The research of the elastic propulsion unit and soil contact area shapes and sizes

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Abstract. Research of the elastic propulsion unit and soil contact area shapes and sizes has been carried out. The basic mathematical methods for solving the problem of the fundamental capabilities of the propulsion unit determination are listed. The main dependencies for solving this problem are given.

Considering the flotation as a result of the vehicle propulsion unit interaction with soil, it can be found that this is a consequence of the propulsion unit and soil contact area properties, in particular, its size and shape [1].

From this point of view, the estimated parameters of the cross-country ability of a vehicle with any type of propulsion unit are precisely the properties of the contact area formed by the vehicle on the soil. Hereinafter we will call it the response area.

It is of interest to explore which of the considered properties (size and shape) of the response area are optimal for obtaining the highest cross-country ability. Each of the known propulsion units (wheeled, tracked, walking, etc.), as well as hypothetical types is characterized by its inherent dimensions (we take into account the specific ones) and the shape of the response area. It is known that the undeformed round wheel on hard ground (for example, a cylinder on a plane surface) forms the straight line response area parallel to the axis of the wheel [2]. If it is the driving wheel, then all the supplied energy is converted into the energy of the vehicle movement on the response area. In this case, the response surface has an infinitely small area. The result is the infinitely large specific loads. For this reason an absolutely rigid round wheel interacting with a non-deformable support surface cannot perform successfully the functions of a driving wheel. That is why the elastic non-round wheels are used as propulsion units of ground vehicles. Most often, they have a form of a pneumatic tire on a hard rim.

Figure 1 shows an example of an all-terrain vehicle «NAMI-094» with the elastic non-round pneumatic tires. Figure 2 shows an example of an all-terrain vehicle TTS-3901 «Aldan» with ultra-low pressure tires manufactured by LLS «Transmash» [6, 7].

In the theory of the cars and ground vehicles and in one of its section - the cross-country ability theory - the non-round wheel is transformed into a round wheel by artificial methods. This allows characterizing the rolling process by one or several radii. However, using elastic wheels for increasing the vehicle's cross-country ability requires further development of the cross-country ability theory relating to the non-round wheels. The process of power converting into the energy of vehicle movement during the power transmission from the engine to the wheel shaft through the power drive
should be considered in passing from the analysis of a round wheel with an elastic tire to the analysis of an elastic wheel. The fundamental capabilities of elastic wheels of the different non-round forms can be analysed and recommendations on the design development of wheels of one form or another are given.

**Figure 1.** Vehicle with the elastic non-round pneumatic tires.

**Figure 2.** Vehicle with the elastic non-round pneumatic tires.
Under the fundamental capabilities of the propulsion unit we mean the best cross-country ability, which can be achieved without regard to the material costs of the propulsion unit.

The conclusions obtained when solving the problem of propulsion unit fundamental capabilities are applied, of course, not only to the cars, but also to other vehicles. It should be noted that no assumptions about the propulsion unit design have been made yet: only its structural model, devoid of substance, is considered.

The problem of fundamental capabilities of the propulsion unit can be solved using only the theoretic probability approach [3]. As a mathematical model of the soil (its passability), should be used only a regular random process, rather than its separate implementation, which in essence is most likely to be not the random, but indefinite in terms of soil properties.

The characteristics of the best propulsion unit (mathematical transformation $\tilde{P}$, performed by the propulsion unit) depend not only on the restrictions imposed on it, but also on the characteristics of the supporting surface at the moment of its interaction with the propulsion unit. The propulsion unit is the best only for the soil of a given bearing capacity. In order for a propulsion unit to be the best for all soils, its characteristics should change with a change of the soil passability. Since it is impossible to predict in advance the passage of vehicle from one soil to another, the best propulsion unit should be self-adjusting.

When a vehicle is moving, the actual characteristics of the soil passability should be determined experimentally with an accuracy that makes it possible to consider this road surface as the implementation of a stationary probability process. The difficulty is in that the properties of soils, which determine their roadability, vary several times over short segments, and that they (properties) depend on humidity, temperature, charges of static electricity and direction and intensity of magnetic fields.

Determining the fundamental capabilities of the propulsion unit is reduced to a mathematical problem that has a single solution and consists in determining such a physically feasible transformation where the random process

$$ U(t) = \tilde{P} \cdot x(t) $$

would provide the minimum of the specified functionality

$$ f = f[y(t)] $$

provided that given functionals are the following

$$ \psi_i = \psi[y(t), x(t)] \leq \lambda_i $$

where $\lambda_i$ – given numbers. A stationary random process is considered as given. This mathematical problem is called the isoperimetric problem of approximation of random processes, since it has much in common with the isoperimetric problem of the calculus of variations. For determination of class of functionals $f$ and $\psi_i$, the problem consists in evaluation of the minimum of the functional

$$ \varphi = f + \sum_{i=1}^{\Sigma} \theta_i \psi_i $$

$\theta_i$ – undetermined Lagrange multipliers.

As applied to the problem of the fundamental capabilities of the propulsion unit, the values in the isoperimetric problem of the random processes approximation correspond to: $x(t)$ – bearing capacity (passability) of the soil; $\tilde{P}$ – transformation carried out by the propulsion unit; $y(t)$ – resultant of forces and moments transmitted by the vehicle propulsion unit to the ground; $f$ – criterion of traction properties and $\psi_i$ – criterion of the propulsion unit slipping on this ground.

The best propulsion unit (the best transformation $\tilde{P}$) and the corresponding characteristics $y(t)$ depend on the type of criteria $f$ and $\psi_i$, as well as on the values $\lambda_i$ that limit the slipping and on the characteristics of the bearing capacity of the soil [4]. The type of criteria $f$ and $\psi_i$ significantly affects the ability to solve the problem in general.
The bearing capacity of the soil $x(t)$ can be determined through the potential energy of the soil deformation or propulsion unit. The potential propulsion unit energy can be calculated by considering the simplified elastic propulsion unit models that accurately reflect the pattern of deformation of the real soil. When the elastic toroid is used as a simplified model, the potential energy of the air inside can be easily calculated: it is known to be equal to the product of the occupied volume by the pressure. The air volume can be found by integrating the transverse (meridian) cross-section area of the toroid along the length of its midline (in the equatorial plane), taking into account the law of variation of the cross-section along the length of the contact area and beyond [5].

Overall, it can be concluded that the practical purpose of the research, i.e. the shapes and sizes of the contact area of an elastic propulsion unit with the soil, is to determine the fundamental capabilities of the propulsion unit of the vehicle for ensuring its best cross-country ability.

In turn, the task of such research is reduced to determination of such physically feasible mathematical transformation $\bar{P}$ of forces and moments supplied to the propulsion unit from the vehicle's engine, which would ensure the best cross-country ability with given restrictions on the soil passability.

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