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Algorithm and analysis of the construction of the geometry of the Movement of Vehicles

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ABSTRACT

The problem of the lack of an algorithm for constructing the movement of special vehicles is considered. The aim of the research work is to develop a software package for calculating the rotation of a multi-link special vehicle, taking into account an algorithm that describes the characteristic features of vehicle movement. The increase in the dimensions and mass of long loads necessitates the creation of new vehicle designs, the distinguishing feature of which is multi-link and long wheelbase, which in turn reduces maneuverability and requires taking into account the peculiarities of movement along a curve. To study the process of moving special vehicles, a geometric modeling method was used to develop an analytical geometric model for the rotation of the tractor and semitrailer. Based on geometric modeling, a method for determining the turning characteristics of a multi-link vehicle has been developed. It is shown that patency of special vehicles is no less important quality in comparison with durability; the law of changing the ratio of the angle of rotation of the steered wheels, the various axles should provide the maximum turning moment at maximum angles of rotation of the front steered wheels, and should also ensure equality of wear at small angles.

Key words: vehicles, algorithm, curvilinear motion modeling, geometric characteristics, link path, automation, software package, rotation angles.

1. INTRODUCTION

In the process of developing an algorithm for constructing the movement of vehicles, comprehensive theoretical studies were performed [1-3], in which the following concepts were analyzed: basic concepts, directions of development and purpose of vehicles [4-6], the development of system tools in building the geometry of movement of aggregates [7-9], the current state of metrological support of vehicles, development trends of wheeled vehicles. As a result, the ways of building the vehicle design process were identified and the general architecture of the movement of the model version of the multi-link vehicle was developed.

2. METHODOLOGY

2.1 Development of an algorithm for geometric modeling of vehicles

The algorithm for constructing and visualizing the geometric model of vehicles is shown in Fig. 1.
At the first level, the requirements laid down in the terms of reference are presented in a general form. In this case, the design process can be considered as some process of making sequentially refined and detailed technical decisions, justified by appropriate calculations, setting up an experiment, manufacturing a prototype and testing it. The development of circuit design solutions in accordance with the requirements of the technical specifications and their design are the main content of the design process.
The initial data for the design are:
- external load, delivered in the form of accelerations, speeds, displacements, as functions of time;
- parameters characterizing strength properties: overload, efforts in characteristic sections, moments;
- layout, that is, the space allotted for placement of the structure and geometric constraints.

At the second level, the primary appearance is formed, an analysis of possible solutions is carried out, and the most appropriate options are selected. In this case, a general view of the structure is established. A positive decision is made when it becomes clear that it is possible to create a structure with the initial data that were originally issued or adjusted within acceptable limits during operation.

At the third level, the formation of the layout scheme is carried out, which consists in the implementation of mutual spatial coordination of the main components to be assembled. The layout is based on the selected scheme, certain basic parameters. During the assembly process, external and internal geometry is determined, the load, equipment, equipment are assembled, units are placed, etc. The assembly process is specific in nature due to the characteristics of vehicles.

At the fourth level, the calculation of the characteristics of vehicles is carried out. According to the layout, the basic dimensions, shapes and mass inertial characteristics are already known. This information is sufficient to determine:

- strength characteristics;
- dynamic characteristics;

Based on the obtained values, a decision is made on the progress of further vehicle design.

At the fifth level, performance characteristics are calculated. These characteristics include:
- indicators of appointment;
- indicators of reliability;
- indicators of manufacturability;
- indicators of standardization and unification;
- ergonomic indicators;
- aesthetic indicators;
- patent - legal indicators;
- economic indicators.

Depending on the conditions and stage of design development, the following methods for determining indicators are used:
- experimental - this method is carried out by technical measuring means during testing or operation of the product to detect and count the number of events.
- calculated - this method is carried out using calculations based on established theoretical or empirical dependencies using values and parameters found by other methods or specified.
- expert - the method is based on the opinions of expert groups.

The sixth level is the final in the formation of the layout of vehicles. If all the requirements of external design are satisfied and there are no contradictions at the stages of internal design, the process of shaping the appearance of vehicles should end with a technical proposal, i.e., the release of general drawings, layouts, three-dimensional models, as well as the issuance of characteristics and results according to particular criteria of all levels.

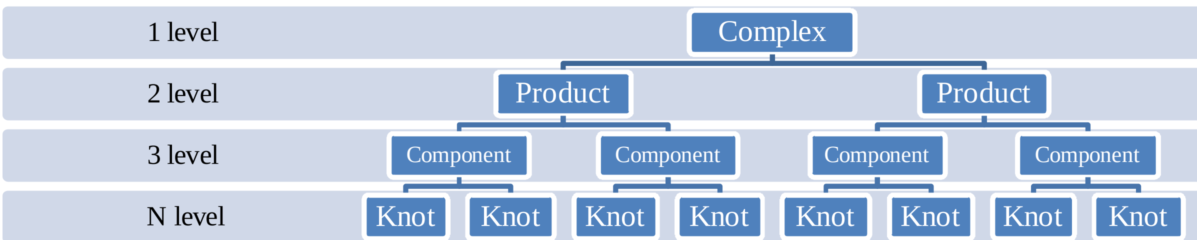

Figure 1:- Block diagram of the process of designing vehicles

It can be seen from the description of the features of the formation of the layout of vehicles, the layout of this type of machines differs from the layout of conventional trucks, the choice of layout of a special part.

3.MATHEMATICAL MODEL OF MULTI-LINK VEHICLE MOVEMENT

To determine the dependencies between the angles of rotation of the wheels of the links of vehicles, we use the scheme presented in Fig. 2.

The width of the corridor B is the difference between the maximum R_1 and minimum R turning radii:

$$B = R_1 - R. \quad (1)$$

We write down the necessary geometric relations for determining the value of B.

$$R_{\text{п}} = \frac{L_{\text{т}} - x_P}{tg\theta_{1\text{ср}}}; \quad (2)$$

$$R_{\text{сц}} = \sqrt{R_{\text{п}}^2 + l_{\text{сц}}^2}; \quad (3)$$

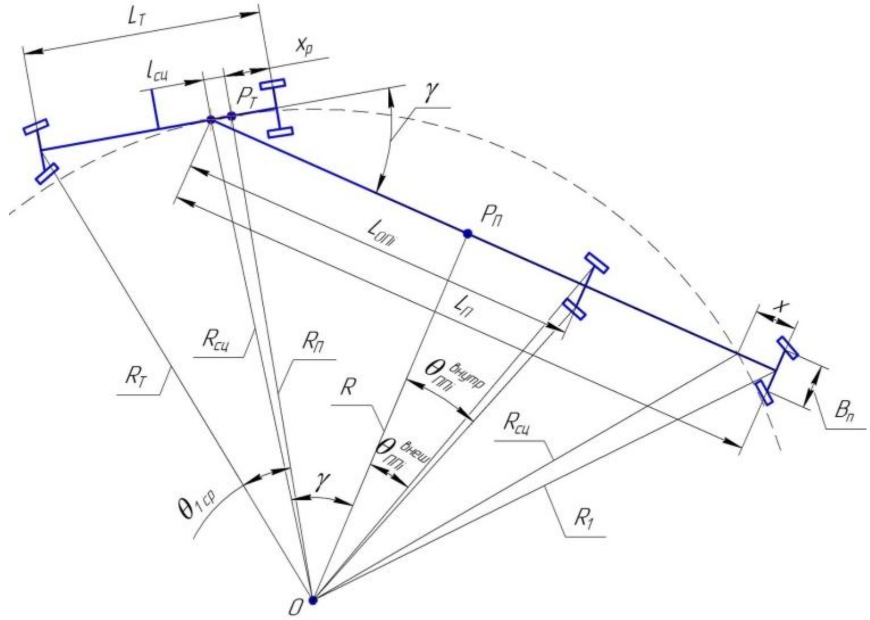

Figure 2 : Scheme of rotation of the vehicle:
$L_т$is wheelbase of the tractor; $L_п$is wheelbase of the semi-trailer; $L_{опi}$is distance from the hitch point to the *i*-th axle of the semi-trailer; *O*is the center of rotation; $P_т$is the pole of rotation of the tractor; $x_P$is distance from the rear axle of the tractor to the turning pole; $l_{сц}$is the distance from the vertical axis of the fifth wheel coupling to the pole of rotation $P_т$ on the longitudinal axis of the tractor; $P_п$is pole of rotation of the semi-trailer; $R_{сц}$is the radius of rotation of the hitch point; $R_1$is the maximum turning radius; $R_п$is tractor turning radius; *R*is the minimum turning radius; γ is the folding angle; γis the folding angle; $\Theta_{1av}$is the average angle of rotation of the steered wheels of the first axle of the tractor; $\Theta_{ппi}^{av}$isthe average angle of rotation of the steered wheels of the *i*-th axle of the semi-traile; *x*is is the distance from the rear axle of the tractor to the point of intersection of its longitudinal axis with $R_{сц}$

$$R = \sqrt{R_{сц}^2 + \left[\frac{L_п - x}{2}\right]^2} = \sqrt{R_п^2 + l_{сц}^2 - \left[\frac{L_п - x}{2}\right]^2}; \quad (4)$$

$$R_1 = \sqrt{R^2 + \left[\frac{L_п - x}{2}\right]^2} = \sqrt{R_п^2 + l_{сц}^2 + L_п x}. \quad (5)$$

When modeling curvilinear motion, it is necessary to specify the rotation angles of the steered wheels. The steering trapezoid is considered ideal, calculating the rotation angles of each wheel according to the known kinematic dependencies. Consider the design scheme for determining the angle of rotation of the wheels of the tractor in Fig. 3.

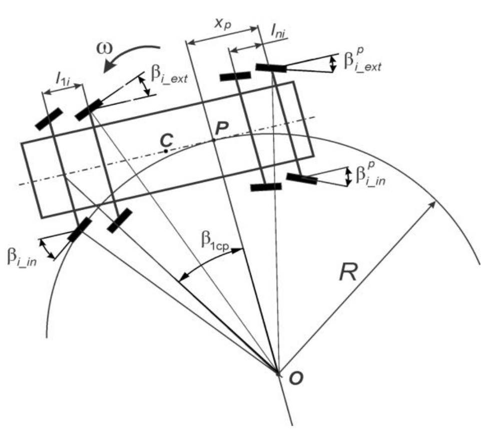

Figure 3 : Calculation scheme for determining the angle of rotation of the steered wheels: *P* - steering pole, *C* - center of mass, *O* - instantaneous center of rotation

The average angle of rotation of the wheels of the front axle is used as the driving signal:

$$\beta_{1cp} = \frac{\beta_1 + \beta_{n+1}}{2} \quad (6)$$

Then, for the external (with respect to the direction of rotation) steering wheels of the *i*-th axis located in front of the rotation pole (Fig. 3):

$$tg\beta_{i\_ext} = \frac{L - l_{1i} - x_p}{L - x_p + \frac{B_k}{2} tg\beta_{1cp}} tg\beta_{1cp} \quad (7)$$

For internal (with respect to the direction of rotation) steered wheels of the *i*-th axis located in front of the turning pole (Fig. 12):

$$tg\beta_{i\_in} = \frac{L - l_{1i} - x_p}{L - x_p - \frac{B_k}{2} tg\beta_{1cp}} tg\beta_{1cp} \quad (8)$$

For external (with respect to the direction of rotation) steered wheels of the *i*-th axis, located behind the rotation pole (Fig. 3):

$$tg\beta^P_{i\_ext} = \frac{-x_p + l_{ni}}{L - x_p + \frac{B_k}{2} tg\beta_{1cp}} tg\beta_{1cp} \quad (9)$$

For internal (in relation to the direction of rotation) steered wheels of the *i*-th axis located behind the rotation pole (Fig. 3):

$$tg\beta^P_{i\_in} = \frac{-x_p + l_{ni}}{L - x_p - \frac{B_k}{2} tg\beta_{1cp}} tg\beta_{1cp} \quad (10)$$

Informulas (6–10):
*L*is the base of the wheeled vehicle;
$l_{1i}$is the distance from the front to the *i*-th axis of the machine;

$l_{ni}$is the distance from the rear to the *i*-th axis of the machine;
$B_k$is the track of the wheeled vehicle;
$x_p$is the distance from the last axis to the rotation pole*P* (Fig. 3).
Now consider the design scheme for determining the angle of rotation of the wheels of the semitrailer in Fig. 3.
The angle of rotation of the inner steered wheel of the rear axle of the semi-trailer $\Theta^{\text{внутр}}_{\text{пп}max}$is determined by the following equation:

$$tg\Theta^{\text{внутр}}_{\text{пп}max} = \frac{\left(\frac{L_{\text{п}}-x}{2}+x\right)}{R-0{,}5B_{\text{п}}} = \frac{L_{\text{п}}+x}{2\sqrt{R^2_{\text{п}min}+l^2_{\text{сц}}-\left[\frac{L_{\text{п}}-x}{2}\right]^2}-B_{\text{п}}}, \quad (11)$$

where$R_{\text{п}min}$is the minimum turning radius of the vehicle;
$B_{\text{п}}$ iswheel track of the semi-trailer,
*x*is the distance between the rear axle and the rear axle of the semi-trailer.
It is important to understand that the rotation value of this wheel cannot exceed the value determined by the design of the steering trapezoid.
The reduced axis refers to the imaginary axis of the semi-trailer, along which the minimum corridor of movement of the entire vehicle is calculated taking into account its external dimensions.

The steering angle of the steered wheels of the semi-trailer:
- for external in relation to the direction of rotation of the wheel:

$$tg\Theta^{\text{внеш}}_{\text{пп}i} = \frac{\left(L_{\text{оп}i}-\frac{L_{\text{п}}+x}{2}\right)}{R+0{,}5B_{\text{п}}} sign\left(L_{\text{оп}i} - \frac{L_{\text{п}}+x}{2}\right); \quad (12)$$

- for internal with respect to the direction of rotation of the wheel:

$$tg\Theta^{\text{внутр}}_{\text{пп}i} = \frac{\left(L_{\text{оп}i}-\frac{L_{\text{п}}+x}{2}\right)}{R-0{,}5B_{\text{п}}} sign\left(L_{\text{оп}i} - \frac{L_{\text{п}}+x}{2}\right). \quad (13)$$

Therefore, to describe the process of turning a multi-link vehicle, it is necessary to draw up a dynamic mathematical model that takes into account both the control system and the side withdrawal phenomenon.

4.RESULTS

For the convenience of describing the process of turning a multi-link vehicle, we introduce the following concepts:
- front driven wheel of the tractor - a fictitious wheel conventionally located in the geometric center of the front wheel drive, the rotation angle of which is determined by the kinematics of the steering drive of this wheel drive;
- the driven rear wheel of the tractor — a fictitious wheel conventionally located in the geometric center of the tractor's rear wheel drive (most often this wheel is not turning, otherwise the steering angle of this wheel is determined by the kinematics of the tractor's rear wheel drive);
- reduced wheel of the semi-trailer - a fictitious wheel conventionally located in the geometric center of the wheel stroke of the semi-trailer, the rotation angle of which is determined by the kinematics of the steering wheel drive of the semi-trailer.

The design scheme for turning a multi-link vehicle is shown in Fig. 4.
The following notation is accepted:
$XOY$is fixed coordinate system;
$\alpha_i$is heading angle of the vehicle link;
$L_i$isbase of the*i*-th link of a multi-link vehicle[1];
$\mu_1$isangle of rotation of the front driven wheel of the tractor;
$e_i$is the displacement of the coupling poin*i*and ($i = 1$) of the links relative to the center of the reduced wheel *i* of the link (the offset is taken positive if the coupling point is shifted forward relative to the center of the reduced wheel *i*of the link and with the opposite sign - otherwise);
$\varphi_i$is the angle of rotation of the reduced wheel*i*of the semi-trailer relative to the frame of this link*i* ($i = 2, \dots, n$);

[1] The base of the tractor ($i = 1$) is the distance between the centers of the front and rear driven wheels, and the base of the semitrailer ($i = 2, \dots, n$) is the distance between the coupling point of the semitrailer with the previous link and the center of the wheel of the given trailer in the direction of the multi-link vehicle .

$\gamma_{i,i+1}$is folding angle between *i*and ($i = 1$) links of the vehicle
($i = 1, \dots n-1$);
$\bar{V}_{si}$is velocity vector of the coupling point*i*and ($i + 1$) links of the vehicle;
$\gamma_{\mu i}$is the angle between the directions of the vector $\bar{V}_{si}$ and the frame *i*of the link ($i = 1, \dots n-1$);
$O_i$is the instantaneous center of rotation of the i link ($i = 1, \dots, n$);
$\bar{V}_{k1}$is speed vector of the rear driven wheel of the tractor;
$\bar{V}_{ki}$is the velocity vector of the reduced wheel of the semi-trailer ($i = 2, \dots, n$).

The equations describing the process of turning a multi-link vehicle were obtained taking into account the following assumptions:

– the magnitude of the velocity vector of the rear driven wheel of the tractor is kept constant;

– a flat bicycle model of a multi-link vehicle is considered;

– the influence of disturbances acting by external forces are not taken into account;

– the phenomenon of lateral tire retraction is not accepted;

– the speed of rotation of the front wheel of the tractor is taken constant.

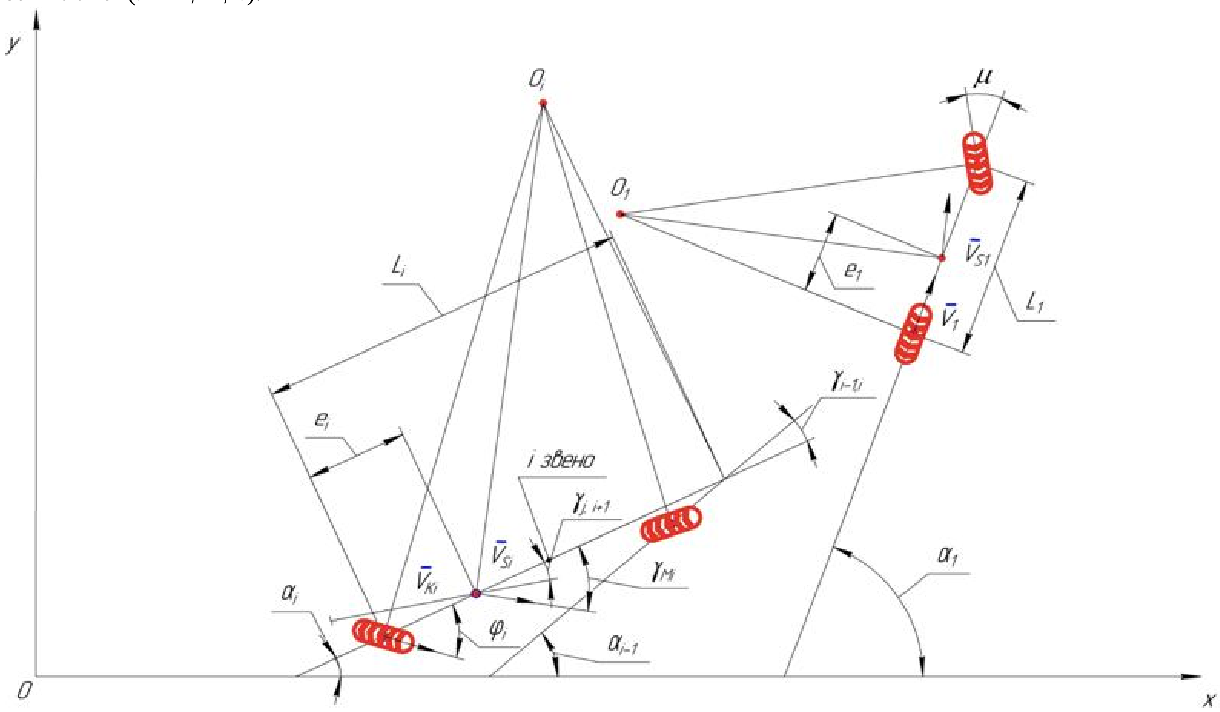

Figure 4: Calculation diagram of the kinematics of rotation of a flat bicycle model of a multi-link vehicle

The family of multi-link vehicles, designed to transport long indivisible goods weighing up to 300 tons on roads of different categories, is implemented according to the scheme of truck trains containing from one to four semi-trailers. Based on this, taking into account the algorithm of movement of vehicles, a software package was developed designed to calculate the characteristics of the curved motion of a multi-link vehicle, which has from one to four semitrailers. The calculation results are:

- geometry of the trajectory of the links of the vehicle;
- heading angles of links and the rate of change;
- angles of folding, rotation of the wheels and the speed of their change.

Calculations are carried out under specified traffic conditions and design parameters of a multi-link vehicle.

The software package allows you to calculate the rotation of a multi-link vehicle at any angle from 0 ° to 360 ° (Fig. 5). In addition, the program allows you to calculate the trajectories of the links of a multi-link vehicle when it is moving along a road consisting of an arbitrary number (up to 50 inclusive) of road sections with a tractor rotation angle of not more than 180 ° in each section. The road section (Fig. 5) includes:

– rectilinear sub-section characterized by length;

– input transitional subsection (this subsection is characterized by a constant speed of rotation of the front driven wheel of the tractor);

– circular sub-section of a given radius;

– output transitional subsection (this subsection, like the input, is characterized by a constant speed of rotation of the front driven wheel of the tractor).

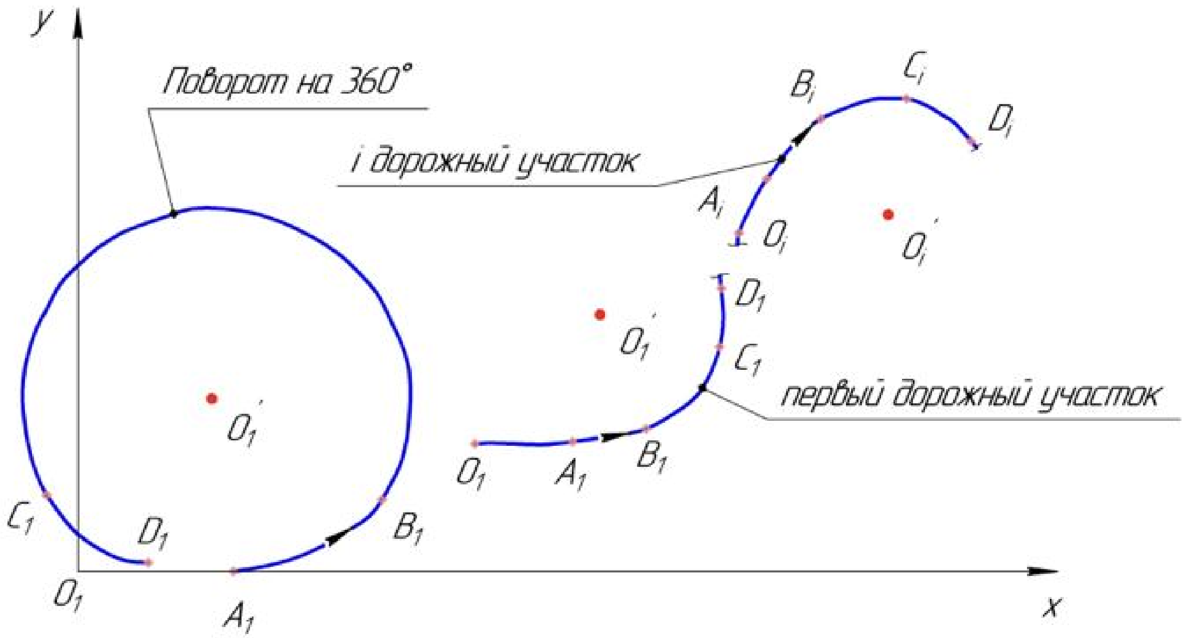

Figure 5 : Road sections:
$O_iA_i$is a rectilinear subarea; A_iB_i is input transitional subsection; B_iC_i is circular subarea;
$C_iD_i$is output transitional subsection; O_i is center of rotation on the *i* circular subsection

5.CONCLUSION

The described model of curvilinear motion of the adhesion point of the semitrailer and the tractor allows us to estimate the degree of deviation of the trajectory of the semitrailer with an accuracy of ± 5%.
The trajectory of a planar curvilinear motion is modeled by simple sections.
A model of the dynamics of movement during the passage of a curved section of a turn is determined.
Complex sections of motion are divided into sections described by simple geometric laws.
The practical implementation of the developed algorithm for constructing the geometry of the movement of vehicles has shown the rationality and prospects of this approach to the problem of determining the degree of deviation of the trajectory of the vehicle semitrailer. This approach allows you to objectively identify the basic geometric characteristics of the movement of a multi-link vehicle and can be the basis for the development of an automation system for controlling the movement of a tractor and semi-trailer.

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