Measuring the Adhesion Coefficient of a Pneumatic Tire to Road Surface

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Abstract. The relevance of developing a method for measuring the adhesion coefficient of a pneumatic tire to the road surface is due to ensuring the objectivity and accuracy of road audits as well as the expertise of road traffic accidents. Based on the results of the analysis, a device for measuring the adhesion coefficient of a pneumatic tire with road surface was designed for cars weighing up to 3.5 T and more than 3.5 T. The device features interchangeable motion slide blocks, a strain gauge transducer, and an electronic computing section which provides calculations of the adhesion coefficient at two-second intervals through a special program and stores the results in the memory of the device. Subsequently, based on the results of the recorded data, a computer program is used to create a diagram of the change in the adhesion coefficient of a pneumatic tire with road surface for the road section under study, as well as and the average value is determined. Experimental studies have obtained the results of measuring the adhesion coefficient of a pneumatic tire with road in case of different conditions of the surface; dry asphalt concrete, wet asphalt concrete, dusty and wet asphalt concrete, packed snow and black ice, at various temperature conditions. The device has been registered as an invention in the Intellectual Property Office of Armenia under No. 852Y, dated 1.11.2023.

Keywords: adhesion coefficient, pneumatic tire, road surface, strain gauge, measurement interval, simulation modelling

1. Introduction

The adhesion coefficient of a pneumatic tire to the road surface under conditions of high intensity and speed of traffic flow on suburban and intercity roads, especially in mountainous areas, is a priority to ensure reliability and safety of road traffic. Determining the adhesion coefficient is necessary when conducting an auditing process of highways and during the examination of traffic accidents.

In particular, when examining a traffic accident, the adhesion coefficient value is selected based on the accident report data compiled at the incident site, which is often very approximate and can significantly affect the objectivity of expert assessments and conclusions.

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The basis for choosing the adhesion coefficient is GOST 33076-2014, along with various information manuals on this issue [2, 3, 4, 5]. However, when choosing the value of the adhesion coefficient, it is necessary to consider several factors through which it is derived [5, 6, 7, 8, 9].

It includes the wear of the road surface, the micro- and macro-profile of the road, unevenness, protrusions, and hollows, the slope of the road in a given area, and various other well-known factors. Without considering the listed factors, the value of the adhesion coefficient will have significant errors.

Choosing the adhesion coefficient of the road was studied in the 1960s–70s of the last century in the works of V.A. Ilarionov [1], Bayetta [2], and Suvorova Yu.B. [3]. In modern conditions, Kuznetsov Yu.V. contributed in this direction [4].

The road surface wears out over time [GOST 33078-2014, GOST R.50597-2017] and bumps and depressions appear, especially in the conditions of the Republic of Armenia, where 90% of roads are located at an altitude of 1000 meters or more above sea level and are characterized by rough terrain, long ups and downs, different temperatures of the road surface, which makes adjustments when choosing the coefficient of adhesion [SNiP 32-01-2022. Yerevan 2022].

For instance, in accident investigations where it is crucial to ascertain the initial speed of a vehicle based on tire tracks during braking on diverse road surfaces or when the track of a pneumatic tire is curved, the expert determines the adhesion coefficient value considering the overall condition of the road [7]. Generally, insufficient attention is given to:
- justification, accuracy and objectivity of the selected value of the adhesion coefficient using special instruments,
- the influence of the type of car on the value of the adhesion coefficient, depending on the specific pressure on the road surface,
- determination of the adhesion coefficient using a specific experimental method,
- by tire type and product material.

Thus, when conducting an audit and monitoring the road surface for acceptance of roads under construction or repair, as well as during the examination of road accidents, the issue of choosing the value of the adhesion coefficient of a pneumatic tire to the road must be solved by differentiating the process of braking a car along a specific section of the road, as well as sections of road accidents for the purpose of objective modeling and identifying the cause-and-effect relationship of the incident.

The primary research method involves simulating the movement of a fully braked wheel on a pneumatic tire over an actual road surface. This simulation includes the application of real and specific pressure on the roadbed while maintaining a constant load.

The research results include the development of a device designed to determine the adhesion coefficient of a pneumatic tire to road surfaces, suitable for vehicles weighing both up to 3.5 tons and more than 3.5 tons.

The device has a replaceable sliding brake block, a strain gauge, and an electronic computer unit, which calculates the adhesion coefficient using a special program at two-second intervals and records it in the device’s memory.
Subsequently, using the recorded data, a diagram depicting changes in the adhesion coefficient of a pneumatic tire to the road is generated for the specific road section under study. The average value of the adhesion coefficient is then determined using the computer program 'Excel'. Experimental studies yielded results from measuring the adhesion coefficient of the tire on various roadbed conditions, including dry asphalt concrete, wet asphalt, dusty and wet asphalt concrete, rolling snow, icy road surfaces, and diverse temperature conditions.

2. Materials and Methods

To determine the adhesion coefficient of a pneumatic tire with the road surface, a portable electronic-mechanical device for measuring the adhesion coefficient of a pneumatic tire with the road surface was developed and manufactured at the Department of Construction Machinery and Traffic Management of the National University of Architecture and Construction of Armenia (NUACA) (Fig. 1).

The device is registered as an invention in the Intellectual Property Bureau of Armenia under No. 852Y dated November 1, 2023.

Fig. 1. A device for measuring the adhesion coefficient of a pneumatic tire to the road surface.
1. sledge frame, 2. load elements, 3. lugs, 4. bearing bracket, 5. pedal grip, 6. tensometric sensor, 7. electronic calculation and measurement unit, 8. counter, 9. electronic storage media, 10. driving cable

The technique for measuring the adhesion coefficient of a pneumatic tire to the road surface involves simulating the process of complete braking of a car wheel, considering the actual condition of the road surface. The rate of motion of the device is 1.2 m/sec, which ensures constant contact of the tire simulator with road unevenness.

As prescribed by regulatory documents, the selection of this technique is motivated by the need to adhere to a specific value of the adhesion coefficient during highway audits and road accident investigations [1].

The fundamental initial requirements and parameters of the device are:
- ensuring the real specific pressure of the tire simulator on the road surface of a passenger car and truck (4.0 km/cm2 for a passenger car, 8.0 kg/cm2 for a truck),
- determination of the coefficient of adhesion along the entire length of the braking distance,
- an electromechanical measuring and computing complex capable of correcting the value of the adhesion coefficient and entering the measurement results into an
- processing measurement results and determining the average value of the coefficient of adhesion in the vehicle braking areas using the Excel program,
- determination of the average value of the adhesion coefficient based on the analysis of the distribution of random variables with the highest probability density.

A schematic block diagram of the device operation algorithm is shown in Fig. 2.

![Schematic block diagram](image)

**Fig. 2.** Schematic block diagram of a device for measuring the adhesion coefficient of a pneumatic tire to a road surface

Upon activation of the device, a signal is received from the strain gauge sensor, amplified, and then digitized before being periodically transmitted to the control unit. When a measurement is required, the process initiation is done by pressing the corresponding button, which triggers the registration process at two-second intervals. The signal is synchronized with a real-time counter and recorded in memory for subsequent processing.

The measurement is completed by pressing the button, which has a fixation ability.

All measurement results are displayed on the device monitor, which also displays the ambient temperature, time and date, as well as the battery charge level and operating mode.

### 3. Results

A detailed analysis of the braking process of a pneumatic tire on a real road shows that the adhesion coefficient, which is not always uniquely selected, has a constant value and reflects the plausibility of the ongoing process.

Based on the results of tests conducted on a dry real road, the results were obtained (Table 1), on the basis of which a diagram of changes in the adhesion coefficient was constructed (Fig. 3). During the experiment, a section of the road with a length of 11.8 m was examined on a dry asphalt road.

**Table 1. Adhesion coefficient value**

<table>
<thead>
<tr>
<th>Time, sec.</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesion coefficient $\phi$</td>
<td>0.75</td>
<td>0.72</td>
<td>0.71</td>
<td>0.71</td>
<td>0.73</td>
<td>0.75</td>
<td>0.75</td>
<td>0.77</td>
</tr>
</tbody>
</table>
The proposed measurement method with a high degree of probability eliminates the possibility of error, which makes it possible to accurately calculate and determine the parameters of the vehicle’s movement during braking.

From the results in Table 1, it follows that the minimum and maximum values of the adhesion coefficient are 0.71 and 0.77, and the average value of the coefficient is 0.75 with a variation coefficient of 0.08 and a root-mean-square deviation of 4.4.

When braking a car at high speeds, the wheel bouncing on bumps and depressions in the road leads to a noticeable distortion of the braking mark, and only at the end of the braking distance does it become constant and pronounced (the adhesion process when the tire slides also plays a role in this).

Note that the beginning of the braking process and wheel locking are random processes. Therefore, the coefficient determined as the average value based on a series of measurements is the most reliable.

A repetitive experiment was carried out on a wet road. The results of the experiment are shown in Table 2 and Fig. 4.

**Table 2. Adhesion coefficient value**

<table>
<thead>
<tr>
<th>Time, sec.</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesion coefficient $\varphi$</td>
<td>0.35</td>
<td>0.31</td>
<td>0.38</td>
<td>0.40</td>
<td>0.38</td>
<td>0.30</td>
<td>0.35</td>
<td>0.37</td>
</tr>
</tbody>
</table>
From the results given in Table 2 it follows that the minimum and maximum values of the adhesion coefficient are $\varphi_{\text{min}} = 0.3$, $\varphi_{\text{max}} = 0.4$, the average value is 0.35, the variation coefficient is 0.11 with a root-mean-square deviation of 6.8. A comparative analysis of the adhesion coefficient distribution series shows that the variation coefficient on a wet road is 0.11, on a dry road, it is 0.08, and the root-mean-square deviation is 6.8 against 4.4 on a dry road. This means that in addition to the fact, that the adhesion coefficient on a dry road is significantly higher than on a wet road, the spread of this coefficient on a wet road is higher than on a dry road: 0.11 versus 0.08 on a wet road.

The conclusion is that the adhesion coefficient on a wet road is more variable than on a dry road.

4. Discussion

The developed device, designed for both experimental and practical applications, employs a method for calculating the adhesion coefficient of a pneumatic tire to the road. This method treats these coefficients as a series of random variables, determining their distribution law and deriving the average value, variation coefficient, and root-mean-square deviation. This approach enables us to determine the adhesion coefficient value with the highest probability density on the road surface under any given condition.

The existing devices for measuring the adhesion coefficient of a pneumatic tire and the road surface, such as Portable adhesion coefficient meters of Russian production (ИКСп-М, ППК-МАДИ, ППК) etc., conduct measurements by applying a load and recording the relative displacement of a washer on a ruler. The contact of the measuring head with the road surface occurs as a result of the impact of brake pads, causing them to shift along the road surface. As a result of this, different values of the adhesion coefficient are obtained in each experimental measurement.

The developed Russian instrument for monitoring the evenness and slipperiness of road surfaces (ПКРС) provides sufficiently high accuracy in measuring the adhesion coefficient; however, it is costly and impractical for everyday use due to the high cost of conducting measurements, especially at accident sites.

In this regard, the developed device has an advantage in terms of measurement accuracy and the low cost of carrying out control measurements.
5. Conclusion

Based on the above, we can conclude:

- The use of the developed device for determining the coefficient of adhesion of a pneumatic tire to the road will allow, technically and experimentally, to most objectively and accurately determine the value of the adhesion coefficient during an audit on the road section under study, as well as during the examination of an accident.
- The device is recommended to use in the following cases:
  a. acceptance of roads under construction,
  b. ongoing road surveys,
  c. identification of dangerous road sections and “black spots”,
  d. determination of the scene of a road traffic accident.

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