

maximum eating feed animals is fractional composition of feed ingredients used to prepare the mixture.

Research conducted using combine in the cooking process feed mixture, which consisted of roughage, showed that the most intensive grinding processes occur when working on dry alfalfa hay, and the use of its straw fractional composition increases.

Key words: *technological scheme, feed, high energy feed mixture, cosmoproletar unit*

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MATHEMATICAL MODEL OF FUNCTIONING OF CONVEYING AND CLEANING SYSTEM

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Abstract. *Development of highly efficient processes of harvesting root crops requires application of the integrated scientific approach to solving the problems of further improvement of conveying and cleaning systems of root crop harvesting machinery to improve their performance values. The problems set are solved on the basis of further improvement of methodology and techniques for optimization of technological parameters of the process of separating impurities from root crops, as well as design and kinematic parameters and operation modes of systems for conveying and cleaning root crop piles. Theoretical studies of functioning of the process of intensification of separation of impurities from root crops were conducted by simulating the process of moving a root crop pile through the tools of the conveying and cleaning system using material balance equations and the concept of "input-output" of the complex dynamic material system. Providing that system function ability was ensured mathematical models were developed describing the process of intensification of separation of impurities from root crops.*

Key words: *root crops, impurities, conveyor, separator, cleaner, feeding of root crop pile, separation factor*

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Introduction. Study of technological parameters ensuring minimization of process parameters of separation of impurities from root crops is a topical scientific problem in terms of further improvement of quality of raw root crop products.

Formulation of problem. In order to separate the impurities that are in different states compared to root crops different modes of mechanical interaction between working surfaces of cleaners and components of impurities having different physical and mechanical properties are applied.

Analysis of recent research results. In this respect, the excessive amount of impurities in root crops (over 8...10%) characterizes quality of raw materials, and excessive damage (over 10...15%) and loss (over 1,5%) of root crops – the bulk quantity of raw materials for processing, which in both cases reduces values of quality and quantity of their derivatives [1, pp. 97-99].

Development and implementation of new highly efficient processes of harvesting root crops requires application of the integrated scientific approach to solving the problems of further improvement of conveying and cleaning systems of root crop harvesting machinery [2, pp. 244-245].

The basis for further formation of the scientific worldview of engineers developing root crop harvesting machines, i.e. further development of the general concept of rational outlines of modern machines, is analysis of international experience in gradual improvement of process of harvesting root crops, layout and operation of the main tools of conveying and technological systems for lifting, cleaning and loading root crops.

The results of analytical researches of the process of cleaning of root crops are presented in the works [1, pp. 188-189, 199; 3, pp. 382-384; 4, pp. 170-172; 5, pp. 222-224]. Generally, the key results of scientific representations are based on study of individual processes of harvesting root crops only, such as feeding of a pile of root crops (RP) during their lifting, separation of impurities, during movement of a RP through individual tools of a harvesting machine, etc. This particular absence of generic models of functioning of complex dynamic conveying and cleaning systems and a root crop harvesting machine in general has determined conduct of these researches.

Purpose of research is improvement of the methodology and techniques for parameters optimization and operation modes of conveying and cleaning systems of machinery.

Results of research. The main principles of the evolution of machinery and equipment designed for harvesting root crops are closely linked to the main general aspects of development of harvesting technologies and methods, as well as improvement of basic processes of

harvesting root crops, especially such as lifting and cleaning of the lifted RP from components of impurities, Fig. 1.

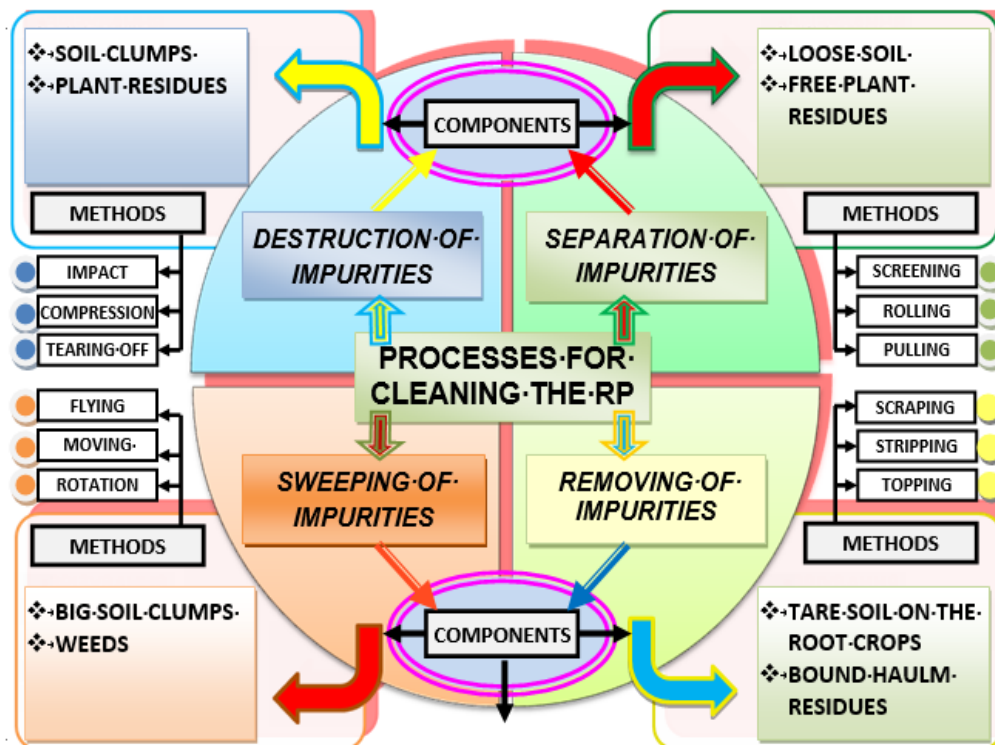


Fig. 1. Block diagram of the basic cleaning processes and methods of cleaning of the RP.

A root crop pile lifted by lifters is a multicomponent and multi-structural process environment or a process able object. Depending on conditions of root crop machinery operation, the average percentage of root crops and the total impurities in a root crop pile lifted ranges quite significantly – 50...70%, the total impurities – 30 to 50% [6, pp. 55-56]. Impurities that are of soil and plant origin, in the RP lifted by lifters are free and “bound” compared to root crops: free soil (loose soil, soil clumps of different diameters – 20 to 100 mm and different moisture – 13 to 28% [7, pp. 151-152] and plant (lost haulm, weeds) impurities, “bound” soil (tare soil on the surface of root crops) and plant (haulm residues on the root crop heads) impurities.

In order to intensify the process of separating impurities from root crops, or to increase quality values of cleaning of the RP, we have developed an improved inventive conveying and cleaning system (CCS) [8, pp. 1-4], which improves process quality of root crop harvesting machinery in general.

In terms of the systemic approach to analysis of subjects of researches it was suggested that theoretical treatment of complex cleaning systems and tools handling the input flow of process bulk

material should be modeled based on material balance equations and the concept of “input-output” of the dynamic system [1, p. 188].

To simulate the process of separation of impurities from root crops while the RP moving through the CCS tools a functional diagram of the operation process that presented in Fig. 2 was examined.

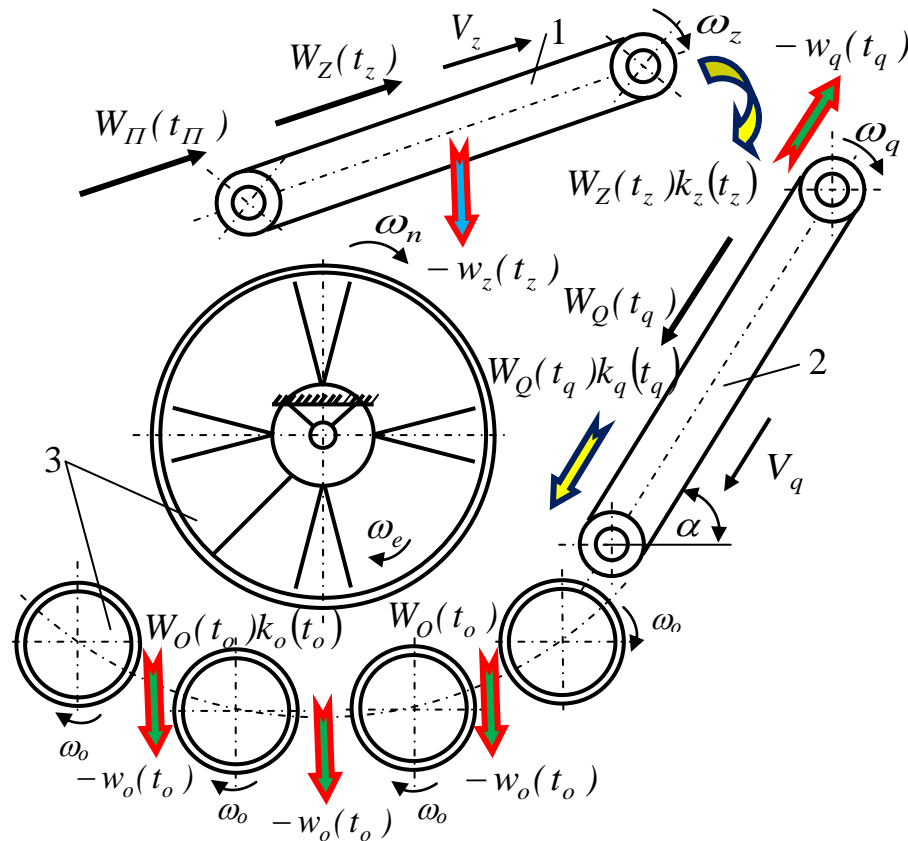


Fig. 2. Functional diagram of the operation process of the CCS: 1 – feeding drag conveyor; 2 – finger separator; 3 – combined cleaner.

This the RP lifted by lifters of the root crop harvesting machine and consisting of components of root crops and impurities (free soil and plant impurities, tare soil, haulm residues on the heads of root crops) are fed to the feeding drag conveyor (1) (Fig. 2), where partial preliminary screening of free impurities through the gaps between the bars of the conveyor is performed. Then, the conveyor (1) moves components of the RP to the finger separator (2) that separates tare soil, and a part of impurities is swept outside the separator. The unscreened RP from the lower step of the separator is fed to the combined cleaner (3), which finally cleans root crops from free soil and plant impurities, tare soil and haulm residues on the heads of root crops, and cleaned root-crops are moved by augers and screws of the hollow cylinder of the combined cleaner to the next process systems – the hopper or the loading conveyor of the root crop harvesting machine.

For analytical analysis of movement of the RP (process bulk material) through the feeding conveyor, the finger separator and the combined cleaner let us denote feeding of the RP lifted by lifters during time t_{II} to the feeding conveyor by $W_{II}(t_{II})$, feeding by the feeding conveyor during t_z to the cleaning separator by $W_Z(t_z)$, feeding by the cleaning separator during t_q to the combined cleaner by $W_Q(t_q)$ and the process federate of the combined cleaner during t_o by $W_O(t_o)$.

Then analytical modeling of the operation process of the complex CCS in terms of preserving its function ability can be written as a condition:

$$W_O(t_o) \geq W_Q(t_q) \geq W_Z(t_z) \geq W_{II}(t_{II}), \quad (1)$$

where: t_c, t_q, t_z – time of stay of the RP on the working surfaces of the combined cleaner, the finger separator, the feeding conveyor;

t_{II} – time of moving of the RP lifted by lifters of the root crop harvesting machine to the feeding conveyor.

Taking into account the relevant separation factors of free impurities on the way of moving through the CCS tools and in accordance with accepted assumptions it can be written that feeding of the lifted RP to the feeding conveyor $W_{II}(t_{II})$ during t_M , feeding by the feeding conveyor $W_Z(t_z)$ during t_z to cleaning separator, feeding by the cleaning separator $W_Q(t_q)$ during t_q to the combined cleaner and the feed rate of the combined cleaner will be:

$$W_{II}(t_{II}) = W_k(t_M)k_c(t_c); W_Z(t_z) = W_{II}(t_{II})k_z(t_z) = W_k(t_M)k_c(t_c)k_z(t_z); \quad (2)$$

$$W_Q(t_q) = W_Z(t_z)k_q(t_q) = W_k(t_M)k_c(t_c)k_z(t_z)k_q(t_q); \quad (3)$$

$$W_O(t_o) = W_Q(t_q)k_o(t_o) = W_k(t_M)k_c(t_c)k_z(t_z)k_q(t_q)k_o(t_o), \quad (4)$$

where: $W_k(t_M)$ – feeding of the RP lifted by lifters of the root crop harvesting machine during t_M ;

$k_c(t_c), k_z(t_z), k_q(t_q), k_o(t_o)$ – the impurity separation factor on the way of moving of the RP lifted by lifters to the feeding conveyor, the free impurity separation factor for the feeding drag conveyor, the free impurity separation factor for the separator, the overall impurity separation factor for the combined cleaner;

t_M – the time of moving of the lifter of the root crop harvesting machine or time of lifting of root crops by the lifter.

Then according to dependencies (2)–(4) the condition (1) of the efficient functioning of the CCS will take the form

$$W_O(t_o)k_o(t_o) \geq W_Q(t_q)k_q(t_q) \geq W_Z(t_z)k_z(t_z) \geq W_k(t_M)k_c(t_c); \quad (5)$$

$$k_z(t_z)k_q(t_q)[k_o(t_o)]^2 \geq k_z(t_z)[k_q(t_q)]^2 \geq [k_z(t_z)]^2 \geq 1. \quad (6)$$

Impurity separation factors $k_c(t_c)$, $k_z(t_z)$, $k_q(t_q)$, $k_o(t_o)$, taking into consideration the amount of impurities, which is separated from root crops on the way of moving the lifted RP to the conveyor ($-w_n(t_n)$), on the working surfaces of the feeding conveyor ($-w_z(t_z)$), the finger separator ($-w_q(t_q)$), the combined cleaner ($-w_o(t_o)$) can be written as:

$$\left\{ \begin{array}{l} k_c(t_c) = \frac{W_{II}(t_M) - w_n(t_M)}{W_{II}(t_M)} = 1 - \frac{w_n(t_M)}{W_{II}(t_M)}; \\ k_z(t_z) = \frac{W_Z(t_z) - w_z(t_z)}{W_Z(t_z)} = 1 - \frac{w_z(t_z)}{W_Z(t_z)}; \\ k_q(t_q) = \frac{W_Q(t_q) - w_q(t_q)}{W_Q(t_q)} = 1 - \frac{w_q(t_q)}{W_Q(t_q)}; \\ k_o(t_o) = \frac{W_O(t_o) - w_o(t_o)}{W_O(t_o)} = 1 - \frac{w_o(t_o)}{W_O(t_o)} \end{array} \right. \quad (7)$$

The time of stay of the RP on the working surfaces of the CCS, and the time of lifting of root crops by the lifter of the root crop harvesting machine can be written as:

$$t_o = dS_o / dV_o; \quad t_q = dS_q / dV'_q; \quad t_z = dS_m / dV_z; \quad t_M = dS_M / dV_M, \quad (8)$$

where: S_o , S_q , S_z , S_M – respectively, the way of moving of the RP by the working surfaces of the combined cleaner, the finger separator, the feeding drag conveyor, from the lifter of the root crop harvesting machine to the feeding drag conveyor, m;

V_o ; V'_q ; V_z ; V_M – the velocity of moving of the RP by the working surfaces of the combined cleaner, the finger separator, the feeding conveyor; on the way from the lifter of the root crop harvesting machine to the feeding conveyor, m/s.

Plugging the values of components of the corresponding factors of separation of the RP and the time the RP stayed on the working surfaces of the CCS from (7), (8) into the dependencies (5) and (6) we obtain:

$$\begin{aligned} W_o \left(\frac{dS_o}{dV_o} \right) \left(1 - \frac{w_o}{W_o} \right) &\geq W_q \left(\frac{dS_q}{dV'_q} \right) \left(1 - \frac{w_q}{W_q} \right) \geq \\ &\geq W_z \left(\frac{dS_z}{dV_m} \right) \left(1 - \frac{w_z}{W_z} \right) \geq W_k \left(\frac{dS_M}{dV_M} \right) \left(1 - \frac{w_n}{W_{II}} \right) \end{aligned} \quad (9)$$

$$\left(1 - \frac{w_z}{W_z} \right) \left(1 - \frac{w_q}{W_q} \right) \left(1 - \frac{w_o}{W_o} \right)^2 \geq \left(1 - \frac{w_z}{W_z} \right) \left(1 - \frac{w_q}{W_q} \right) \geq \left(1 - \frac{w_z}{W_z} \right)^2 \geq 1. \quad (10)$$

Let us denote components: $S_o = L_o$, where L_o – length of the auger shaft of the combined cleaner; $S_z = L_z$, where L_z – length of the carrying

run of the feeding conveyor; $S_q = H_q = L_q \sin \alpha \lambda_q$, where H_q – height of movement of the RP from its point of contact with the carrying run of the finger separator to the working surface of the combined cleaner, L_q – length of the carrying run of the finger separator; α – a finger separator angle in relation to horizon (deg.), λ_q – a factor for proportionality of height of movement H_q of the RP relative to length L_q of the carrying

run; $V_o = V_{o,m} k_{V_o} = \frac{T_o \omega_o k_{V_o}}{2\pi} = \frac{T_o k_{V_o}}{2\pi} \frac{d\varphi_o}{dt}$, where $V_{o,m}$ – a theoretical velocity of axial movement of auger screws (m/s), k_{V_o} – a factor for a decrease in V_o relative to $V_{o,m}$, T_o – a step of the auger (m), $\omega_o = d\varphi_o / dt$ – an angular velocity of the auger (rad/s), φ_o – a rotation angle of the auger, deg.; $V'_q = \sqrt{2gH_q} = \sqrt{2gL_q \sin \alpha \lambda_q}$, where g – gravitational acceleration, m/s²;

$V_z = V_{z,m} k_{V_z} = \omega_z R_z k_{V_z} = R_z k_{V_z} \frac{d\varphi_z}{dt}$, where $V_{z,m}$ – a theoretical velocity of the carrying run of the feeding conveyor (m/s), k_{V_z} – a factor for a decrease in V_z relative to $V_{z,m}$, R_z – the radius of the driving sprocket of the feeding conveyor (m), $\omega_z = d\varphi_z / dt$ – an angular velocity of the driving sprocket (rad/s), φ_z – a rotation angle of the driving sprocket, deg.

In addition, let us denote the $w_i(t_i)/W_i(t_i)$ as a symbolic operator or as a transfer function $w_i(t_i)/W_i(t_i) = W_i(s_i)$.

Plugging the values of components into the dependencies (7), (9), (10) and according to (1) we obtain the terminal condition for efficient functioning of the CCS

$$W_o \left[\frac{d(2\pi L_o)}{d(T_o k_{V_o})} \left(\frac{d\varphi_o}{dt} \right)^{-1} \right] \left(1 - \frac{w_o}{W_o} \right) \geq W_q \left[\frac{d(L_q \sin \alpha \lambda_q)}{d(\sqrt{2gL_q \sin \alpha \lambda_q})} \right] \left(1 - \frac{w_q}{W_q} \right) \geq ; \quad (11)$$

$$\geq W_z \left[\frac{dL_m}{d(R_z k_{V_m})} \left(\frac{d\varphi_o}{dt} \right)^{-1} \right] \left(1 - \frac{w_z}{W_z} \right) \geq W_k \left(\frac{dS_M}{dV_M} \right) \left(1 - \frac{w_n}{W_{II}} \right) \\ \left\{ \begin{array}{l} k_c(t_c) = 1 - W_n(s_n); k_z(t_z) = 1 - W_z(s_z); \\ k_q(t_q) = 1 - W_q(s_q); k_o(t_o) = 1 - W_o(s_o) \end{array} \right. ; \quad (12)$$

$$[1 - W_z(s_z)][1 - W_q(s_q)][1 - W_o(s_o)]^2 \geq [1 - W_z(s_z)][1 - W_q(s_q)]^2 \geq [1 - W_z(s_z)]^2 \geq 1. \quad (13)$$

The resulting dependencies are the mathematical models describing the functional process of separation of impurities from root crops by the CCS expressed in the parametric (11) and the operator (12), (13) format.

Conclusions. Based on examination of the material balance of input and output flows of the RP mathematical models were developed for intensification of the process of separating impurities from root crops, which characterize the relationship of movement of impurity components and root crops on the working surfaces of the CCS. General solution of the models using, for example, the direct and inverse Laplace transform, will optimize design and kinematic parameters and operation modes of conveying and technological systems and root crop harvesting machinery in general.

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МАТЕМАТИЧНА МОДЕЛЬ ФУНКЦІОНУВАННЯ ТРАНСПОРТНО-ОЧИСНОЇ СИСТЕМИ

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Анотація. Розробка високоефективних технологічних процесів збирання коренеплодів передбачає інтегрований науковий підхід до вирішення завдань подальшого удосконалення транспортно-очисних систем коренезбиральних машин з метою підвищення їх показників якості роботи. Поставлені завдання вирішуються на підставі подальшого удосконалення методології і методики оптимізації технологічних показників процесу відділення домішок від коренеплодів і конструктивно-кінематичних параметрів і режимів роботи робочих органів транспортно-очисних систем вороху коренеплодів. Теоретичні дослідження функціонування технологічного процесу інтенсифікації відділення домішок від коренеплодів проведено шляхом моделювання процесу

переміщення вороху коренеплодів по робочих органах транспортно-очисної системи з використанням рівнянь матеріального балансу і поняття «вхід-вихід» складної матеріальної динамічної системи. З умови забезпечення технологічності функціонування системи розроблено математичні моделі, які характеризують процес інтенсифікації відділення домішок від коренеплодів.

Ключові слова: коренеплоди, домішки, транспортер, гірка, очищувач, подача вороху коренеплодів, коефіцієнт сепарації

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ФУНКЦИОНИРОВАНИЯ ТРАНСПОРТНО-ОЧИСТИТЕЛЬНОЙ СИСТЕМЫ

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Аннотация. Разработка высокоэффективных технологических процессов уборки корнеплодов предполагает интегрированный научный подход до решения задач последующего усовершенствования транспортно-очистительных систем корнеуборочных машин с целью повышения их показателей качества работы. Поставленные задачи решаются на основании последующего усовершенствования методологии и методики оптимизации технологических показателей процесса отделения примесей от корнеплодов и конструктивно-кинематических параметров и режимов работы рабочих органов транспортно-очистительных систем вороха корнеплодов. Теоретические исследования функционирования технологического процесса интенсификации отделения примесей от корнеплодов проведено путем моделирования процесса перемещения вороха корнеплодов по рабочих органах транспортно-очистительной системы с использованием уравнений материального баланса и понятия «вход-выход» сложной материальной динамической системы. С условия обеспечения технологичности функционирования системы разработано математические модели, которые характеризуют процесс интенсификации отделения примесей от корнеплодов.

Ключевые слова: корнеплоды, примеси, транспортер, горка, очиститель, подача вороха корнеплодов, коэффициент сепарации