Development of adaptive anti-slipping spike for vehicle tires

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Abstract. The article describes the purpose of anti-slipping spikes, which are set into tire treads of vehicles. The advantages and disadvantages of using anti-slipping spikes are revealed. The assessment of the destructive effect of the use of anti-slipping spikes on the road surface is given. The inability to simultaneously solve the problems to ensure maximum adhesion of the vehicle’s wheel to the road surface and to minimize the destructive effect of anti-slipping spikes on this surface actualize the development of an adaptive anti-slipping spike. Unlike traditional anti-slipping spikes, the pin of the designed device is retractable. The article presents the variants of the design of the developed adaptive anti-slipping spike for vehicle tires.

1. Introduction
Roads are designed for vehicle traffic with relatively high speeds in relation to dirt, field, gravel, sand and other types of roads. High speeds of vehicles on the roads increase their traffic capacity, make it possible to increase traffic intensity, and, consequently, increase productivity and reduce the travel time of vehicles. However, these advantages of high speeds largely depend on the adhesion characteristics of the road surface, which are changing depending on the temperature and humidity of the ambient air and the speed of the vehicle [1].

The condition and parameters of vehicle tires (tire structure and, firstly, tread pattern, and air pressure), and the presence of anti-slipping devices (spikes or chains) play an important role in ensuring high adhesion indices.

The adhesion coefficient of the pneumatic tire and the road surface can vary from 0.8 (the standard roughness of the road, dry surface, a certain speed of the vehicle, the normal air pressure in the tires, etc.) to 0.1 and lower (ice, dirt, greasy road section, rain, worn-out tread pattern, locking of wheels when braking, etc.). The use of anti-slipping spikes for winter tires on icy roads can increase the coefficient of adhesion to 0.3-0.4 [2].

However, the use of spikes and anti-slipping chains during the operation of vehicles leads to the destruction of the road surface [3].

According to one of the Russian studies, one spike of a light vehicle tire wears out about 100 mcg of coating material for 1 km of run, and the entire surface of the spiked tire wears out about 24 g of coating material for the same distance. The European researchers’ calculations show that an increase in the average speed from 90 km/h to 110 km/h raises the intensity of destruction of the road surface twice [2].

Over time, the destruction of the road surface takes the form of a wheel track. Significant ways to combat wheel tracking can be a speed restriction for vehicles during the usage period of spiked tires, refusal of the use of anti-slipping spikes or reducing their permitted weight [4]. However, the use of
such methods will deprive roads of their main advantage – the advantages of high speed.

The inability to ensure maximum adhesion of the vehicle wheel to the road surface, while minimizing the destructive effect of the use of anti-slipping spikes on the road surface is a significant disadvantage of the use of traditional anti-slipping spikes.

The unpredictability of the conditions of tire slippage against the road surface poses the problem of ensuring the adaptability of the mode of change of the tire-to-surface adhesion coefficient.

2. Materials and methods

In the course of research work, developments with technical characteristics, able to solve the assigned problem in varying degrees, are identified.

There are anti-slipping spikes with retractable pins. The invention involves the use of radio-controlled spikes with retractable pins, the extent of the protrusion of which is determined by radio-control signals [5].

The disadvantage of this device is the need for a system with automatic or manual method of control of spikes and their operating modes on the basis of the use of radio channels of control, wireless power supply technology for controlled spikes, energy-converting devices in the radio-controlled spikes and the use of telemetric information for sustainable vehicle management in difficult road conditions.

There are also retractable spikes. They include a fluid reservoir in co-operation with a spring, and the spike pin is mounted onto this spring. The change in ambient temperature pushes the spike pin up and moves it back against the outer surface of the tread of pneumatic tire [6].

The disadvantage of this device is that the retractable spikes significantly complicate the structure of the base (tires or soles) on which they are installed: it is preferable to place the end of the fluid reservoir in the tread groove, that is, outside the main base material to determine the ambient temperature. At the same time, the reservoir may be damaged during operation. In addition, the device structure is complicated by the presence in the reservoir of an elastomeric element pushing the spike up or moving it back into the groove, depending on temperature changes. The use of elastomer is necessary to seal the fluid reservoir.

3. Adaptive anti-slipping spike

Employees of FSBEI HE “Pskov State University” developed an adaptive anti-slipping spike for vehicle tires, which solved the technical problem of improving the operation reliability of the device and simplifying a design of the spike.

The classic design of the anti-slipping spike consists of a hard-alloy wear-resistant insert, which is in contact with the road surface, and a steel body that holds the hard-alloy insert in the rubber [7].

The developed device solves the technical problem due to the fact that an adaptive anti-slipping spike contains a body (1) and a pin telescopically moved inside the body (3), and the pin is in contact with the temperature-sensitive element (2), which is located inside the body and is made of a material capable of expansion at negative temperatures. The body material is a material with high thermal conductivity (Figure 1), and the material of the temperature-sensitive element has a negative coefficient of thermal expansion (shape memory). When the ambient temperature drops below 0°C, the temperature-sensitive element expands, providing the extrusion of the pin from the body of the anti-slipping spike.
Figure 1. Configuration of the adaptive anti-slipping spike.

Figure 1 A shows the developed adaptive anti-slipping spike at ambient temperature, providing the maximum degree of compression of the temperature-sensitive element. Figure 1 B shows the adaptive anti-slipping spike at ambient temperature, ensuring the maximum extrusion of the pin from the body of the spike.

The temperature-sensitive element of the adaptive anti-slipping spike for vehicle tires ensures the longitudinal movement of the pin when the ambient temperature changes. It can be made in the form of a prism (2), and there is a gap between it and the side wall of the body (Figure 2 A). An alternative is that the temperature-sensitive element is made in the form of a cylindrical spiral (2), the outer surface of which is in contact with the side wall of the body (Figure 2 B). In this case, non-freezing grease can be applied to the entire surface of the spiral, and the body may have a pin (4), around which the temperature-sensitive element (2) is located (Figure 2 C). The pin may have a contact area with the temperature-sensitive element larger than the contact area with the road surface.

Figure 2. Design variants of the temperature-sensitive element of the adaptive anti-slipping spike.

The body material of the adaptive spike can be steel or aluminum. The material of the pin is a hard alloy VK8 or its analogue in hardness and wear resistance. The use of these materials will provide a high coefficient of thermal conductivity from the environment and the surface, on which the vehicle is moving, to the temperature-sensitive element.

Water, graphene, copper oxide, zirconium tungstate, hafnium tungstate, zirconium molybdate, hafnium molybdate, scandium trifluoride and other materials with a negative coefficient of thermal expansion can be a material for the temperature-sensitive element [8]. In addition, titanium nickelide,
ferrum nickelide, copper-zinc-aluminum alloy, ferrum-manganese-silicon alloy, copper-aluminum alloy, copper-manganese alloy, cobalt-nickel alloy, nickel-aluminum alloy and others with a shape memory at temperatures below 0°C can be a material for the temperature-sensitive element [9,10].

The principle of operation of the developed adaptive anti-slipping spike for vehicle tires is as follows: when the ambient temperature drops below 0°C, the temperature-sensitive element expands, ensuring the extrusion of the pin from the body of the anti-slipping spike. When the ambient temperature rises above 0°C, the temperature-sensitive element compresses, allowing the pin to move back into the body of the spike. The same principle of operation can be provided by the components of the material with a shape memory, from which the temperature-sensitive element is made.

The result of the use of the developed adaptive anti-slipping spike will be ensuring of maximum adhesion of the vehicle’s wheel to the road surface and minimizing of the destructive effect of anti-slipping spikes on the road surface.

4. Conclusions
An important role in ensuring high adhesion of the vehicle tire to the road surface is played by the presence of anti-slipping devices – spikes or chains. In ice conditions, the coefficient of adhesion of the tire to the road surface may be reduced to 0.1 and lower. In such conditions, the use of anti-slipping spikes on winter tires can increase the coefficient of adhesion to 0.3-0.4.

However, the use of anti-slipping spikes leads to the destruction of the road surface. One spike of an automobile tire wears out about 100 mcg of coating material for 1 km of run. An increase in the average speed on the road section from 90 km/h to 110 km/h raises the intensity of destruction twice.

Over time, the destruction of the road surface takes the shape of a wheel track.

A significant disadvantage of the use of traditional anti-slipping spikes is the inability to ensure maximum adhesion of the vehicle’s wheel to the road surface and to minimize the destructive effect of anti-slipping spikes on the road surface.

In the course of research work, developments with technical characteristics, able to solve the problem in varying degrees, are identified. However, each of them has serious disadvantages: the need for a system with automatic or manual method of control of spikes and their operating modes, added complexity of the tire structure, etc.

The employees of FSBEI HE “Pskov state University” developed the adaptive anti-slipping spike for vehicle tires, containing body and a pin telescopically moved inside the body. The pin is in contact with the temperature-sensitive element, which is located inside the body and is made of a material having a negative coefficient of thermal expansion (shape memory). When the ambient temperature drops below 0°C, the temperature-sensitive element expands, providing the extrusion of the pin from the body of the anti-slipping spike.

The adaptability assurance of the mode of change of the adhesion coefficient to the road surface will preserve the safety of movement of a vehicle on the icy road and, at the same time, will significantly reduce the wheel tracking of the road surface formed by the pins of traditional anti-slipping spikes.

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