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MATHEMATICAL MODELING OF THE TECHNOLOGICAL PROCESS OF FORAGE HARVESTING FROM GRASSES

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Insufficient study of the characteristics of the material of harvested feed from herbs complicates the transition to more rational methods of work and restrains the creation of fundamentally new machines and technologies, which allows for reasonable to design equipment, choose the most effective ways of influence of working bodies on the material and ensure high quality of operations. The study of the physical and mechanical properties of agricultural materials is a prerequisite for the proper organization of the process and the design of machines.

Technological operations performed by feeding machines are aimed at changing the structure of these materials. In the process of processing, the hay is brought to a state that corresponds to agro -demands.

The type of working body and its parameters are determined by many factors: the necessary productivity, physical condition and nature of the material, quality and accuracy of processing, the efficiency of the machine and the level of its energy consumption.

The modern harvesting of legumes is aimed at improving the productivity of machines for their production, improving quality and feed value, introducing new methods of influence of working bodies on the material of the workpiece. Thus, the mathematical modeling of the work of the working bodies of feed harvesting machines should be based on the study of the physical and mechanical and technological characteristics of harvested feed mass with minimal nutrient loss and vitamins. Theoretical analysis of the processes of harvesting from herbs confirms the possibility of establishing estimated dependencies between productivity, energy costs and structural parameters of the working bodies of the machines, if the properties of the material are known.

Further development of prospective technologies and technical means in the field of feed harvesting requires a generalization of available theoretical and calculated research. This creates the basis for the emergence of new mechanization tools that can provide high productivity at minimal cost of material and energy resources per unit of quality feed.

The work analyzes the theoretical and calculated data of the functioning of the working bodies of machines in the process of influence on plant material during the harvesting of herbs. The calculations of parameters are related to the physical and mechanical properties of raw materials and agrotechnical requirements for the performance of operations.

Key words: *fodder grasses, alfalfa, hay, quality, harvesting, technology, drying, modeling, parameters, humidity, physical and mechanical properties, moisture, rotary working bodies, rakes.*

Eq. 20. Ref. 16.

1. Problem formulation

When developing and modeling technological processes, it is necessary to have a clear understanding of the physical and mechanical properties of the environment, which is subject to processing by the working bodies, to avoid the resistance of the material and as a result of additional energy costs.

Agricultural production has a significant number of hay harvesting technologies. But whatever the difference between them, the integral process of any technology is the drying of herbs in the field. This process is accompanied not only by the loss of plants of moisture, but also by nutrients due to the course of biochemical processes, the development of microorganisms, the washing of precipitation. The size of these losses increases with increasing duration of field drying. They can be reduced by intensification of this process [1].

The most common methods of accelerating the drying of mown grass are tedding swaths, raking them, and turning windrows. The application of these operations in haymaking technologies makes it possible not only to accelerate the drying process of mown grass by 1.3 to 2 times but also to ensure a uniform moisture content of the wilted mass. For these tasks, wheel-finger, rotary, drum, and other types of tedders are used. Particular attention should be given to rotary rake-tedders, which are advantageous due to their simple design, low metal consumption, and reliable performance of the technological process [2].

2. Analysis of recent research and publications

The research of the scientific works of many scientists [1–9] shows that an attempt to intensify the process of field drying of grasses by moving or turned over, while reducing the mechanical losses that accompany these operations at the expense of different technological approaches, improvement of existing ones and the development of new working bodies of rakes-luggage.

It is proved in the writings [3, 7–11] that the action of the working organs of rakes of the spacing on the attached herbs, especially legumes, is accompanied by the upholstery of vegetative parts of leaves of leaves, inflorescences, tops of stems, etc. Some upholstered parts are lost as a result of scattering, but much more remains in the grass in the free state, that is, not bound to the stems of plants. As a result, a heterogeneous herbal mass is formed, which consists of upholstered (free) vegetative parts and plants that have lost some of their components, that is, a grassy belt is formed.

Scientists have suggested that it is possible to reduce the mechanical losses that accompany the stirring, raking and turning of mowed herbs, if in some way the free parts of the plants from the enemy [5, 7].

As a result of research and design work, as well as analysis of the schemes of pneumatic separation systems in agricultural machinery, it was established that the most appropriate method to implement the proposed approach is the use of an inclined aspirating air flow. Furthermore, rotary rake-tedders with centrifugal working bodies were identified as suitable implements for accelerating the drying of forage [1, 5, 11, 12].

3. The purpose of the article

The purpose of this study is investigation the influence of the design parameters of rotary working bodies on the quality of hay harvesting.

4. Results and discussion

According to the method of testing of cars for harvesting hay [14-16] we use the method of determining the loss of leaf and inflorescences when performing rakes-lifetime surgery for the intensification of drying of mowed herbs. The losses are determined in three places of the score on the grounds, each of which has a length of 1 m, and its width is equal to the width of the machine, according to the formula:

$$n_{up} = \frac{100 \cdot (m_l - m'_{in})}{m}, \quad (1)$$

where n_{up} – losses due to the upholstery of leaves and inflorescences, %; m_l and m'_{in} – mass of free leaves and inflorescences from the test plot before and after raking, kg; m – total mass of plants from the test plot after raking, kg.

The content of free leaves and inflorescences is determined by the allocation of them from the mass of the entire grass.

The main purpose of the rake-tedders is to rake the alfalfa to the rolls in the rolls, the humidity of 50...55%. Let us accept that the yield of grass by green mass is 350 c /ha, and its humidity during mowing is 80%. The minimum length of plants in the herbaceous is 0.2 m, and the height of the grass of grass before its raking is also 0.2 m.

Determine the limit value of the angle of tilt of the rake to the horizon at the lowest point of their trajectory relative to the surface of the field, according to the formula:

$$\varphi_r = \arcsin(d / l_{\min}), \quad (2)$$

where l_{min} – the minimum length of mowed plants for ramping which is intended, m; d – spacing of the rake tines, m; in existing rake-tedders it ranges from 0.10 to 0.15 m; let us assume d = 0.12 m; φ_r = arcsin(0.12/0.2) = 37 °.

Since the inclination angle of the rake tines must be greater than or equal to the critical value, we assume φ_r = 40 °.

The width of the grip of each of the rakes will be determined by the formula:

$$b = d/\sin\varphi, \tag{3}$$

where $b = 0{,}12/\sin 40 = 0{,}187$ m.

The required length of inner and outer fingers of the rakes will be determined by:

$$l \geq h \cdot l_{\min}/d, \tag{4}$$

$$l_1 \geq l_{\min}\left[h/d + \sqrt{1-(d/l_{\min})^2}\right], \tag{5}$$

where l_{min} – the minimum length of mowed plants, m; *d* – the rake tine spacing**,** m.; *h* – safe installation height of the rotor rim above the field surface, h = 0.06...0.1 m [13].

We take at *h* = 0,08 m.

$$l \geq \frac{0,08 \cdot 0,2}{0,12} \geq 0{,}133 \text{ m},$$

$$l \geq 0,2\left[\frac{0,08}{0,12} + \sqrt{1-\left(\frac{0,12}{0,2}\right)^2}\right] \geq 0,293 \text{m}.$$

We take at l= 0,135 м, a l_1= 0,295m.

The rotor radius is determined by the formula:

$$R = \sqrt{l_1^2 \cdot \cos^2(\varphi-\psi) + R_0^2 + 2 \cdot R_0 \cdot l_1 \cdot \cos(\varphi-\psi) \cdot \cos\delta}\ , \tag{6}$$

where δ – the angle of deviation of the fingers of the rake from their radial position, δ=60˚; Ψ – the angle of deviation of the rotor axis from the vertical (in existing rakes-tedders ψ = 5...7^0, we take ψ = 7°); l_1 – length of the outer finger of the rake, m; R_0 – is the radius of the rim of the rotor, m. R_o = 1,1 m.

$$R = \sqrt{0,295^2 \cdot \cos^2(40°-7°) + 1{,}1^2 + 2 \cdot 1{,}1 \cdot 0,295 \cdot \cos(40°-7°) \cdot \cos 60°} = 1,24 \text{ m}.$$

The theoretical width of the grip of the traveler-separator is determined by the:

$$B = 2 \cdot \sqrt{2 \cdot R \cdot h_1/\sin\psi - h_1^2/\sin^2\psi}\ . \tag{7}$$

The actual grip width:

$$B_g = (0{,}18...0,24) + B\ = 2{,}55, \text{ m}.$$

The number of rakes to be set on the rotor rim:

$$2 \cdot \pi \cdot \lambda / z = d / R \cdot \sin\alpha, \tag{8}$$

where λ – kinematic parameter that depends on moisture, λ = 0,3 m [13]; *R* – *t*he rotor radius, m; *d* – fingers of the fingers of the rake, m; φ – The limit value of the angle of tilt of the rakes to the horizon.

$$\frac{2 \cdot 0,3 \cdot \pi}{z} = \frac{0{,}12}{1,24 \cdot \sin 40°},$$

$$z = \frac{2 \cdot 0,3 \cdot \pi \cdot 1,24 \cdot \sin 40°}{0{,}12} = 12,48.$$

The calculated value of the number of rakes is rounded to a larger number. So let's get z = 14.

The speed of throwing a gap into the air flow will determine for [8]:

$$V_r = R \cdot \omega \cdot \sqrt{1 + \lambda^2 + 2 \cdot \lambda \cdot \cos(\omega \cdot t)_r \cdot \cos\psi}\ , \tag{9}$$

where *R* – the rotor radius, m; λ – kinematic parameter that depends on moisture, λ = 0,3 m; ψ – the angle of deviation of the rotor axis from the vertical, ψ=7°; $(\omega \cdot t)_r$ – the angle of rotation of the rakes at which there is an material leaves their fingers, $(\omega \cdot t)_r$ = 120°; ω – the angular speed of working bodies, s^{-1}.

Under accepted conditions, the circle speed of working bodies should not exceed 7,4 m/s.

Then the angular speed of the working bodies ω = 7,4/1,24 = 6 s^{-1}.

$$V_r = 1,24 \cdot 6 \cdot \sqrt{1 + 0,3^2 + 2 \cdot 0,3 \cdot \cos 120° \cdot \cos 7°} \ .$$

For [12] the optimal value of air flow rate in separation V_r = 14...14,5 m/s. We accept V_r = 14 m/s then the coefficient μ= 2,1.

Calculate the length of the camera by the formula:

$$L = \frac{(\mu \cdot \cos\beta + \cos\gamma) \cdot \ln\left(\dfrac{\cos\gamma}{\mu \cdot \cos\beta} + 1\right) - \cos\gamma}{K_{\min} \cdot \sqrt{1 + \mu^2 + 2 \cdot \mu \cdot \cos(\beta + \gamma)}} \quad , \tag{10}$$

where $K_{\min}$ – windage factor, m^{-1}, K_{min} = 0,25 m^{-1}; γ– the angle of heap injection into the air flow. We accept that he will equal to the angle of deviation of the rotor axis from the vertical $\gamma = \psi = 7°$; β – angle of inclination of the air flow to the horizon, β = 50°.

$$L = \frac{(2,1 \cdot \cos 50° + \cos 7°) \cdot \ln\left(\dfrac{\cos 7°}{2,1 \cdot \cos 50°} + 1\right) - \cos 7°}{0,25 \cdot \sqrt{1 + 2,1^2 + 2 \cdot 2,1 \cdot \cos(50° + 7°)}} = 0,43 \text{ m.}$$

The working length of the selection chamber is determined by the formula:

$$L_p = \eta \cdot L, \tag{11}$$

where η — coefficient that accounts for the influence of the release of mutual adhesion and collision forces between the feed particles on the chamber length (η = 1.48–1.8) [8].

$$L_p = 1,48 \cdot 0,43 = 0,6 \text{ m.}$$

The required fan performance will be determined by [8]:

$$Q = L \cdot C \cdot V_C \cdot \upsilon, \tag{12}$$

where L – working length of the chamber, m; C – width of the separation chamber, m (C = 0.4 m); V_c – airflow velocity, m/s; the required fan capacity is determined by υ – a coefficient that accounts for system air leakage (υ = 1.1…1.2) [8]. In calculations, we take υ = 1.1.

$$Q = 0,6 \cdot 0,4 \cdot 14 \cdot 1,1 = 3,7 \text{ m}^3\text{/s.}$$

Separation of separation is determined by the [8]:

$$M^1 = P \cdot V \cdot B, \tag{13}$$

where B – The actual grip width, m; V – The speed of aggregating the machine, m/s, V = 3 m/s; P – power, kg/m^2.

When the yield of green mass, its humidity during ramping is the power P = 1 kg/m^2.

$$M^1 = 1 \cdot 3 \cdot 3,55 = 10,65 \text{ kg/s.}$$

The mass of a dry matter that is separated per unit of time is determined by [8]:

$$M_C = \frac{M^1 \cdot E \cdot C_0^1 \cdot (100 - W)}{10000} \cdot \left(1 + \frac{E^1}{100}\right), \tag{14}$$

where M^1 – feed supply, kg/s; C_0^1 – a proportion of dry matter of upholstered parts in the material, C_0^1 = 0,1; E – the coefficient of selection of upholstered parts, %, E = 50%; E^1 – The coefficient of clogging of the selected product by stems, %, E^1 =10%; W – The humidity of the material, %, W = 50%.

$$M_C = \frac{10,65 \cdot 50 \cdot 0,1 \cdot (100 - 50)}{10000} \cdot \left(1 + \frac{10}{100}\right) = 0,29 \text{ kg/s.}$$

Aerodynamic concentration ratio is determined by the formula:

$$\mu_0 = \frac{100 \cdot M_C}{(100 - W_n) \cdot Q \cdot \rho}, \tag{15}$$

where W_n – respectively the mass of dry matter of the selected product per unit time and its relative humidity, W_n – 25%, [8]; Q – fan performance, m^3/s; ρ – Air density, kg/m^3, ρ = 1,2 kg/m^3.

$$\mu_0 = \frac{100 \cdot 0,21}{(100 - 25) \cdot 3,7 \cdot 1,2} = 0,087 \ .$$

Loss of pressure on lifting mass will determine by formula:

$$H_l = \rho \cdot g \cdot \mu_0 \cdot h_2, \tag{16}$$

where g – acceleration of free fall, m²/s; μ_0 – air mixture concentration ratio; h_2 – height of mass transportation, m.

From the calculation H_l = 1,63 Pa.

Pressure losses in the suction network consist of losses to overcome the local resistances of the air mixture. These losses can be determined from the following dependence:

$$H_a = 0,5 \cdot V_{C1}^2 \cdot \rho \cdot (\zeta_1 + \zeta_2) \cdot (1 + \mu_0 \cdot k_0), \tag{17}$$

where $V_{CI} = F \cdot V_c / F_1$ – Air speed at the exit of the camera; V_c – The air flow rate, m/s; F_1, F – Accordingly, the area of larger and smaller camera cross section, m².

When calculations we assume that the area of the smaller cross – section of the camera is 0,15 m²; ρ – air density, kg/m³; ξ_1 *and* ξ_2 – the coefficients of the local resistance of the camera and knee, ξ_1 =0,1; ξ_2 = 0,23; μ_0 – air mixture concentration ratio; κ_0 – a coefficient that depends on μ_0, k_0 =0,75.

$$V_{Cl} = 0,6 \cdot 0,4 \cdot 13/0,15 = 22,4 \text{ m/s}.$$

$$H_a = 0,5 \cdot 22,4^2 \cdot 1,2 \cdot (0,1 + 0,23) \cdot (1 + 0,063 \cdot 0,75) = 104 \text{ Pa}.$$

Pressure loss in the discharge network (diffuser) determine by the formula:

$$H_d = 0,5 \cdot V_{C2}^2 \cdot \rho \cdot \zeta_3 \cdot (1 + \mu_0 \cdot k_0), \tag{18}$$

where, V_{C2}^2 – the air velocity at the entrance, m/s.

We accept that it is equal to speed at the exit then V_{C2}^2 = 22,4 m/s; ρ – air density, kg/m³; ξ_3 – diffusor resistance factor, ξ_3 = 0,1; μ_0 – air mixture concentration ratio; κ_0 – a coefficient that depends on μ_0, k_o= 0,75;

$$H_d = 31,5 \text{ Pa}.$$

Loss of pressure on blowing an enemy by flow of air will determine for:

$$H_{d.a} = 862 + 2,78 \cdot X_1 + 2,43 \cdot X_5 + 6,43 \cdot X_7 - 6 \cdot X_8 - 1,93 \cdot X_1 \cdot X_8 \tag{19}$$

where $X_1 = V_C$–14; V_c – The air flow rate, m/s; X_5=(V_s–7)/1,5; V_s – the speed of ejection of the material into the air, m/s; X_7 = (M^1–8)/2; M^1 – Submission of material for separation, kg/s; X_8= (h –0,275) /0,05; h– Safe height of rotor rim above the field surface.

$$X_1 = 14–14 = 0; \quad X_7 = (7,65–8)/2 = –0,18;$$

$$X_5 = (6,6 – 7) /1,5 = –0,27; \quad X_8 = (0,08 – 0,275) / 0,05 = –0,5$$

$$H_{d.a} = 163,2 \text{ Pa}.$$

Full pressure that the fan should be set by the formula:

$$H = H_l + H_a + H_d + H_{d.a}, \tag{20}$$

where H_a – Pressure loss in the aspiration network, Pa; H_d – Pressure loss in the discharge network, *Pa*; H_l – loss of pressure on lifting a selected product, Pa; $H_{d.a}$ – loss of pressure on the extra resistance that the material is in passing through it the flow of air, Pa

$$H = 300,3 \text{ Pa}.$$

According to a certain productivity (Q = 13300 m³/h) and full pressure, the appropriate fan will need to be selected.

5. Conclusion

Agricultural production has a significant number of hay and hay production technologies, and an integral process of any technology is the drying of grass in the field. This process is accompanied not only by the loss of plants of moisture, but also by nutrients due to the course of biochemical processes, the development of microorganisms, the washing of precipitation. The size of these losses increases with increasing duration of field drying. They can be reduced by intensifying this process.

When performing operations with existing rakes-lifetime, losses can reach 20% of the weight of the original dry matter of the herb. This not only reduces the collection of hay, but also significantly affects its value, because the lost parts of the plants in the content of nutrients are 2 ... 3 times exceeding the stems.

It is determined that the air that creates a fan, installed on the frame of the machine and separation from the grass enemy can reduce the loss from the upholstery of vegetative parts of herbs.

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ТЕХНОЛОГІЧНОГО ПРОЦЕСУ ЗАГОТІВЛІ КОРМІВ ІЗ ТРАВ

Недостатнє вивчення характеристик матеріалу зібраних кормів із трав ускладнює перехід до раціональніших методів роботи та стримує створення принципово нових машин і технологій. Це, своєю чергою, не дозволяє обґрунтовано проєктувати обладнання, обирати найбільш ефективні способи впливу робочих органів на матеріал і забезпечувати високу якість виконання операцій. Вивчення фізико-механічних властивостей сільськогосподарських матеріалів є необхідною передумовою для правильної організації технологічного процесу та проєктування машин.

Технологічні операції, які виконують кормозаготівельні машини, спрямовані на зміну структури рослинних матеріалів. У процесі обробки сіно доводиться до стану, що відповідає агротехнічним вимогам. Тип робочого органа та його параметри визначаються багатьма *факторами: необхідною продуктивністю, фізичним станом і природою матеріалу, якістю та точністю обробки, ефективністю машини й рівнем її енергоспоживання.*

Сучасна заготівля бобових культур орієнтована на підвищення продуктивності машин, покращення якості й поживної цінності кормів, а також на впровадження нових способів впливу робочих органів на матеріал заготовки. Тому математичне моделювання роботи робочих органів кормозаготівельних машин має ґрунтуватися на дослідженні фізико-механічних і технологічних характеристик зібраної кормової маси з мінімальними втратами поживних речовин і вітамінів. Теоретичний аналіз процесів заготівлі трав підтверджує можливість встановлення розрахункових залежностей між продуктивністю, енерговитратами та конструктивними параметрами робочих органів машин, за умови відомих властивостей матеріалу.

Подальший розвиток перспективних технологій і технічних засобів у галузі кормозаготівлі потребує узагальнення наявних теоретичних і розрахункових досліджень. Це створює основу для появи нових засобів механізації, здатних забезпечити високу продуктивність за мінімальних витрат матеріальних та енергетичних ресурсів на одиницю якісного корму.

У роботі проаналізовано теоретичні та розрахункові дані функціонування робочих органів машин у процесі їхнього впливу на рослинний матеріал під час заготівлі трав. Розрахункові параметри пов'язані з фізико-механічними властивостями сировини та агротехнічними вимогами до виконання технологічних операцій.

Ключові слова: *кормові трави, люцерна, сіно, якість, заготівля, технологія, сушіння, моделювання, параметри, вологість, фізичні та механічні властивості, вологовміст, ротаційні робочі органи, граблі.*

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