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Modified Method for Estimating the Static Lateral Stability of Vehicles as Amended by the Design Changes

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Abstract

Testing methods for vehicles for static lateral stability are considered. The objects of research are vehicles (trucks and specialized vehicles) that are in operation and have undergone the amendment process. The subject of research is the motor vehicle testing procedure for static lateral stability and errors arising therefore. The aim is to provide a method for testing the vehicle for static lateral stability eliminating the need for applying a bench with a tipping platform and providing equivalent measurement to the method regulated by GOST 31507-2012.

The authors propose an original way to test vehicle [Blyankinshtein (2016)] that includes placing the vehicle on the supporting horizontal surface, creating a tilting moment relative to the longitudinal axis of the vehicle until the wheels on one side are detached from the bearing horizontal surface with force attached to the sprung portion of the vehicle perpendicular to its longitudinal axis in a plane passing through the geometric center of mass, and the lean angle φ of the sprung mass is measured, the height of the center of mass h is determined, the static lateral stability angle αcy of the vehicle is calculated. The results of primary testing method are given, variants of application of the tilting moment and the determining the lean angle of the sprung mass are considered.

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Keywords: Testing method, motor vehicle amendments, assessment of compliance with safety requirements, static lateral stability.

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1. Main text

Transport support of the emerging industries of Siberia and the Far North (oil and gas, timber, mining, metallurgy, etc.) is based on road transport, most of which is carried out in the winter time via the temporary roads (winter roads). In the off-season and during summer the rolling stock is left on the "mainland", amended and used on public roads, if necessary. Most of the amendments of commercial vehicles consist in the replacement of superstructures with a lot of variation, both for the functional purpose, and for weight and size parameters. Due to the remoteness of the service depots from motor vehicle manufacturers, these works are carried out at the regional specialized maintenance and repair stations, where the experts perform all basic technological operations to change the design of the vehicle.

Although the goal of the amendment is to improve functional, operational, economic and other characteristics of the vehicle, the amendment process inevitably affects the motor vehicle safety settings. It can be argued that almost half of the changes made to the motor vehicle design can significantly affect the handling characteristics and stability. This makes it urgent to assess the conformity of design of the amended motor vehicles to the established safety requirements in terms of handling and stability.

In the world practice, regulations establishing requirements for handling and stability of vehicles and procedures for evaluating these properties have been developed and applied at the legislative level. For example, in the United States, the Society of Automotive Engineers (SAE) formulated these requirements in the standard J2180 [SAE International Surface Vehicle recommended practice (2011)]. In Europe there is the UNECE Regulation No. 111 [UNECE (2000)], which is also applied in our country. In Russia, the technical requirements for the stability of vehicles are set out in the technical regulations of the Customs Union 018/2011 [Customs Union Commission (2011)], and the testing method for static lateral stability is given in GOST 31507-2012 [Standartinform (2013)].

UNECE Regulation No.111 displays classical testing procedures for static lateral stability with the use of the test bench with a tipping platform, they apply only to tank vehicles of category N_2, N_3, O_3 and O_4 intended for the transport of dangerous cargo and establish strict requirements for static stability.

GOST 31507-2012 also implies that during the testing the test bench with a rigid platform should be used, the dimensions of which allow to fully accommodate a vehicle, the standard applies to motor vehicles of category M, N and O (regarding the M_1 category - only for vehicles of category G), so the dimensions of the test bench must comply with the maximum dimensions of the motor vehicles under testing.

SAE J2180 covers heavy-duty motor vehicles, it has a more flexible procedure of testing, in particular, the option of using a test bench with a rigid platform (in the size of the car), as well as the option of using several small platforms that are placed just under the vehicle axes and synchronously perform leaning of a motor vehicle, thus reducing the design metal consumption.

All three of the above regulatory documents provide the use of a test bench with a tipping platform, the design of which must be either solid and conform to the dimensions of the vehicle, or to ensure a smooth synchronous tipping of axes of the vehicle at a predetermined angular velocity in the range of 0.25º/s to 0.5º/s. All the attention in the regulations is paid to safety issues, configuring hardware adjustment and debugging - the test bench design must provide the use of stops to prevent the vehicle from slipping during tipping, as well as of safety devices that prevent full tipping of motor vehicle.

In the context of motor vehicle use, as a rule, there are no benches and alternative methods to determine the angle of the static lateral stability. In addition, this parameter is not determined during technical inspections of motor vehicles. These circumstances are explained by the shortcomings of existing methods, involving the use of tipping benches to lean motor vehicles to the angle, at which there is detachment of wheels on one side from the bearing surface. These shortcomings include:

- Large dimensions and weight of the test bench;
- Metal consumption and complexity of the design of both the tipping platform and its drive mechanism of its longitudinal axis rotation;
- Occasional use and, as a result, high operating costs and long payback period.

Thus, the current method of experimental assessment of the motor vehicle static lateral stability cannot be implemented in the absence of the test bench with a tipping platform, and if the bench is available, is characterized by complexity and high cost of testing.

The authors have developed an alternative method of experimental and computational assessment of parameters of the vehicle stability (the angle of static lateral stability and lean angle of the sprung mass) [Boyarkin and Blyankinshtein (2015)], which feature elements of singularity (RF Patent No. 2573028, IPC G01M 17/04, B66F 7/22, 01.20.2016).

We used a motor vehicle lean diagram (Fig. 1) standing on a slope with an angle α with regard to the deformation of the elastic suspension elements and the radial deformation of tires for developing theoretical prerequisites of the alternative method.

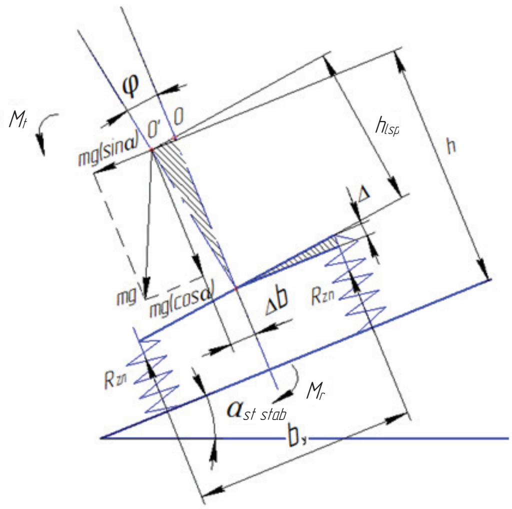

Fig. 1. Diagram of lateral tilt of motor vehicle in the presence of elastic elements.

Tilting moment has a value determined by the formula (1), and the part of the restoring moment is played by the moment of elasticity of the motor vehicle sprung mass in the unstable "neutral" equilibrium, formula (2).

$$M_t = G_{spr} \cdot sin(\alpha) \cdot h_{lspr} \quad (1)$$

where, G_{spr} is mass of sprung portion of motor vehicle
h_{lspr} is lean arm of sprung mass

$$M_{el} = C_{\sum el} \cdot \Delta_{el} \cdot b_y \quad (2)$$

where, $C_{\sum el}$ is total rigidity of elastic elements;
Δ_{el} is deformation of elastic elements;
b_y is spring base.

From the equation $M_t = M_{spr}$ the lean arm of sprung mass is determined.

$$h_{lspr} = C_{\sum el} \cdot \Delta_{el} \cdot b_y / G_{spr} \cdot sin(\alpha) \quad (3)$$

The equations of vertical reactions for the right and left sides, respectively, will have the form (4) and (5).

$$Z_l = G_a \cdot cos(\alpha) \cdot (0{,}5 + tg\varphi / tg(\alpha_{max})) + C_{\sum el} \cdot \Delta_{el} \quad (4)$$

where, φ is lean arm of sprung mass.

$$Z_r = G_a \cdot cos(\alpha) \cdot (0,5 - \Delta b / b) \tag{5}$$

where, b is vehicle track;
Δb is center of mass displacement value, formula (6).

$$\Delta b = h_{lspr} \cdot tg(\varphi) \tag{6}$$

The final version of the equation of distribution of vertical responses for the right side of motor vehicle, resulting from a joint solution of equations (5) and (6) and the equation (3) will have the following form:

$$Z_r = G_a \cdot cos(\alpha) \cdot (0,5 - h_{lspr} \cdot tg(\varphi) / b) \tag{7}$$

$$Z_r = G_a \cdot cos(\alpha) \cdot \left(\left(0,5 - \left[\left(C_{\sum el} \cdot \Delta_{el} \cdot b_y / G_{spr} \cdot sin(\alpha) \right) \cdot tg(\varphi) \right] / b \right) \right) \tag{8}$$

At the start of tipping the motor vehicle the right response Z_{spr} is zero. This condition can be used for determining the angle α based on formula (8).

Alternative testing method is based on application of an external tilting moment to the sprung portion of motor vehicle, located on a horizontal supporting surface. Let us consider the experimental layout of leaning the motor vehicle standing on a horizontal plane (Fig. 2), with deformation of the elastic elements in the suspension and the tire radial deformation caused by application of lateral force F to the truck body at least prior to the detachment of right side wheels from the bearing surface.

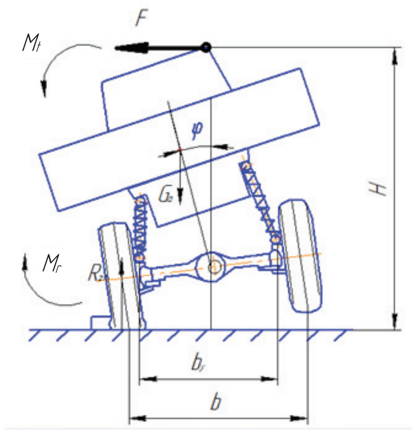

Fig. 2. Diagram of motor vehicle located on horizontal plane with application of lateral force F.

Tilting moment M_t and restoring moment M_r are determined by the following formulas:

$$M_t = F \cdot H \tag{9}$$

where, F is lateral force;
H is arm of force F application.

$$M_r = F_{\sum el} \cdot b \tag{10}$$

where, $F_{\sum el}$ is the elastic force of the elastic suspension elements, determined by the formula:

$$F_{\sum el} = F \cdot H / b \tag{11}$$

$$F_{\sum el} = C_{\sum el} \cdot \Delta_{el} \tag{12}$$

Let us consider the equation of vertical reaction of the right side of the motor vehicle $Z_п$ in a position of detachment of the right side wheels from the bearing surface at the time of the unstable ("neutral") equilibrium. The equilibrium equation (8) will be zero if its constituents are zero (13)

$$(0.5–[(C_{\sum el}\cdot\Delta_{el}\cdot b_y/G_{spr}\cdot sin(\alpha))\cdot tg(\varphi)]/b) = 0 \tag{13}$$

Solving (13) and (11) together, we obtain the equation for the angle of the static lateral stability of the motor vehicle:

$$sin(\alpha) = \left(F_{\sum el}\cdot b_y / G_{spr}\cdot b\cdot 0,5\right)\cdot tg(\varphi) \tag{14}$$

The proposed method for determining the angle of the static lateral stability of the motor vehicle ($\alpha_{st\ stab}$) on a horizontal bearing surface reduces the number of unknowns to one variable G_{spr} (weight of the sprung part of the motor vehicle), while all other components of the formulas (11), (14) can be easily measured, which creates the possibility of determining the angle of static lateral stability without the use of a bench with a tilting platform.

To solve the problem of finding the angle of static lateral stability $\alpha_{st\ stab}$ the authors considered another variant of the method, based on the application of an external tilting moment to the motor vehicle, standing on horizontal ground and not requiring the use of G_{spr} parameter. The angle of the static lateral stability $\alpha_{st\ stab}$ of the vehicle can be represented as the difference between the maximum limit (without considering elastic suspension and tires) angle of the static lateral stability α [Grishkevich (1986)] and the lean angle of the sprung mass, $\alpha_{st\ stab} = \alpha - \varphi$, which allows to determine the actual $\alpha_{st\ stab}$ value:

$$\alpha_{st-stab} = arctg\cdot(0.5\cdot b/h) - \varphi \tag{15}$$

where, b is wheels track, reduced to the cross-section of the motor vehicle in a plane passing through its center of mass, mm;
h is height of the center of mass above the bearing surface, mm.
φ is lean angle of the sprung mass.

The value of the height of the mass h center is evaluated experimentally according to known methods described in the UNECE Regulations No.66 [UNECE (2006)] and the value of the sprung mass lean angle φ is determined experimentally by application of an external tilting moment to the motor vehicle located on the horizontal bearing surface until the wheels of one of the sides of the motor vehicle are detached.

Possible applications of tilting moment to the motor vehicle located on the horizontal surface until the detachment of wheels on the one side are shown in Fig. 3. A Honda Accord vehicle was loaded with a horizontal tilting force F, produced by a winch and applied to the roof of the body - till the detachment of the wheels on the right side, first the rear axle wheel, then the front wheel. A ZIL 4331 truck was loaded with the tilting moment created by using a garage jack, which was applied to the sprung part of the center of mass of motor vehicle, in a vertical plane perpendicular to the bearing surface till the detachment of the wheels of one side of the motor vehicle.

(a) (b)

(a) – application of horizontal force to honda accord vehicle with winch;
(b) – application of vertical force to ZiL 4331 vehicle with jack

Fig. 3. Diagrams of applying tilting force F to motor vehicle placed on horizontal bearing surface.

To prevent displacement of motor vehicle in the transverse plane, stops were installed under the support wheels of the vehicle.

Measurement of value *φ*, the lean angle of the sprung mass was carried out by changing the heights of symmetrical marks relative to the bearing surface, placed on the body of the tested vehicle in the plane of the front and rear axles (Fig. 4.). The markers' heights are recorded in the motor vehicle initial position on the horizontal support surface and in a position where the vehicle's wheels on the one side are detached from the bearing surface under the impact of the tilting moment.

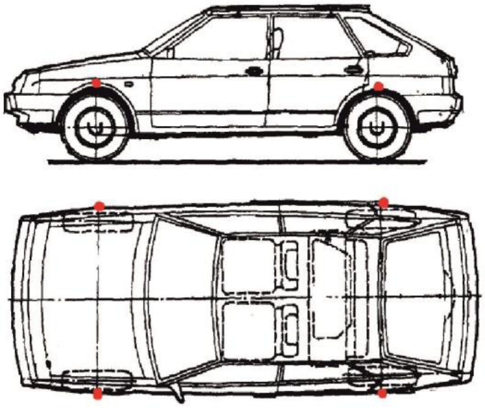

Fig. 4. Position of markers to measure the lean angle of the sprung mass.

They are used to build the line rotation diagram (segment *AB*, Fig. 5), connecting these points, in the moment of detachment of the wheels on one side of the vehicle from the bearing surface. In case of rotation of the body by the force applied to it, the center of rotation of the segment *AB* will also be displaced by a certain amount in the lean direction. The body lean angle φ can be determined from the trigonometric ratios of right-angled triangles A_1A_2M and B_1B_2M:

$$sin\varphi = A_1A_2 / A_1M \; u \; sin\varphi = B_1B_2 / B_1M \qquad (16)$$

Taking the length of the segment A_1M for x and equating the expression (16), we find the desired value (17), and the segment B_1M for $(y - x)$, where y is the distance between the symmetrical markers on the car body

$$A_1A_2 / x = B_1B_2 / A_1B_1 - x$$

$$x = A_1A_2 \cdot A_1B_1 / \; A_1A_2 + B_1B_2 \qquad (17)$$

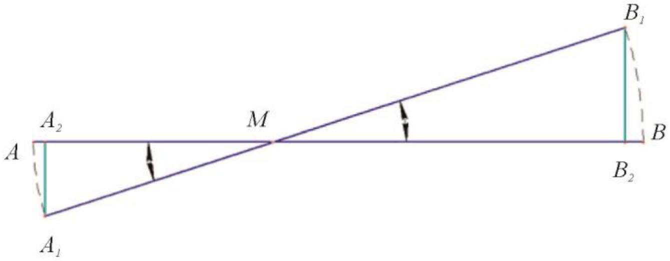

Fig. 5. Diagram of displacement of markers on car body during leaning.

According to the available data, we calculate the lean angle of the car body φ_f in the front part of the body, which included a lean angle of a vehicle as a result of radial deformation of the tire. Similarly, a symmetric marker is recorded in the rear of the body, and the lean angle of the body φ_r in the rear of the motor vehicle is calculated.

The value of the lean angle of the sprung mass during the detachment of the motor vehicle wheels on the left side from the bearing surface, reduced to the center of mass of the motor vehicle is determined by the known formula:

$$\varphi = \varphi_f \cdot l_2 \; + \varphi_r \cdot l_1 / l_1 + l_2 \qquad (18)$$

where, l_1 is the distance from the front axle to the center of mass of motor vehicle; l_2 is the distance from the rear section, in which the lean measurement is carried out, to the center of mass of the motor vehicle.

The final stage of the above lateral stability testing method is the calculation of the critical angle of lateral stability by the formula (15).

The advantage of the developed testing method is the elimination of the need for a bench with a tipping platform. This makes it possible to evaluate the static lateral stability of motor vehicles in remote regions where they are operated and are subject to amendments. This method also provides efficiency, cost reduction and simplification of testing procedures.

The UNECE Regulations and the US standard provide a clause that for the procedure to determine the transverse static stability alternative testing methods may be used, if they provide equivalent data. The considered testing method can be regarded as an alternative methodology for determining the transverse static stability. However, it requires verification via comparative testing.

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