INVESTIGATION OF TECHNOLOGICAL PROPERTIES OF WIDE SPAN TRACTORS FOR CONTROLLED TRAFFIC FARMING

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Abstract. Practical use of wide span tractors (vehicles) for controlled traffic farming needs further motivation of the principles of their automatic steering, allowing maximum reduction of area losses of the field under the engineering zone at least 1.5 times. The use of contemporary wide span tractors (vehicles) with a track width more than 7.5 m allows reaching a value of the area losses of the field under the engineering zone not more than 5…6 %, which is quite acceptable. The presented brands of such tractors are provided with various technological equipment and means of automation, the technological significance of which can be estimated only by means of objective assessment methods. The developed equation for the estimation of the potential efficiency of the wide span tractors makes it possible to conduct analysis of the degree of impact upon them made by their design parameters and indicators of technical characteristics. Estimation of the degree of potential efficiency, which the contemporary wide span tractors should have, showed that the result exceeds the potential efficiency of the conventional machine and tractor aggregates by 1.5-2 times.

Keywords: controlled traffic farming, wide span tractor, efficiency.

Introduction

When the agricultural machinery is used haphazardly, with different working widths, most of the fertile soil is subject to the unfavourable impact of the wheels (undercarriage) of the tractors [1; 2]. Controlled traffic farming (CTF) is considered as one of the most perspective directions in the use of agricultural machinery for soil tillage, sowing and crop cultivation, and is a tool, which is used to reduce the damage to soils caused by heavy or repeated agricultural machinery passes on the land. For CTF a very important factor is the choice of the appropriate traction aggregates (tractors). The wide span tractors (vehicles) for controlled traffic farming turn our present production systems on their head by leaving 80-90 % of fields permanently without compaction. CTF aims to confine soil compaction to the least possible area of permanent traffic lines.

On the whole, the technological properties of the wide span tractors (vehicles) are entirely determined by the requirements of the technological process. In controlled span farming the quantitative (e.g., efficiency) and the qualitative indicators of the technological process performed by a wide span tractor depend, to a certain degree, on their design parameters and technical characteristics. There is a clearly expressed dependency between the indicators of the technological process and the technical characteristics of the wide span tractors. However, certain characteristics are connected not with one but several technological indicators. For instance, their reliability, the automation level etc. influence not only their efficiency but also the economic indicators of the technological process.

The link of the design parameters of the wide span tractors with the technical characteristics and their technological indicators is not as straightforward as the link between the characteristics and the indicators. One and the same design parameter affects several indicators and characteristics. For example, the track width, the agrotechnical clearance, the parameters of the actuators of the wide span tractors make an impact on all the indicators of the technological process and on most technical characteristics, except the prescribed and regulated (controllability, stability and smoothness of movement, etc.) ones. If the requirements of the technological process and the design parameters of the wide span tractors are compared, then a conclusion can be made about the degree of their technological effectivity. Therefore, the study of the theory of technological operation of wide span tractors, as well as the development of methods for the analysis and estimation of conformity of the parameters and their characteristics with the requirements of the technologies of controlled traffic farming today is a highly important and sufficiently topical task.

The world science has already accumulated certain experience in issues on the study and practical implementation of controlled traffic farming [3-6]. The technical basis of these systems are wide span vehicles or wide span tractors [7-10].Lately, the interest in wide span tractors (vehicles) has essentially

increased. In their development there are engaged the scientists in the USA, Great Britain, Japan, Poland, the Netherlands, Russia, Ukraine and other countries [12]. By the technological properties of wide span tractors we will understand the properties that characterise the conformity of the particular wide span vehicle or wide span tractor with the technological requirements in the entire complex of agricultural operations of controlled traffic farming for which they are designed.

The known methods of the theory of technological operation of the conventional tractors allow quantitative estimation of the technological level of the developed tractor or the tractor offered by the market, the degree of conformity of its design parameters and technical characteristics, as well as the technological properties, on the whole, with the requirements of the technological process of agricultural production [13]. By means of these methods it is possible to calculate the quantitative value of the complex indicator of the technological level and to conduct analysis of the degree of impact upon its individual design parameter and indicator of the technical characteristic of the tractor. However, the familiar methodologies, developed for the conventional tractor and combine technologies, cannot practically be applied to wide span tractors mainly because of their atypical layout scheme, usage specificity and performance conditions in controlled traffic farming. The peculiarities of structurally-technological and functional operation of wide span tractors need the development of a principally new estimation methodology of their technological properties.

The aim of the investigation is a study of the technological properties of wide span tractors (vehicles) for controlled traffic farming and justification of their design and other parameters in order to raise the efficiency of their use.

Materials and methods

Theoretical investigations, synthesis of the design map and parameters of wide span tractors were carried out by simulating the conditions of their operation on the PC. The basis for the research methods were the methods of the theory of the technological operation of mobile energetic means, the tractor theory, using the Mathcad packet.

In our opinion, the entire diversity of the requirements of a particular technological process of controlled traffic farming imposed to the wide span tractors (Fig. 1) can be expressed by the following generalised indicators: technological versatility, efficiency, agrotechnical quality of the performed operation, costs of the operations and ecological conditions.

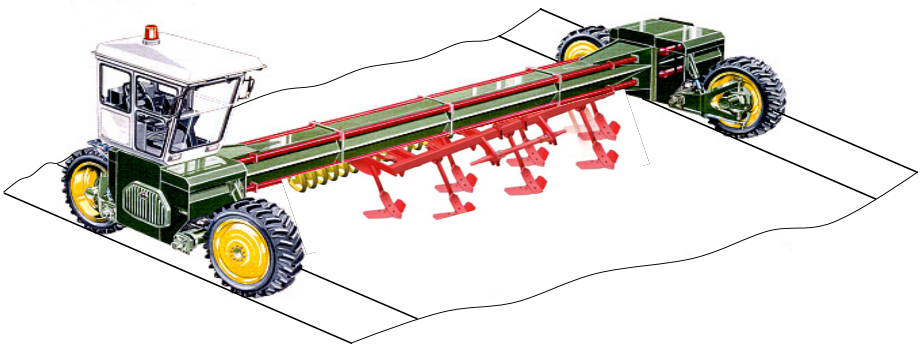

Fig. 1. **Design map of a wide span tractor (vehicle) for controlled traffic farming**

By technological versatility of a wide span tractor one should understand its ability to perform efficiently the largest set of agricultural operations of controlled traffic farming from their total number. Versatility should be regarded as the basic problem of the technical concept of wide span tractors during their designing: the more versatile they are, the more efficient is their application for controlled traffic farming. Particular indicators which determine the technological versatility should be the indicators of a possibility of their efficient application for soil tillage, sowing and harvesting operations, including forage harvesting, as well as for the transport operations. The issue about the estimation of the impact degree upon its individual design parameters and indicators of the technical characteristics of the wide span tractors remains for the time being open and poorly explored.

The agrotechnical properties of the wide span tractors are determined by the degree of the area losses of the field as the engineering zone, and damage of the cultivated plants. These properties

depend on the kinematic indicators, manoeuvrability, controllability, stability of the movement, visibility from the driver's seat, and some other indicators of the technical characteristic of the wide span tractors. The structure of the generalised indicator of the agrotechnical properties depends on the purpose of the estimated wide span tractor (vehicle) and the aim of the task to be solved. The machines and the mechanisation means of agricultural production are one of the basic sources of a negative technogenic impact upon the surrounding environment of harmful combustion products of fuel, leakage of the materials used, the acoustic influence, vibrations, and so on. Therefore, considering the generalised indicator of the ecological properties allows estimation of the conformity of the discussed wide span tractor with the technological requirements from the position of ecological safety in the entire complex of agricultural operations of controlled traffic farming when growing cultivated plants.

The efficiency depends on the tractive properties of the wide span tractor, the power of its energy installations, aggregation ability with agricultural machines and tools, the reserve of the carrying capacity of the actuator tyres. The operator's comfort and safety of work are of great importance, as well as the reliability of the wide span tractor.The cost indicators depend on the price of the wide span tractor, its energy efficiency andoperating costs. Let us discuss in a more detailed way the methodology for quantitative efficiency estimation of wide span tractors, which will allow analysis of the degree of influence on its definite design parameters and indicators of the technical characteristic.

Conceptually regarded, each wide span tractor (vehicle) is a single energy technological complex with a constant efficiency indicator (W_p = *const*). The potential efficiency is determined by the maximum tractive ability of the wide span tractor, but the speed of its movement is maximal at the particular power of its energy installations, yet not exceeding the speed, set by the agrotechnical rules. On this condition the potential efficiency can be quite assumed as one of the basic indicators of the operation of the wide span tractors, and it is expedient to include it into the number of the indicators of their technical and technological characteristics in addition to the existing ones. The potential efficiency characterises the potential possibilities, and it does not depend on concrete conditions of work of the wide span tractors, the characteristics of the machines and tools aggregated with them, the parameters of the technological conditions, and so on. This is why the potential efficiency may serve as a basic indicator in relation to which one should estimate suitability of wide span tractors to perform particular operations with maximum efficiency under various conditions of operation.

In a general case, it is accepted to qualify efficiency as one of the basic technical and economic indicators. Besides, it characterises the duration of the execution time of this or that individual agricultural operation or their complex. Consequently, efficiency may also be referred to the number of indirect indicators that characterise the agrotechnical properties of wide span tractors.

Let us consider the interrelation between the potential efficiency and the basic parameters and characteristics of wide span tractors (vehicles) (Fig. 2).

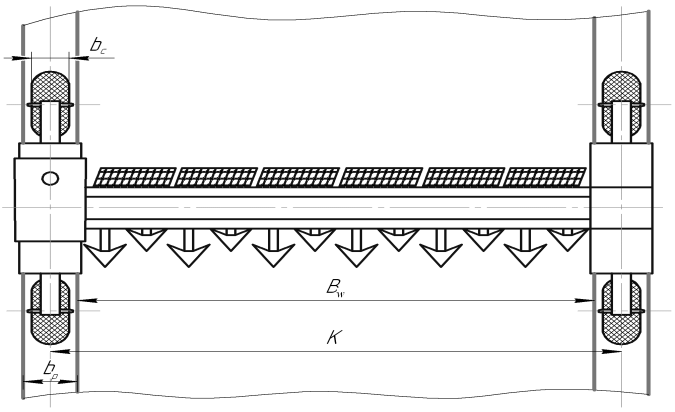

Fig. 2. **Scheme of the working area of controlled traffic farming with a wide span tractor**

For this we will use the well-known dependencies from the tractor theory and operation of the machine and tractor fleet [14] :

$$W_p = B_w V_w \tau , \quad (1)$$

where W_p – shift performance;
B_w – working width of the wide span tractor;
V_w – speed of the wide span tractor;
τ – coefficient of time used per shift.

The working width of the wide span tractor is connected with its track width by the following dependency:

$$B_w = K - b_p, \tag{2}$$

where b_p – width of the tractor transport technological track on the engineering zone of the field.

Results and discussion

We will present the width of the transport technological track b_p by the sum of the width of the track b_c from the actuator tires of the wide span tractor (vehicle) and a certain width of the technological tolerance c, determined, among other factors, by the amplitudes of its lateral deviation from the rectilinear movement:

$$b_p = b_c + c. \tag{3}$$

The rated speed of the wide span tractor can be determined considering the impact of the operational factors upon it:

$$V_{\mathrm{w}} = \frac{\eta_t \chi_d k_N N_e}{P_{t.n.}}, \tag{4}$$

where η_t – traction coefficient of efficiency of the wide span tractor;
χ_d – coefficient of possible loading of the engine by the resistance moment;
k_N – coefficient of possible use of the engine efficiency;
N_e – rated operational efficiency of the energy installations;
$P_{t.n.}$ – rated tractive effort of the wide span tractor.

The realisable rated tractive effort of the wide span tractor is proportional to its operational weight:

$$P_{t.n.} = \varphi_w G_e, \tag{5}$$

where φ_w – weight utilisation factor of the wide span tractor;
G_e – operational weight of the wide span tractor.

By substituting expressions (2)-(5) into (1) we obtain:

$$W_p = \frac{(K - b_c - c)\eta_t \chi_d k_N N_e \tau}{\varphi_w G_e}. \tag{6}$$

Each term of the right side of expression (6) can be presented in the form of a functional dependency on a series of parameters. Depending on the target setting, for instance, the traction coefficient of efficiency can be presented in the form:

$$\eta_t = \eta_{tr} \eta_f \eta_\delta = \frac{\eta_{tr} \varphi_w (1 - \delta)}{\varphi_w + f}, \tag{7}$$

where η_{tr} – coefficient of efficiency of the transmission of the wide span tractor;
η_f – coefficient of efficiency of the rolling resistance of the wide span tractor;
η_δ – coefficient of slipping efficiency of the wide span tractor;
δ – slipping coefficient of the wide span tractor;
f – coefficient of the rolling resistance of the wide span tractor.

When estimating the technological properties of wide span tractors, one should exclude from the estimate of the coefficient of time used per shift τ the components of the time used per shift, which are

not dependent on the properties of the tractor. These are the losses of time per shift for organisational reasons because of weather conditions, physiological needs of operators, violation of the technological process. Then:

$$\tau = 1 - \sum_{з=1}^{n} \tau_з , \quad (8)$$

where $\sum_{i=1}^{n} \tau_i$ – sum of the coefficients of time per shift, reflecting the losses of time per shift during the preparatory operations for aggregation of the wide span tractors with the agricultural machines and tools τ_a, technological service τ_s, fault removal τ_f and holding every shift technical maintenance $\tau_{e.s.}$, idle travel τ_o;
n – number of coefficients τ.

Let us consider the impact of the design parameters and technical characteristics of wide span tractors (vehicles) upon the coefficients listed above. The time of preparation of the wide span tractor for the work, considered by the coefficient τ_a, depends on the labour intensity of aggregation of the tractor with the agricultural machines and tools, easiness of their mutual interconnection. The connecting devices should be convenient to use, without application of a special instrument. The time of the technological service of wide span tractors, considered by the coefficient τ_s, depends most essentially on the presence of a platform on which a container with the technological material is placed, as the reserve of the technological material allows reduction of time for its refilling at the expense of their reduced quantity. The time spent for the technical service per shift and fault removal $\tau_{e.s.}$ is determined by the degree of technical perfection of the wide span tractor, its technical level. The coefficient τ_o, which considers the time of idle travels, depends mainly on the kinematic characteristics of the wide span tractor (vehicle) and the duration of its transfer from a working position to the transport position.

Expression (6) also allows quantitative assessment of the value of the potential efficiency, which the contemporary wide span tractors should have. For this in (6) we will replace the relation of the operational efficiency N_e to the weight G_e by the indicator of the energy intensity E_t:

$$\frac{N_e}{G_e} = E_t . \quad (9)$$

The value of energy intensity of the wide span tractors must be $E_t = 2.35$ kW·kN^{-1} [14]. Accepting the remaining parameters of the technical possibilities of contemporary wide span tractors (vehicles), which are necessary for the calculation according to (6) on the level: $K_N = 0.9$; $\chi_d = 1.35$; $\eta_{tr} = 0.9$; $\varphi_w = 0.45$; $\tau = 0.9$; $f = 0.08$; $\delta = 0.16$, it is possible to estimate by means of the Mathcad packet the value of the potential efficiency depending on the width of the track K and the width of the actuator tires b_c (Table 1).

Table 1

Potential efficiency W_p (ha·h^{-1}) of contemporary wide span tractors (vehicles) depending on the width of the track K and the width of the actuator tires b_c

Width of the actuator tires b_c	Width of the track K of the wide span tractors (vehicles)			
	K = 6 m	K = 9 m	K = 12 m	K = 15 m
b_c = 0.4 m	6.86	10.67	14.48	18.30
b_c = 0.5 m	6.67	10.48	14.29	18.11
b_c = 0.6 m	6.48	10.29	14.10	17.92

An analysis of Table 1 shows that the level of the potential efficiency of contemporary wide span tractors within the range of their track width from 6 m to 16 m must be 6.48-18.3 ha·h^{-1}. Such a result exceeds, as a minimum, 1.5-2 times the potential efficiency of the conventional machine and tractor aggregates. This is an additional confirmation for efficiency and perspectivity of the wide span tractors for controlled traffic farming from a position of their technological properties. Increasing the width of the actuator tires of the wide span tractors from 0.4 m to 0.6 m reduces their potential efficiency by 2-

5 %. In terms of the technological properties, such a result is of small importance. However, it should be taken into account that increasing the width of the actuator tires of the wide span tractors increases the area of the field under the engineering zone of controlled traffic farming, which is not desired.

Conclusions

1. The entire diversity of the requirements of a technological process of controlled traffic farming imposed to the wide span tractors (vehicles) can be expressed by the following generalised indicators: technological versatility, efficiency, agrotechnical quality of the performed operation, ecological conditions, and costs of the operations.
2. The developed equation for the estimation of the potential efficiency of the wide span tractors (vehicles) makes it possible to conduct analysis of the degree of impact upon them made by their design parameters and indicators of technical characteristics. Estimation of the degree of potential efficiency, which the contemporary wide span tractors (vehicles) should have, showed that the result exceeds the potential efficiency of the conventional machine and tractor aggregates by 1.5-2 times.

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