TECHNOLOGIES FOR PRECESSIONAL PLANETARY TRANSMISSIONS TOOTHING GENERATION

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Abstract: *Development of precessional planetary transmissions, in their evolution from conceptual idea to production, imposed the necessity of extending the area of scientific research in various fields, including the technological research, that can provide the manufacturer with the possibility of a low cost quality production, so that the product to be competitive on the market. Manufacture of any product, based on a new type of gear wheels mechanical transmission with teeth profiles different from the common profile and standardized, first of all, requires the development of a specific technology for teeth generation. In the absence of this important segment of technological design, the process of development and implementation of this transmission stops at the phase of idea.*

Keywords: planetary transmissions, multiplicity, profile convex-concave, technology, machine tools.

1. General Introduction

Development of a mechanical transmission gear different from the classical require complex research in various fields. This finding refers to precessional planetary gear transmissions multiparous [1,2], which is characterized by constructive and kinematic features essential. For solving complex problems related to "synthetic gear - – manufacturing profile study" is important to develop effective methods of manufacturing teeth, which ensures maximum productivity, reduced cost and quality.

Manufacture of gear wheels precessional convex-concave profile and variable tooth can not be achieved by existing generation technologies through technology but fundamentally new. Generation technology precessional wheel teeth must ensure continuity of movement transformation function under the following conditions: tooth profile is non-standard and variable and moving sfero-space satellite carried a fixed point. To this end we propose a new method for processing by the method of rolling teeth with precessional tool against revolving blank [2]. To develop the theoretical basis of tooth profile generation tool by running the precession is necessary to establish whether contact continuously tool cutting edge and tooth profile wheel worked full precessional cycle semi – tool. Thus was developed the mathematical model of the method of generating tooth by running the tool precession [2], which fully reflect real interaction teeth precessional transmission.

2. System generation technology teeth by moving sfero-space tool

2.1. Generation system kinematics teeth

To develop the method of generating tooth was built tool holder mechanism, principled scheme of which is shown in fig. 1. [1, 2]. The mechanism which causes the tool developed node sfero-spatial movement is stopped from rotating around the common axis spindle-workpiece by a kinematic joint connection. Rotating workpiece spindle 3 and 1 is coordinated kinematic chain of the machine tools division. Kinematic joint connection with the body of the tool should be constructed to ensure continuity function of transmitting rotary motion, so the motion continuity transformation function of rotation an analysis of the movement trajectory of point C, which belongs to mobile coordinate system. To examine the mechanism which causes the tool kinematics precessional motion. Satellite imaginary wheel (tool generates profile) 2 imaginary number of teeth Z_2 (determined by kinematics machine tools) enters three blank gear, fixed-gear machine table with number of teeth Z_2 $Z_3 = \pm 1$. At a speed spindle rotates one blank angle ψ 3, which corresponds to the angle contained by difference wheel teeth:

$$\psi_3 = \frac{2\pi}{Z_3}(Z_2 - Z_3). \qquad (1)$$

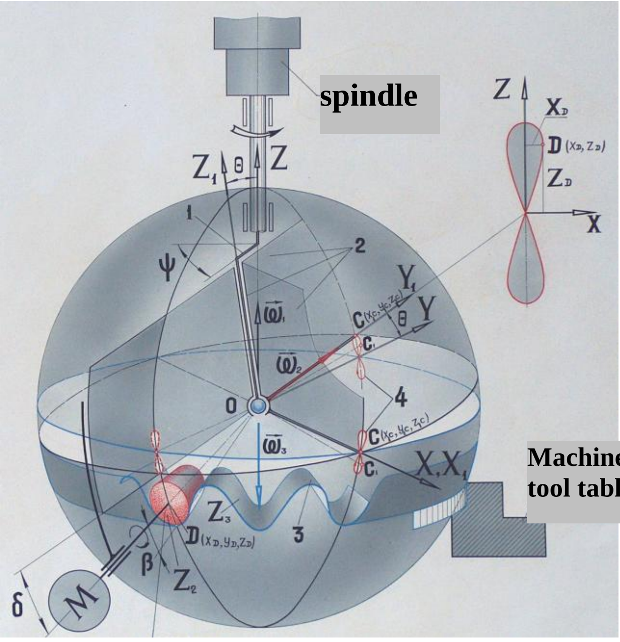

Figure 1. *Spatial scheme principled tool holder mechanism for processing method of teeth by running the tool precession.*

To establish function given position mechanism is needed to determine in advance the tool motion equations OXYZ building systems and mobile $OX_1Y_1Z_1$ coordinates. The link between the coordinates mentioned systems is established by Euler angles [2]. For if the point C is located OY_1 axis, its position is defined by coordinates $Z_1C = 0$, and becomes:

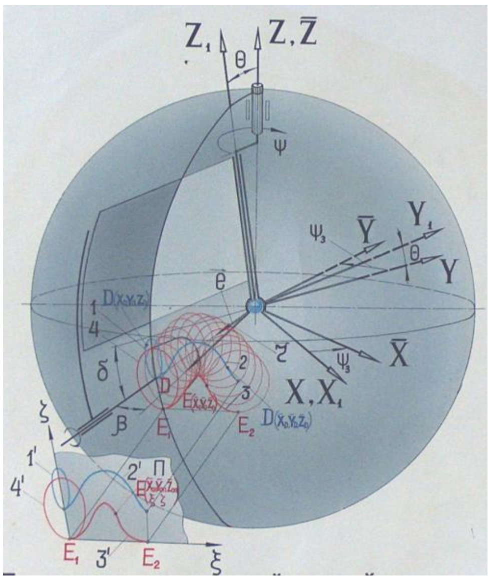

Figure 2. *Determination of the clearance surfaces family of precessional tool.*

$$\begin{aligned} X_C &= R_C(1 - \cos\theta)\cos\psi \sin\psi; \\ Y_C &= R_C\left(\sin^2\psi + \cos\theta\cos^2\psi\right); \qquad (2) \\ Z_C &= R_C \sin\theta \sin\psi. \end{aligned}$$

Equations (2) describe the edge of the grooved profile with limited finger movement rotation tool fixed axis OZ form a joint which provides condition i_{31} = const .. Achieving this technical solution is described in 2.4 p.

2.2. Description analytical tool path precessional motion

In accordance with the principle of generation scula moving teeth with sfero-spatial tool to copy with some precision bolt shape and motion trajectory in real gear (consisting of central toothed wheel - the wheel bolts-satellite). To explore the tool motion trajectory angle to the plane of location OX_1Y_1, $\delta \geq 0$. Tool axis was identified point D (Fig. 2) with coordinates X1D, Y_1D, Z_1D mobile coordinate system $OX_1Y_1Z_1$. Parametric equations of motion of point D in the mobile system of coordinates for i_{31} = const., Depending on the rotation angle ψ after a series of transformations:

$$\begin{aligned} X_D &= -R_u(1 - \cos\Theta)\cos\varphi\sin\varphi, \\ Y_D &= -R_u(\sin^2\varphi + \cos\Theta\cos\varphi), \qquad (3) \\ Z_D &= -R_u \sin\Theta\cos\varphi. \end{aligned}$$

Making just point D motion trajectory of the tool according to equation (3) was taken into account in drafting tool holder device shown in fig. 1.5.

2.3 Determination of the clearance of the tool generating contours family

Tooth profile is machined wheel contour envelope generator family of tool movement relative to the tooth [1,2]. Envelope is determined by the equations work surface and generating tool for coil relative motion parameters. To simplify the determination envelope goes to the coordinates of the tool center D cell coordinate system (Fig. 2), tied with blank 3 and the clearance equations described in coordinates X, Y, Z coordinate system OXYZ transcribe them into equations in two dimensions ξ and ζ in E_1 ξ ζ coordinate system (Fig. 2), related to the plan described by the equations

$$E_1E_2 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}$$
$$E_1E = \sqrt{\xi^2 + \varsigma^2} \qquad (4)$$
$$E_2E = \sqrt{(E_1E_2 - \xi)^2 + \varsigma^2}$$

From equation (4) we obtain the clearance equations in two coordinates ξ and ζ in E_1 ξ ζ coordinate system, which is generated tooth profile tool precession:

$$\xi = \frac{(E_1E_2)^2 + (X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2 -}{2E_1E_2}$$
$$\frac{-(X - X_2)^2 - (Y - Y_2)^2 - (Z - Z_2)^2}{2E_1E_2} \qquad (5)$$
$$\varsigma = \sqrt{(X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2 - \xi^2}$$

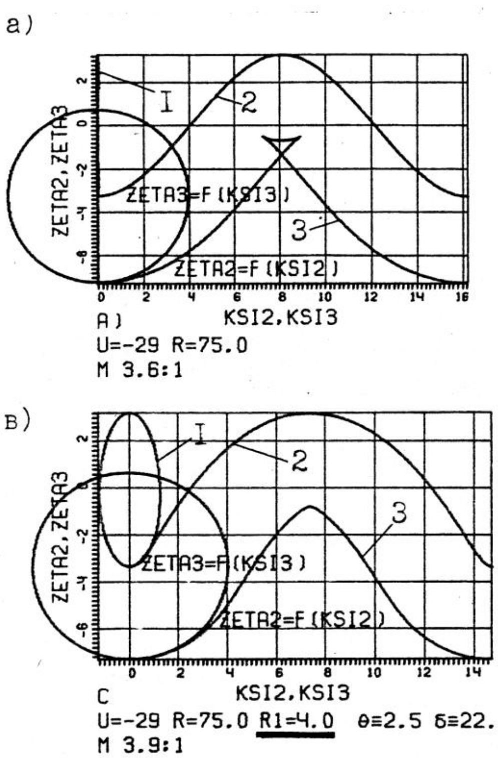

Fig. 1.3. *Profilograme of tooth profile generation with precessional cone shaped tool: 1, 2 - movement trajectories of the tool center in immovable coordinate system OXYZ and respectively mobile OX'Y'Z ', 3 - tooth profile, 4 - general contour of the tool .*

In fig. 1.4 are presented profilogramele tooth profile generation tool precessional executed with system modeling CAD / CAM / CAE / CATIA V5R7. On profilograme curve 1 (Fig. 1.4, a) is the tool center path movement building coordinate system OXYZ and motion trajectory curve 2 – mobile system tool center coordinates, curve 3 – tool envelope surfaces precessional family (tooth profile) curve 4 – outline generating.

2.4 Technological equipment for generating moving teeth sfero-space tool

Central wheel gear tooth profile precession varies depending on the angle b values conical angle of taper rollers, nutation angle, the number of sprocket teeth Z_1, Z_2 and the correlation between them [1, 2]. Manufacture these profiles by traditional methods is practically impossible because each correlation value of all the parameters and Z tooth profile changes shape, which requires the design and manufacture of tool profile.

For these reasons the proposed new generation technology that ensures the achievement of a set of teeth profiles using a tool with the same geometrical parameters. To achieve the new technology of generating convex-concave teeth and profile variable based on principled scheme for generating space by rolling the precessional tool, shown in Fig. 1 and the use of theoretical descriptions and technical solutions proposed in p 1.2.1-1.2.3, was developed construction tool holder device processing teeth (Fig. 4). The method consists of the following: tool (or cutter grinding geometric truncated cone shaped) shall receive a series of coordinated movements between them relative to the rotating blank. Using rolling powertrain gear grinding machine tool, gear blank and tool make a coordinated movement – rolling movement, which reproduces engagement with blank imaginary wheel. Every change basic tool position relative to the blank space in this part of the metal is removed.

Fig. 1.4. *Gear cutting machine-tool model 53A30P with the grinding device with tool disc shaped profile*

Therefore the working surface of the wheel teeth processed to obtain the envelope a consecutive series of positions of contour profile generator tool to the workpiece rotating. To achieve the necessary movements of the tool was developed tool holder device (Fig. 1.4), which can be adjusted gear grinding machines models: 5K32P53, 5330P, 53A50, 5A60, 5342, with accuracy class GOST 6-77.

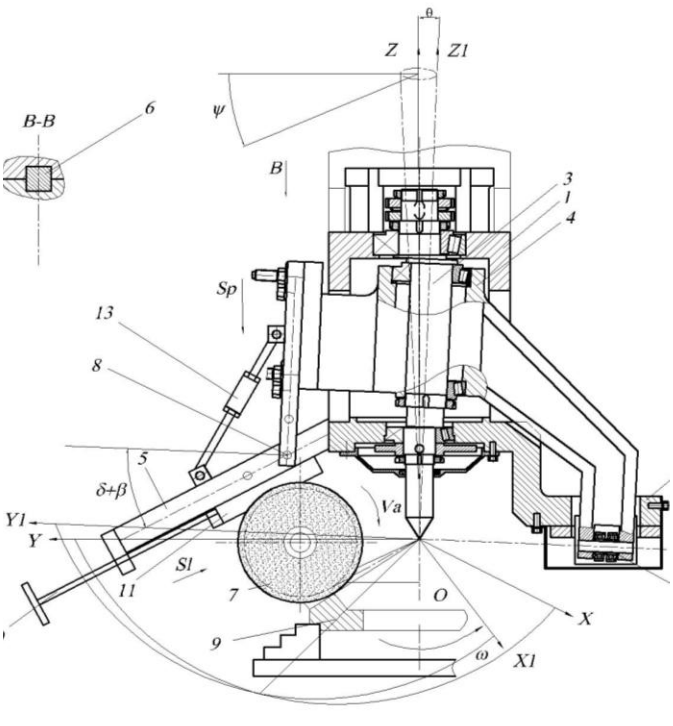

Fig. 1.5. *Device for generating teeth by grinding with a disc-shaped tool.*

The device (Fig. 1.5) includes a body 1, cross 2, 3 crank crank-shaft installed in the body 1, watch 5 by Which the advance is made along the tooth, grinding head with the tool 7, 9 blank fixed in the device on the machine tool table, stick 4 in Which the grinding head is fixed with the tool. *OXYZ* coordinate system is fixed and the mobile system is connected to the shaft $OX_1Y_1Z_1$-crank 3, *3;* ψ, θ, δ şi β is respectively the angles of precession, nutation, generator and taper cone tool. When rotating the major axis of the machine tool, connected to the shaft, crank 3, 7 installed on grinding tool or milling head (tool holder) is communicated a series of Coordinated Movements between Them, Which repeat cyclically at each rotation of the major axis. Grinding process CAN be done with ordinary tools or by using the tool 7 (Fig. 5), Consisting of three grinding wheels 14, 15, 16, Profiled the Interstate between Them That it is variable. The discs have Placed on the mandrel 17, spaced from washers 18 and attached with a nut 19. Tools 7 receives the movement from year engine rotation (on the figures not shown). The discs have Placed at year Greater Than the nutation angle angle Θ. Such a construction of the tool 7 allows us to ensure at processing the movement of grinding grains in the direction of tool axis. The area of cutting at a rotation of the tool changes ITS position, ie the rotation of the tool 7 with grinding wheels 14, 15, 16, every peripheral points of cuting Performance Areas along the axis of rotation motion of the tool 7. Due to the movement of the cutting edges of the disks 14, 15, 16, there is a grinding Due to this movement of the cutting edges of the disks 14, 15, 16, there is a correction to break with time, leading to a temperature Decrease in the area of cutting compared to the traditional. In the process of correction with Such tool has not burnt and cracked surfaces Shown. Angle of inclination of discs 14, 15, 16 allows us to Increase the number of grinding grains That Participate in cutting. At traditional correction Participate at cutting about 5 ... 15% of the granules. Flexible shares of discs, no matter of semi-normal force, work under variable pressures. If the tool performs the movement of precession, flexible elements consecutive contacts with the tooth profiles, working it alternately in different parts. At the combined cutting with the grain movement in the longitudinal and axial direction is formed a network of traces and year microrelief analog to the Rectification with one Vibratory motion. Such a process of productivity is 2-5 times higher Than the usual of grinding. At the same time the grinding tool wear 7 is Reduced with 30%.

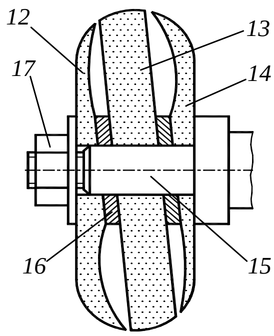

Fig. 6. *Profiled tool composed of 3 discs wth variable interstice.*

3. Experimental researches methodology

The researches were performed on a gearing machine 53A30P modified to grind gears. Some technical characteristics of this machine tool are the following: number of up-and down strokes

$n=100 – 315\ min^{-1}$, the size of the table speed p_o = 80 – 800 mm/min. The accuracy characteristics of machine tool were determined in accordance with the rules included in the standards GOST 8001-78 and GOST 13 142-90.

The feed motion necessary to establish the set up the grinding wheel penetration was achieved by rotating the wheel of the screw mechanism. The machine tool was endowed with a device for dressing the abrasive wheel. As abrasive wheel, the disc type ПО having the diameter D = 20 – 100 mm and the width H=5 – 15 mm and abrasive granules 99A were used; the granule hardness was of 60-80, the disc hardness H, I, J, K, L, M; the structure was 5, 7, 8, 25, and a binder type V, was used.

The abrasive disc hardness was determined by the method Grindo-Some.

The dynamic equilibration was determined on the machine K300BR Rava Torno. The size of the balance accuracy was of 1 μm. The rotation speed during the equilibration was of 1000 min^{-1}. The abrasive disc was dressed after the grinding of each gear; the dressing depth of cut was of 0.05 mm and the speed was of 0.1 mm/min.

Teeth of conical gears with not standard profile were grinded; the tooth height was h=10-15 mm, the number of teeth z=20-32, the tooth length b=10-25 mm, the workpiece materials were the steels 40H, 45H, 20H2N4A, the material hardness was of 40-62 HRC.

The grinding wheel penetration was of 0.03 – 0.12 mm, and the side machining allowance was of 0.12-0.35 mm.

As work liquid, the oil emulsion ER, with a report of 1:40, transported in the grinding zone with the speed of 15 dm^3/min and a pollution admissible size of 40 μm/l was used.

The residual stresses appeared in the external layer of the gears teeth were studied by means of the Roentgen method. The surface layer was dissolved by the electrochemical method (65 % H_3PO_4 solution, electrolytic density 8-8.2 A), with ulterior measuring of the residual stresses (evaluated by the Roentgen method sin 2φ, on difracotmeter 1130, goniometer PW 1050, produced by the company AMR, goniometer HZG3 and registration apparata.

The hardness, microhardness, surface roughness and the metallographic aspect were studied. For studying the state of the external layer, the following apparata were used: universal device for gear teeth measuring Carl Zeiss Jena, with optical transducer, measuring accuracy size being of 1 μm, universal evolventmeterVG450, produced by the same company and having the measuring accuracy of 0.001 mm, the measuring rolls type MLCbA and micrometer type Mm CC, with measuring accuracy of 0.002 mm, profilometer Carl Zeiss type ME-10, hardness measuring device type Rockwell (Kabial Press) and, respectively, PRL-510, metallographic microscope Neophot -2 with device for measuring the hardness type PMT-3 and microscope-scanner type IDOL.

3.1. The influence exerted by the oscillations generated during the grinding process on the residual stresses from the external layer of the gears teeth

In the technological system, the oscillations are generated not only by the disequilibrium of the abrasive wheel, but also by the reaction or by the insufficient action of the tool. To obtain adequate properties of the external layer, the disequilibrium of the grinding disc must have a limited size. The disequilibrium generates the increasing of the tooth machined surface roughness and waviness and it decreases the physical properties of the external layers of the teeth, by increasing their non uniformity.

The residual stresses appeared in the teeth surface layers generate essential modifications of the sizes of the tensile stresses at the tooth base and of compressive stresses at the tooth top.

Studying the micro hardness modifying in correspondence with the tool disequilibrium, one can notice that the layers with diminished hardness appear in a direction parallel to the direction of the quenched layers. The maximum diminishing of the disc disequilibrium can significantly reduce the shape and dimensional errors which appear in the transversal and longitudinal section and, of course, can determine the obtaining of more favorable physical and chemical properties in the external layer of the grinded tooth.

But not only the disequilibrium exerts a great influence on the machining results; other factors specific to the rolling method with abrasive disc can be considered.

The system grinding disc – machined piece is characterized by the accumulation of the deforming energy and this fact influences the abrasive binder resistance, which can be influenced by the frequency of the free oscillations.

For the grinding process, the parametrical oscillations, defined by the action of the summarized cutting components (normal and tangential) during the grinding process and by the dynamic rigidity of the system.

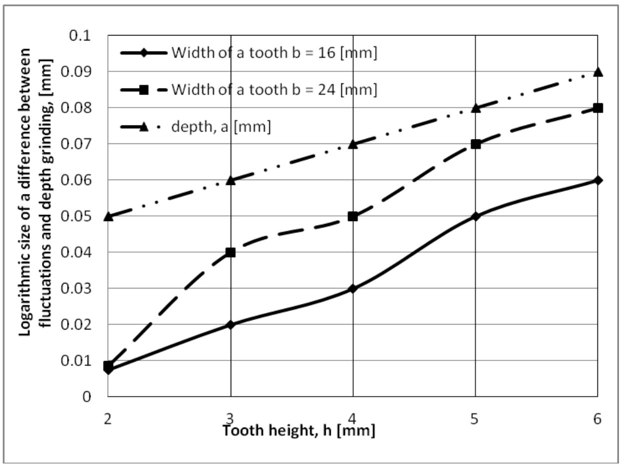

Fig. 7. *Distinction between the set depth (a) and variable depth of grinding as a result of influence of amplitude of fluctuation*

One established that the sinusoidal relative motion of the grinding disc and of the machined gear is accompanied by the modifying of the cutting forces in the normal and tangential direction and sinusoidal modifying of the grinding force amplitude can be noticed. The forces generate the increasing of the oscillations frequency as result of the thickness of the layer removed during the grinding process and of the diminishing of the abrasive disc volume.

In the point of contact between the abrasive disc and the gear tooth, the composed motions of the grinding disc appear as result of the sum of the motion components. This motion offers an image about the system oscillations.

In figure 7, the modifying of the grinding wheel penetration (determined by the modifying of the oscillations amplitude during the grinding process) can be observed.

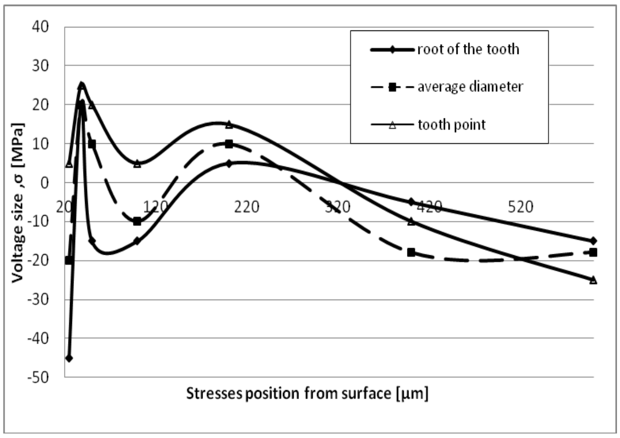

Fig. 8. *Influence of amplitude of fluctuation on size and sing on residual pressure*

The modifying of the grinding wheel penetration, determined by the variation of the oscillations amplitude, showed that this modifying of the wheel penetration during the grinding depends on the size of the tooth height and on the width of the gear tooth. Thus, the bigger gear mass is, the bigger the modifying of the amplitude size is. If the amplitude of the oscillations is bigger than the grinding wheel penetration during the grinding process (fig. 7), then a zone where the grinding disc does not remove the metallic material and only a friction of the grinding disc of the gear tooth surface occurs.

For this reason, the selected size of the grinding wheel penetration must be bigger than the size of the oscillations amplitude. In this case, one can know that the tooth height and the gear width must be bigger than the sizes presented in the figure 1. Then, one could be sure that a grinding process and not a simple friction process develops. This fact has an essential importance from the point of view of the gear machining accuracy and of the burned zone as consequence of the grinding process and, simultaneously, of the generating the big internal residual stresses in the gear surface layer in the case of gears obtained by the rolling method . The distribution, the character and the modifying of the residual stresses are used to appreciate the state of the gear tooth state (fig, 8).

The researchers showed that the residual stresses generated in the surface layer of the gear tooth are tensile stresses on the tooth height.

Firstly, on a thickness of 25 µm, there are compressive stresses; at a depth of 39 µm, these stresses are transformed in tensile stresses. At a depth of 50 µm, there are tensile stresses and at the root of tooth there are compressive stresses. The changes of the residual stresses are determined by the modification of the metallic material volume; at the tooth basis, this volume modification is bigger.

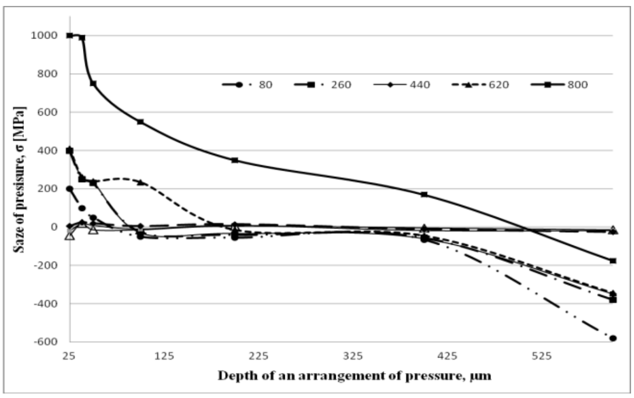

Fig. 9. *Influence of disttrict giving on residual in a blanket of teetks*

At depths of about 100 μm, there are compressive stresses, while along the tooth flank there are tensile stresses and the size of these stresses is of about 10 MPa. If the grinding wheel penetration increases, the compressive stresses become dominant and there is its increasing trend.

On can notice that the size of the stresses in the surface layer at the root of tooth are smaller than the sizes of the stresses at the tooth head or at the zone of passing from the concave zone to the convex zone; this shows that the oscillations amplitude is in connection with the wheel penetration at grinding and with the residual stresses.

The oscillations frequency and the size of the feed have an important role; this fact is proved by experiments made by the rolling method with a disc having a conical shape. The increasing of the feed size determines the increasing of the amplitude size. At its turn, the size of the amplitude exerts influence on the oscillations frequency in the contact zone between the tool and the machined workpiece. If the oscillations amplitude has a significant influence in comparison with the wheel penetration, then the influence of the friction increases and plastic and elastic deformations could appear. This fact generates the increasing of the temperature and, as result, tensile stresses appear in the external layer of the gear teeth.

3.2 Influence of the grinding conditions on the characteristics of the external layer

The influence of the up-and down strokes number of the grinding disc, of the rotative feed of the table, of the tool and of the wheel penetration on the residual stresses in the external layer of the gear teeth was studied. The influence of the double strikes number of the tool (n_s) is significantly reflected in the tensile stresses at a depth of about 100 μm.

If the number of up-and down strokes of the grinding disc increases, the size of the tensile stresses diminishes and compressive stresses appear. The residual stresses diminish at the increasing of the disc up-and down strokes number and the depth of their position decreases, too and the compressive stresses take their place. This fact is determined by the increasing of the grinding disc speed in contact with the grinded surface of the gear teeth, which diminishes the quantity of heat delivered and a positive effect can be noticed on the faster cooling of the teeth external layer. As result, an increasing of the compressive stresses occurs at big depths of cut.

The influence of the table rotative feed on the residual stresses in the external layer of the gears teeth is expressed by the fact that, so the experiments showed, simultaneously with the increasing of the rotative feed, the size of the residual stresses increases, too (fig. 9) and at a depth of about 100 μm, there are compressive stresses.

The size of the residual stresses is variable along the layer depth. At the increasing of the layer depth, the size of the tensile residual stresses diminishes and, at a depth of about 100 μm, the residual stresses become tensile stresses. At a table rotative maximal feed p_0=800 mm/min, the size of the tensile stresses diminishes, transforming themselves into compressive stresses and their maximal size is reached at a bigger depth. This fact proves the significant influence of the heat (developed in the zone of contact between the grinding disc and the machined tooth), whose importance was emphasized by. Tensile stresses appear, but their size diminishes at the increasing of the table rotative feed size (fig. 9).

Taking into consideration the big tensile residual stresses generated at a maximal size of the feed, one must avoid their using due to the size and positioning of these stresses in the external layer. Thus, by diminishing the size of the rotative feed size, the size of the tensile stresses (which are in connection with the structural changes) in the external layer diminishes, too.

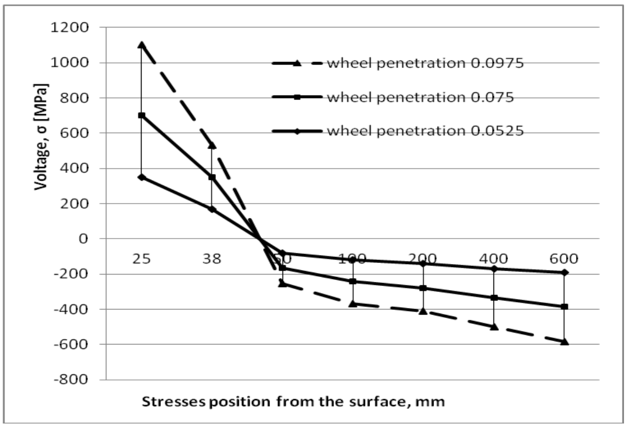

Fig. 10. *Influence of the rottion feed on thesize of the residual stresses exting in the surface layer of the gears teeth*

The influence of the grinding wheel penetration on the generating the initial stresses in the external layer of the gears teeth is reflected by the increasing of the stresses size. The character of the residual stresses changes along the layer depth is the same at the grinding with different depths of cut in the field of 0.05 to 0.1 mm.

These are surface tensile stresses and they diminishes from 400 MPa to 0 on a depth of about 500 mm from the surface (fig. 10). This fact occurs due to the heat influence and, on the other hand, due to the variation of the cutting forces.

The heat generates structural changes in the external layer and this fact determines the appearance of the tensile residual stresses, which can be observed at small depths of cut.

If the grinding wheel penetrations are bigger in the external layer of the gear teeth, residual stresses of not too big size can be signalized. If the wheel penetrations are big, the residual stresses become compressive stresses (fig. 11 and 12). They have the same character along the toot height and at the root of tooth. But for small grinding wheel penetrations,

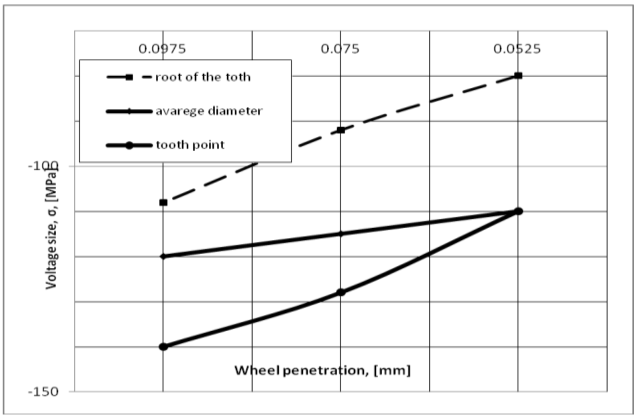

Fig. 11. *Distribution of residual presure in a bilaket after grinding on depth h=0,2 mm*

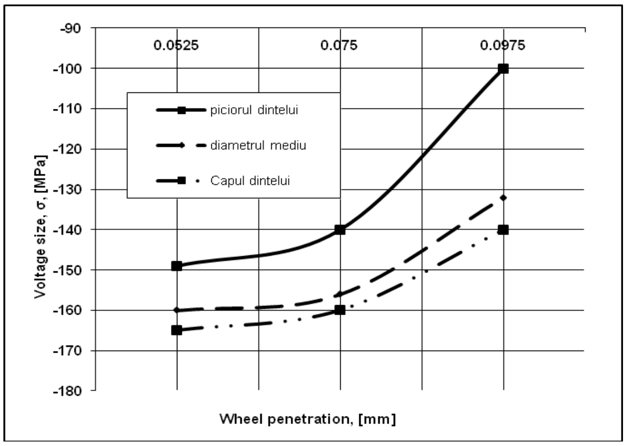

Fig. 12. *Distribution of residual presure in a bilaket after grinding on depth h=0,4 mm*

the size of the compressive stresses is smaller and it increases when the depth of their emplacement in the external layer increases, too. As consequence of the residual stresses analysis along the tooth height, the smallest compressive stresses were observed in the zone corresponding to the average diameter, not depending on the grinding wheel penetration.

The increasing of the compressive stresses occurs more intensively in the external layer of the root of the gear tooth (fig. 11 and 12). The size of these stresses increases when the wheel penetration increases, too, due to the bigger volume of the material removed from the tooth surface, but also to the considerable increasing of the cutting forces. As result of the increasing of the volume of metallic material removed from the tooth surface (from the root of tooth), a more rapid penetration of the heat on the depth of the metallic layer occurs and this fact generates the increasing of the residual stresses.

4. CONCLUSIONS

The hypothesis concerning the changes of the outer layer properties and the structural changes developing during the grinding process were proved. The changes refer to the microstructure of the grinded outer layer, to the width of the crystalline line and to the dimensions of the "crystal mosaic".

References

[1] BOSTAN, I. *Precessionny'e peredachi s mnogoparny'm zacepleniem:* [monogr.]. Red. S. SUVALOVA. Ch.: Ştiinţa, 1991. 355 p.

[2] Antologia invenţiilor: [în 4 vol.]. Vol. 2; Transmisii Planetare Precesionale / I.Bostan, V. Dulgheru, S. Mazuru [et. al]. – Ch.: "Bons Offices" SRL. 2011. -542 p.- ISBN 978-9975-80-283-3.

[3] Bostan I., Mazuru S., Vaculenco M., Scaticailov S. Issues technology manufacturing precessional gears with nonstandard profile generating. IX international congress "Machines, Technologies, Materials 2012", Varna, Bulgaria. 2012, Vol. I. ISBN-1310-3946.

[4] Mazuru S. System reliability and optimization processing parametrs for its accuracy of elements. First part. The 14th International Confercence Modern Tehnologies, Quality and Innovation. ModTech 2009, 21-23 May, 2009 Slănic Moldova Romania.