DEVELOPMENT OF DESIGN AND INVESTIGATION OF OPERATION PROCESSES OF SMALL-SCLALE ROOT CROP AND POTATO HARVESTERS
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РОЗРОБКА КОНСТРУКЦІЙ ТА ДОСЛІДЖЕННЯ ПРОЦЕСІВ РОБОТИ МАЛОГАБАРАТНИХ КОРЕНЕБУЛЬБОЗБИРАЛЬНИХ МАШИН

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ABSTRACT
Having analyzed the designs and the technological process performance of root crop and potato harvesting machines, new approaches to the designing of such types of machines, which allow to reduce their longitudinal clearance due to the use of a multilevel root crop and potato cleaning system and the decrease of the intensity of the effect of operating elements on root crops and potatoes as they move away from a digger, have been suggested. The article presents the developed designs of root crop and potato harvesters with alternating direction of conveyance and cleaning of root crops and potatoes and the results of their testing.

РЕЗЮМЕ
На основі аналізу конструкцій та показників якості виконання технологічних процесів малогабаритними корене- та картоплезбиральними машинами запропоновано нові підходи до проектування машин даного типу, які дозволяють зменшити їх повздовжні габаритні розміри за рахунок застосування багатоярусної системи очищення коренебульбоплодів та зниження інтенсивності дії робочих органів на коренебульбоплоди по мірі їх віддалення від копача. В статті представлено розроблені конструкції корене- та картоплезбиральних машин із знакозмінним напрямком транспортування та очищення коренебульбоплодів, а також наведено результати їх випробувань.

INTRODUCTION
A review of scientific and patent literature, technical and economic performance of machines, technologies of root crops and potato harvesting *(Kotsiuk V.V.et al., 2006; Bonchyk V.S., 2007; Hrushetskiy S.M., 2008; Heruk S.M. et. al., 2008; Klybanskyi O. P., 2010; Osukhovskyi V.M.and Saputskyi V.M., 2010; Kalverkamp Klemens, 2011; Dumych V. and Salo Ya., 2013)* with the help of mechanized complexes and machinery shows that they satisfy most of the requirements to a certain extent, but most of the machines have a great weight, material capacity and big overall dimensions. That is why, in order to satisfy the needs of the market, more attention should be paid to the development of small-scale equipment (one-, two- and three-row machines). In addition to that, it is necessary to eliminate technical contradiction between providing high quality performance of the technological process and optimum longitudinal and transverse size of the machines. Another important factor is the minimization of the material capacity of machines, which, on the one hand, allows to reduce specific pressure on the soil and, on the other hand, to decrease power inputs in order to move them on the field. Moreover, it is necessary to provide maximum possible limits for regulating design and kinematic parameters of operating elements as well as to provide fast replacement of technological units for the adjustment of the machines to specific soil and climatic conditions.

The aim of this research work was designing, constructing and testing trailing machines for harvesting sugar beets and potatoes with alternating and multilevel direction of conveyance and cleaning of root crops and potatoes and determining the effect of the design and kinematic parameters of operating elements on technological process performance.

MATERIAL AND METHOD

In order to provide minimum indices of damaging and satisfactory cleaning of root crops and potatoes with the help of harvesting machines and combines, a certain principle has been applied, which lies in the fact, that as moving away from the area of digging, the aggressive influence of the operating elements on root crops and potatoes must be reduced, since in the process of heap separation, the mass of soil stuck to root crops and potatoes decreases. At this point, there is an increased possibility of the direct contact of an operating element and a root crop, which leads to its damage.

In order to improve the process of separation of a heap of root crops, namely to reduce the degree of their damage at satisfactory separation of soil impurities and crop residues, a new system of cleaning has been suggested *(Fedirko P.P. et. al., 2014)*, the flow sheet of which is shown in Fig. 1. For performing this system of root crop cleaning, consecutive arrangement of the operating elements has been suggested: digging element 1, active shaking rod conveyer 2, beater shafts 3, and cleaning rolls 4.

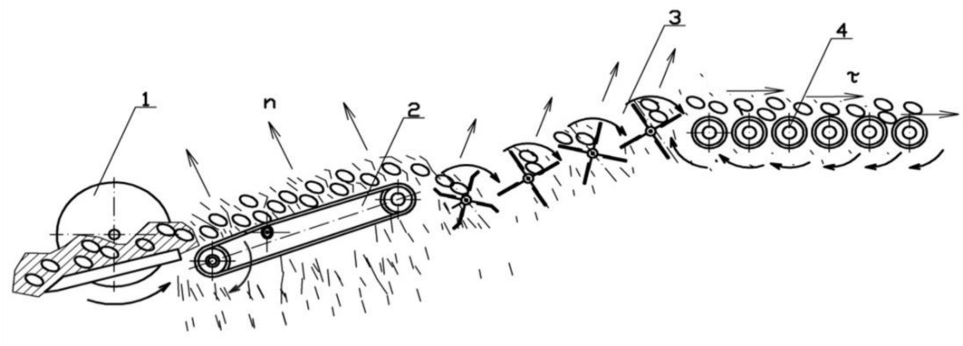

Fig.1 – Root crop and potato cleaning system

In the process of harvester operation, root crops and potatoes are dug with the help of a digger 1, after that the heap is conveyed to cleaning operating elements, namely to an active shaking rod conveyor, where it is scattered and partially cleaned up from soil and crop residues. Since at the first stage of cleaning there is a great amount of soil, that comes together with root crops and potatoes, the possibility of the direct hard contact of an operating element and the surface of a dug root crop is minor, that is why the intensity of the separation process must be at its peak level. Thus, the separation process of a root crop and potato heap at its first stage is carried out along a normal *n***,** which is perpendicularly to the surface of their body.

In the process of moving away from a digger, the amount of soil in the heap of root crops and potatoes decreases, that is why the intensity of the effect of an operating element on the product of cleaning must be reduced. Henceforward, the heap of root crops and potatoes is conveyed to beater shafts and cleaning rolls with smooth transition to the action of operating elements on root crops and potatoes along the tangent τ, (the tangential direction towards the body surface of root crops and potatoes).

The suggested system allows to improve the layout diagrams of small-scale harvesters and to improve the quality of cleaning of the heap of root crops and potatoes.

On the basis of this principle a potato harvesting machine *(Nalobina O.O. and Shymko A.V., 2015)* and a root crop harvester *(Hevko R.B. et. al., 2015)* have been developed; their design and process flow sheets being shown in Fig. 2 and 3. A frame 1 is attached to a tractor, it has 2 running wheels 2 and in the process of operation the right one can be placed closer or further apart according to the distance between the rows. In the process of operation a track roller 3 copies the surface of rakes and holds digging shares 5 at a given depth. Each flat cut off disk 4 is arranged on an axle with a slight spread and is rack-mounted to a frame. Two dissymmetric digging shares 5 are trapezoidal and are equipped with clapper valves in their rear parts. The valves improve the process of soil separation, prevent the rods of an intake conveyor 6 from becoming jammed and damaged because of hard clods and stones. Deepening of disks and shares into the soil can be regulated. When digging, vegetable soil is deformed by disks in horizontal and vertical directions and lifted by shares; that is why a clod, which comes for separation, has previously damaged bonds in its structure.

The main part of heap separation function, namely the separation of soil and the removal of crop residues, is done by an intake conveyor 6. As this takes place, a heap moves up to a receiving roll 8 and a transmission L-shaped conveyor. Rods 9, which are hinge mounted to a frame, are pressed to the canvas of an intake conveyor by their running ends and are used for removing the heap of crop residues. A receiving roll 8 (a hollow shaft), which turns towards the canvas of an intake conveyor, has several functions: it helps to tear tops off roots and to clean the rods 9; it shakes, turns over and presses heap components to the canvas of an intake conveyor and drops soil impurities, clods, stones and tops on the field; it reduces the impact force of roots and the canvas of a conveyor. The arrangement of a receiving roll relative to the conveyors can be regulated according to the conditions of harvesting.

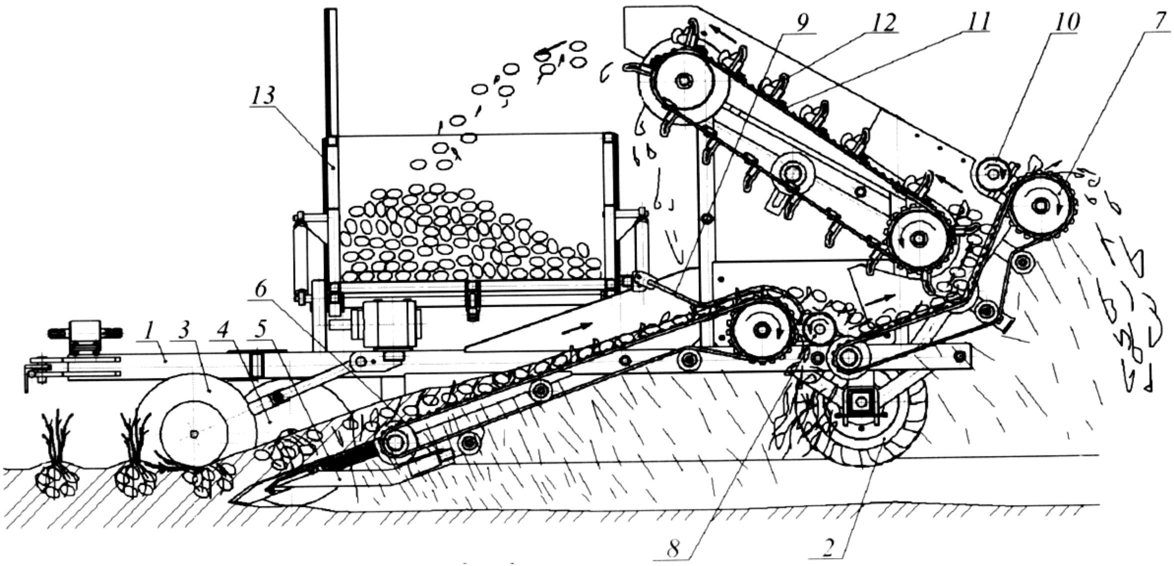

Fig.2 – Design and process flow sheet of a potato harvesting machine
1 – frame; 2 – running wheels; 3 – track roller; 4 – cut off disk; 5 – shares; 6 – intake conveyor; 7 – transmission L-shaped conveyer; 8 – receiving roll; 9 – top separator rods; 10 – beater roll; 11 – loader conveyor; 12 – scrapers; 13 – hopper

Transmission L-shaped conveyor 7 is used for intensive heap separation and conveying of potatoes with the remains of impurities to a scraping loader conveyor 11. The front part of a transmission conveyor 7 is inclined at an angle, which is close to the slope angle of the canvas of an intake conveyor 6 and intensively performs similar heap separation. A higher slope angle of the rear part of the canvas of an intake conveyor allows to remove crop residues in the process of heap separation on the principle of a finishing separator and to discharge them onto the field. In the process of separation, potatoes roll down into the L-shaped bend of a conveyor. In order to reduce damage in the process of potato conveying, the surface of rods is coated with an elastic material.

A beater roll 10 rotates in the same direction with the drive shaft of a transmission conveyor 7 and is used to prevent potatoes from being removed together with crop residues and discharged onto the field by this conveyor. The clearance (gap) between a roll and a conveyor can be regulated depending on the operating conditions.

A loader conveyor 11 traps a potato from the bend of a transmission conveyor 7 with the help of scrapers and conveys it to a hopper 13. A driven drum of a loader conveyor is mounted above the hopper with a clearance relative to it. Due to such arrangement, potatoes from a conveyor reach a hopper and crop residues get to a gap in front of a hopper and then to a conveyor 6 or to the harvested field.

A storage hopper 13 is made in the form of a box, the right panel of which is opened with the help of a hydraulic cylinder. The design of the machine provides side unloading of the gathered potatoes from the hopper on the principle of self-dumping truck operation – hydraulic cylinders open the right panel and tilt the bottom. The machine is equipped with a hopper of relatively little capacity (750kg) with a side panel, which provides: small overall dimensions of the machine (which means good mobility), little soil panning when operating, careful unloading of potatoes from a low height directing them onto a low surface. Overall view of the designed semi-trailing root crop harvested is shown in Fig.3. The machine is equipped with a special loading system and can be ganged up with type 14 kN or type 20 kN tractors. It has a frame *1*, a transmission *2*, digging wheels *3*, an intake of two-element separating conveyor *4*, an L-shaped loader conveyor *5*, a hopper *6*, which is made of two parts and a hydraulic system *7*.

An intake conveyor *4* consists of a frame *9*, lower and upper sections of which can be moved relative to the frame independently of one another; a power shaft, the driving drums *8* of which have the diameter of

240 mm and are made with slots for coupling the teeth of canvas; bottom rolls *10* with the diameter of 140 mm; and bearing rollers *11* with the diameter of 90 mm.

An operating surface of a conveyor is canvas *12*, which is made of two toothed rubber and cord belts, on which metal rods with the diameter of 12 mm are fixed with the spacing of 40 mm. The width of the canvas is 900 mm. Elastic scraper activators with the height of 40 mm are arranged on the rods with the possibility to change spacing according to certain soil and climatic conditions.

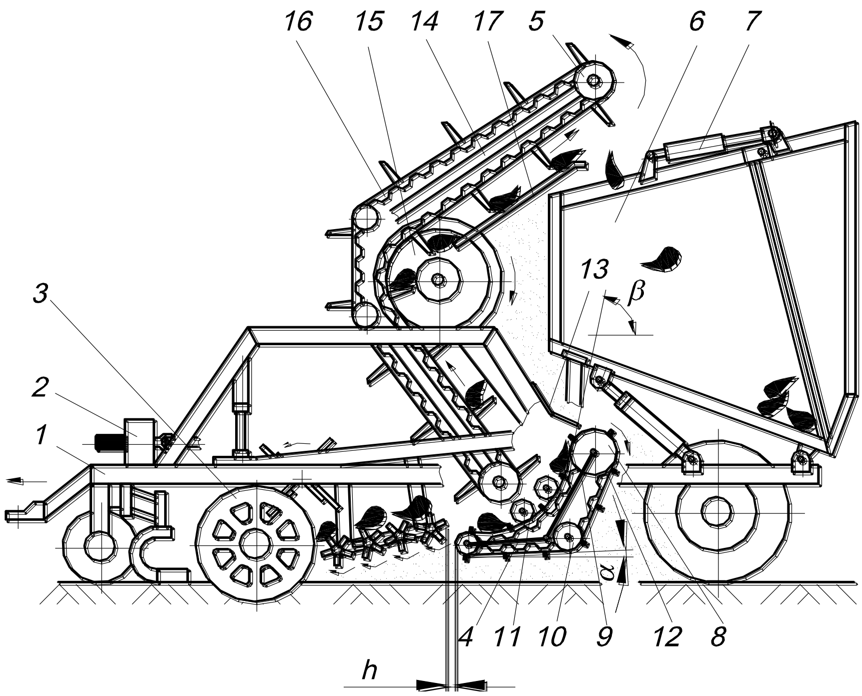

Fig.3 – Design and process flow sheet of a semi-trailing root crop harvester

1 – frame; 2 – transmission; 3 – digging wheels; 4 –intake two-element separating conveyor; 5 –loader conveyor; 6 – hopper; 7 – hydraulic system; 8 – driving drums; 9 – frame of intake conveyor; 10 – bottom rolls; 11 – bearing rollers; 12 – canvas; 13 – casing; 14 – frame of a loader conveyor; 15 – drum; 16 – canvas;17 – guide grid

A loader conveyor has a frame *14*, which is hard and the angle between its upper and lower parts is 90°. A drum *15* is used for smooth alteration of the conveying direction of root crops; it is stepped. The diameter of side discs, on which canvas bears, is 630 mm, and the diameter of a quill shaft, where root crops are conveyed, is 250 mm.

The canvas *16* of a loader conveyor is of similar design as that of an intake conveyor, but its width is 700 mm and it is equipped with scrapers, which have the height of 175 mm. In its bottom part, the conveyor canvas is cased, which prevents root crops from being removed by an intake conveyor and their loss. In the upper part, under the caring run of an intake conveyor canvas, there is a guide grid *17*, which is made of rods with the diameter of 16 mm, that are arranged with the clearance of 30 mm relative to each other.

In the process of its operation a digger digs up a root crop heap, partially cleans it from soil and crop residues and conveys it to an intake conveyor, which is arranged with a regulated clearance h. A conveyor canvas picks up root crops and conveys them with the growing angle from α to β. The degree of angle β is chosen in such a way, that root crops cannot hold on the canvas and roll down, and impurities are removed behind the machine. A casing *13* prevents root crops from being discharged onto the field.

After the main stage of separation, root crops are picked by a scraping canvas of a loader conveyor and move to a drum. Before being transferred to a discharging element of a conveyor, root crops move between the canvas and the drum. Due to powered side disks and a quill shaft, root crops are thrown on a rod guide grid. After that, with the help of the scrapers of a loader conveyor, root crops move along the grid, where they are entirely cleaned from soil and then enter a hopper. After the hopper is filled up, the unloading of root crops takes place with the help of hydraulic cylinders.

A two-element separating conveyor provides the removal of the lumps of soil and crop residues. The regulation of a slope angle of a discharging element of a separating conveyor allows to select rational parameters of an operating element for the machine performance under various natural and production conditions.

The overall view of a potato harvesting machine and a root crop harvester is shown in Fig.4 and Fig.5.

Fig.4 – Overall view of a potato harvesting machine

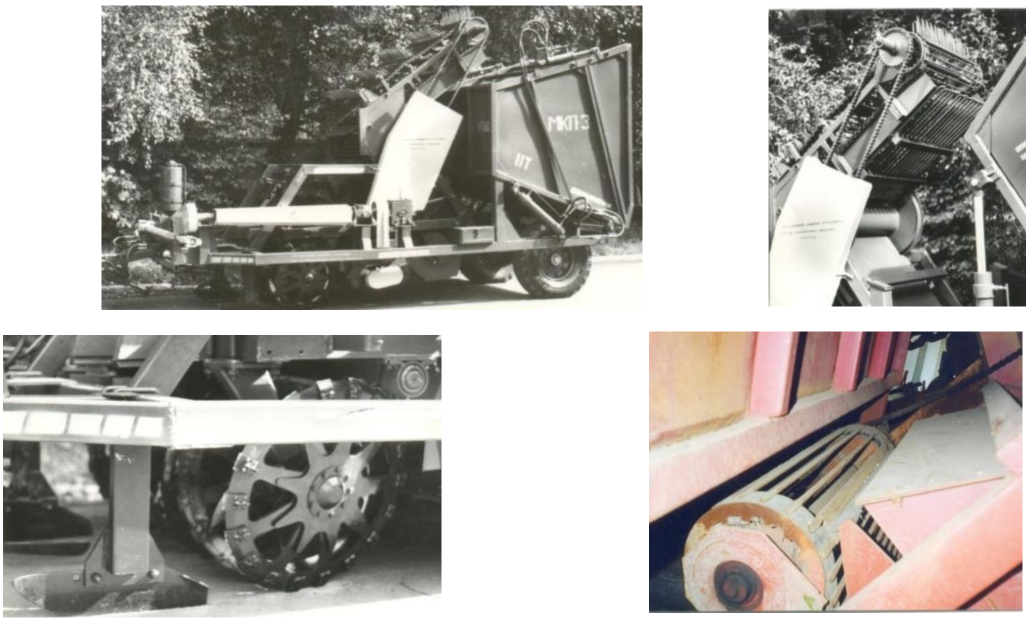

Fig.5 – Overall view of a root crop harvester and its operating elements

RESULTS

Main technical specifications of a potato harvesting machine (Fig.2) are the following: type – one-row trailing; unitizing 0.6 – 1.4 kN; overall dimensions: length – 4035 mm; width – 1875 mm; height – 1930 mm; weight – 1350 kg; hopper capacity – 0.75 t; distance between rows – 500-700 mm; operating rate 5.0 km/h; travelling speed 20 km/h; efficiency 0.2 ha/h; digging depth - 250 mm. On the basis of field experiments it has been determined that, the production process quality of this machine meets agro-technical requirements.

In the process of the experimental studies of a root crop harvester (Fig.3) the following parameters were variable: operating rate V_m = 0.79...1.85 m/s; running speed of an intake conveyor canvas V_c = 0.88...1.25 m/s; slope angle of an intake conveyor bottom section α = 10...25° and slope angle of an intake conveyor upper section β = 50...80°. After processing numerical values, regression equations, which define losses *L*, damage *D* and impurity *I* of root crops according to the change of the above mentioned parameters, have been obtained:

$$L = 1.59 + 0.06LnV_m + 0,06LnV_c + 0.04Ln\alpha - 0.08Ln\beta \quad (1)$$

$$D = 5.19 + 0.19LnV_m + 0,43LnV_c + 0.02Ln\alpha - 0.4Ln\beta \quad (2)$$

$$I = 3.99 + 0.4LnV_m + 0,77LnV_c + 0.06Ln\alpha - 0.93Ln\beta \quad (3)$$

Having analyzed regression equations (1) – (3) and the constructed response surfaces (Fig. 6, 7), it has been determined, that the losses L and the damage D of root crops do not exceed the acceptable ones, following agro-technical requirements, within the change of operative factors, that falls in the range of: L = 1.28…1.44 %, D = 3.2…3.8 %. As V_m and V_c increase, the loss L of root crops increases as well, which can be explained by the acceleration of per-second conveyance of a root crop heap; in the second case it can be explained by an increase in kinematic contact effect of operating elements on root crops.

The change in root crop damage D relative to a change in canvas running speed V_c and a slope angle of an intake conveyor upper section β has an inverse effect. As V_c increases from 0.9 to 1.3 m/s, the damage of root crop decreases from 3.6 % to 3.2 % respectively, and as β increases from 50° to 80°, the damage of root crop decreases from 3.6 % to 3.3 % respectively.

Minimum values of root crop losses L= 1.28…1.3 % have been obtained at operating rate of a machine V_m = 0.8…1.2 m/s, running speed of an intake conveyor canvas V_c = 0.9…1.2 m/s, angle α = 10...12° and angle β = 60...75° of an intake conveyor sections.

Minimum approximate function $D = f(V_m, V_c, \alpha, \beta)$, which defines the change in root crop damage and the values of which fall in the range of D = 3.2…3.3 %, has been obtained at the following change in operating factors: operating rate of a machine V_m= 0.8…1.3 m/s, running speed of an intake conveyor canvas V_c = 1.1…1.3 m/s, slope angle of its bottom section α = 15...20° and slope angle of its upper section β = 70...80°.

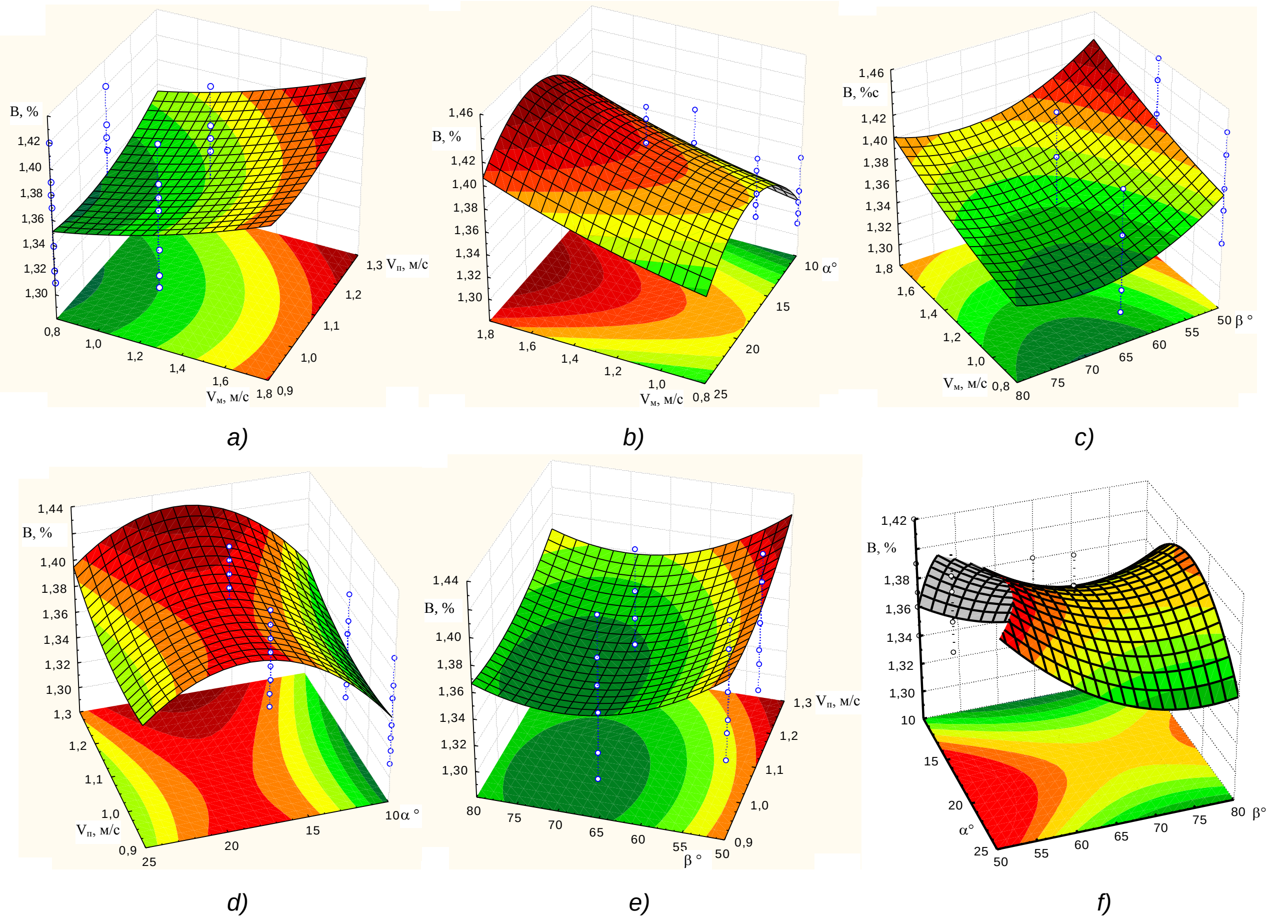

Fig.6 – Response surfaces of losses L, % of root crops from
a): L = f(V_m, V_c); b): L = f(V_m, α); c): L = f(V_m, β); d): L = f(V_c, α); e): L = f(V_c, β); f: L = f(α, β)

If the value of machine operating rate V_m is more than 1.5 m/s, the value of the running speed of an intake conveyor canvas V_c is less than 1.2 m/s, the value of a slope angle of an intake conveyor bottom section α is more than 20° and the value of a slope angle of an intake conveyor upper section β is more than 70°, the overall amount of impurities I in a gathered root crop heap exceeds the standard limits for 8%

(Fig.8). Minimum I= 7.2%…7.6% has been obtained at the least values of V_m and β and the highest value of the running speed of an intake conveyor canvas V_c. Within the range of change in a slope angle of a conveyor bottom section α = 10...25°, the change in I is insignificant.

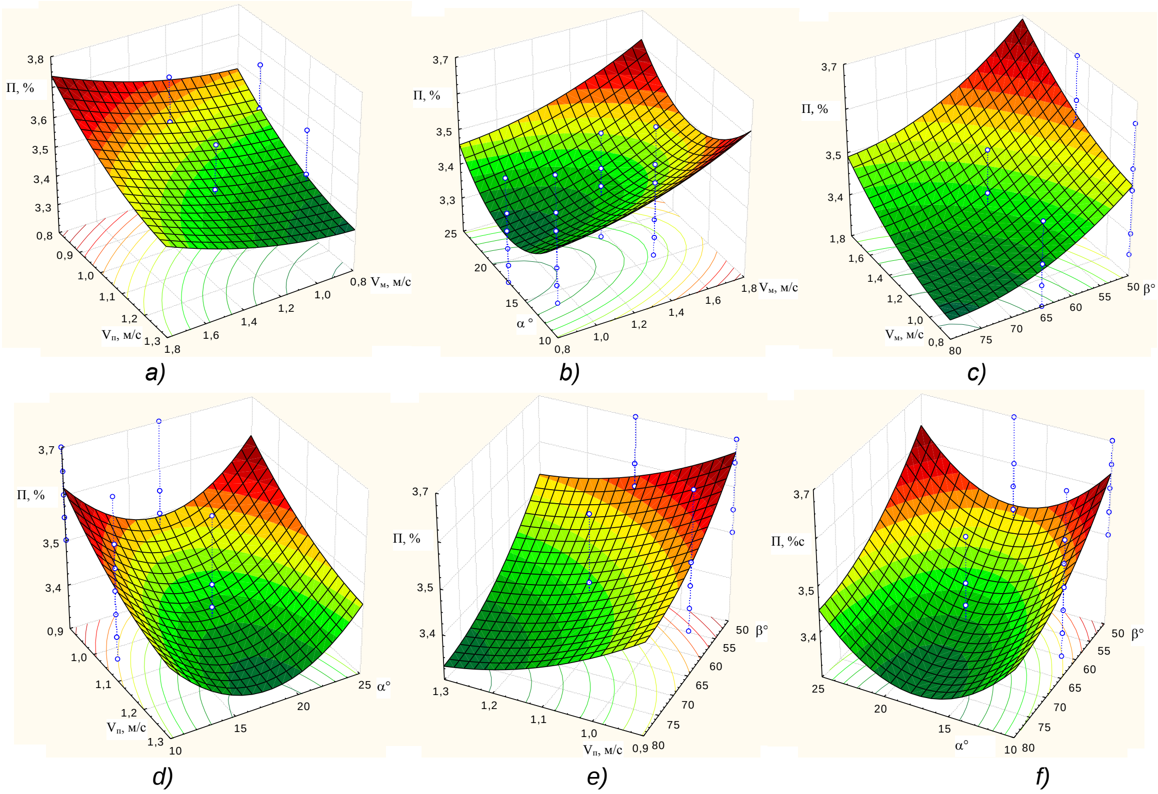

Fig.7 – Response surfaces of damage *D*, % of root crops from

a): D= f(V_c, V_c); b): D = f(α, V_m); c): D = f(β, V_m); d): D = f(α, V_c); e): D = f(β, V_c); f: D = f(α, β)

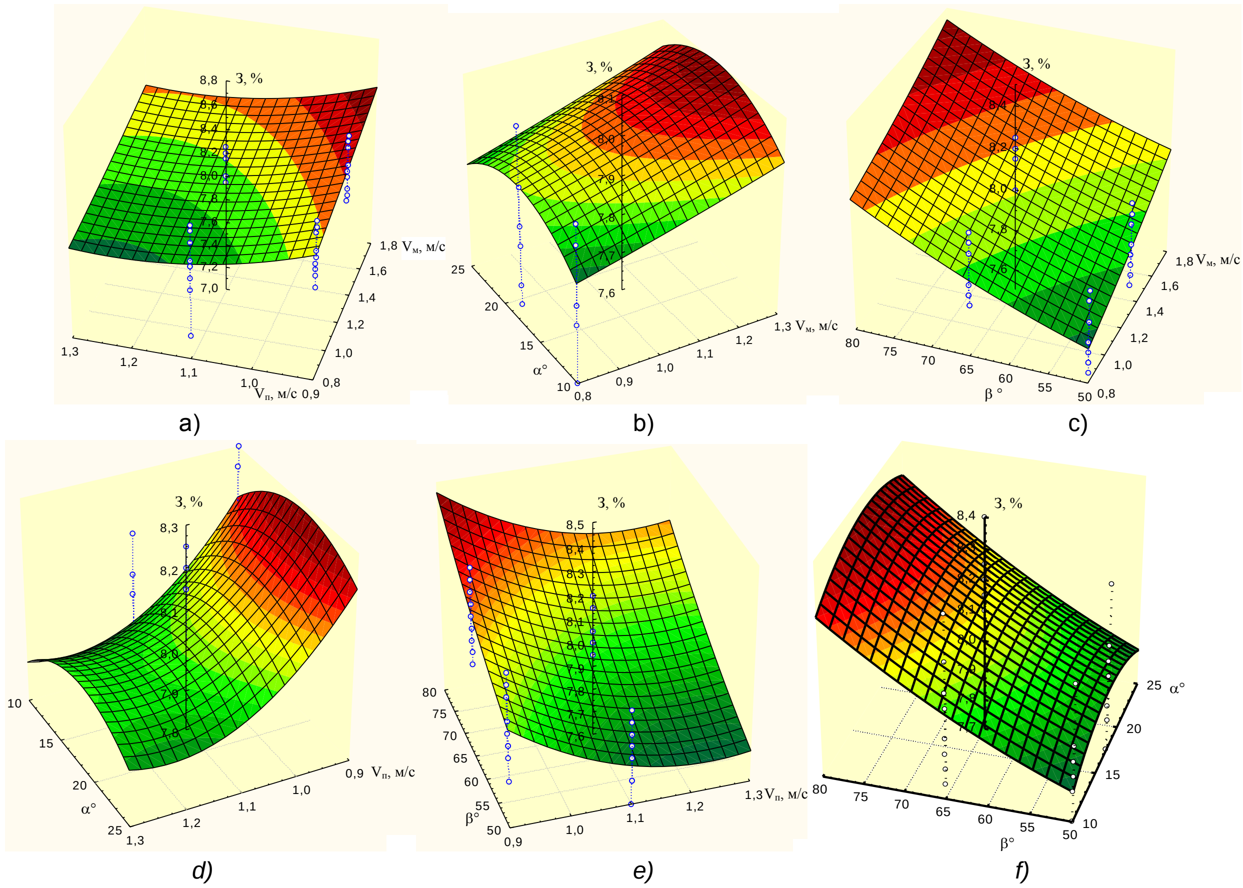

Fig.8 – Response surfaces of impurity *I*, % of root crops from

a): I = f(V_c, V_m); b): I = f(α, V_m; c): I = f(β, V_m); d): I = f(α. V_c); e): I = f(β, V_c); f): I = f(α, β)

CONCLUSIONS

The analysis of present situation and progress trends of the machines for low power-consuming harvesting of root crops and potatoes has been conducted. Moreover, a new system of cleaning root crops and potatoes from soil impurities and crop residues, which provides the decrease in the intensity of the effect of operating elements on root crops and potatoes as they move away from a digger, has been suggested. On the basis of this principle a potato harvesting machine and a root crop harvester have been designed and constructed and their field experiments have been conducted as well.

Having analyzed the performance indicators of the designed semi-trailing root crop harvester МКР-3, rational values of its design and kinematic parameters and of its operating elements have been determined: operating rate of a machine V_m = 1.3 m/s, running speed of an intake conveyor canvas V_c = 1.2 m/s, slope angle of an intake conveyor bottom section α = 15°, slope angle of an intake conveyor upper section β = 70°.

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