INFLUENCE OF TRACTOR HITCH LINKAGE SYSTEM ON PLOWING UNIT PERFORMANCE

Volodymyr Bulgakov[1], Semjons Ivanovs[2], Valerii Adamchuk[3], Volodymyr Nadykto[4],
Anatoliy Zaryshnyak[5], Vadym Yaremenko[1], Liudmyla Krasiuk[6]
[1]National University of Life and Environmental Sciences of Ukraine, Ukraine;
[2]Latvia University of Life Sciences and Technologies, Latvia;
[3]Institute of Mechanics and Automation of Agricultural Production
of the National Academy of Agrarian Sciences of Ukraine, Ukraine;
[4]Dmytro Motornyi Tavria State Agrotechnological University, Ukraine;
[5]National Academy of Agrarian Sciences of Ukraine, Ukraine;
[6]National Scientific Center "Institute of Agriculture of the
National Academy of Agrarian Sciences of Ukraine", Ukraine
semjons@apollo.lv

Abstract. The quality indicators of the ploughing unit largely depend on the joining diagram of the mounted plough with the tractor. Most often, this joining, performed according to a two-point or three-point diagram, is asymmetric. As a result, momentum arises that tries to turn the tractor in a horizontal plane. Depending on the chosen diagram for joining the tractor with a mounted plough, this momentum will be greater or less, and the performance of the ploughing unit will be worse or better. This paper evaluates the dependence of the momentum value on the plough rotation angle and the asymmetry of its joining to the tractor with two-point and three-point diagrams for adjusting the rear hitch linkage system. Calculations have established that the increase in the specified momentum occurs more intensively with a two-point diagram for joining the plough to the tractor. In this regard, its use is advisable only for specific ratios between the plough width and the parameters of the tractor running system. At the same time, with a certain adjustment of the tractor's rear hitch linkage system according to the three-point diagram, it is possible to achieve such a position when its centre of mass practically coincides with the point of the plough traction resistance application. Ultimately, this ensures the momentum value is reduced to a minimum (almost zero) value. Experimental studies have established, when setting the convergence angle of the lower links of the tractor hitch linkage system according to the three-point diagram at the level of 0.49 rad, the null hypothesis about the equality of the plough operating width variances in comparison with the option of its joining according to the two-point diagram does not deviate. The frequency distributions of the plough rotation angle oscillations (β) are also almost identical. The maxima of the normalized spectral densities of the parameter β oscillations fall on the same frequency equal to 0.1 s^{-1}. The oscillation variances of the angle β for both plough joining diagrams are concentrated in the same range of rather low frequencies: 0-1.0 s^{-1}, i.e. 0-0.16 Hz.

Keywords: plough, momentum, plough resistance centre, plough turning angle.

Introduction

The joining diagram of a mounted plough with a tractor determines the traction and energy performance, productivity, stability of the rectilinear movement, controllability and agrotechnical quality of the ploughing unit. It is not easy to achieve the optimal ratio between the plough width and the tractor track width. Due to the inconsistency of these parameters, a momentum arises that tries to turn the ploughing unit into a horizontal plane [1; 2]. Its impact cannot be ruled out even with a front plough [3] or a caterpillar tractor [4]. Depending on how well the joining diagram between the tractor and the mounted plough is chosen, this momentum will be greater or less, and the performance of the arable unit will be worse or better. The nature of the momentum action from the side of the plough is determined mainly by the tractor's hitch linkage system (THLS) diagram. Currently, two diagrams are predominantly used: i) three-point; ii) two-point.

The appearance of the first of them is due to the next moment. The tractor driver, during ploughing, tracks the trajectory of the previous furrow by influencing the tractor controls. The latter's reaction is to change the course through a corresponding rotation of its frame. So that this transient process does not affect the quality of ploughing, the design of THLS must provide it (within certain limits, of course) with the possibility of independent rotation relative to the plough in the horizontal plane. To do this, the lower links of THLS are not installed in parallel but at a certain convergence angle. The two attachment points of the lower links, as well as the point of attachment of the central link to the tractor, express the essence of the three-point diagram for setting up its hitch linkage system. This diagram is quite widespread in practice and, therefore, more thoroughly studied.

However, primary attention is paid to the kinematic [5; 6] and power [7-9] analyses of the rear THLS in the longitudinal-vertical direction plane. Similar studies take the same direction regarding using the front THLS [10]. There are known attempts to analyze the kinematics of a three-point THLS in a horizontal plane [11; 12]. However, this analysis does not determine or evaluate the momentum the plough traction resistance creates. And what is especially important, the deviation of this force from the tractor symmetry longitudinal axis is not considered. Issues related to studying the three-point THLS influence on the ploughing unit performance did not remain without some attention. But this was done without comparison with the two-point diagram of THLS.

The appearance of this diagram is due to the peculiarity of the ploughing unit operation based on a caterpillar tractor. It is known that a rotation of the entire body accompanies correcting its rectilinear movement in the horizontal plane. Because of this, a caterpillar tractor responds much faster to a control action than a wheeled one. In case of its poor angular mobility relative to the plough, the latter may impair the stability of its movement. And this is associated with a deterioration in the ploughing quality. In practice, it was found that this disadvantage can be eliminated by increasing the convergence angle of the THLS lower links by attaching them to the tractor frame at almost one point.

It should be noted that there are very few studies on the analysis of the two-point THLS. Known results reflect the transverse displacement influence of the plough's point attachment to the tractor. But they do not consider the case of the angle presence between their symmetry axes at all [13]. Moreover, a comparative analysis with a three-point diagram of THLS is not provided. And this, in turn, does not allow practitioners to make a reasoned choice in favour of one or another option for plough joining.

To eliminate this shortcoming, this article analyzes the effect of two-point and three-point diagrams of the tractor's hitch linkage system on the ploughing unit performance. The research results obtained in this case are valid for the wheeled and caterpillar tractor undercarriage systems.

Theoretical premises

First, consider a two-point diagram for setting up the rear THLS. The converging lower links of this system form point O, which is located to the right of the tractor's symmetry longitudinal axis YY at a distance d and distant from its centre of mass (point S_o) at a distance s (Fig. 1). The second point of THLS is located at its central link attachments to the tractor frame. For this reason, this point is not shown in Fig. 1. The plough traction resistance centre is concentrated at point D. The direction of the force P, in this case, passes through point O and deviates from the plough longitudinal axis OO_y by some angle γ. This phenomenon is explained by [14]. As noted above, the two-point joining of the plough to the tractor provides them with greater angular agility relative to each other. The measure of this agility is the angle β, which has an alternating value during the working movement of the ploughing unit. At the same time, as the practice has shown, its value does not contradict the assumption that $\cos\beta \cong 1$ and $\sin\beta \cong \beta$. One of the reasons for the realization of this angle is the momentum M_{r2}, acting relative to the point S_o and created by the force of the plough traction resistance P:

$$M_{r2} = P[d \cdot \cos(\gamma \pm \beta) - s \cdot \sin(\gamma \pm \beta)]. \tag{1}$$

In a three-point THLS, its lower links are set at a certain convergence angle α, the top of which is located at point O (Fig. 2). This point, called the "instantaneous centre of rotation" of THLS, is the application point of the plough traction resistance P.

During the ploughing unit operating movement, the plough rotates relative to the tractor's symmetry longitudinal axis by a certain angle ε. At the same time, point O moves to position O_1 and accordingly changes the direction of the force P. As a result, momentum occurs relative to the tractor mass centre (point S_o), the value of which can be determined from the following equation:

$$M_{r3} = P \cdot [l \cdot \cos(\gamma \pm \varepsilon) + (h + c) \cdot \sin(\gamma \pm \varepsilon)], \tag{2}$$

where l, h, c – design parameters, m (see Fig. 2).

In parentheses of equation (2), the "–" sign between its two terms is taken when the angles γ and ε change in antiphase during the operation of the ploughing unit. The plough rotation angle ε to the right corresponds to the deviation of the force P direction (and hence the angle *γ*) to the left concerning the plough symmetry longitudinal axis and vice versa. In the case of an in-phase change in these angular

parameters, the "+" sign is taken between the terms of the parentheses of equation (2). It should be noted that with a three-point plough joining, the angle ε (see Fig. 2) is slightly less than the angle β. This is because the latter's value is different for the left and right lower links of THLS when they are simultaneously rotated in the horizontal plane.
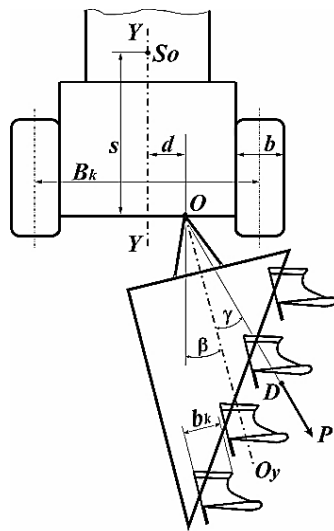
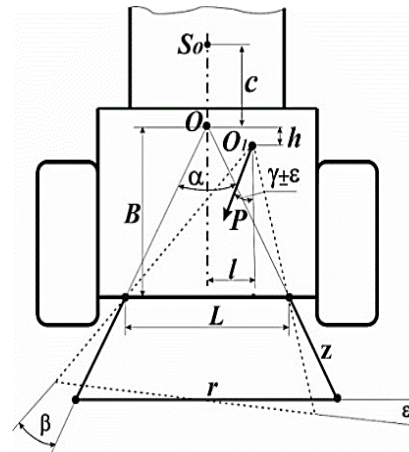Fig. 1. **Two-point diagram for joining the plough to the tractor**   Fig. 2. **Three-point diagram of THLS**

With sufficient accuracy for practice, the value of the angle ε can be determined from the equation:

$$\varepsilon = \left(1 - \frac{L}{r}\right) \cdot \beta, \qquad (3)$$

where L, r – THLS parameters, indicated in Fig. 2.

Then, taking into account (3), equation (2) will take the following form:

$$M_{r3} = P \cdot \left\{ l \cdot \cos\left[\gamma \pm \left(1 - \frac{L}{r}\right) \cdot \beta\right] + (h + c) \cdot \sin\left[\gamma \pm \left(1 - \frac{L}{r}\right) \cdot \beta\right]\right\}. \qquad (4)$$

In principle, the condition $\varepsilon < \beta$, means that the two-point diagram generally provides a large angular mobility of the plough relative to the tractor. However, even with a three-point diagram, ensuring their required mutual agility is possible. As a result, the tractor's turns will not disturb the plough's stable movement in the horizontal plane. To do this, the convergence angle of THLS lower links must meet the following condition:

$$\alpha = 2\arccos\left[B \cdot \left(\frac{r - L}{L \cdot z}\right)\right] > 0.38 \text{ rad}, \qquad (5)$$

where B – distance from the axis (m) passing through the attachment points of THLS lower links to its "instantaneous centre of rotation" (see Fig. 2);
z – length of THLS lower links, m.

Materials and methods

Theoretical studies included the study of the two-point and three-point diagrams' influence on joining the plough to the tractor on the momentum value created by it (the plough). To do this, dependencies (1), (4), (12), and (13) were used, the calculations for which were carried out in the Mathcad 15.0 software environment. The physical object of the experimental studies was the ploughing unit consisting of a tractor HTZ-150K-09 (Ukraine) and a five-bottom plough PLN-5-35. A brief technical description of this unit is presented in Table 1.

The mentioned plough was joined to the tractor, first on a two-point and then on a three-point diagram. The setting ploughing depth was constant and amounted to 25 cm. The field was divided into two sets, each 250 m long. The first 25 m of each set were used to accelerate the ploughing unit, and the next 200 m for its controlled functional movement. On the first field operating sets, the tractor moved with a plough joined in a two-point diagram and a three-point one in the second. The speed mode of the ploughing unit movement in both parts of the field was the same. Before the research, the moisture content and soil bulk density of the field sets in the 0-30 cm layer were determined.

Table 1

Ploughing unit technical characteristics

Tractor HTZ-150K-09	Value		Plough PLN-5-35	Value
Engine power, kW	132		Bottom number	5
Weight, kg	8100		Operating width, cm	175
Tires	21.3R24		Traction resistance, kN	30
Track, cm	168			
Tire width, cm	54.1			
Parameter s (Fig. 1), cm	230			
Parameter B (Fig. 2), cm	150			
Parameter c (Fig. 2), cm	80			
Parameter L (Fig. 2), cm	58			
Parameter r (Fig. 2), cm	91			
Parameter z (Fig. 2), cm	88			

In the research process, the following parameters were measured in duplicate: i) the time for the ploughing unit to pass through a working section 200 m long; ii) the plough operating width; iii) the plough angle of rotation in the horizontal plane relative to the tractor. The list of instruments and equipment and the method used for determining the soil moisture and bulk density, ploughing unit movement speed and its working width is quite fully described [14].

The plough rotation angle in the horizontal plane was recorded using a variable resistor SP-3A (Ukraine), which has a linear characteristic and a nominal value of 470 Ω. This sensor in both variants of plough joining was installed at a point located on the axis of attachment of the THLS right lower link to the tractor frame. At the same time, the rotor of the SP-3A resistor was connected to the lower link of THLS, which rotated during ploughing, and the fixed stator was connected to the tractor frame. In each experiment, the electrical signal from the sensor was applied for at least 60 s to the analogue input of the Arduino Uno (Italy). Using it, the incoming signal was digitized with an interval of 0.1 s and formed as a separate data file. The latter was used to calculate and analyze such statistical characteristics of the plough angle fluctuations as the mean value, mean error, LSD_{05}, standard, variance, and normalized spectral density.

Results and discussion

The analysis of equations (1) and (4) shows that one of the conditions for a significant decrease in the momentum values is the zero values of the angles γ and β. However, the angle γ will only be zero when the plough resistance centre (point D, Fig. 1) is located in its longitudinal-vertical plane of symmetry. But this is only achieved with specific ratios of the plough width and the parameters of the tractor running system [14]. The angle β during the movement of the plough changes according to a random law and takes a zero value only as an instantaneous one when fluctuating from a positive value to a negative one and vice versa.

The same analysis of equations (1) and (4) shows that, theoretically, the momentums can vanish altogether under the following conditions:

- for the two-point joining diagram of the plough (Fig. 1):

$$d = 0. \tag{6}$$

$$s = 0. \tag{7}$$

- for the three-point joining diagram of the plough (Fig. 2):

$$l = 0. \tag{8}$$

$$c + h = 0. \tag{9}$$

The requirement (6) can be met in practice, but only under the following conditions [14]:

$$B_k = B_p + b_k - 2A - b. \tag{10}$$

$$\hat{B}_k = B_p + b_k + b, \tag{11}$$

where $B_k, \hat{B}_k$ – tractor track when it is moving with a plough with right wheels outside the furrow
and in the furrow, respectively, m;
B_p – plough operating width, m;
b_k – plough bottom operating width, m;
b – tractor wheel tire width, m;
A – distance from furrow wall to tractor wheel tire, m.

However, as noted above, conditions (10) and (11) may not always be satisfied. As a result, for many ploughing units, the value of the parameter d turns out to be greater than zero. If we consider that condition (7) cannot be fulfilled in principle, the following conclusion follows: with a two-point plough joining diagram, it is impossible to exclude the momentum (M_{r2}) action completely. Its value can only be reduced if conditions (10) or (11) are true. In the case of joining the plough according to the three-point diagram, conditions (8) and (9) are functions of the angles of rotation (β) and convergence (α) of the THLS lower links. With sufficient accuracy for practice, the values of l and h can be determined from the following equations proposed by us:

$$l = \frac{L \cdot \beta}{2\tan\left(\frac{\alpha}{2}\right)}. \tag{12}$$

$$h = \frac{1}{2} \cdot \left[\frac{L}{\tan\frac{\alpha}{2}} - \frac{2l + L}{\tan\left(\frac{\alpha}{2} + \beta\right)} \right]. \tag{13}$$

As follows from the analysis of equations (12) and (13), only at zero value of the angle β the values of l and h will be equal to zero. Moreover, at the time when the angle β will take a zero value, the fulfilment of condition (9) will ensure that the pole of the THLS lower links rotation (point O) coincides with the point lying on the axis that passes through its centre of mass (point S_o, Fig. 2). This helps reduce to zero the value of the momentum M_{r3}.

In practice, the value $c = 0$ can be achieved by selecting the values of the THLS parameters using equation (5). Next, we analyze the nature of the change in the moments M_{r2} and M_{r3} on the example of using the HTZ-150K-09 tractor when aggregated with a mounted plough of the PLN-5-35 type. The characteristics of this unit are presented in Table 1. It should be noted that the O coordinate (Fig. 2) of the "instantaneous centre of rotation" of the HTZ-150K-09 three-point THLS does not coincide with the S_o coordinate of its centre of mass by $c \approx 0.8$ m. To achieve their alignment at one point and at the same time obtain the minimum value of the momentum, it is necessary, within the framework of condition (5), to increase (if it is technically possible) the value of the parameter L or decrease the value of the parameter r.

First, let us consider the symmetrical aggregation of the plough when with a two-point diagram for setting up THLS $d = \gamma = 0$, and with a three-point one – only $\gamma = 0$. In this case, as the rotation angle of the THLS lower links β increases, the momentum acting from the side of the plough increases too. Moreover, with a two-point diagram of its joining, this process occurs more intensively than with a three-point one (Fig. 3).

This is despite the fact that with the two-point diagram for setting up THLS, under the condition $d = 0$, the momentum M_{r2} is formed only due to the transverse component of the plough traction resistance. But this force acts on the shoulder $s = 2.3$ m (see Fig. 1). And this is much more than the values of the shoulders $l = 0.12$ m and $(c + h) = 0.83$ m, which, together with the force of the plough traction resistance, create the momentum M_{r3} [see equation (4)]. Asymmetric plough aggregation with

a three-point joining diagram of THLS occurs when the angle $\gamma \neq 0$. With a two-point diagram, such plough joining is possible under the following conditions:

$$\gamma \neq 0; d = 0; \tag{14}$$

$$\gamma \neq 0; d \neq 0. \tag{15}$$

In the variant of the two-point diagram of THLS with conditions (14), the momentum is not only much larger than with the three-point one but is also characterized by a significantly greater growth rate as the angle γ increases (Fig. 4).
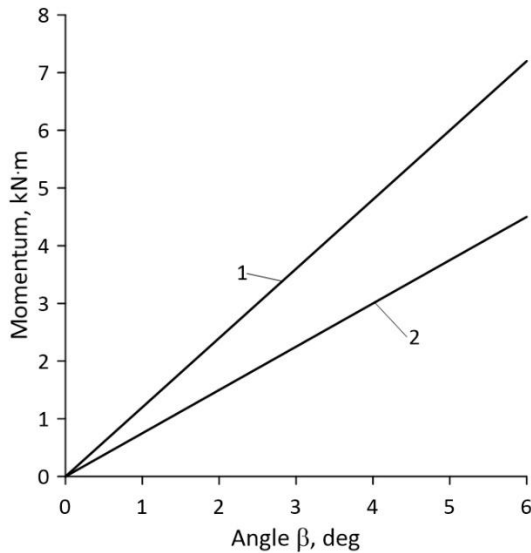
Fig. 3. **Dependence of the momentum on the angle β with two-point (1) and three-point (2) plough joining diagrams**
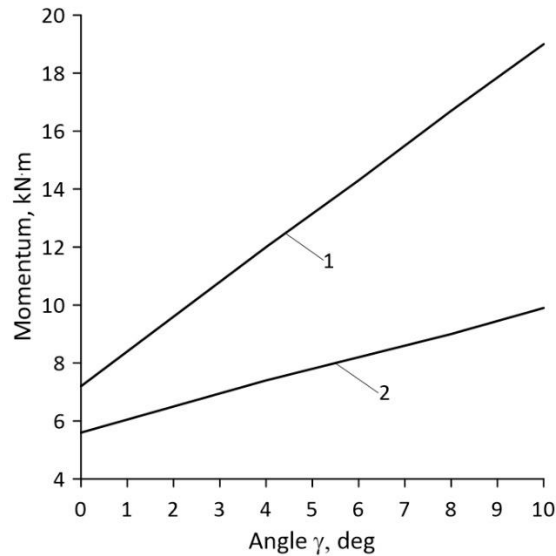
Fig. 4. **Dependence of the momentum on the angle γ with two-point (1) and three-point (2) diagrams plough joining and condition $\beta = 6^o$**

It should be noted that the data in Fig. 4 were obtained under the condition that the force P is constant when the angle γ changes. In reality, this is not entirely true. As shown by [14], the greater the plough traction resistance, the greater the value of the right-sided transverse displacement of its resistance centre from the symmetry axis. The magnitude of this shift determines the value of the angle γ. With this in mind, dependencies 1 and 2 in Fig. 4 will differ quantitatively. But since their qualitative representation remains similar, the presented in Fig. 4 results can be considered as those that do not distort the logic of our reasoning.

When adjusting the two-point of the THLS diagram according to the condition (15), the value of the momentum M_{r2} at $d = 0$ is almost two times greater than the value of the momentum M_{r3} (Fig. 5). As the right-side transverse displacement (d) of the THLS lower links convergence point increases, the value of this momentum decreases. At $d \geq 0.25$ m, its value becomes equal and even less than the value of the momentum acting on the tractor with a three-point plough joining diagram.

From this, however, it does not follow that the right-sided transverse displacement of the plough joining point to the tractor with a two-point scheme of its THLS is advantageous. The thing is that the values of the angle β have a sign-changing character. With a positive value of this angle, the reason for the decrease at the moment M_{r2} is as follows. As the value of d increases, the term $d \cdot \cos(\gamma + \beta)$ of equation (1) also increases. But even at $d = 0.3$ m and $\gamma = \beta = 6^o$, its value (0.29 m) remains less than the value of the term $s \cdot \sin(\gamma + \beta)$ equal to 0.48 m. As a result, as the value of d increases from 0 to 0.30 m, an increase in the term $d \cdot \cos(\gamma + \beta)$ from 0 to 0.29 m, respectively, reduces the value of the term $s \cdot \sin(\gamma + \beta)$, and along with this, the value of the moment M_{r2} (see Fig. 5).
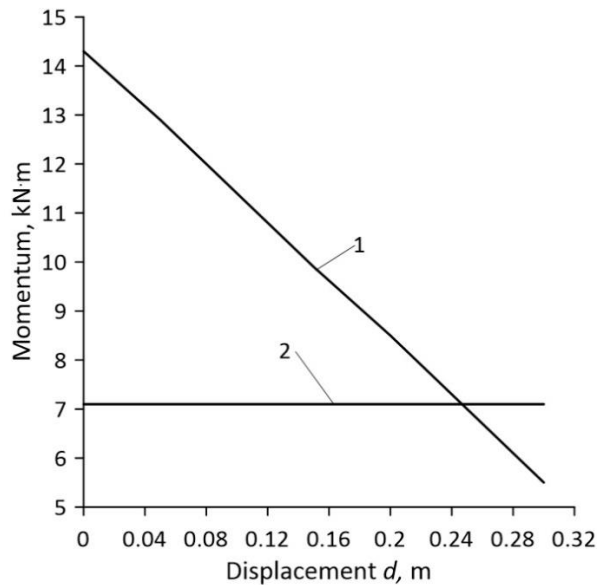
Fig. 5. **Dependence of the momentum M_{r2} (1) on the value of the parameter d in comparison with the value of the momentum M_{r3} (2) at $\gamma = \beta = 6^\circ$**
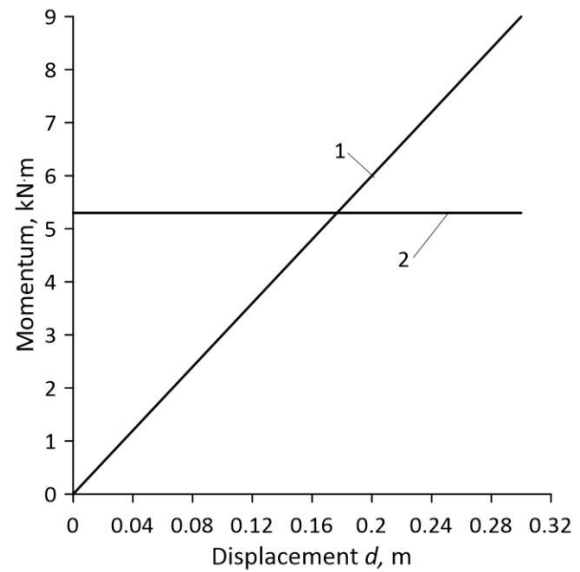
Fig. 6. **Dependence of the momentum M_{r2} (1) on the value of the parameter d in comparison with the value of the momentum M_{r3} (2) at $\gamma = 6^\circ$ and $\beta = -6^\circ$**

With a negative value of the angle $\beta = -6^\circ$ (and $\gamma = 6^\circ$), the nature of the change in the momentum M_{r2} becomes different (Fig. 6). In this case, the value of the second term of equation (1) becomes equal to zero, and the value of the specified momentum is determined only by the product of the plough traction force P and arm d. As we can see from the analysis of Fig. 6, in the range d from 0 to 0.18 m, the value of the momentum M_{r2} is less than the value of the momentum M_{r3}, which emphasizes the advantage of the two-point of THLS in this particular case. An increase in the right-sided transverse displacement of the plough point joining to the tractor by more than 0.18 m leads to excess the momentum M_{r2} over the momentum M_{r3}. And this unequivocally indicates the advantage of the three-point diagram for adjusting the rear THLS.

The above analysis shows that neither two-point nor three-point diagrams for joining a plough to a tractor make it possible to eliminate the momentum completely. But even if the tractor mass centre does not coincide with the "instant centre of rotation" of THLS, the momentum acting on it from the side of the plough joined according to the three-point diagram is less than with the two-point diagram. From this point of view, the first of them (i.e. three-point), provided that the requirement presented by equation (5), is clearly preferable to the second. As noted above, setting the convergence angle of the THLS lower links following requirement (5) provides it (the tractor) with satisfactory angular mobility in the horizontal plane relative to the plough.

Field studies of ploughing units were conducted in the soil and climatic conditions of the south of Ukraine (Zaporizhzhia region) on winter wheat stubble. Under the conditions of the field experiment, the rear hitch system of the HTZ-150K-09 tractor was adjusted so that the value of the angle α was 0.49 rad. This fully met condition (5).

The average soil moisture value in the 0-30 cm layer was 19.3%, and the bulk density was 1.23 g·cm⁻³. The analysis of the obtained experimental data showed that the adjustment diagram of the rear THLS of the HTZ-150K-09 has practically no effect on the statistical characteristics of the fluctuations in the plough rotation angle in the horizontal plane. With a confidence probability of 95%, it can be argued that the null hypothesis about the equality of the average values of this parameter is not denied. This is confirmed by the fact that the actual difference of the obtained average values of the angle β, equal to 0.02 deg, is less than $LSD_{05} = 0.04$ deg (Table 2).

Table 2

Influence of the THLS diagram on the uniformity of the plough rotation angle

Index	Plough joining diagram	
	two-point	three-point
Operating speed (m·s⁻¹)	2.32	2.24
Plough rotation angle:		
– mean (deg)	0.10	0.08
– mean error (cm)	0.016	0.015
– standard deviation ($\pm$ deg)	0.84	0.75
– variance (deg²)	0.70	0.56
– LSD$_{05}$ (deg)	0.04	

Moreover, the zero hypothesis about the equality of this parameter dispersion fluctuations is not denied. Comparing these statistical parameters shows that the actual value of the F-test (1.25) is less than the tabular value of 1.39. Additionally, it can be noted that the inner nature of the oscillation processes of the plough rotation angle with two-point and three-point THLS diagrams is almost the same. This statement is supported by comparing the normalized spectral fluctuation densities of this parameter (Fig. 7). Namely, the maxima of these statistical characteristics fall on the same frequency equal to 0.1 s⁻¹. The oscillation dispersions of the angle β for both oscillatory processes are concentrated in the same range of relatively low frequencies: 0-1.0 s⁻¹, i.e. 0-0.16 Hz. Almost the exact nature of the plough angular displacements with different THLS diagrams was accordingly reflected in the statistical characteristics of the ploughing unit operating width. It was found that the compared average values of this parameter are almost equal (Table 3). Comparison of the angle β fluctuation dispersions for both variants of connecting the plough to the tractor showed that the zero hypothesis about their equality is not rejected. This is confirmed by the fact that the F-test actual value, which in this case is 1.17, is less than the tabular value, which is 1.39.
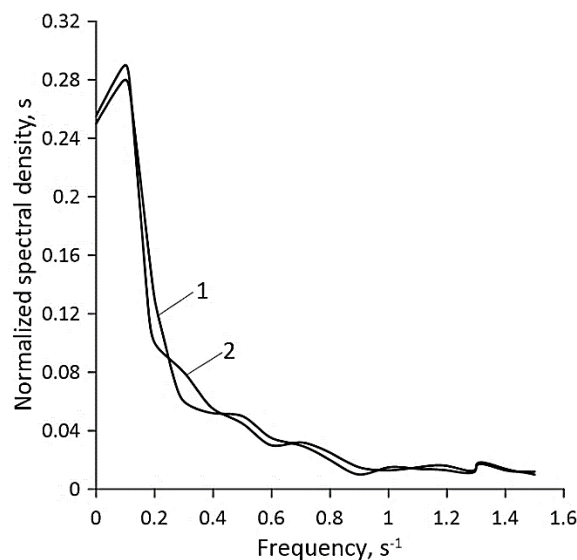
Fig. 7. **Normalized spectral oscillation densities plough turning angles
with its two-point (1) and three-point (2) THLS**

The correlation coefficient values of the plough width fluctuations for its different diagram connection to the tractor (Table 3) are 0-10%, indicating a low variability of the oscillatory process [15]. As it can be seen, from the standpoint of the momentum value reduction, the above analysis clearly indicates the advantages of a three-point diagram for joining a plough to a tractor over a two-point one.

However, this is unambiguously true only if the ploughing unit meets conditions (10) or (11). That is when it is symmetrical. With asymmetric plough aggregation, its right-sided transverse displacement is required relative to the tractor symmetry axis. With a three-point joining diagram, this displacement can only be carried out by moving the plough relative to its own hitch, i.e. connecting yokes. This constructive solution leads to the appearance of the angle γ considered in the article. Its presence not

only causes an increase in the momentum (which we have already considered above) but also leads to the appearance of the tractor's draft lateral (transverse) component. This force, in turn, creates an additional friction force of the plough landside against the furrow wall. The result is an increase in plough resistance. So, according to [16], with a right-sided transverse displacement of the plow relative to its own coupling device (i.e. yokes) by only 100 mm, the increase in its traction resistance was 9%, while the fuel consumption of the tractor increased by 5%. With a two-point diagram, the plough right-sided transverse displacement can be carried out both as described above and by appropriately moving the convergence point of the THLS lower links by a given value (parameter d, Fig. 1). But since, in this case, the value of the angle γ does not change, the plough traction resistance remains practically constant. This is the advantage of a two-point plough joining diagram if its right-sided transverse displacement relative to the longitudinal axis of the tractor is required. Thus, the following can be stated.

Table 3

**Influence of the THLS diagrams on the uniformity
of the ploughing unit operating width**

Index	Plough joining diagram	
	two-point	three-point
Operating speed, m·s^{-1}	2.32	2.24
Operating width		
– mean, cm	176	177
– standard deviation, ± cm	5.4	5.0
– variance, cm^2	29.2	25.0
– variation coefficient, %	3.1	2.8

If according to conditions (10) or (11), the parameters of the tractor's running system do not allow joining the plough to it symmetrically, it is better to use a two-point adjustment diagram for the tractor rear hitch linkage system. At the same time, the right-sided transverse displacement of the plough should primarily be carried out by moving the THLS lower links. And only if this displacement is not enough is it necessary to move the plough frame relative to its own connecting yokes. Suppose the parameters of the tractor running system allow symmetrical aggregation of the plough. In that case, the tractor can have only one adjustment diagram for the rear hitch linkage system – a three-point one. The advantages in reducing the perturbing momentum acting on the tractor from the side of the mounted plough are presented above.

Conclusions

Theoretical studies have established that it is impossible to completely eliminate the momentum acting on the tractor from the side of the plough with its two-point or three-point joining diagrams. The value of this momentum can only be reduced. With a two-point adjustment diagram for the tractor's hitch linkage system, this can be achieved by symmetrically joining the plough. In the case of using a three-point diagram, such a result is possible when the THLS lower links converge at a point as close as possible to the vertical axis is passing through the tractor's mass centre.

When choosing the adjustment diagram for the rear THLS, it must be considered that the intensity of the increase in the momentum from the side of the plough with its two-point joining is higher than with the three-point one. If in the second variant of the plough joining this momentum has an increase of 0.75 kN·m·deg^{-1}, then in the first one it increases to 1.2 kN·m·deg^{-1}, i.e. by 1.6 times. And this pattern is observed both with symmetrical and asymmetric diagrams of the ploughing unit.

The advantage of the three-point diagram for joining the tractor's rear linkage system over the two-point one is clearly manifested with an increase in the right-sided transverse displacement of the plough joining point to the tractor to a level of more than 0.18 m.

Installing the lower links of the tractor's three-point hitch linkage system with a convergence angle of 0.49 rad provided the plough with the same angular mobility as the two-point joining diagram. This conclusion is supported by the approximate equality of the fluctuations in statistical characteristics of the plough rotation angle in the horizontal plane and the ploughing unit width for both considered diagrams for setting up the tractor's rear hitch linkage system. The normalized spectral densities maxima

of the parameter β oscillations falls on the same frequency equal to 0.1 s^{-1}. The oscillation variances of the angle β for both plough joining diagrams are concentrated in the same range of rather low frequencies: 0-1.0 s^{-1}, i.e., 0-0.16Hz.

If the tractor running system parameters do not allow symmetrically joining the plough, using a two-point diagram for the tractor's rear hitch linkage system is better. With a symmetrical joining of the plough, the tractor can only have a three-point diagram for its rear hitch linkage system.

Author contributions

All the authors have contributed equally to creation of this article.

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