Tire tread optimization method to improve to push aside the water from the road contact patch

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Abstract. The paper is devoted to the development of a method for optimizing the tread pattern to push aside the water from the road contact patch. This technique works with ready-made tread patterns of any type. Today, the methodology under consideration is relevant, since it prevents the occurrence of one of the most common causes of road accidents - aquaplaning. Currently, it is impossible to eliminate the risk of such an effect. It can only be reduced by slowing down or ensuring a uniform load on all wheels, trying to drive through the puddle with all four wheels.

1. Introduction
Aquaplaning is an effect that occurs when driving a car at high speed in wet weather. It can be observed at speeds ranging from 90 km/h. Aquaplaning occurs when the car slides on water and the feel between the tire and the road will be lost. A water wedge arising in front of the wheel raises the machine and deprives it of control. Most often, aquaplaning occurs in shallow puddles, in which the least water resistance to the wheel [2].

Automakers are struggling with the effect of aquaplaning by applying special patterns to the tread of the tire that pushes aside water from the contact area with the road and improves the grip, handling, and passability. Nevertheless, one needs to monitor the degree of tread wear-out, since the coefficient of the contact area between the worn-out tire and the asphalt is much less. Despite the huge selection of different tread patterns, universal tires that would be far ahead of the rest ones are almost impossible to create.

The method described below optimize absolutely any tread pattern. It can be used to calculate both a completely new tire and a worn one. In the future, there will be possible not to create the perfect tire, at least improve the performance indicators of any existing tires.

2. Problem statement
The case of a car colliding at high speed on a water volume simulating a puddle is considered in this paper. Calculations were performed on the basis of CML-Bench using commercial licenses LS-DYNA and computational resources of CNTI. The fluid volume is set using the SPH method. This method - Smoothed Particle Hydrodynamic - simulates the volume of fluid in the form of pseudoparticles interacting with each other, connected by a general equation of state. Each pseudoparticle has its mass, speed, energy, and the so-called smoothing length, within which the core
function “smooths” its properties. Thus, each of the particles can be calculated by summing the parameters of neighboring particles - within two smoothing lengths [5].

To simulate fluid flow using SPH in LS-DYNA, only a couple of points are different from conventional structural analysis. To ensure quasi-incompressibility, the Murnaghan equation of state can be used, allowing a reasonable time step in explicit calculations. Water is also modeled using the Grünenzein or Mi-Grüneisen equations. In this problem, Murnagan equation was chosen because confirmed constants from experiments were found.

Murnagan’s equation of state defines pressure as

$$p = k_0 \left( \frac{\rho}{\rho_0} \right)^\gamma - 1$$

where $\gamma$ and $k_0$ – constants.

For accurate modeling of fluid flows $\gamma$ is often equal to 7, and $k_0$ is chosen so that

$$c_0 = \sqrt{\frac{\gamma k_0}{\rho_0} \geq 10 \nu_{\text{max}}}$$

where $\nu_{\text{max}}$ – maximum expected fluid flow rate.

This provides low compressibility, given the relatively large time step size.

The task is divided into two main stages:

1) a preparatory stage for setting sph-elements, finding the optimization criteria and the evaluation of the model as a whole
2) parametric optimization to assess the performance of this technique

A. The first stage. Optimization preparation

The preparatory phase is carried out to determine and verify possible criteria for future optimization, as well as to configure the correct interaction of sph elements.

Due to the complexity of the geometrical shape of the parts, this problem cannot be solved by analytical methods; therefore, the calculation in LS-DYNA is carried out using the numerical finite element method. The design is divided into simple elements that connect at nodal points. To them, equations are written that describe their states, which add up to systems that work for the entire structure as a whole [1].

In order to reduce the necessary computing power, a reduced wheel model is considered instead of the whole car, taking into consideration the impact of the car on the wheel itself.

The test computational model is a car tire without a tread pattern, mounted on an aluminum rim (Fig. 1). It runs into a water volume created using SPH elements. The set speed of the wheel is 90 km/h.

![Test computational model](image)

**Figure 1.** Test computational model.

At the center of mass of the tire, the concentrated mass of 300 kg is hung, simulating the effect of the machine on the wheel. This corresponds to the mass of the car per wheel with a total mass of 1200 kg and an ideal weight.
The tread consists of two layers: a rubber layer of SOLID type elements (ELFORM 3) and a simplified cord model, which is a homogenized layer of rubber and steel elements of the SHELL type (ELFORM 2). The sectional finite element tire model is shown in Fig. 2.

![Finite element model of the tire](image)

**Figure 2.** Finite element model of the tire.

The main properties of the materials of which the tire is made are presented in Table 1.

| Material     | Young's module, MPa | Poisson's ratio | Density, kg/m³ |
|--------------|---------------------|-----------------|----------------|
| Rubber       | 5                   | 0.3             | 1500           |
| Rubber+Steel | 30000               | 0.3             | 7850           |

**Table 1.** Material properties.

B. *The second stage. Optimization*

The optimized computational model is a tire with an arbitrary tread pattern (Fig. 3). In order to reduce computing power, one-fourth of the tire will be considered, which not influence the results. The statement of the problem with two different tire speeds - 90 and 110 km/h is examined that allows comparing optimization performance indicators.

![Optimized computational model](image)

**Figure 3.** Optimized computational model.

The possible optimization criteria will be the resistance forces that are controlled by the system that simulates the car's suspension. The car body is imitated as two plates moving along the line of its movement and connecting to the center of mass of the wheel using control elements to remove the force.
At the point of their connection, there is a hinge working on torsion, so that the plates do not limit the rotation of the wheel.

Parametric optimization is carried out using the LS-OPT software package. This graphical tool allows the user to structure the design process, explore the design space, and calculate optimal projects according to specified constraints and goals.

The LS-OPT graphical tool interacts with LS-DYNA and provides an environment for setting optimization input, monitoring, and managing parallel modeling and optimization data after processing, as well as viewing multiple projects using LS-PREPOST.

The goal of optimization is to modify the tread pattern to a more effective one; the criterion is to reduce the water resistance force. The optimization parameter is the thickness and shape of the tread pattern grooves. Longitudinal grooves can vary in thickness from -3 to 3 mm, diagonal ones - from -2 to 2 mm. The extreme diagonal grooves change symmetrically, the middle ones change similarly.

Along the entire length of each diagonal groove, individually changing parameterizing points are set for the possibility of obtaining a curved shape (Fig. 4).

![Parameters for changing diagonal grooves.](image)

3. Results

A. The first stage. Optimization preparation

At the first stage, it was necessary to check the operability of sph particles as well as to find a suitable criterion for optimization. The estimated time is 0.015 s. At this point, the effect of aquaplaning is already observed. This time is sufficient to visualize the tire hits the puddle and analyze the behavior of SPH particles.

Figure 5 shows the visualization of how SPH particles work after the wheel hits them at different times. It can be noted that the particles interact with each other and act as a single unit, working effectively. The SPH method is suitable for modeling a puddle in the problem under study.
At the first stage, the calculation resulted in finding the optimization criterion. The vertical force of water resistance – the upward force - was chosen as this criterion. Minimizing the force means more successful removal of water from the road contact patch. The graph of the upward force is shown in Fig. 6.

As can be seen on the chart, first, there is a small jump during hit the puddle, and then the force begins to increase rapidly, reaching its peak at the certain point. When the optimization is set, the force will be minimized directly in this time period.

**B. The second stage. Optimization**

The objective of the work was to develop the methodology for optimizing any tread pattern; therefore, a ready-made pattern was taken as the basis (Fig. 7). The symmetrical directional pattern was chosen because such ones are considered as the best way to prevent aquaplaning.
The optimization criterion is the upward force, which has to be minimized. The first optimization calculation was performed at the tire speed of 90 km/h. It took a long time to go through the options for changing the original tread pattern due to the limited power of computer resources. Later, this method can be improved using more powerful computing technology, which would set a greater number of possible changes. The optimization process came together in 10 iterations, and the intermediate steps are shown in Fig. 8. The final tread pattern is shown in figure 9.
At the same time, the force of pushing the tire out of the water decreased by 9%. The graph of changes in the indicators of this force depending on iterations is shown in Fig. 10.

![Optimization graph at a speed of 90 km/h.](image)

**Figure 10.** Optimization graph at a speed of 90 km/h.

The optimization process at the speed of 110 km/h converged in 10 iterations; the intermediate results are shown in Fig. 11. The final tread pattern is shown in Fig. 12.

![Intermediate steps to optimize the tread pattern at a speed of 110 km/h.](image)

**Figure 11.** Intermediate steps to optimize the tread pattern at a speed of 110 km/h.

![Tread pattern after optimization at a speed of 110 km/h.](image)

**Figure 12.** Tread pattern after optimization at a speed of 110 km/h.

At the same time, the force of pushing the tire out of the water decreased by about 12%. The graph of changes in the indicators of this force depending on iterations is shown in Fig. 13.
The comparison of dependence graphs of the value of the upward force on the time before and after optimization is given below (Fig. 14). Before optimization, the maximum upward force was 916.8 N, and after that - 811.4. The decrease in strength indicators was 12%.

4. Conclusion
This article has developed a method for parametric optimization of the tread pattern in order to reduce the risk of aquaplaning. This method is relevant, in view of the fact that today there is no ideal tread pattern that would exclude the possibility of such an effect. However, this method can be used to improve the efficiency of any existing tread pattern.

This method has been tested in the problem of driving a wheel over a volume of water at high speed, which creates a dangerous aquaplaning effect. Two design cases were considered, with a vehicle speed of 90 and 110 km / h. The force of water pushing was used as an optimization criterion. As a result of optimization, it decreased by 9 and 12%, respectively.

This technique can be improved, made more flexible and efficient. This requires more powerful computers that can be used to input more parameters into the optimization. Also, this technique can be adapted for other important calculations related to the cross-country ability of vehicles on various complex surfaces, which can be easily modeled using the sph method.

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