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Using In-Vehicle Monitoring Data to Assess Road Conditions of Traffic Flows

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ABSTRACT

Developments in adaptive systems for maintenance and repair of automotive vehicles set the task of monitoring the conditions of their operation. One of the main factors determining these conditions is the type of road surface.

The article describes the results of identification of the type (and condition) of the road surface obtained by theoretical and experimental methods based on the analysis of vertical accelerations recorded on the vehicle body.

The purpose of research was to provide a possibility of continuous monitoring of the type of road surface on which a vehicle is driving, with the subsequent application of the obtained data to correct maintenance intervals. The results of experiments have shown the dependence of the vertical acceleration of the body on the micro-profile of the road surface. The described experimentally obtained profiles of vertical accelerations refer to different types of road surface in different conditions. For quantitative assessment, it is proposed to calculate the average level of accelerations as an integral average over a certain time interval.

The results of the experiments have allowed to substantiate the empirical dependence of the average level of accelerations on speed of a vehicle. Based on this dependence, a method is proposed for recalculating the current values of the average levels of accelerations obtained at different speeds into values adjusted to the base speed to ensure the possibility of their comparison.

It is shown that based on the values of average acceleration levels obtained through operation monitoring regarding a previously known type of road surface, it is possible to determine its condition. A short algorithm is formulated for practical implementation and assessment of road conditions of traffic flows. As for hardware, it is proposed not to equip a vehicle with additional sensors but to use operational standard accelerometers as part of in-vehicle emergency call systems, e.g., ERA-GLONASS equipment units.

Keywords: transport, road transport, vehicle operation monitoring, operating conditions, adaptive maintenance systems, GLONASS, ERA-GLONASS.

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INTRODUCTION

In current conditions characterized by downsizing of motor enterprises and an increase in the share of vehicles operated by individual owners [1], the scheduled preventive system for organising vehicles' technical maintenance and repair processes (TM and R) loses its effectiveness while being continuously used in most cases [2; 3].

Hence the relevance of developing the so-called adaptive systems of maintenance and repair, which will make it possible to decide on implementation of technical actions individually for each vehicle, thereby increasing the efficiency of the processes of ensuring their technical readiness [4–6]. The modern level of technology and information technology facilitates solution of this problem making it possible to implement such a component of intelligent transport systems as monitoring of vehicle operation [7].

World practices in development of vehicle operation systems show that large world manufacturers of automotive equipment have started implementation of flexible maintenance schedules for new models being adjusted in real time depending on operating conditions [8]. First, this approach to maintenance is being implemented for trucks and special equipment, vehicles operated in special conditions, for which increasing the efficiency of operation is especially important and gives a significant economic effect [9]. So, flexible maintenance plans can be applied today to trucks of Mercedes, Scania, Volvo brands [10]. Russian domestic manufacturers (KamAZ) are also developing similar systems, though they have not been widely used yet [11].

However, both international [12–16] and domestic [7; 17; 18] approaches consider mainly telemetry data on working processes in the vehicle's units, control actions of the driver and vehicle speed as sources of information for making decisions on when to proceed with maintenance. The type of road surface is not considered while it is one of the main factors of external environment.

In this regard, the *purpose* of the article is to present the results of research aimed at developing a method for assessing road conditions of traffic flow based on operation monitoring data.

RESULTS

As shown above, one of the main standards for maintenance and repair is the frequency of maintenance. In the scheduled preventive system, it is determined considering the basic maintenance frequency and the values of correction factors, which take into consideration, among other things, road conditions [19].

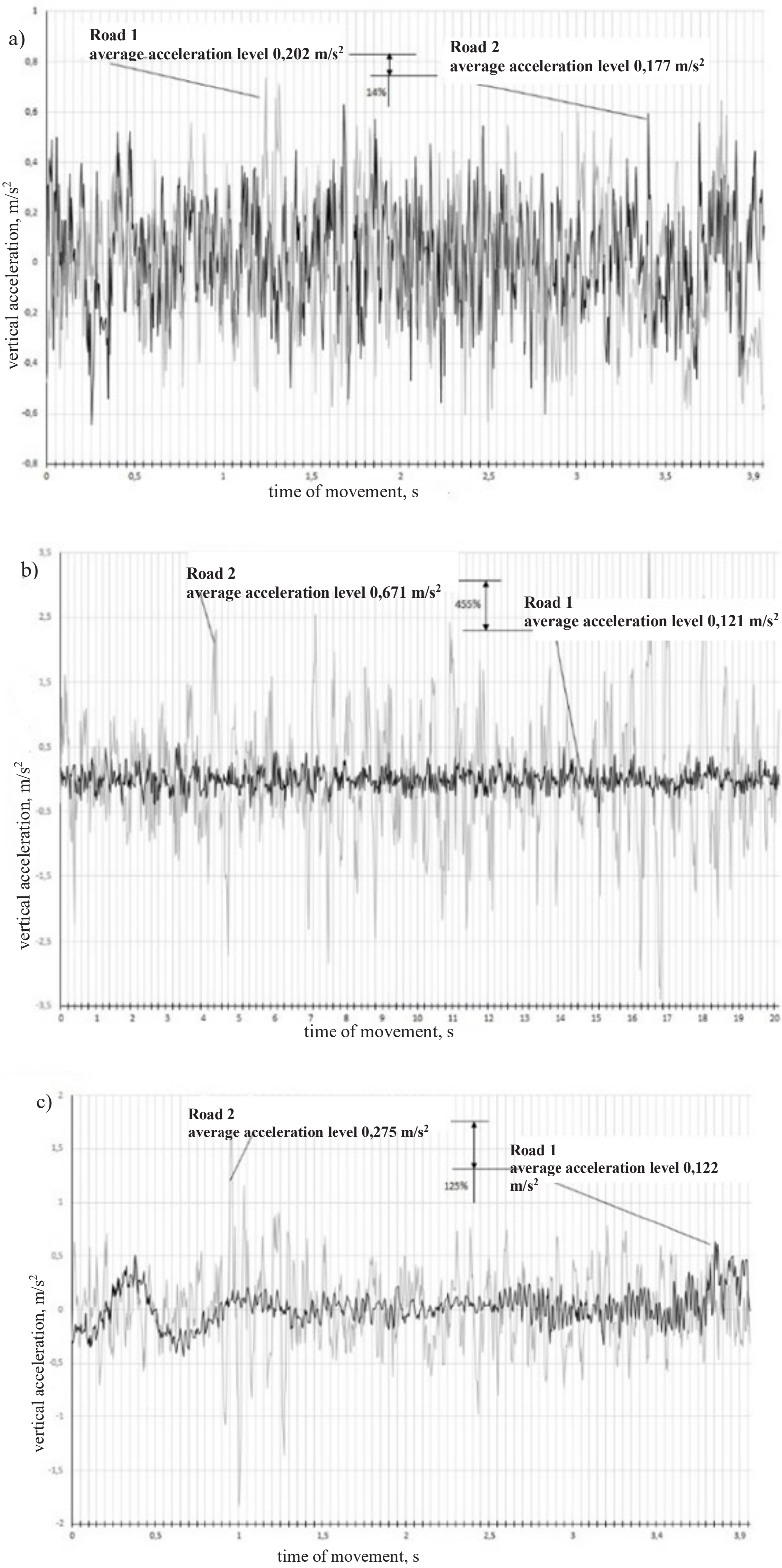
A version of the adaptive TM and R system determines values of correction factors individually for each vehicle based on the operation monitoring data. When implementing this approach, to determine in real time the type of road surface on which the vehicle is driving, it is proposed to use continuous monitoring of vertical accelerations of sprung masses recorded on the vehicle body.

This method is based on the interaction of vehicle's wheels with road irregularities which is the main source of forced oscillations of vehicle's structural elements. The degree of force action of oscillatory processes on structural elements is estimated by the parameters associated with accelerations, and the parameters of oscillatory processes of vehicle's structural elements during movement are directly related to a micro-profile of the road along which this movement is carried out [20]. The micro-profile, in turn, determines not only the type, but also the condition of the road surface. Thus, to determine in real time the type and condition of the road surface, it is possible to use continuous monitoring of vertical accelerations recorded on the vehicle body.

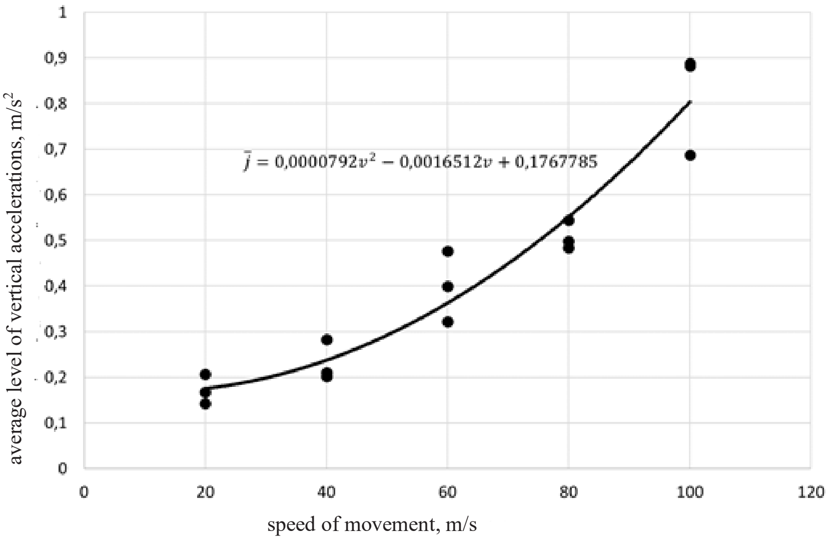
To confirm this hypothesis, experimental research *methods* were used: vertical acceleration profiles were constructed with a step of recording parameters of 5…10 ms were built using the signals from a three-position accelerometer, rigidly fixed on the vehicle body. The results are shown in Pic. 1.

To ensure the possibility to identify the type and condition of the road surface not only by a visual method (in the form of graphs), but also in an automatic mode based on mathematical processing of an array of data on vertical accelerations, the value of the average level of accelerations is suggested calculated by the formula:

$$\bar{j}(t) = \frac{1}{\delta} \int_{t-\delta}^{t} j(t)dt, \quad (1)$$



Pic. 1. Profiles of vertical acceleration of the M1 vehicle body when driving on roads with different types of surfaces in different conditions (speed 30 km/h):
a) Road 1 and road 2: asphalt concrete in good condition.
b) Road 1: asphalt concrete; road 2: soil, improved with local materials.
c) Road 1: asphalt concrete in good condition; road 2: asphalt concrete in satisfactory condition (compiled by the authors).



Pic. 2. Dependence of the average level of vertical acceleration of the body on speed of the vehicle (compiled by the authors).

where $j(t)$ is current value of acceleration at time t, m/s^2;

δ – period of time to determine the average level of acceleration, s;

$\bar{j}(t)$ – value of the average level of accelerations at time t, m/s^2.

The formula (1) is an analogue of the formulas used in the analysis of acceleration profiles to determine the level of force action and the values of impact severity index (ASI) in the ERA-GLONASS system [1]. The considered case assessed the result of the same processes, except that the object of impact is not a person (passenger), but a vehicle. In this regard, the use of formula (1) can be recognised as adequate assumption.

Experimental data and calculation results suggest that the values of average levels of acceleration can be used to identify the type of road surface. So, the same road surfaces have similar acceleration profiles and slightly different values of the average level of acceleration (Pic. 1a), while average levels of acceleration for asphalt concrete and unpaved surfaces can differ by up to 4,5 times (Pic. 1b).

At the same time, for an asphalt concrete pavement in a satisfactory condition, the value of the average level of accelerations can exceed the value for a pavement in good condition by more than two times (Pic. 1c). From the point of view of implementation of the adaptive TM and R systems, for making decisions on performing the next maintenance, it is only important to assess the force action of the road on structural elements of the vehicle, which leads to a deterioration in its technical condition. At the same time, both a native soil surface in good condition and an asphalt concrete surface in a satisfactory condition can have a similar force impact. However, if the type of road surface on which movement is carried out is known in advance, then the monitoring data of vertical accelerations and their calculated average level can be used to assess the condition of the road surface.

It should be said that the experimental data shown in Pic. 1 are valid for a single constant vehicle speed value. Since the magnitude of the force action of the road cannot but depends on speed, and speed of the vehicle is not constant during its motion, practical application of the proposed method for assessing the condition of the road surface requires an assessment of the nature of the dependence of the average level of vertical accelerations of the vehicle body on speed of movement.

For this, experimental measurements of the average level of vertical accelerations were performed for the case when the same vehicle moved along the same segment of the road with an asphalt concrete surface at different speeds.

[1] GOST [State Standard] R 54620-2011. Global navigation satellite system. Emergency response system in case of accidents. In-vehicle emergency call system. General technical requirements [Electronic resource]: https://docs.cntd.ru/document/1200095073. Last accessed 14.07.2021.

The experimental results, together with the approximating dependence, are shown in Pic. 2.

The dependence of the average level of vertical accelerations of the vehicle body on speed of movement is approximated by a power-law dependence of the second degree since forced oscillations of the body are associated with the kinetic energy possessed by the vehicle interacting with irregularities of the road micro-profile, and the kinetic energy is proportional to the square of speed.

The nonlinearity of the real dependence of the level of force parameters of the impact on the vehicle on the micro-profile of the road is also confirmed by the provisions of the current guidelines for the study of the flatness of road surfaces[2]. However, in practice, to simplify the application, it is proposed to use linear dependences of the form $\bar{j} = kv$. Their use will not lead to a significant loss of accuracy (the approximation accuracy is less by 3 % compared to the second-order polynomial dependence). This will allow to consider the condition that the average level of acceleration is equal to zero at zero speed and to bring the values of the average level of acceleration to the same «base» speed to enable a comparative assessment of the condition of the road surface at different segments without preliminary tests to determine the exact nature of the dependencies. If speed equal to 60 km/h is taken as the base speed, then the adjusted value of the average level of accelerations will be calculated using the following formula:

$$\bar{j}_{60}(t) = 60\frac{\bar{j}(t)}{v(t)}. \quad (2)$$

Also, for practical application of the described method, it is necessary to substantiate the value of the time interval δ, which is the basic one for calculating the average level of accelerations. For this, it should be borne in mind that the condition of the road surface is determined on a road segment of a certain length. Since using the described method, the condition of the road surface is assessed locally, in accordance with the recommendations[2], the length of the road segment in this case should be from 25 to 100 m. As a first approximation, an average value of 50 m is chosen to ensure accuracy. In this case, the time base for calculating the average level of accelerations will depend on speed of the vehicle at the current time:

$$\delta = 50v^{-1}. \quad (3)$$

CONCLUSION

Thus, to assess road conditions based on data on vertical acceleration of the vehicle body, the following sequence of actions can be proposed:

- Determining the coordinates of the vehicle (*φ, λ*) and the current moment of time *t*.
- Determining the vehicle speed at the current time *v (t)*.
- Determining the time base for calculating the average level of accelerations according to formula 3.
- Determining the average level of acceleration according to formula 1.
- Adjusting the average level of accelerations to the base speed according to formula 2.
- Determining the condition of the road surface by comparing the adjusted level of the average level of acceleration with predetermined threshold values.

The implementation of the proposed mechanism is possible as an additional functionality of the ERA-GLONASS system or similar systems in other countries. Its implementation will allow not only to provide individual adjustment of the frequency of vehicle maintenance, but also to carry out express monitoring of the condition of the road surface in real time.

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