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NORWEGIAN JOURNAL OF DEVELOPMENT OF THE INTERNATIONAL SCIENCE

№83/2022

Norwegian Journal of development of the International Science

ISSN 3453-9875

It was established in November 2016 with support from the Norwegian Academy of Science.

DESCRIPTION

The Scientific journal "Norwegian Journal of development of the International Science" is issued 24 times a year and is a scientific publication on topical problems of science.

1000 copies

Norwegian Journal of development of the International Science

Iduns gate 4A, 0178, Oslo, Norway

email: publish@njd-iscience.com

site: http://www.njd-iscience.com

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PHILOLOGICAL SCIENCES

PHILOSOPHICAL SCIENCES

PHYSICAL SCIENCES

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DEVELOPMENT OF METHODS OF EXPERIMENTAL AND ANALYTICAL RESEARCH OF METAL FLOW IN THE CENTER OF DEFORMATION OF ALUMINUM ALLOYS DURING COMBINE PARTS ROLLING

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Abstract

It is proved that the efficiency of grain harvesting equipment decreases after three or four harvest periods, which leads to increased downtime and, consequently, partial crop losses. To increase the reliability of combines, high-quality production of the most worn transmission parts is required. For this purpose, an experimental-analytical method of studying the flow of metal in the deformation center in the transition and steady zones during rolling of workpieces, taking into account the development of deformation over time, during their volumetric deformation, is proposed.

Keywords: ductility, deformation, metal flow.

Introduction

Because of the growing need for expensive steels that are difficult to deform, titanium, magnesium alloys, the research of non-uniformity is very important. Due to their mechanical, physical and technical properties, they are widely used, not only in mechanical engineering, but also in the agricultural production of machinery and equipment for crop and livestock production.

The use of hot deformation reduces the effort, which increases the ductility of alloys. In the absence of zones of difficult deformation and local overheating, comprehensive restoration of the metal structure takes place.

Grain harvesting equipment consists of a large number of standard mechanisms that are necessary for harvesting cereals and other crops, such as sunflower, corn, soybeans, canola, buckwheat and sugar beets [1, 2].

Breakdown and downtime of a combine harvester in the field entails delay of harvesting process, violation of the delivery terms, and also may result in partial or full loss of a crop harvest. Therefore, the problem of the reliability of grain harvesters remains topical, especially for those combines that have worked for several seasons.

The experimental research conducted by the authors [3, 4] revealed that the coefficient of readiness, as an indicator of the technical condition of combines such as "DON-1500", begins to decline after about 500-600 hours, which corresponds to the time of two harvests, and for combines produced by the world leading companies – after operating 1200-1400 hours. That is, combines work steadily for three or four seasons.

To increase the reliability and durability of Ukrainian combines, a comprehensive approach at all stages of their production and assembly is required. The development and implementation of the latest scientifically substantiated processing methods, working out traditional methods of manufacturing heavy-duty parts of agricultural machinery will allow reaching a new level of efficiency and reliability of their operation [5, 6].

It will reduce downtime, change the technical condition of combines with increasing service life. This, in turn, should decrease crop losses, which depend on the productivity of the machinery.

One of the methods of manufacturing heavy-duty parts of combines such as shafts, transmission parts is the method of hot rolling, which produces profiles of different shapes and sizes for further machining.

To obtain workpieces with given mechanical characteristics in this way, it is necessary to follow the laws of metal flow in the center of local deformation, which depend on the geometry of the gauges, the speed of the workpiece, the amount of compression, etc. [7, 8].

During the development of technological processes of metal forming, questions arise on the determination of effort, energy consumption, selection of optimal technological parameters of deformation, indication of non-uniformity of deformation, etc. To solve these complex problems, various methods of metal forming research are used, which are divided into analytical, experimental and experimental-analytical ones [9, 10].

Analysis of recent research and publications

A special place in the theory of rolling is occupied by the movement of metal in the deformation center. The development of rolling requires the disclosure of patterns and physical essence of the phenomena occurring during the deformation of the metal in the center of deformation.

In [9], a review of the research of metal flow in the deformation center is described by analytical and experimental-analytical methods. Thus, A. Hollenberg drilled holes in the middle of the width of the strip, into which he pressed rods. A. Hollenberg judged the movement of metal in the center of deformation by the nature of the curvature of the rods. N. Metz replaced the smooth rods with screws, which made it possible to determine the distribution of deformation along the height of the strip by changing the pitch of the screw. In addition, he applied a coordinate grid on the side surfaces of the strip. Observation of the curvature of screws or rods after rolling can only provide an approximate quantitative estimate of the distribution of deformation in the deformation center. The violation of the integrity of the pumped metal is the disadvantage of this method. W. Trinks made lead strips from two halves, on the surfaces of which he applied vertical lines with a cutting tool. To detect the flow of metal in the center of the strip, these lines were filled with paint, after which the halves of the sample were soldered in several places at the coincidence of the lines on the side surface and in the middle of the sample. G. Ungel used composite samples to determine the flow of metal in the deformation center. M.L. Zaroshchynskyi judged the nature and distribution of deformation by the curvature of screws and lines on the side faces; the length of the adhesion zone was determined by measuring the distances between the lines on the contact surface of the deformation center on the strip braked in the rolls. O.H. Muzaliovskyi studied the flow velocities of metal in the deformation zone by moving the coordinate grid during hot rolling of aluminum alloys by the method of high-speed filming. T.M. Golubiev studied the movement of separate layers of metal on a lateral surface of lead samples with a device of an original design. The device made it possible to graphically depict the movement of the points of the sample, taken at different heights in one plane of the cross section, and flow velocities were plotted according to the obtained data. T.M. Golubiev used two methods to determine the boundaries of the adhesion zone on the contact surface: samples of colored plasticine were rolled in rolls of transparent material with lines along the generatrix, applied at a certain distance from each other; the plastic sample with the lead needles inserted into it was illuminated by X-rays in the course of rolling. The Ural Institute of Ferrous Metallurgy used layered lead samples with a printed grid in the research of the metal flow in the deformation center. A.I. Kolpashnikov conducted significant and original research in the field of determining the flow of metal in the center of deformation. The research was carried out by the methods of filming and recrystallized grain when rolling aluminum alloys AMC and D16 with a slight expansion, which was not taken into account. The limits of the actual deformation center, the length and position of the adhesion zone, the nature of the velocity distribution in wide, thin and thick workpieces under different conditions of deformation – degrees of deformation, rolling speeds and lubrications were determined.

The theoretical analysis of metal forming processes is carried out by different methods, each of which is characterized by certain possibilities and limitations.

In [11] it is emphasized that the study of issues related to determining the patterns of metal movement during rolling of workpieces depending on various factors influencing the unevenness of deformation (shape and size of gauges, speed and degree of deformation, the ratio of geometric shapes of gauge and rolled workpiece, edging in the rolling process, etc.) will make it possible to improve the quality of the deformed metal: to avoid a flash at rolling, to reduce unevenness of deformation or to obtain a profile with the set unevenness of deformation, to improve the structure of metal and mechanical properties of a profile.

It should be noted that the non-uniformity of the metal flow process is the result of different concentrations of plastic deformation in its volume. The non-uniformity of deformation can be determined by studying the nature of the movement of the metal in the research area, choosing for this purpose one of the above methods, which are widely covered in the literature on the theory of metal forming.

Formulation of the problem

Due to the growing need for the use of expensive steels that are difficult to deform, titanium, magnesium alloys, the study of non-uniformity is very important.

The analysis of the above methods revealed that the correct choice of the actual resistance to deformation and boundary conditions on the contact surfaces of the tool is especially important for solving the metal forming problems depending on their class.

As can be seen, the theoretical analysis of metal forming processes is given much attention, a significant number of analytical and experimental-analytical methods for determining the deforming forces and deformations, the nature of the movement of the metal during deformation are developed. These methods are successfully applied depending on the necessary conditions in solving flat and axisymmetric problems. However, they do not allow determining the movement of metal in the center of the researched area (deformation center) and the non-uniformity of deformation depending on the geometric ratios of the caliber and the rolled workpiece when solving problems in three-dimensional space (volumetric problem).

This shortcoming is eliminated by the method developed by DSc (Eng.) S.O. Skryabin on the basis of deformation theory of plasticity, application of imaginary coordinate grid, method of finite differences and variable parameter of elasticity, method of theoretical research of metal flow process during rolling of volume deformation workpieces in deformation center with arbitrary contour and discretely set boundary conditions [12-14].

The method makes it possible to reveal the pattern of metal movement in the researched area both for steady (deformation under constant compression) and unsteady (deformation with increasing or decreasing deformation) processes of hot deformation, to determine the non-uniformity of deformation depending on the ratio of geometric shapes and gauges as well as the area of possible concentration of stress.

Material and methods of 3D problems of plasticity theory

The stress state of a deformed body is determined by the stress tensor:

$$\mathrm{T}_{\sigma}=\begin{Vmatrix}\sigma_{x} & \tau_{xy} & \tau_{xz}\\ \tau_{yx} & \sigma_{y} & \tau_{yz}\\ \tau_{zx} & \tau_{xy} & \sigma_{z}\end{Vmatrix}, \quad (1)$$

whose components meet balance equations

$$\begin{cases}\dfrac{\partial\sigma_x}{\partial x}+\dfrac{\partial\tau_{xy}}{\partial y}+\dfrac{\partial\tau_{xz}}{\partial z}+X=0;\\ \dfrac{\partial\tau_{yx}}{\partial x}+\dfrac{\partial\sigma_{y}}{\partial y}+\dfrac{\partial\tau_{xz}}{\partial z}+Ó=0;\\ \dfrac{\partial\tau_{zx}}{\partial x}+\dfrac{\partial\tau_{zy}}{\partial y}+\dfrac{\partial\sigma_{z}}{\partial z}+Z=0,\end{cases} \quad (2)$$

where *X*, *Y*, *Z* —the components of external forces.

Body deformation is determined by the deformation tensor:

$$T_{\varepsilon}=\begin{Vmatrix}\varepsilon_x & \frac{1}{2}\gamma_{xy} & \frac{1}{2}\gamma_{xz}\\ \frac{1}{2}\gamma_{yx} & \varepsilon_y & \frac{1}{2}\gamma_{xz}\\ \frac{1}{2}\gamma_{zx} & \frac{1}{2}\gamma_{zy} & \varepsilon_y\end{Vmatrix} \quad (3)$$

The components of the deformation tensor can be calculated if vector $\overline{u}$ (u,υ, w) of displacement of arbitrary point of the deformed body is known via formulas:

$$\varepsilon_x=\frac{\partial u}{\partial x};\ \varepsilon_y=\frac{\partial \upsilon}{\partial y};\ \varepsilon_z=\frac{\partial w}{\partial z}; \quad (4)$$

$$\gamma_{yz}=\frac{\partial w}{\partial y}+\frac{\partial \upsilon}{\partial z};\ \gamma_{zx}=\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x};\ \gamma_{yx}=\frac{\partial \upsilon}{\partial x}+\frac{\partial u}{\partial y}.$$

In the linear theory of elasticity, the components of the displacement vector, as well as their derivatives, are small quantities, the squares of which and their derivatives can be neglected.

The calculation of the components of the deformation tensor by formulas (3, 4) is possible only with an accuracy up to constants [15, 16], i.e. with an accuracy of rigid displacement of the body as a whole. The components of deformation T_ε and stress T_σ tensors are interconnected by the relations of Hooke's law.

In the case of a homogeneous isotropic body, they are of the following form:

$$\begin{cases}\sigma_x=\lambda\theta+2\mu\varepsilon_x; & \tau_{yz}=\mu\gamma_{yz};\\ \sigma_y=\lambda\theta+2\mu\varepsilon_y; & \tau_{zx}=\mu\gamma_{zx};\\ \sigma_z=\lambda\theta+2\mu\varepsilon_z; & \tau_{xy}=\mu\gamma_{xy},\end{cases} \quad (5)$$

where $\theta=\varepsilon_x+\varepsilon_y+\varepsilon_z=\dfrac{\partial u}{\partial x}+\dfrac{\partial \upsilon}{\partial y}+\dfrac{\partial w}{\partial z};$

λ, μ— Lame's elastic constants.

The basic equations of statics of an elastic body can be written in displacements (Lame's equation), substituting formulas (5) in equilibrium equation (2) and using relation (4):

$$\begin{cases}(\lambda+\mu)\dfrac{\partial\theta}{\partial x}+\mu\nabla^2 è+\tilde{O}=0;\\ (\lambda+\mu)\dfrac{\partial\theta}{\partial y}+\mu\nabla^2\upsilon+Ó=0;\\ (\lambda+\mu)\dfrac{\partial\theta}{\partial z}+\mu\nabla^2 \mathrm{w}+Z=0,\end{cases} \quad (6)$$

where $\nabla^2=\dfrac{\partial^2}{\partial x^2}+\dfrac{\partial^2}{\partial y^2}+\dfrac{\partial^2}{\partial z^2}$.

As the direction of coordinate *OZ* includes deformation elongations ε_z, and hence displacements *w*, these components are determined from Hooke's generalized law

$$\varepsilon_x=\frac{1}{E}(\sigma_x-\nu\sigma_y);\ \varepsilon_y=\frac{1}{E}(\sigma_y-\nu\sigma_x);$$

$$\varepsilon_z=\frac{\nu}{E}(\sigma_x+\sigma_y);\ \gamma_{xy}=\frac{2(1+\nu)}{E}\tau_{xy},\ G=\frac{E}{2(1+\nu)} \quad (7)$$

where *E* –Young's module, ν –Poisson's ratio,

Lame's differential equations under incompressibility εx+εy+εz=0 are expressed by the following formulas:

$$\begin{cases}(\lambda+\mu)\dfrac{\partial\theta}{\partial x}+\mu\nabla^2 è=0;\\ (\lambda+\mu)\dfrac{\partial\theta}{\partial x}+\mu\nabla^2\upsilon=0;\\ \dfrac{\lambda}{2\mu+\lambda}\left(\dfrac{\partial è}{\partial \tilde{o}}+\dfrac{\partial\upsilon}{\partial ó}\right)z+\mathrm{w}=0.\end{cases} \quad (8)$$

The conditions of the deformed workpiece contour are written down in the form:

$$P_{x\nu}=\sigma_x\cos(\nu,x)+\tau_{xy}\cos(\nu,y),$$
$$P_{y\nu}=\tau_{yx}\cos(\nu,x)+\sigma_y\cos(\nu,y). \quad (9)$$

Using geometric equations:

$$\varepsilon_x=\frac{\partial u}{\partial x};\ \varepsilon_y=\frac{\partial \upsilon}{\partial y};\ \varepsilon_z=\mathrm{w}\frac{1}{z};\ \gamma_{xy}=\frac{\partial u}{\partial y}+\frac{\partial \upsilon}{\partial x},$$

and the equation of deformations continuity

$$\frac{\partial^2\varepsilon_x}{\partial y^2}+\frac{\partial^2\varepsilon_y}{\partial x^2}=\frac{\partial^2\gamma_{xy}}{\partial x\,\partial y}, \quad (10)$$

we get eight equations with eight unknowns. This system is closed and can be solved by different methods (force method, displacement method, mixed method).

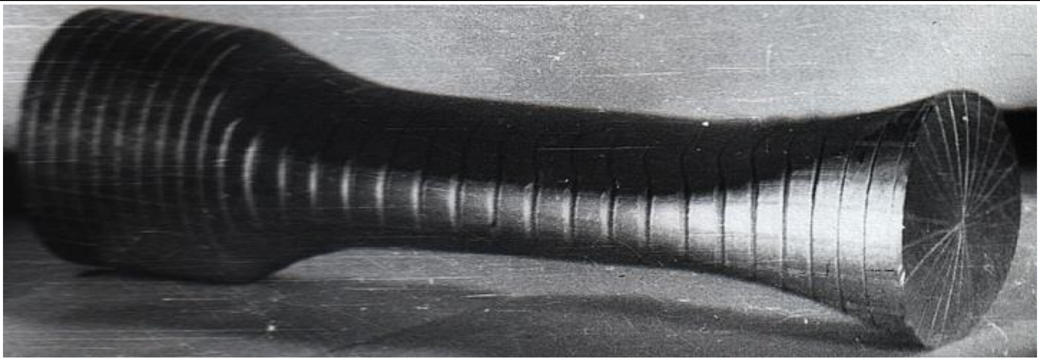

Fig.1 –A sample after rolling with increasing and decreasing compression

For a clearer representation of the non-uniformity of the deformation distribution, this problem was solved by the method of displacements. To determine the boundary conditions on the end and the surface of the workpiece Ø 50 × 150 mm from the alloy AK6 a 5 × 5 mm grid was applied, which after deformation of the workpiece – the sample was used to determine the displacements on the surface of the researched area, Fig.1.

The samples consisted of several diameters with an applied grid, Fig.2. The displacements of the grid point on the deformed samples after rolling were measured with a large instrumental microscope VMI-1. The measurement error did not exceed ± 0.005.

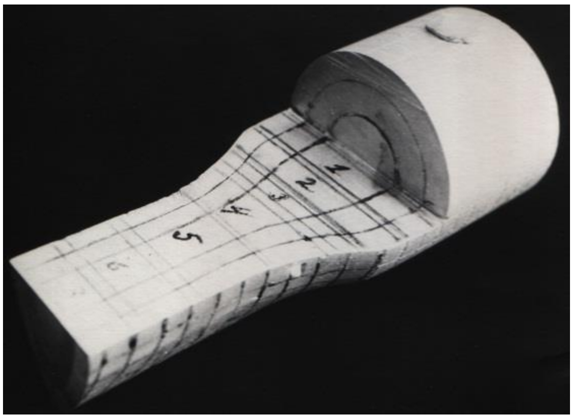

Fig. 2 –A sample consisting of several diameters with an applied grid

Research of metal flow in transition and steady zones during rolling of workpieces in the deformation center, taking into account the development of deformation over time.

The development of a method for the theoretical research of the flow of metal in the transition and steady zones during the rolling of workpieces in the center of deformation, taking into account the development of deformation over time, is a further development of the theoretical method for studying the flow of metal in the center of deformation during volumetric deformation worked out by DSc (Eng.) Skryabin S.O. [11, 16-18]. The method described in these papers was taken as a basis for the theoretical research of the process of metal flow during volumetric deformation of workpieces in calibers. The research problem is solved in stages: the elastic problem as the first approximation to the elastic-plastic one, the elastic-plastic problem for small plastic deformations. The nature of the movement of the metal in the calibers is described using the finite difference method and a variable parameter.

To solve the volumetric problem by determining the process of metal flow in the deformation center, the following conditions were adopted:

- in the plastic area of the deformation center there is no change in volume $\varepsilon_x + \varepsilon_y + \varepsilon_z = 0.$

- stress and deformation tensors for each point of the deformed layer dz, Figs 2.3, are of the form:

$$T_\sigma = \begin{pmatrix} \sigma_x & \tau_{xy} & 0 \\ \tau_{xy} & \sigma_y & 0 \\ 0 & 0 & \sigma_z \end{pmatrix};$$

$$T_\varepsilon = \begin{pmatrix} \varepsilon_x & \frac{1}{2}\gamma_{xy} & 0 \\ \frac{1}{2}\gamma_{yx} & \varepsilon_{б} & 0 \\ 0 & 0 & \varepsilon_z \end{pmatrix}; \qquad (11)$$

- the stress state at each point of the deformed medium during plastic deformations depends not only on the deviator part of the stress tensor, but also on the normal octahedral stress

$$T_\sigma = \begin{pmatrix} \sigma_x - \sigma_{cp} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y - \sigma_{cp} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & -\sigma_{cp} \end{pmatrix} + \begin{pmatrix} \sigma_{cp} & 0 & 0 \\ 0 & \sigma_{cp} & 0 \\ 0 & 0 & \sigma_{cp} \end{pmatrix}, \qquad (12)$$

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where $\begin{pmatrix} \sigma_x - \sigma_{cp} & \tau_{xy} & 0 \\ \tau_{yx} & \sigma_y - \sigma_{cp} & 0 \\ 0 & 0 & -\sigma_{cp} \end{pmatrix}$ - the deviator part of the stress tensor;

$\begin{pmatrix} \sigma_{cp} & 0 & 0 \\ 0 & \sigma_{cp} & 0 \\ 0 & 0 & \sigma_{cp} \end{pmatrix}$ - ball stress tensor;

σ_{cp} – the normal octahedral stress in the point.

- in each deforming layer dz of the deformation center, the stress state is characterized by a three-dimensional circuit with three compressive stresses $|\sigma_1| > |\sigma_2| > |\sigma_3|$;- in the plastic area of the deformation center, the elastic component of the plastic deformation is not taken into account;

- in each deforming layer dz of the deformation center, the plastic deformation begins only when the stress reaches the yield strength;

- stressed-deformed state of the deforming medium meets the law of rigid-plastic deformation;

- the loading process at each point of the deformation center is characterized by the absence of rotation of the main axes of stress and deformation tensors;

- the loading process at each point of the deformation center is proportional to the value of the growth of the stress tensor of some parameter, which in the plastic area of deformation is equal to twice the value of the shear modulus of the second kind, i.e. 2G*.

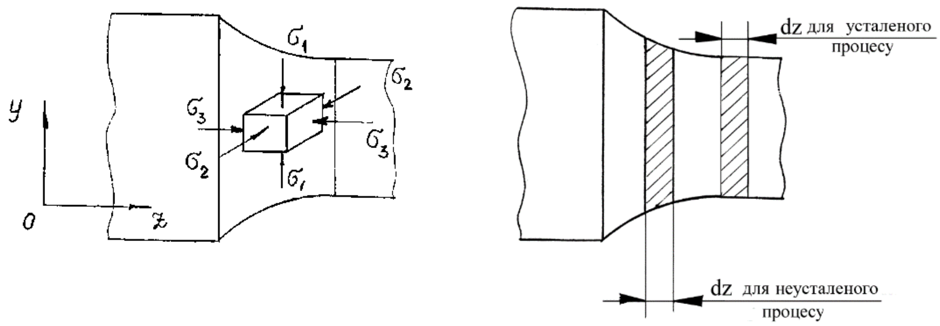


Fig.3 –Scheme of the stress state in the transition zone of the rolled workpiece

For a steady rolling process, with volumetric deformation of the workpiece, the deformation tensor T_ε is of form (13), since direction OZ contains elongation deformations ε_z, hence, displacement W.

$$T_\varepsilon = \begin{pmatrix} \varepsilon_x & \frac{1}{2}\gamma_{xy} & 0 \\ \frac{1}{2}\gamma_{yx} & \varepsilon_y & 0 \\ 0 & 0 & \varepsilon_z \end{pmatrix}. \quad (13)$$

With this ratio of the deformation tensor, the amount of displacement W for layer *dz*, Figure 2.3, will be determined by formula:

$$W = \varepsilon_z \cdot z \quad (14)$$

Since the direction of coordinate OZ contains deformations of elongation ε_z, hence, displacement *w*, these components are determined from Hooke's generalized law,

$$\varepsilon_x = \frac{1}{E}\left(\sigma_x - \nu\sigma_y\right);\ \varepsilon_y = \frac{1}{E}\left(\sigma_y - \nu\sigma_x\right);$$

$$\varepsilon_z = \frac{\nu}{E}\left(\sigma_x + \sigma_y\right); \gamma_{xy} = \frac{2(1+\nu)}{E}\tau_{xy} \quad (15)$$

where E —Young's modulus; ν - Poisson's ratio, we obtain:

$$w = \frac{\nu}{E}\left(\sigma_x + \sigma_y\right)z, \quad (16)$$

$$\sigma_x + \sigma_y = \frac{E}{1-\nu}\left(\varepsilon_x + \varepsilon_y\right). \quad (17)$$

After substituting the right-hand part of equation (17) into formula (16) we obtain

$$w = \frac{\nu}{1-\nu}\left(\varepsilon_x + \varepsilon_y\right)z, \quad (18)$$

Using relation (19),

$$\varepsilon_x = \frac{\partial u}{\partial x};\ \varepsilon_y = \frac{\partial \upsilon}{\partial y};\ \varepsilon_z = \frac{\partial w}{\partial z}; \quad (19)$$

$$\gamma_{yz} = \frac{\partial w}{\partial y} + \frac{\partial \upsilon}{\partial z};\ \gamma_{zx} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x};\ \gamma_{yx} = \frac{\partial \upsilon}{\partial x} + \frac{\partial u}{\partial y},$$

we obtain w —moving in a layer equal to the step of the grid in the direction of the axis oz

$$w = \frac{\nu}{1-\nu}\left(\frac{\partial u}{\partial x} + \frac{\partial \upsilon}{\partial y}\right)z. \quad (20)$$

Substituting the parts of the derivatives by their finite differences in formula (20), we obtain the formula for determining the displacements along axis OZ for the transition zone

$$w = \frac{\nu}{1-\nu}\left(\frac{u_{i+1,j} - u_{i,j}}{{}^{+}h^{i}_{\alpha 1}} + \frac{\upsilon_{i+1,j} - \upsilon_{i,j}}{{}^{+}h^{i}_{\alpha 2}}\right)z. \quad (21)$$

To determine the flow of metal during the unsteady rolling process (transition zone), the calculation method is used with the previous division of the transition zone into a number of elementary sections dz (Fig. 3), in each of which the process is considered as established.

Values $u_{i,j}$ and $\upsilon_{i,j}$ are determined by the method described in paper [2], Fig. 4

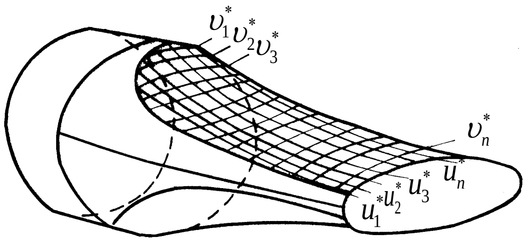


Fig. 4 –The area of the deformation center

To determine the nature of the metal flow in the transition zone of the rolled workpiece, the sample was cut by a plane parallel to XOZ (Fig. 5) into sections (2; 2) (4; 4) (6; 6) (8; 8) (10; 10) (11; 11); by the plane of the parallel YOZ (Fig. 6) into sections (1; 1), (2; 2), (4; 4), (6; 6), (8; 8); by a plane parallel to XOY (Fig. 7) into sections (1; 1), (2; 2), (3; 3), (4; 4), (5; 5).

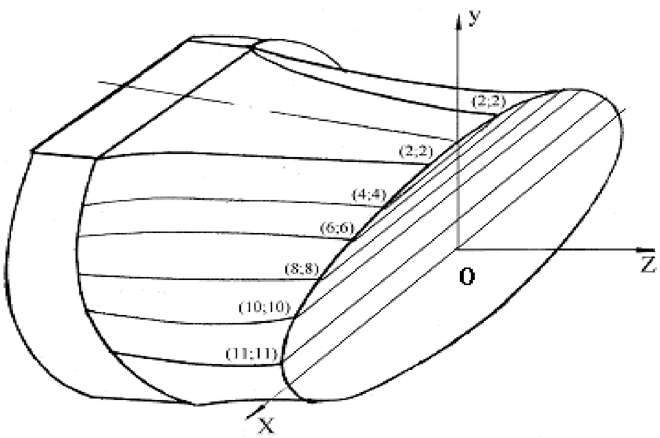


Fig. 5 – The general view of the sections

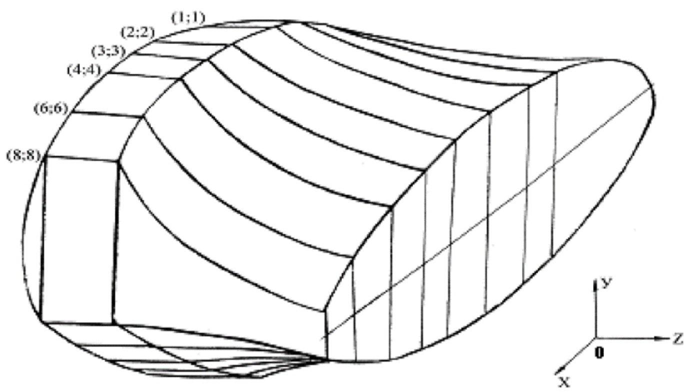


Fig. 6 – The general view of the side section

Fig. 7 contains a view of the surface of the end of the rolled workpiece after volumetric deformation in oval caliber (first approximation)

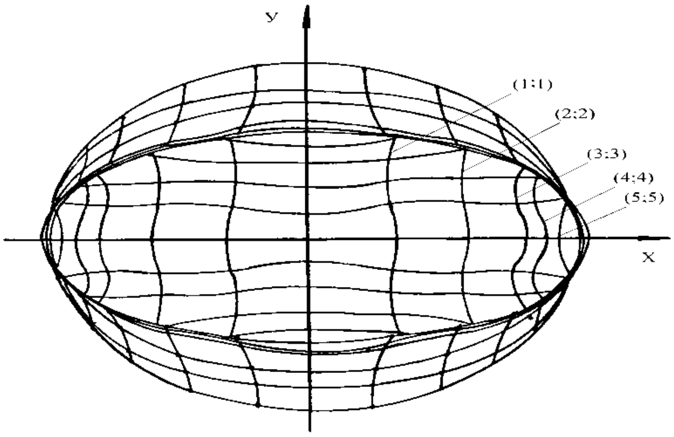
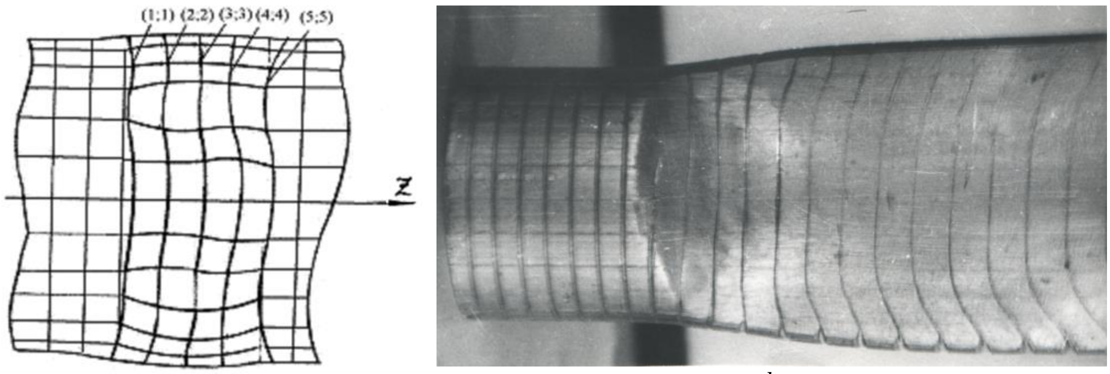


Fig. 7 – Change of "plastic waves" in the center of deformation with taking into account the development of deformation over time, s: (1- 1) – 0.0145; (2 - 2) – 0. 0290; (3 - 3) – 0. 043; (4 - 4) – 0. 0580; (5 - 5) – 0. 0725

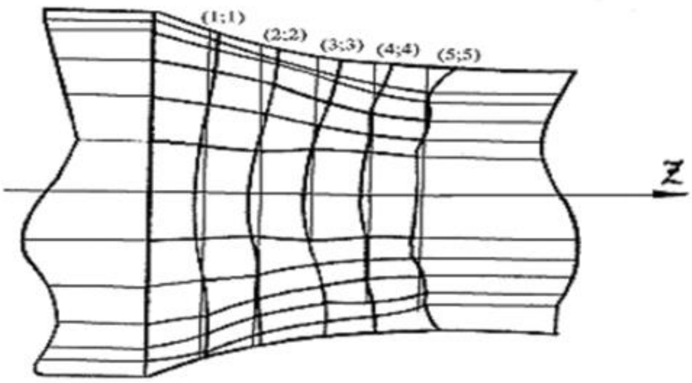
Figs. 8, 9 contain a pattern of the flow of metal in the research area in the analytical (a) and experimental (b) forms



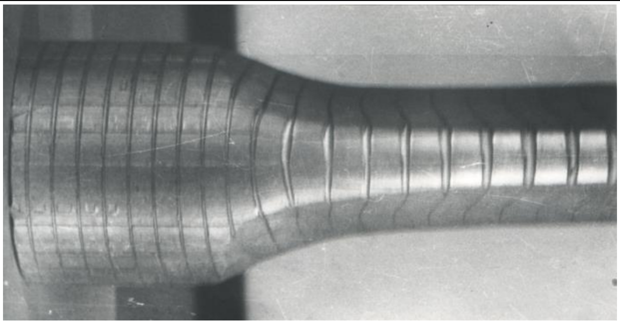
a *b*

Top view: a –analytical research; b –experimental research) taking into account the development of deformation in time, s:

Fig .8 –Change of "plastic waves" in the center of deformation on the surface (1-1) – 0.0145; (2-2) – 0.0290; (3-3) – 0.0435; (4-4) – 0.0580; (5-5) – 0.0725



a



b

a –analytical research; b –experimental research

Fig. 9 – Change of "plastic waves" in the center of deformation on the surface of the test specimen (side view) taking into account the development of deformation over time, s: (1 -1) – 0.0145; (2-2) – 0.0290; (3-3) – 0.0435; (4-4) – 0.0580; (5-5) – 0.0725

From the analysis and comparison of experimental data shown in Figs. 8, 9 it is seen that the solution to the problem in three-dimensional formulation in the field of small elastic-plastic deformations, using the methods of finite differences and variable parameter, gives a true pattern of the metal movement during rolling of round sections in oval calibers.

Fig. 10 presents a general view of the flow of metal in the volumetric deformation of the workpieces in the oval caliber

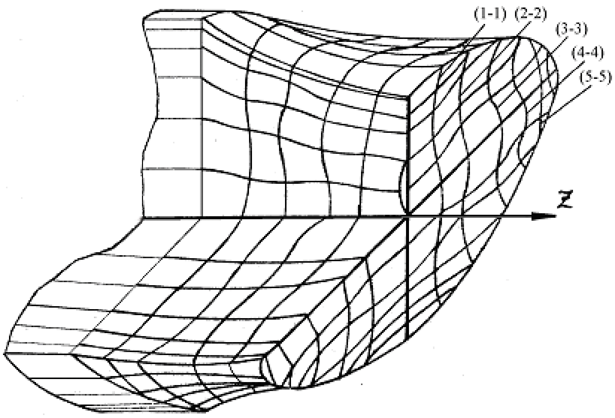


Fig.10 –The general type of change of "plastic waves" at volumetric deformation of workpieces in oval caliber (first approximation) taking into account the development of deformation over time, s: (1-1) – 0.0145; (2-2) – 0.0290; (3-3) – 0.0435; (4-4) – 0.0580; (5-5) – 0.0725

The movements of coordinate grids ("plastic waves") presented in Figs. 7, 8a, 9a, 10 were researched using experimental data obtained by DSc. (Eng.) Skryabin S.O. in the study of metal flow during volumetric deformation of workpieces in oval caliber and determined taking into account the development of deformation over time (lines: 1; 1 – 0. 0145 s; 2; 2 – 0.0290 s; 3; 3 – 0. 0435 s; 4; 4 – 0.0580 s; 5; 5 – 0.0725 s).

As another approach to solving the problem that characterizes the flow, when rolling in the center of deformation, taking into account the development of deformation over time, consider rolling workpieces with dimensions Ø 25×150 mm of aluminum alloy AK6 in oval caliber of the following dimensions: height 13 mm, width 29 mm, caliber radius 20.5 mm, rolls working radius 66.5 mm, gap between rolls 1.0 mm. Rolling temperature 450 °C. Rollers rotation frequency 37 min -1.

The angle of contact of the rolled workpiece with the tool is determined by formula

$$\alpha = \arccos\left(1 - \frac{2R_З - \Delta h}{2R_p}\right) = \text{arc cos } (0.9022) = 0.4458\,, \qquad (22)$$

where – R3 –workpiece radius, mm;
Rp –rollers working radius, mm;
Δh –absolute compression, mm.
The intervals of deformation of the workpiece over time were determined by formula (23), Table 1

$$t = 10^{-3}\left(\frac{R_p \cdot \alpha}{\upsilon_в}\right) = 10^{-3}\left(\frac{66,5 \cdot 0,4458}{0,2}\right) = 0,145\,, \qquad (23)$$

where υв - rollers rotation speed, m/s.

Table 1

The intervals of deformation of the workpiece over time

αi	5	10	15	20	25
ti, s	0.029	0.058	0.087	0.1160	0.1450

Other intervals of deformation over time are determined similarly.

The values of the contact angle in the cross section of the deformation center were determined by formula (24), Table 2

$$\varphi_i = \frac{\upsilon_в \cdot t_i \left(1 - \frac{\Delta h}{2R_к}\right)}{R_p \cdot \alpha}, \quad (24)$$

where Rк –caliber radius, mm.

Table 2

The value of the contact angle in the cross section of the deformation center

ti, s	0.029	0.058	0.087	0.1160	0.1450
φi	0.1312	0.2624	0.3936	0.5248	0.6561

The lengths of the cross-sectional arcs of the contact zone for each value of current angle φi were determined by formula (25), Table 3

$$l_{\varphi\iota} = \text{Rp}\varphi\text{I} . \quad (25)$$

Table3 –The lengths of the arcs of the cross section of the contact zone for each the value of the current angle

φi	0.1312	0.2624	0.3936	0.5248	0.6381
Rk	20.5	20.5	20.5	20.5	20.5
lφi	2.689	5.379	8.068	10.758	13.450

The coefficients of deformation along the contact arc are determined by formulas (26), Table 4

$$K_x = \frac{b_{îâ}^{(i)}}{2R_з}; \quad K_y = \frac{h_{îâ}^{(i)}}{2R_з} . \quad (26)$$

Table 4

Coefficients of deformations along the contact arc

ti,s	0.29	0.085	0.087	0.1160	0.1450
Kx(i)	1.048	1.092	1.140	1.188	1.240
Ky(i)	0.876	0.7352	0.6320	0.5640	0.5400

The change in the width of the oval caliber depending on the time of deformation is determined by formula (27), Table 5

$$b_{ов} = \frac{(b_{ов} + 2R_к)}{\alpha \cdot R_p} \cdot \upsilon_в \cdot t_i + 2R_з , \quad (27)$$

where $b_з$ - oval caliber width, mm;

t_i - deformation time, s.

Table 5

The width of the oval caliber depending on the time of deformation

ti, s	0.029	0.058	0.087	0.1160	0.145
Bов(i)	26.2	27.3	28.4	29.7	31.0

The contact area in each period of the deformation time is determined by formula (28), Table 6

$$F_ê^{(i)} = R_ê \frac{\upsilon_â \cdot t_i}{R_p} [(R_p + R_ê) \frac{\varphi\upsilon_â \cdot t_i}{2R_p \cdot \alpha} - R_ê \sin(\frac{\varphi\upsilon_â \cdot t_i}{2R_p \cdot \alpha})] \quad (28)$$

Table 6

The contact area in each period of the deformation time

ti,s	0.029	0.058	0.087	0.116	0.145
Fk(i)	16.7	66.9	157.8	268.9	431.5

The step in the direction of the coordinate axes is determined by the formulas:

in the direction of OX axis (29), Table 7

$$h_{\alpha_1}^{(i,j)} = R_з K_x^{(i)} (\sin\beta_{i+1,j} - \sin\beta_{i,j+1}) ;(29)$$

in the direction of OY (30), mm

$$h_{\alpha 2}^{(i,j)} = R_з K_y^{(i)} (\cos\beta_{i,j+1} - \cos\beta_{i+1,j}) .(30)$$

Boundary conditions on the surface of the deformable workpiece along the contact arc are determined by formulas (31, 32), Table 2.8

$$u^{(г)}_{i,j+1} = R_3(1-K_x^{(i)})\sin\beta_{i,j+1};$$
$$u^{(г)}_{i+1,j} = R_3(1-K_x^{(i)})\sin\beta_{i+1,j}; \quad (31)$$

$$\upsilon^{(г)}_{i,j+1} = R_3(1-K_y^{(i)})\cos\beta_{i,j+1};$$
$$\upsilon^{(г)}_{i+1,j} = R_3(1-K_y^{(i)})\cos\beta_{i+1,j}. \quad (32)$$

Table 7

Step in the directions of axes OX and OY

t,s	t = 0.029					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
hα1(i,j)	3.3902	3.1597	2.71301	2.0815	1.3086	0.4467
hα2(i,j)	0.3733	1.0939	1.7399	2.2677	2.6411	2.8338
t,s	t = 0.058					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
hα1(i,j)	3.5326	3.2923	2.8268	2.1703	1.3635	0.4654
hα2(i,j)	0.3133	0.9180	1.4424	1.9032	2.2166	2.3783
t,s	t = 0.087					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
hα1(i,j)	3.6879	3.4371	2.9511	2.2657	1.4235	0.4858
hα2(i,j)	0.2693	0.7891	1.2399	1.6360	1.9054	2.044
t,s	t = 0.116					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
h21(i,j)	3.8431	3.5818	3.0753	2.3611	1.4854	0.5063
h22(i,j)	0.2403	0.7042	1.1202	1.4600	1.7004	1.8245
t,s	t = 0.145					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
h21(i,j)	4.014	3.7386	3.2099	2.4645	1.5483	0.5284
h22(i,j)	0.2301	0.6733	1.0725	1.3978	1.6281	1.7469

Table 8

The value of the boundary conditions on the surface of the deformable workpiece along the contact arc lφi

ti,s	t1=0.029 s					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
$u_{i,j+1}$	0.0000	-0.1552	-0.3000	-0.4242	-0.5136	-0.5754
$u_{i+1,j}$	-0.1552	-0.3000	-1.4242	-0.5196	-0.5754	-0.6000
υ i,j+1®	1.5500	1.4971	1.3423	1.0960	0.7750	0.4011
υ i+i,j®	1.4971	1.3423	1.0960	0.7750	0.4011	0.000
ti,s	t2=0.058 s					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
$u_{i,j+1}$	0.000	-2976	-05750	-0.8131	-0.9959	-1.1107
$u_{i+1,j}$	-0.2976	-0.575	-0.8131	-0.9959	-1.1107	-1.150
υ i,j+1®	3.3100	3.1971	2.8664	2.3405	1.155	0.8566
υ i+1,j®	3.1971	2.8664	2.3405	1.155	0.8566	0.0000
ti,s	t3=0.087					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
$u_{i,j+1}$	0.000	-0.4528	-0.8750	-1.2374	-1.5155	-1.6903
$u_{i+1,j}$	-0.4528	-0.8750	-1.2374	-1.5155	-1.6903	-1.7500
υ i+1,j®	4.4431	3.9836	3.2526	2.3000	1.19048	0.0000
υ i,j+1®	4.6000	4.4431	3.9836	3.2526	2.300	1.19048
ti,s	t4=0.116 s					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
$u_{i,j+1}$	0.000	-0.6081	-1.1750	-1.6616	-2.0351	-2.2698
$u_{i+1,j}$	-0.6081	-1.175	-1.6616	-2.0351	-2.2698	-2.3500

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$\upsilon_{i,j+1}$®	5.4500	5.2641	4.7197	3.8536	2.7260	1.4106
$\upsilon_{i+1,j}$®	5.2641	4.7197	3.8536	2.7260	1.4106	0.0000
ti,s	t5=0.145s					
i, j	(1;1)	(3;3)	(5;5)	(7;7)	(9;9)	(11;11)
$u_{i,j+1}$	0.0000	-0.7764	-1.500	-2.1213	-2.5980	-2.8977
$u_{i+1,j}$	-0.7769	-1.500	-2.1213	-2.598	-2.8577	-3.0000
$\upsilon_{i+1,j}$®	5.5539	4.9795	4.0658	2.8750	1.4881	0.0000
$\upsilon_{i,j+1}$®	5.7500	5.5539	4.9795	4.0658	2.8750	1.4881

Fig. 11 shows the nature of the change of "plastic waves" in the center of deformation during rolling of the workpieces in oval caliber with the dimensions described above (view of the end face of the workpiece, the first approximation).

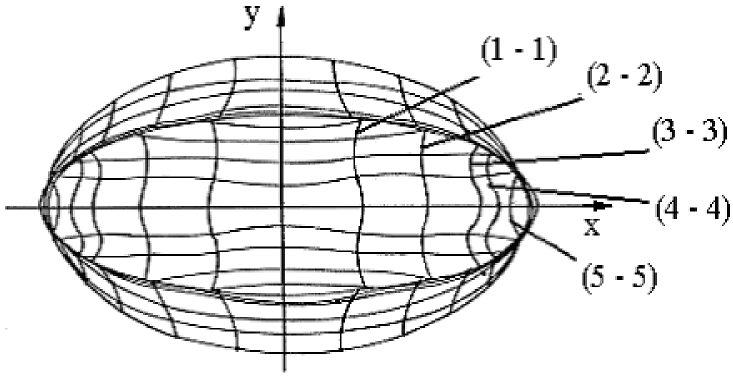

Fig. 11 –Change of "plastic waves" in the center of deformation with taking into account the development of deformation over time, s:
(1 - 1) – 0.0145; (2 – 2) – 0. 0290; (3 – 3) – 0. 0435;
(4 – 4) – 0. 0580; (5 – 5) – 0. 0725

The above figures demonstrate the nature of the flow of metal during workpiece rolling in the deformation center in a three-dimensional setting (volumetric problem), performed by the method described in [11, 14-19] and such that received further development, which takes into account the development deformation over time.

Experimental verification of the results of theoretical and experimental research of metal flow during workpiece rolling by volumetric deformation in the deformation center confirmed that the developed method makes it possible to reveal the pattern of metal movement for both steady (deformation under constant compression) and unsteady (with increasing or decreasing deformation) hot deformation processes, to determine the non-uniformity of deformation depending on the ratio of geometric shapes of the caliber and the deformable workpiece, find the area of possible stress concentration.

The maximum discrepancy between theoretical and experimental research in testing the proposed method does not exceed 10% for the third approximation, which confirms the possibility of using this method to research the flow of metal in the deformation center during workpiece rolling in gauges of arbitrary shape.

Conclusions.

Theoretical and experimental research of metal flow in the deformation center in the transition and steady zones during rolling of workpieces, taking into account the development of deformation over time, with their volumetric deformation, has been further developed.

The method of theoretical research of metal flow in the deformation center during workpiece rolling by volumetric deformation, taking into account the development of deformation over time has been developed and experimentally confirmed. The maximum discrepancy between theoretical and experimental research in testing the proposed method does not exceed 10% for the third approximation, which confirms the possibility of using this method to study the flow of metal in the deformation cell.

Experimental verification of the results of theoretical and experimental research of metal flow during rolling of workpieces with their volumetric deformation in the deformation center taking into account the development of deformation over time has confirmed that the developed method allows revealing the pattern of metal movement for both steady and unsteady deformation processes.

The application of the method of calculating the flow of metal in the local center of deformation makes it possible to predict the mechanical characteristics of the product, as well as to vary them in a wide range, based on functional features and operating conditions. This enables avoiding parts rejects and reducing the debugging time at the design stage of the technological

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process. With regard to the transmission parts of combines and other grain harvesting equipment, the use of the method will increase the strength of heavily loaded parts due to plastic deformation of the internal cross section of the part, healing cracks and defects in the structure of the workpiece. During the operation of such a part in the mechanisms of the combine, the zones of strong load strengthened by plastic deformation will not change their operability for a long time.

REFERENCES:

1. Sonka S. 2014. Big Data and the Ag Sector: More than Lots of Numbers. International Food and Agribusiness Management Review. № 17. PP. 1-20.

2. Andreas D. 2013. Special Issue on Artificial Intelligence in Agriculture. Editorial Kunstl Intell. № 27. PP. 309-311.

3. Garkuha S., Skazhennik1 M., Chizhikov V., Kiselev E., Petrushin A. 2020. Analysis of the use of a combine harvester equipped with a precision farming system in rice growing conditions. IOP Conf. Ser.: Mater. Sci. Eng. 1001, 012027.

4. Nozdrovický L., Macák M., Šima T. 2013. Current trends in the development of agricultural machinery and their impact on the knowledge and skills of the human factor. Proceedings of the 5 th International Conference on Trends in Agricultural Engineering. Prague. PP. 467– 474.

5 Bulgakov V., Adamchuk V. 2015. Mathematical Modelling of the Process of Renewal of the Fleet of Combine Harvesters. Agriculture and Agricultural Science Procedia. Vol 7. PP. 35-39.

6. Puzyr R.H., Shchetynin V.T., Arhat R.H., Muravlov V.V., Kravchenko S.I. 2021. Numerical modeling of pipe parts of agricultural machinery expansion by stepped punches. IOP Conference Series: Materials Science and Engineering. 1018(1), 012013.

7. Haikova T.V., Puzyr R.H., Levchenko R.V. 2020. Experimental Studies on the Stress-Strain State under Drawing Aluminum–Copper Bimetal Parts Rectangular in Plan. Russian Journal of Non-Ferrous Metals. № 61(4), PP. 404–412.

8. Kurpe O., Kukhar V., Puzyr R., Balalayeva E., Klimov E. 2020. Electric Motors Power Modes at Synchronization of Roughing Rolling Stands of Hot Strip Mill. Proceedings of the 25th IEEE International Conference on Problems of Automated Electric Drive. Theory and Practice, PAEP. 9240818.

9. Kuzman K., Kardelj E., Pirtovsek M. 1988 Forge Rolling-Computer Aided Process Planning and Tool Design.4 Semin. Plast. Umforming, Gjör, 16-18 l [Juni,. Budapest], p. 57 - 62.

10. Haikova, T., Puzyr, R., Savelov, D., ...Argat, R., Sivak, R. The Research of the Morphology and Mechanical Characteristics of Electric Bimetallic Contacts. Proceedings of the 25th IEEE International Conference on Problems of Automated Electric Drive. Theory and Practice, PAEP 2020, 2020, 9240847.

11. Skryabin S.A. 2007 Technology of hot deformation of billets from aluminum alloys on forging rollers. Vinnytsia: A. Vlasyuk. 284 s. (In Russian)

12. Skryabin S.A., Shvets L.V., Chaika D.S. 2006. Investigation of the metal flow in the transition and steady-state zones during the rolling of blanks in the deformation zone, taking into account the development of deformation in time. Technological systems. No. 4. S. 32 - 38. (In Russian)

13. Skryabin S.A., Shvets L.V. 2007. Investigation of the plasticity of alloys AK6 and D16, reinforced with whiskers made of SiC material, under conditions of isothermal deformation. Technological systems. No. 1 (37). S. 56 - 62. (In Russian)

14. Pulupec M., Shvets L. 2019. Characteristics and thermomechanical modes of aluminum alloys hot deformation. Current Problems of Transport: Proceedings of the 1st International Scientific Conference. Ternopil Ivan Puluj National Technical University and Scientific Publishing House «SciView». Ternopil, 195-204. ISSN: 978-966-305-101-7

15. Posviatenko E., Budyak R., Shvets L., Paladiichuk Y. 2018. Influence of a material and the technological factors on improvement of operating properties of machine parts by reliefs and film coatings. Eastern-European Journal of Enterprise Technologies. № 5/12 (95). P. 48-56. SNIP: 0.558 | 2018

16. Shvets L. 2020. Methods of experimental and analytical research of metal in the center of deformation during hot compression heating. The scientific heritage. Vol. 1., № 48. P. 54-75.

17. Shvets L. 2020. The essence and possibility of the method of isothermal deformation Slovak international scientific journal. Vol. 1., № 42. P. 16-24.

18. Shvets L. 2020. Extension value, with hot rolled aluminum alloy specimens, round section in smooth rollers. Scientific foundations of modern engineering: monograph. Boston: Primedia e Launch. 528 p. ISBN 978-1-64871-656-0. doi : 10.46299/isg.2020.mono.tech.i

19. Arhat R., Puzyr R., Shchetynin V., Puzyr V., Haikova T. 2021. The Contact Pressure in Drawing Parts Without Clamping the Workpiece Flange. Lecture Notes in Mechanical Engineering. PP. 12–20.

№83/2022

Norwegian Journal of development of the International Science

ISSN 3453-9875

It was established in November 2016 with support from the Norwegian Academy of Science.

DESCRIPTION

The Scientific journal "Norwegian Journal of development of the International Science" is issued 24 times a year and is a scientific publication on topical problems of science.

1000 copies

Norwegian Journal of development of the International Science

Iduns gate 4A, 0178, Oslo, Norway

email: publish@njd-iscience.com

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