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SUBSTANTIATION AND EVALUATION OF EFFECTIVENESS OF PERSPECTIVE CONSTRUCTIONS OF FOREST TRACTORS ANCILLARY EQUIPMENT

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ABSTRACT

The main methods of the known methods of regulation of operating devices of mounted tillers at a given depth of processing are: altitude, position, power, and combined. However, these methods are effective mainly for massive hinged agricultural tillage equipment operating in more favorable conditions and with special design elements in the form of one or more of the supporting wheels, skis, soles of operating devices, etc. A more promising way to improve penetrability of disc operating devices is the use of forced vibration. The results of experimental verification on a production forest disc harrow KLB-1.7, conducted in VSAFE, confirmed the effectiveness of this method. An in-depth analysis of the functioning of various possible variants of structural embodiment of tractor ancillary equipment allowed offering the following solution to the problem. Using the developed device with a hydraulic drive which is mounted between the tractor ancillary equipment and mounted disc tool, it's necessary to ensure the ability to regulate the links of tractor ancillary equipment with the help of SCW, during the movement of the device. The conducted analysis confirmed the effectiveness of the proposed design tools.

Keywords: efficiency, forest tools, tractor ancillary equipment.

INTRODUCTION

The main methods of the known methods of regulation of operating devices of mounted tillers at a given depth of processing are: altitude, position, power, and combined. However, these methods are effective mainly for massive hinged agricultural tillage equipment operating in more favorable conditions and with special design elements in the form of one or more of the supporting wheels, skis, soles of operating devices, etc. (Bartenev, 2010; Lurie, 1977; Zelikov, 2014).

A more promising way to improve penetrability of disc operating devices is the use of forced vibration. The results of experimental verification on a production forest disc harrow KLB-1.7, conducted in VSAFE, confirmed the effectiveness of this method. For forced vibration of operating devices, the special constructions of hydromechanical (Posmetiev *et al.*, 2008) and hydropulsator (Posmetiev *et al.*, 2010) drives were developed. Using vibration of working bodies allowed not only improving penetrability of discs, but also improving crumbling and loosening of soil, as well as self-cleaning of working bodies of adhering soil and weeds (Zelikov, 2011). At that, the energy consumption of the engine for vibrational mechanism hydraulic drive was compensated by the decrease of working tool resistance by 20-25%. The disadvantages of this method are the complexity and high cost of the tool, as well as need for continuous operation of the hydraulic system of mounted tractor (Posmetiev and Tretiakov, 2011).

Currently, in order to improve the penetrability of working bodies of forest and agricultural disc harrows, the operators have to load them with additional weights in the form of massive metal elements, concrete blocks, logs, sandbags, etc. (See Figure-1).

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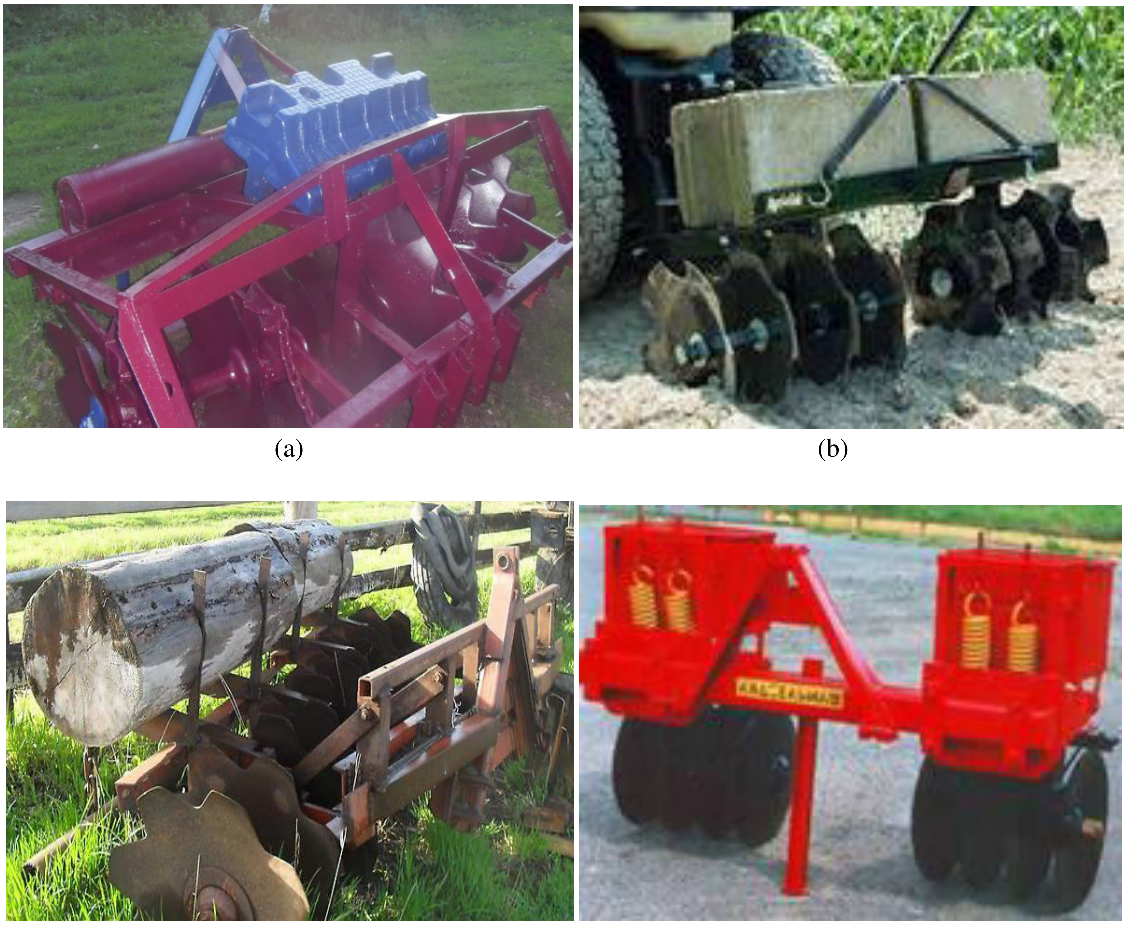

(a) (b)

(c) (d)

Figure-1. Increasing penetrability of disc harrows with additional weights on the frames and working bodies: (a) - metal elements; (b) - concrete blocks; (c) - logs; (d) - sandbags.

Additional weight is set on a tool frame, or on each frame of disc batteries section. Forest tillage designed to work on cutting, due to the large number of the major obstacles on the latter (stumps, surface and deep roots, boulders, rock outcrops), have no bearing structural elements, to which adjustment of the working bodies at a given depth of tillage is done. Installation of such support elements on forest tools would inevitably lead to frequent breakdowns of both the elements and tools in general (Posmetiev, 1999).

Such forest tools are traditionally designed with regard of using additional weights which provide the regulation of the depth of working bodies. For weights, various materials available at forest sites may be used - sand, rocks, logs, etc., which are placed in the special boxes, fixed on tools frames - e.g., cultivators KLB-1.7 (see Figure-2, g), ploughs PLD-1.2 and PRN-40D and others. In this regard, the rational selection of the mass and placement of additional weight on disk tool become important, as underload and overload implements the same negative impact on its effectiveness (Nartov and Posmetiev, 1982).

When designing mounted unsupported disk tools, the developers often underestimate the impact of the instantaneous center of rotation (SCW) of the ancillary equipment units of tractor on the penetrability of spherical disc working tools into the soil. The main reason for this is mass use on the agricultural tractors of all line-up of drawbar category (from 0.6 to 8) of serial rear mounted devices of dimensions NU-2, NU-3 and NU-4, the parameters and constructions of which are regulated by national standards. However, these standards do not cover mounted devices of the tractors of special use, including forest ones. The attachments, designed to meet the requirements of this standard, do not allow changing the position of the SCW device links according to height in necessary limits; it is limited by the height from the axis of tool's suspension to the bearing surface of the tractor. This does not affect the tools with plough working elements, for which these devices are recommended by the standard. At the same time, the efficiency of the unsupported disk mounted tools largely depends on the ability of the attachment to install SCW significantly below the axis of the tool's suspension and reference plane of the tractor (surface of the treated soil) [8, 9].

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In order to determine the effect of the position of standard attachment mechanism SCW on the amount of additional load, we shall perform a calculation in accordance with the scheme shown in Figure-2 for the serial forest disc cultivator KLB-1.7 in the unit with wheel tractor "Belorus 82.1", equipped with ancillary mechanism of size NU-2, intended for tractors of drawbar category 0.6-2. To simplify the calculations, we introduce the following main admissions which do not significantly affect the accuracy of the final result: friction force in the joints of the attachment mechanism are insignificant - we shall ignore them; we shall ignore the forces influencing the tool in the transverse vertical plane, due to their smallness; height position of the suspension axis of the tool m_o is invariably located at a distance of 400 mm from the reference plane of the tractor, recommended by the standard; unit movement is assumed to be steady and linear, and the surface of the processed row of forest plants is even; physical and technological properties of the soil at the cutting, treated by the cultivator, are unchanged; working resistance of the cultivator and of the reactions at the working bodies are constant; disc motion on a given working depth is stable (Zelikov *et al*., 2008).

The equilibrium condition of the forest disc cultivator KLB-1.7 in the longitudinal vertical plane shall be defined (Sviridov and Vershinin, 2002) from the equation of moments as to the axis of the front ends of the lower arms of the tractor ancillary equipment (tool suspension axis), i.e. point O (see Figure-2). Then, taking into account the equality $P_x = R_x$, we have

$$\Sigma M_o = G_н \cdot l_1 + G_{op} \cdot l_2 + G_г \cdot l_3 - R_z \cdot l_4 - P_z \cdot l_4 = 0. \quad (1)$$

From this formula, the value of the weight $G_г$ can be found as follows:

$$G_г = (-G_н \cdot l_1 - G_{op} \cdot l_2 + R_z \cdot l_4 + P_z \cdot l_4) / l_3, \quad (2)$$

Where $G_н$, G_{op} –weight force of attachment mechanism and tool, respectively, N; R_z and P_z – vertical components of the resultant R_{xz} of soil reaction and tractor's hauling capacity P_{xz}, applied to the axis O_1 of disk battery, N; l_1, l_2, l_3, l_4 – shoulders of the forces, respectively $G_н$, G_{op}, $G_г$, R_z and P_z, m.

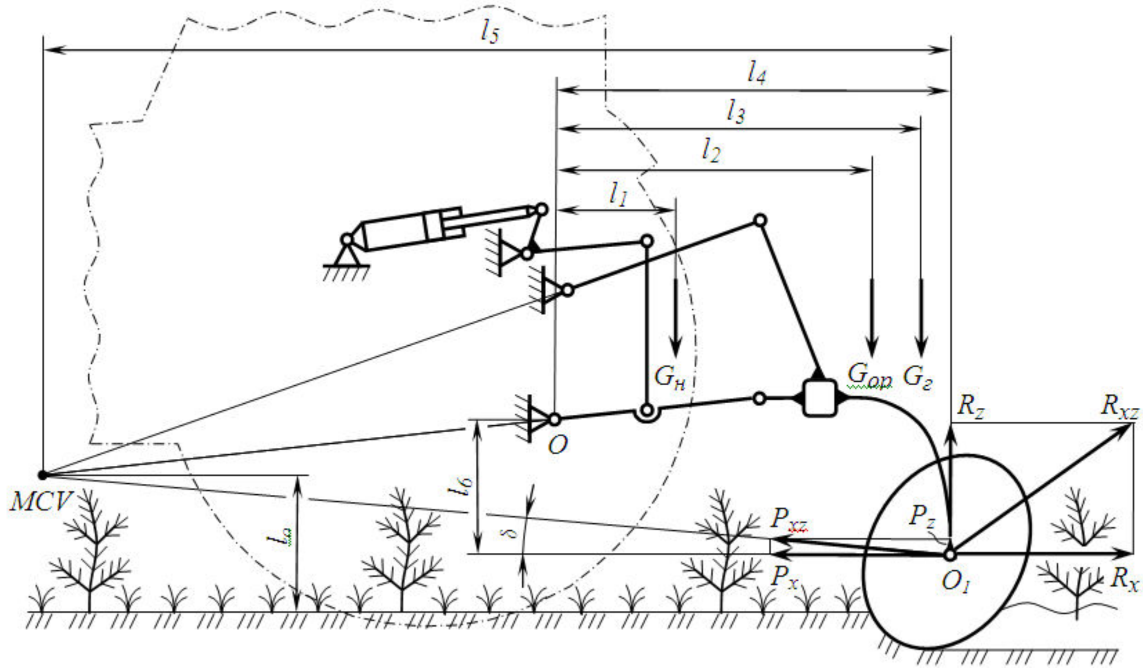

Figure-2. The calculation scheme for determining the amount of additional load $G_г$ for forest disc cultivator KLB-1.7.

Components of the resultant tractor hauling capacity $P_{xz,}$ in accordance with the calculation scheme (Figure-2), can be determined from the obvious equalities $P_x = R_x$, and $P_z = P_x \cdot tg\delta = P_x \cdot l_6 / l_5$. Here: R_x and P_x – horizontal components of resultant R_{xz}, of soil reaction and tractor hauling capacity P_{xz}, applied to the axis O_1 of disk battery; l_5 and l_6 – projections of segments on vertical and horizontal planes, respectively, connecting points SCW and the axis O_1 of disc battery; δ – conditional angle of disc tool thrust, degr., in the working position of the ancillary equipment, in which the distance from the SCW point to the tractor supports surface is equal to its default values, i.e. l_0 = 0.4 m. According to (Sineokov and Panov, 1982), for discs with a diameter of 510 mm, the angle of attack of 15^0 and processing depth of 6-10 cm, the value R_z is recommended to be taken as R_z = 1.5R_x. After substitution of reactions of R_z and P_z expressed through R_x, in equation (2) and simple transformations, we obtain the final formula for the approximate determination of the

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amount of additional load $G_г$ of researched cultivator (Zelikov, 2014; Posmetiev *et al*., 2013)

$$G_г = [-G_н \cdot l_1 - G_{op} \cdot l_2 + R_x(1.5 \cdot l_4 + l_4 \cdot l_6 / l_5)] / l_3. \quad (3)$$

To determine from the expression (3) the sought quantity Gg, we shall accept the following data: $G_н = m_н \cdot g$ = 1200 H, $G_{op} = m_{op} \cdot g$ = 5250 H, where $m_н$ = 122 and m_{op} = 536 kg - the weight of the ancillary equipment and the tool, g = 9,8 - acceleration of gravity, m/s^2; l_1 = 0.44 m, l_2= 1.23 m; l_3 = 1.45 m; l_4 = 1.53 m; l_5 = 4.88 m; l_6 = 0.4 m.

The variable R_x is to be found from the known expression (Sviridov and Vershinin, 2002)

$$R_x = K\,(B - em),$$

where K – specific tractive resistance of the tool, N/m; B – width of tool grasp, m; e – value of the protection zone on each side of crops row, m; m – number of crop rows.

Here, variable K depends on physical and technological properties of soil, including its hardness. According to various published sources (Sviridov and Vershinin, 2002; Sineokov and Panov, 1982), for disc harrows, used for the care of forest cultures, variable K varies between 2000-4000 N/m at the cultivation depth of 6-10 cm (with the maximum possible depth of 12 cm, according to the passport). The sought variable Gg is defined for the three following cases of the care of disk cultivator for forest plantations: K which is equal to minimum, average and maximum of the possible values, i.e. K_1 = 2000, K_2 =3000 and K_3 = 4000 N/m.

After inserting in the expression (3) the original data, the following values G_g were obtained. With K_1, the force of additional load equaled to G_g = -812 N, which corresponds to the load weight $m_g = G_g$/g =-83 kg. The negative sign in the force Gg of additional load, received at K_1, indicates the excess value of the total mass of cultivator and tractor ancillary equipment for the current conditions of the task. It is obvious that in this case the mass of the cultivator and of the ancillary equipment is enough, and additional weight is not required. With K_2, variables G_g и m_g constituted 1190 N and 121 kg, respectively, with K_3 - 3193 N and 326 kg, respectively. (Posmetiev *et al*., 2014).

Analysis of the data allows us to conclude the following. Parameters of the design of serial cultivator KLB-1.7 and standard ancillary equipment of size NU-2, mounted on the tractor "Belarus 82.1", provide normal operation of the tool, even without any additional load, during the work with forest plantations in clearings with soil of light mechanical composition group (sand and sandy loam, with light turfiness and thickets). At that, the excessive weight of the cultivator, equal to 83 kg, provides the work of discs at the maximum depth of 10-12 cm. With soils of the middle group (loam, turfy and with moderate thickets), it is necessary to load the cultivator with additional weight above the disc batteries (in ballast boxes) with a total mass of at least 121 kg, in order to provide the desired working depth of 6-12 cm. With soils of hard group (clay, a lot of weed shoots), normal maintenance of forest plantations is possible only with installation on the cultivator of additional load of total weight not less than 326 kg.

Consequently, the serial cultivator KLB-1.7 can be used in clearings with soils of light and medium mechanical composition groups, with moderate turfiness and weed saturation. At that, in clearings which do not have within the same rut the soils with different physical and technological properties, it is impossible to ensure the stability of discs motion at a given depth. Tractor operator is not able to timely and fully implement the necessary adjustment of the tool by changing the value of additional load. Due to the great discomfort from the necessity to frequently change the value of the load weight (loading, unloading, search, and availability of the suitable material, etc.), machine operators often do not use it, so the depth of the disc tillage is not maintained within the specified limits. Because of these reasons, the quality of care for forest plantations with disc harrows is still insufficient. To improve the quality of tillage in cuttings, machine operators perform repeated passes with the cultivator, which leads to excessive fuel consumption and longer periods of care for forest plantations. Besides, the need of carrying ballast (20-40% or more of the tool weight) while working at cuttings with soils of medium and hard, significantly reduces the reliability and efficiency of such tillage tool.

Another significant drawback of standard ancillary equipment is its inability to provide a full copy of the soil with both disc batteries of the cultivator at the clearings. This is due to significant inequalities of the treated surface, typical for clearings, as well as the insufficient angle of inclination of the suspension axis in the vertical transverse plane in relation to the reference surface of the tractor (see Figure-3a). Slopes of treated furrow φ_b and the reference surface of the tractor φ_m in vertical transverse plane can reach 15-20 degrees or more, and, relative to the total slope of the soil surface at the cutting, they may have different directions. In the latter case, the total slope $\varphi_b + \varphi_m$ can reach 30 degrees or more, whereas skewing of cultivator frame φk, guaranteed by standard ancillary equipment of the tractor, does not exceed 10-15^0, which inevitably leads to partial or complete shank out of one of the disc batteries. As a result, under the influence of the lateral component P_{Tby} of embedded battery, it shifts to the containment zone of the processed row by the value y_2, and its innermost disc damages the seedling (see Figure-3b). The value of flaw $S_{oг}$ also depends on the angles of the disc batteries: α - attack in the horizontal and β – to the bottom of the furrow in cross-vertical planes.

Thus, the design and admissible adjustment parameters of the standard tractor ancillary equipment, as well as the use of loads on disc batteries, do not ensure the cultivator achieving the required quality of soil treatment

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in the rows of forest crops at clearings. Besides, the efficiency of such tillage tool is unnecessarily reduced because of excessive fuel consumption and lack of productivity.

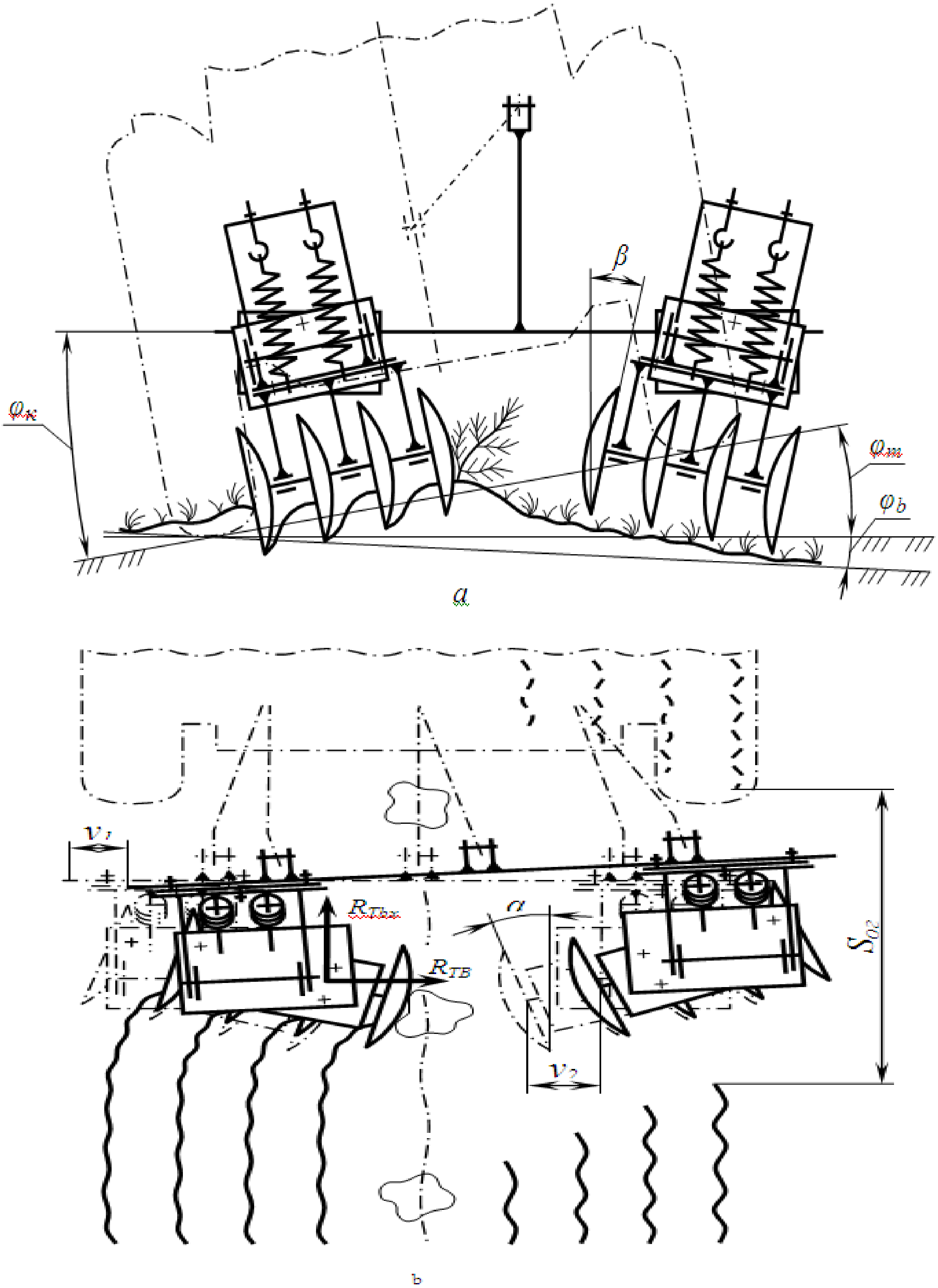

Figure-3. Formation of flaw S_{og} and damage to forest plantations as a result of influence of component R_{Tbu} of the tractive resistance force of the embedded disc battery and lateral displacement of the frame y_1 and discs y_2 of serial cultivator, attached to the tractor with a standard ancillary equipment.

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RESULTS

An in-depth analysis of the functioning of various possible variants of structural embodiment of tractor ancillary equipment allowed offering the following solution to the problem. Using the developed device with a hydraulic drive which is mounted between the tractor ancillary equipment and mounted disc tool, it's necessary to ensure the ability to regulate the links of tractor ancillary equipment with the help of SCW, during the movement of the device. In this regard, we shall perform the calculation and analyze the effectiveness of the proposed design of the device.

Calculations are performed similarly to the previous ones, made for standard ancillary equipment of tractor "Belarus 82.1" and of serial cultivator KLB-1.7, based on the assumptions and input data and taking into account the design parameters of the offered device. Then, in accordance with the calculation scheme (see Figure-4), the equation of moments as to point O will take the following form:

$$\Sigma M_o = G_н{\cdot}l_1 + G_п{\cdot}l_2 + G_{op}{\cdot}l_3 + G_г{\cdot}l_4 - R_z{\cdot}l_5 + P_z{\cdot}l_5 = 0. \qquad (4)$$

From equation (4), after expressing reaction R_z and force P_z through reaction R_x and simple transformations, the value of the goods G_g is defined as

$$G_г = [-G_н{\cdot}l_1 - G_п{\cdot}l_2 - G_{op}{\cdot}l_3 + R_x{\cdot}\, l_5\,(1{,}5 - l_7/l_8)] \,/\, l_4, \qquad (5)$$

where G_H, G_p and G_{or} - weight force of ancillary mechanism, devices, and instruments, respectively, H; R_x - horizontal component of the resultant R_{hz} on the working bodies of the soil reaction, applied to the axis O_1 of disc battery, H; l_1, l_2, l_3, l_4 and l_5 - shoulders of the forces and reactions, respectively, G_H, G_p, G_{or}, G_g, R_z and P_z, m; l_7 and l_8 – projections of segments on vertical and horizontal planes, respectively, that connect points SCW and axis O_1 of disc battery.

The initial data for determining the value Gg using the found expression (5) are the following: GH = MN· g = 1200 N, Gor = mor· g = 5250 N, Gp = MP· g = 1000 N, where MN = 122 kg mor = 536 kg and MP = 102 kg - weight of ancillary equipment, tool, and accessories; g = 9,8 - acceleration of gravity, m/s2; l_1 = 0.44 m, l_2 = 1.0 m; l_3 = 1.23 m; l_4 = 1.45 m; l_5 = 1.53 m; l_7 = 0.5 m; l_8 = 4.88 m. Values of input data R_x and K are supposed to be the same as in the above formula (3).

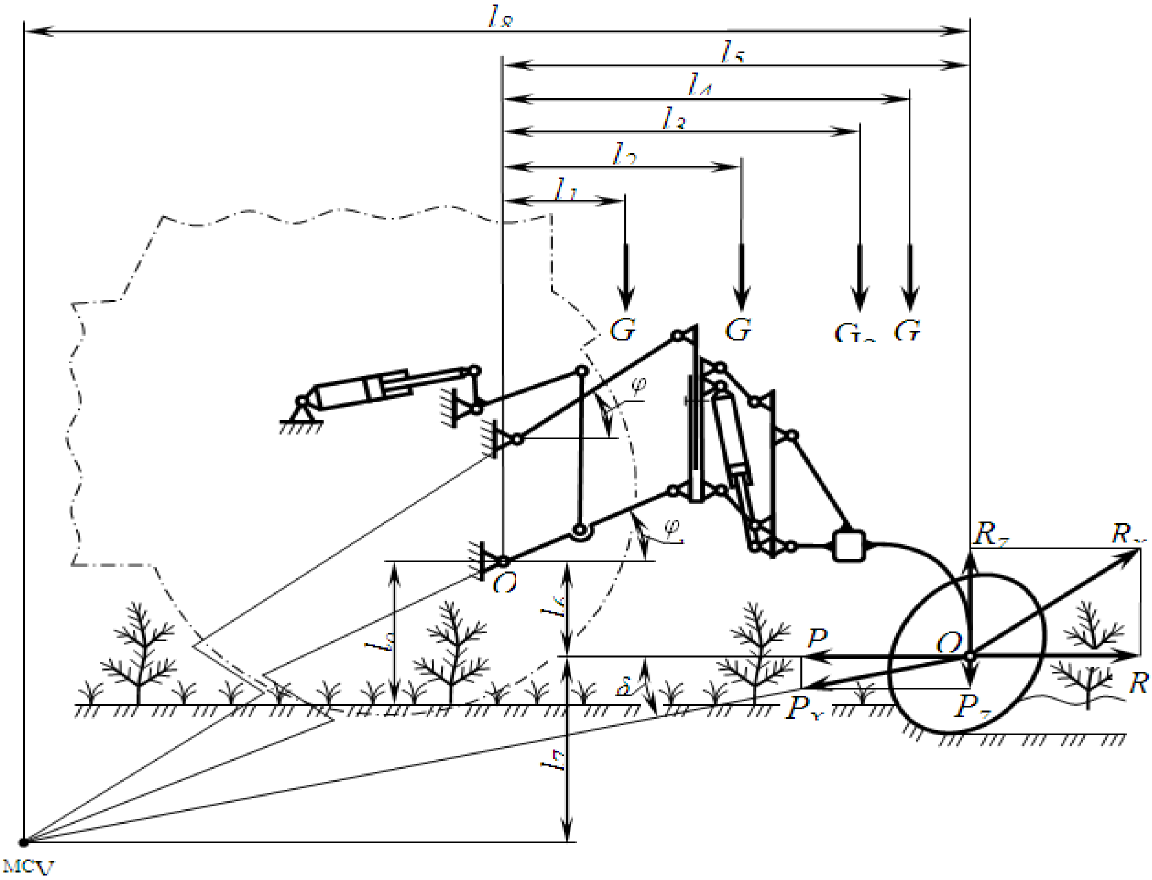

Figure-4. The design scheme for the definition of the amount of additional load G_g of forest disc cultivator KLB-1.7 with PNGA attachment for the tractor ancillary equipment.

where G_H, G_p and G_{or} - weight force of ancillary mechanism, devices, and instruments, respectively, H; R_x - horizontal component of the resultant R_{hz} on the working bodies of the soil reaction, applied to the axis O_1 of disc battery, *H;* l_1, l_2, l_3, l_4 and l_5 - shoulders of the forces and reactions, respectively, G_H, G_p, G_{or}, G_g, R_z and P_z, m; l_7 and l_8 – projections of segments on vertical and horizontal planes, respectively, that connect points SCW and axis O_1 of disc battery.

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Results of calculation as to expression (5) for the case of use of PGNA device when attaching a serial cultivator on a tractor with a standard ancillary equipment and installed with the help of a hydraulic cylinder, the maximum value of the conditional thrust angle δ of the tool showed the following. With the hardness of the treated soil K_1 = 2000 N/m, the force of additional load constituted G_g = -2071 N, which corresponds to the load weight M_g = -211 kg. The negative sign and substantial value of the load weight indicate a large excessive embedding moment on the working bodies with cultivator working on forest soils with low hardness level. In this case, by controlling with hydraulic cylinder the device from the workstation, it is easy to set the desired value of the working depth of the disc batteries cultivator.

With soil hardness K_2 = 3000 and K_3 = 4000 N/m, the values of mass Mg of additional load constituted -36 and 139 kg, respectively. In the first case, the device provides reliable penetration of the discs without load at maximum operating depth, equal to 12 cm. In the second case, without the load, the working depth constitutes no more than 6 cm, and 10-12 cm - with the load weight of 139 kg. However, given that the soil with hardness of 4000 N/m is rare on the clearings, the need for additional load on the tool disappears.

Thus, the proposed fixture design of PNGA allows providing the reliable penetration of serial cultivator disc batteries to the desired depth without the use of additional load, on cuttings with various forest soil hardness.

Performing the adopted scheme and basic design and operating parameters of the proposed device allowed designing and manufacturing its prototype (Posmetiev *et al.*, 2013). The device design (see Figure-5) includes a frame, consisting of interconnected vertical *1* and horizontal bars *2*. Vertical tool bar includes a retractable stand with eye *3* for joining the rear end of the top link *19* of tractor ancillary equipment. The stand is regulated to the desired height with the Finger-4, inserted into the hole in the beam *1* and in the corresponding hole in the stand. The rear ends of the two lower links *20* of the tractor ancillary equipment are hinged on the axes, formed at both ends of the horizontal beam *2* of the device's beam. With the help of the upper *8* and upper and lower levers *9*, by means of arms *5* and *14*, as well as eyelets *6* and *7*, the frame is hinged to a connecting triangle of coupler *10*. The connecting triangle is hinged by a counterpart with the cultivator *18*. With the help of spacer plates, the lower ends of the connecting triangle are rigidly connected to the beam *11*, in the center of which the support *15* is mounted. Between the supports *5* and *15*, the hydraulic cylinder *16* is pivotally mounted, connected by flexible piping to tractor hydraulic system distributive valve (not shown at the Figure). In the transport position, the device with attached cultivator is securely held by chain *17*, with the help of the finger in the support *5*. To disconnect the mounted tool *18* from the device from the tractor cab, one should use the handle *12* with cable thread, held in the operating position by a spring *13*. The handle is connected kinematically to a catch, located in the connecting triangle *10;* with its help, the tool is securely connected to the device when attaching, without the tractor driver or support staff.

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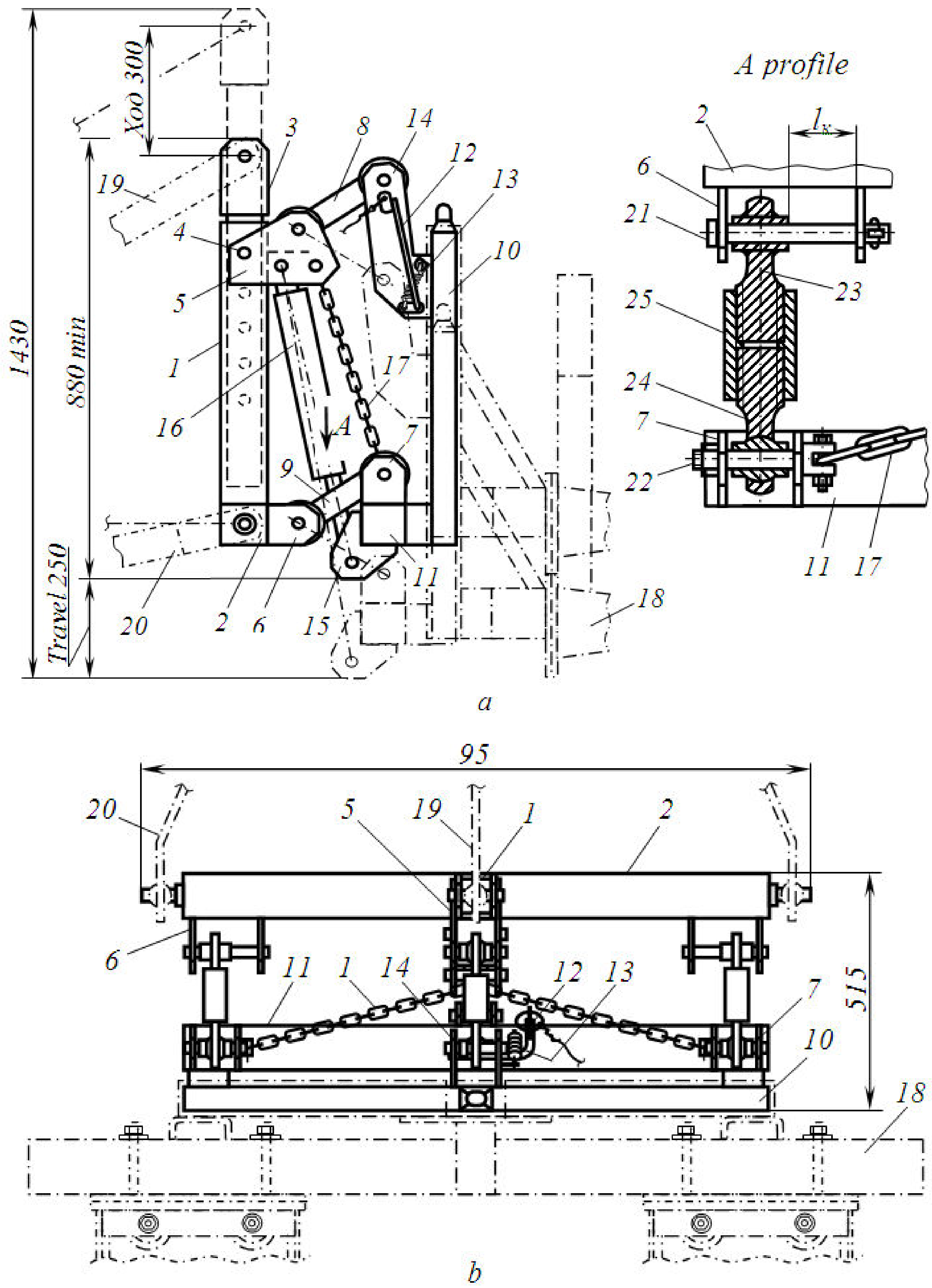

Figure-5. Device with hydraulic PGNA for tractor ancillary equipment with aggregating it with disc tools, equipped with a coupler: *a, b* - side and top views; *1* and *2* - vertical and horizontal frame beams; *3* - retractable stand with eyelet; *4* - catch; *5* - support; *6* and *7* - eyelets; *8* and *9* - upper and lower control arms; *10…15* – respectively: connecting triangle, beam, catch handle, spring, upper and lower supports of coupler frame; *16* – hydraulic cylinder; *17* - chain; *18* - cultivator; *19 and 20* - upper and lower links of the tractor ancillary equipment; *21 and 22* - fingers; *23 and 24* – heads with cylindrical and spherical bushings; *25* - threaded bushing.

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PGNA device operates as follows. Before mounting cultivator, a tractor is equipped with the device. For this purpose, the upper arm *19* of the tractor ancillary equipment is fixed in the eyelet *3* of the extendable stand of vertical bar *1* (with the help of the finger), and the two lower arms *20* are mounted and fixed with locks on the horizontal axis of the frame beam *2*. At that, the moving part of the device – beam *11* with the connecting triangle *10* of the coupler, is at the uppermost position and fixed with the chain *17*. After this, the tractor operator, maneuvering the tractor in reverse, performs the connection of connecting triangles of the coupler of the device *10* and cultivator *18*. Then, lifting the tool in the transport position with the hydraulic cylinder of tractor ancillary equipment, the tillage combine moves to the forest object.

Before the start, the tool is lowered to the ground, and the upper end of the chain *17* is detached from the support *5*. Then, with the help of fixing finger *4* which is inserted into the hole of vertical beam *1* of the device and into one of the holes in the stand with eyelet *3*, the stand is pushed and fixed at the desired height within the stroke of 300 mm. At the same time, it should be taken into account that smaller values of this variable parameter correspond to the largest displacement of SCW rod of ancillary equipment - forwards, in the direction of travel of the tractor and downwards, in the vertical longitudinal plane. Thus, the largest effect from the influence of P_z effort on the disc batteries is reached (see Figure-4). And on the contrary, with the stand going up, the value of deepening effort P_z decreases. Besides, the adjustment procedure should also include the controllability and of the front wheels and adhesion to the soil of the drive rear wheels of the tractor. Having thus established the top rod of the tractor ancillary equipment in the desired position, with regard to hardness and condition of soil, the cultivator is lowered to the ground with “floating” position of hydraulic drive distributive valve of the tractor ancillary equipment – and the unit starts to work.

During the movement of the unit at the cutting, with local changes of the hardness of the treated soil, holding disc batteries at the given depth of processing is carried out by the operator from the tractor workplace. To do this, use the appropriate section of the tractor distribution valve and of the hydraulic cylinder *16* to move the movable part of the device (beam *11*, connecting triangle *10*) up or down, as to the fixed frame of the device (beams *1* and *2*). At that, the value of the displacement stroke constitutes 250 mm which is sufficient to ensure the location of the SCW, in which the penetrability of disc batteries without the use of ballast when working on soils with different hardness is provided. Transition of the tool from working to transport position is performed in reverse order.

The peculiarity of the construction of suggested device PNGA is its ability to provide a mounted tool hinged frame, while moving at the cutting, the turns in the transverse vertical plane as to the connecting triangle of the tractor ancillary equipment at the angle β up to 20^0 in both directions (see Figure-6). This is achieved by using pivot balls at the upper *8* and lower *9* arm, and also in the eyelets of the hydraulic cylinder *14*. Thus, considering the standard turning angle of ancillary equipment connecting triangle as to the frame of the tractor, which is equal to 10-15^0, the total turning angle of the frame of the tool, mounted on the device, would always constitute 30^0. When the tool’s frame turns, the natural reduction of the distance between lower control arms *9* of horizontal beam *2* of the device is compensated by the increased distance $l_к$ in eyelets *6* (see Fig. 6a). Due to the significant increase of the angle of frame rotation, the disc batteries copy the soil surface with large curvature of the surface better, and, consequently, the quality of care for forest plantations in cuttings increases. Unlike the traditional aggregation of forest cultivators, use of the device eliminates the need for repeated passes in the clearings.

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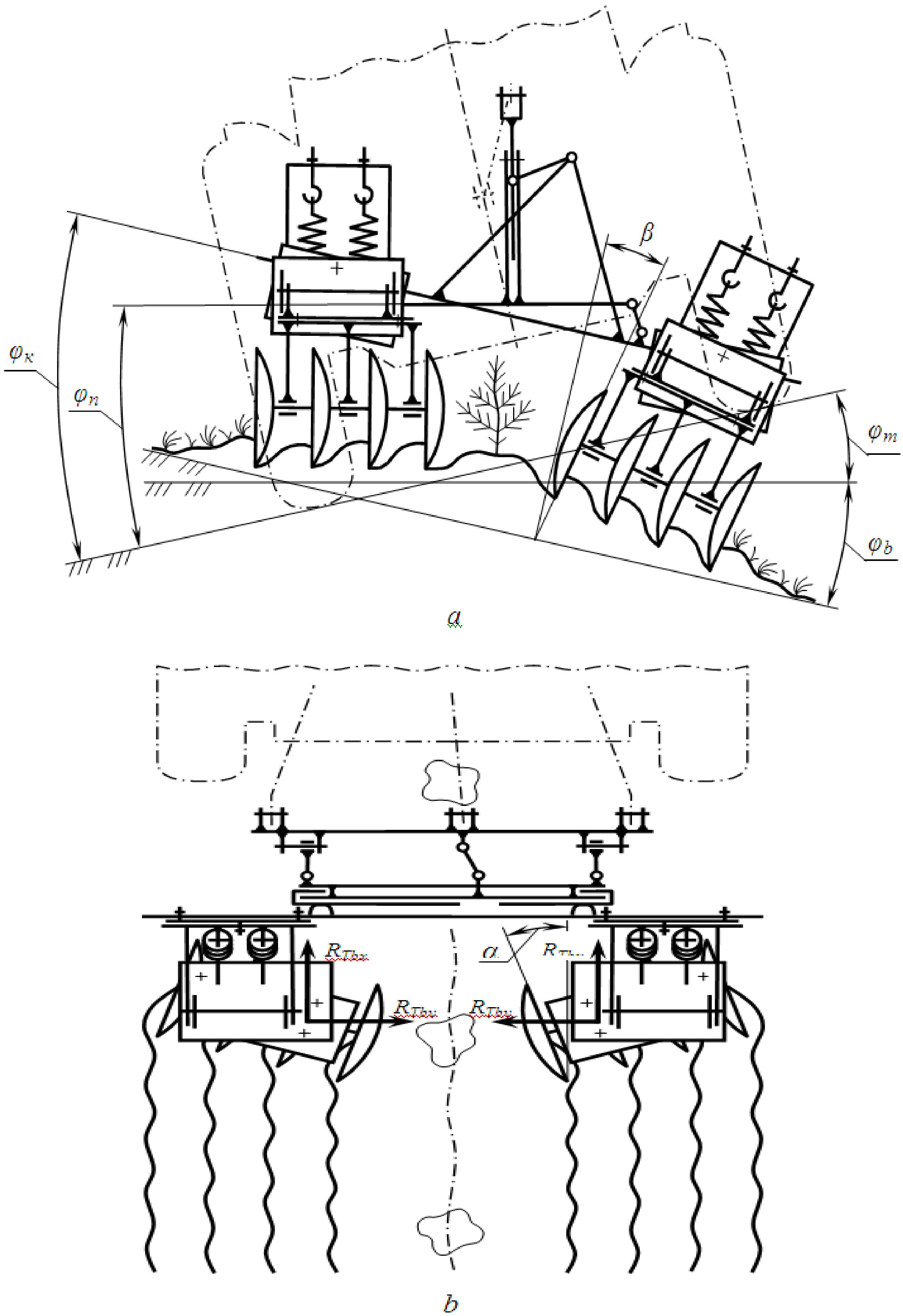

Figure-6. Scheme of the serial forest disc cultivator movement in the clearing; the cultivator is mounted on the tractor ancillary equipment using the PNGA device.

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DISCUSSIONS

The proposed design of PNGA device allows expanding the capabilities of standard ancillary equipment, especially while aggregation of tractors with mounted disc tools. This is achieved by the ability of the device to change the angle δ of the tool to a much greater extent, than is allowed by standard ancillary equipment. Thus, with the movement of the unit, the tractor operator controls from his workplace the value of the vertical component P_z of the tractor's hauling capacity, compensating vertical component P_z of the soil reaction, pushing the discs to the surface. Thus, there is no need for additional load, when the cultivator works in the clearings with different types of soil.

The authors have also developed two simpler designs of the device for similar purpose: for disc tools that are not equipped with a coupler (PN) (see Figure-7) and for tools, equipped with it (PNA) (see Figure-8).

In both designs, the rear ends of the upper rods of the tractor ancillary equipment are rearranged in the traditional way, with the help of fingers and holes in the stands. Installation and operation of devices is similar to that described above for PNGA device.

The principal difference between the two designs from the PNGA device PNGA is the need to manually swap the rear ends of the lower rods of the tractor ancillary equipment, depending on the hardness of the treated soil at the clearing. Besides, the designs of PN and PNA devices do not provide frame distortions of the mounted tool as to

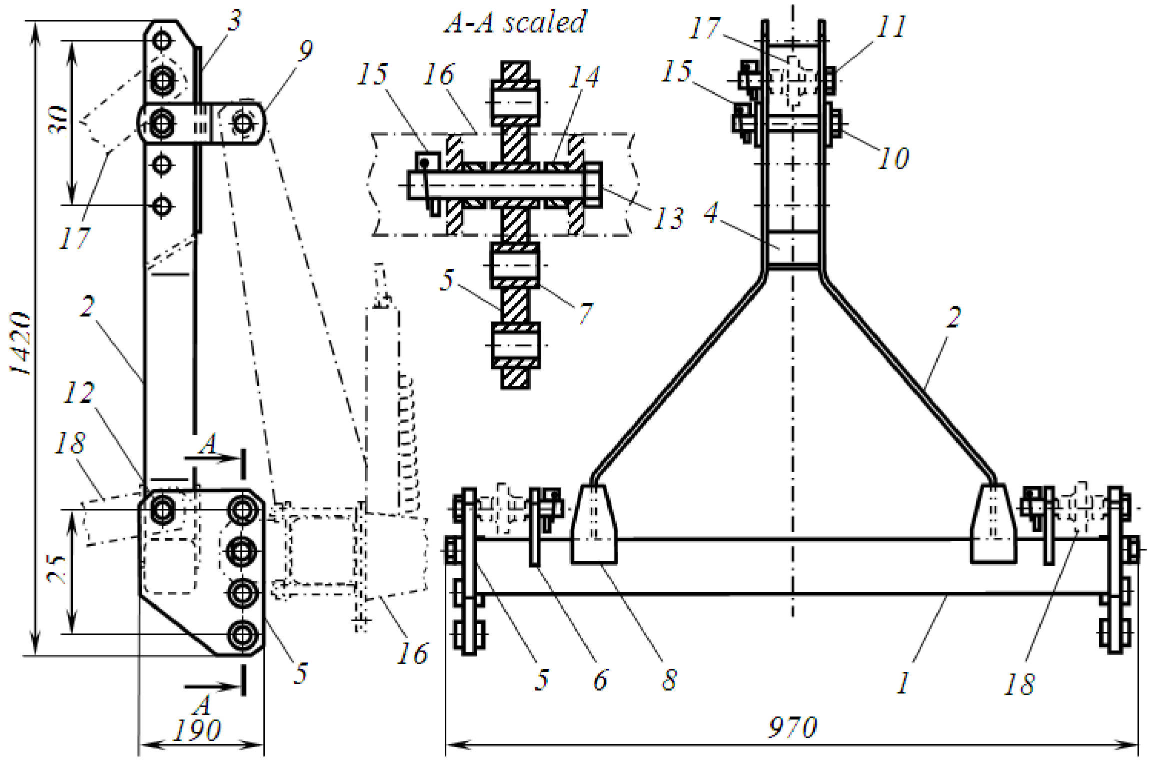

Figure-7. Adaptation of PN for tractor ancillary equipment for its aggregation with disc tools without a coupler: 1 - beam; 2 – diagonal stand; 3 - wall; 4 - strut; 5 and 6 – frontal and inner eyelets; 7 - liner; 8 - kneepiece; 9 - clip; 10, 11, 12, 13 - fingers; 14 - ring; 15 - lock; 16 - cultivator; 17 and 18 - upper and lower links of tractor ancillary equipment.

the tractor ancillary equipment of over 10-15^0, which impairs the copying of the surface by discs. Despite the simplicity of the design, these devices, unlike the standard ancillary equipment, allow serial disc tools to provide better treatment of the soil with no additional load.

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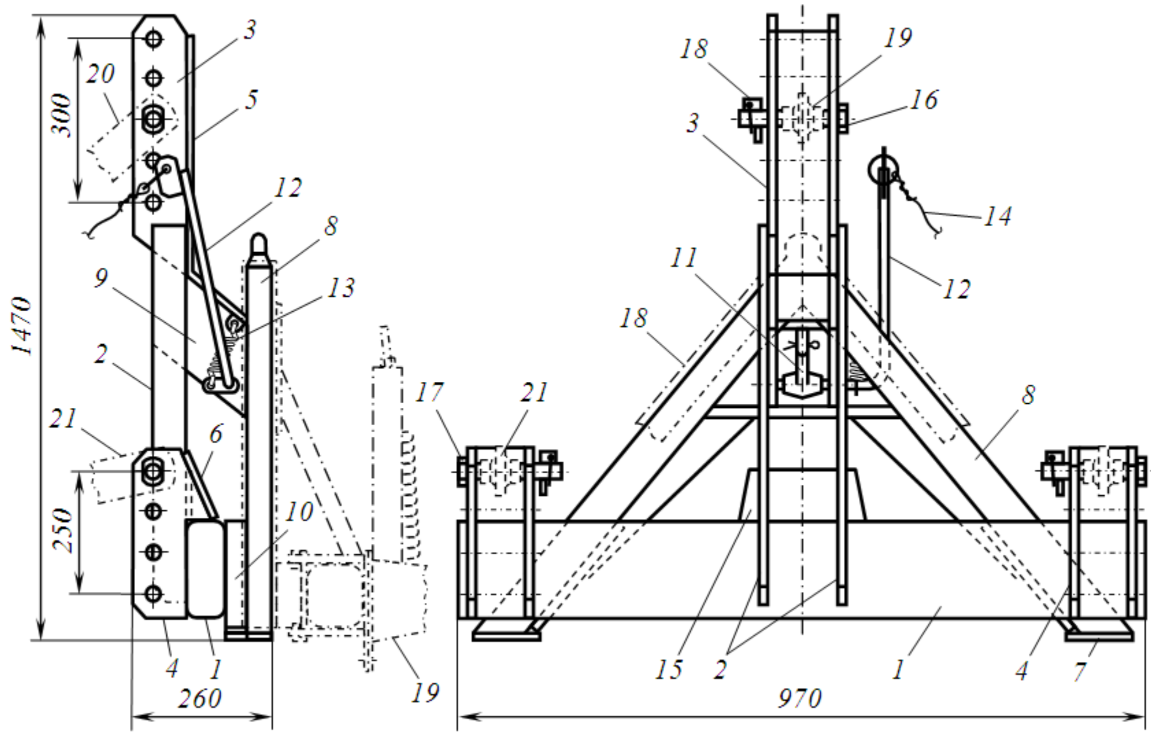

Figure-8. PN device for tractor ancillary equipment for its aggregation with disc tools with a coupler: 1 - beam; 2 - stand; 3 and 4 - upper and lower eyelets; 5 - wall; 6 and 7 - straps; 8 - frame; 9 – cheek-piece; 10 - strut; 11 - catch; 12 - handle; 13 - spring; 14 – cable thread; 15 - kneepiece; 16 and 17 - fingers; 18 - lock; 19 - cultivator; 20 and 21 - upper and lower links of tractor ancillary equipment.

In order to check the workability of the proposed designs of devices, experimental samples of them were fabricated and tested in a universal laboratory complex for field studies of tractor ancillary equipment, tillage tools and machines, running parts of wheeled and tracked vehicles (Posmetiev *et al.,* 2013). Scheme of the stand with mounted serial cultivator KLB-1.7 is shown at Figure-9, and the example of the work element on the stand during experiments with the cultivator and PNGA device - at Figure-10.

In accordance with the established methodology of laboratory experiments, as well as with the help of various additional removable devices and modern instruments, the experiments for studying the impact on the qualitative parameters of the cultivator's work with the use of proposed PN, PNA, and PNGA devices were conducted. Each series of experiments was performed three times, and was compared with the serial cultivator, mounted in the ancillary device of the stand without the device.

As removable devices during experiments on the stand, various obstacle simulators were used (stumps, roots that could or could not be cut by the discs, shoots), and soils with various hardness levels. Necessary soil hardness within the range of 2, 000-4, 000 N/m was achieved by layer-by-layer compaction and vibrating rammer after each pass of the cultivator. Working stroke of the trolley *8* in guides *9* with installed removable equipment *10* on it was provided by means of telescopic hydraulic cylinder *7* to the maximum stroke of 3 m, with a hauling capacity of up to 1 t and movement speed of 0.5-1.5 m/s.

During the experiments at the stand, the following 12 parameters were measured at the same time: efforts at the top and both bottom links of the tractor ancillary equipment; work fluid pressure in the hydraulic cylinder of PNGA device; horizontal and vertical displacements, rotation angles of cultivator's frames and of the device in the transverse vertical plane; operating depth of each of the two disc batteries. The first four parameters were recorded by a wireless remote strain measurement, and the rest - by digital video recording, image recognition, processing, transmission, storage, and analysis of data about the researched objects.

Wireless strain measurement of the recorded parameters was conducted the following way. Deformation from mechanical stress in the links of the tractor ancillary equipment and of the pressure sensor was registered by

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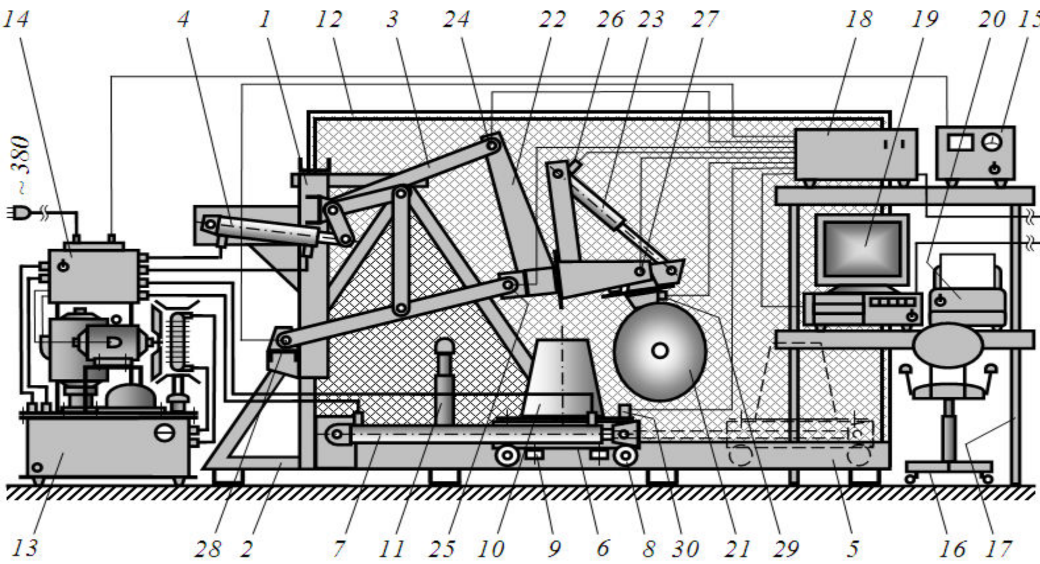

Figure-9. Scheme of universal laboratory complex for field studies of tractor ancillary equipment, tillage tools and machines, running parts of wheeled and tracked vehicles: 1 - wall; 2 - sidewall; 3 - removable ancillary equipment; 4 – hydraulic cylinder of the ancillary equipment drive; 5 - guides; 6 - trolley; 7 – hydraulic cylinder of trolley drive; 8 and 9 – leading and guide wheels of the trolley; 10 – obstacle simulator; 11 - mounted device links rotation limiter; 12 - fencing; 13 – hydraulic pump unit; 14 - pilot valve assembly; 15 - hydraulic pump unit remote control; 16 – operator's workplace; 17 - equipment rack; 18 - strain measurement equipment; 19 - computer; 20 - printer; 21 - cultivator disc battery; 22 and 23 - frame and hydraulic cylinder of cultivator safety lever; 24-30 – strain gauges, respectively: upper and lower strain measuring fingers, of pressure in hydraulic cylinder of cultivator safety lever, of disc batteries and lower link of mounted device rotation, of strain on disc battery stand, of linear trolley accelerations.

strain gauges and converted into electrical signals that were amplified by differential and normed amplifiers to the desired value. After filtration, they were transferred to analogue-digital converter of the microcontroller, coded and shaped in the form of relevant protocols. Next, the digital signal went in the radio and, after amplification using wireless Wi-Fi connection, was transferred to the computer.

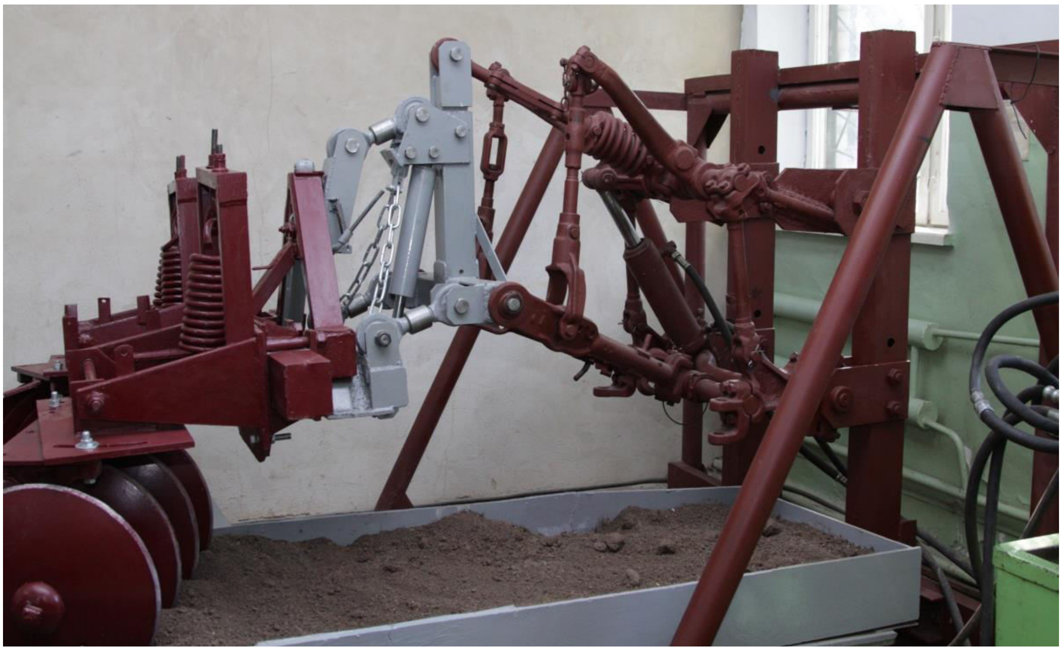

Figure-10. The working element of the experiment on the test stand on the example of PNGA device with mounted serial forest disc cultivator KLB-1.7.

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The developed methodology and the results of experiments made it possible to check the performance and with sufficient precision and accuracy evaluate the effectiveness of the proposed designs of the devices for the standard tractor ancillary equipment (see Table-1). As a result of the experiments performed at the stand trolley speed of 1.0 m/s, the following results were found.

Table-1. Specifications of devices for tractor's standard ancillary equipment.

Parameters	Type of device		
	PN	PNA	PNGA
1 Dimensions of standard used tractor ancillary equipment (class of tractor)	NU-2 (0.6-2)		
2 Mounting dimensions of the tractor and mounted tool	Corresponds to GOST 10677-2001 hitch attachment rear device for agricultural tractors of classes 0,6-8,0. Types, basic parameters, and dimensions		
3 Admissible weight of mounted tool at a distance of 610 mm from the suspension axis, kg: without automatic coupler SA-1 with automatic coupler SA-1	 1600 1400		
4 Maximum working depth, cm, with soil hardness, N/m: 2000 3000 4000	 12 10 –	 12 12 –	 12 12 6
5 Maximum angle of the mounted tool frame in cross-vertical plane as to the reference surface of the tractor, degr.	10-15	10-15	25-30
6 Displacement of internal discs into a protective area of simulated processed row, cm, with a value of cultivator frame total skewing, degr.: 10 20 30	 5 17 30	 5 17 30	 2 4 6
7 Working fluid pressure in the hydraulic drive, MPa	–	–	>= 5
8 Overall dimensions, mm: width height, max/min length	 190 1,420/- 970	 260 1,470/- 970	 515 1,430/880 955
9 Weight, kg	51	65	85
10 Ability of setting depth of soil by the disc tool working bodies from the tractor cab	no	no	yes

When using the devices, the values of strain on the tractor ancillary equipment links increased on average by 20%. This is due to higher operating resistance of the tool, by the means of increased depth of processing of its working bodies, as well as to the increase in the time from the action of reactive forces on the disc batteries by the means of greater height of the tool suspension axes.

The data table shows that all three constructions of the devices ensure operation of the disc cultivator operation on soils with hardness within the range of 2, 000-4,000 N/m, processing depth of 10-12 cm, average movement speed of 1 m/s, and uneven soil surface with deviations within the range of 10-30^0. Under the same experimental conditions, the cultivator KLB-1.7 without the device ensured the desired cutting depth of 10-12 cm on the soil with hardness of up to 2, 000 N/m, without any additional load; with hardness of up to 3, 000 N/m - with load of 90 kg and with hardness of up to 4,000 N/m - with load of 250 kg. Here the difference between the similar theoretical values of the same load weights (121 and 326 kg, respectively) at soil hardness of 3,000 and 4,000 N/m may be explained by the allowances, as well as by neglect during the experiments of the presence of plant inclusions in the soil and weed growths on the surface of the processed row.

Measurements of displacement y_2 (see Figure-3, b) of inner battery discs of the cultivator in the protection zone of the processed row show the effectiveness of PNGA device, the use of which will limit the shift by the safe value of 2-6 cm. This is achieved by the provided ability of PNGA design to copy the surface of the processed row with cultivator frame skewing to 30^0. During the similar conditions of experiments at the stand, the PN and PNA devices showed the same values of disc shift in the protection zone, safe - 5 cm, with cultivator frame skewing up to $10\text{-}15^0$, and unacceptably large shifts - 17-30 cm with skewing of $20\text{-}30^0$. In the latter case, the probability of damage to seedlings is very high, as the value of protection zone is 20-25 cm from each side of the row. The similar high values of disc shifts were recorded for the cultivator, mounted on the tractor without the device. Unacceptably large disc shifts in the cultivators with or without the PN and PNA devices are explained by their inability to provide a full copying by the working bodies of the processed surface of the row. The main reason for this is the inability of these devices to ensure the frames of the mounted tools have the skewing angles in cross-vertical plane of over $10\text{-}15^0$. For this reason, when total value of the tool frame and tractor support surface skewing angle is over 15^0, one of the disc batteries partially or completely loses contact with the ground, and as the disc are set at the angle of attack ($10\text{-}30^0$) along the path of the unit, the displacement of the whole tool as to the row axis is inevitable.

The results of the research allow us to conclude the following. The proposed constructions of PN, PNA, and PNGA devices are supplementary to the standard ancillary equipment of tractors of drawbar category of 0.6-2. 0, they can be easily installed and removed by one person, do not require any modifications of tractor ancillary equipment and of connecting device (coupler) of the mounted disc tool. The mechanisms are simple in construction and maintenance, and their production does not require scarce materials and may be performed by mechanizers in machine-repair shops.

The method for improving the penetrating ability of disc working bodies with the help of removable devices, which provides a wide-scale correction of SCW position of standard mounted devices' units, was constructed on an example of forest mounted disc cultivator. It may be applied with other forest mounted forest and agricultural tools. For heavier mounted disc tools - ploughs, harrows, etc., with the dimensions of ancillary equipment of tractors NU-3 and NU-4, respectively, for aggregation with tractors of drawbar category 3-4 and 5-8, it is possible to use the reinforced devices, similar to design to PN, PNA, and PNGA. Use of the offered devices for forest tractors' ancillary equipment allows:

-increasing productivity of forest tillage machines and decreasing agronomic time, required for technological operations of forest restoration on the clearing which are not stump, due to lack of need for repeated passes on the processed plantations rows, and decreasing the wait caused by tool damage due to decrease of strain on working bodies during clearing of obstructions;

-improving the quality of soil treatment by means of better penetrability and stability of disc run at the required depth and by means of decreasing the damage to forest plantations due to lesser lateral displacement of working bodies;

-decreasing weight and bulk of tools by means of refusing the use of the ballast and decreasing the loads;

-decreasing fuel consumption by the aggregated tractor during work at the clearings, which are not stump, due to decrease of repeated passes, decreasing weight, and working resistance of tillage tool.

The next stage of the research is the conduct of technical test of developed ancillary equipment in real conditions of forest disc tools exploiting on the clearings. Results of this test and detailing of main constructive parameters of mounted devices will be the basis for recommendations as to their effective use and manufacturing application.

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