Experimental and calculated procedure for determining the adhesion properties of the vehicle pneumatic tires in use

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ABSTRACT
The article describes the possibility of obtaining the dependence adhesion co-efficient in real-time on the relative slipping coefficient lengthwise for the identification of the road surface type, the experimental results are presented.

INTRODUCTION

An important interaction characteristic of a pneumatic-tire with supporting surface, on which the algorithms of the active safety systems are based, is the adhesion co-efficient dependence lengthwise \( \mu_x \) upon the relative slipping coefficient \( s_x \), or so-called "\( \mu \)-s-graph [1] (in the domestic literature – "\( \phi \)-s-graph).

Adhesion performance definition in contact of the pneumatical tire with the supporting surface consists of two sequential steps. The first step is to obtain the adhesion co-efficient current value lengthwise \( \mu_x \) and subsequent characterization of the adhesion with paired values: the adhesion co-efficient \( u \) and the relative slipping coefficient \( s \). All forces arising in the wheel contact with the supporting surface must be known to calculate the \( \mu \)-s characteristics.

The limit of adhesion is characterized by the maximum adhesion co-efficient value \( \mu_{\text{max}} \). In the absence of an emergency braking or acceleration, the maximum adhesion co-efficient value can’t be achieved [3]. For this reason, we define only the actual value of the concerned parameters at this point in time.

Main part:

As the design scheme "bicycle configuration" was used, in which the speed of the front and rear wheels were equal to the arithmetic average speeds of the front and rear wheels, respectively:

\[
\begin{align*}
  v_f &= \frac{v_1 + v_2}{2}, \\
  v_r &= \frac{v_3 + v_4}{2},
\end{align*}
\]

where:

- \( v_f \) – arithmetic average speed of the front wheels (vehicle front axle center velocity);
$v_r$ – arithmetic average speed of the rear wheels (vehicle rear axle center velocity).

The relative slipping coefficient lengthwise ($s_x$), taking into account linear movement and traction condition only, as well as the fact that the object-to-be-tested was a front-wheel drive vehicle will be calculated as follows:

$$s_x = \frac{\omega_f \cdot r_d - v_a}{v_a} \approx \frac{v_f - v_r}{v_r}, \quad (3)$$

where:

- $\omega_f$ – the average front wheels rotational speed;
- $r_d$ – the dynamic roller radius

The equation of the vehicle movement along the straight trajectory in the traction condition, without taking into account the roadway slope, is as follows [4]:

$$m_a \cdot a_x = F_T - F_k - F_a, \quad (4)$$

where:

- $m_a$ – vehicle weight;
- $a_x$ – vehicle linear acceleration lengthwise;
- $F_T$ – total pulling power;
- $F_k$ – total force of the rolling resistance;
- $F_a$ – force of the aerodynamic resistance.

The total pulling power, in turn, can be calculated by the formula:

$$F_T = \mu_x \cdot m_e \cdot g, \quad (5)$$

where:

- $m_e$ – adhesion vehicle weight (the weight on the leading wheels);
- $g$ – free fall acceleration.

In the case of linear movement in the traction condition and relatively low speed (experiment was conducted in the urban settings), we can introduce the following assumptions:

- adhesion weight front wheel drive /rear-wheel drive vehicle is constant and equal to the weight acting on the driving axle;
- force of the aerodynamic resistance is slight, and it can be neglected;
- force of rolling resistance can be replaced by the equivalent resistance force to motion with the respective coefficient $f_{C} \approx 0.04$ [5].

By taking into account the assumptions, the formula (4) looks like this:

$$m_a \cdot a_x = \mu_x \cdot m_e \cdot g - f_{C} \cdot m_a \cdot g \quad (6)$$

Next, we obtain the dependency for the calculation of the adhesion co-efficient lengthwise at this point in time:

$$\mu_x = \frac{m_a \cdot (a_x + f_{C} \cdot g)}{m_e \cdot g} \quad (7)$$

The acceleration of the vehicle lengthwise will be determined by the numerical differentiation method of the linear vehicle speed readings.

To test the correctness of these stated provisions the natural experiment was planned, prepared and carried out using the following object-to-be-tested – vehicles of category M1 – Chevrolet Orlando 1.8 LT AT of 2012 production year, equipped with the system of data collection and recording with on-board high-speed CAN of the transfer data [6, 7].

The vehicle in question, as well as the majority of modern wheeled vehicles, is equipped with the original equipment high-speed CAN bus of the data transfer, which, in this case, applies to CAN buses of class "C" with the data transfer rate 500 Kbit/s. Individual wheel speed values do not apply to OBD standardized parameters and, accordingly, may not be obtained by standard requests sent to ECU of the combustion engine. However, it is known that the vehicle is equipped with ABS, which presupposes the existence of the appropriate sensors for the wheels speed, and so the wheel speed values are presented in the onboard CAN bus.

For the determination of CAN messages, containing the wheels speed values of the tested vehicle knowing of State Technical University "method of the data decoding transmitted via CAN-buses of the transport and technological machines" was applied. The following data have been decoded and later on they were used in the calculation:
- the linear speed of the vehicle movement;
- linear velocity of four wheels;
- steering-wheel angle;
- throttle pedal position;
- brake pedal position.

Since the calculations were made only for the linear movement, the following calculations were introduced:
- minimum vehicle speed is 10 km/h;
- steering wheel-rotation angles are within ± 5 degrees [8].

Another condition for the calculations was the traction condition, so the calculations were not carried out when pressing on the brake pedal and in the absence of the fact of the acceleration pedal pressing.

The tests were conducted under the traffic conditions in the urban environment with speeds of not more than 80 km/h. The calculation data of the actual adhesion co-efficient lengthwise and relative slipping coefficient for one driving cycle are shown in Figure 1.

![Fig. 1: Results of the experimental calculations μₓ and sₓ.](image)

For a further analysis the approximation of experimental μₓ-sₓ of the linear curve was carried out and the comparison with theoretical μₓ-sₓ characteristics [9] was conducted to determine, according the slope of the linear zone, road surface type, which is currently under the vehicle wheels. The comparison result of the actual experiment and calculated characteristics with theoretical ones is shown in figure 2.

![Fig. 2: Design μₓ-sₓ characteristic, combined with the theoretical ones.](image)
According to the conducted test, it does not seem possible to determine exactly what type of pavement the vehicle was moving on, because the resulting $\mu_x$ coincides with linear zones of the theoretical characteristics corresponding the movement on dry asphalt, wet asphalt or dry concrete. In fact, the experiment was conducted on the wet asphalt. In any case, the experimental verification of the executability of the proposed approach for determining the adhesion properties of the vehicle pneumatic tires in use.

The results and conclusions:
Thus, the results of the experiment has confirmed the validity of the developed method, allowing to identify the actual $\mu_x$ features to further defining the road surface type, which is currently under the vehicle wheels. The technique can be improved by eliminating the adopted assumptions, as well through evaluation of the considered characteristics and for the braking process [10]. The technique can be implemented as a composite subroutine solution of the active safety systems of the wheeled transport. This material may be useful for the educational purposes.

REFERENCES