}\ h^{0{,}237}$

Table 8. Machinability particulary functions for the groove

Particular conditions for experimenting	Machinability function connecetd with the processing precision		
Groove module: m = 1,058 mm	OLC 15	17MoCr11	OLC 35
Number of teeth: z = 28 teeth Pressure angle: α = 45°	$dDr = 0{,}010 \cdot l^{0{,}609} \cdot h^{0{,}333}$	$dDr = 0{,}045 \cdot l^{0{,}588} \cdot h^{0{,}065}$	$dDr = 0{,}026 \cdot l^{0{,}662} \cdot h^{0{,}237}$

In summary, for a certain initial adjustment of workpiece-rack tool, the process variables with the most important influences on the parameter precision are considered the rolling length, the deformation depth and the nature of the processed material.

In principle, determination of the workpiece size is based on the volume constancy law. The relations determined for different types of profiles can not be applied directly, because it does not take into account the deformation scheme used, the deformed material properties and the effective dimensions of the rolling tool. Therefore, depending on the parameters listed above, there must be done some corrections of this dimension.

Taking into consideration the progress made in modelling and simulation processes of cold plastic deformation, the numerical modelling and simulation of the plastic deformation volume process is a viable perspective for completing the analysis and development of knowledge in the rolling of profiles, which will be studied within the research grant.

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