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GRAPHIC-ANALYTICAL DETERMINATION OF THE DEPENDENCE OF THE GEAR RATIO OF ROAD TRAINS IN CURVILINEAR MOTION

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Keywords: Road train, multi-link, road transport, trajectory, wheeled vehicles, deviation of the trajectory, gear ratio, guidelines, practical recommendations.

ABSTRACT
Providing the possibility of unification of the trajectory of movement with the existing infrastructure is a technical problem, the solution of which can be largely facilitated with the existence of sufficiently accurate productive methods of structural-parametric analysis of the geometry of curvilinear movement as a whole.

Therefore, the team of authors decided to identify a methodological basis for determining the dependence of the gear ratio of two and three-link road trains. This will simplify calculations in the future, receive comprehensive and practical recommendations on the design of the wheel drive and the number of links of the road train.

INTRODUCTION

The growing dimensions of the transported cargo [1], which cannot be divided into parts [2] [3], requires more and more new equipment and transportation technology, regardless of the region of use, for example, in the Arctic [4] or hot countries.

Among the methods by which the angle of rotation of the wheels of the trailer link of the road train is determined, today the most common are systems that carry out practical control, depending on the value of the folding angle [5]. The main characteristic with such control will be expressed in the subordinate ratio *i*, which means the dependence of the angle of rotation of the given semi-trailer wheel $\varphi_{\text{пр}}$ relative to the folding angle α. To select the value of i related to the wheels of the

trailed link, it is necessary to study the conditions for the steady motion of the centers of these wheels and its links relative to the circular path of a constant radius. In most cases, the turning radius R should be designated as 35 m [6-8].

A calculation of the trajectory of the links of road trains of two and three links was carried out to find the influence of the type of turn relative to the nature of the change in the trajectory of the semitrailer [9] (Figure 1).

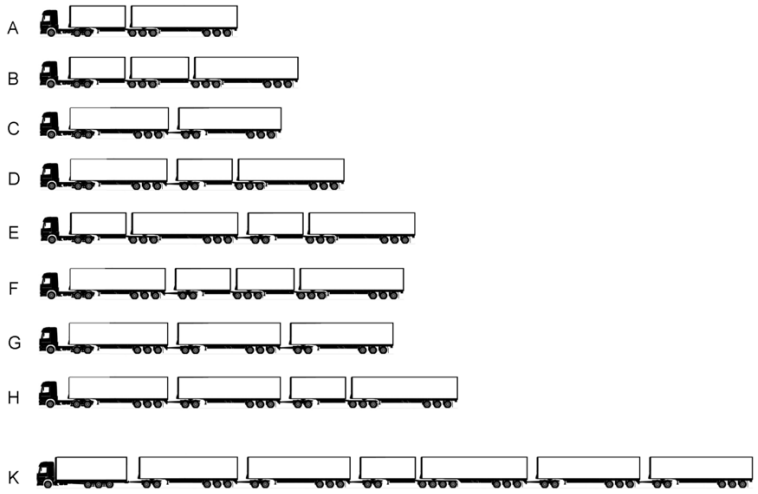


Figure 1 - Multi-link road trains.

Movement pattern in a 90°turn

$L_т$ m is defined as the basis of the tractor of the road train of two and three links. The basis of the intermediate bogie of the road train of three links is $L_{тел}$m. The base value of semi-trailers of the road train of two and three links is variable. The link points are identical with respect to the reference points of the corresponding link for all calculation schemes

Next, let's examine the rotation equal to 90°. There are trajectories of the pivot point of the tractor and semi-trailers with bases in figures 2 and 3. The supports correspond to 20 and 25 m of a road train of three links, with different values of the gear ratio.

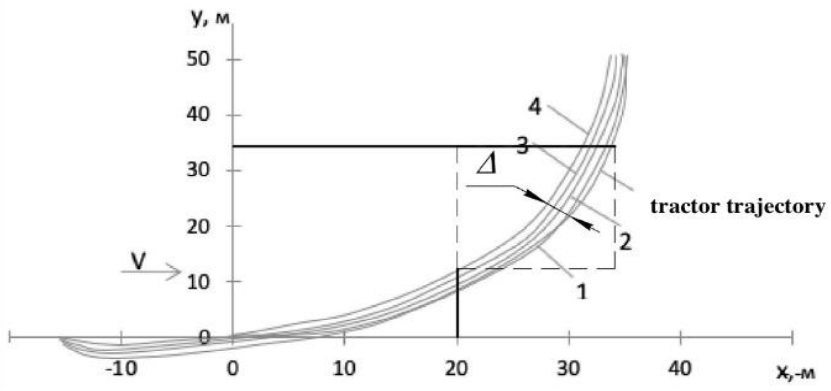


Figure 2 - Trajectories of a tractor and a semitrailer with a base = 20 m and a three-link one (with the base of an intermediate bogie) at various values of the gear ratio *i* when turning 90 ° with a radius of R = 35 m

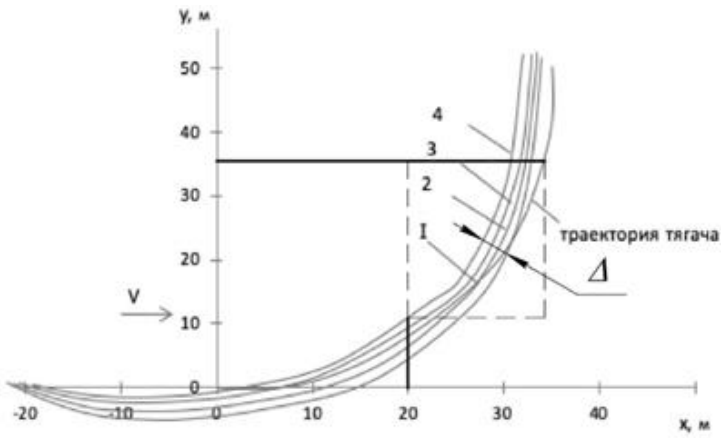


Figure 3 - Trajectories of a tractor and a semitrailer with a base $L_п$ = 25 m of a three-link (with the base of an intermediate bogie $L_т$) road train at different values of the gear ratio *i* when turning 90 ° with a radius of R = 35 m

Based on the calculations carried out in Figures 4 (road train of two links) and 5 (three links), the dependences of the change in the trajectory of the semitrailers with respect to the module of the gear ratio of the $|i|$ system controlling the rotation of the wheels for different values of the bases of the semitrailers $L_п$ were constructed.

There is a dependence of the displacement at the entrance to the turn on the size of the modulus of the relative ratio $|i|$, and this dependence is linear. It is also important to note that the smaller the value of $|i|$|, the smaller the displacement Δ corresponds to it. This is suitable for both a two-link road train and a three-link one.

As an example, we can consider the growth of the modulus of the additional ratio of the $|i|$ steering system of all wheels of a semitrailer, which is included in a three-link road train. From 0.5 to 1 offset, as a result, it increases by about 2 times.

Considering a semi-trailer, two- and three-link road train, it can be seen that the difference in displacements at the entrance to the turn equal to 90 ° is only quantitative. The displacement of a three-link semitrailer is greater than that of an identical two-link one, having an equal value of the base $L_п$ and the modulus of the gear ratio $|i|$

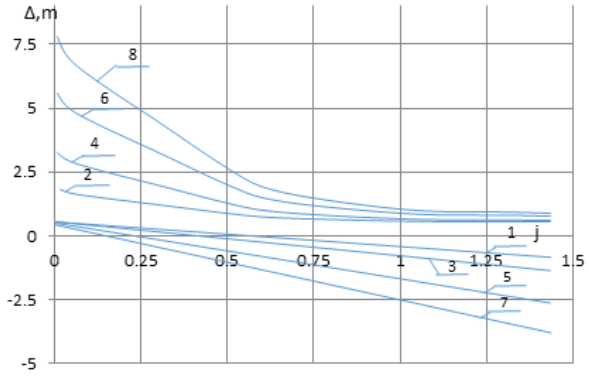


Figure 4 - Displacements of the trajectories of the semitrailer of a two-link road train from the trajectory of the reference point when turning 90°

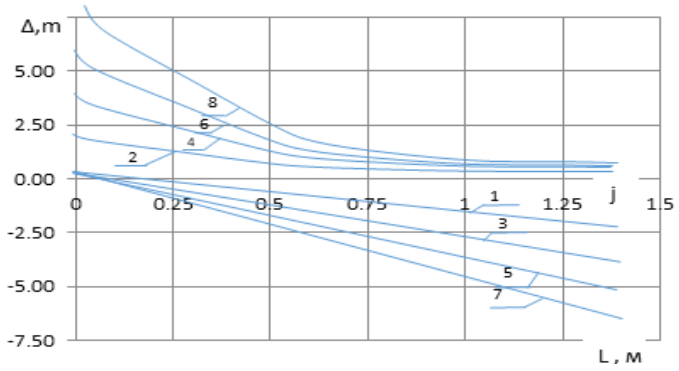


Figure 5 - Displacements of the trajectories of the semitrailer of a three-link road train from the trajectory of the reference point, depending on the gear ratio i and the base of the semitrailer $L_п$ when turning 90 °

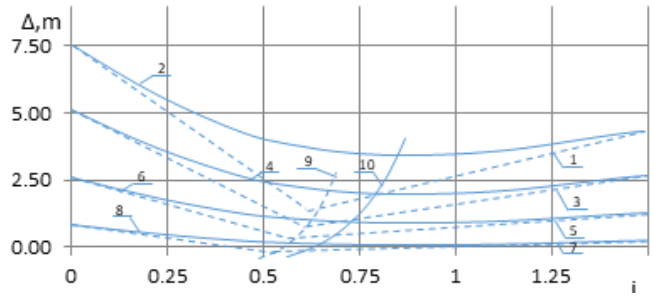
As shown in Figures 4 and 5, the situation when exiting a 90 ° turn is the opposite of what we see when entering. In this case, the larger the value of $|i|$ becomes, the smaller the displacements become, in accordance with the law, which is close to the hyperbolic one. At the same time, different from entering a turn, when the semitrailer "runs" to the outside of the trajectory of the tractor, the exit from the turn causes a shift inward (tending to the center), relative to the trajectory of the tractor, respectively.

The maximum amount of displacement at the exit from the turn can be observed if $i = 0$ (wheels not performing the turn) of the semitrailer. Identically with the case of entering a turn, the displacement of a semitrailer of a road train consisting of three links in number exceeds the cases of the same two-link [10] [11].

It should be noted that from 0 to a specific value of the gear ratio $|i_{min90°}|$ corner exit offsets are more important than corner entry.

Having $i = i_{min}$ offset, it can be argued that the input and output values will be the same. However, if $i > i_{min90°}$ the offset when entering the turn exceeds the value when leaving.

Figures 6 and 7 show the curves of the maximum displacement values of the trajectories of semi-trailers and road trains from two and three links. These curves are plotted as follows. From 0 to $i_{min90°}$, the displacements at the exit from the turn are taken as a sample of the maximum, and when $i > i_{min90°}$, the absolute values are used at the exit.



6 - Maximum displacement of the trajectories of the semi-trailer of a two-link road train when turning 90° (with a radius of R = 35 m)

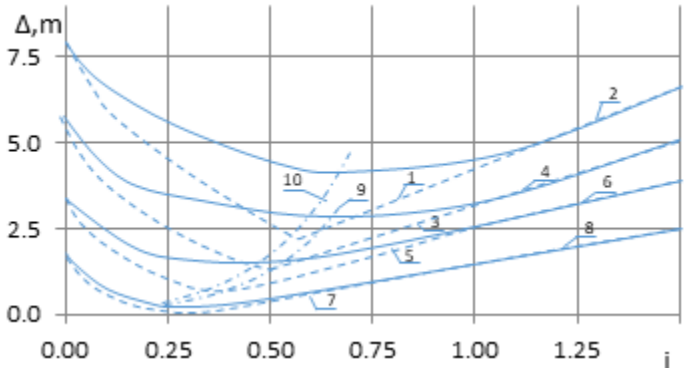


Figure 7 - Maximum displacement of the trajectories of a three-link semi-trailer (with an intermediate bogie $L_т$) of a road train when turning 90° (with a radius of R = 35 m)

DISCUSSION

Based on the maximum values of the curves with the displacement of the trajectory of the semi-trailers of the road train of two links, when turning equal to 90°, the nomogram was constructed in Figure 8. It allows to determine the magnitude of the modulus of the gear ratio of the $|i|$ system of turning the wheels of the semi-trailer and proportional displacements of the trajectories Δ_{90}, having a given value at $L_п$.

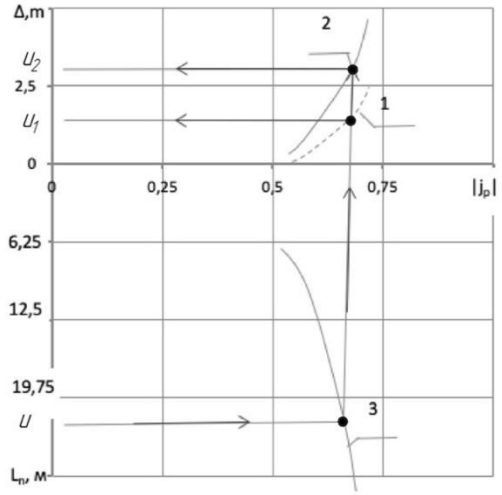


Figure 8 - Nomogram for determining the value of the gear ratio *i* of a two-link road train and displacement of the trajectory at a given value of the base $L_п$

It can be seen that points with coordinates $\{i_{min90};\ \Delta_{min90}\}$ where the relative ratios of the semitrailer wheel steering system allow minimizing the displacement value when turning 90°.

However, it is necessary to define a certain gear ratio that allows the unit to have displacements, even if greater than the minimum, but not very far from it. In this case, the optimal value of i in the interval$\{i_{min90};\ i_{minS}\}$, which provides an increase in the displacement value when making turns by 90°.

The value $L_п$, which was found, allows to ensure the minimum width of the roadbed, which is required by the road train while driving along curved sections of the road [12]. A similar nomogram for a three-link train is shown in Figure 9

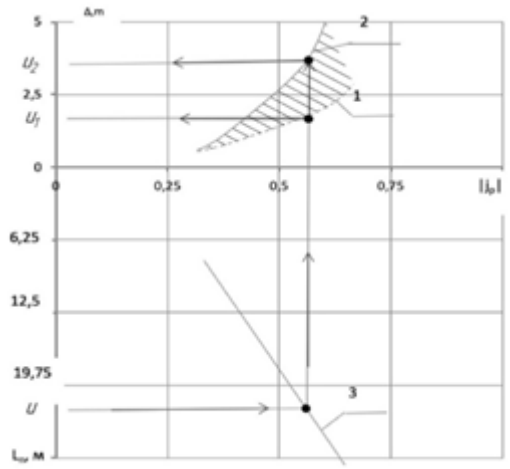


Figure 9 - Nomogram for determining the value of the gear ratio *i* of a three-link semi-trailer (base of the intermediate bogie $L_т$) of the road train and the displacement of the trajectory Δ at a given value of the base $L_п$

A similar pattern can be observed in relation to a three-link road train, the difference will consist only in the value of the displacement of the three-link when turning by 90°, it decreases by 30–35% (with a value of 60–65% for a two-link) [13].

For all studied cases, the gear ratio of the semitrailer ranged from –0.15 to –0.8.

Figure 11 shows the displacement of the trajectory of the semitrailer, corresponding to two values of the gear ratio: $i = -0{,}76$ is the calculated value, which is determined based on the conditions of movement in a circle of all the links of the road train, relative to the circle R = 35 m and $i = -0{,}595$ is the value is determined based on the nomogram shown in Figure 13. Figure 10 also shows the displacement of the trajectory of the tractor, depending on the magnitude of the modulus of the gear ratio $|i|$ and radius on different segments.

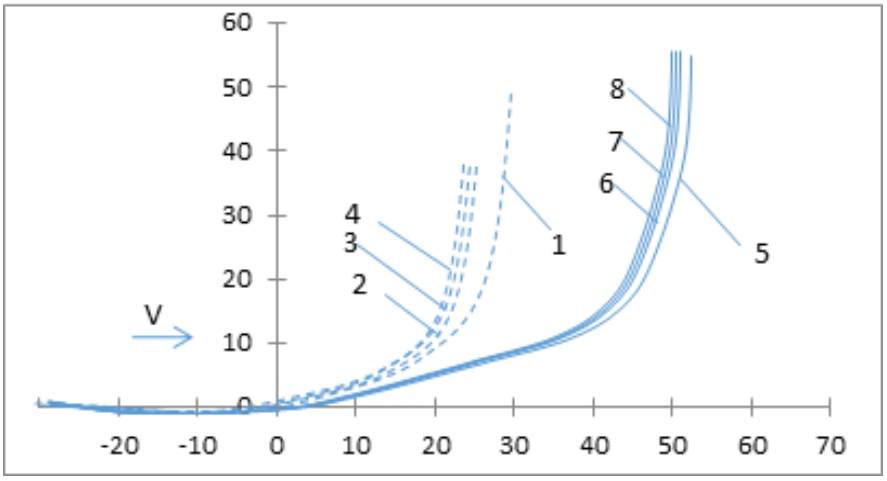


Figure 10 - Trajectories of a tractor and a semitrailer with a base $L_п = 25$ m of a three-link road train (with a base of an intermediate bogie $L_т$) with different values of gear ratios i when turning at different values of gear ratios i when turning 90°

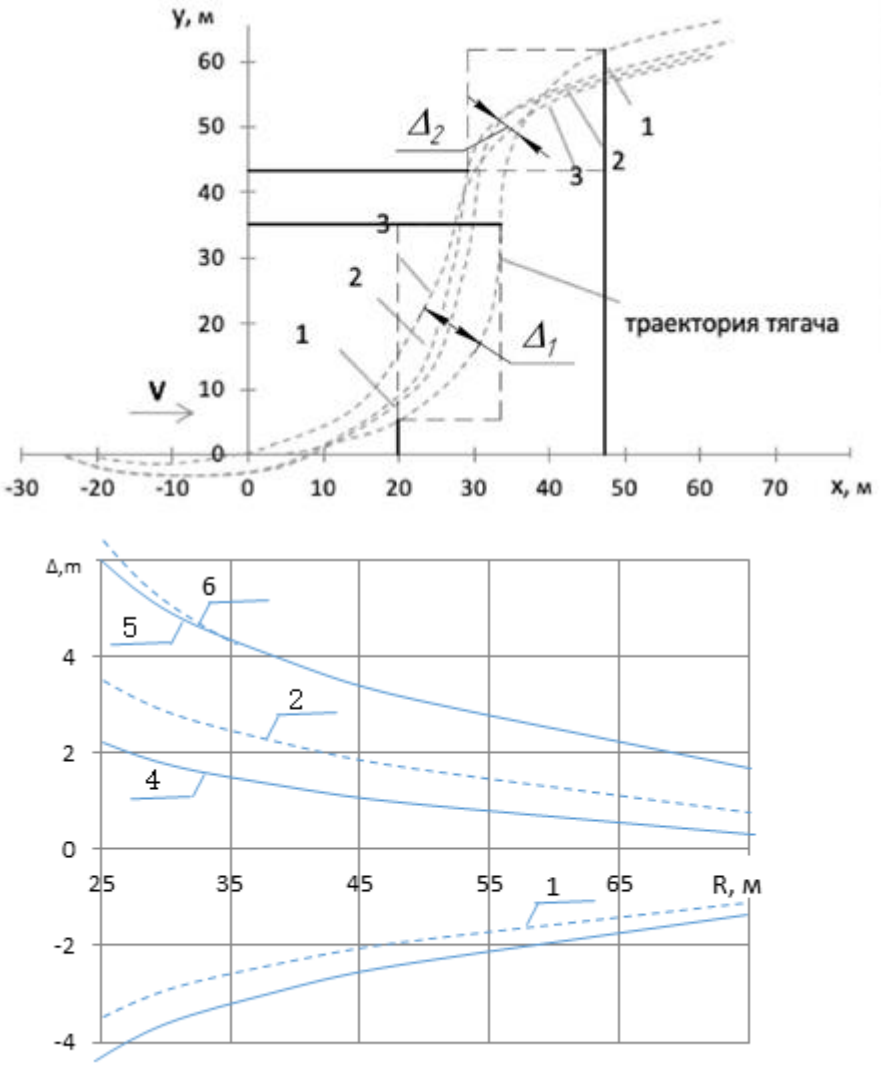


Figure 11 - Displacement of the trajectory of a semi-trailer (with a base $L_п = 25$ m) of a three-link (with a base of an intermediate bogie $L_т$) road train, depending on the turning radius R and the gear ratio i at different sections of turns by 90 °

Figure 11 shows that when entering a turn equal to 90°, as well as an S-shaped turn, the displacement of the semi-trailer with $i_р$ will have a smaller value than with i by approximately 30%. When exiting a 90 ° turn, a different picture can be observed. The displacements of the semi-trailer with $i_р$ exceed the same, but with i, by about 50-60%. However, this does not affect the required expansion of the roadbed, since the broadening is due to the maximum displacement values. The displacement of the semi-trailer with $i_р$, when entering a turn on the entire segment of the studied radii values, exceed in absolute value the corresponding ones when exiting a turn [14].

RESULT

The obtained result is based on the study of the final data and is presented in a block diagram format. (fig. 12)

The study begins by organizing the initial data. This stage is characterized by the collection of basic information about the object of use, this includes: the functions of the object, the scope of its use, topological characteristics of the situation, and so on.

After that, the process of preliminary assessment of the possibility of using the method begins. During this stage, the information found should be processed and the possibility of applying the chosen method should be studied. A positive analysis result is considered if there is a set of results that meets the requirements of the technical task. If the method cannot be used, another way to get the result must be found.

If the result is positive, the order of the processes should be passed. Let's consider more specifically:

Decomposition of cargo transportation methods is a process that is mandatory for finding the hierarchical level to which the method is applied.

The process of creating models and geometric appearance of loads, which allows to find the common mandatory geometric parameters of loads that cannot be separated [15].

The creation of models of the geometric parameters of the trajectory and the search for the minimum displacement value allows finding the properties of the infrastructure boundaries of the transportation area and identifying the critical segments of the route.

The process of creating dependencies for finding best practices is necessary to establish mathematical and geometric relationships between the results of previous processes [16].

When performing all actions, it is possible to obtain practical recommendations on the use of the work results

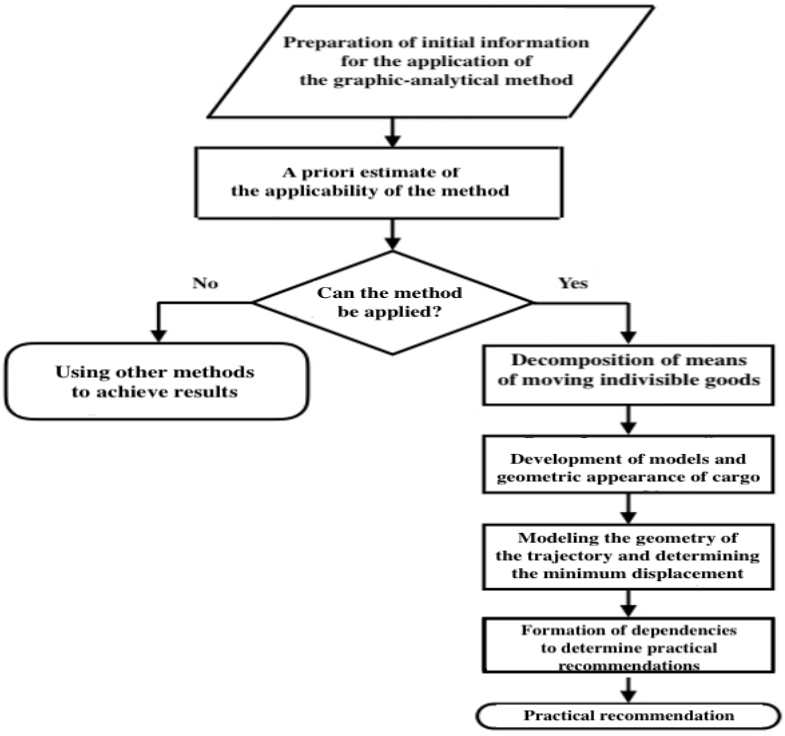


Figure 12 - Block diagram of the analytical method for determining the dependence.

CONCLUSIONS

Considering the graphical and analytical parts of the method, it can be seen that each road train having a certain base of the semitrailer has such a gear ratio i, which ensures optimal displacement of the trajectory of the semitrailer, taking into account 90° turns.

The displacement of the trajectory of semitrailers with a gear ratio, selected on the basis of nomograms, when making a turn equal to 90°, is less by 60-65% and 30-35% for a two-link and three-link, having an intermediate bogie base $L_{тел}$, respectively.

The maximum value of the displacement of the trajectory of the links with the gear ratios of the semitrailer wheel steering system, which was selected based on the nomogram, is less than them, with the gear ratios selected from the circular motion, if the radii R> 35 m.

Considering a road train of two links, the choice of the size of the additional ratio *i* from the condition of movement in a circle of all links of the road train relative to one turning center, these displacements would be 2.8 m, 3.6 m, respectively. Based on this, the optimal choice of the gear ratio makes it possible to reduce the level of displacement when turning 90° by almost 60-65%.

In addition, the knowledge that i_p has a smaller value than i, selected from the condition of driving in a circle, allows you to reduce the steering angle of the steered wheels. All this leads to a lighter wheel travel design and makes production cheaper.

Further work on the method can make it possible to represent it in the form of some simple parametric dependencies and can be incorporated into the basic training course [17]. Confirmation of the methodology is in the process of approbation [18] and confirmation with the help of mock-ups made using additive technologies [19].

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