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STUDY OF AGROROBOT RESISTANCE TO MOVEMENT DURING PLANT PROTECTION OPERATIONS

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Abstract

Conventional robotic systems in agriculture are driven by operator control or are those that move along an established path. Unfortunately, however, in the field an established path is a very conditional concept. It is not possible to fix the route along which the robot will move, because different crops alternate on the same field. It is necessary to assess whether the robot is taking samples from the terrain and the crop, whether it will perform a plant protection event or other type of operation. Plant protection operations are accompanied by a constant change in the mass of the agricultural robot. During the operation, the mass of the sprayed solution decreases. This change leads to a decrease in its resistance.

In order to be able to design an agricultural robot, it is necessary to establish its stability in different terrains. This article discusses the main points in determining the longitudinal sustainability of agricultural robots. Dependencies for the conditions of sustainability of the agricultural robot when climbing and descending are derived. The article is an overview and helps to determine the robot's resilience faster.

Keywords: agro robots, stability, robots suspension, study, models, design

INTRODUCTION

Nowadays, terrestrial mobile robots are the most common category of robots and their application is much better than that of industrial robots. Terrestrial mobile robots include a robot with wheels, a walking robot and a crawler robot (Jin, 2021). Wheeled robots can move easily and efficiently at high speed and stably on flat and complex roads or sloping terrain (Kececi, 2015; Reddy, 2016), but in unstructured environments, the use of leg and chain robots is also a valuable option. Crawler robots can move over highly rugged terrain and terrain with weak soil, as their contact surface with the ground is much larger than that of wheels and robots with legs (Chung, 2016). They can make the operation more stable, but they usually move slower and with lower energy efficiency (Zhao, 2021).

It is necessary for the robot to be able to transform the movement of the wheel in order to adapt to different road conditions: high-speed long-distance movement to cross obstacles and adapt to complex terrain environments (Zhao, 2021).

For a robot, the wheel is the most common movement element among other options, including legs, flying, swimming, and rolling. A wheel provides controlled speed, accuracy and stability for a robot (Nikpour, 2020). These three characteristics are very important when designing and building robots. Wheeled robots move around the ground using motorized wheels to drive themselves. This design is easier to implement than using feet. It is easier to design, build and program to move in flat, less rugged terrain with the help of wheels. They are actually better controlled than other types of robots (Murali, 2016).

The demand for autonomous mobile robots is growing rapidly due to their services. The motion system of the robot is an important aspect to consider with respect to the robot design. The design itself depends on the environment and the technical criteria such as its mobility and stability. Wheeled robots have the features that ensure their stability maintaining the contact of the wheels with the ground. However, due to different forms of surfaces, such as rough terrain and different soil rigidity, the robot's wheels can lose ground contact and cause the robot to turn or lose resistance. Therefore, realtime surface geometry recognition will allow the robot to act quickly to maintain its stability. The contact angle between the wheel and the ground is a critical parameter that determines the wheels position relative to the surface, which indicates whether the robot wheel is climbing vertical, inclined or uneven surface (Pico, 2022; Hu, 2021).

Resistance is the ability of a machine to move along the supporting surface without reversal and lateral sliding is called resistance. During the movement of the machine as a result of the acting forces and moments, resistance can be lost by turning around the x or y axes. The loss of resistance in the first case is called lateral, and in the second longitudinal. When the agrorobot slides with one or both of its bridges laterally and rotates around its vertical axis, there is a loss of resistance under a lateral sliding condition.

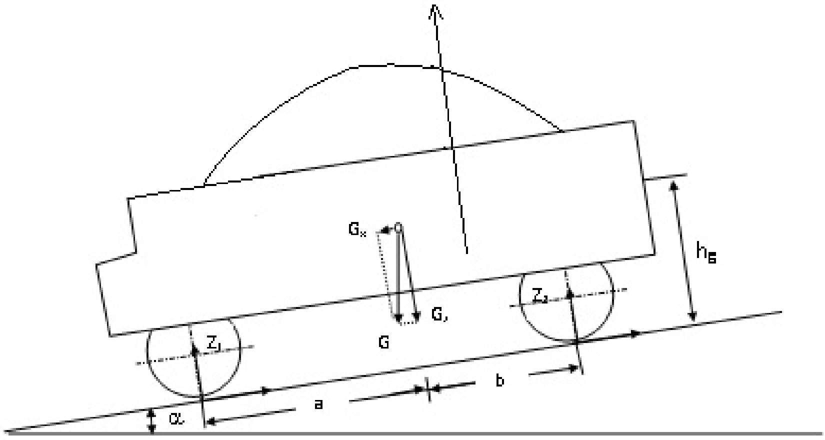

Fig.1. Scheme of the forces and moments of an agrorobot when moving in a slope

MATERIALS AND METHODS

The topicality of the problem in the article is aimed at studying the resistance to movement of an agrorobot for plant protection in different operating conditions, which is of utmost importance due to the danger they pose to nature and man because of the pesticides transported in them.

However, the deployment of such agrorobots in agriculture is hampered by the lack of sufficiently efficient technology to reduce the production costs of agrorobots compared to traditionally used agricultural machines.

This article is an overview and serves as a basis for a deeper calculation of the sustainability of agricultural robots. The conditions for sustainability are in the most general form without taking into account the specifics of each operation. With the correct selection of conditions, load and terrain, it can help determine the maximum angles at which resistance of the machine is present.

RESULTS AND DISCUSSION

Longitudinal resistance of the agrorobot is present when the machine overcomes a longitudinal slope as a result of the action of the slope forces and tangential reactions (Fig.1). A moment is created that seeks to turn the machine relative to one of the bridges and turn it around (Evtimov,2016).

This trend is opposed by the stabilizing moment that creates the force of gravity (1) (Goryachkin, 1968):

$$G_z = G\cos\alpha, \qquad (1)$$

where G is the force of gravity;

α – field tilt angle.

The arm a is when descending and the arm b is when climbing and strives to ensure a stable position of the machine on the traffic roadway.

The conditions of persistence are (2) and (3) (Goryachkin, 1968):

- on descent

$$Gh_g \sin\alpha \le Ga\cos\alpha, \qquad tga \le \frac{a}{h_g}; \quad (2)$$

- when climbing

$$Gh_g \sin\alpha \le Gb\cos\alpha, \qquad tga \le \frac{b}{h_g}. \quad (3)$$

The analysis of the relationships obtained shows that the maximum angle of longitudinal inclination along which the machine can move sustainably depends entirely on the coordinates of the center of gravity. With a decrease in the height of the center of gravity, the longitudinal resistance improves. When the coordinate *a* is changed, at the expense of *b* and vice versa, the climb resistance changes at the expense of the slope resistance.

Dependencies (2) and (3) take into account the disturbance of the static equilibrium of the system provided that sufficient traction is present. At a sharp start from a place or at an abrupt stoppage, the value of the horizontal forces reaches the value of the adhesion force. For these cases the boundary conditions are (4) and (5) (Goryachkin, 1968):

- on descent

$$Gh_g\ \varphi\cos\alpha \le Ga\cos\alpha, \qquad h_g \le \frac{a}{\varphi}; \quad (4)$$

- when climbing

$$Gh_g\ \varphi\cos\alpha \le Gb\cos\alpha, \qquad h_g \le \frac{b}{\varphi}. \quad (5)$$

Where the center of gravity is halfway between the wheel axles, the condition of

$$h_g \le \frac{L}{2\varphi} \qquad (6)$$

With abrupt braking, a stable position of the machine on the field is ensured, since the maximum horizontal force is limited by the traction force. The machine will slide on its tires without a rotation across a bridge. Reversal around the front axle will occur when impacting a solid object, due to the occurrence of additional inertial force.

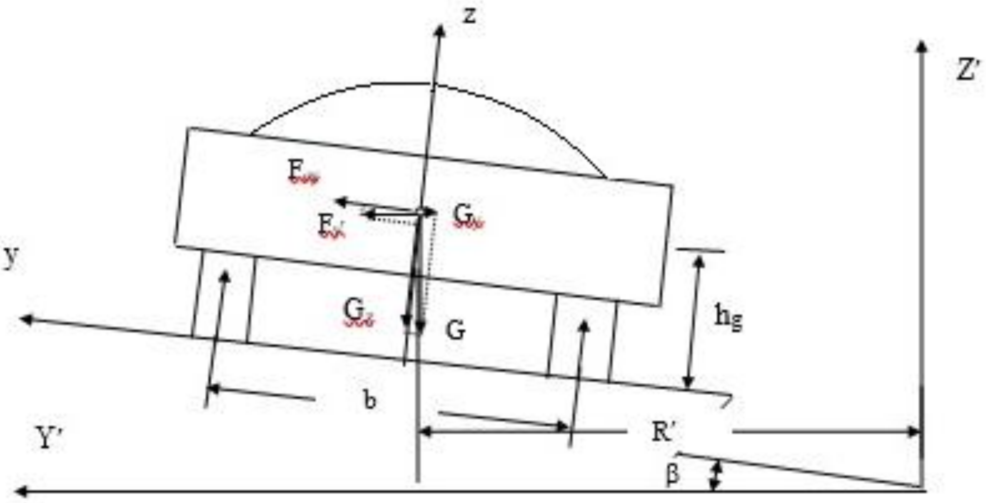

Fig. 2. Scheme of the forces of an agrorobot in a lateral slope and curvilinear motion

In transverse resistance of the agrorobot, the forces and moments that create relative to the longitudinal axis tend to turn or slide the vehicle onto the roadway. 2.

A curvilinear motion on a road in a bend of radius R′ and lateral inclination β is considered. The steered wheels are diverted from the neutral position at an angle q. The following forces (7) and (8) are at work in the mass centre:

- force by weight G which decomposes in on the y and z axes respectively (Goryachkin, 1968):

$$G_y=G\sin\beta; \tag{7}$$

$$G_z=G\cos\beta; \tag{8}$$

- centrifugal force $F_{y'} = mv^2/R'$, which decomposes on the same axes (9) and (10) (Goryachkin, 1968):

$$F_{y'y} = F_{y'}\cos\beta; \tag{9}$$

$$F_{y'z} = F_{y'}\sin\beta; \tag{10}$$

- the lateral component F_{cy} defined by (15).

The analysis of Fig. 2 shows that the stable position of the machine on the canvas depends on the ratio of forces acting on the axes y and z. The former seek to turn or slide the machine and the latter to stabilize it.

Sustainability conditions are expressed by inequalities (11) (Goryachkin, 1968):

- condition against lateral reversal

$$F_y h_g \le F_z \frac{B}{2},\ \ F_y \le F_z \frac{B}{2h_g} = F_z \eta_y; \tag{11}$$

The anti-side-drag condition is given in formula (12):

$$F_y \le F_z \varphi \ \ . \tag{12}$$

The analysis of the resulting inequalities shows that when the coefficient of adhesion is less than the coefficient of the lateral resistance $\eta_y = B/2h_g$, the machine loses resistance under a lateral sliding condition, which is a more favourable case. For this reason, the agrorobot is designed with a lateral resistance coefficient $\eta_y > 0{,}8$, which excludes the possibility of inverting the machine over the entire possible range of adhesion variation without lateral sliding having begun.

In the process of operation, depending on the location of the load on the platform, it is possible to violate the favorable condition. Therefore, when transporting oversized loads in height, certain precautions should be taken.

Due to the fact that a reversal of the machine without being preceded by lateral sliding is a rare event in the following analysis we will consider only anti-slip resistance.

Transverse resistance in lateral slope at increased lateral slope the machine may lose resistance due to the dominant importance of the force G_y. The condition of resistance is determined by inequalities (13) (Goryachkin, 1968):

$$(G_y - F_{y'} - F_{cy})h_g \le (G_z + F_z)\varphi \tag{13}$$

After expressing the forces through the slope and solving the inequality relative to β one obtains (14) (Goryachkin, 1968):

$$tg\beta \le \frac{G\varphi + F_{y'}}{G - F_{y'}\varphi} + \frac{F_{cy}}{\cos\beta\ (G - F_{y'}\varphi)} \tag{14}$$

This result shows that in curvilinear motion in lateral slope and straight virage, the force $F_{y'}$ has a positive influence on the resistance. The second collectable on the right side of the inequality has a positive value when descending along the vorage, and in the opposite case the sign is reversed. This means that with each slide down, with a small sharp deviation of the steered wheels in the same direction, stabilization of the machine is possible.

In straight-line movement in lateral slope the condition of resistance is $tg\beta \le \varphi$. At maximum value φ=0.8 Without relying on the positive influence of a straight turn the theoretical value of the lateral slope on which a vehicle can move is $\beta_{max} < 38^o$.

Transverse stability on horizontal path when driving on horizontal path $\beta=0$. Then $F_y=0$ and after solving (9,10) versus F_{cy} we obtain the inequality (15) (Goryachkin, 1968):

$$F_{cy} = m\left(\frac{v^2}{L}\theta + \frac{b}{L}\dot{v}\theta + \frac{b}{L}v\dot{\theta}\right) \le G\varphi; \qquad (15)$$

$$v^2\theta + b\dot{v}\theta + bv\dot{\theta} \le Lg\varphi$$

Dependence (15) shows that the transverse stability of the vehicle on a horizontal road is influenced by the coordinates of the center of gravity, speed and acceleration of the machine, the control impact θ and the speed of its modification $\dot{\theta}$. At constant speed and constant control $\dot{\theta}$=0 the maximum permissible speed is (16):

$$v_{\max} \le \sqrt{Rg\varphi}, \quad R = \frac{L}{\theta} \qquad (16)$$

With a rectilinear motion θ=0, the consequence of which the steady motion equation takes the form (17) (Goryachkin, 1968):

$$\dot{\theta} \le \frac{gL\varphi}{bv} \qquad (17)$$

This means that when driving at high speed and low traction of the wheels with the road, it is sufficient to give a small but sharp deviation to the steered wheels from their neutral position in order to violate a condition (17).

The fact that the sharp rotation of the steering wheel even at a small angle causes a significant value of the lateral component of the inertia force F_{cy} can be used to restore the resistance after it has already been violated. Two cases are possible. Lateral sliding of the front and lateral sliding of the rear axle.

In lateral sliding of the rear axle Fig. 3 an inertial force is generated directed in the direction of the slide. This circumstance defines the system as dynamically unstable and action should be taken to neutralize the force.

The goal is achieved with a small but sharp deviation of the steered wheels in the direction of the sliding. In this way, the force is generated (18) (Goryachkin, 1968):

$$F_{cy} = m\frac{b}{L}v\dot{\theta}, \qquad (18)$$

directed in the opposite direction. In the lateral sliding of the front axle such an impact is not necessary, since the transient occurring is damping. This is demonstrated by an analysis of the processs in Fig. 4.

The resulting inertia force is in the opposite direction to the slide, which is why the process is sustainable. For this reason, lateral sliding of the front axle is rarely observed.

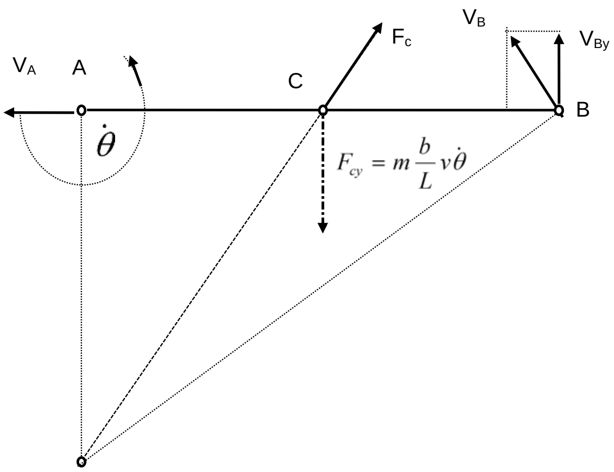

Fig. 3. Scheme of the speeds and forces arising from lateral sliding of a rear axle

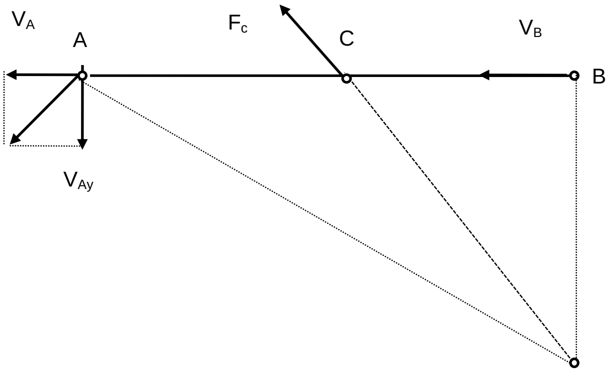

Fig.4. Schematic of the speeds and forces that arise when sliding a rear axle laterally

The suspension of agrorobots is one of the most important elements of the chassis whose main task is to provide a stable and secure connection between the terrain and the wheels of agrorobots, because when moving on rough terrain the quality of their work deteriorates, it also disrupts the operation of sensors and other electrical components. The functions that each type of suspension performs are three:

- Connects the wheels to the hull
- Absorbs vibrations that occur when moving
-Ensures the mobility of the wheels relative to the frame of the machine

Dependent suspension (Fig. 5) in which this type of wheel suspension is on both sides of the agrorobot. This type of suspension includes a reinforced axle, which is located along the entire width of the frame. The two wheels are connected to the axle, which means that they work as a pair and perform the same functions. We will look at several design developments of this type of suspension:

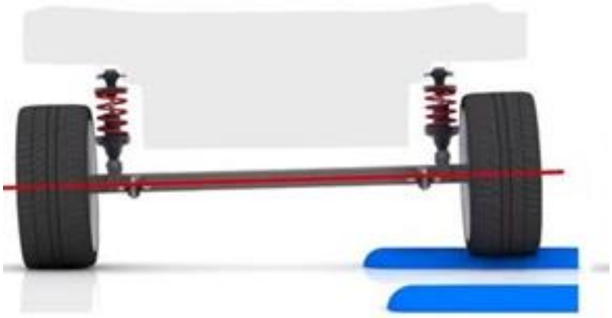

Fig. 5. Scheme of dependent suspension

Independent suspension (Fig. 6) in this type of suspension does not have a bridge that connects the wheels in pairs. Instead, each wheel has a different reaction to the terrain on which it moves. This means that if one wheel encounters a bump in the road, it will not affect the other wheel. Unlike the dependent suspension, which is much stiffer and not very suitable for rugged terrain, Independent suspension ensures better patency.

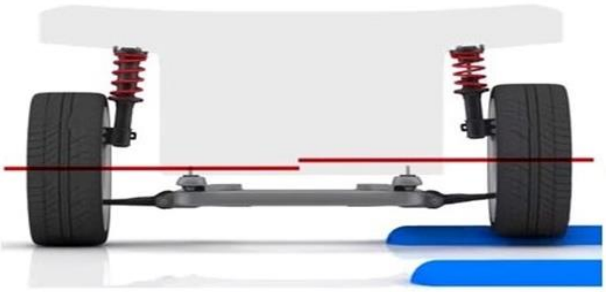

Fig. 6. Independent suspension

The special feature of this type of suspension is that on each side of the axle there are two longitudinal levers, which are combined with transversely arranged elastic suspension elements. The advantages of the two-arm suspension (Fig. 7) are its compactness and the provided comfort of the shooting and scanning equipment of the agrorobot for plant protection.

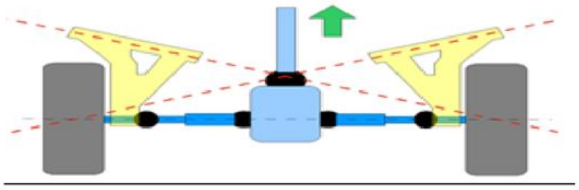

Fig. 7. Two-arm suspension

Multi-point suspension is a type in which there are three or more side arms and one or more longitudinal arms. This type of suspension is quite effective as it provides excellent wheel guidance and a great cornering stability. Multi-point suspension (Fig. 8) can be mounted on the front axle, also on the rear axle, as well as on both axles.

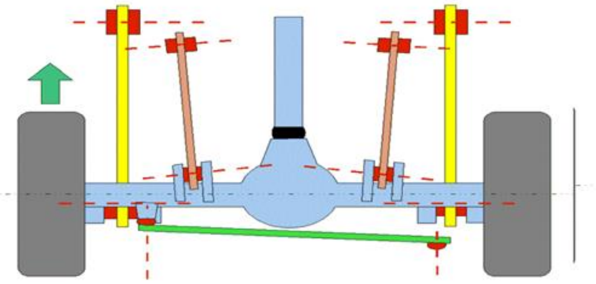

Fig. 8. Multi-point suspension

CONCLUSION

The article discusses different types of suspension of self-propelled machines, which are also applicable to agricultural robots. Updated dependencies on the sustainability of farm robots have been proposed. The longitudinal and transverse resistance dependencies of the agricultural robot are derived. The functions performed by the robot suspension are listed. The conditions for resistance to rectilinear motion and stopping of the robot are given.

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