Alternative method for evaluation of vehicle static transverse stability

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Abstract. Methods of testing vehicles for static lateral stability are considered. The object of the study is service of vehicles (trucks and specialized equipment) which have undergone the conversion. Subject of research is the procedure for testing vehicles for static lateral stability and the resulting errors. This article discusses the original method of testing vehicles for static lateral stability, eliminating the need for a stand with a tilt table and ensuring the equivalence of measurement to the method regulated by GOST 31507-2012. The authors proposed a method for testing a vehicle (RF Patent No. 2693140, published on July 1, 2019), which provides its placing on a horizontal supporting surface, creating a tipping moment relative to the longitudinal axis of the vehicle and brining the vehicle to an unstable position by means of a lifting device with a cargo system slings and safety ropes. In this position, the roll angle $\phi$ of the sprung masses is measured, the height of the center of mass $h$ is determined; the angle $\alpha_{sy}$ of the static lateral rollover stability of the vehicle is calculated. It is shown that the developed test method will be equivalent to the method regulated by GOST 31507-2012.

1. The relevance of the problem
The rolling stock of commercial enterprises, as well as private automobile transport time and again undergoes changes in design. All these changes are aimed at changing certain vehicle parameters. Most of the changes in the design of road freight and passenger transport relate to the replacement of superstructures with a large number of variations, both in terms of their performance and weight and size parameters. By the large the structural and design changes undergo such vehicle systems as transmission, suspension, power trains. Despite the fact that changes in the design of the vehicle are made to improve its functional, operational, economic and other indicators, the conversion process can take a serious toll on the safety parameters of vehicles by changing the technical characteristics of the vehicle due to possible changes in weight and size parameters, load distribution, changes in the coordinates of the center of gravity. Considering that a need arises to assess the compliance of converted vehicles with the applicable safety requirements, specifically in terms of steerability and stability.

2. Analysis of regulatory documents
Regulatory documents have been developed and applied worldwide at the legislative level, establishing the requirements for vehicle safety parameters, in particular, for the vehicle steerability and stability and procedures for evaluating these qualities. Thus, in the United States of America these requirements were formulated by the Society of Automotive Engineers (SAE) in the J2180 [1] standard, and in Europe by UN Regulation No. 111 [2]. In Russia, the technical requirements for the rollover stability of vehicles are described in the technical regulations of the Customs Union TR CU 018/2011 [3], and the test method for static lateral rollover stability is formulated in GOST 31507-2012 [4].

The UN Regulation No. 111 reflects the classical procedure for testing static lateral stability, which consists in using a tilt table with a rollover platform. These rules establish stringent requirements regarding the lateral static stability for tankers of categories N2, N3, O3, O4 intended for the transport of dangerous goods.

GOST 31507-2012 regulates the method of using the table with a rigid platform, the dimensions of which will allow to fully accommodate the vehicle. GOST 31507-2012 applies to vehicles of the categories MG, N and O, respectively, the dimensions of the stand must meet the maximum dimensions of the vehicle.

The SAE J2180 standard applies to heavy tonnage vehicles. The test procedure allows the option of using a table with a rigid platform aligning with the dimensions of the vehicle, as well as the option of using several small platforms that are placed only under the axles of the car. The tilt of the vehicle is performed synchronously. This reduces the metal consumption of the design of the test table.

All three reviewed regulatory documents provide for the use of a table with a rollover platform, the design of which should ensure full-fledged testing. Tables with a tilt platform are not widespread due to the inconvenience of use, high cost and their cumbersomeness. There are no alternative methods for determining the angle of the static lateral stability of the vehicles available for effective use. Furthermore, this parameter is not determined during technical inspections of vehicles. All these issues determine the urgency of the problem of evaluating the stability of in-service vehicles with changes in the design.

3. Overview of technical solutions

As a result of a review of technical solutions for tilt tables, structures were found, which represent a platform for placing a test vehicle that tilts about its longitudinal axis by rolling over the platform, or by lifting one side of the car relative to the other one.

In terms of simplicity of execution, the tilting platform of the Testing Center LLC (Chelyabinsk) is of interest [11]. This model includes a metal platform freely lying on a horizontal plane that can be tilted to the required angle, access ramps for the vehicle, brackets with eyelets for a cable and brackets with chains to protect a vehicle from rolling over on one side of the platform, as well as supporting bars the other side. The platform is tilted using an automobile hydraulic crane. The advantage of this model is the simplicity in manufacturing; the limitation is that the whole process of testing vehicles for static lateral rollover stability is performed outdoors.

Based on the foregoing, it is possible to identify the following disadvantages of methods based on the use of a tilting platform:

- large overall dimensions and heavy weight of the tilt table;
- high metal consumption and the complexity of the design of the platform and the drive mechanism for its rotation along the longitudinal axis;
- occasional use and, as a consequence, the high operational costs and the long payback period of this equipment.

Thus, there is the problem of implementing a method for determining the parameters of static lateral stability in connection with the unprofitability of applying the regulated method and the absence of valid alternative test method.
In the theory of automobiles [7], there is a solution to the problem of finding the angle of static lateral stability $\alpha_{su}$, namely: the value of the angle of lateral static stability $\alpha_{su}$ of the vehicle is represented as the difference between the maximum limit (excluding suspension springing and tire flexibility) angle of static lateral stability $\alpha$ and the angle of heel of the sprung masses, i.e., $\alpha_{su} = \alpha - \varphi$.

$$\alpha_{su} = \arctg \left(0.5 \cdot b / h \right) - \varphi$$  \hspace{1cm} (1)

where $b$ is the track of the wheels reduced to the cross section of the vehicle in the plane passing through its center of mass, mm;

$h$ is the height of the center of mass above the supporting surface, mm

$\varphi$ is sprung masses roll angle.

The value of the height of the center of mass $h$ is calculated experimentally by the known method described in UN Regulation No. 111 [2], and value of roll angle $\varphi$ is determined experimentally.

4. Analysis of the prototype

The closest technical solution to the one being developed is a vehicle test method [6], which includes placing the test vehicle on a supporting horizontal surface, creating a roll couple that occurs when the raised side of the test car is lifted until the corresponding wheels get away from the supporting horizontal surface, measuring the roll angle $\varphi$ of the test vehicle in the get-off position of the corresponding wheels of its lifting side from the horizontal support surface and determining its angle $\alpha_{su}$ static shear stability (to the formula 1) with the measured roll angle $\varphi$ of the test vehicle.

![Figure 1. Scheme of implementation of the proposed method: 1 - supporting horizontal surface; 2 – roll bar; 3 - winch; 4 - cable; 5 - roulette; 6 - test vehicle.](image)

5. The disadvantages of the prototype

It should be noted that when implementing the above method at the time of the wheels get off the surface on one side of the test vehicle, only the part of the mass of the test vehicle falls on the rollover side, since the other part of the mass of the car falls on the load device in the form of a jack creating a roll couple, whereas when testing a car on a tilt table according to the procedure regulated by GOST 31507-2012, at the time the wheels get off the surface, the entire mass of the car falls on the rollover side.

As a result of this, as the disadvantage of the above method may be considered a high measurement error of the sprung mass roll angle $\varphi$ of the test vehicle compared to the measurement error of the said angle, regulated by GOST 31507-2012, and, as a result, the low accuracy of determining the angle $\alpha_{cy}$ of the static lateral stability of the test vehicle. In other words, the equivalence of the above method to the method regulated by GOST 31507-2012 has not been proved.

The UN regulations governing vehicle testing methods stipulate the possibility of using alternative test procedures, but also highlight that these procedures should be equivalent to the regulated methods. However, the UN regulations do not specify how to prove the equivalence of an alternative method to the regulated one and who should do it and by what criteria the equivalence should be evaluated.

Therefore, let’s formulate the concept of the equivalence of the method as applied to vehicle lateral stability tests:
• the loading scheme of the vehicle in the alternative method should be identical to that of the regulated method;
• the loads attributable to the suspension elements in both methods, a regulated and alternative, should be identical.

Only when these conditions are met can it be expected that the determined lateral stability parameters determined by these methods will have the closest possible values. Having analyzed the method [5] for compliance with the above equivalence requirements, we can state that it does not fully comply with them, and, therefore, its equivalence to the regulated GOST 31507-2012 has not been proved.

6. Problem setting and solving
The objective was to develop a method of testing the car for static lateral stability without using a tilt table, equivalent to the method according to GOST 31507-2012. Namely, the loading scheme and static loads acting on the suspension and tires of the vehicle when using the developed alternative method should be the same as on the tilt table provided by GOST 31507-2012, and should provide an error in measuring sprung mass roll angle \( \phi \) of the test vehicle not worse than the measurement error of the mentioned angle, regulated by GOST 31507-2012.

The problem set is solved in that in the method of testing the vehicle for stability, including placing the test vehicle on a supporting horizontal surface, creating a roll couple relative to the longitudinal axis of the test vehicle until the wheels of one side get off the supporting horizontal surface by applying force to the sprung part of the test vehicle perpendicularly its longitudinal axis in a plane passing through the geometric center of mass, measurement of the sprung mass roll angle \( \phi \) of the test vehicle in the position of the wheels getting off on one of its sides from the supporting horizontal surface and determining the angle \( \alpha_{cy} \) its static transverse, taking into account the measured sprung mass roll angle \( \phi \) of the test vehicle, according to the proposed solution, the wheels of one of the sides of the test vehicle are installed on a stationary plate of the dolly lift, and the wheels of its opposite side - on the corresponding platform scales are installed on the dolly-type trolley, which is equipped with a vehicle a hoist, to create a rollover moment relative to the longitudinal axis of the test car a car hoist is used which kinematically connected by means of at least two load-lifting lines to the sprung part of the test car, to prevent uncontrolled rollover of the test car and spontaneous rolling due to the inertia of the dolly-type platform, a safety system consisting of at least four safety ropes pulled through appropriate safety blocks, the test vehicle is lifted on one side to the position close to unstable equilibrium, in which the mass of the test vehicle is measured on the scales of the dolly-type trolley, in this position of the test car close to unstable equilibrium, the measure sprung mass roll angle \( \phi \) is measured, than taking into account the measured value of the sprung mass roll angle \( \phi \), the angle \( \alpha_{cy} \) of its static transverse is determined.

In one particular case, the implementation of the method a two-legged car hoist is used.

Also in this particular case of the method under consideration, the corresponding ends of at least two load-lifting slings are pulled under the bottom of the test vehicle and, accordingly, by grasping the suspension elements of the corresponding wheels of the opposite side of the test vehicle on the corresponding platform scales of the dolly-type trolley, are tightened to the ends of the corresponding fastening lugs of one of the racks two-legged car hoist from the stationary plate.

In addition, in this particular case of implementing the method in question to prevent uncontrolled rollover of the car, at least two safety ropes are pulled from the corresponding fastening lugs of one of the racks of a two-legged car hoist through the appropriate safety blocks and are fastened to the corresponding wheels of one side of the test car, and to prevent spontaneous inertia dolly-type trolley at least another two safety ropes are pulled from the fastening lugs of the other leg of the two-legged car hoist via respective blocks and are fixed on the lateral side of the dolly-type platform.

An advantage of the proposed method is no need to use large and technically complex stands with a tilt table when testing the car for static lateral rollover stability, which therefore, makes the method more cost effective.
In the proposed method, the use of a car lift kinematically connected by means of at least two load-lifting lines with a sprung part of the test vehicle to lift the wheels of one side of it from a fixed platform and create a rollover moment relative to the longitudinal axis of the test vehicle, as well as the use of a safety system to prevent uncontrolled rollover of the test vehicle and spontaneous rolling by inertia of the dolly-type trolley is the position of the test vehicle, close to unstable equilibrium, in which the weight of the test vehicle, close to its total mass, falls on the corresponding platform scales. In this position of the test vehicle, close to unstable equilibrium, a higher accuracy of measuring the sprung masses roll angle $\phi$ is provided than in the method presented in figure 3 [6].

**Figure 2.** Method of vehicle rollover stability: 1, 2 – Hoist leg; 3, 3, 4, 4 – Hoist lugs; 5, 5, 5, 5, 12, 12, 12, 12 – blocks of the safety system; 6 – Stationary plate; 7 – Dolly-type trolley; 8 – Test vehicle; 9, 9, 10, 10 – Safety ropes; 11, 11 – Sling; 13, 13 – Rail.
Figure 3. A scheme of the second special case of the proposed method of testing the vehicle for rollover stability (front view).

This is achieved by the fact that when using the proposed method, at the time of measurement, the entire mass of the car falls on one side of the vehicle, and, therefore, the deformation of the suspension and tires will be the same as when using the method regulated by GOST 31507-2012, which proves the equivalence of the method proposed to the method regulated by GOST 31507-2012.

7. Conclusion
An alternative method for testing vehicles for static lateral rollover stability has been developed.

The method shall not require using a tilt table. All it takes is the components necessary for the implementation of the proposed method. This allows all-purpose use of a car hoist both for its intended purpose and during testing, which benefits to its cost-effectiveness.

The developed method is equivalent to the method regulated by GOST 31507-2012, since when it is implemented in the suspension elements of the car and the chassis, the loads applied are similar to the loads applied according to GOST testing requirements.

The developed method allows determining the angle of static lateral stability and sprung mass roll angle with the accuracy regulated by GOST 31507-2012.

The application of this method is possible for the in-service vehicles, which facilitates the assessment of the conformity of the conversions made to the original design of the vehicles and secure their safety.

The Patent of the Russian Federation No. 2693140 dated July 1, 2019 [8] was obtained for the developed test method.

References
[1] SAE J2180 - A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks - SAE International surface vehicle recommended practice, 2011
[2] UN Regulation No. 111 - Uniform provisions concerning the approval of tanks of categories N and O with regard to their rollover stability, 2000
[3] Technical Regulation of the Customs Union TR CU 018/2011 - On the safety of wheeled vehicles, 2013 p 465
[4] GOST 31507-2012 Motor vehicles steerability and stability, Technical requirements test methods (Moscow: Standartinform)
[5] Boyarkin S V et al 2012 Development of a method for assessing the static lateral rollover stability of vehicles equivalent to GOST 31507-2012 CAR FOR SIBERIA AND THE FAR NORTH. DESIGN, OPERATION, ECONOMY: Proceedings of the 90th International scientific conference. (Irkutsk, April 9-10, 2015) p 482

[6] Blyankinshtein I M, Boyarkin S V et al 2016 Patent 2573028 Russian Federation Vehicle test method (options) Rosstandart 2 11

[7] Grishkevich A I 1986 Cars (Ministry of Higher School)

[8] Blyankinshtein I M, Boyarkin S V et al 2019 Patent 2693140 of the Russian Federation The method of testing the car for rollover stability Rosstandart 19 2