Method of roadholding control of the vehicle of category M1 under operating conditions

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Abstract. The article presents the results of the study aimed at improving the safety of motor vehicles (hereinafter - vehicle) under operating conditions. The estimation of indicators of vehicle stability is made by controlling the parameters characterizing change of the trajectory of the vehicle under the action of a lateral force when crossing a single irregularity. The results of the study are presented in the form of graphs and functional dependences. Using the revealed functional dependences reflecting the effects of the technical condition of the vehicle shock absorbers with the parameters, characterizing the change in its movement trajectory under the action of a lateral force, when crossing a single irregularity, a method for controlling the vehicle road holding of M1 category was devised.

1. Introduction

In modern conditions, the loss of the vehicle roadholding and the deviation of the car from a given direction of movement are most common causes of motor vehicle accidents (MVA). Often, the loss of stability is accompanied by an uncontrolled drift of the rear axle and the rollover of the vehicle. The roadholding of the vehicle is inextricably linked to the contact stability and the characteristics of the lateral adhesion of the wheel tires to the support surface of the road. The stability of the tire contact with the road is ensured by the efficient operation of shock absorbers and suspension elements [1,6].

The development of an effective method, allowing to assess the stability of the vehicles in operation, taking into account the stability of the contact spot and the amount of lateral adhesion of tires to the support surface of the road, is an urgent scientific task, the solution of which will improve the safety of the vehicle during operation.

2. Methods

Currently, testing a vehicle for the stability of motion is governed by the technical requirements and government standard, GOST 31507-2012 [1]. The standard provides for the following types of stability tests, being carried out only on the types of vehicles (chassis), which are in circulation.

- Roll-over test (the angle of static stability and the roll angle of the sprung masses are estimated).
- Steering hitch (the vehicle roadholding is estimated by the dependence of the rotation angle on the steady-state lateral acceleration, the angular overspeed and the time of the 90 % reaction on the angular velocity).
- Turning and Moose (elk) test (the maximum speed of the maneuver is estimated).
- Running (the permissible speed in operating movement modes is estimated).

During the vehicle operation, the technical condition of shock absorbers and suspension components deteriorate. They lose the ability to ensure a stable contact of tires with the road surface, this leads to a decrease in the vehicle roadholding. However, there is still no method of assessing the impact of the technical condition of shock absorbers on the roadholding of the vehicle in operation.

For the development and scientific justification of such technique, a study of the process of category M1 car movement under the centrifugal force action and its crossing a single irregularity with the varying of shock absorbers functional characteristics was conducted.

For this purpose, a mathematical apparatus was developed that describes the movement of vehicle masses in space, as well as the processes of interaction of its elastic tires with the support surface of the road when moving around the circle [1-2-3].

In the adopted model, the dynamics of the body (sprung mass) movement is calculated by six degrees of freedom, and the dynamics of the vehicle unsprung masses movement is calculated along the vertical axis OZ (Figure 1).

![Spatial calculation scheme of the vehicle movement around the circle.](image)

Based on D’Alambert’s principle, the equations of dynamic equilibrium of the sprung mass, as well as the moment equations acting with respect to the axes of the moving coordinates (1) and the equation of dynamic equilibrium (2) of the vehicle unsprung mass during its motion under the action of a lateral force were set up:
The solution of these equations by the Eulerian method of numerical integration allows to calculate the displacement of the sprung and unsprung masses relative to the moving coordinates [2].

The longitudinal and crossover reactions of \( R_x \) and \( R_y \) acting on the wheels of a moving vehicle are determined using the normalized slip function for the unsteady rolling mode of the wheel with an elastic tire (5), (6) [4]:

\[
f(S_{xy}) = \cos \delta_y - \frac{\alpha_{xy} \cdot r_w - k_y}{V_y},
\]

\[
f(S_{yz}) = \sin \left( \alpha \cdot \arctg \left( b \cdot S_c - b \cdot \frac{\dot{y}}{V_y} \right) \right).
\]

The single irregularity impact on the tires at the time of moving is represented by a smoothing function (7) [5]:

\[
a_y = a_0 \cdot \frac{1 - \cos \left( \frac{2 \cdot \pi \cdot t_s}{T} \right)}{2},
\]

The technical state of shock absorbers determines its functional characteristics (Figure 2), which is the dependence of the hydraulic resistance force on the piston stroke speed relative to the working cylinder [6].
The mathematical description of the hydraulic shock absorber functional characteristics is presented as a function of the force $F_D$ of the shock absorber hydraulic resistance from the velocity $V_S$ of its piston displacement. It is developed on the basis of piecewise linear approximation of the graph (Figure 2). For this purpose, the graph was conditionally divided into four sections, each of which was approximated by linear dependencies of the following form (8) [7]:

$$F_D = \begin{cases} F_{D1}(V_S), & V_1 \leq V_S < V_2 \\ F_{D2}(V_S), & V_2 \leq V_S < V_3 \\ F_{D3}(V_S), & V_3 \leq V_S < V_4 \\ F_{D4}(V_S), & V_4 \leq V_S \leq V_5 \end{cases}$$

(8)

The resulting mathematical description was used in the mathematical model of the process under study. The method of studying the vehicle movement under the influence of the centrifugal force with the single irregularity crossing, varying the shock absorbers technical state, allows to identify the influence of the shock absorbers functional characteristics on the stability indicators [8-9-10].

The parameters, allowing to control the vehicle stability during experimental studies, are the rotation angle relative to the axis OZ and the movement of the unsprung masses relative to the sprung ones. To register these parameters, the measuring system of the rotation angle for the aircraft gyro device G-3M (Figure 3a), which converts the vehicle rotation angle relative to its vertical axis to the voltage supplied to the ADC input, was developed. The movement of wheel assemblies relative to the vehicle sprung mass was recorded, using the sensors (Figure 3b), in the form of elastic plates with tensoresistors. The sensor plates are attached to the body and kinematically connected to the suspension.

Figure 3. The measuring system with gyroscopes and strain gauges on a Ford Focus test vehicle.
The vehicle movement mode in the process of its stability controlling implies a continuous action of the lateral force on the vehicle and a single force effect on the wheels from the road, causing vibrations of the sprung and unsprung masses. During the study the technical state of the shock absorbers installed on the test car was varied.

The experimental study was carried out on a flat horizontal section of the asphalt concrete pavement, with the separation of the vehicle acceleration zone, the zone of moving along a circular path of a given radius and the braking zone (Figure 4).

In the center of the rotation area a single obstacle is set, the cross section of which is 50x50 mm, exciting damped oscillations in the suspension.

![Figure 4](image)

*Figure. 4 – The experimental investigation area of the vehicle stability when moving along a circular path and crossing a single obstacle.*

The experimental research was performed on a Ford Focus curb weight vehicle, on a circular path with a radius of 15 m at a speed of 40 kilometers per hour.

3. Results and Discussion

As a result of the experimental study, it was found that, with other conditions being equal, the change in the technical condition of the shock absorbers changes the controlled parameters characterizing the vehicle stability. The suspension system oscillations and their amplitude significantly affect the stability of the tire contact spots with the road and the vehicle stability (Figure 5) [11].

![Figure 5](image)

*Figure 5. The motion of $z_{ul}$ vehicle unsprung masses of the front left (-a) and rear left (-b) wheels of the Ford Focus car along the axis OZ when it moves at an initial speed of $V=40$ kilometers per hour along a circle, $R=15$ m, and crossing a single obstacle of a rectangular profile 50×50mm.*

The continuous action of the centrifugal force on the vehicle causes its deviation from the given trajectory. In this case, its trajectory depends on the technical state of the shock absorbers installed on its front and rear axles (Figure 6).
Figure 6. Graphics: (a) the angle of rotation, (b) the trajectory of the mass center of the Ford Focus car when it moves along a circle with a radius of 15 m at a speed of 40 kilometers per hour, crossing a single irregularity with a profile of 50×50mm, varying the technical condition of the shock absorbers.

During the experimental study, the technical condition of the shock absorbers was evaluated in points: 10 points – serviceable and fully functional technical condition, 1 point - faulty and inoperable technical condition.

The results of experimental and analytical studies of the vehicle stability are shown in Figure 7.

Figure 7. The graph of changing the rotation angle of the Ford Focus sprung mass, when it moves round a circle with a radius of 15 m at a speed of 40 kilometers per hour, crossing a single irregularity with a profile of 50 = 50mm, changing the technical condition of the shock absorbers: 1 – all shock absorbers are serviceable; 2 – front shock absorbers are faulty; 3 – rear shock absorbers are faulty.
The study result analysis allows us to conclude that the change of the shock absorbers technical condition significantly affects the characteristics of the rotation angle change relative to the OZ axis when the vehicle moves under the action of the centrifugal force.

The rate of deviation of the longitudinal axis from the given direction is more informative concerning the change in the vehicle stability, moving under the influence of the lateral force and crossing a single irregularity. It is found that its values are very much dependent on the technical condition of the shock absorbers (Figure 8).

![Figure 8. The graph of the rotation angle change rate of the vehicle sprung mass relative to the axis OZ, when the vehicle moves under the action of lateral forces crossing a single irregularity: (a) due to the change of the shock absorbers technical condition of the front suspension from 1 to 10 points; (b) when the variation of the shock absorbers technical condition of the rear suspension is from 1 to 10 points.](image)

The obtained dependencies integration of the deflection angle rate change of the vehicle longitudinal axis from a given direction allows to determine the front axle deviation angle $\gamma_1$ (9), the rear axle deviation angle $\gamma_2$ (10), when it crosses a single irregularity with the front and rear wheels, as well as find the difference between these angles $\Delta\gamma$ (11):

$$\gamma_1 = \int_{t_1}^{t_2} \omega_1(t)\, dt,$$

$$\gamma_2 = \int_{t_1}^{t_2} \omega_2(t)\, dt,$$

$$\Delta\gamma = |\gamma_1| - |\gamma_2|.$$

where, $\omega_1$ – the deviation angle change rate of the vehicle longitudinal axis from the given direction when the front wheels cross a single irregularity;

$\omega_2$ – the deviation angle change rate of the vehicle longitudinal axis from the given direction when the rear wheels cross a single irregularity.

The normalized values of the obtained diagnostic parameters are proposed as the criteria for assessing the vehicle stability when moving under the action of the lateral force.
Criteria # 1 – the longitudinal axis deviation angle $\gamma_1$, when the front wheels cross a single irregularity;

Criterion # 2 – the longitudinal axis deviation angle $\gamma_2$, when the rear wheels cross a single irregularity;

Criteria # 3 – the longitudinal axis angle deflection difference $\Delta \gamma$, when the vehicle wheels cross a single irregularity (cornering ability assessing).

The results of the study of the longitudinal axis deviation angles and their difference during the vehicle movement under the action of the lateral force and damped oscillation excitation of the unsprung masses, when the technical condition of the shock absorbers is changed, are the dependences that link the technical condition of the shock absorbers of the front and rear suspension with the found diagnostic parameters (Figure 9 and 10).

**Figure 9.** The charts of the technical condition influence of the front shock absorbers on the deflection angles of the longitudinal axis from a given direction, when the vehicle moves under the action of lateral forces and crosses: 1 – a single irregularity $\gamma_1$ by its front wheels; 2 – a single irregularity $\gamma_2$ by its rear wheels; 3 – the longitudinal axis angle deflection difference $\Delta \gamma$.

**Figure 10.** The chart of the technical condition influence of the rear shock absorbers on the deflection angles of the longitudinal axis from a given direction, when the vehicle moves under the action of lateral forces and crosses: 1 – a single irregularity $\gamma_1$ by the front wheels; 2 – a single irregularity $\gamma_2$ by the rear wheels; 3 – the longitudinal axis angle deflection difference $\Delta \gamma$. 
4. Conclusion

The experimental evaluation method of the shock absorbers technical condition impact on the category M1 vehicle stability. The revealed functional dependences reflect the influence of the vehicle shock absorbers technical condition on the parameters characterizing the change of its movement trajectory under the action of the lateral force, when crossing a single irregularity.

The indicators, allowing quantitatively assessing the vehicle roadholding, moving under the influence of the centrifugal force and crossing a single irregularity, can be used as sensitive and informative diagnostic parameters for monitoring the vehicle shock absorbers technical condition both in their operation and in testing new ones.

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