THE SUBSTANTIATION OF THE OPTIMUM TYPE OF THE MACHINE FOR THE AGGREGATION WITH THE TILLAGE SOWING COMPLEX

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The method for the optimum power determination and material capacity of a tractor for a specific width of the tillage sowing complex and a given field area is given in the article. The recommendations on the compilation of machine-tractor units in the composition of the tillage sowing complex are given.

Keywords: machine, tractor, complex, tillage, sowing

INTRODUCTION

The strategy of machine and technological support of agricultural production in Ukraine should ensure transition to low-cost resource-saving technologies using highly efficient tillage units and sowing complexes.

In the field of plant technology, large transformations should be carried out by introducing into the technological process of crop production of complex units - sowing complexes, for the purpose of performing in a single processing pass, two or three levels of application of fertilizers, treatment with herbicides, precise sowing of various plants seeds and subsequent soil compaction in a row. Such technical solutions should reduce to 2.5 times the necessary number of machines for technologies for the production of plant products by 30-60% to reduce the metal capacity of the machinery fleet by 10-15% to reduce the cost of production [Kryuchkov M.M, 2013].

Agrotechnical methods, units and machines used in effective resource-saving soil protection technologies should maximize the positive impact of natural factors and resources. The main thing is a technique that works effectively, minimally affects the soil, ensures the preservation of its fertility, microflora and fauna, retains moisture and eliminates erosion. Its use requires a minimum of chemicals to protect plants against diseases and weeds. This is a step towards highly effective resource-saving soil protection technologies.

The basis of the modern tractor market is the unified mobile machines of the wheel formula 4k4a of various sizes with variables in a wide range of mass - energy parameters. A special feature of the adaptation of such tractors in zonal tillage, fertilization and sowing technologies is the choice of the optimum tractor power and the gradual replacement of the operational mass by ballasting, installing the dual wheels and the use of loaders [Selivanov N.I., 2013; Pastukhov V.I., 2001; Fortuna V.I., 1979; Khrobotov S.N., 1973; Kurochkin I.M., 1996].

In the works of Selivanov N.I. 2015, the ballasting conditions of wheeled 4k4a tractors with the established energy potential for adapting to modern technologies of tillage are grounded. Models are formulated; an algorithm for rational ballasting and a nomogram for determining the parameters of additional ballast are developed. When selecting and preparing tractors of different manufacturers and sizes in operation, the method of determining the degree of ballasting of a tractor with an optimally selected power with a certain slippage index and using the resistivity of the tillage sowing complex, the working width and the geometrical parameters of the field is more versatile.

MATERIALS AND METHODS

For the objective function to justify the capacity of the machine, we take the minimum of the energy costs listed:

$$Q = \frac{N_{н} \cdot T_{р} + N_{х} \cdot T_{х}}{W_{см} \cdot (T_{р} + T_{х})}, \; Q \rightarrow min \qquad (1)$$

where: $N_{н}$ – rated capacity, kW;
$N_{х}$ – - idle power, kW;
$T_{р}$ – spent time on working strokes, h;

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$T_х$ – spent time on idling, m;
$W_{см}$– replaceable productivity of the unit, ha/h.

The capacity of the unit is determined by the well-known formula: $W_{зм} = 0.1 \cdot B \cdot \vartheta_р \cdot \tau$. Where: τ - the coefficient of working time use [Kirtbaya Yu.K., 1961; Ageev L.E., 1978; Guskov V.V., 1966; Kutkov G.M., 2004; Zavora V.A., 2010; Serbii V.K., 2011].

$$\tau = \frac{T_р}{T_р + T_х} = \frac{1}{1 + \frac{T_х}{T_р}} \quad (2)$$

$$T_р = \frac{L_р \cdot n_р}{10^3 \cdot \vartheta_р} \quad (3)$$

$$T_х = \frac{L_х \cdot n_х}{10^3 \cdot \vartheta_х} \quad (4)$$

where: $L_р$ – the length of the line, m, (we take $L_р = const \approx 500$ м);
$\vartheta_х$– the speed of the unit at idling, km/h (we take $\vartheta_х = 3{,}5$ km / h);
$n_р$– the number of working strokes, pcs.;
$n_х$– the number of idling, pcs. $n_х = n_р - 1$;
$L_х$ – the length of idling, m (Fig. 1).

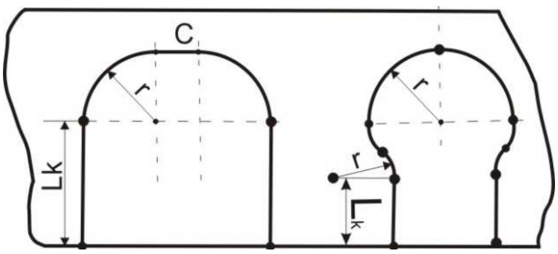


Figure 1. The execution diagram of semi-circular and pear-shaped movement in the zone of the turn strip

To determine the working stroke ratio, we calculate the length of idling. The condition for performing a semicircular mode of motion is $2 \cdot r \leq B$. And the parameters of the trajectory of motion are determined by the system:

$$\begin{cases} 2 \cdot r = B \rightarrow C = 0 \\ 2 \cdot r < B \rightarrow C = B - 2 \cdot r \\ L_х = 2 \cdot L_к + 2 \cdot r + C \end{cases} \quad (5)$$

The condition for performing the pear-shaped mode of motion is: $2 \cdot r > B$. And the length of idling is determined by the expression:

$$L_х = 2 \cdot L_к + 2 \cdot r + 4 \cdot \frac{\pi \cdot r \cdot \arccos\left(1 - \frac{2 \cdot r - B}{4 \cdot r}\right)}{180} \quad (6)$$

where: $L_к$ – the kinematic length of the unit, m;
r – turning radius of the machine, m;
B – working width of the tillage sowing complex, m.

To determine the productivity of the unit and the traction resistance (7) of the tillage sowing complex, we calculate the unit speed according to the expression (10) after some transformations:

$$P_{кр} = B \cdot \left(P_{уд} + \varepsilon \cdot \rho \cdot S \cdot \left(\vartheta_р^2 - \vartheta_0^2\right)\right) \quad (7)$$

where: $P_{уд}$ - specific tractive effort, kN / m;
ϑ_0^2 – the initial speed of the unit, where there is no significant increase in the traction resistance of agricultural machinery, m / s;
ε – is a coefficient that takes into account the continuity of the treatment and part of the particles to which the velocity is transmitted $\vartheta_{р_i}^2$;
ρ– the soil density, kg / m3;
S – is the cross-sectional area of the treated soil by the working bodies per running meter of the width of the machine, m2 / m;
$\vartheta_р^2$ – the design speed of the unit, m / s.

$$\begin{cases} \vartheta_р = \frac{N_{кр}}{P_{кр}} \\ \tilde{N}_н = N_{кр} + P_f \cdot \vartheta_р \\ B = \frac{P_{кр}}{P_{уд} + \varepsilon \cdot \rho \cdot \left(\vartheta_р^2 - \vartheta_0^2\right) \cdot S} \end{cases} \quad (8)$$

where: $N_{кр}$– hook capacity of the unit, kW;
P_f – is the force is necessary for the rolling of the power facility, kN;

$$P_f = G_{зч} \cdot f \quad (9)$$

where: $G_{зч}$ – coupling weight of the machine, kN;
f – is the coefficient of rolling resistance of the machine.

After the substitutions in system (8) we obtain:

$$B = \frac{\tilde{N}_н - P_f \cdot \vartheta_р}{\vartheta_р \cdot \left(P_{уд} + \varepsilon \cdot \rho \cdot S \cdot \left(\vartheta_р^2 - \vartheta_0^2\right)\right)} \quad (10)$$

We replace α = ε · ρ · S. From equation (10), we express the unity velocity θ_ρ:

$$\vartheta_р = Z - \frac{1}{3 \cdot Z}\left(\frac{P_{уд}}{\alpha} - \vartheta_o^2 + \frac{P_f}{B \cdot \alpha}\right), \quad (11)$$

According to expression (7), having the actual speed of the unit, it is possible to

$$Z := \left(\sqrt{\frac{P^3}{27 \cdot \alpha^3} - \frac{\upsilon o^6}{27} + \frac{P \cdot \upsilon o^4}{9 \cdot \alpha} + \frac{N^2}{4 \cdot B^2 \cdot \alpha^2} + \frac{Pf^3}{27 \cdot B^3 \cdot \alpha^3} - \frac{P^2 \cdot \upsilon o^2}{9 \cdot \alpha^2} - \frac{Pf^2 \cdot \upsilon o^2}{9 \cdot B^2 \cdot \alpha^2} + \frac{P^2 \cdot Pf}{9 \cdot B \cdot \alpha^3} + \frac{P \cdot Pf^2}{9 \cdot B^2 \cdot \alpha^3} + \frac{Pf \cdot \upsilon o^4}{9 \cdot B \cdot \alpha} - \frac{2 \cdot P \cdot Pf \cdot \upsilon o^2}{9 \cdot B \cdot \alpha^2}} + \frac{N}{2 \cdot B \cdot \alpha}\right)^{\frac{1}{3}} \quad (12)$$

calculate the tractive resistance and determine the utilization factor of the coupling weight of the power facility, $\varphi_{сц} = \frac{P_{кр}}{G_{сц}}$ and the slipping δ, and then you can calculate the power used, taking into account slippage:

$$N_{вп} = \tilde{N}_{н}/(1-\delta) \qquad (13)$$

Determine the nominal capacity of the machine:

$$N_{н} = N_{вп}/\eta_{н} \qquad (14)$$

where: $\eta_{н}$ =0,9 – coefficient of utilization of the rated power of the tractor.

To automate the process of searching for the optimal power of the machine, we compile a flowchart of the algorithm and a program in the VBA programming language.

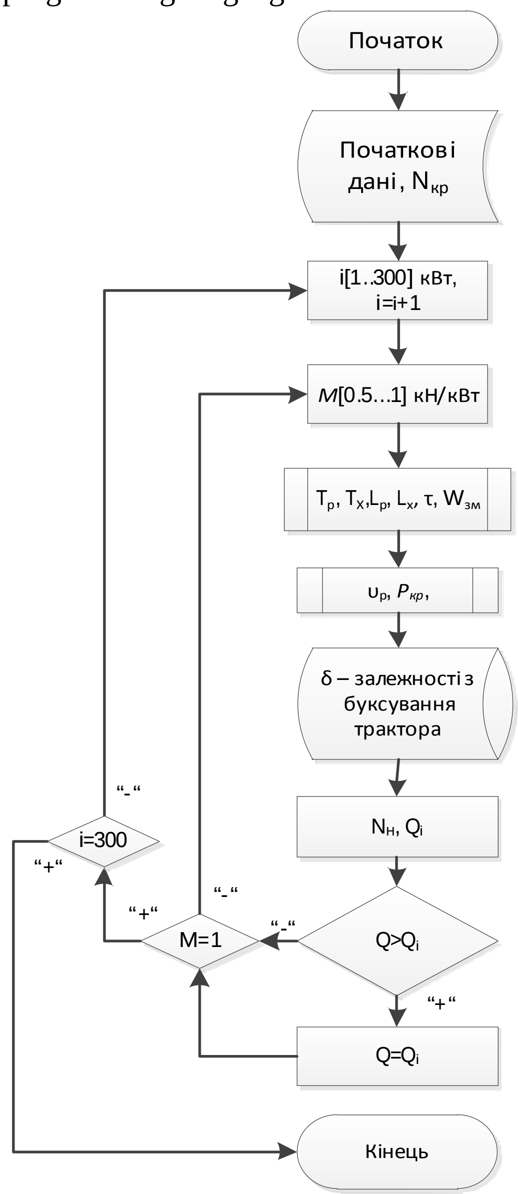


Figure 2. Block diagram of the algorithm for simulating the power capacity of the machine in a unit with a sowing complex $N_н$, kW

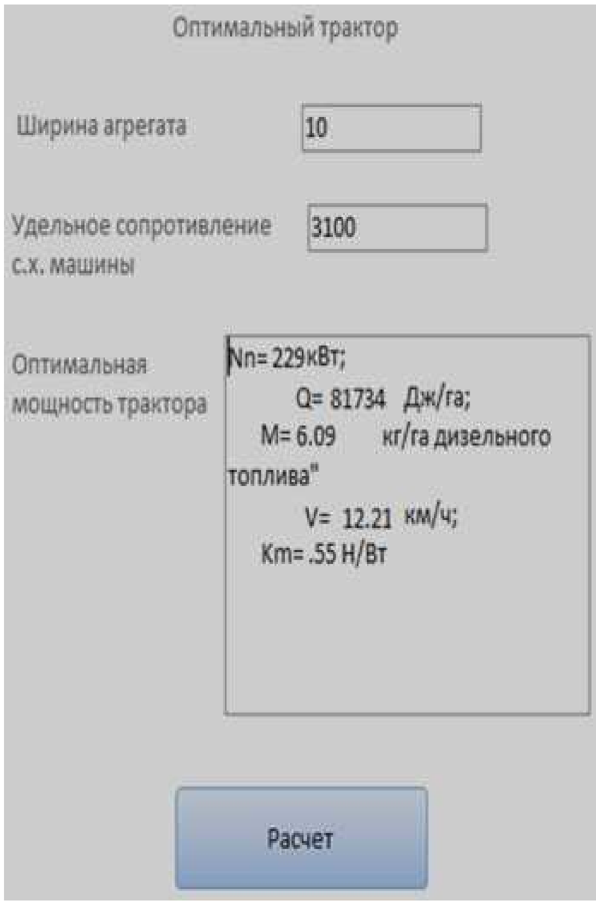


Figure 3. Screenshot programs for calculating the optimal type of the machine in the unit with the sowing complex.

The dependence of the power of the machine on the width of the capture of the tillage sowing complex (Figure 4) was approximated:

$$N_{н} = 10.8 \cdot B \qquad (15)$$

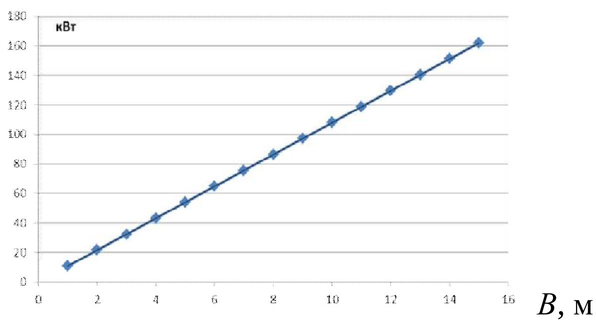


Figure 4. The graph of the dependence of the optimum power of the machine on the width of the capture of the tillage sowing complex by the criterion of the minimum fuel consumption

We will also find the optimal material capacity by using the simulation method on the block diagram (Fig. 2), where this algorithm is incorporated. And we will give the essence of the method of ballasting according to a particular program (Fig.3) of the required material capacity of the machine.

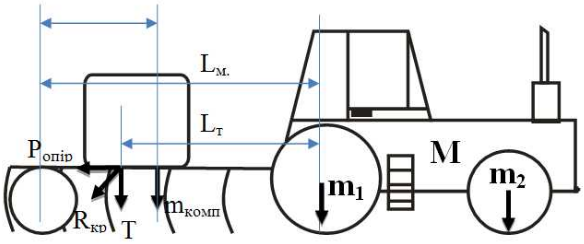


Figure 5. The diagram of the ballasting of the machine in the unit with a tillage sowing complex

Let's determine the mass of ballast, which must be added to the mass of the machine:

$$\Delta M = M_p - M, \quad (16)$$

where: M_p – is the estimated mass of the machine, kg;

M – is the actual operating mass of machine, kg.

$$M = m_1 + m_2, \quad (17)$$

where: m_1 – is the part of the mass of the machine that falls on the rear axle, kg;

m_2 – is the part of the mass of the machine, which falls on the front axle, kg.

According to the diagram shown in Fig. 5 the part of the mass of the tillage sowing complex is transferred to the rear axle of the machine, in addition, the vertical component of T reaction of the traction resistance of the complex $R_{кр}$ additionally loads the rear axle. The influence of the mass of the tillage sowing complex is expressed as follows:

$$M_{компл} = m_{компл} \cdot \frac{L_{ц.м.}}{L_м} + \frac{R_{кр} \cdot sin\alpha}{g} \cdot \left(1 - \frac{L_т}{L_м}\right) \quad (18)$$

So, we rewrite expression (17) and (16)

$$m_1 = m_1 + M_{компл}, \quad (19)$$

$$M = m_1 + m_2 + M_{компл}, \quad (20)$$

$$\Delta M = M_p - m_1 + m_2 + M_{компл}. \quad (21)$$

where: ΔM – the total weight of ballast, kg.

As is known the machine with a wheel formula 4K2, 4K4 loses its controllability with the coefficient of load of the front wheels is less than 0.2 [4].

Therefore, let's check the condition of the unit:

$$\frac{m_2}{M} \geq 0{,}2, \quad (22)$$

If the condition (22) is satisfied, then the balancing of the machine will have the form:

$$\Delta x = \frac{m_2}{M} - 0.2, \quad (23)$$

$$\Delta M_x = \Delta M - M \cdot \Delta x, \quad (24)$$

$$\Delta m_1 = M \cdot \Delta x + \frac{\Delta M_x}{2}, \quad (25)$$

$$\Delta m_2 = \frac{\Delta M_x}{2}, \quad (26)$$

where: Δm_1 – is the mass of ballast, which must be loaded rear axle, kg;

Δm_2 – is the mass of the ballast, which must be loaded with the front axle, kg;

Δx – is the mass of the ballast, which is necessary to load the front axle to meet the minimum value of the index of the machine manageability;

ΔM_x – is the total mass of the ballast for the installation on the machine, kg.

If the condition (22) is not satisfied, then the machine balancing will be performed as follows:

$$\Delta x = 0.2 - \frac{m_2}{M}, \quad (27)$$

$$\Delta m_1 = \frac{\Delta M_x}{2}, \quad (28)$$

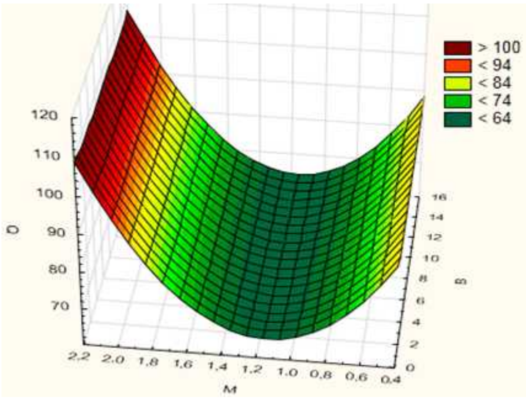
$$\Delta m_2 = M \cdot \Delta x + \frac{\Delta M_x}{2}. \quad (29)$$

Modeling the work of the tillage sowing unit according to the above algorithm in the program (Fig.3) we received the operating data of its functioning with various operational parameters at a speed of work from $\vartheta_p = 2 \ldots 4$ m/s.

When we have analyzed Fig. 6-7, we established that the most effective is the material capacity, which is equal to unit. At the same time, the optimum, i.e. the lowest fuel consumption is attained.

CONCLUSIONS

According to the developed methodology, a program has been created for the calculating of the optimal type of the machine. The criterion of the optimization is adopted the minimum of the given energy costs. It is determined that for the specific size of the tillage sowing complex, the optimal machine should be selected in terms of capacity together with its ballasting. The most effective in the unit with a tillage sowing complex is the machine with a material capacity coefficient equal to 1.



H/W

Figure 6. The surface of the response of the dependence of the reduced fuel costs on the material capacity of the machine and the width of the tillage sowing complex

Q, МДж/га

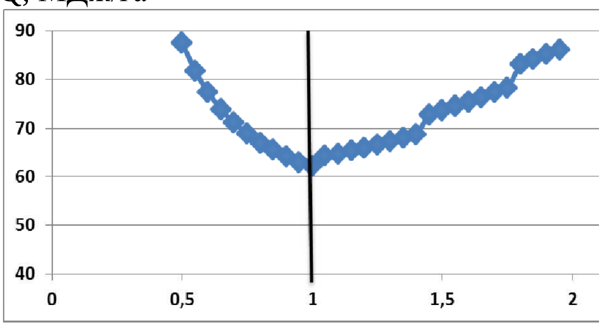


Figure 7. The graph of the change in the given energy costs from the material consumption of the machine for B = 6 m

Modern tractors have a material capacity ratio of 0.55-0.59. That is, the optimal machine in terms of fuel economy is that one whose mass is 2 times greater than that of modern machines.

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