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Reduction of technogenic impact on the soil by increasing the stability of road trains movement within the field

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Abstract. The outcomes of assessing the possibility of reducing the technogenic impact on the soil during field operations in crop production are presented by increasing the stability of the transport movement and technological means in agricultural fields. An increase in the number of passes, a distortion of the tramline shape, an increase in slippage, wobbling and sliding of technical equipment on the field lead to a significant deterioration in the topography and structure of the soil layer, which causes soil destruction and a decrease in its productivity. Transport work performed on agricultural fields leads to a significant negative technogenic impact on the soil due to the numerous passes, large transported weight, and the application of trailers. The impact on the stability of the road trains movement is considered in the paper. Characteristics of damped oscillations are used to evaluate the efficiency of impacts on stability. The method of changing the inclination angle of the turntable kingpin of the road train trailer is chosen by the method of influencing the movement stability. It is established that changing the inclination angle of the turntable kingpin of the road train trailer allows reducing the average amplitude of oscillations of the trailer front side by 26.5–28%, increasing the period of oscillations by 33.3%, and also slightly changing the decrement of oscillations by 0.5 –2.5%. Therefore, structural changes in the towing device of vehicles, by providing better directional stability, will reduce the technogenic load on the soil: decrease compaction and destruction of the soil layer.

1. Introduction
The research issues, assessment and minimization of the technogenic impact of production processes on the environment, in order to preserve the fertility of cultivated soils, remain relevant and of significant practical importance. The problem of overconsolidation of arable soils, violation of their structure during the performance of technological operations of plant growing (tillage of soil and cultivated crops, transport work, etc.) is of particular concern. Deviation from the optimal technological regimes (violation of the technological track, "extra" passages of technological units across the field, destruction of the soil layer during the "wagging" and skidding of technical equipment on the field, etc.) also significantly increases fuel consumption, which leads to an enlargement in the

cost of products and supplementary expenses for the implementation of soil protection measures. "According to the Federal Scientific Agro engineering Center VIM, today more than 80% of agricultural land is subject to overconsolidation in our country, which leads to the loss of more than 30% of crops and incomes among agricultural producers. The crop shortfall from soil compaction in the Russian Federation is annually up to 30 million tons, fuel overrun is up to three million tons" [1].

Numerous studies of the problems of technogenic impact on the soil during the performance of technological operations in crop production [2, 3] often consider the issues of reducing the pressure on the soil from technical means when they perform field work (reducing the weight of technical means, decreasing the specific pressure on the soil by using caterpillar propellers, increasing the width of tires, lowering the pressure in them, etc.), optimizing the number and parameters of technological passes of agricultural units across the field [4], etc. Besides, little attention is given to the issues of ensuring the movement stability of technical means when performing field operations in crop production (preserving the technological track).

The possibility of maintaining a given tramline directly depends on the controllability of the used transport and technological complexes, and their movement stability.

Figure 1. Consequences of moving transport and technological machines on the field [5].

Significant compaction and destruction of the fertile soil layer occurs during transport operations in agriculture. Frequent passages of equipment through the fields along very arbitrary trajectories with slipping (due to stability loss) lead to a negative impact on the soil. The given issue is complicated by almost constant unfavorable conditions (high humidity, uneven field surface, high mass of transported goods, the use of trailers, road trains (ATT), etc.), the consequences of which are often catastrophic (Figure 1) and have little dependence on the year time.

Consequently, increasing the controllability and stability of the movement of large, heavy vehicles transporting loads within agricultural fields can reduce the number of "extra" passages of equipment across the field, stabilize the transport track, and decrease the compaction of the soil layer and its structure destruction.

The purpose of the paper is to assess the possibility of reducing the technogenic impact on the soil of road trains by increasing their movement stability on the field.

2. Materials and Methods

The movement stability of a technical means assumes [6] the absence of deviations from the given (optimal) trajectory of its movement, as well as the probability of returning to this trajectory after external disturbing influences (collision with an obstacle, heterogeneity of the soil layer, a sharp turn of the steering wheel, etc.). The issue of ensuring traffic stability, when applying autotractor trains for transport work in agricultural fields, is of particular significance.

In the work [6], the process of the road train movement after an external impact was presented as an oscillatory one. To assess the efficiency of the proposed design and technological impacts on this process, it is proposed to apply the characteristics [7, 8] of damped oscillations (Figure 2), which are described by the equation:

$$X = A_0 e^{-\beta t} cos\,(\omega t + \varphi), \tag{1}$$

where A_0 – initial amplitude, β – damping factor.

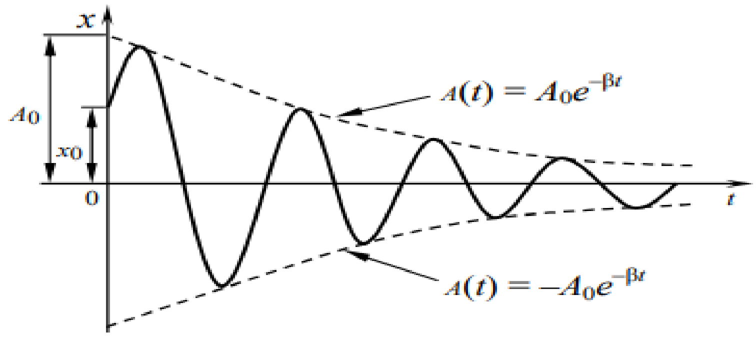

Figure 2. Parameters of the damped oscillatory process.

It is advisable to use the following parameters of the damped oscillatory process as an efficiency assessment of the stability of a road train movement:

Amplitude of A fluctuations will allow us to estimate the range of displacement of ATT elements beyond the boundaries of the optimal transport corridor (owing to which the soil area that is subjected to compaction and destruction of the structure increases).

Damping time of τ_{damp} will allow estimating the duration of the ATT response to external influences.

Damping decrement Δ will allow estimating "quenching" intensity (speed) of ATT oscillations (the application efficiency of design and technological solutions to improve the movement stability).

Damping coefficient β is advisable to use for evaluating the overall effectiveness of the ATT design (the ability to provide motion stability).

Quality factor of oscillations makes it possible to assess application efficiency of design and technological solutions to improve the movement stability from an energy point of view (energy loss intensity of the oscillatory process).

Oscillation phase φ is of interest for a detailed study of the ATT movement process after external influence.

The studies were carried out by comparing the characteristics of the movement stability of a vehicle with a trailer and a similar device with a changed angle of inclination of the trailer turntable kingpin [9] in order to increase its movement stability. External influence, namely, a side push was used to start ATT oscillations.

The survey demonstrated below are the outcomes of processing video materials (Figure 3) of field tests. The magnitude of the external influence in all experiments was taken to be identical.

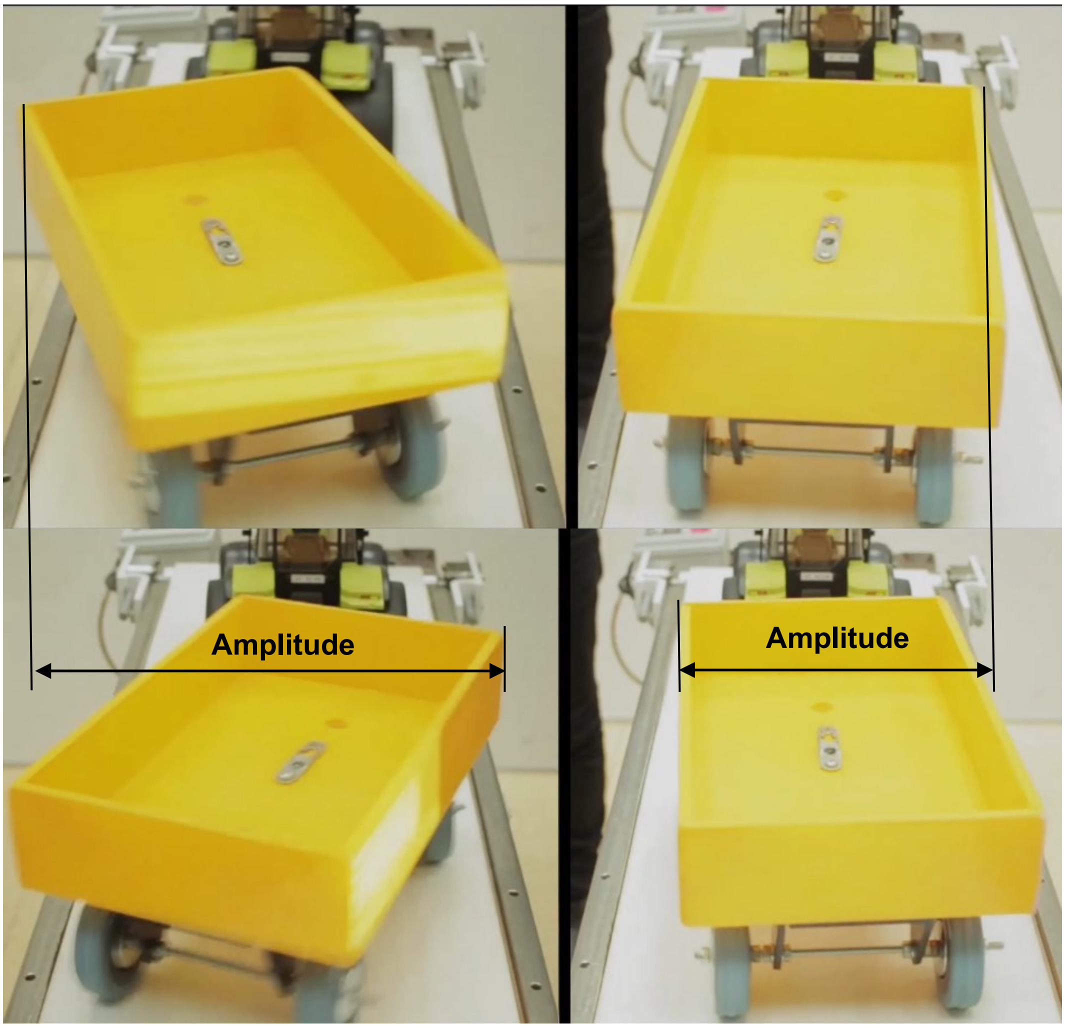

Figure 3. Fluctuations in the ATT movement under external influence: (a) – trailer in the initial state; (b) – trailer with a modified inclination angle of a trailer turntable kingpin.

3. Results and Discussion

Processing of experimental data has revealed that changing the inclination angle of the trailer turntable kingpin significantly changes both the amplitude and the period of the ATT movement oscillations occurring when an external influence is applied to it (Figure 4, Table 1).

According to the presented data, changing a modified inclination angle of a trailer turntable kingpin makes it possible to reduce the average oscillation amplitude by 26.5–28% and increase the oscillation period by 33.3%. The decrement of fluctuations changes insignificantly (0.5–2.5%). The exclusion from the calculations of points characterizing unstable oscillations (No. 1 for the initial and No. 1–5 for the modernized trailer), a variation in the decrement only enhances.

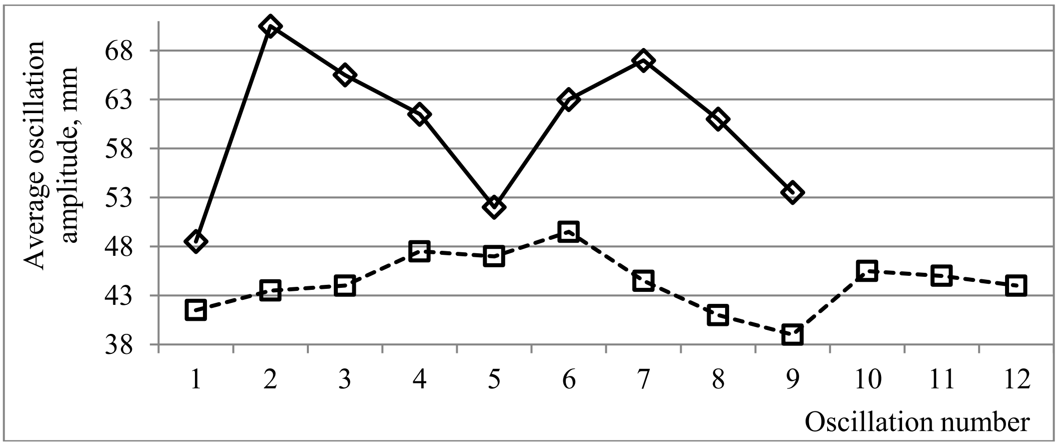

Figure 4. Oscillation amplitudes of the initial ATT trailer (solid line) and with a modified kingpin angle (dashed line).

Table 1. Evaluation outcomes of ATT trailer oscillations in the initial state and with a modified inclination angle of a trailer turntable kingpin.

Oscillation no.	1	2	3	4	5	6	7	8	9	10	11	12	Average	σ
ATT trailer without a modified inclination angle of a trailer turntable kingpin														
Average amplitude, mm	48.5	70.5	65.5	61.5	52	63	67	61	53.5	-	-	-	60.3	6.99
Decrement	-	0.688	1.076	1.065	1.183	0.825	0.940	1.098	1.140	-	-	-	1.002	0.16
Decrement for 2-9th oscillation	-	-	-	-	-	-	-	-	-	-	-	-	1.047	-
ATT trailer with a modified inclination angle of a trailer turntable kingpin														
Average amplitude, mm	41.5	43.5	44	47.5	47	49.5	44.5	41	39	45.5	45	44	44.3	2.8
Decrement		0.954	0.989	0.926	1.011	0.949	1.112	1.085	1.051	0.857	1.01	1.02	0.9972	0.07
Decrement for 6-12th oscillation	-	-	-	-	-	-	-	-	-	-	-	-	1.020	0.08

4. Conclusion

The analysis of the test outcomes allows us to state that the impact on the design parameters of the ATT trailer (change in the inclination angle of a trailer turntable kingpin) significantly reduces the instability of the ATT movement, which manifests itself when an external impact is applied to it (unevenness and heterogeneity of the soil, vibrations of the vehicle steering wheel, pushes, etc.). Thus, the method application [6] reduces the average amplitude of oscillations of the extreme points of the trailer front side by 26.5–28%, and enhances the period of oscillations by 33.3%, and also slightly changes the decrement of oscillations by 0.5–2.5%.

Improving the movement stability of heavy and large vehicles on agricultural fields diminishes the magnitude of the anthropogenic impact on the environment in the crop production process, namely, it decreases the size and distortion of the transport track shape ("wagging"), compaction, and destruction of the soil structure.

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