INVESTIGATION OF DRAFT COEFFICIENT OF EFFICIENCY OF WHEELED TRACTOR

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Abstract. The choice of optimum conditions for the motion of a machine and tractor aggregate allows ensuring its maximum output with minimum fuel consumption. But efficient solution of this task is impossible without taking into consideration the character of the variations in the draft coefficient of efficiency of the tractor. The results of the conducted investigations indicate that, in order to avoid excessive compaction of soil and destruction of its structure, the wheel spin of the running wheels of the wheeled tractor with the engine capacity of about 147 kW in the early spring season should not be more than 15 %, but for the tractors with the installed engine capacity within the range of 60…75 kW the limiting value of the spin wheel should be even lower – approximately 9 %. Impact of the agricultural background of the field upon the character of the variations in the draft coefficient of efficiency of a wheeled tractor has been established by theoretical investigations.

Keywords: tractor, draft coefficient of efficiency, wheel spin.

Introduction

One of the most important characteristics of a tractor is its draft coefficient of efficiency (η_t). The value of this indicator points to the potential possibilities of the means of energy used as part of this or that machine and tractor aggregate.

Analysis of the draft coefficient of efficiency of a tractor has been in the focus of attention of many scientists. Yet, some of them treated this parameter either as a simple relation of the tractive capacity of the tractor to the effective capacity of its engine [1], or, in the best case, as the known product of the coefficients of efficiency reflecting the mechanical losses in the transmission of the means of energy, the losses of efficiency due to its rolling motion and wheel spin δ[2].The researchers who are studying the nature of the draft coefficient of efficiency to a greater extent presented it more often as the function of the utilisation coefficient of the adhesive force of the tractor φ_{dr} [3-6]. Their methodological approaches were characterised by one peculiarity. Its essence was that in studying the dependency $\eta_t = f(\varphi_{dr})$ the functional relationship $\varphi_{dr} = f(\delta)$ had a pronounced non-linear character [4; 5]. Besides, the maximum value of the wheel spin of the tractor considered by them was 24 % [3] and even more [6].

It has been established by the recent studies [7] that, in order to avoid excessive compaction of soil and destruction of its structure, the wheel spin of the running wheels of the wheeled tractor with the engine capacity of about 147kW in the early spring season should not be more than 15 % but for the tractors with the installed engine capacity within the range of 60…75 kW the limiting value of the spin wheel should be even lower – 9 %. At this limitation of the wheel spin of the tractor wheels the relationship $\varphi_{dr} = f(\delta)$ will be of a linear character. And this, in its turn, means that the functional dependency $\eta_t = f(\varphi_{dr})$ will change in a corresponding manner. Besides, in a quantitative aspect it will essentially depend on the condition of the agricultural background of the field across which the tractor is moving as part of this or that machine and tractor aggregate.

Materials and methods

The aim of this work is a theoretical study of the draft coefficient of efficiency of a tractor depending on the utilisation coefficient of its adhesive force with a linear character of its wheel spin on various agricultural backgrounds.

Generally, the theoretical studies of the draft coefficient of efficiency of a means of energy with a linear character of its wheel spin were carried out applying the fundamentals of the tractor theory and elements of higher mathematics.

Investigations into the impact of the utilisation coefficient of the adhesive force of the tractor upon the character of the change of its draft coefficient of efficiency were conducted on two typical backgrounds: a) in the field prepared for sowing, i.e. in the soil prepared by a plough and a cultivator; b) in an uncultivated field after harvesting cereals (a stubble field).

It is known that generally the draft coefficient of efficiency (η_t) expresses a relation between the tractive capacity of energy means N_{dr} and the effective capacity N_e, developed by its engine:

$$\eta_t = \frac{N_{dr}}{N_e}. \tag{1}$$

On the basis of the analysis of the equation of the energy balance of a wheeled tractor this coefficient is generally presented as the following product [2]:

$$\eta_t = \eta_{tr} \cdot \eta_f \cdot \eta_\delta , \tag{2}$$

where η_{tr}, η_f, η_δ – coefficients of efficiency reflecting mechanical losses in the transmission of the means of energy, the losses of capacity due to its rolling motion and the wheel spin, respectively.

The value of the mechanical coefficient of efficiency of contemporary tractor gear transmissions η_{tr} at operating loads, close to the nominal ones, varies little, and it is within a range from 0.90 to 0.93.

The essence of the coefficient of efficiency reflecting the losses of capacity due to the rolling motion of the tractor is revealed by the following expression [2]:

$$\eta_t = \frac{\varphi_{dr}}{\varphi_{dr} + f}. \tag{3}$$

In equation (3) f is the coefficient of rolling resistance, but φ_{dr} is the utilisation coefficient of the adhesive force of the tractor G_t. By its essence this coefficient can be calculated as:

$$\varphi_{dr} = \frac{P_{dr}}{G_t}, \tag{4}$$

where P_{dr} – the draft resistance developed by the tractor.

As regards the coefficient of efficiency reflecting the losses of the engine capacity of the means of energy (the tractor) due to its wheel spin (δ), it is determined from such a dependency:

$$\eta_\delta = 1 - \delta . \tag{5}$$

Results and discussion

In order to solve the assigned task, we will make transformations of the generally known dependencies mentioned in the previous chapter. If expressions (3) and (5) are inserted into equation (2), then the draft coefficient of efficiency (η_t)in its final form will be equal to:

$$\eta_t = \eta_{tr} \cdot \frac{\varphi_{dr}}{\varphi_{dr} + f} \cdot (1 - \delta). \tag{6}$$

In fact, expression (6) is the potential draft characteristics of a tractor in dimensionless coordinates. As underlined above, it represents the dependence of the draft coefficient of efficiency η_t on φ_{dr}, since the wheel spin (δ) in equation (6) is generally expressed as its dependence on the same parameter (i.e. φ_{dr}). As for coefficients η_{tr} and f, their variationsφ_{dr} within the range from 0 to $\varphi_{dr.\max}$ may be ignored and considered as constant.

One of the most wide-spread functional dependencies $\delta = f(\varphi_{dr})$ is the following [4]:

$$\delta = \frac{a \cdot \varphi_{dr}}{1 - b \cdot \varphi_{dr}^n}, \tag{7}$$

where a, b – constant coefficients;
$n \geq 2$.

For accuracy, sufficient for practice, the values of the index of the degree n in equations that are similar to (7) most often are chosen as 2 [3; 6]. In this case the considered maximum value of the wheel spin of a wheeled means of energy (a tractor) is 20… 24 % and more.

Taking into consideration the limitations on the wheel spin value presented in [7], its dependence on the parameter φ_{dr} will have a linear character in the form:

$$\delta = a \cdot \varphi_{dr} + b. \tag{8}$$

Considering (8) expression (6) is transformed in the following way:

$$\eta_t = \frac{\eta_{tr} \cdot \varphi_{dr} \cdot (1 - a \cdot \varphi_{dr} - b)}{\varphi_{dr} + f}. \tag{9}$$

Due to its novelty, dependency (9) should be studied so that it could be used in theoretical calculations and investigations. First of all, in order to determine the optimum and the character of its dependence on the utilisation coefficient of the adhesive force φ_{dr} of the tractor.

Let us present equation (9) in the following form:

$$\eta_t = \frac{C_1 \cdot \varphi_{dr} \cdot (1 - C_2 \cdot \varphi_{dr} - C_3)}{\varphi_{dr} + C_4}, \tag{10}$$

where $C_1 = \eta_{tr}$; $C_2 = a$; $C_3 = b$ and $C_4 = f$.

We will study function (10) to determine the extremum on condition $\varphi_{dr} \in (0, \varphi_{dr\max})$.

The coefficient C_1 will not be taken into consideration in this case since it, being a positive value, affects only the numerical value of the extremum and has no impact on its position.

Let us introduce designation 1-C_3 = C_5 and regard the function:

$$f(\varphi_{dr}) = \frac{\varphi_{dr} \cdot (C_5 - C_2 \cdot \varphi_{dr})}{\varphi_{dr} + C_4}.$$

Its first derivative will be equal to:

$$f'(\varphi_{dr}) = -\frac{C_2}{(\varphi_{dr} + C_4)^2} \cdot \left(\varphi_{dr}^2 + 2C_4 \cdot \varphi_{dr} + C_6\right), \tag{11}$$

where $C_6 = -\dfrac{C_4 \cdot C_5}{C_2}$.

It is quite evident that function (11) will be equal to zero if:

$$\varphi_{dr}^2 + 2C_4 \cdot \varphi_{dr} + C_6 = 0. \tag{12}$$

Further we will study the discriminant of equation (12), which is equal to:

$$D = 4 \cdot \left(C_4^2 + \frac{C_4 \cdot C_5}{C_2} \right).$$

For this we will consider the following conditions:

1. if the discriminant $D < 0$, then function (10) has no extremums, and, in the interval, it monotonically decreases;
2. if $D = 0$, then ≤ 0, and in the interval $\varphi_{dr} \in (0, \varphi_{dr\max})$ function (10) monotonically decreases;
3. if the value of the discriminant $D > 0$, the value is additionally determined $V = C_2 \cdot [C_2 + (1 - C_3)/C_2]$, when it turns out that $V \leq 0$, then function (10) has no extremes, and it decreases.

In case $V > 0$, it is necessary to check the inequality:

$$C_4 < \sqrt{V} = t < C_4 + \varphi_{dr\max} . \quad (13)$$

If condition (13) is not executed, then function (10) has no extremums. When condition (13) is executed, function (10) has an extremum (maximum) the coordinate of which (φ_{dr}) is determined from the equation:

$$\varphi_{dr} = \sqrt{C_4 \cdot \left(C_4 + \frac{1 - C_3}{C_2} \right)} - C_4 \quad (14)$$

First of all, according to the methodology laid out above, let us analyse function (10) that describes the dependence of the draft coefficient of efficiency of the tractor under the condition of its motion across the field prepared for sowing. According to the data obtained after processing a large amount of experimental draft characteristics of the wheeled tractors, the average value of the coefficient of rolling resistance on such an agricultural background is $f = 0.14$ [2], the coefficients of equation (8) are $a = 0.352$ and $b = 0.002$. At the limiting value of the wheel spin δ = 15 %, the maximum value of the utilisation coefficient of the adhesive force of the tractor $\varphi_{\mathrm{dr.max}} = 0.33$.

The value of the discriminant D of equation (12) is positive and equal to 1.6. Value $V = 0.416$ is also above zero. Yet, in this case condition (13) is not executed since it turns out that the evaluation value $t = 0.645$ is greater than the sum $C_4 + \varphi_{dr.\max}$, which is equal to 0.47. Hence it unambiguously follows that in the operation of a wheeled tractor in the field prepared for sowing with the wheel spin not exceeding 15 %, dependency (10) has no extremum (curve 2, Fig. 1).

A maximum value η_t can be reached only on condition $\varphi_{dr} = 0.5$. But the wheel spin of the tractor in this case will be essentially higher than 15 %, which is not acceptable from a position that excessive compaction of soil and destruction of its structure must be avoided [8; 9].

When the tractor is moving across an uncultivated field after cereal harvesting (the stubble field) the limiting value of its wheel spin constitutes 20 % [7]. In this case the coefficient of the rolling resistance $f = 0.10$ [2], but the maximum value of the utilisation coefficient of the adhesive force of a wheeled energy means $\varphi_{dr.\max} = 0.47$.

In this case the discriminant D of equation (12) is also positive and equal to 1.29. In addition, condition (13) is executed completely since the evaluation value $t = 0.567$ is less than the sum $C_4 + \varphi_{dr.\max}$, equal to 0.57.

Such a result indicates that the investigated function (10) has an extremum. In this case this maximum is equal to 0.65, and it can be attained at $\varphi_{dr.\mathrm{opt}} = 0.47$ (curve 1, Fig. 1).

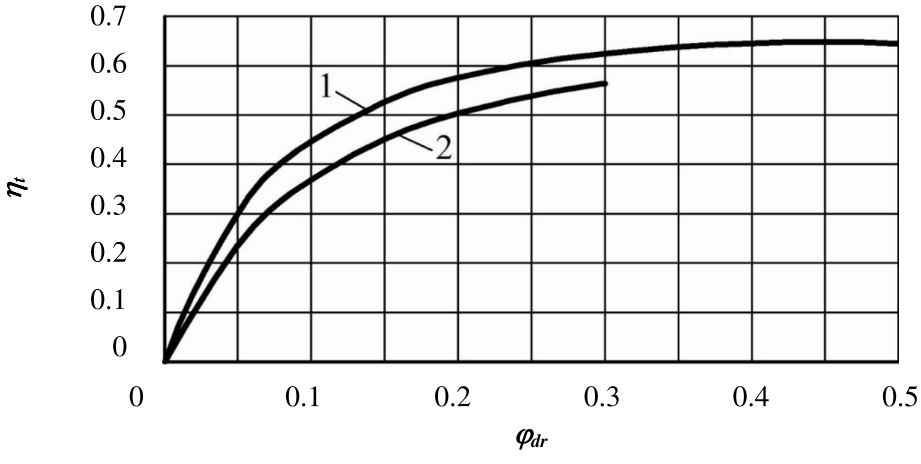

Fig. 1. **Dependencies of the draft coefficient of efficiency (η_t) of a tractor on the utilisation coefficient of the adhesive force (φ_{dr}),moving across an uncultivated field, after the harvest of cereals (the stubble field) (1) and the field with a soil prepared for sowing (2)**

Attention should be paid to the fact that the optimal and the limiting values of the utilisation coefficients of the adhesive force of a tractor operating on such an agricultural background as an uncultivated field after the harvest of cereals coincide and will be equal: $\varphi_{dr.\max} = \varphi_{dr.\mathrm{opt}} = 0.47$.

The analysis of expressions (9) and (8) shows that the most efficient way how to increase the values of the utilisation coefficient of the adhesive force of a tractor is reducing the coefficients *a* and *b*. In practice such a requirement manifests itself in real reduction of the wheel spin $\delta$of its undercarriage.

Besides, we will add that application of the most apparent, at the first sight, technical means, such as increasing the mass of the tractor at the expense of hanged-up ballast to solve this task needs careful analysis. The problem is that an increased adhesive force G_t, if the mass of the energy means is increased, creates preconditions for an increase in the draft resistance P_{dr}. Yet, the analysis of expression (4) shows that simultaneous increase of these parameters may lead both to the reduction and increase of the coefficient φ_{dr}. As it results from Figure 1, it is possible to increase this coefficient only to quite definite values. As regards the increase of φ_{dr}, this promotes reduction of the wheel spin of the tractor, see Formula (7), on the one hand, but it is a precondition for undesirable reduction of its draft coefficient of efficiency, on the other.

In an ideal case such a technical or technological solution is necessary which would promote achievement of the required efficiency of the machine and tractor aggregate with simultaneous removal of the problem connected with the wheel spin of the tractor. One of the examples of such a solution may be application of a technology using a technological track (controlled traffic farming) or a bridge-crane farming system [9-11]. Just their application allows the solution of the issue how to improve the draft properties of the energy means without considering the soil compaction problem.

Conclusions

1. If the wheel spin of a wheeled tractor is limited to 15 %, an optimum value of its draft coefficient of efficiency cannot be reached (the function has no extremum).
2. Operation of a tractor on an agricultural background after harvesting of cereals (the stubble field) with a limiting wheel spin 20 % allows reaching the optimum value of the draft coefficient of efficiency.
3. Considering the wheel spin limiting values, the highest value of the draft coefficient of efficiency of a tractor can be reached at a maximum value of its utilisation coefficient of the adhesive force.
4. A real way how to raise the value of the draft coefficient of efficiency of a tractor is reduction of the wheel spin of its undercarriage. One of the efficient solutions for this may be application of technologies using a technological track (controlled traffic farming).

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