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INFLUENCE OF RHEOLOGICAL PROPERTIES OF A SOIL LAYER ADJACENT TO THE WORKING BODY CUTTING ELEMENT ON THE MECHANISM OF SOIL CULTIVATION

Victor AULIN[1], Oleg LYASHUK[2]*, Andrii TYKHYI[1], Sergiy KARPUSHYN[1], Nadia DENYSIUK[2]

[1]Central Ukrainian National Technical University, Ukraine
[2]Ternopil Ivan Puluj National Technical University, Ukraine

On the basis of rheological characteristics, stress fields and deformations, new methods of improving the mechanism of soil cultivation are substantiated in this article. The mechanism of soil destruction is observed. Paper investigates the process of changing the stressed-deformed state of the soil under the influence of the working body. To study the viscoelastic properties of black earth soil, the method of amplitude sweeping with a measuring system of parallel high planes was applied using a modular rheometer MCR-302 (Anton Paar, Austria). Range of linear viscoelasticity of virgin soil was found to reach 0.1% deformation; range of linear viscoelasticity of cultivated field area is smaller by an order of magnitude – to 0.02% deformation. Structure destruction (the point of equality of modules) of virgin soil occurs at 20% deformation; structure of long steam soil destructs at 8% deformation. Technique of measuring the isobar zones distribution in horizontal and vertical planes by means of special strain gauges of the LPX 5000 model was developed. To reproduce the force pattern of the working bodies' effect on soil environment, the measuring complex MIC 400D is used; stress-strain state of the soil is defined.

Keywords: stress field; modulus of elasticity; internal friction; external friction; rheological model; stress-strain state

One of the most important energy indicators of any soil cultivation machine is the resistance of the working bodies to wear due to movement in the soil. The extent of wear grows linearly with the time of operation (Ťavodová et al., 2018; Tolnai et al., 2006; Ľuptáčiková and Ťavodová, 2018).This indicator limits the seizing width and, hence, the aggregate's performance. Traction resistance of single working body operating in conditions of blocked cutting at depth from 0.25 to 0.30 m reaches 10 kN, what is a reason why the high performance of these aggregates during deep cultivation cannot be achieved.

Existing methods of soil cultivation are based on the mechanical effect of soil cultivation machines' working bodies (SCMWB) on the soil during shrinkage. Despite the significant amount of theoretical and experimental studies conducted in this area (Vasylkovska et al., 2016; Kováč and Tolnai, 2006), the fundamental qualitative changes in the impacts on the soil with consideration of SCMWB design have not been actually observed. Processes taking place in soil should be observed at different structural levels, taking into account the stress-strain state (SSS) of a soil layer adjacent to SCMWB and its rheological properties and characteristics (Bird et al., 1983).

Challenge is to prove the availability of effective approaches for detection of the soil destruction mechanism and to develop energy-saving technologies for soil cultivation. For this purpose, the characteristics of internal and external friction, density distribution, viscosity, plasticity, stress and deformation fields, destruction energy quantification of a soil layer adjacent to SCMWB and adequate soil rheological models should be taken into account (Beris et al., 1985).

Soil solid phase consists of a wide range of particles (Aulin and Tykhyi, 2017), what is confirmed by a large variety of soil types, their characteristics and properties. In this case, the soil should be referred to as a triboelement consisting of a system of material particles interacting with each other according to physical laws and having rheological characteristics and properties (Aulin, 2014; Aulin and Tykhyi, 2016a).

Essential phenomena in the soil rheology are relaxation, creep and long durability. All processes in soil are assumed to occur under the isothermal conditions (Aulin and Tykhyi, 2017). External (gravity and applied loads) and internal forces (inside the particles and between them) act in the solid-phase subsystem of the soil. All these forces create corresponding physical fields with a certain energy influence. In regards to stress and deformation fields, rheological properties, soil destruction mechanism has not been fully considered in research and thus no effective energy-saving cultivation technology has been developed.

Research objective is to substantiate approaches to defining the mechanism of soil destruction and to develop effective energy-saving cultivation technologies based on stress and deformation fields, rheological properties of the soil layer adjacent to SCMWB.

Contact address: Oleg Lyashuk, Ternopil Ivan Puluj National Technical University, Ukraine, e-mail: Oleg-lashyk@rambler.ru

Material and methods

In recent years, rheological methods have been actively applied to study the mechanical properties and microstructure of the soil. Rheometers are highly sensitive devices for measuring the interaction between the soil particles within the cultivated layer. Rheometer application for studying the microstructure is discussed in numerous works (Huang et al., 2014; Aulin et al., 2016b; Teamrat and Dani, 2001).

To study the viscoelastic properties of Haplic Chernozems (CHh), amplitude sweeping method with a measuring system of parallel high planes by means of a modular rheometer MCR-302 was applied. Studied samples of Haplic Chernozems are typical for Kirovograd region (Ukraine); they were obtained from uncultivated field. To conduct rheological studies of medium loamy soil, the following physical and chemical properties were determined in the range of 0–0.3 m: density – 1.5·103 kg·m^{-3}; soil moisture – 12.9%; elastic modulus E = 36.15 MPa; destruction rate v_p = 2.87 m·s^{-1}; carbon content C = 1.21%; structurality coefficient K_{st} = 2.1; specific surface S_{sp} = 4.53·104 m^2·kg^{-1}. Furthermore, in the range of 0.3–0.5 m, these properties were as follows: density – 1.7·103 kg·m^{-3}; soil moisture – 11.8%; elastic modulus E = 42.3 MPa; destruction rate v_p = 2.03 m·s^{-1}; carbon content C = 0.39%; structurality coefficient K_{st} = 2.25, specific surface S_{sp} = 3.42·104 m^2·kg^{-1}. Soil samples were analysed after daily capillary moistening. To solve a wide range of tasks, especially to ensure high accuracy of measurements, Modal Compact Rheometers (MCRs) with air bearing motors were designed.

In order to reproduce the power of SCMWB impact on soil environment and to determine its SSS, method of measuring the isobar zones distribution in horizontal and vertical planes by means of special strain gauges LPX 5000 was developed. Timing of measuring channels of the strain gauges and the photocell was synchronized using the module ME-020. Measuring complex MIC 400D (Fig. 1a) was used for recording.

Technique for studying the soil's SSS under the impact of SCMWB can be described as follows: three cylindrical strain gauges are installed in the soil channel (Fig. 1b) before SCMWB at the cultivation depth. Initial observation distance between the location of strain gauges and the photocell line is 0.1 m and increases gradually by 0.1 m. When SCMWB passes through the indicated line, photocell will send a signal to the measuring complex; voltage values in the placement of strain gauges are constant. On the basis of obtained data, the isobars of stress distribution in the given horizontal plane were developed for each fixed distance at a certain depth h.

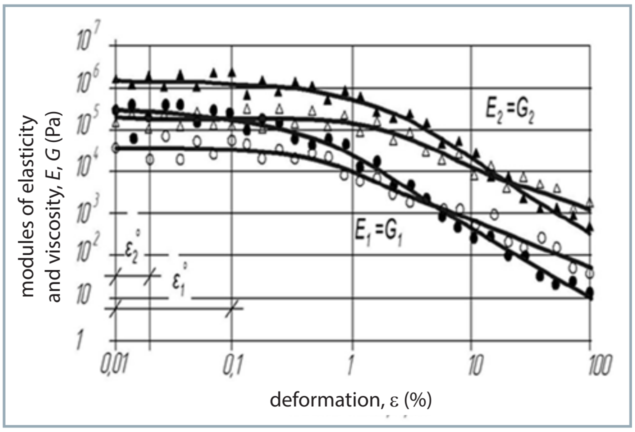

Fig. 2 Rheological curves of elasticity and viscosity moduli
E_1, E_2 – moduli of soil elasticity of cultivated and uncultivated field areas; G_1, G_2 – moduli of soil viscosity of cultivated and uncultivated field areas; ε_1^0, ε_2^0 – zero level of soil deformation of cultivated and uncultivated field areas

On the basis of described procedure, similar measurements were performed with changes in the immersion depth of sensors at every 0.05 m: 0; 0.05; 0.1; 0.15; 0.2; 0.25; 0.3. The SCMWB velocity was close to operational. The field of soil's stress and deformations was analysed and calculated applying the finite element method using the software COSMOSWorks.

Following rheological parameters were determined:

1. E – modulus of elasticity (accumulation module) as a component of viscoelastic behaviour;
2. G – modulus of viscosity (loss module) as a component of viscoelastic behaviour;
3. ε^0 – range of linear viscoelasticity (limits of soil mixture resistance to structure destruction);
4. $E = G$ – point of structure destruction (point of equality of elasticity and viscosity moduli).

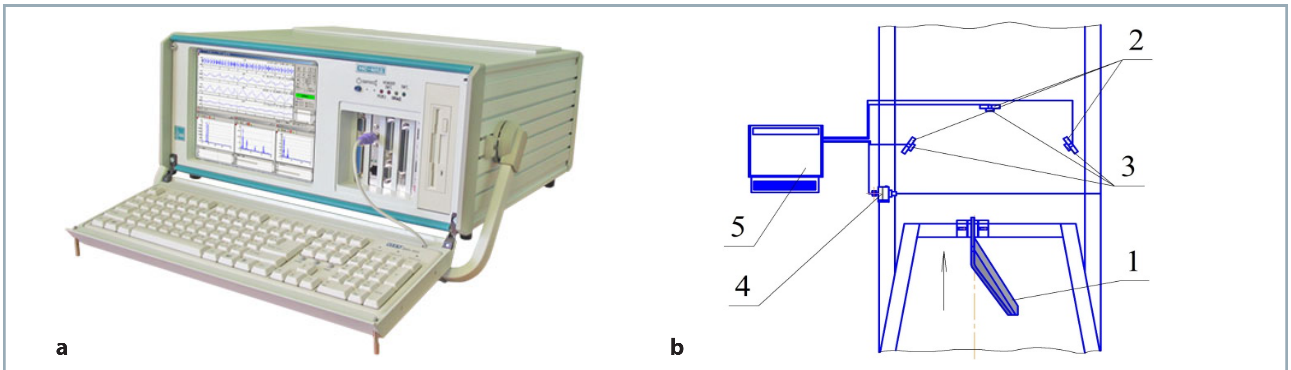

Fig. 1 a – Measuring complex MIC 400D; b – Scheme of installation operation used for determination of the SSS of soil environment
1 – SCMWB; 2 – special holders; 3 – cylindrical strain gauges; 4 – photocell; 5 – measuring complex

Results and discussion

Study results of the dependence of elasticity and viscosity moduli on deformation are shown in Fig. 2. Modulus of elasticity and range of linear viscoelasticity of the virgin soil were significantly higher in comparison to continuously cultivated soils (*E* – 106 Pa and *G* – 105 Pa at zero deformation). Range of linear viscoelasticity of the virgin soil extended to 0.1% of deformation; for the cultivated soils, it extended to 0.02% of deformation). Structure destruction (the point of equality of moduli) in the virgin soil occurred at deformation of 20%, in the soil after fallow tillage, it occurs at 8% deformation. Obtained data indicate a significant difference in the rheological behaviour of the studied soils.

Conducted studies prove that rheometers are highly sensitive devices for measuring the interaction between particles and provide an opportunity to predict more accurately the initial changes in the structure of soils during interaction with the SCMWB cutting elements (CE).

The results of stress distribution studies in the horizontal and vertical planes of soil environment under the impact of a one-sided hoe are shown in Figs. 3 and 4, and under the impact of a slit cutter in Figs. 5 and 6. Stress distribution in the horizontal plane is shown in Fig. 4. Stress concentration was observed in the lower part before the cutting edge. Nature of isobar distribution before the deformer was similar to the isolines of stress. The isobar occurs in sandy soil, under the action of vertical knives, as documented experimentally by different authors (Aulin and Tykhyi, 2010). The density of stress isolines in the soil, which are developed by the results of experimental studies, decreased in horizontal and vertical planes with an increase in distance from the surface of a one-sided hoe. Moreover, value of voltage decreased as well. A similar distribution of stresses' isolines in the soil was observed in the relevant planes before the slit cutter (Figs. 5, 6). Lines were ideally round in the horizontal plane and fell down more steeply at small depths in the vertical plane; at deep depths, they were flatter. Such behaviour of the curves can be explained by the uneven soil deformations in the loosening zone and in the zone of elastic and plastic deformations (Aulin and Tykhyi, 2010).

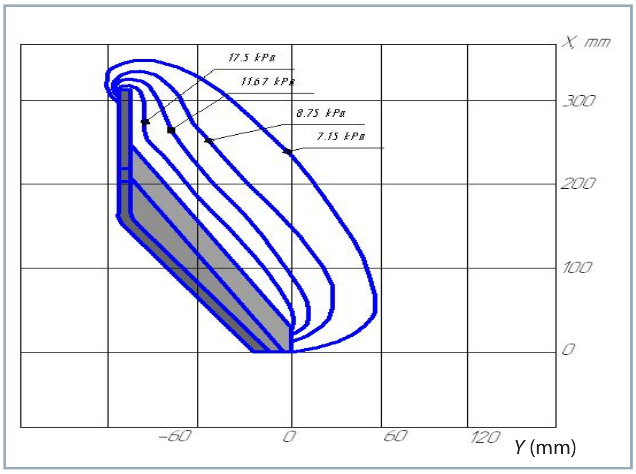

Fig. 3 Distribution of stresses' isolines before a one-sided hoe in the horizontal soil plane (W = 12%, depth is 0.05 m)

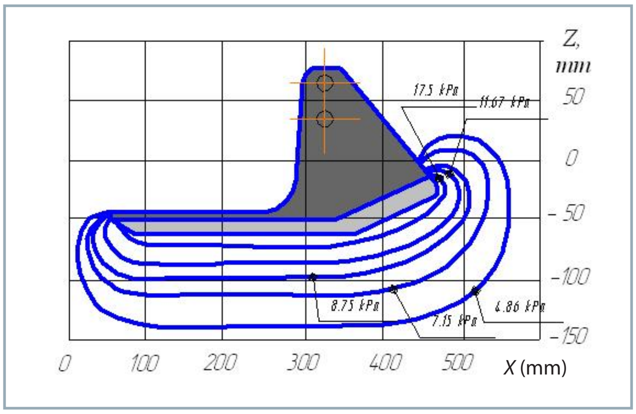

Fig. 4 Isolines of stresses σ_z before the vertical stand of a one-sided hoe (W = 12%)

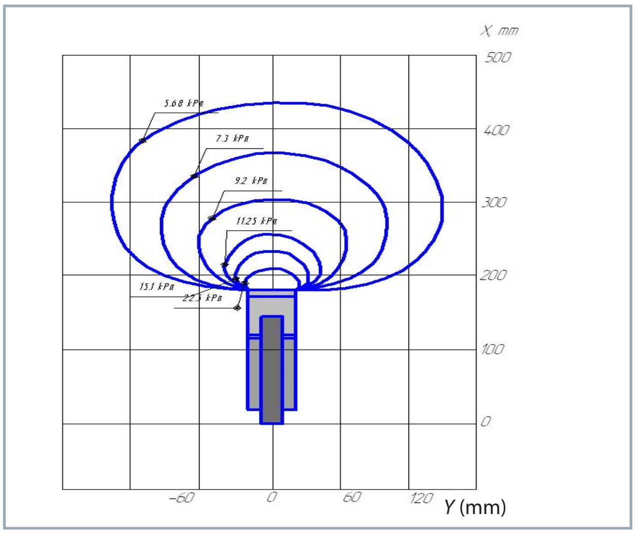

Fig. 5. Distribution of the stresses' field (isobar) in the horizontal soil plane (depth is 0.05 m, W = 12%) before the vertical stand of a slit cutter

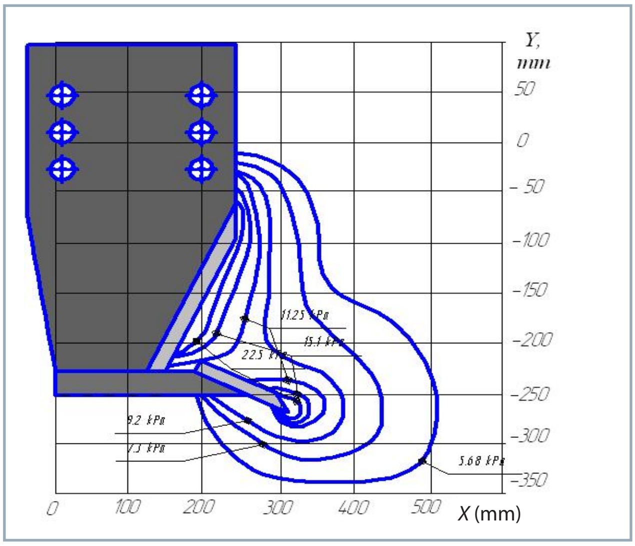

Fig. 6 Isolines of stress σ_z before the vertical stand of a slit cutter (W = 12%)

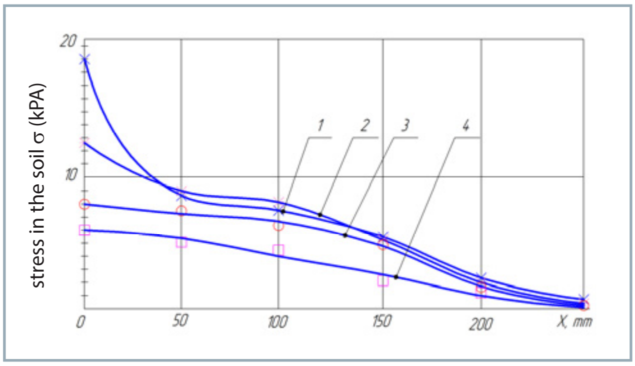

Fig. 7 Dependence of stress in the horizontal soil plane in observed distances from the nozzle of a one-sided hoe at different depths
1 – 0.05 m; 2 – 0.1 m; 3 – 0.15 m; 4 – 0.2 m

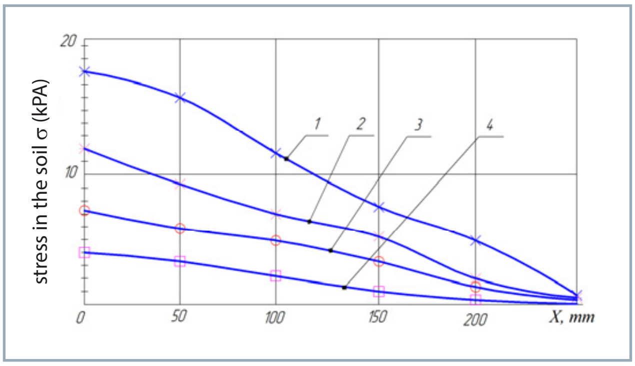

Fig. 8 Dependence of the stress in the horizontal soil plane before the centre of the one-sided hoe CE at various depths
1 – 0.05 m; 2 – 0.1 m; 3 – 0.15 m; 4 – 0.2 m

Dependence of the change in stress value at various distances on the working surface of one-sided hoe (Figs. 7–9) and slit cutter (Fig. 7) was determined in the soil layers adjacent to the working surfaces.

Figs. 7–10 show that the stress dependence in soil on the distance in horizontal and vertical planes was nonlinear. Therefore, the maximum stress occurred in the zone of CE direct action and practically fades at a distance of 0.25–0.3 m. Experimental studies prove the dependence of regularities of the stress value distribution in the soil in the distance from the SCMWB working surface on the type of SCMWB and the depth of the soil layer.

Research results of the soil SSS during its interaction with the SCMWB allow stating the following: in the loosening zone and in the zone of elastic and plastic deformations, the laws of stress distribution are similar and are of form of exponential curves; in the loosening zone, the stress curves fall more steeply than curves in the zone of elastic and plastic deformations; isobars are symmetrical in relation to the normal, which passes through the symmetry centre of the SCMWB cutting surface; stress is distributed unevenly in vertical planes that coincide with the normals passing through the centres of the cutting surfaces; stress values and nature of their dependence on the cutting depth are determined by the distance from the slit axis in the soil; elements of the soil layer adjacent to SCMWB are in different conditions of deformation depending on the depth.

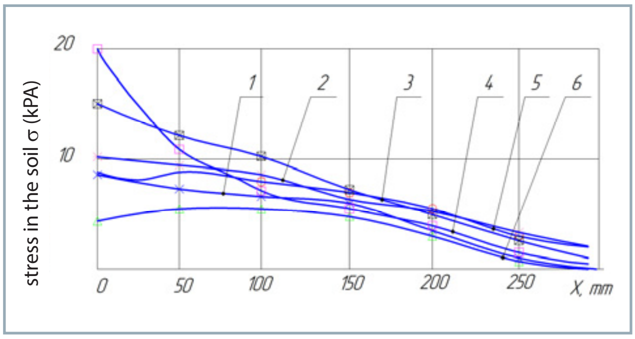

Fig. 9 Dependence of the stress before the centre of the vertical CE slit cutter at various depths
1 – 0.05 m; 2 – 0.1 m; 3 – 0.15 m; 4 – 0.2 m

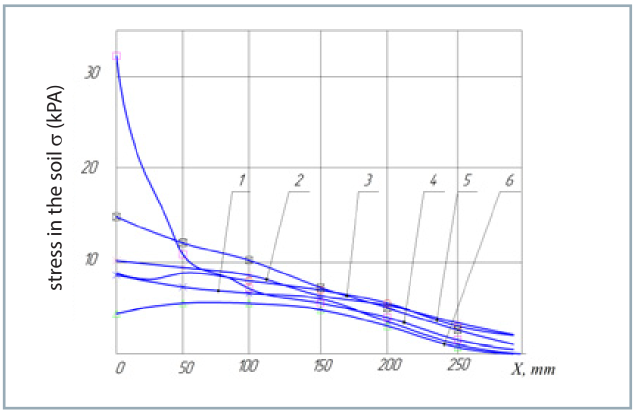

Fig. 10 Dependence of the stress before the centre of the horizontal CE slit cutter at various depths
1 – 0.05 m; 2 – 0.1 m; 3 – 0.15 m; 4 – 0.2 m; 5 – 0.25 m

The value and direction of the destructive force were stochastic, and therefore, it was more appropriate to use the energy approach, i.e. to assess the energy necessary for soil cultivation; usage of the Griffith's energy-based analysis – observing the energy spent on the destruction of the material with the formation of slits – was sufficient. Surface energy of the slit formed in the layer adjacent to the SCMWB working surface under the action of SCMWB with the force N and velocity v was equal to:

$$W_p = U_n = \frac{Nvt}{2} - \frac{\pi l^3 \sigma^2}{2E} + 4\alpha_n S_n \qquad (1)$$

where:
$Nvt/2$ – potential energy accumulated in the soil layer adjacent to SCMWB as a result of its shrinkage, J
$\pi l^3 \sigma^2/2E$ – potential energy released due to the created splits (plane) of displacement, J
$4\alpha_n S_n$ – surface energy of the formed split, J

Surface energy of the soil mass destruction was the specific energy of its crumbling A_n caused by SCMWB:

$$A_n = \frac{W_p}{\Delta m} = \alpha_n (S_{nov}^{num} - S_{nov.\partial}^{num}) \qquad (2)$$

where:
α_n – surface tension of a soil particle

S^{num}_{nov}, $S^{num}_{nov.\partial}$ – correspondingly, agrotechnically essential specific soil surface and actual specific soil surface, $m^2 \cdot kg^{-1}$

In Ukraine, the agrotechnical specific surface of chernozems in the steppe zones in the natural riotous state is assumed to be 13·105 $m^2 \cdot kg^{-1}$, while the average actual surface area is 0.90·105 $m^2 \cdot kg^{-1}$; density of the soil layer adjacent to the SCMWB equals to 1.5·103 $kg \cdot m^{-3}$ (Aulin, 2014; Lutsak et al., 2016). Based on these data, the cost of energy for soil crusting was estimated to be 436 kJ according the following formula:

$$U_{total} = \frac{N^2_{str} l_n}{2E_{str}ab} \qquad (3)$$

where:
N_{shr} – total shrinkage force of the adjacent soil layer, N
ℓ_n – its length, m
E_{shr} – shrinkage module, Pa
a, b – thickness and width of the layer, m

Therefore, the shrinkage force providing a certain overall crushing energy equalled to:

$$N_{str} = \sqrt{\frac{2E_{str}abU_{total}}{l_n}} \qquad (4)$$

Based on the Eq. 4 and experimental data, to provide the necessary shrinkage force to the layer with its subsequent destruction, the SCMWB operation speed should be increased by more than 1.5 times. As a result, the SCMWB traction resistance increases and consequently, the power consumption in soil cultivation increases as well.

To conduct the tribophysical studies of behaviour of the soil layer adjacent to SCMWB, the rheological methods should be applied.

It should be emphasized that majority of tasks related to soil mechanics are nonlinear in both physical and geometric terms; application of methods of linear classical continuum mechanics is associated with significant errors and requires a reasonable estimation of such a transition.

Generalized rheological equation (Bird et al., 1983) is as follows:

$$\tau - \tau_T = G \times \gamma + \eta \times \ddot{\gamma} - T_p \times \ddot{\tau} = G\left(\gamma + T_p \times \ddot{\gamma}\right) - \ddot{T}_p \tau \qquad (5)$$

It gives an opportunity to obtain both separate equations for rheological bodies and their combination when certain parameters are equal to zero. Soil rheological model developed by Bird (1983) has several advantages, however, soil structure including the solid, liquid and gas phases is not fully taken into account.

Diagrams in Fig. 11 reflect schematically the nature of the processes occurring in time under the impact of SCMWB on the soil taking into consideration the components of complete deformation in general form.

The areas of increasing loading, steady loading and unloading can be noticed during the soil loading by SCMWB (Fig. 11a). In the deformation graph (Fig. 11b), curve 0–4 represents a deformation graph during loading. It consists of vertical section 0–2 of instantaneous deformation and section 2–4 of continuous deformation and proceeds from the point 3 with an almost constant rate. In time moment t2, the loading is stopped. Section of deformation curve 4–7 is a graph of reverse instantaneous deformation consisting of a section 4–6 and continuous reverse elastic deformation after unloading (section 6–7).

In addition to this, the fading curve of continuous elastic deformation 0–1 is plotted, as well as the rectilinear (approximate) graph 2–5 of the continuous deformation of the viscoplastic flow in the soil. To develop the graph 2–5, the straight is plotted parallel to the section 3–4 through the point 2, which is the end of the instantaneous deformation segment. If we want to plot a segment, which is equal to the value of instantaneous elastic deformation during unloading (4–6), along the ordinate axis from the point 0, we obtain the point 7 that cuts off the value of instantaneous elastic deformation. Difference between the ordinates of the points 2 and 1 results in the instantaneous plastic deformation $\varepsilon_{pl.d}$.

Graph 2–5 crosses the curve 4–7 at the point 5. Difference between the ordinates of the points 1 and 5 results in the

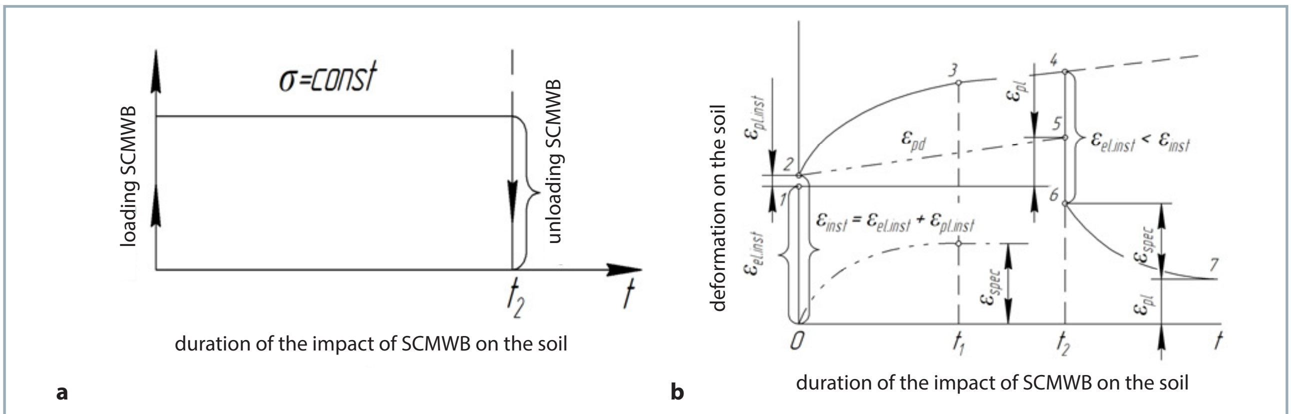

Fig. 11 a – Curves of loading (unloading) of the soil by SCMWB; b – Deformation process in the soil layer durability
$\varepsilon_{el.inst}$ – elastic instantaneous deformation; $\varepsilon_{pl.inst}$ – plastic instantaneous deformation; ε_{spec} – specific deformation; $\varepsilon_{pl.}$ – plastic deformation; ε_{pd} – plastic durability deformation

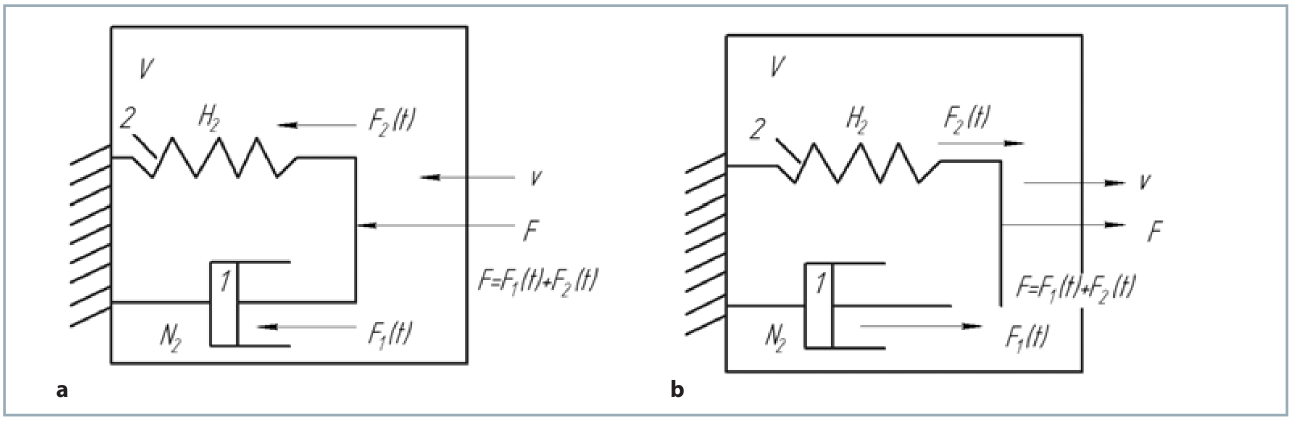

Fig. 12 Pattern of the effect of forces on the soil layer volume in shrinkage deformation (a) tension (b)
1 – element of viscosity (Newton's rheological model) of the soil; 2 – element of elasticity (Hooke's rheological model)

total plastic deformation ε_{pl}. Ordinate of the final horizontal section of the curve 6–7 is of the same value. The abscis of the point 3 can be understood as the time t_1 of continuous elastic deformation fading.

Shrinkage and tension deformations occur in the soil layer with a volume V under the SCMWB impact (Fig. 12).

Analysis of the effect of forces in different soil deformations can be described by the following stress equations:

In deformation of shrinkage:

$$\tau = \left(\tau_0 \exp\left(-\frac{G_{3C}}{\eta_M + \eta_K} t\right)\right)_I + (G_{3C}\dot{\gamma} + \eta_N \dot{\gamma})_{II} + \left[\frac{2\dot{\gamma}}{\lambda_M} + \left(\frac{2\dot{\gamma}}{\lambda_M} + \eta\dot{\gamma}\right)\right]_{III} \quad (6)$$

In strain deformation:

$$\tau = 0.5\left\{\left(\tau_0 \exp\left(-\frac{G_{3C}}{\eta_M + \eta_K} t\right)\right)_I - (G_{3C}\dot{\gamma} + \eta_N \dot{\gamma})_{II} - \left[\frac{2\dot{\gamma}}{\lambda_M} + \left(\frac{2\dot{\gamma}}{\lambda_M} + \eta\dot{\gamma}\right)\right]_{III}\right\} \quad (7)$$

where:
τ_0 – initial shear stress, N·m^{-2}
G_{3C} – shear module, N·m^{-2}
η_M, η_K, η_N – coefficients of dynamic viscosity of the elements according to Maxwell, Kelvin, and Newton's rheological models, Pa·s^{-1}
$\dot{\gamma}$ – shear-strain rate, m·s^{-1}
λ_M – coefficient of proportionality, N·m^{-1}
t – duration of deformation, s

From the point of view of classic rheology (Aulin and Tykhyi, 2010; Bird et al., 1983), the soil can change its state from liquid to very hard state. It is appropriate to cultivate it in a state of ripeness at soil moisture content from of 18 to 28%. Soil structure is not distorted at the initial stage of cultivation and has a maximum viscosity. However, at the final stage of cultivation, soil structure is distorted and its viscosity is minimal.

Conclusion

The process of continuous self-tillage is found to be one of the forms of self-organization occurring in the soil due to the interaction of soil particles and soil phases, as well as the adsorption of water vapour from the environment.

Conducted studies have shown that the soil is not a simple set of solid particles, but it is a system of material particles that interact with each other according to physical laws that need to be taken into account when designing new energy-saving soil cultivation technologies.

Value and direction of the destructive force under the conditions of the high-speed mode of SCMWB motion and the shrinkage deformation are of a stochastic nature; therefore, it is only appropriate to estimate the energy used for soil cultivation. Speed of modern SCMWB should be increased if soil shrinkage deformation takes place, what leads to the increase in energy intensity of soil cultivation. Therefore, not only new methods of soil cultivation, but also new SCMWB are required.

Soil viscosity was proven to be a variable value; it is in maximum in the initial stage of the SCMWB mechanical action on the soil and in minimum at the end of the cultivating process, when the soil structure is destructed. Considered rheological properties can be used as theoretical foundation for the development of combined SCMWB and SCMWB with variable form and geometry of soil slip surfaces, as well as energy-saving technologies that involve preliminary loosening of the soil and thus a change in nature of the soil deformation from shrinkage to tension.

References

AULIN, V. V. – TYKHYI, A. A. 2017. Tribophysical Bases of Increasing Wear Resistance and Reliability of Working Parts of Soil Cultivating Machines with Cutting Elements: monograph. Kropyvnytskyi, 279 pp.

AULIN, V. V. – TYKHYI, A. A. 2016a. Dynamics of wear of cutting elements of working parts of soil-cultivating machines while interacting with soil. MOTROL: Commission of Motorization and Energetics in Agriculture. In An International Journal on Operation of Farm and Agri-Food Industry Machinery, vol. 18, no. 2, pp. 41–48.

AULIN, V. V. 2014. Physical Bases of Processes and Conditions of Self-Organization in Tribo-Technical Systems: monograph. Kropyvnytskyi, 370 pp. ISBN 978-966-2570-91-5.

AULIN, V. – ARIFA, W. – LYSENKO, S. – KUZYK, A. 2016b. Improving of the wear resistance of working parts agricultural machinery by the implementation of the effect of self-sharpening. In International Journal of Engineering and Technology (UAE), vol. 5, no. 4, pp. 126–130.

AULIN, V. V. – TYKHYI, A. A. 2010. Dynamics of change of stress-deformed and deteriorated state of cutting element of workings organs of tillage machines at various variants of hardening. In Problems of Tribology, vol. 10, pp. 54–59.

BERIS, A. N. – TSAMOPOULOS, J. A. – ARMSTRONG, R. C. – BROWN, R. A. 1985. Creeping motion of a sphere through a Bingham plastic. In Journal of Fluid Mechanics, vol. 158, pp.219–244.

BIRD, R. B. – DAI, G. C. – YARUSSO, B. J. 1983. The rheology and flow of visco-plastic materials. In Reviews in Chemical Engineering, vol. 1, pp.1–70.

HUANG, W. – LIU, D. Y. – ZHAO, B. Y. – FENG, Y. B. – XIA, Y. C. 2014. Study on the rheological properties and constitutive model of Shenzhen mucky soft soil. In Journal of Engineering Science and Technology Review, vol. 7, no. 3 pp. 55–61.

KOVÁČ, I. – TOLNAI, R. 2006. An improvement in the mechanical properties of boron-saturated surface layers of steel 14 220 and 15 203. In Acta Technologica Agriculturae, vol. 9, no. 1, pp. 1–3.

ĽUPTÁČIKOVÁ, V. – ŤAVODOVÁ, M. 2018. Methods for increasing the material resistance of the mulching tool body against its deformation in operation. In Technological Engineering, vol. 14, no. 2, pp. 17–20.

LUTSAK, D. – PRYSYAZHNYUK, P. – BURDA, M. – AULIN, V. 2016. Development of a method and an apparatus for tribotechnical tests of materials under loose abrasive friction. In Eastern European Journal of Enterprise Technologies, vol. 5, pp.19–26.

ŤAVODOVÁ, M. – KALINCOVÁ, D. – KOTUS, M. – PAVLÍK, Ľ. 2018. The possibility of increasing the wearing resistance of mulcher tools. In Acta Technologica Agriculturae, vol. 21, no. 2, pp. 94–100.

TEAMRAT, A. G. – DANI, O. R. 2001 Rheological properties of wet soils and clays under steady and oscillatory stresses. In Soil Science Society of America Journal, vol. 65, no. 3, pp. 624–637.

TOLNAI, R. – ČIČO, P. – KOVÁČ, I. 2006. Impact strength of steels as a criterion of material resistance. In Acta Technologica Agriculturae, vol. 9, no. 1, pp. 17–19.

VASYLKOVSKA, K. V. – LESHCHENKO, S. M. – VASYLKOVSKYI, O. M. – PETRENKO, D. I. 2016. Improvement of equipment for basic tillage and sowing as initial stage of harvest forecasting. In MATEH – Agricultural Engineering. Sep.–Dec., vol. 50, no. 3. pp. 13–20.