Theoretical Studies of the Relationship Between the Parameters of the Bridge Tractor and the Engineering Area of the Field

Volodymyr Bulgakov, Stanislav Nikolaenko, Simone Pascuzzi, Valerii Adamchuk, Volodymyr Kuvachov, Valentyna Krutyakova, Francesco Santoro, and Janusz Nowak

Abstract The planning of the field under the bridge system of agriculture should be carried out taking into account the size of both the bridge tractor, which moves on specially created tracks of the permanent technological track, and auxiliary means of mechanization. The purpose of the research is to study the processes of field planning and organization of the movement of bridge tractors, considering the prospects for further automation of all technological processes that they perform, including transport. Theoretical research was carried out by modeling the conditions of the bridge tractor operation on the PC using the provisions of theoretical mechanics and tractor theory. Experimental studies of the bridge tractor were carried out according to both generally accepted and developed methods and involved the use of modern and specially designed equipment. As a result of research, mathematical models and algorithms were developed to allow interdependent choice of construction parameters of bridge tractors, in particular, the width of its track and propulsion, stable traffic conditions (taking into account the value of technological tolerance) and parameters of the field for its permanent technological track. Mathematical analysis of the obtained models substantiates the rational track width of these bridge tractors at the

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S. Pascuzzi and F. Santoro (eds.), *Farm Machinery and Processes Management in Sustainable Agriculture*, Lecture Notes in Civil Engineering 289,
https://doi.org/10.1007/978-3-031-13090-8_5

level of 7.5…9 m, according to which the loss of field area under the engineering zone when using them is not more than 5…6%.

Keywords Bridge tractor · Permanent technological track · Engineering and technological zone of the field · Theoretical and experimental research

1 Introduction

In track and bridge agriculture, part of the total field area is allocated for the engineering zone, which reduces the productive part of the field – agro-technical zone [1–6]. The engineering zone includes a transport system for the movement of all means of mechanization, communication for energy and water supply, telecommunication channels and orientation system [7, 8]. The area of the engineering zone depends mainly on the parameters of the transport system, which, in turn, are determined by the parameters of technological and transport machines [9, 10]. According to the requirements of automation, mechanization should be subordinated to the principles of the coordinate transport system, in which machines can move only in two mutually perpendicular directions and for the implementation of which the field must have strictly defined dimensions [11–13].

When analyzing the use of productive field area in bridge farming, it is necessary to consider, first of all, the issues of planning and organization of machine movement, taking into account the prospects of further automation of all technological processes, including transport [14–20].

It is obvious that with the increase of the track width of the bridge tractor the losses of the fertile area of the field under the engineering zone decrease [21]. The nature of this pattern depends on many factors, including the design parameters of the bridge tractor and the stability and controllability of its movement, organization and mode of its rotation on the turning lane, etc. [22]. From the standpoint of efficient use of the productive field area, it is advisable to have an accessible method and be able to determine the rational track width of the bridge tractor under specific conditions of its use.

Study of regularities of influence of parameters of agricultural bridge systems and conditions of their operation on the character of field planning and organization of movement of bridge tractors, taking into account prospects for further automation of all technological processes performed by them, including transport.

2 Materials and Methods

Theoretical research was carried out by modeling the conditions of the bridge tractor operation on the PC using the provisions of theoretical mechanics and tractor theory. Experimental studies of the bridge tractor (Fig. 1) were carried out according to both generally accepted and developed methods and involved the use of modern and specially designed equipment. Processing of experimental data was performed on a PC using regression and correlation-spectral analyzes. The research methods are based on the foundations of theoretical mechanics using the Mathcad package.

Experimental studies were conducted in a specially equipped laboratory for testing a bridge tractor with a test length of 50 m.

During the experimental studies after the working movement of the bridge tractor, the amplitude of its transverse deviation from the axis of symmetry of the constant technological track was measured. For this purpose, the amplitude of the transverse deviation from the axis of symmetry of the constant technological track of the tracks of its front x_s and rear x_r wheels from one side of the bridge tractor was determined with a step of 0.2 m (Fig. 2).

From the obtained implementations, statistical characteristics such as standard deviations and normalized spectral densities were determined according to the method presented in [23, 24].

The experimental amplitude-frequency characteristic of the oscillations of the linear transverse displacement of the bridge tractor as part of the harrowing unit was calculated from the expression [23, 24]:

Fig. 1 Experimental studies of a bridge tractor of new construction

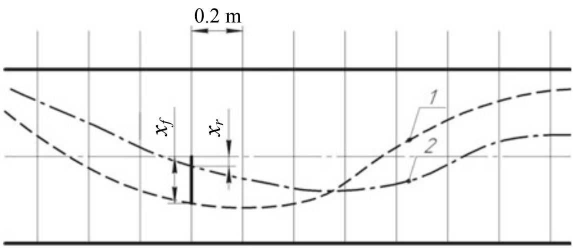

Fig. 2 Scheme for determining the transverse displacement of the bridge tractor: 1, 2 – respectively, the middle of the trajectories of its front and rear wheels within the width of the technological track

$$A(\omega) = \frac{\sigma_y}{\sigma_x} \cdot \left(\frac{S_y(\omega)}{S_x(\omega)}\right)^{\frac{1}{2}} \quad (1)$$

where σ_x, $S_x(\omega)$ – standard deviations and normalized spectral density of the input value; σ_y,, $S_y(\omega)$ – standard deviations and normalized spectral density of the original value; ω – frequency of oscillations of the control effect, s^{-1}.

The theoretical spectral density of oscillations of the initial parameter was found from the expression [23, 24]:

$$S_y(\omega) = \frac{A(\omega)^2 \cdot S_x(\omega) \cdot \sigma_x}{\sigma_y} \quad (2)$$

where $S_x(\omega)$ – normalized spectral density of oscillations of the input quantity.

3 Results and Discussion

Consider the scheme of planning the engineering zone of the field in the track system of agriculture for the operation of the bridge tractor on the coordinate-transport principle of their movement on the land of rectangular correct configuration (Fig. 3).

Changing the direction of movement of the bridge tractor on the turning lane should be done in a circular turn (Fig. 4). The center of rotation of the bridge tractor must be in the area of the transport technological track of one of its sides (left or right, depending on the direction of rotation). Only in this case you can get the desired minimum turning radius and width of the turning lane. At the same time, with this method of reversal, the bridge tractor is moved to the next race in the minimum period of time, which increases productivity. Technically, this can be realized through swivel wheels. Otherwise, when the wheels of the bridge tractor are uncontrollable, its turn on the spot can be realized by lifting one of the sides, where, leaning on the propulsion of the other side as they move, you can rotate around the center of rotation.

Loss of field area under the engineering zone (w_i) in Fig. 3 will be evaluated by a relative indicator, numerically equal:

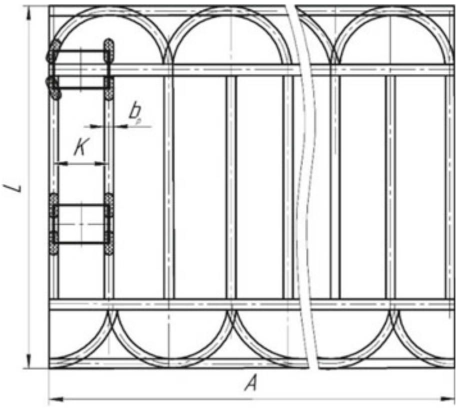

Fig. 3 Scheme of field map planning for the track system of agriculture for the operation of the bridge tractor

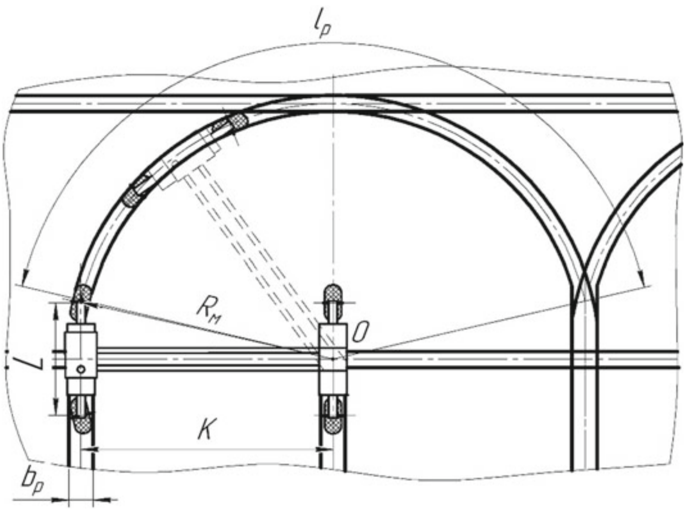

Fig. 4 Diagram of the rotation of the bridge tractor by its circular rotation relative to the center of rotation (point O)

$$w_i = \frac{S_i}{A \cdot L}, \quad (3)$$

where S_i – the area of the engineering zone of the field; L and A – length and width of the field.

The land use ratio (k_s) will be equal to:

$$k_S = 1 - w_i = 1 - \frac{S_i}{A \cdot L}. \quad (4)$$

The area of the engineering zone in Fig. 3 can be determined by the sum of three components:

$$S_i = S_o + S_{ot} + S_{tt}, \tag{5}$$

where S_o, S_{ot} – the area of traces of transport technological tracks on the main field and turning lanes, respectively; S_{tt} – the total area of traces of the running system of the bridge tractor when making turns.

Area S_o for Fig. 3 will be equal to:

$$S_o = b_p \cdot \left[L - 2\left(K + b_p\right)\right] \cdot \left[\frac{A - b_p}{K} + 1\right], \tag{6}$$

where b_p – width of the transport technological track; K – track width of the tractor.

The width of the transport technological track b_r is represented as the sum of the track width b_s from the tires of the bridge tractor and some width of the technological tolerance c, due, in particular, to the amplitudes of its transverse deviations from rectilinear motion:

$$b_p = b_c + c. \tag{7}$$

In the presented scheme of field map planning according to Fig. 3 on each turning lane there are only two transport technological paths, which is sufficient both for the passage of the bridge tractor and for making turns. Therefore, the S_{ot} area for the two turning lanes on the field will be:

$$S_{\mathrm{ot}} = 4 \cdot b_p \cdot A. \tag{8}$$

The total area S_{tt} traces of the running system of the bridge tractor when making it turns folding:

$$S_{\mathrm{tt}} = \pi \cdot b_p \cdot \left(A - b_p\right). \tag{9}$$

After substitution of Eqs. (5–9) in (3) the coefficient of losses of the field area under the engineering zone w_i will be equal to:

$$w_i = \frac{b_c + c}{L \cdot A} \cdot \left([L - 2(K + b_c + c)] \cdot \left[\frac{A - b_c - c}{K} + 1\right] + 4 \cdot A + \pi[A - b_c - c]\right). \tag{10}$$

Analysis of expression (10) confirms the previously mentioned inversely proportional nature of the dependence of w_i on the track width K of the bridge tractor. In this case, increasing the width of the tires b_c of its propulsion and technological tolerance on the contrary increases the loss of field area under the engineering zone. Equation (10) does not have an extremum of the function w_i from the argument K, but allows to establish the point of rational optimum of this dependence, as well

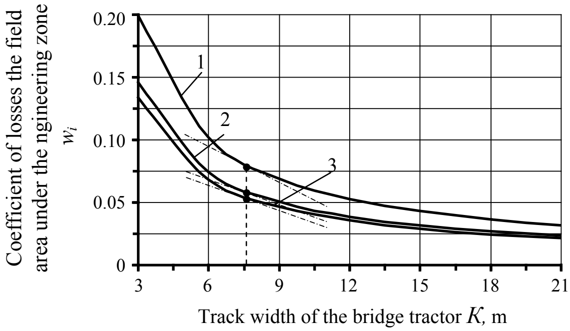

Fig. 5 Dependence of the coefficient of losses of the field area under the engineering zone w_i on the track width K of the bridge tractor depending on the width of the tires of its engines: 1 – $b_{c1} = 0.586$; 2 – $b_{c2} = 0.429$; 3 – $b_{c3} = 0.394$ m

as to estimate the influence of parameters of the bridge tractor running system and technological tolerance from the standpoint of efficient land use in track agriculture. To do this, in the Mathcad environment, three curves of dependence w_i and K were constructed for three variants of tractor tires of the bridge tractor: 1 – $b_{c1} = 0.586$; 2 – $b_{c2} = 0.429$; 3 – $b_{c3} = 0.394$ m (Fig. 5).

In Fig. 5 the area of change of argument K can be conditionally divided into two intervals. In each of the intervals, the dependence w_i on K is close to linear. Moreover, in the range of initial values of K, the function w_i decreases intensively, and for higher values of K – slowly. Suppose that the rational value of K corresponds to the optimum point of the specified two-band curve, which divides the latter into two parts with significantly different properties. Using the least squares method to determine the parameters of the rational function [25], the points of the rational optimum of two-band curves in Fig. 5.

For the considered variants of parameters of tires of engines of the bridge tractor the rational size of track width of the last is necessary for $K = 7.5$ m. The obtained value of the track width when using tires with a width of 0.429 and 0.393 m allows to have the number of losses of the field area under the engineering zone not more than 6%. And when increasing the track width to 9 m, the amount of area loss is at the level of 5%.

The calculations on the influence of the length of field A on the loss of area under the engineering zone w_i and found that the quantitative values of this effect can be considered insignificant. Since, for example, for the path of a bridge tractor $K = 3$ m with tire wheels 15.5R38 diameter which is 0.394 m when reducing the length of the field from 1000 to 100 m loss of field area under the engineering zone w_i changes from 0.151 to 0.133, and at $K = 30$ m – from 0.033 to 0.015 – also changes less than 2.0%. In general, in the range of change A from 100 to 1000 m the value of w_i varies by no more than 2%.

Consider the degree of influence of technological tolerance c on the nature of the increase in field area losses under the engineering zone w_i.

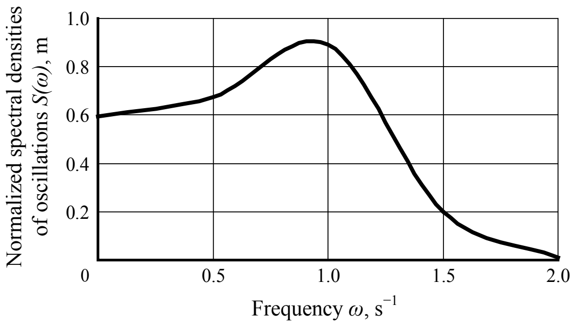

Fig. 6 Normalized spectral densities of oscillations linear transverse displacement of the bridge tractor

The oscillations of the transverse displacement of bridge tractor in the harrowing unit during its working movement are also low-frequency (Fig. 6). The main spectrum of variances is concentrated in the frequency range 0…2.0 s^{-1}. The standard of oscillations of this parameter was $\pm$ 0.05 m.

The calculation of the experimental amplitude-frequency characteristic according to expression (1) and its comparison with the theoretical one showed (Fig. 7) that in the operating frequency range (0…2 s^{-1}) of the input signal oscillations the largest difference between theoretical and field data does not exceed 15%.

Analysis of the dependence of w_i and c (Fig. 8) shows that the width of the technological tolerance c significantly affects the loss of field area under the engineering zone.

Thus, for the considered variants of tractor tires, the engines of the bridge tractor with an increase from 0.3 m to the loss of the field area under the engineering zone are increased by 1.5–1.75 times. Therefore, the use of a bridge tractor in the track system of agriculture requires substantiation of the principles of their automatic driving,

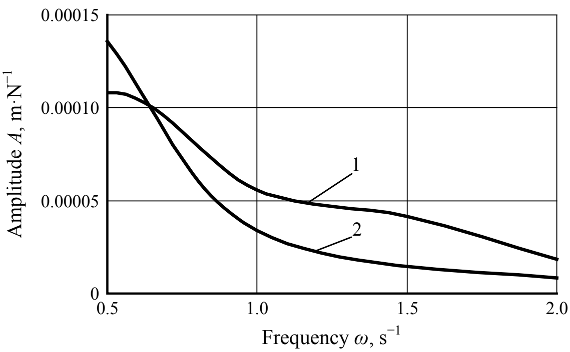

Fig. 7 Theoretical (1) and experimental (2) amplitude-frequency characteristics of oscillations of linear transverse displacement during testing of a bridge tractor as part of a harrowing control unit

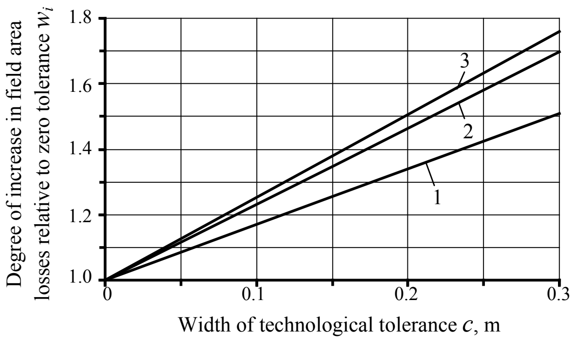

Fig. 8 Influence of technological tolerance width *c* on the degree of field area losses under the engineering zone relative to zero tolerance depending on the width of the tires of the bridge tractor: 1 – bc1 = 0.586 m; 2 – bc2 = 0.429 m; 3 – bc3 = 0.394 m

which minimizes the amplitude of transverse deviations from a given rectilinear trajectory, and, as a consequence, directly reduce the value of *c*.

As a result of the conducted researches it is possible to conclude that planning of the field under track system of agriculture with use of the bridge tractor has to consider width of a track of the last and parameters of transport system. The use of modern bridge tractors with a track width of more than 7.5 m allows to achieve the amount of losses of the field area under the engineering zone of not more than 5–6%, which is quite acceptable.

The practical use of the bridge tractor in the track system of agriculture requires substantiation of the principles of their automatic driving, which will minimize the loss of field area under the engineering zone at least 1.5 times.

4 Conclusions

Studies have shown that the loss of field area under the engineering zone significantly depends on the width of the track for the movement of the bridge tractor, the value of which is directly determined by the width of the tires of their wheels. Calculations have established that according to the criterion of the minimum coefficient of losses of the field area under the engineering zone, the rational value of the track width of the latter is $K = 7.5$ m. In practice, this means that when using the tires of a bridge tractor with a width of 0.393…0.429 m, allows you to have the amount of losses of the field area under the engineering zone not more than 6%. At the same time, when increasing the width of the track tractor to 9 m, which is typical for foreign models of so-called “bridge” tractors, the amount of area loss is reduced to 5%.

The loss of the field area under the engineering zone is practically independent of its length. Proof of this is the fact that when reducing the length of the field from 1000 to 100 m, this value changes by no more than 2% in the range of variations in the track width of the road tractor to 30 m. Therefore, in practice, the size of the field when it is arranged under the track system of agriculture does not significantly affect the value of the coefficient of losses of the field area under the engineering zone.

With large transverse deviations of the bridge tractor from the rectilinear trajectory of its movement, increasing the width of the technological tolerance of the permanent technological track by only 0.3 m increases the loss of field area under the engineering zone by 1.5…1.75 times. In practice, this means that the use of a bridge tractor in the track system of agriculture requires justification of the principles of their automatic driving, which, by improving the stability of their movement, will minimize the loss of field area under the engineering zone at least 1.5 times).

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