# JUSTIFICATION OF DESIGN AND TECHNOLOGICAL PARAMETERS OF THE ONION HARVESTER BED-SHAPING ROLLER SPIRAL DRUM
# /
# *ОБОСНОВАНИЕ КОНСТРУКТИВНЫХ И ТЕХНОЛОГИЧЕСКИХ ПАРАМЕТРОВ СПИРАЛЬНОГО ВАЛЬЦА КАТКА-ЛОЖЕОБРАЗОВАТЕЛЯ МАШИНЫ ДЛЯ УБОРКИ ЛУКА*

**Dorokhov A.S., Aksenov A.G., Sibirev A.V., Sazonov N.V.** [1]
FSBSI "Federal Scientific Agronomic and Engineering Centre VIM" / Russian
*Telephone: 89645843518; E-mail: sibirev2011@yandex.ru*
DOI*: https://doi.org/10.35633/inmateh-60-12*

***Keywords:*** *onion sets, cleaning, repair work, finishing working bodies, design and technological parameters, roller-forming agent*

## ABSTRACT

*One feature of harvesting seed onions is that the impurities of the onion-soil pile coming from the digging executive devices to the separating executive devices contain soil lumps that are similar in size with the seed onion bulbs and hard to separate at the slotted (bar elevators, screens) executive devices (M. Tauseef Asghar, 2014). This problem is most urgent when collecting seed onions from the rolls, because together with the bulbs the separating executive devices receive the soil layer loosened by the digging executive devices during the first phase of harvesting seed onions, the fractional composition core of which is soil lumps similar to bulbs and hardly separable on slotted executive devices. This circumstance is explained by the fact that after the soil layer is undercut together with the saleable produce, a significant amount of soil lumps, hardly separable on the separating executive devices and causing damage to root crops and bulbs during their interaction, arrives to the separating executive device. In addition, separation of soil lumps on slotted executive devices (bar conveyors and screens) occurs according to dimensional properties and this does not solve the existing problem – separation of soil lumps comparable in size with seed onion bulbs. Consequently, to ensure qualitative indicators of harvesting seed onions, namely, the separation completeness of the bulbs from soil impurities, it is necessary to ensure a reduction or complete elimination of the flow of soil lumps to the separating executive devices at the second harvesting phase.*

## РЕЗЮМЕ

*Особенностью уборки лука-севка является то, что состав примесей луко-почвенного вороха, поступающего с выкапывающих на сепарирующие рабочие органы, составляют почвенные комки, соизмеримые по размерам с луковицами лука-севка, которые являются трудноотделимыми на щелевых (прутковые элеваторы, грохоты) рабочих органах. Данная проблема является наиболее актуальной при подборе лука-севка из валков, так как совместно с луковицами на сепарирующие рабочие органы поступает почвенный слой, взрыхленный подкапывающими рабочими органами в первой фазе уборки лука-севка, основу фракционного состава которого составляют почвенные комки соизмеримые с луковицами и являющиеся трудноотделимыми на щелевых рабочих органах. Данное обстоятельство объясняется тем, что после подкапывания пласта почвы совместно с товарной продукцией, на сепарирующие рабочие органы поступает значительное количество почвенных комков, которые являются трудноотделимыми на сепарирующих рабочих органах и приводят к повреждению корнеплодов и луковиц при их взаимодействии. Кроме того, выделение почвенных комков на щелевых рабочих органах (прутковые транспортеры и грохоты) происходит по размерным признакам и это не приводит к решению существующей проблемы – сепарации почвенных комков, соизмеримых по размерам с луковицами лука-севка. Следовательно, для обеспечения качественных показателей уборки лука-севка, а именно – полноты отделения луковиц от почвенных примесей необходимо обеспечить снижение или полнейшее исключение поступления на сепарирующие рабочие органы почвенных комков во второй фазе уборки, что и интенсифицирует предлагаемый каток-ложеобразователь машины для уборки лука.*

---

[1] *Dorokhov. A.S., Prof. PhD. Eng.Sc.; Aksenov A.G., PhD. Eng.Sc.; Sibirev A.V., PhD. Eng.Sc.; Sazonov N.V., Eng.Sc.*

## INTRODUCTION

Analysis of the current state of methods and technical means to reduce the content of soil impurities in commercial products of seed onions showed that the development of science-based technical solutions facilitating the reduction in the content of soil impurities during onion harvesting requires, first of all, additional theoretical and practical research on the effects of executive devices and factors affecting the separation completeness of soil lumps when harvesting seed onions during both the first and the second phases *(Aksenov A.G., Sibirev A.V., Emelianov P.A., 2018).*

Based on the technological process of harvesting seed onions, it is known that formation of a high-quality prepared bed for laying bulbs in a roll is the final operation in a complex chain of industrial production. Therefore, qualitative indicators of harvesting are determined by how well the previous process operations have been performed *(Lobachevsky Ya.P., Emelyanov P.A., Aksenov A.G., Sibirev A.V., 2016)*. Bearing this in mind, in order to increase the efficiency of harvesting machines, the search for structural and technological solutions shall be aimed at restricting the supply of over-compacted particles by levelling the surface of a dense bed *(Natenadze N., 2016).*

Eventually, the next operation of harvesting seed onions, which is collection of bulbs from the rolls after post-ripening in vivo, depends on the quality of the prepared bed.
Most onion harvesters, by foreign ("*Simon", France, "Krukowiak", Poland*) and domestic manufacturers of agricultural machinery, currently use passive press wheels (fig. 1) made of various materials to form the bed-forming area, and some even have none whatsoever *(Lobachevsky Ya.P., Emelyanov P.A., Aksenov A.G., Sibirev A.V., 2016)*.

**Fig. 1 – Bed-forming device of the Z-653/1 onion harvester, "Krukowiak", Poland**

The roller of the onion harvester prepares the surface before laying the roll, which facilitates faster drying of the onions. The increased diameter and plastic surface ensure smooth rotation and keep wet soil from sticking.

The disadvantage of this bed-forming device is the inability to prepare an optimally flat ridge for efficient collection of seed onions, because of the insufficient functionality to level the surface of the bed being formed *(Kurdyumov V.I., Zykin E.S., Lazutkina S.A., 2016).*

The bed-forming device of the onion harvester manufactured by *"Samon" and "IMAC" Holland,* is a passive cylindrical roller with wave-shaped protrusions along the shell, in parallel with the roller axis (fig. 2).


*a)* *b)*

**Fig. 2 – Bed-forming device of the disk onion harvester «Samon» (A) and «IMAC» (B) (Holland)**

A serious disadvantage of the known bed-forming device is that a dimple-shaped profile is formed on the surface of the created bed, where bulbs are accumulated in the indentations that formed, and when collection is performed, more soil is lifted to the separating executive devices, and more bulbs are lost, due to the inability to collect the bulbs efficiently.

There is also a known bed-forming device of a root lifter.

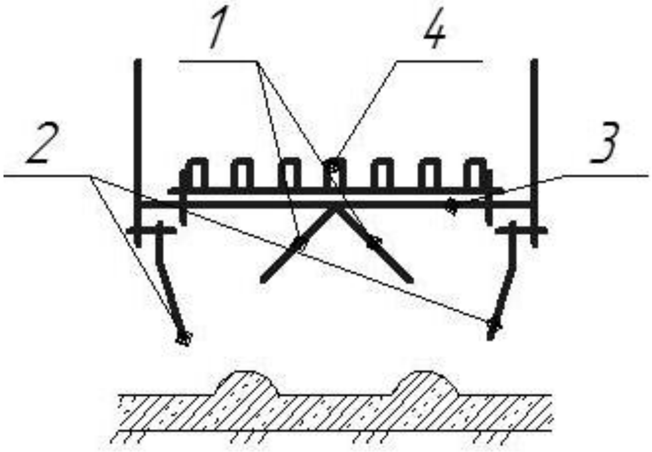


**Fig. 3 – Bed-forming device:**
*1 – tray; 2 – deflector shields; 3 – separating device; 4 – sieves*

This device (fig. 3) is made in the form of a duo-pitch tray *1* and deflector shields *2*, where the top of the duo-pitch tray *2* faces the separating surface *3*, with the pitches made as wedges, with tops aimed at the raising executive device, and the deflector shields are attached to the sides of the separating executive device, leaned towards one another.

The disadvantage of the said bed-forming device is the complexity and metal consumption of the structure, and the bed formed by the device contributes to the bulbs rolling away across the field and, as a consequence, increased loss when collecting the seed onions from the rolls.

## MATERIALS AND METHODS

In this regard, to reduce the flow of soil lumps to the separating executive devices together with seed onion bulbs during the second harvesting phase, i.e. when collecting from the rollers, as well as to intensify separation of seed onions from comparable soil lumps, a bed-shaping roller (RF patent № 2601060) for an onion harvester has been developed, which facilitates the reduction of the flow of soil lumps to the separating executive devices during the second harvesting phase of seed onions *(Aksenov A.G., Pryamov S.A., Sibirev A.V., 2016*).

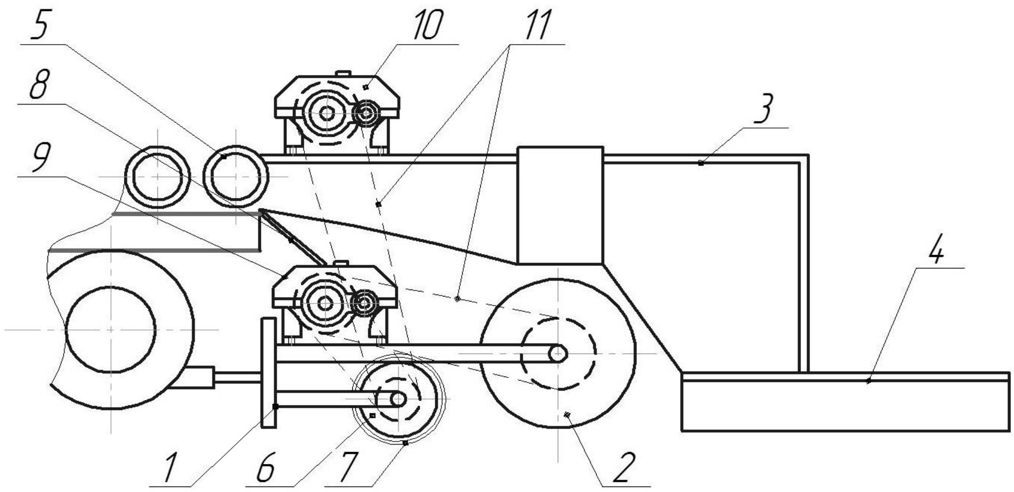


**Fig. 4 – Structure diagram of an onion harvester bed-shaping roller**
*1 – frame; 2 – spiral drum; 3 – narrowing tray; 4 – roller shaper; 5 – roller separator; 6 – spiral drum; 7 – segment; 8 – impurity discharge tray; 9, 10 – gear units; 11 – chain transmission*

A bed-shaping roller (figure 4) consists of frame *1*, cylindrical drum *2*, narrowing tray *3* and roller shaper *4*, separating elevator *5*, under which spiral drum *6* is mounted on frame *1* with a peripheral cross-section shaped along its entire length in the form of segment *7*, impurity discharge tray *8*, gearbox *9* and *10* adjusting the rotation speed of the rollers and chain transmission *11*.

Bed-shaping roller operates as follows.

Along with progressive rotation of spiral roller *6* across the field, it compresses the soil to the optimal value with its cylindrical surface, while its protrusions located on the surface of spiral roller *6* in the form of segment *7* symmetrically relative to the transverse axis create a wavy terrain on the soil surface. Spirals *7* of roller *6* form a depression on the surface of the field, and due to the fact that the beginning and the end of each protrusion of segment *7* are on the same shaping line of spiral roller *6* and coincide with the middle of the next protrusion, the roller's movement is uniform, it does not displace the soil and produces no shock impact. Smooth cylindrical drum *2* mounted behind spiral roller *6* solidifies and forms restrictive ridges located along the edges of the harvested field surface.

Thus, the bed shaped by the bed-shaping roller prevents the bulbs from rolling away and is formed from loose, separated, fine-grained soil without compaction, which eliminates or reduces to the minimum the subsequent flow of soil lumps to the machine separating devices when collecting the bulbs from the swath, and, as a result, reduces the content of soil and plant impurities, as well as injury to the seed onions when they are collected from the rollers, by forming a bed of adjustable density for the swath, ensuring product bletting on its surface.

One of the main parameters, along with the structural composition of the lumps of soil in the onion roll, which determine the quality of the roller-bed forger of the onion harvesting machine, is the degree of loosening of the soil (*Sojka R.E., Horne D.J, Ross C.W, Baker C.J., 1997*).

An increase in the rotational speed of the rollers of the bed-forming machine leads to an increase in the peripheral speed of the spiral $v_0$and cylindrical $v_{CF}$ rollers, which positively affects the quality of soil grinding, i.e. increase the degree of soil loosening (*Farhadi R., Sakenian N., Azizi P., 2012*).

## RESULTS AND DISCUSSION

To ensure a well-prepared bed for a seed onion swath, it is necessary for the spiral drum of the bed-shaping roller to grind soil lumps to sizes smaller than the minimum diameter of a standard onion fraction, so that the bulbs on the separating executive devices get cleaned from small soil impurities (since the receiving-undercutting part of the onion harvesting machine, together with the bulbs, collects soil clumps that are hard to separate, due to their size comparable with standard bulbs) (*Hevko R.B., Tkachenko I.G., Synii S.V., 2016).*

Based on the foregoing, it follows that the maximum diameter $\mathrm{d_{Kmax}}$ of a soil lump should be less than the minimum diameter $\mathrm{D_{Lmin}}$ of a standard seed onion fraction, i.e.*:*

$$\mathrm{d_{Kmax}} \leq \mathrm{D_{Lmin}} \tag{1}$$

where:

$\mathrm{d_{Kmax}}$ – is the maximum diameter of a soil lump, m.

The minimum diameter of the $\mathrm{d_{CP}}$ bed-shaping roller spiral drum is determined based on the maximum size $\mathrm{d_{Kmax}}$ of the soil lump formed after the plough of the onion harvester undercuts the soil layer, to ensure that the soil clump is caught between the spiral and the drum of the bed-shaping roller:

$$\mathrm{d_{CP_B}} \geq \frac{\mathrm{d_{Kmax}} \cdot \cos\varphi}{(1-\cos\varphi)} \tag{2}$$

This condition is met when the soil lumps, after passing the spiral drum of the bed-shaping roller, compose a single fraction, since according to agrotechnical requirements, the quality of soil grinding is estimated by its fractional composition (*Kamaletdinov R.R., 2012*)

We shall consider the geometrical dimensions of soil lumps ground by the bed-shaping roller spiral drum (figure 5).

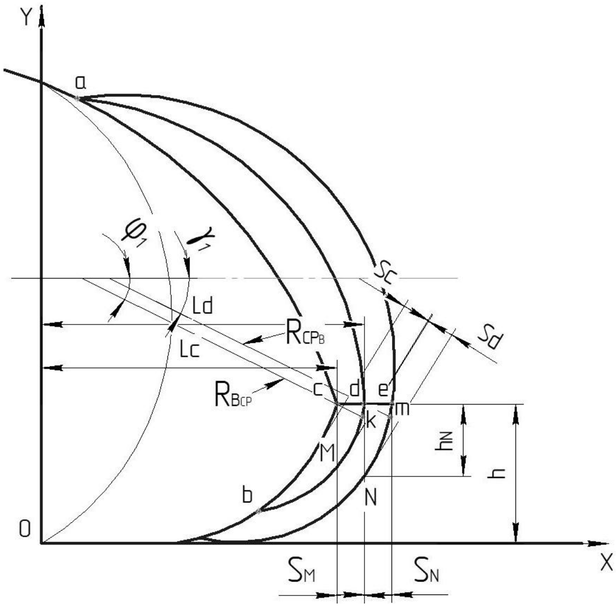


**Fig. 5 – Diagram for determining the diameter of the onion harvester bed-shaping roller spiral drum**

The width and height of soil lumps M and N depend on the thickness of the inverted soil layer and coverage $B_{CP_B}$ of the bed-shaping roller spiral drum.

Therefore, in order for soil lumps M and N to constitute one fraction, it is necessary to ensure uniformity of their maximum thickness.

For this, the soil clump (M + N) limited by two trajectories — the spiral and the drum of the spiral roller, must be divided in the longitudinal section of the spiral path in such a way that the maximum soil clump thickness F –($\delta^{M}_{MAX}$) in the inverted soil layer is equal to the maximum thickness of soil clump G – ($\delta^{N}_{MAX}$).

Let's assume that the equality

$$\delta^{M}_{MAX} = \delta^{N}_{MAX_2} \tag{3}$$

is valid when the roller spiral path $\delta^{(M+N)}_{MAX}$ is divided in half.

The value $R_{CP_B}$ should be such that the points of contact $R_{B_{CP}}$ and $R_{CP_B}$ with the surface of the inverted soil layer in the longitudinal-vertical plane are located at a distance

$$S_M = S_N = \frac{2\pi \cdot R_{B_{CP}}}{\varrho\lambda} \tag{4}$$

where:

$\varrho$ – is the angle between the turns of the bed-shaping roller drum spiral, degrees;

$\lambda$ – kinematic indicator of the bed-shaping roller spiral drum.

$$\lambda = \frac{v_0}{v_D} \tag{5}$$

where:

$v_0$ – is the circumferential speed of a bed-shaping roller drum spiral, m/s;

$v_D$ – is the progressive speed of the harvester movement, m/s.

In coordinates XOY segment $S_F$ is parallel to the abscissa axis, therefore the distance from the ordinate axis to point *d* must be greater than the distance from the ordinate axis to point *c* by the value $S_M$:

$$L_d = L_c + \frac{2\pi \cdot R_{B_{CP}}}{\varrho\lambda} \tag{6}$$

Value $L_c$ is determined by the sum of projection of segment $R_{B_{CP}}$ on the abscissa axis and the progressive movement of the bed-shaping roller spiral drum during turn $R_{B_{CP}}$ until contact with the soil, i.e. at angle $\varphi_1$:

$$L_c = \frac{\varphi_1 \cdot R_{B_{CP}}}{\lambda} + R_{B_{CP}} \cdot \cos\varphi_1 \tag{7}$$

Angle $\varphi_1$ of turn $R_{CP_B}$ until contact with the surface of the inverted layer:

$$\varphi_1 = (\alpha + \gamma_1) \tag{8}$$

where:

$\gamma_1$ – is the angle at which the bed-shaping roller spiral drum enters the soil, deg.

Therefore, value $L_d$ is determined by the sum of projection of segment $R_{CP_B}$ on the abscissa axis and the progressive movement of the bed-shaping roller spiral drum for the period $t$ during the turn at angle $\varphi_1$:

$$\varphi_1 = (\alpha + \gamma_1) \tag{9}$$

$$L_d = \frac{(\alpha+\gamma_1)\cdot R_{B_{CP}}}{\lambda} + R_{CP_B} \cdot \cos\gamma_1 \tag{10}$$

By inserting (7) and (10) into equation (6) we obtain:

$$\frac{(\alpha+\gamma_1)\cdot R_{B_{CP}}}{\lambda} + R_{CP_B} \cdot \cos\gamma_1 = \frac{\varphi_1 \cdot R_{B_{CP}}}{\lambda} + R_{B_{CP}} \cdot \cos\varphi_1 + \frac{2\pi \cdot R_{B_{CP}}}{\varrho\lambda} \tag{11}$$

Using expression (11) we shall express angle $\gamma_1$, for which we shall determine the distance from the abscissa axis to points *d* and *c,* and also equate them, thus.

$$\gamma_1 = \arcsin\left(\frac{\sin\varphi_1}{R_{CP_B}/R_{B_{CP}}}\right) \tag{12}$$

By inserting (12) into formula (11) we have:

$$\frac{\pi/\varrho - \varphi_1 + \arcsin\left(\frac{\sin\varphi_1}{R_{CP_B}/R_{B_{CP}}}\right)}{\cos\varphi_1 - \sqrt{\left(R_{CP_B}/R_{B_{CP}}\right)^2 - \sin^2\varphi_1}} = \lambda \tag{13}$$

Expression (13) makes sense when:

$$R_{CP_B}/R_{B_{CP}} > \sin\varphi_1. \tag{14}$$

Coverage $B_{CP_B}$ of the bed-shaping roller spiral drum (figure 6) is determined by the technological width of the undercutting device $B_K$, which in turn depends on the technological pattern of sowing onions, the width of the screening conveyor $B_T$ and the distance $S_K$ between the guards narrowing the pile which leaves the executive device of the harvester.

Since the last factor affecting the width of the formed swath based on the technological process of harvesting onions is distance $S_K$ between the narrowing guards *1*, coverage $B_{C\Pi_B}$ of bed-shaping roller spiral drum *2* should meet the inequality:

$$B_{CP_B} \geq S_K \tag{15}$$

The loose soil layer is formed as a result of crumbling and grinding soil lumps after the bulbs are removed from the soil by the plowshares of the onion harvester (*V. Mayer, D. Vejchar, L. Pastorková, 2017*). The spiral winding on the roller contributes to intensification of the process of crushing soil lumps by the harvester bed-shaping roller.

To determine winding pitch $t_{CP}$ of the spiral and angle $\Sigma$ of its inclination to horizontal axis OO of the roller, we shall consider the forces affecting a soil clump. Soil clump K is affected by the impact force of spiral $F_{CP}$ (figure 7), which can be split in two components – normal $F_N$ and tangential $F_\tau$.

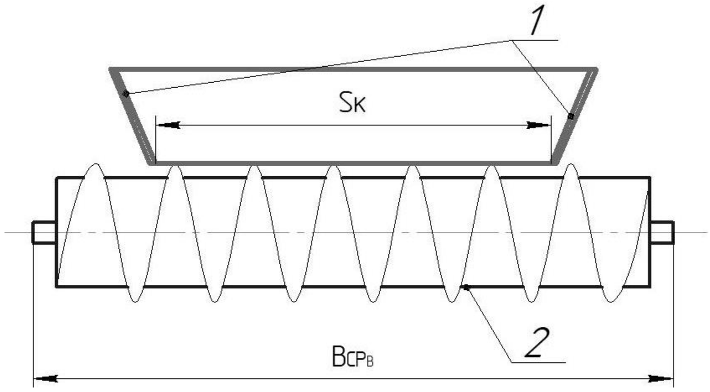


**Fig. 6 – Diagram for determining the spiral drum width**:
*1 – narrowing guards; 2 – spiral drum*

A soil clump is moved along the surface of the spiral on condition that:

$$F_\tau \geq F_{TP} \tag{16}$$

where:

$F_{TP}$ – is the friction force of the soil against the surface of the spiral, N.

Determining the friction force (figure 7):

$$F_{TP} = F_N \cdot \mathrm{tg}\varphi_P \tag{17}$$

where:

$\varphi_P$ – is the friction angle of soil clumps against the surface of the spiral, deg.

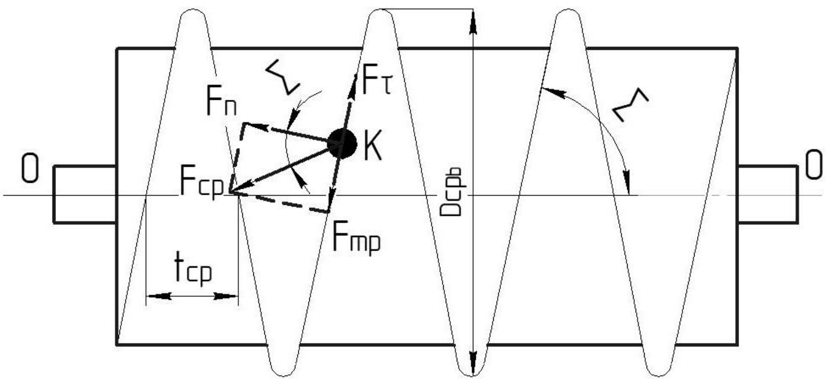


**Fig. 7 – Diagram of the forces affecting a soil clump through the drum spiral**

Determining $F_\tau$ the tangential component of the force $F_{CP}$:

$$F_\tau = F_N \cdot tg\Sigma \tag{18}$$

Taking into account formulae (17) and (18), condition (16) will be written as:

$$tg\Sigma \geq tg\varphi_P \tag{19}$$

Thus, angle $\Sigma$ of inclination of the spiral to horizontal axis OO should be greater than angle $\varphi_P$ of friction of soil lumps on the surface of the spiral.

Based on the theory for calculation of the design parameters of screw machines, we have:

$$t_{CP} = tg\Sigma \cdot \pi \cdot D_{CP_B} \tag{20}$$

where:

$D_{CP_B}$ – is the diameter of the spiral drum, m.

Besides, it is known that in order to prevent soil loading by the bed-shaping roller spiral drum, diameter $D_{CP_B}$ of the drum should be determined:

$$D_{CP_B} = d_{Kmax} \cdot ctg^2(\varphi_1 + \varphi_P) \tag{21}$$

where:

$d_{Kmax}$ – is the maximum diameter of a soil clump, m;

$\varphi_1$ – is the angle of internal friction between soil lumps, deg.

Taking into account formula (21), the expression determining the pitch of the spiral shall be written as follows:

$$t_{CP} = tg\Sigma \cdot \pi \cdot [d_{Kmax} \cdot ctg^2(\varphi_1 + \varphi_P)] \tag{22}$$

Due to the fact that the onion harvester bed-shaping roller spiral drum performs the technological process of working in line with the onion harvesting machine with the progressive $v_D$ movement speed within 2.8...5.6 km/h, then with a known range $\lambda = 6 \dots 9$ of the spiral drum kinematic indicator, based on the results of earlier studies related to operation of rotary soil tillage machines for tilled crops (*Sun D.X, Zhang A.M, Gong J.X., 2016*), providing high-quality grinding of the inverted soil layer, we shall determine rotational speed $n_{CP_B}$ of the bed-shaping roller spiral drum.

It is known that

$$\lambda = \frac{v_0}{v_D} = \frac{\omega_{CP_B} \cdot R_{CP_B}}{v_D} \tag{23}$$

Due to the fact that

$$\omega_{CP_B} = \frac{\pi \cdot n_{CP_B}}{30} \tag{24}$$

where:

$n_{CP_B}$ – is the rotation speed of the bed-shaping roller spiral drum, rpm.

By inserting expression (24) into expression (23) we get:

$$n_{CP_B} = \frac{30 \cdot v_D \cdot \lambda}{\pi \cdot R_{CP_B}} \tag{25}$$

## CONCLUSIONS

Theoretical studies of the bed-shaping roller of an onion harvester made it possible to obtain dependencies for determining diameter (2) and pitch (22) of the spiral, as well as width (15) of coverage, kinematic indicator (23) and rotation frequency (25) of the bed-shaping roller spiral drum.

Based on the theoretical studies performed, a bed-shaping roller was made, which was subjected to laboratory and field tests to justify the optimal design and technological parameters.

## REFERENCES


[1] Aksenov A.G., Sibirev A.V., Emelianov P.A., (2018), Oriented Bulbs Planting with Forked-Roller Planting Apparatus, *Vestnik of Mordovia University*, Issue number 1, pp. 20-24, Saransk / Russia;

[2] Farhadi R., Sakenian N., Azizi P., (2012), Design and construction of rotary potato grader, *Bulgarian Journal of Agricultural Science*. Issue number 2, pp. 304-314, Sofia / Bulgaria;

[3] Hevko R.B., Tkachenko I.G., Synii S.V., (2016), Development of design and investigation of operation processes of small-scale root crop and potato harvesters, *INMATEH-agricultural engineering.* Vol. 49 (2). pp. 53 – 60, Bucharest / Romania;

[4] Kamaletdinov R.R., (2012), Object-oriented simulation modeling in the information theory environment (information modeling*), News of the International Academy of Agrarian Education*, Issue number 14, pp. 186–194, Moscow / Russia;

[5] Kurdyumov V.I., Zykin E.S., Lazutkina S.A. (2016), Justification of the distance between flat disks of inter-row cultivator, *Herald of Ulyanovsk State Agricultural Academy*, Issue number 3, pp. 174 – 178, Ulyanovsk / Russia;

[6] Lobachevsky Ya. P., Emelyanov P.A., Aksenov A.G., Sibirev A.V., (2016), *Onion production machine technology*, M.: Federal State Budgetary Scientific Institution Federal Scientific Agroengineering Centre, 168 p., Moscow / Russia;

[7] Mayer V., Vejchar D., Pastorková L., (2017), Measurement of potato tubers resistance against mechanical loading, *Research in Agricultural Engineering*, Issue number 2, pp. 22-31, Prague / Czech Republic;

[8] Natenadze N., (2016), The design and theoretical justification of a vibratory digger shovel, *Scientific technical union of mechanical engineering Bulgarian association of mechanization in agriculture*. Issue number 5, pp. 9–12;

[9] Sun D.X, Zhang A.M, Gong J.X., (2016), Design and experiment on 1SZL-250A type subsoiling rotary tillage fertilizer combined soil working machine, *Journal of Chinese Agricultural Mechanization*, Issue number 37(4), pp. 1 – 6, Beijing / China;

[10] Sojka R.E, Horne D.J, Ross C.W, Baker C.J., (1997), Subsoiling and surface tillage effects on soil physical properties and forage oat stand and yield, *Soil and Tillage Research*, Issue number 40 (3-4), pp. 25–144, Amsterdam / Netherlands;

[11] Tauseef Asghar M., Ghafoor Abdul, Munir Anjum, Iqbal Muhammad, Ahmad Manzoor., (2014). Design modification and field testing of groundnut digger, *Asian Journal of Science and Technology*, Issue number 5. pp. 389–394, Delhi / India;

[12] ***Patent №. 2585481 Russia, IPC A01 D17/00. Seed onions harvester / A.G. Aksyonov, S.A. Pryamov, A.V. Sibirev. – №. 2585481; Appl. 24.06.2015; Publ. 27.05.2016, Bull. №. 15.