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MATHEMATICAL SIMULATION OF THE FLEET OF MACHINE AND TRACTOR UNITS FOR ROOT CROP HARVESTING BY THE CRITERION OF POWER CONSUMPTION

Summary

Analytical research in the substantiation and choice of optimum parameters of the units which include a tractor and a hook-on sugar-beet harvester is given. The calculations, carried out on a PC, allow defining optimum parameters of the specified units by the criterion of power consumption.

1. Introduction

High efficiency of the mobile agricultural machine unit is achieved at the expense of a correct correlation between its technical parameters, modes of operation and external conditions of production: physical and mechanical properties of soil, surface inclinations of the field, characteristics of the processed materials, agrotechnical requirements of its cultivation, etc.

Prognostication of the degree of efficiency of beet harvesters depending on the specific capital investments is dealt with in a monograph [1]. However the issues concerning the determination of optimal parameters of beet harvesting units by the criteria of their efficiency and output still need fundamental theoretical treatise.

2. Materials and method

First we will substantiate the choice of the optimal parameters of the hook-on beet harvesters by the criterion of the efficiency of the tractor aggregating them.

The efficiency of the use of the hook-on beet harvesting units must be substantiated by means of quantitative criteria which would determine to a sufficient degree of exactness their performance attributes. To these criteria belong efficiency, minimum maintenance costs, specific efficiency per 1 kW of the tractor efficiency and other indices.

The efficiency of the machine and tractor unit can be calculated with the help of the following correlation [2]:

$$W = 0{,}1 B \cdot v_r\,,\ [ha/h], \qquad (1)$$

where: B - the operating width, $[m]$; v_r - the forward speed of the movement of the unit $[km/h]$.

It follows from equation (1) that the efficiency of the unit increases in direct proportion to the increase in the speed of its movement or the operating width. Yet there is no direct proportional dependency, of course, since these values are not absolutely independent. So, when the operating width of the unit is increased, the speed of its movement will diminish, and vice versa, when the speed of the movement increases (or in order to ensure its high value) the allowed operating width is diminished. The functional relationship between the speed of the movement and the operating width is determined by the draft balance and the balance of efficiency of the machine unit. The equation of the balance of efficiency for a draft-driving unit can be presented in a general way by the following dependency [3]:

$$N_e \cdot \chi = \frac{R_a \cdot v_r}{3600 \cdot \eta_t (1-\delta)} = \frac{N_p \cdot B \cdot v_r \cdot H}{360 \cdot \eta_v}\,,\ [kW], \qquad (2)$$

where: R_a - the draft resistance of the hook-on beet harvesting unit, $[N]$;

N_p - specific consumption of energy for the execution of the technological process of sugar beet, $[kW \cdot s/kg]$; H - the yield of sugar beet, $[cnt/ha]$; N_e - the rated capacity of the engine, $[kW]$; χ - the coefficient of the engine load; η_t - the coefficient of efficiency of the tractor transmission; η_v - the coefficient of efficiency of the tractor power shaft; δ - skidding of the tractor.

The draft resistance of the hook-on sugar beet harvesting unit will be determined by means of this relationship:

$$R_a = R_i + R_f + R_m\,,\ [N], \qquad (3)$$

where R_i, R_f - the resistance of the tractor to rise and rolling over, $[N]$; R_m - the draft resistance of the root crop harvester during the technological process of harvesting, $[N]$.

The left side of the equation of the draft balance (2) is quantitatively equal to the driving force of the tractor, which ensures overcoming of the resistance forces generally acting upon the entire harvesting unit. Let us determine the constituents of the draft resistance:

$$R_i = mg \cdot \sin\alpha\,, \qquad (4)$$

$$R_f = mg \cdot f \cos\alpha\,, \qquad (5)$$

$$R_m = k \cdot B\,, \qquad (6)$$

where: α - the angle of ascent, $[rad.]$; m - the mass of the tractor, $[kg]$; g - acceleration of gravity, $[m/s^2]$; f - the coefficient of resistance to the movement of the tractor; k - specific resistance of the root crop harvester, $[N/m]$.

Coefficient k takes into account both the useful technological deformations during the harvesting process, and the resistance to the movement of the hook-on beet harvester in the direction of the movement of the unit. At small angles of ascent value α in $sin\alpha \cdot 100$ represents the percent of ascent i.

Considering expressions (3), and (4), (5), (6) the balance equation of capacity (2) can be written in the following way:

$$N_e \cdot \chi = V_r \frac{(kB + mg \cdot \psi)\eta_v + 10N_p B \cdot H\eta_t (1-\delta)}{3600\eta_t \eta_v (1-\delta)}, \quad (7)$$

where: ψ - the resistance coefficient of the movement of the tractor, which will be equal to $\psi = sin\alpha + f\,cos\alpha$.

3. Results and discussion

By solving equation (7) in relation to V_r we find the value of the speed of the movement of the beet harvesting unit across the field:

$$V_r = \frac{3600 \cdot \chi \cdot N_e \eta_t \eta_e (1-\delta)}{(k\,B + mg\,\psi)\eta_v + 10 N_p B \cdot H \eta_t (1-\delta)}, \; [km/h], \quad (8)$$

After calculating the working speed of the movement of the unit from equation (8) in accordance with relationship (1) we can obtain its efficiency.

However, coefficients χ, η_t and η_v in equation (8) can be regarded as given but skidding δ of the unit, on the contrary, must be determined. In practical calculations various empirical formulae are used in order to build the skidding curve of the tractor. To find out the value of skidding in the given case, we use the dependency presented in [3]. It has the following appearance:

$$\varphi = \varphi_m - a\,e^{-b\delta}, \quad (9)$$

where φ - the coefficient of the use of the hook-up weight; φ_m - the friction coefficient; a, b - constant coefficients which depend on the type of the tractor and soil fertility.

In expression (9) the dependence of skidding δ on the coefficient of the use of the hook-up weight φ, is given in an implicit form, which is not very convenient for particular calculations. By means of algebraic transformations of expression (9), we obtain a formula of skidding which will be convenient in this case for practical use:

$$\delta = -\frac{1}{b} ln \frac{\varphi_m - \varphi}{a} . \quad (10)$$

Variable φ in equation (10) can be calculated with the help of such a formula:

$$\varphi = \frac{mg\;\psi + kB}{\lambda\; mg}, \quad (11)$$

where: λ - the coefficient of the hook-up weight.

In fact, equations (1), (8), (10) and (11) are mathematical models enabling calculation of the speed of the movement and efficiency of any hook-on beet harvesting unit.

During the calculations it is necessary to take into consideration the agrotechnical requirements for the speed of the movement of the root crop harvester across the field, $4.0 \le V_r \le 10.0$ $[km/h]$, as well as the restrictions imposed upon the cohesion of the tractor movers with soil of the kind $\varphi < \varphi_m$.

For practical implementation of the developed mathematical model a calculation programme was created on the PC which allows performing calculations in a single calculation operation for several tractor prototypes which can be aggregated with a hook-on root crop harvester for any individual type of soil.

Further, it is necessary, first of all, to take into account that the type of the tractor determines its mass m, the engine capacity N_e, coefficient λ, but coefficients φ_m, a and b are assumed for any particular type of soil. Besides this, it is necessary to set the yield H of sugar beet for any variant of calculation, specific consumption of energy for the performation of the technological process N_p, maximum percent of ascents i, the resistance coefficient to the movement of the tractor f, the efficiency coefficient η_v of the power shaft of the tractor. The efficiency coefficient η_t of the tractor transmission varies depending on the type of the tractor (for a caterpillar tractor it is equal to $\eta_t = 0.87$, for a wheeled tractor – $\eta_t = 0.92$). The specific resistance k of a hook-on beet harvesting unit will vary for any type of tractors and root crop harvesters, and will be within the limits from 6000 to 10000 $[N/m]$. Changing the working width of the hook-on root crop harvester is carried out within the range from 0.90 to 3.15 [*m*], with the step 0.45 [*m*], i.e., in fact, from a two-row variant to a six-row variant.

In every variant of calculation there were calculated and recorded in a file of results the specific resistance for any working width and its corresponding speed V_r of the movement of the unit, the efficiency W of the unit, the draft resistance R_a of the unit, the coefficients of the use of the hook-up weight φ and skidding δ.

Concrete values of parameters were set for the calculation of the developed mathematical model which enter into it. Namely: the average yield of sugar beet was assumed to be equal to $H = 300\,[cnt/ha]$; the specific consumption of energy for the performation of the technological process of sugar beet harvesting $N_p = 1.75\;[kW \cdot s/kg]$; coefficients $\chi = 0.90$; $\eta_v = 0.95$; $f = 0.07$; it was assumed that there may be ascents on the beet growing field not more than 5%; the specific resistance of the hook-on beet harvesting unit is $k = 6000...10000\;[N/m]$ (in calculations the step of the change of the specific resistance was assumed to be equal to $\Delta k = 1000\;[N/m]$).

72 calculation variants were conducted to be used as the given input parameters of the discussed system. By the way, such optimal parameters were obtained for the hook-on root crop harvesters that are aggregated with various types of tractors.

The highest efficiency $W = 0.60\;[ha/h]$ for the tractor of the type 9 kN is possible when the working width is

$B = 0.9$ [m]; for the specific resistance of the hook-on root crop harvester $k = 7000$ $[N/m]$ when the speed of its movement is $v_r = 6.63$ $[km/h]$. Thus such a type of tractor ensures maximum efficiency if it is aggregated only with a two-row hook-on root crop harvester.

For the tractor of the type MTZ -82 (14 kN) the maximum efficiency $W = 1.02$ $[ha/h]$ will practically be at two values of the specific resistance of the hook-on root crop harvester: $k = 7000$ $[N/m]$ and $k = 9000$ $[N/m]$, with the working width $B = 1.80\ [m]$ and the speed of the movement $v_r = 5.68$ $[km/h]$. These indices are obtained for the four-row variant of the hook-on root crop harvester. When the working width is $B = 2.70$ [m] (the six-row variant) and when the specific resistance of the hook-on root crop harvester is $k = 10000$ $[N/m]$, the unit with a wheeled tractor MTZ-80 does not ensure aggregation and the required efficiency because of the insufficient adhesion of its wheels to soil.

For the tractor 20kN of the draft category the maximum efficiency $W = 1.03$ $[ha/h]$ will be when its working width is $B = 2.7$ $[m]$, the specific resistance of the hook-on root crop harvester is $k = 7000\ [N/m]$ and the speed of its movement is $v_r = 3.80$ $[km/h]$. When the working width is $B = 2.7$ $[m]$ and the specific resistance of the hook-on root crop harvester is $k = 10000$ $[N/m]$, the efficiency of the unit will be equal to $W = 0.86$ $[ha/h]$ and the speed of its movement is $v_r = 3.18$ $[km/h]$.

4. Conclusions

The developed mathematical model in which concrete values of the input data can be inserted may be used to determine optimal parameters for various hook-on root crop harvesters to be aggregated with different types of tractors.

5. Reference

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