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INCREASING TRANSVERSE STABILITY OF MULTI-PURPOSE TRACTOR-TRANSPORT TRAINS BY THE USE OF A TRACTION-COUPLING DEVICE CHANGING KINEMATIC MOVEMENT PARAMETERS

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ABSTRACT

Transport work is an integral part of technological processes for cultivating agricultural crops. They require significant energy and labor costs. Statistics show that the share of costs for transportation of goods in agriculture is 25-40% of the total costs of manufactured products, while the share of tractor in-farm shipments reaches 60%. Significant interest in improving transport operations is the use of multi-link tractor-transport trains with two or more trailers. At the same time, several indicators improve at once: The coefficient of utilization of the machine and tractor fleet and the productivity of the tractor are increasing; improves the mode of operation and loading the engine; the overall impact on the soil is reduced by distributing the load along the axes. The carrying capacity and speed of tractor-transport trains are often limited not by engine power, but as studies have shown insufficient towing capacity, low ride smoothness, stability and braking qualities of multi-link tractor-transport trains. It should also be noted that common tractor trailers have a smaller margin of transverse stability compared to tractors, since they have a larger mass, a higher center of gravity and a significant roll of the cargo platform. In this regard, the work, which is aimed at increasing the lateral stability of the tractor-transport train, is relevant and of great importance. The article deals with the increase of lateral stability of multi-link tractor-transport trains due to the use of a traction-coupling device that changes the kinematic parameters of train movement. The theoretical substantiation of the possibility of increasing the stability of a multi-link tractor transport train is provided by using a traction-coupling device. The mathematical model of the movement of a multi-link tractor train with a towing and towing device on a turn, takes into account the influence of tire characteristics, road background and changes in the kinematic parameters of the train. The developed design of the active traction and towing device, which allows changing the kinematic parameters of the tractor-transport train movement, is substantiated and its effect on performance indicators is established.

Keywords: tractor-transport train, towing device, transverse stability, tractor trailer.

INTRODUCTION

A tractor with a trailer or trailers is a complex mechanical system consisting of a large number of elements connected by various kinds of connections. In the process of movement, there are movements of its individual elements relative to each other, affecting in one way or another general parameters of the movement, and hence the controllability and stability of the tractor. Investigating the parameters of the tractor's movement, taking into account all the links between its individual elements, is a task of great complexity [1], [7], [15]. Therefore, when researching any operational properties of a tractor with a trailer or a tractor-transport train, including its handling and stability, the latter is replaced by a calculation model reflecting the real object to a greater or lesser degree. The complexity of the computational model and the degree of its approximation to a real vehicle is dictated by a number of considerations [2], [3], [9], [16].

First of all, when choosing a calculation model, it is necessary to take into account the objectives of the problem being solved. For example, when it is necessary to establish basically the qualitative characteristics of the tractor as a whole, its design model can be very simple and it does not take into account the characteristics of the links of the individual elements of the running gear or frame (for example, the characteristics of the suspension of the front and rear wheels, characteristics of the steering trapezoid, mechanisms that distribute the torque between the wheels, etc.). At the same time, if it is required to obtain more or less accurate quantitative results, then part of these characteristics, which significantly affect the parameters of motion, must be taken into account. And for different traffic conditions and vehicles, carried out according to different schemes, different connections should be taken into account and with an uneven degree of simplification of their characteristics [6], [10], [11].

A. Development of a mathematical model of a tractor-transport train

The tractor-transport train can be considered as a moving mechanical system of solids with masses concentrated in the centers of gravity, having between their links certain connections: dynamic, kinematic, control signals (or the law of rotation of steered wheels) [12].

Until now, the theoretically unresolved issue of rolling modeling when rotating an elastic tire is of particular complexity in the compilation of the model. At the same time, many researchers decided this question too

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simplistically, which led to obvious limitations in solving general problems [13].

To obtain the optimal mathematical model, we accept the following assumptions:

a) The system has a finite number of degrees of freedom;

b) All links of the train are considered material points;

c) The tractor and trailer skeletons, frames and axles of the wheels are considered absolutely rigid;

d) The tractor train is controlled so that the center of gravity of the tractor moves exactly along the specified trajectory;

e) There are no vertical movements and rotation around the vertical axis of the tractor and trailer;

f) The tractor and trailer body have a central axis of symmetry;

g) There is a definite relationship between the coefficient of lateral withdrawal and the normal load on the tire;

h) There are no clearances in the coupling;

i) The towing device has a directly proportional stiffness characteristic at close to the extreme points, and is directly proportional to the damping coefficient at the stem positions in the middle of the piston;

j) The rolling of the wheels takes place without slippage and slippage.

In Figure-1 presents a planar diagram of the forces acting on the tractor train when making a turn [14]. It can be seen from this scheme that when creating an additional dynamic force between the P_{cil} links, the forces $P\,/_{kr1i}$ or (and) $P\,/_{kr2i}$ are created, which counteract the overturning [17], [18].

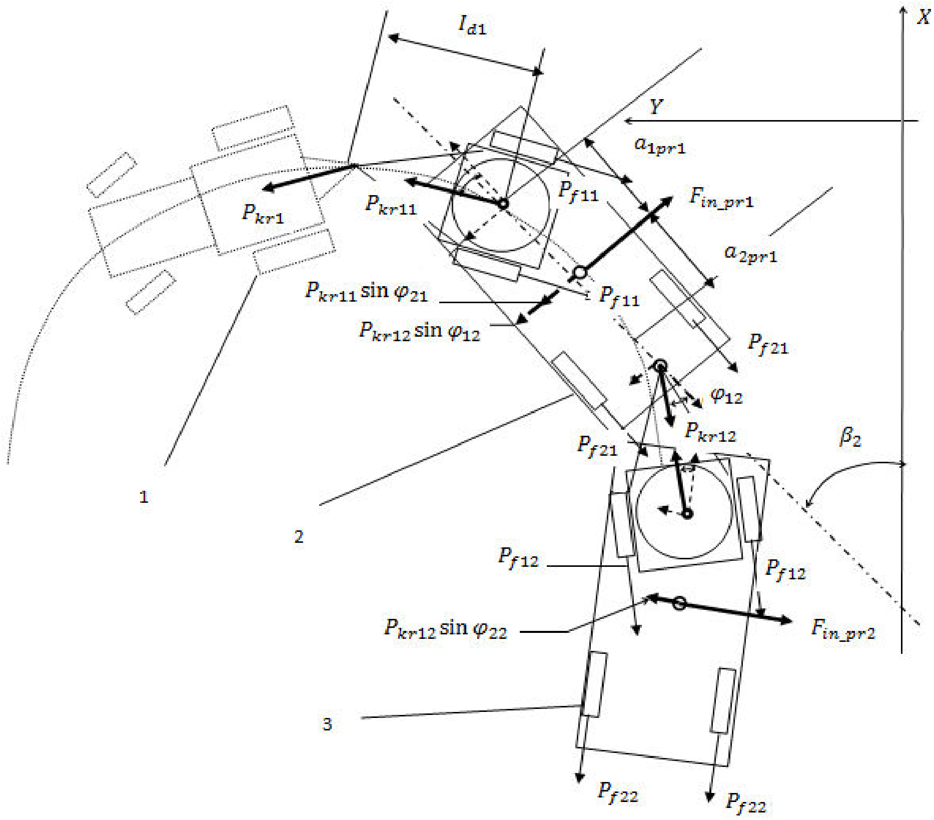

Figure-1. Flat dynamic diagram of the movement of a multi-link tractor-transport train and forces acting on the trailer. 1 - tractor, 2 - the first trailer, 3 - the second trailer.

The total moment of the rollover forces has its own counteraction, in the form of moments of several forces [19]:

- gravity (mg);
- dynamic force in the suspension elements (refer only to the active suspension) (P_{pod});
- reactions in the links between links (P_{kr}).

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Thus, it was decided to calculate the necessary force P'_{kr1i} in the towing device of the i-th trailer in order to provide the required level of the roll-over resistance against the formula (1):

$$M_{стаб\_pr\_i} = P'_{kr1i}h_{pr2i} + P'_{kr2i}h_{pr1i} + mg\frac{B_{pr}}{2} \quad (1)$$

$$M_{опр\_pr\_i} = F_{in\_pr2i}h_{pr2i\_in} \quad (2)$$

$$F_{in\_pr2i} = m_{pr2i}(v_{pr2i})^2 / R_{pov} \quad (3)$$

where

h_{rr_i} - the height of the attachment of the trailer and trailer coupling, m;

B_{pr} transverse trailer base, m;

$h_{rr}\_in\_i$ - height of the center of gravity of the trailer, m;

P'_{kr1i} - hook force on the turntable of the trailer, counter-tipping, m;

P'_{kr2i} - hook force on the hook of the trailer in the presence of a subsequent trailer, resisting overturning, m;

m_{pr2i} - the mass of the second kinematic link of the i-th trailer, kg;

R_{pov} - tractor turning radius, m;

The value of the forces P'_{kr1i}, P'_{kr2i} are equal to:

$$P'_{kr1i} = P_{kr1i}\sin\varphi_{2i} \quad (4)$$
$$P'_{kr2i} = P_{kr2i}\sin\varphi_{1i+1}$$

where

P_{kr1i} is the traction force on the hook of the i-th trailer, H;

P_{kr2i} - full hook force on the turntable of the trailer, m;

φ_{2i} is the angle between the longitudinal axial lines of the first kinematic link and the second kinematic link of the trailer;

φ_{1i+1} is the angle between the longitudinal center lines of the first kinematic link of the subsequent trailer and the second kinematic link of the first trailer.

$$P'_{kr1i} + P'_{kr2i} = \frac{F_{in\_pr\_i} \cdot h_{pr\_in\_i}}{h_{pr\_i}(1-\mu_{опрок})} - m_{pr\_i}g \cdot \frac{B_{pr\_i}}{2h_{pr\_i}} \quad (5)$$

$$P'_{kr1i} = \frac{\left(\frac{F_{in\_pr\_i} \cdot h_{pr\_in\_i}}{1-\mu_{опрок}} - mg \cdot \frac{B_{pr\_i}}{2h_{pr\_i}}\right)}{h_{pr\_i}} - P'_{kr2i} \quad (6)$$

$$P'_{kr1i} = \frac{\left(\frac{F_{in\_pr_i} \cdot h_{pr\_in\_i}}{1-\mu_{опрок}} - m_{pr\_i}g \cdot \frac{B_{pr\_i}}{2}\right)}{h_{pr\_i}} \quad (7)$$

According to the obtained formulas (5, 6), it is possible to determine the required force on the hooks of the trailer or tractor, however, even with a single trailer, you can determine the required hook force (7).

Thus, it is possible to determine the value of the total force on the hook in order to provide a certain value of μ, which can be set in advance to ensure safety against rollover, based on driving conditions, maneuvering and road profile, cargo weight, etc.

In the diagrams below, you can determine the required force in the towing device P_{kr1i} to provide transverse stability of the trailed links, taking into account that already on the coupling devices, when traction forces are applied (rolling resistance and resistance to lateral pulling of the train links), there is already a hook force P_{kr} [20].

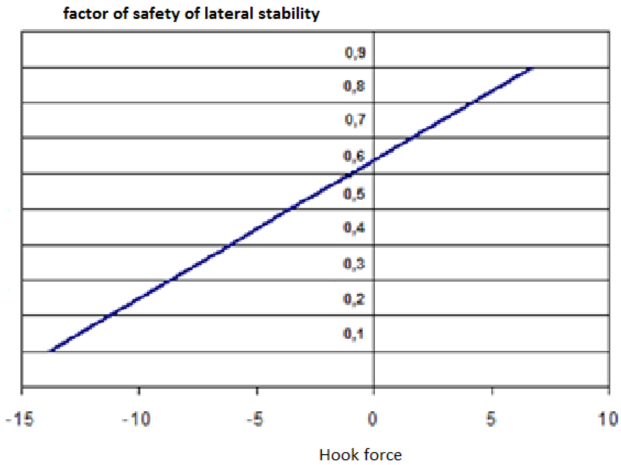

Figure-2. Dependence of the hook force on the safety factor of lateral stability.

The analysis of Figure-2 allows theoretically to estimate the value of the hook force to provide the required margin of lateral stability.

Further, taking for the initial value μ = 0, 7, we determine the dynamic forces (P_{kr}, F_{in}, P_{kr1i}, P_{cil}) arising from the movement of trains with trailers of different masses with different speeds on a 10-m radius turn (Figure-3). Here you can clearly notice that with increasing speed, the centrifugal force of inertia increases significantly, which leads to a significant increase in the necessary additional effort. An analogous picture is given by the analysis in Figure-4 shows the dynamic force at 25 km / h for various turning radii.

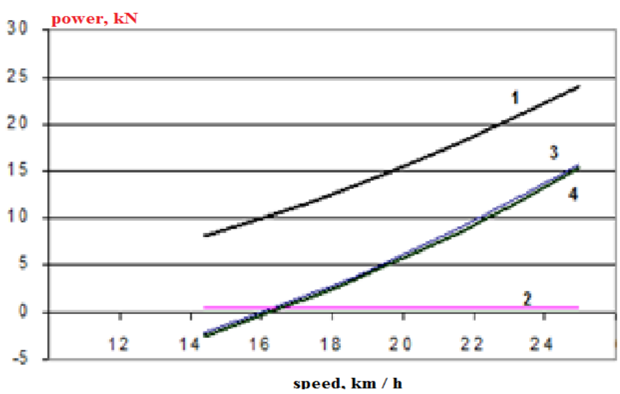

Figure-3. Dependence of hook forces on the speed of motion, mass 5 tons and a turning radius of 10 m.
1- F_{in}, 2 -P_{kr}, 3 -P_{kr1i}, 4 -P_{cil}.

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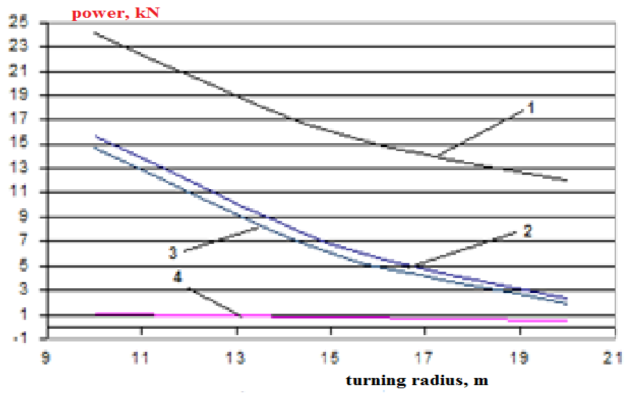

Figure-4. Dependence of hook forces on the turning radius of the train, the mass of trailers is 5 tons; the speed is 25 km / h. 1 - F_{in}, 2 -P_{kr}, 3 -P_{kr1i}, 4 -P_{cil}.

Analyzing the obtained graphs and taking into account the most efficient speed of the turn (taking into account the distribution of the radius of rotation [5]), we determine that for radii of rotation from 10 to 20 m and speeds corresponding to the regime from 10 to 25 km / h, in the TFC is required in the range of 1 - 5 kN.

From the foregoing it follows that an increase in the lateral stability of a multi-link tractor-transport train is determined taking into account the influence of all the main factors capable of affecting the reduction in the effect of the centrifugal inertia force, including by increasing the hook force by a certain amount, depending on the driving conditions.

The hook force P_{kr} is the force that, depending on the type of coupling, has a different design formula [4], [8].

The active work of the towing device is simulated through P_{cil_i}, which is set either by the driving mode or by the conditions for the presence of critical inertial forces P_{in_krit} (8-9) or the angle of rotation of the drawbar relative to the trailer φ_{pr2i}, which is determined from the expression (10-11).

$$P_{in\_i\_krit} > 10\,000\,\{P_{cil\_i} = pS_{cil}\} \tag{8}$$

$$P_{in\_i\_krit} < 10\,000\,\{P_{cil\_i} = 0\} \tag{9}$$

$$5^{\circ} < \varphi_{pr2i} < \theta_{max}\{P_{cil\_i} = pS_{cil}\} \tag{10}$$

$$0^{\circ} < \varphi_{pr2i} < 5^{\circ}\{P_{cil\_i} = 0\} \tag{11}$$

At the same time, the values of the traction-towing device coefficients are: ξi limits 1-10 kN / m, μi 20-60 kNs / m. Taking into account the values of the displacement and the speed of the rod moving, we set the coordinates of the centers of gravity of the kinematic links relative to the fixed coordinate system OXYZ, that is:

$$\dot{\Delta_\mathrm{i}} = (\upsilon_{tr} + \omega_{tr}(a_2 + c))\cos\varphi_{pr1i} - \upsilon_{pr1\_i}; \quad i = 1, 2 \ldots \tag{12}$$

$$\Delta_i = \int \dot{\Delta_i} dt \tag{13}$$

It follows from the above that the mathematical model of the movement of a multi-link tractor train allows us to take into account the different ways and manner of driving, the quality of the road surface, the wagging of the engine, and also to assess the effect of the presence of an active towing device in the train.

B. Description of trailer coupling

As a result of the computational work carried out during the simulation of the movement of a multi-link tractor-transport train, the optimum characteristics were obtained on the basis of which the original design of the towing device was proposed.

The invention relates to transport engineering and can be used to improve the performance of multi - link transport trains due to increased safety and maneuverability. The towing device consists of a hydraulic cylinder rigidly connected to a trailer drawbar equipped with a hydraulic system consisting of a hydraulic distributor, a pump, a hydraulic accumulator, a tank, and the towing device has an autonomous drive system from the wheels of the turn axis of the trolley with electric control from the control unit with energy sensors and turning, and included in the general electric system of the tractor, the sensor of the smallest length located on the hydraulic cylinder; in all cases, the sensors close the excitation circuit of the electric generator (supplying the winding of the power electromagnetic clutch), which supplies the electromagnetic power clutch. The technical result is an increase in the margin of lateral stability of the transport train when traveling along a curvilinear trajectory in different conditions.

The invention relates to transport engineering.

A towing device is known, consisting of a ring gear, a gear wheel with a crank connected to the rod of the master cylinder, connected by pipelines to the master cylinder in a closed circuit, the rod actuates the hydraulic cylinder to the four-link mechanism of the drawbar. The disadvantage of this device is the presence of a large number of articulated joints and the unreliability of gears, increased resistance on the turntable.

The closest to the proposed device is a towing device consisting of two series-connected actuators in the form of two hydraulic cylinders with spring-loaded rods equipped with throttling holes in the pistons, with an electromagnetic distributor, a threshold inertial force sensor included in the control circuit of the hydraulic distributor, cross-section of the drain line.

The disadvantage of this device is that it does not have the autonomy of the action, especially for trailers that are far from the main power units. Also a disadvantage is the constant drive of the pump of the hydraulic system, regardless of the frequency of application of the device, and therefore a high indicator of the idle time; the device does not regulate the work process in accordance with the speed of movement.

The technical task of the proposed device is to increase the operational characteristics of a multilink transport train due to the variable dynamic and kinematic parameters of the towing device.

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The problem is achieved by the fact that the towing device of a multi-link transport train comprising a hydraulic cylinder rigidly connected to the trailer drawbar and equipped with a spring-loaded rod with throttling holes, a hydraulic system with electromagnetic control of the distributor, when transmitting a torque from the wheels starting when the turntable is turned or when it is triggered threshold sensor under the action of critical centrifugal forces of inertia, the hydraulic fluid is supplied under pressure into the cavity of the hydraulic cylinder, changing kinematic parameters of the train, increasing agility, reducing the impact and shock loads off the corner drawbar is returned to the original corresponding parameters.

Analysis of the design of the towing device compared with the prototype led to the conclusion that the claimed technical solution is novel, since it has a drive independent of the tractor; an executive body made in the form of a single hydraulic cylinder. And it has a complex of independent sensors.

The presence of the invention in the proposed technical solution is proved by the fact that in this towing device, in contrast to existing structures, it is possible to integrate the length of the drawbar and the transverse stability index on the turn, depending on the speed of rotation and movement, independently of the tractor's hydraulic system.

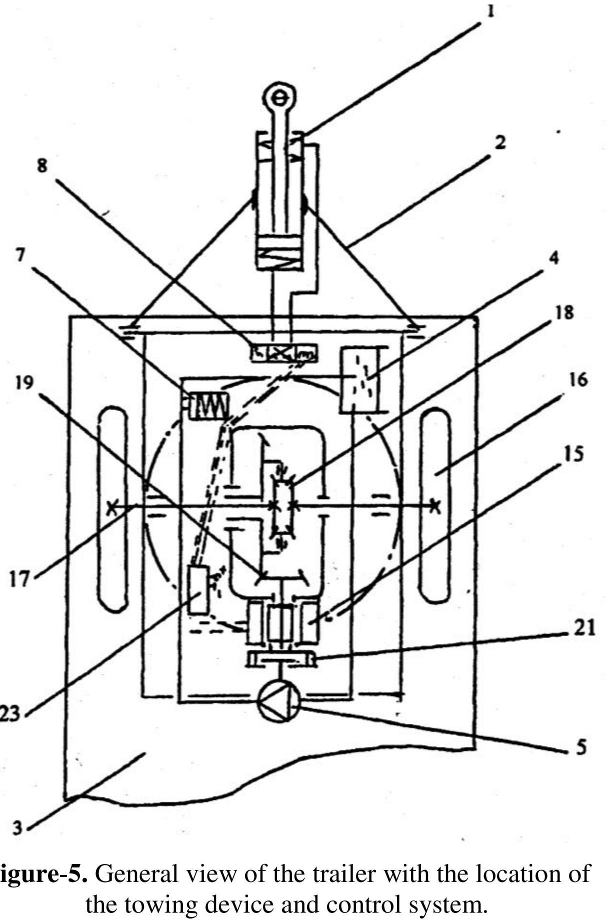

Figure-5. General view of the trailer with the location of the towing device and control system.

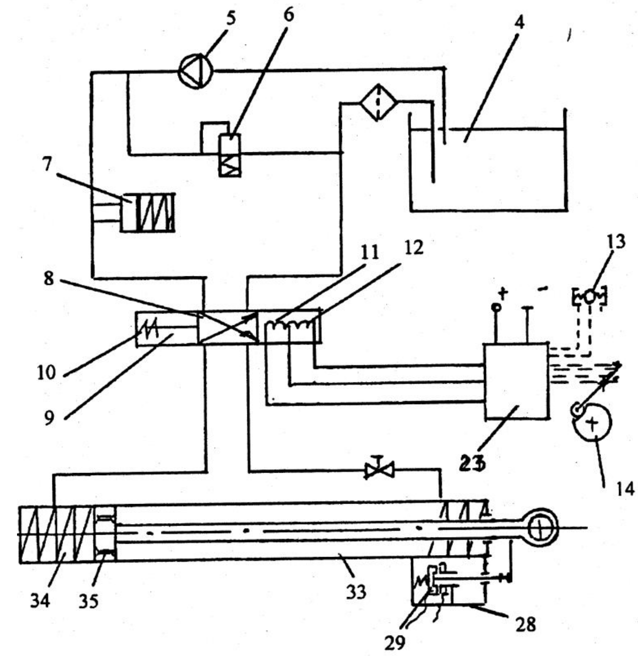

Figure-6. Schematic diagram of the hydraulic system of the towing device.

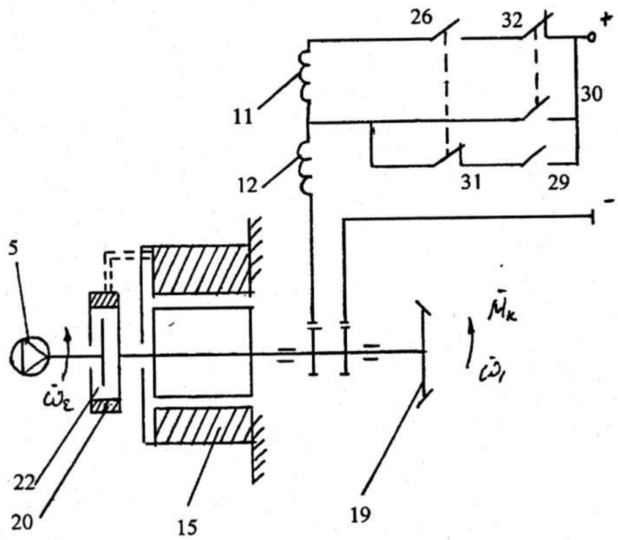

Figure-7. Control system.

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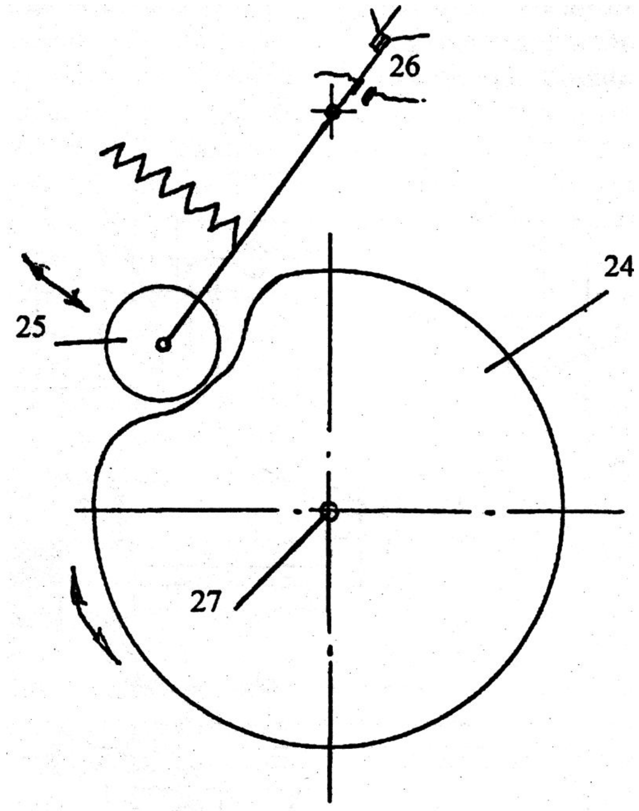

Figure-8. The sensor of rotation.

The towing device consists of a hydraulic cylinder 1, which is connected via a drawbar 2 to a trailer 3, a hydraulic system consisting of a hydraulic reservoir 4, a gear pump 5 with a safety valve 6, a hydraulic accumulator 7, a hydraulic distributor 8, a spool 9 of which is spring-loaded by a spring 10 and changes its position when including retracting windings 11 and 12, which are included in the trailer equipment system. The closing occurs under the action of the inertial sensor 13 and the turn sensor 14. The same sensors close the drive circuit of the drive system generator 15.

The drive system consists of the wheels of the trolley 16 which, through the axle 17, the conical differential 18 and the main gear 19, transmit the main torque to the generator 15 and the drive disk 20 of the electromagnetic clutch 21, the generator 15 and the disc 20 being mounted on one shaft. The driven disk 22 of the electromagnetic clutch 21 is mated by one shaft to the hydraulic pump 5 and transmits a secondary torque to the pump 5. The sensors 13, 14 and the controls are integrated in the control unit 23. The turn sensor 13 consists of a disc cam 24 with a spring-loaded lever pusher 25 and pair of contacts 26, and is fixed to the housing of the differential 18, and the drive is carried out by the roller 27. The device is provided with a sensor of the shortest length of the towing device 28 with the contacts 29, and in the control unit, 6 of the turn sensor 14, the contacts 30 of the inertia sensor 14, as well as the NC contacts 31 of the shortest length TCU, and the contacts 32 of the turn sensor 14. The hydraulic cylinder itself is divided into cavities 33 and 34 that are connected by throttling holes 35.

The device operates in the following way: During straight motion, the device is in the initial state: the piston of the hydraulic cylinder 1 is in a floating position, when dynamic loads occur, the liquid flows from the cavity 33 into the cavity 34 and back through the conduits through the distributor 8, and also partly through the throttling holes 35 in the piston, while the load peaks are smoothed by converting the kinetic energy of the trailer into a thermal one. As the length of the coupling increases, the sensor of the smallest length of the towing device 28 is triggered, the excitation circuit of the generator 15 is closed, and the torque from the trailer wheels is transmitted to the pump 5, and, insofar as the closed coil 12 is flowing, the liquid flow is supplied to the cavity 33, the length. The towing device (TD) is reduced until the contact of the smallest length sensor of the towing device 28 opens. When the turn is turned on, the turn sensor 14 operates which has a free-running angle (5 degrees), the excitation circuit of the generator 15 closes, which, depending on teeing off speed generates an appropriate force on current in a predetermined range. Proportional to this current, the torque is transmitted to the driven shaft of the electromagnetic clutch 21 leading to the driven shaft of the electromagnetic clutch 21 and then to the gear shaft of the pump 5. The number of revolutions on the driven shaft and the value of the torque depend on the current generated by the generator 15. When the turn signal sensor 14 is activated, the control circuit of the distributor 8, and the spool 9 under the action of the retracting force of the coils 11, 12 changes the floating position to the position corresponding to the injection of liquid into the cavity 34, creating on the rod the braking force of the trailing links along zda and increases the kinematic length of the trailer coupling, which increases the maneuverability of the train. As soon as the magnitude of the inertia forces becomes higher than the critical value, the threshold inertial sensor 13 is triggered and the control circuit of the coil 12 opens. The distributor spool 9 occupies a position at which the cavity 34 is connected to the master drain, the cavity 33 to the discharge line, the length of the trailing coupling device and creates a force on the rod, and the energy stored by the accumulator. 7, allows you to create the necessary action on the time and the magnitude of the force on the rod to counter the tipping trailer inertial forces. When the value of the inertial forces decreases, the contacts 30 of the inertial sensor 13 open and the contacts 32 of the turn sensor 14 close, the contacts 31 are opened due to the location of the lever pusher 25 in the pivot position. The valve changes its position and the liquid begins to be pumped into the cavity 34, continuing to increase the length of the towing device until the trailer leaves the bend, the turn signal circuit 14 opens (contacts 26) and the shortest length of the trailer device, which returns the towing device to its original position, at which the kinematic length of the device corresponds to the optimum for straight train movement.

CONCLUSIONS

The proposed traction and towing device in comparison with existing analogues has a number of advantages, expressed in the fact that this towing device allows the formation of multilink transport trains that meet the requirements of safety, maneuverability, controllability, stability, as well as having good performance in speed.

The design of the towing device with variable kinematic parameters is developed, the application of which allows to increase traffic safety, transverse stability of the train, as well as maneuverability at high speeds; The technique of calculation of the towing device for different brands of tractors was developed. The results of the research can be used in the calculation of multi-link transport trains in the design of traction-coupling devices in the design bureaus of agricultural machinery plants, as well as in studying the stability of trains with various damping devices and in the educational process of agricultural universities.

REFERENCES

[1] Avramov V.I., Fomin S.D. 2004. Reduction of dynamic load on transient modes of MTA. Mechanization and electrification of S.-Kh. (8): 24-25.

[2] Avramov V.I., Fomin, S.D., Boromensky V.P. 2003. On the influence of the moment of resistance and unevenness of the rolling surface on the dynamic loading of a wheeled tractor Problems of agro-industrial complex, Materials of the international scientific and practical conference, Volgograd.

[3] Babanin N.V. 2015. Experimental studies on the smooth running, performance and fuel economy of the machine-tractor unit based on the tractor class 1.4 equipped with a gas-hydraulic elastic-damping drive / N.V. Babanin, O.I. Polivaev// Bulletin of Voronezh State Agrarian University, No 3 (46): 112-118.

[4] Eviev V.A. 2015. Determination of operational parameters of the machine-tractor unit according to the tractor's characteristic with a constant traction power plot / Eviev V.A., Bukadzhinov P.V., Ochirov N.G. / / Tractors and agricultural machinery. (12): 18-21.

[5] Fedorenko V.F. 2016. Tractors for agricultural purposes abroad: development trends and innovative developments / V.F. Fedorenko, V.Ya. Goltyapin //Engineering and equipment for the village. (1): 2-7.

[6] Fomin S. D. 2011. Stability of controlled motion of MTA with different type of kinematic connection of driving. Proceedings of the lower Volga agro-University complex: science and higher professional education. 4(24): 243-249.

[7] Fomin S. D. 2017. Energy efficiency of the machine-tractor unit on transient modes / S. D. Fomin, V. I. Avramov, D. S. Gapich, E. S. Vorontsova // Proceedings of the Moscow state technical University MAMI. 1(31): 2-7.

[8] Fomin S.D. 2012. Modeling the dynamics of mass interaction of the subsystem "tractor-trailer" for unsteady curvilinear motion / S.D. Fomin // Proceedings of the lower Volga agro-University complex: science and higher professional education. No. 4 (28): 202-207.

[9] Fomin S.D. 2017. Mathematical model for investigation of uninstalled curvilinear movement of a load-transport unit. Proceedings of the lower Volga agro-University complex: science and higher education, 2017, AN - RU2017000904, V. 1 (45): 234-245.

[10] Gapich D.S. 2014. Stabilization of loading modes of wheeled machine-tractor units [Text]: dis. ... doctors of techn. Sciences / D.S. Gapich. - Volgograd.

[11] Gerasun V.M., Nesmiyanov I.A., Fomin S.D. 2013. Investigation of the stability of a transport aggregate with a manipulator. Proceedings of the lower Volga agro-University complex: science and higher professional education. No. 1 (29): 204-211.

[12] Karsakov A.A., Fomin S.D. 2012. On the possibility of reducing energy losses in transmissions of mobile machines.Agrarian science is the basis for the successful development of the agro-industrial complex and conservation of ecosystems. Materials of the International Scientific and Practical Conference. T. 3. - pp. 158-163.

[13] Kravchenko V.A. 2015. Influence of the elastic-damping mechanism on the parameters of the arable unit based on the tractor of class 1.4 / V.A. Kravchenko, V.V. Duryagin// Bulletin of Agrarian Science of the Don, *No* 3 (31): 13-21.

[14] Kuznetsov N.G. 2014. Automation of calculation of technical characteristics of horizontal load stabilizers MTA / NG.Kuznetsov, D.S. Gapich // Tractors and agricultural machinery. (4): 36-38.

[15] Ovchinnikov A. S., Mezhevova A. S., Novikov A. E., Fomin S. D., Pleskachev Y. N., Borisenko I. B., . . . Vorontsova E. S. 2017. Energy and agrotechnical indicators in the testing of machine-tractor units with subsoiler. ARPN Journal of Engineering and Applied

Sciences. 12(24): 7150-7160. Retrieved from www.scopus.com

[16] Ovchinnikov A. S., Ryadnov A. I., Fedorova O. A., Fomin S. D. & Sharipov R. V. 2017. Evaluation of reliability of sorghum harvester. ARPN Journal of Engineering and Applied Sciences. 12(7): 2277-2284. Retrieved from www.scopus.com

[17] Polivaev O.I. 2017. The spring-damping drive of the tractor's driving wheels / O.I. Polivaev, K.S. Zhidenko, I.I. Maksimov, I.G. Levkin // Modern trends in the development of technologies and technical means in agriculture. Mat. Int. scientific-practical. Conf. - Voronezh. pp. 185-190.

[18] Pyndak V.I., Fomin S.D., Dyashkin A.V. 2013. Complex indicators of the effectiveness of improvements in agricultural machinery. Bulletin of the Russian Academy of Agricultural Sciences. (2): 81-83.

[19] Strokov V.L., Fomin S.D., Karsakov A.A. 1990. Simulation of the unsteady curvilinear motion of a transport aggregate Agricultural Mechanics and Crop Programming: Tez. doc. All-Union. Scientific and technical. Conf. - Volgograd. pp. 104-105.

[20] Uspensky I.A. 2013. Innovative solutions in technology and technology of transportation of crop production / I.A. Uspensky, I.A. Yukhin, S.N. Kulik, D.S. Ryabchikov // Engineering and equipment for the village. (7): 6-8.