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Regarding the issue of aquaplaning and the interaction of a car tire with the road surface through a layer of water

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Abstract. Problem. *The process of interaction of a pneumatic tire of a car wheel with the surface of the road surface, which is covered with a layer of water, affects the safety of the vehicle movement, therefore, the assessment of the effect of aquaplaning when writing the conclusions of the auto technical examination is an actual direction of research. The study of the effect of aquaplaning will allow forensic experts and specialists in the automotive industry to make an objective analysis and form non-subjective conclusions.* ***Goal.*** *The purpose of the work is to determine the design parameters and operational features of the pneumatic tire, as well as the speed of the vehicle on the process of interaction of the car wheel tire with the surface of the road coating, which is covered with a layer of water.* ***Methodology.*** *The approaches adopted in the work to solve the set goals are based on the theory of aquaplaning, the theory of the interaction of the pneumatic tire with the road surface, the theory of the vehicle and the laws of theoretical mechanics.* ***Results****. The obtained results of the research in the form of an analysis make it possible to assess the impact of the aquaplaning effect of a pneumatic tire on road safety. It was established that the thickness of the water layer affects the conditions for meeting the requirements established by the traffic rules, since the decrease in the height of the tire tread pattern leads to unstable contact of the tire with the road surface.* ***Originality****. The results of the study provided an opportunity to get an idea of the influence of the design parameters of tires on road safety in terms of forming the conclusions of the motor-technical examination.* ***Practical value****. The obtained results can be recommended to forensic experts when writing expert opinions and for expert research.*

Key words: *aquaplaning, car wheel, road surface, tire, adhesion utilized, adhesion ratio.*

Introduction

It is known that due to the friction and adhesion of the tire of the car wheel with the surface of the road surface, the reliability of the movement of the vehicle in a given direction is ensured. The magnitude of the friction and adhesion forces depend on many factors, including the speed of movement and the degree of wetting of the road surface. With an increase in the thickness of the water film and the speed of the vehicle, the friction and adhesion forces of the tire with the road surface decrease, this occurs as a result of the difficult removal of moisture from the patch of the tire.

As the speed of the vehicle increases, the forces necessary to overcome the inertia and viscosity of water increase. With a certain thickness of the film of water and the speed of the vehicle, due to the action of hydrodynamic forces in the contact zone, the tire floats on the liquid film. In this case, the adhesion forces of the car wheel tire with the road surface have low values due to the friction in the liquid layer, while the car wheel tire is unable to transmit or perceive external forces. This condition of a car tire on a wet road surface is called aquaplaning, and the speed at which it occurs is called critical. It is known that the efficiency of liquid removal from the contact zone is ensured primarily by the pattern of the tread.

Today, there are a large number of car tires from different manufacturers, which have different design parameters, which include: the width, height of the tire profile, the type of tread pattern, as well as the type of material from which the tire is made. Taking into account the above, the process of researching the impact of aquaplaning on the process of interaction of a car wheel tire with the road surface is relevant and directly affects the safety of vehicle movement and therefore requires additional attention when investigating the circumstances of the traffic accident.

Analysis of publications

The process of interaction of a car wheel with the road surface was considered in the works of various scientists of the world [1-7], who combine both research related to the effect of aquaplaning and the influence of tire geometry on the process of aquaplaning.

Thus, in work [1], a global study of the impact of aquaplaning on road safety was carried out as part of the German In-Depth Accident Study (GIDAS) project. The project showed that aquaplaning is one of the main causes of traffic accidents during rain on roads with high-speed traffic.

In work [2], the authors tried using machine learning to predict a high ability to predict the occurrence of an emergency situation on the road during rain. Studies have shown that the forecast regarding the occurrence of aquaplaning came true by 71%.

The authors of the work [3] claim that during the occurrence of traffic incidents related to aquaplaning, the blame should rest on the drivers, and not on the road maintenance service, since it is the drivers who do not react correctly to the effect of aquaplaning, they panic and provoke the formation of traffic incidents.

As shown by the studies given in [4], the effect of aquaplaning is significantly influenced by the patch of the tire with the road surface. The authors of the paper conclude that the patch area and the shape of the patch significantly depend on the transparency of the liquid and the smoothness of the road surface. The authors also conclude that it is possible to predict the probability of reducing the tire contact patch using 3-axial acceleration sensors mounted in the tire.

In the paper [5], the authors show that modern modeling methods cannot be used to simulate the aquaplaning process, but if you combine the methods of computational hydrodynamics and the finite element method, you can get results close to the real values obtained during experimental research. So the authors of the paper [5] suggest together with the specified methods, use the physical properties of the interaction between the tire and the road surface.

In paper [6], based on a comparison of different methods, the authors prove that it is possible to increase the safety of the movement of wheeled vehicles during aquaplaning due to the use of a course stability system and control of the traction force on the driving wheels of the vehicle.

Therefore, the study of aquaplaning of tires of wheeled vehicles when drawing up an expert's opinion and during expert studies is relevant and requires comprehensive consideration.

Purpose and Tasks

The purpose of the work is to determine the design parameters and operational features of the pneumatic tire, as well as the speed of the vehicle on the process of interaction of the car wheel tire with the surface of the road surface, which is covered with a layer of water.

To fulfill the set goal, the following tasks must be completed:

- make an overview of the characteristics of the structure of tires;
- make an overview of methods for evaluating the impact of tires on vehicle handling;
- make an overview of the phenomenon of tire aquaplaning;
– make an overview of the requirements of the traffic rules of Ukraine regarding the tread parameters of vehicle tires;
– make an analysis of the aquaplaning effect.

Overview of the characteristics of the structure of tires

With the modern development of the automobile industry, the improvement of automobile tires is aimed at the use of more advanced materials for the manufacture of tires, increasing the strength of the cord, the manufacture of so-called low-profile tires and wide-profile tires, increasing the depth of the tread pattern in the tire, which are intended for work in difficult road conditions. The improvement of automobile tires also consists in increasing their service life, permissible loads, and simplifying the technology of their production.

The development of the design of automobile tires is directly related to the improvement of the design of vehicles and is carried out in the direction of the most complete correspondence of the characteristics of tires, the characteristics and operating conditions of vehicles. With the expansion of the network of improved highways, the increase in the speed and intensity of traffic, the question of increasing the stability and controllability of vehicles, which directly affects road safety, is becoming increasingly acute.

The creation of tubeless tires was an important step on the way to improving the safety of vehicles on pneumatic tires. Tubeless tires are installed on cars and trucks, buses, tractors and other wheeled vehicles. They were quickly and widely distributed because their advantages over conventional tube tires are significant. Compared to tube tires, tubeless tires have less weight, a longer service life, less rolling resistance, provide constant pressure for a long time, simplify their installation or removal from the wheel, which is very important in road conditions.

Vehicle tires have a significant impact on the stability and handling of the vehicle. The same vehicle with the same suspension and steering components, depending on the characteristics of the tires, can have unsatisfactory or excellent indicators of stability and handling. Among the characteristics of tires that affect the stability and controllability of the vehicle, the resistance to lateral input, lateral and angular stiffness and the nature of their deformation depending on the vertical load, internal air pressure in the tire, and others are decisive.

The issues of vehicle stability and controllability, which are related to tires, determine not only road safety. Since this question refers to the "vehicle - driver - road" system, it must be considered from the economic aspect as well. Deterioration of the vehicle's stability and controllability affects the reduction of movement speeds, the increase of driver fatigue (an additional factor of reduced safety), and, accordingly, the reduction of the labor productivity of the driver and the vehicle as a whole. Such vehicle handling qualities as its response to lateral forces, directional stability, excess or insufficient controllability at high lateral accelerations depend on the characteristics of car tires.

In addition, the ease of turning the steering wheel when maneuvering the vehicle at a low speed or at a standstill is conditionally included in the drivability indicators determined by the tires.

Overview of methods for evaluating the impact of tires on vehicle handling

To date, there are two ways of evaluating the impact of tires on vehicle handling, namely objective and subjective. An objective assessment involves measuring a number of parameters with the help of devices when the car performs certain maneuvers. There are quite a few different methods of objectively evaluating the effect of tires on vehicle handling. All existing methods of objective evaluation make it possible to one degree or another to analyze the influence of various design parameters of tires on the stability and controllability of the vehicle, allow to find a way to improve the characteristics of tires that affect the controllability of the car, through structural or technological modification and thus, necessary when working out the design of the tire for the corresponding vehicle. However, the main drawback of all existing methods of objective evaluation of the impact of tires on vehicle handling is the lack of an admissibility criterion or a criterion of tire acceptability both in absolute (without a standard) and in relative (with a standard) assessment. Therefore, in the final acceptance evaluation of the acceptability of tires, the advantage always belongs to subjective or semi-subjective methods of evaluation of experienced drivers when performing certain maneuvers. It is worth noting that, as a rule, the subjective assessment method is based on a comparison with the so-called reference tire, the quality of which is known and assessed as acceptable in terms of the controllability provided to the vehicle.

Overview of the phenomenon of tire aquaplaning

Passenger vehicle tires differ from truck tires in terms of design, overall dimensions, and the quality of the materials used. Car tires have a more elastic frame, a lower height and a more complex tread pattern, a smaller outer and seating diameter. One of the main criteria when comparing passenger vehicle tires with truck tires is the operation of passenger vehicle tires at higher speeds in relation to truck tires. It is known that at a critical speed, the movement of the vehicle becomes unstable and a minor external influence, such as aquaplaning, can cause a deviation of the trajectory of the vehicle (the vehicle loses course stability). It also limits the vehicle's acceleration and braking capabilities.

The phenomenon of aquaplaning, which occurs between a tire of a car wheel and the road surface, is more complex than on a dry surface of the road surface. At speeds that precede the occurrence of aquaplaning, three characteristic areas can be distinguished in the contact of a vehicle tire [7, 10] (see Fig. 1 below the text).

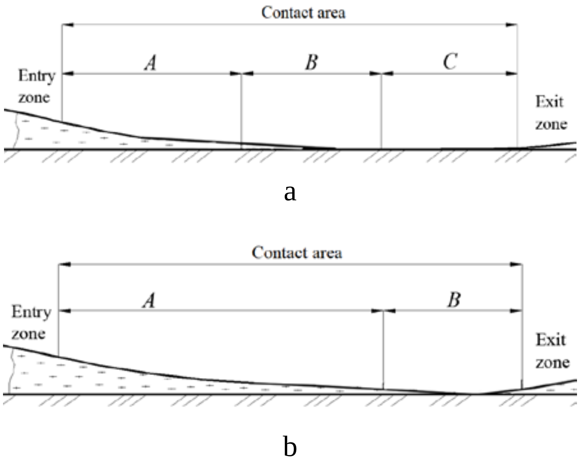


Fig. 1 Interaction of a vehicle wheel tire with a wet road surface: a – there is no aquaplaning; b - the case of aquaplaning

Section A is the front part of the contact, has a non-separated water layer, the so-called water wedge. Water does not have time to drain into the grooves of the tread and to the sides. At the same time, the coupling coefficient is close to zero (see Fig. 1 "a").

Section B is a transition zone following section A. In this contact zone, the water layer is partially broken, as a result of which liquid and dry friction occur, and the adhesion coefficient takes an intermediate value between the coefficient corresponding to liquid and dry friction.

Section C - there is no water in the back part of the contact, there is dry friction here. It is in this zone that the forces transmitted from the pneumatic tire to the road surface are realized.

Depending on the increase in speed, the water wedge spreads from the front part of the contact to the back, the length of sections A and B increases, while section C shortens. At the speed of the vehicle, which corresponds to the beginning of aquaplaning, the water layer spreads over the entire contact zone of the car tire with the road surface.

In order to maintain the contact of the car tire with the surface of the road surface, it is necessary that the appropriate volume of liquid be removed from the contact zone through the drainage grooves.

The volume of liquid that must be removed from the contact zone increases linearly with an increase in the speed of the vehicle and the thickness of the liquid film on the support surface. Effective removal of liquid from the contact zone is primarily ensured by the pattern of the tread. Important importance is played by the type of pattern and tread material, as well as design parameters, such as the ratio of the height of the tire profile to its width, the diameter of the rim, and others. An analysis of the scientific and technical literature showed that wide and straight grooves facilitate the removal of liquid from the water wedge immediately before the contact zone. Narrow edges or elements of the protector effectively reduce the path of movement of the liquid, thereby contributing to a reduction in time of the process of pushing out the liquid film from the contact zone. The notches of the protector elements act as reservoirs and shorten the path of movement of liquid from the contacting surfaces.

Overview of the requirements of the traffic rules of Ukraine regarding the tread parameters of vehicle tires

Increasing tread wear reduces its ability to remove the required volume of fluid from the contact zone. The greater the wear of the tread, the greater the drop in the grip properties of car tires with the surface of the road surface on which there is a layer of liquid. Therefore, in order to ensure the safety of road traffic in Ukraine, it is prohibited to operate passenger cars with a residual tread pattern height of less than 1.6 mm. In accordance with the requirements of paragraph 31.4, 31.4.5 "a" of the Road Traffic Rules of Ukraine follows:

*"Clause **31.4**. It is prohibited to operate vehicles in accordance with the legislation in the presence of the following technical malfunctions and non-compliance with the following requirements:*

*clause **31.4.5.** Wheels and tires:*

a) tires of passenger cars and trucks with a maximum permissible mass of up to 3.5 tons have a residual tread pattern height of less than 1.6 mm, trucks with a maximum permissible mass of more than 3.5 tons - 1.0 mm, buses - 2.0 mm, motorcycles and mopeds - 0.8 mm".

An increase in the speed of movement reduces the time of removal of the volume of liquid from the contact zone, as a result of which the critical speed of aquaplaning decreases.

The theoretical dependence for determining the critical speed of aquaplaning is based on the theory of hydrodynamic pressure in the water layer. At the same time, it is assumed that there is a complete balance between the load on the wheel and the resulting force from the hydrodynamic pressure, which is described in detail in works [7-15].

Analysis of the aquaplaning effect

Tires with a smooth tread pattern have twice the lift coefficient of tires with a serial pattern. The roughness of the road surface has a significant influence on the traction properties of a tire with a wet road surface. The roughness of the road surface is typical for asphalt and concrete surfaces. They are characterized by the greatest drop in the coefficient of adhesion when they are covered with liquid and, accordingly, the greatest tendency to aquaplaning.

Coarse-grained pavement is more resistant to aquaplaning because the stone protrusions create a network of channels through which liquid is removed from the contact zone. The main influence on the traction qualities of a tire with a shallow grain coating is provided by the pattern of the tread. The segmentation of the tread improves water drainage, reduces the path of water movement, and improves the distribution of contact pressure.

The analysis of scientific and technical literature [7-15] showed that aquaplaning begins on road surfaces when the liquid covers the ridges on such a surface. Other factors also affect the development process of aquaplaning. In the presence of an input angle, the speed of aquaplaning decreases. The lateral force drops to zero when the amount of tire slip relative to the road surface is 25%.

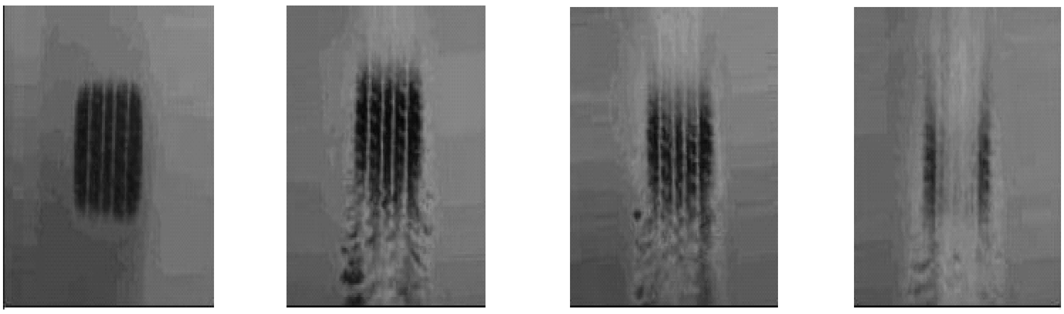
If you brake a wheel that is rolling at a high speed in a straight line or with an angle of input on a road that is covered with a layer of water, then the wheel will not rotate after releasing the brakes.

This sliding process corresponds in such conditions to close to the maximum value of the coefficient of adhesion. The lack of rotation of the wheel is probably due to the presence of forward wear of the reaction of hydrodynamic pressure on the tire in contact.

When conducting experimental studies in works [12-15], it was established that in some cases the speed at which aquaplaning occurs drops to very low values. As a result, the wheels are blocked, and the tires receive characteristic tread damage along the length of the contact. During the research, two types of damage were found: the first was a slightly melted area, the second was an overheated layer of rubber below the surface of the tread. Both types of damage were sometimes encountered separately or together during road tests of cars and trucks on the track, and were also reproduced in bench conditions. It was established that this phenomenon can appear during the operation of tires of freight vehicles, which have a contact pressure of the order of 7 kgf/cm2 and does not appear for tires operating at nominal load values and internal air pressure.

Provided that the pressure is below 3.5 kgf/cm2, this phenomenon does not manifest itself. The damage occurred only when braking to a complete locking of the wheels from a speed of 100 km/h and was typical for smooth surfaces that were covered with a thin layer of water (about 1 mm).

The effect of aquaplaning occurs under the influence of high driving speed during rain, when the highway is covered with a thin layer of water; falling into a strong stream of water flowing along the road; driving into an uneven water obstacle on an uneven road; tire tread wear.



a) b) c) d)

Fig. 2 The contact patch of a new car tire at different vehicle speeds: a – full contact (the vehicle speed is close to 0 km/h); b – partial contact (vehicle speed 60 km/h); c – partial aquaplaning (vehicle speed 80 km/h); d - aquaplaning (vehicle speed 100 km/h).

The speed of movement and the depth of the puddle have a great influence on the occurrence of the aquaplaning effect. When driving a serviceable car on new tires in a puddle with a depth of 5 mm at a speed of 90 km/h, the process of aquaplaning will definitely occur.

In order to reduce the impact of aquaplaning on the process of interaction between a car tire and the road surface, it is necessary to install tires with a rain protector, the so-called "herringbone"; keep the pressure in the tires not below the norm; reduce speed on a wet road and in front of puddles; monitor tread wear; exclude sharp maneuvers on a wet road. Braking in a puddle increases aquaplaning and causes uncontrolled skidding. On rear-wheel drive vehicles, you can deal with the situation by gradually reducing the speed (releasing the accelerator pedal). On a vehicle with front-wheel drive, you cannot release the accelerator pedal when driving into a puddle.

When driving on a wet surface, if there is a lot of water, the tires gradually start not having time to drain the water. Part of it begins to collect in front of the wheel, and a so-called water shaft appears. The shaft gradually increases, and the contact of the tire with the surface of the road surface decreases accordingly. A critical moment comes, two factors contribute to it: either an increase in speed or an increase in the layer of water on the road, and both of them lead to such a phenomenon as aquaplaning.

The wave of water is so big that the tire begins to simply pile up on it and lose contact with the road. The clutch simply disappears and the vehicle literally begins to float. It is worth noting that this process rarely occurs on all four wheels at once. Rain, puddles, poorly visible road surface, high speed of the vehicle, these are the first steps to the occurrence of aquaplaning. There is a theory that the higher the speed of the vehicle, the faster it will float.

A lot really depends on the speed of the vehicle, but other factors also have a great influence, namely:

Condition of tires. On heavily worn tires, the groove depth is mostly small and they are simply not able to release the contact spot from water in a timely manner. Even with a layer of water of 1 mm and a vehicle speed of 100 km/h, the tires will not be able to cope with the moisture and, most likely, the process of aquaplaning will occur. Emergency braking will not help in any way, and under some circumstances can even harm;

Tire type. If the special rain tires will keep contact with the road, then the first stage of floating may already begin in the case of ordinary summer tires at that moment. Usually, rain tires are distinguished by a central longitudinal deep groove and branched transverse grooves. But there may be different modifications of them;

The thickness of water between the tire and the road surface. Here everything is relatively simple, the thicker the layer, the more chances to go aquaplaning. But in reality, it is not so difficult to float even with a smaller layer of water. If the tires are in good condition, then speed comes into play;

Speed. The higher the speed, the greater the risk. Tires basically have some threshold of critical speed, above which the irreversible happens. Therefore, you cannot drive into puddles at high speed;

Type of road. The occurrence of aquaplaning on a smooth road is significantly higher than on coarse-grained concrete, because concrete requires several millimeters more water to cover the road surface. On normal roads, the risk is even lower, although there are very long puddles in low sections of the road.

Tire pressure. Tire pressure also has an effect on the probability of aquaplaning, since the area of interaction with the road surface decreases in a tire with pressure above the standard. The same applies to tires in which the pressure is below the standard (see Fig. 3 below the text). Pressure is always measured only in cold tires.

a b c

Fig. 3. Area of interaction of a car tire with the road surface depending on the pressure in the tire: a - normative pressure in the tire; b – pressure in the tire is higher than standard; c – the pressure in the tire is below the standard

Temperature. Temperature significantly affects the change in tire pressure. The temperature in a warm garage can be 30°C higher than outside. If you measure the pressure in the garage, it will be too low for the temperature outside.

<u>Example:</u> The temperature in the garage is 20°C and the temperature outside is 10°C, if the pressure is adjusted in the garage, the tire pressure will be 4.35 psi higher than what is recommended to ensure the correct pressure level according to to ambient temperature.

The effect of temperature on passenger car tire pressure is approximately 1.45 psi at 14ºF (minus 10ºC). In addition to properly adjusting the tire pressure, you should also check that the unidirectional tires are installed correctly. The arrow on the side of the tire indicates the direction of rotation.

To increase the service life of car tires, front and rear tires can be changed from one axle to another every 5,000-10,000 km. As a result, the tires will wear evenly and their degree of wear will not differ significantly.

According to the rules of operation and maintenance of car tires, it is recommended to pre-run in winter tires marked "M+S", that is, to avoid sharp accelerations and braking during the first 500 km. The inscription "M+S" (Mud and Snow) indicates that the car tire provides better traction. Soft braking increases the service life of the studs: the studs stay securely in place and remain on the tires.

Proper storage can slow down the process of tire wear, namely the temperature in the storage room should not exceed 25°C. It is desirable that the room itself was dark, and the temperature was below 15°C. If the temperature is higher than 25°C or lower than 0°C, the properties of the rubber may change, which will adversely affect the rubber products.

Tire handling. Tires must not be dropped during tire operations. Falling overboard can damage the tire. As a rule, as a result of such a fall, the board bends.

Conclusion

Taking into account the work carried out above, one should come to the conclusion that an increase in the speed of the vehicle reduces the time of removal of the volume of liquid from the contact zone, as a result of which the critical speed of aquaplaning decreases.

One of the main factors in the occurrence of aquaplaning is the design parameters of the car wheel tire, as well as the speed of the vehicle.

Car wheel tires with a smooth tread pattern have twice the lift coefficient of tires with a serial pattern.

The roughness of the road surface has a significant influence on the traction properties of a car wheel tire with a wet road surface.

Car tires have a significant impact on the stability and handling of the vehicle.

The same vehicle with the same suspension and steering components, depending on the characteristics of the tires, can have unsatisfactory or excellent indicators of stability and handling.

There are a number of side factors that often depend on random circumstances, but they are also important. The condition of the shock absorbers and their wear, the condition of the suspension, steering mechanism, camber/toe parameters, axle load, tire pressure.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Щодо питання акваланування та взаємодії автомобільної шини з поверхнею дорожнього покриття через шар води

Анотація. Проблема. *Процес взаємодії пневматичної шини автомобільного колеса з поверхнею дорожнього покриття, яке вкрите шаром води, впливає на безпеку дорожнього руху транспортного засобу, тому оцінка впливу ефекту акваланування при написанні висновків автотехнічної експертизи є актуальним напрямком дослідження. Дослідження ефекту акволанування дозволить зробити об'єктивний аналіз та сформувати не суб'єктивні висновки судовим експертам та спеціалістам автомобільної галузі.* ***Мета.*** *Метою роботи є визначення конструктивних параметрів та експлуатаційних особливостей пневматичної шини, а також швидкості руху транспортного засобу на процес взаємодії шини автомобільного колеса з поверхнею дорожнього покриття, яке вкрите шаром води.* ***Методологія.*** *Підходи, що прийняті в роботі для рішення поставлених цілей, базуються на теорії акваланування, теорії взаємодії пневматичної шини з поверхнею дорожнього покриття, теорії автомобіля та законах теоретичної механіки.* ***Результати.*** *Отримані результати дослідження у вигляді аналізу дають змогу оцінити вплив ефекту акваланування пневматичної шини на безпеку дорожнього руху. Встановлено, що товщина шару води впливає на умови виконання вимог встановлених правилами дорожнього руху, оскільки зменшення висоти рисунку протектори шини призводить до не стабільного контакту шини з поверхнею дорожнього покриття.* ***Оригінальність.*** *Результати дослідження надали можливість отримати уявлення про вплив конструктивних параметрів шин на безпеку дорожнього руху з точки зору формування висновків автотехнічної експертизи.* ***Практичне значення.*** *Отримані результати можуть бути рекомендовані судовим експертам при написанні висновків експерта та експертного дослідження.*

Ключові слова: *акваланування, автомобільне колесо, дорожнє покриття, шина, реалізоване зчеплення, коефіцієнт зчеплення.*

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