RESEARCH ON THE TURNING ABILITY OF A TWO- MACHINE AGGREGATE
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ИССЛЕДОВАНИЕ РАЗВОРАЧИВАЕМОСТИ ПОСЕВНОГО ДВУХМАШИННОГО АГРЕГАТА

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ABSTRACT

On a turning strip of minimum width, a two-machine sowing aggregate can perform loop turns with a mode indicator close to the optimal, and loopless ones **–** *with an indicator almost twice as large. Implementation of both types of turning of the aggregate, studied under optimum conditions, takes place on the turning strip the working width of which is greater than the calculated minimum and the multiple working width of the aggregate. The most efficient solution for the problem of making a turn of such an aggregate is the use of a coupling device that could automatically change the velocity of its movement on the turning strip, depending on the angular velocity of the tractor driven wheels turning.*

АНОТАЦІЯ

На поворотній смузі мінімальної ширини двухмашинні посівні агрегат можуть здійснювати петлеві повороти з показником режиму, близьким до оптимального, а безпетлеві – з показником майже удвічі більше. Реалізація обох видів поворотів агрегату, який досліджено, в оптимальному режимі має місце на поворотній смузі, дійсна ширина якої більше мінімально розрахованою і кратна ширині захвату агрегату. Найбільш ефективним рішенням проблеми здійснення повороту даного агрегату з оптимальним значенням показника режиму є застосування зчіпного пристрою, який би автоматично змінював швидкість його руху на поворотній смузі залежно від кутової швидкості повороту керованих коліс агрегатуючого трактора.

INTRODUCTION

The efficiency of the sowing operations is very important both from the economic point of view and in order to meet the optimal agrotechnical terms *(Aseeva et al., 2013; Barwicki, 2012; Meca & Cardei, 2012).*

One of the directions to increase the efficiency of the machine-and-tractor aggregates is to increase their working width. There are two real ways of implementing this direction: the use of wide-span machines of monoblock *(Nadykto, 2009; Kyurchev, 2013, Mitkov, 2010)* constructions and the use of couplings.

The first way has both disadvantages and advantages. The monoblock wide-span machine can be aggregated only with one power source of the corresponding traction class. The process of aggregation and adjustment to the working position of a monoblock machine takes less time. At the same time, the transportation complexity of the machine leads to a significant complication of its design and increased price *(Moiseenko, 2013; Rubec, 2012, Bulgakov et al., 2017).*

The use of couplings makes it possible to use narrow-span machines more efficiently: in the coupling they are aggregated with one tractor, and each separately with the other. To a large extent, this applies to the machine-and-tractor sowing aggregates based on multipurpose cultivating tractors of traction class 1.4.

The conventional use of a coupling in the trailed version is characterised by increased length of the set-off of the sowing aggregate. As a result, this leads to a significant (not less than 38%) increase in the specific time spent on the turns *(Karabanicky, 2009; Nadykto, 2005; Smolinsky, 2016)*.

The most promising option for increasing the operating width of the aggregate is the use of a semi-mounted coupling. Besides, its design should exclude collision of the trailed machines on the turning strip, and the indicator of the turning mode of the machine-and-tractor aggregate should ensure increased technical and economic indicators of its operation. It is the practical solution of exactly this task that determines the topicality of this work.

A significant contribution to the theory and practice of this issue has been made by many scientists *(Iofinov, 1986; Bulgakov et al., 2017; Makarenko, 2011)*. At the same time, the theoretical dependencies developed by them and the obtained practical results cannot be used to justify the design and technological parameters of the machine-and-tractor sowing aggregate developed by us as part of a multipurpose tractor, traction class 1.4 (MTZ-80), two SZ-3 seeders SZ-3.6, and a semi-mounted coupling *(Nadykto, 2009; Masalabov, 2012)* (such a design was not tackled in the researches, in general).

The known indicators of the aggregate turning mode do not reflect adequately enough the link of its design parameters with its movement mode on the turning strip. As a result, this does not provide an opportunity to achieve essential increase in the technical and economic performance of the sowing aggregate. In this paper, an attempt is made to search for a new scientifically grounded indicator of the turning mode of an aggregate with a semi-mounted coupling, aimed at eliminating these shortcomings.

The aim of the work is to study and determine the optimum turning mode of a two-machine sowing aggregate with a semi-mounted coupling.

MATERIALS AND METHODS

As a research object, a machine-and-tractor sowing aggregate was selected, assembled from a tractor of traction class 1.4 (MTZ-80), a semi-mounted two-machine coupling SS-7.2, developed according to our design, and two trailed grain seeders SZ-3.6 (Fig. 1).

Fig. 1 – An experimental two-machine sowing aggregate with a semi-mounted coupling

When carrying out experimental studies on the turning strip, the actual value of the turning radius (R_a) of the two-machine sowing aggregate was fixed in duplicate repetition, depending on the turning angle of its driven wheels. For this purpose the diameters of the conditional circles, left on the field by the rear wheels of the tractor, were determined (Fig. 2) and R_a was calculated according to the equation:

$$R_a = \frac{(D_1 + D_2)}{4}, \tag{1}$$

where D_1 and D_2 – the diameters of conditional circles, left on the field by the rear left and right wheels of the tractor.

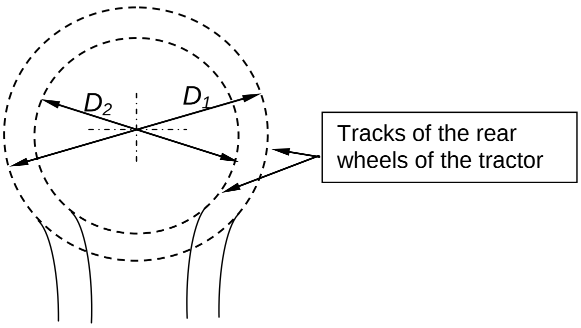

Fig. 2 – A scheme for determination of the turning radius of the sowing aggregate

The actual velocity of the movement of the tractor (V_r) on the turning strip was found as follows. A circle with a diameter of 20 m and, respectively, a length of 62.8 m was drawn on the field. The tractor was moving on a given gear and with full fuel delivery. The driver operated the tractor so that the landmark placed in front moved along the path of the circumscribed circle (Fig.3).

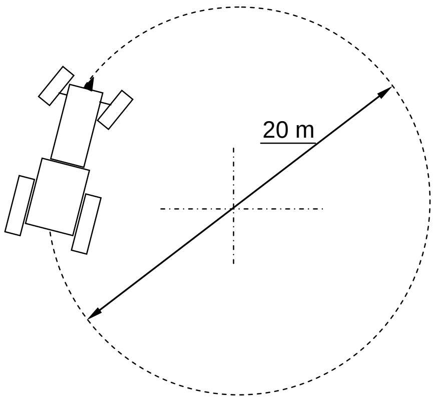

Fig. 3 – A scheme of the section for determination of the real velocity of the aggregating wheeled tractor

The value of V_r was determined from this expression:

$$V_r = \frac{62.8}{t_0}, \tag{2}$$

where t_0 – the time (duration) of the tractor movement along the given circle, s.

The kinematic parameters of the two-machine sowing aggregate were determined according to the scheme in Fig. 4. Here E and d_k are the length of the set-off and the kinematic width of the machine-and-tractor aggregate.

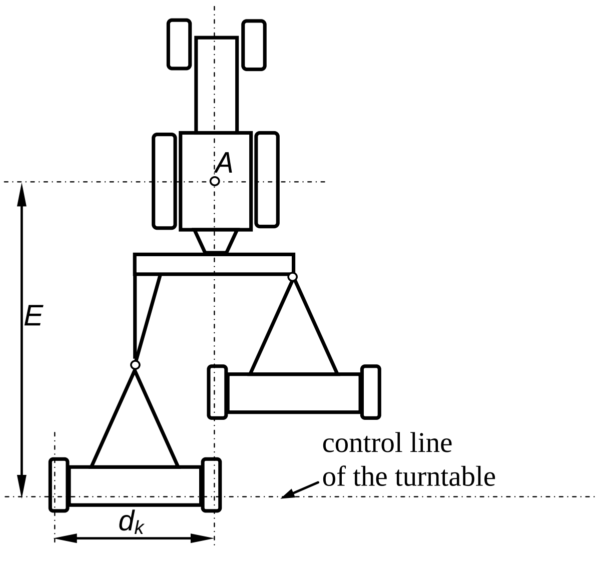

Fig. 4 – Scheme for determining the kinematic parameters of a machine-and-tractor sowing aggregate

A set-off length of the machine-and-tractor aggregate (E) was defined as the rectilinear path on the turning strip passing through the kinematic centre of the aggregate (point A, Fig. 4) until the last row of the working implements of its sowing machines come onto the control line. For the machine-and-tractor aggregate under study the kinematic length is E = 5.95 m. The essence of the kinematic width of the aggregate is clear from Fig. 4. For asymmetric aggregates it is, of course, different. In this case, with sufficient accuracy for practice, we can assume that this parameter is equal to the working width of the seeder d_k = 3.6 m.

During the experimental field research of the two-machine sowing aggregate on the basis of the MTZ-80 tractor, a specially developed hardware-measuring complex using an analogue-to-digital converter and a PC was used (Fig. 5), on which were synchronously recorded the following:

– the turning angles (α_1, α_2) of the tractor left and the right driven wheels;

– revolutions (n_1, n_2) of the tractor rear wheels.

Fig. 5 – Arrangement of the recording complex in the tractor cab

To record the turning angles of the driven wheels of the tractor, we used rheochord linear sensors SP-3A with the nominal value of 470 Ohm. The stator of this sensor was fixed relative to the frontal semi-axis of the tractor, and the rotary rotor was connected to the axis of the centre pivot of the driven wheel. During the movement of the machine-and-tractor aggregate the driven wheel, under the impact of the control action on the part of the driver, turned in a vertical plane. Together with the centre pivot of the propulsor, the rotor of the SP-3A sensor turned at the same angle. By means of the analogue-to-digital converter the electrical signal from the sensor was recorded on the screen and in the PC memory in the form of a corresponding data file. To register the rotation frequencies of the rear wheels of the MTZ-80 tractor, specially designed current collectors were used, which were mounted on the hubs of these propulsors. During the movement of the machine-and-tractor sowing aggregate the signal from each current collector was displayed via the analogue-to-digital converter on the screen and also mapped in the PC memory in the form of a respective data file.

RESULTS

It is known that the movement of the machine-and-tractor aggregate with an optimum turning radius is possible when the indicator of the mode of this manoeuvre (K_t) appropriately correlates together the design and kinematic parameters of the machine-and-tractor aggregate *(Masalabov, 2012):*

$$K_t = \frac{V_r}{\omega} = \frac{2\varepsilon_{\max}\left[\dfrac{l_t}{\tan(\varphi_3)} + \dfrac{l_{sh}}{\sin(\varphi_3)} - \dfrac{l_c}{2}\right]^2}{L}\ , \tag{3}$$

where $\varphi_3 = 90 - \arccos\left[\dfrac{(l_{sh} - r_{wh})}{R_1}\right]$ – the turning angle of the seeder;

V_r – velocity of the aggregate movement on the turning strip, m·s^{-1};

ω – average angular velocity of the tractor driven wheels turning, rad·s^{-1};

l_t – distance from the axis of the tractor rear wheels to the coupling frame, m;

l_{sh} – length of the seeder tow bar, m;

l_c – front of the coupling, m;

r_{wh} – radius of the seeder wheel, m;

R_1 – distance from the right wheel of the seeder to the point of its attachment to the coupling extender, m;

ε_{max} – the maximum turning angle of the aggregate at the moment when it completes "entering into the turn", rad;

L – the base of the tractor, m.

While carrying out experimental studies, the design parameters included in expressions (3) were the following: l_t = 1.04 m; l_{sh} = 2.15 m; l_c = 3.6 m; L = 2.37 m; r_{wh} = 0.59 m; R_1 = 2.52 m; $\varepsilon_{max} = \pi \cdot 2^{-1}$ – for loop turns; $\varepsilon_{max} = \pi \cdot 4^{-1}$ – for loopless turns of the sowing aggregate.

Substituting these values into (3), we find out that the actual value of the indicator of this machine-and-tractor aggregate turning mode is:

– when performing a loop turn – 11.9 m·rad^{-1};

– when performing a loopless turn – 5.9 m·rad^{-1}.

At the same time, as it was established in the course of mathematical simulation (*Masalabov, 2011, Masalabov, 2012)*, when the frame of the coupling was removed from the rear wheel axis of the tractor to a distance l_t = 1.95 m, the true value of the indicator of the machine-and-tractor aggregate turning mode is equal to the optimal value of 11.4 m·rad^{-1}.

The movement of the experimental two-machine sowing aggregate was carried out on a turning strip the width of which (E_t), for each of the two types of turning (loopless and loop) considered, was found from the expression:

$$E_t = B_w \,\mathrm{integr}\left(\frac{E_{t\min}}{B_w}\right), \tag{4}$$

where $E_{t\,min}$ – the minimum width of the turning strip, m;

B_w – the working width of the aggregate, m.

The minimum width of the turning strip ($E_{t\,min}$) was determined by procedure *(Bulgakov et al., 2017):*

– for the loopless turn

$$E_{t\min} = R_r + E + d_k, \tag{5}$$

– for the loop turn:

$$E_{t\min} = 2.7R_r + E + d_k, \tag{6}$$

where R_r – the conditional turning radius.

According to definition *(Iofinov, 1986)*, R_r is the radius at which the machine-and-tractor aggregate would perform a manoeuvre exclusively along a circle, that is, without transitional sections of the aggregate entering into a turn and leaving it.

By the definition *(Iofinov, 1986)* the conditional turning radius of the aggregate R_r can be defined as follows:

$$R_r = R_{a\min} + \frac{K_t L}{\pi R_{a\min}}, \tag{7}$$

where $R_{a\,min}$ – the minimum turning radius of the machine-and-tractor aggregate.

However, since:

$$R_{a\min} = \sqrt{\frac{K_t L}{2\varepsilon_{\max}}}, \tag{8}$$

then

$$R_r = \sqrt{\frac{K_t L}{2\varepsilon_{\max}}} + \frac{K_t L}{\sqrt{\dfrac{K_t L}{2\varepsilon_{\max}}}}. \tag{9}$$

Taking into account the concrete value of ε_{max}, we have:

– for the loopless turn

$$R_r = \sqrt{\frac{2K_t L}{\pi}} + \frac{K_t L}{\sqrt{\frac{2K_t L}{\pi}}}\,; \tag{10}$$

– for the loop turn:

$$R_r = \sqrt{\frac{\hat{E}_t L}{\pi}} + \frac{\hat{E}_t L}{\sqrt{\frac{\hat{E}_t L}{\pi}}}\,. \tag{11}$$

After carrying out the appropriate calculations it was established that for a loopless mode of rotation $E_{t\,\min}$ = 16.15 m, and for loop mode $E_{t\,\min}$ = 27.37 m.

Considering expression (4) and the fact that B_w = 7.2 m, we finally have for the loopless turn E_t = 21.60 m, and for the loop turn E_t = 28.80 m.

It is on the strips of this width that the experimental machine-and-tractor aggregate must make turns in the process of real operation.

However, under the conditions of experimental studies the manoeuvring of the aggregate was first carried out on strips, where the width of each strip was equal to $E_{\min}$. Only under such a condition can be tracked the impact upon the turning process of its mode indicator, especially when making a loopless turn.

To make sure of this, we will consider the calculated and the real values of the width of each turning strip. For the loopless turning the difference between E_t = 28.80 m and $E_{\min}$ = 27.37 m is only 1.43 m. At the same time, for the loopless turn we have (E_t – $E_{\min}$) = 5.45 m. Besides, it can be assumed that the dynamics of the turning process of the experimental machine-and-tractor aggregate on a 16.15 m wide strip can differ significantly from the nature of this process on a strip wider by 5.45 m. As it turned out, during the experimental studies, implementation of a loop (pear-shaped) turning by the experimental aggregate occurred at an average velocity V_r = 1.88 m·s^{-1}. The average value of the angular velocity (ω) of turning of the tractor driven wheels was ω = 0.155 rad·s^{-1}.

As a result, the two-machine sowing aggregate made a turn with the real value of the indicator of the turning mode 1.88 / 0.155 = 12.1 rad·s^{-1}. This is only 1.7% more than the calculated value K_t, which is 11.9 m·rad^{-1} for the given type of turning performed by the experimental machine-and-tractor aggregate. Even with respect to the optimal (11.4 m·rad^{-1}), the true value of the turning mode indicator is higher only by 6.1%.

When a loopless turn is performed, the situation looks different. In this case, the phases of aggregate entrance into the turn and exit from it are shorter than in the loop manoeuvre. Because of this and also because of the smaller width of the turning strip, the machine operator must exert more intense impact upon the tractor steering wheel at the same velocity of the aggregate movement, which ultimately leads to a lower indicator value of the aggregate turning mode – K_t. Thus, when the velocity of the machine-and-tractor aggregate movement during the turn is V_r = 1.90 m·s^{-1}, the value of the angular velocity of turning the steering wheel at the aggregate entrance into the turn and exit from it was 0.30 rad·s^{-1}. Only such a mode of changing the control impact allowed fitting into the turning strip with a width of 16.15 m. This was the reason for the implementation of a manoeuvre with an indicator of the mode K_t = 6.3 m·rad^{-1}. In contrast to the calculated value (5.9 m·rad^{-1}), it is higher by 6.8%. At the same time, with respect to the optimum, the true value of K_t is only 55.3%, which is almost twice less.

It should be said that the true value of the angular velocity of turning the tractor driven wheels (0.30 rad·s^{-1}) was by 36% higher than the recommended one (0.22 rad·s^{-1}). However, otherwise, that is, when the value of ω is decreased, it was not possible to fit into the width of the 16.15 m turning strip. Hence it follows that, in order to reduce value ω of the angular velocity of turning the tractor driven wheels to such a level as to ensure execution of a loopless turn with an optimum value of the indicator of the K_t regime, in practice it is not possible.

You cannot practically achieve this even in case you remove the frame of the coupling from the axis of the tractor rear wheels, that is, you increase the value of parameter l_t. The point is that, according to the results of mathematical simulation *(Masalabov, 2012)*, the increase in the value of this parameter allows reducing the turning radius of the machine-and-tractor aggregate, but only as long as the conditions for manoeuvring the machine-and-tractor aggregate are not violated. In our case, this is topical for the left-side turning of the machine-and-tractor aggregate in which angle φ_3, and hence the turning radius R_a of the aggregate, can be reduced until there arises a risk that the left wheel of the left seeder comes into contact with the frame of the coupling. In other words, as long as it is possible to increase the turning angle φ_3 of the left seeder until increase in parameter l_t (within certain limits, respectively) helps reducing the turning radius R_a of the machine-and-tractor aggregate.

When the maximum possible values of angles α (the turning angle of the tractor driven wheels, rad) and φ_3 are reached, we obtain the minimum value of the aggregate turning radius. After that, further removal of the seeder frame from the tractor (increase l_t) causes increase in indicator K_t of the turning mode, as it follows from expression (3). Consequently, execution of the loopless turns by the experimental machine-and-tractor aggregate is possible with a mode index almost twice as high as the optimal value. However, this is only in case the width of the turning strip is really at least of the minimum necessary value. Under real operating conditions it turned out that, in case the actual width of the turning strip, calculated above, is 21.60 m, the experimental machine-and-tractor aggregate can perform even a loopless turn with a mode index close to the optimal one. Thus, during a manoeuvre of the machine-and-tractor aggregate on the strip of the mentioned length at a velocity of 1.92 $m \cdot s^{-1}$, the angular turning velocity of the driven wheels of the tractor was 0.185 $rad \cdot s^{-1}$. In this case, the actual value of indicator K_t is 10.4 $m \cdot rad^{-1}$, which is only by 8.7% lower than the optimal value (11.4 $m \cdot rad^{-1}$). The machine-and-tractor aggregate, performing a manoeuvre, that is, executing a loopless turn, completely fitted into the width of the turning strip, the value of which was 21.60 m.

From the above analysis it follows that there is no practical need to increase the distance between the semi-mounted coupling frame and the axis of the tractor rear wheels (parameter l_t). First, such a solution complicates to a certain extent the design of the machine-and-tractor aggregate. Second, on the one hand, an increase in the value of l_t brings a decrease in the turning radius of the machine-and-tractor aggregate, and, on the other hand, it leads to an increase in the length of its exit on the turning strip. As a result, the time for the manoeuvre may remain almost the same.

On the basis of the research results it can be concluded that, in order to make a two-machine sowing aggregate execute a turn in the optimal mode, it is necessary that the ratio of the velocity of its movement on the turning strip to the angular velocity of tractor driven wheels turning varied within a range of 11...12 $m \cdot rad^{-1}$. Such a task can be practically solved by equipping the aggregate with a special automatic device.

CONCLUSIONS

1. As a result of the research, it was established that, in case the two-machine sowing aggregate performs loop turns, the actual value of the indicator of their implementation mode 11.45 $m \cdot rad^{-1}$ practically corresponds to the optimal value of 11.40 $m \cdot rad^{-1}$. Besides, the loopless turns will be carried out with a mode indicator of 5.7 $m \cdot rad^{-1}$, which, although it enters the allowed range of its variations (4.5...25.0 $m \cdot rad^{-1}$), it is still less than the optimal level.

2. On the turning strip of minimum width the two-machine sowing aggregate can perform loop turns with a mode index close to the optimum, and loopless ones with an indicator almost twice as high. Implementation of both types of turning in the optimum mode takes place on a turning strip the actual width of which is greater than the minimal calculated one and multiple working width of the aggregate.

3. The most efficient solution for the problem of performing a turn by a two-machine sowing aggregate with an optimum value of the mode index is to use a device that automatically changes the velocity of its movement on the turning strip, depending on the angular speed of the tractor driven wheels turning.

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