STUDY OF SPECIAL ASPECTS OF HITCHING TO WIDE SPAN TRACTORS (VEHICLES)

ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ АГРЕГАТИРОВАНИЯ МОСТОВЫХ ТРАКТОРОВ

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Abstract. *The paper presents the research into the specific aspects of hitching agricultural machines and implements to wide span tractors (vehicles). According to the results of the performed investigations, the redistribution of the normal reaction forces on the tractor's front and rear wheels depends to a significant extent not only on the inclination of the hitch links of the wide span tractor (vehicle), but also on such design parameters as the distance from the linkage to the centre of resistance and the carrier wheel of the agricultural machine or implement. In order to exclude in practical terms completely the effect of the machines' running gear compacting the soil in the yielding (agronomic) zones of the field, it is recommended to implement on the wide span tractors (vehicles) the controlling devices that allow adjusting the normal vertical load on the agricultural machine or implement's carrying wheels. Such controlling devices can operate on the principle of the known weight transfer traction boosters used in conventional tractors.*

1. Introduction

In view of the rather high versatility of the wide span tractors (vehicles) employed in controlled traffic farming, they can (and surely have to) be ganged up with trailing, semi-mounted and fully mounted agricultural machines and implements [2]. The latter's weight and tractive resistance can cause substantial redistribution of the vertical loads on the wide span tractor's wheels. The main problem is that the use of an inappropriate layout in the attachment of agricultural machines and implements to the tractor can result in the situation, where, instead of additionally loading the steering and driving wheels of the wide span tractor (vehicle), their load will be relieved, with all the ensuing consequences. At the same time, the vertical load on the carrier wheels of the attached agricultural machines and implements, which are usually situated in the agronomic (yielding) zone of the field, can increase substantially. Whereby, the excessive compacting of the soil by the machines' running gear will bring to nought all the benefits from controlled traffic farming.

2. Preconditions and means for resolving the problem

2.1. Analysis of recent research and publications

The accumulated worldwide experience of hitching to wide span tractors (vehicles) proves that they can be used with three-point hitch linkages (Fig. 1). But the research into the design features of the latter in terms of their operation with wide span tractors (vehicles) is given virtually no coverage in the scientific literature. Meanwhile, it is well known that the inclination angles of the central (upper) and lower hitch links of the conventional tractor's implement-attaching unit have a significant effect on the redistribution of the normal reaction forces acting on the tractor's wheels. The pattern of the said redistribution of the normal reaction forces on the tractor's wheels is determined by the design parameters of its hitch linkage and the agricultural machine or implement hitched to it.

Also, it ought to be noted that certain trends have recently been outlined in the improvement of the design of the three-point hitch linkages of tractors. Still, the issue of investigating the effect that the parameters of the hitch linkage installed on a wide span tractor (vehicle) and the layout of the attachment to it of machines and implements have on the pattern of changes in the vertical loads on its wheels is not paid sufficient attention.

Fig. 1. *Hitch linkages of wide span tractor ASALift WS9600*

2.2. Purpose of the study

The aim of the study was to improve the grip properties, stability and controllability of motion of wide span tractors (vehicles) and also to reduce the compacting of soil in the yielding zone of the field by the machines' running gear through the substantiation of the parameters of their hitch linkages and the layout of attaching to them agricultural machines and implements.

3. Results and discussion

A wide span vehicle designed in Ukraine (Fig. 2) is taken as the physical object of the investigation.

Fig. 2. *Wide span vehicle of new design*

In order to analyse and solve the set problem, the wide span vehicle is represented by a planar equivalent model (Fig. 3). The tools of the hitched agricultural machines and implements are represented in the model (Fig. 3) by a projection of one tool, in

which the tractive resistance of the machines and implements is concentrated in the form of the resultant force (its horizontal R_X and vertical R_Y components). The said equivalent tool is hitched to the wide span vehicle by means of its central and lower hitch links. All carrier wheels that the hitched agricultural machine or implement can have are represented in the schematic model by one equivalent carrier wheel.

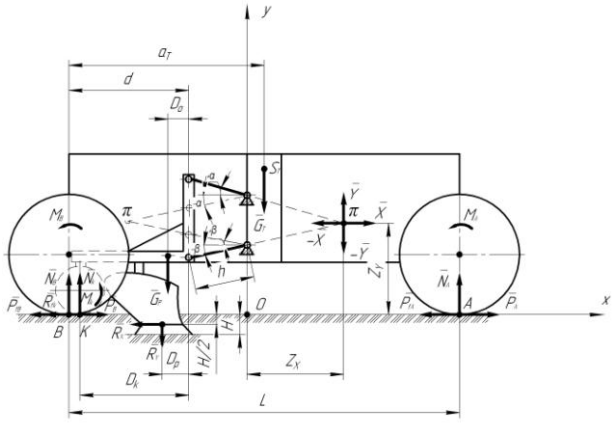

Fig. 3. *Schematic model of forces and moments acting on wide span vehicle in longitudinal vertical plane*

The moments M_A and M_B (Fig. 3) can be expressed as follows:

$$\begin{aligned} M_A &= \left(P_A - P_{fA}\right) r_A, \\ M_B &= \left(P_B - P_{fB}\right) r_B, \end{aligned} \tag{1}$$

where P_A, P_B – tangential traction forces applied to the front and rear wheels of the tractor, respectively;

P_{fA}, P_{fB} – rolling resistance forces acting on the front and rear wheels of the tractor, respectively;

r_A, r_B – rolling radii of the front and rear wheels of the tractor.

Subsequently:

$$\begin{aligned} P_A &= N_A; \quad P_{fA} = f N_A; \\ P_{\hat{A}} &= N_{\hat{A}}; \quad P_{f\hat{A}} = f N_{\hat{A}}, \end{aligned} \tag{2}$$

where f – coefficient of rolling resistance;

φ – tractor's adhesion weight utilization factor.

The force P_{fk} and moment M_k of rolling resistance of the agricultural implement's carrier wheel can be found as follows:

$$\begin{aligned} P_{fk} &= f N_k, \\ M_k &= f N_k r_k, \end{aligned} \tag{3}$$

where r_k – radius of the agricultural implement's carrier wheel.

Depending on the values of the angles α and β of the inclination of the wide span vehicle's central and lower hitch links, respectively, the coordinates of the linkage's instantaneous centre of turn (Z_X and Z_Y) can be expressed in terms of its own design parameters (Fig. 4).

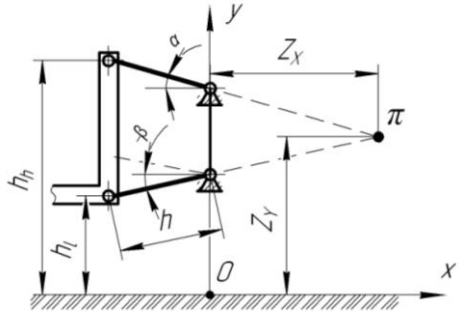

Fig. 4. *Schematic model for determining coordinates of instantaneous centre of turn of wide span vehicle's hitch linkage*

The coordinates of the hitch linkage's instantaneous centre of turn in accordance with Fig. 4 can be determined as follows:

$$\begin{aligned} Z_{\bar{O}} &= \frac{h_h - h_l}{TAN(\alpha) - TAN(\beta)}; \\ Z_Y &= h_l - \frac{(h_h - h_l) TAN(\beta)}{TAN(\alpha) - TAN(\beta)}, \end{aligned} \tag{4}$$

where Z_X, Z_Y – longitudinal and transverse coordinates of instantaneous centre of turn of wide span vehicle's hitch linkage;

h_h, h_l – design parameters, the nature of which can be seen in Fig. 4.

The vertical reaction forces N_A and N_B in accordance with the adopted schematic model of acting forces (Fig. 3) and in view of the above are determined as follows:

$$\left.\begin{aligned} N_B &= G_T - Y - N_A, \\ N_A &= \frac{G_T \cdot a_T - (G_T - Y) \cdot r_B (\varphi - f) \pm Y \left(Z_X + h \cdot \cos|\beta| + d\right) \pm X \cdot Z_Y}{L - (\varphi - f) \cdot (r_B - r_A)}, \end{aligned}\right\} \tag{5}$$

where G_T, a_T – tractor's weight and the horizontal coordinate of its centre of mass;

M_A, M_B – moments of rolling resistance of the tractor's front and rear wheels, respectively;

L – wheel base of the tractor;

d – distance from the attachment device of the attached agricultural implement to the rear wheel axle of the wide span vehicle;

h – length of a lower link of the hitch linkage.

The choice of the sign "+" or "–" between the last summands in the second equation of the system (5) depends on the position of the hitch linkage's instantaneous centre of turn (point π) with respect to the point B. For example, if the moment produced by the reaction forces X and Y rotates in a clockwise sense, then the sign "+" is assumed, otherwise "–" is chosen.

In accordance with the adopted schematic model of acting forces (Fig. 3) and taking into account the above, the unknown reaction forces X and Y as well as N_k are determined as follows:

$$\left.\begin{aligned} Y &= N_K - G_\Pi - R_Z, \\ X &= f \cdot N_K + R_X, \\ N_K &= \frac{\pm G_\Pi \left(D_0 + h\cos|\beta| + Z_X\right) \pm R_Y \left(D_\Pi + h\cos|\beta| + Z_X\right) \pm R_X \left(Z_Y + \frac{H}{2}\right)}{\pm \left(D_K + h \cdot \cos|\beta| + Z_X\right) \pm f \cdot Z_Y - f \cdot r_\kappa}, \end{aligned}\right\} \tag{6}$$

where H – depth of tilling of the soil by the agricultural implement;

G_P – weight of the agricultural implement;

D_0, D_P, D_k – design parameters of the agricultural implement, the nature of which can be seen in Fig. 3.

In the third equation of the system (6), the sign "+" is chosen, when the respective forces produce a moment with respect to the point π (Fig. 3), which rotates in a clockwise sense, otherwise the sign "–" is required.

The systems of equations (5) and (6) provide for finding the optimum values of the angles of inclination (α and β) of the hitch links as well as other design parameters of the wide span vehicle in terms of the desirable redistribution of the normal reaction forces on its front and rear wheels. The analysis of the mentioned expressions provides evidence that, apart from the angles of inclination of the hitch links, the redistribution of the normal reaction forces acting on the wide span vehicle's wheels is substantially influenced by such design parameters as the distance from the hitch linkage to the agricultural implement's centre of resistance (D_P) and carrier wheel (D_k).

The analysis of the data obtained by mathematical modelling results in the conclusion (Fig. 5) that the degree of redistribution of the normal reaction forces on the front and rear wheels of the wide span vehicle of our design and the carrier wheels of the agricultural implement depends to a considerable extent on the angle of inclination α of the central hitch link.

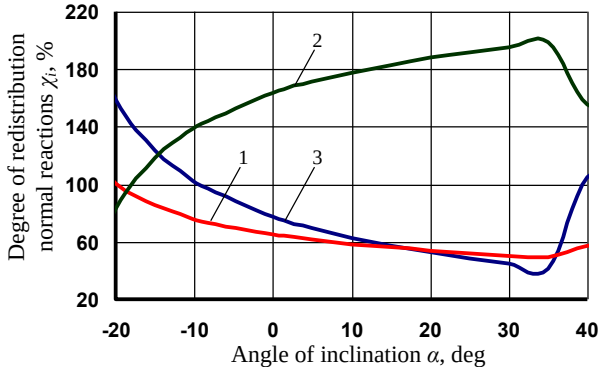

Fig. 5. *Degree of redistribution of normal reaction forces on front (1) and rear (2) wheels of wide span vehicle designed by TSATU and carrier wheels of agricultural implement (3) as function of angle of inclination α of central hitch link at a negative angle of inclination of lower hitch links (β = –10 deg)*

At a negative angle of inclination β of the lower hitch links, the most appropriate set-up of the hitch linkage of the wide span vehicle of our design is when the angle of inclination α of the central link has a positive value of up to 40 deg. In that case, the vertical load on its rear wheels is on the average 1.5 times greater than in the static condition, the normal reaction forces on the front wheels are reduced to 60%, which is acceptable in terms of ensuring the sufficient controllability of the wide span vehicle's motion in case of the kinematic method of its steering. At the same time, the normal reaction force acting on the agricultural implement's carrier wheel is desirably reduced or virtually equal to its static value.

However, it ought to be noted that the set-up of a three-link hitch mechanism with a large positive angle of inclination of the central link (reaching 40 deg and higher) and a negative angle of inclination of the lower links can become practicable only after the detailed study of the kinematics of its operation, which can provide the basis for further investigations.

At a positive angle of inclination of the lower hitch links of the wide span vehicle of our design the most desirable set-up of the upper link includes inclination angles within a range of 25 to 35 deg. In this case, a certain decrease in the compacting of the soil in the yielding zone of the field by the agricultural implement's carrier wheels is observed as well as the weight transfer on the tractor's rear wheels and the resulting acceptable reduction (down to 30%) of the vertical load on its front wheels.

It has been established by the completed investigations that, even if it is possible to eliminate the negative effect of the agricultural machines' and implements' carrier wheels compacting the soil in the agronomical (yielding) zone of the field, the degree of elimination will not exceed 50%. In view of this situation, employing additionally a regulating device for the adjustment of the normal loads on the agricultural implement's carrier wheels will allow to achieve virtually complete elimination of the effect of the machines' running gear compacting the soil in the yielding zone of the field. The operating principle of the said regulating device is similar to that of the widely known hydraulic tractor adhesion weight boosters. The latter, as is known, produce the effort needed for lifting the hitch linkage with the mounted agricultural machine or implement. In this process, the position of the instantaneous centre of turn of the hitch linkage remains unchanged. The mentioned provision is observed as long as the magnitude of the force that lifts the agricultural implement does not exceed the level, at which the implement is shallowed up out of the soil.

Alongside with that, it has been established that, in the majority of the possible cases of set-up of the wide span vehicle's hitch linkage, the relief of the load on its front wheels is observed. In order to increase the said load, which means retaining the sufficient controllability of the wide span vehicle in case of the kinematic method of its steering, it is advisable to place all vehicle-borne process containers possibly closer to its front wheel axle. That will increase the vertical load on the front wheels by adding the weight of the process containers with the materials.

4. Conclusions

As a result of the investigations, it has been established that, apart from the angles of inclination of the hitch links of the wide span tractor (vehicle), the redistribution of the normal reaction forces acting on its front and rear wheels is substantially influenced also by such design parameters as the distance from the hitch linkage to the agricultural machine or implement's centre of resistance and carrier wheel.

Setting up the three-link hitch unit of a wide span tractor (vehicle) with a large positive angle of inclination of the central link (reaching a level of 40 deg and higher) and a negative angle of inclination of the lower links will become possible only after studying in detail the kinematics of its operation, which can provide the basis for further investigations.

In order to eliminate virtually completely the effect of the machines' running gear compacting the soil in the yielding (agronomical) zone of the field, it is recommended to implement on the wide span tractors (vehicles) controlling devices, which will allow adjusting the normal vertical load on the agricultural machine or implement's carrying wheels. The controlling devices can operate on the principle of the known weight transfer traction boosters used in conventional tractors.

The results of the investigations have shown that, in the majority of the possible cases of set-up of the wide span vehicle's hitch unit, relief of the load on its front wheels is observed. In order to increase the said load, which implies retaining the sufficient controllability of the wide span vehicle in case of the kinematic method of its steering, it is advisable to place all process containers borne by the vehicle possibly closer to its front wheel axle. That will increase the vertical load on the front wheels by adding the weight of the process containers with the materials.

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