Ways to Improve the Durability of Pneumatic Tires

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Abstract. Current trends of functional improvement of pneumatic car tires are described in the article. As a rule, these are the structural features of a car wheel that allow getting the nearest service station after a tire damage. The airless tire design eliminates the damages specific for pneumatic tires. They have been used for construction vehicles and military vehicles exclusively. However, improving the durability of pneumatic tires is relevant. This is due to the increase of free speed. There are two ways to improve the durability of automobile tires. The first way is to use tire damping, thanks to the new material structure of the tire. The second way is to use thermoelectric cooling to reduce thermal effects on the tire.

1 Introduction
Recently, the development direction of pneumatic tires is mainly connected with a wear resistance increase and with an ensuring movement when interacting with water and with ice.

In addition, a large amount of work is done to ensure the functionality of pneumatic tires for punctures and damages. This is an automatic repair using a sealant placed inside the tire - Goodyear’s Dura Seal system; reinforcement of tire sidewalls — Run Flat system and use of supporting rings located inside the tire - a system of type ContiSupportRing. All these systems provide safe traffic conditions to the nearest service station after tire damage (refer with Figure 1, Figure 2).

Figure 1. Run Flat system - the side parts strengthening of the tire [2]
The development and implementation of airless tires allow eliminating a number of disadvantages inherent in pneumatic tires. However, the operation of such tires at high speeds is connected with increased vibration, noise and heating; therefore, their field of application today is limited by the use for construction machines and some types of vehicles (refer with Figure 3).

However, in the near future the need to significantly increase the durability of pneumatic tires may become particularly relevant. First of all, the reason for this is connected with the development of unmanned vehicles, which in the future will move at much higher speeds than the current ones.

Two factors that limit the increase of durability of pneumatic tires: the critical rolling speed of tires and their heating are considered in this paper. Solutions to these problems are suggested.

2. Reducing of tire vibrations with the new structure of its material
The cars speed change from 1940 to 2016 is shown in the table. The speeds given in the table are achieved, as a rule, on tracks or on special sections of roads.

Today, the limit top speed on public roads is from 150 to 200 km/h. The tendency to increase the speed on highways is reflected in the construction of high-speed roads. For example, the Arrivo startup in the USA, intends to build a road with a speed limit of 320 km/h already in 2021.
Table 1. Maximum speeds of each decade

| Decade      | Car                           | Speed, [km/h] |
|-------------|--------------------------------|---------------|
| 1940-1949   | Jaguar XK120                   | 195           |
| 1950-1959   | Aston Martin DV4 GT            | 245           |
| 1960-1969   | Ferrari 365 GTB14 Daytona      | 280           |
| 1970-1979   | Ferrari GT4 Berlinette Boxer   | 280           |
| 1980-1989   | Ferrari F 40                   | 325           |
| 1990-1999   | McLaren F 1                    | 385           |
| 2000-2009   | Shelby SSC Aero                | 430           |
| 2010-2016   | Hennessy Venom GT              | 435           |

In connection with the steady increase of the free speed, the problem of the critical rolling speed, at which tire destruction is possible, becomes urgent. The initial cause of the critical rolling speed is mainly due to the fact that at high speeds, in the area of the tire exit from the road, the tire experiences intense fluctuations. The emergence of such fluctuations clearly demonstrates the modeling of a pneumatic tire using a mechanical rotating brush working with some tension. It is obvious that the damping of vibrations in the area of the tire exit from the contact zone can increase the level of occurrence of the critical rolling speed.

Given the nature and conditions of vibrations, a bionic approach is proposed to use, considering the nature of the vibration protection of such a bird as a woodpecker. The speed of the woodpecker’s beak can be up to 25km / h. However, the negative acceleration with the woodpecker’s head is thrown back does not cause physical damages. It is found that there is a layer of intracranial fluid between the skull and the bird’s brain, which does not allow vibration to have a dangerous effect on the brain. This fluid is quite viscous - it quenches the waves arising from the impact that can damage the nerve center. Studies have shown that the structure of a woodpecker’s intracranial bones, contains spongy porous tissue almost all of them, which is an additional shock-absorber. In addition, a hyoid - complex bone cartilage is involved in protecting the brain from shock loads.

The analogue of a natural vibration damping device can be used to dampen vibrations at the tire exit from the contact patch. Porous rubber is proposed as an alternative solution, the pores are partially or completely filled with a viscous fluid. The creation of such tires is facilitated by the following circumstance.

In a number of countries in Eastern Europe, in Germany, in the Netherlands, in Portugal and in Japan, winter studded tires are prohibited. Used non-studdable winter tires have a microporous structure that provides the formation of micro capacities on the abrading surface of the tire, that absorb the water formed between the tire and the ice surface. Therefore, the company Bridgestone produces non-studdable tires Blizzak Revo GZ (refer with Figure 4), similar microporous tires manufactured by Yokohama (refer with Figure 5) and Nokian. In that way the company, Bridgestone produces non-studdable tires Blizzak DM-V1 on technology Tube Multicell Compound, which is a microporous rubber with solid particles in the pores. Similar microporous tires are produced by Yokohama and Nokian. Thus, filling the pores in a rubber with a viscous fluid can provide active vibration damping of the oscillations that occur when the tire leaves the contact patch, thereby raising the threshold of the appearance of the critical tire speed.

3. Using the Peltier effect to increase tire durability
The second factor limiting the durability of tires is connected with their inevitable heating at hyper-velocities, and the thermal problem concerns not only pneumatic, but also airless tires. It is known that the optimum mode of the tire is the temperature from 70 to 750C. When heated to 100°C, rubber durability and the bond strength between rubber and cord are reduced by 1.5 to 2 times, and heating to 120°C is already considered dangerous.
4. Results

However, strong cooling also has a negative effect on tires. At a temperature of $-40 \, ^\circ C$ and lower, cold tires made from non-frost resistant rubber can crack if they take off and hit hard. To avoid this, within the framework of the Dutch project Clean2Antartic, when developing the Solar Voyager all-terrain vehicle intended to move to the South Pole, instead of off-road tires, soft pneumatics with an external electric heating band were used to warm the pneumatics and to warm the ice if necessary.

Thus, the device allows to cool or heat the tire, would significantly increase its durability. Such a solution can be a device based on the Peltier effect, which is a thermoelectric converter that, when energized, can create a temperature difference across the contacting semiconductors, that is, perform cooling or heating (to ensure the latter, it is enough to change the polarity). Peltier elements located on the inner of the tire should be connected to the on-board system via electrically conductive rubber, which in a number of companies (Continental, Pirelli) is used in a driver information system on the tire temperature. The use of direct (cooling) or reverse (heating) effects on the tire can improve its performance.

5. Summary
The novelty of this work lies in the proposal of the new structure of the tire material. This structure can increase the threshold of the formation of critical rolling velocity. In addition, the thermoelectric effect will allow to reduce the thermal effect on the tire at high speeds.

The practical value lies in proposing ways to increase the durability of pneumatic tires.

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