EVALUATION OF VEHICLE PERFORMANCE ON SNOW

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Transportation is one of the largest strategic industries, and has a direct influence on the socio-economic development, national defense, and national security of a country.

Due to the lack of paved roads, more than 10 percent of Russia‘s population (15 million people) is cut off from transport communications in the spring and autumn. There are 466,000 localities, or 31% of the total number, which lack paved roads. 260 of these localities have a population of more than 1,000 people. [1]

The presented figures show that 90% of the entire territory of Russia is permanently covered with snow for 5 to 10 months of the year. The mean snow depth is 0.3–0.6 m (in ravines it is up to 1–3 m), but can reach up to 1.2 m or even more (in ravines up to 4–10 m) in some regions of Siberia and the Far East. Approximately 30% of the total area of the country is covered by snow with a load capacity of less than 0.02 MPa. Another 30% of the territory has snow with a load capacity of 0.02–0.04 MPa, while the remaining area is covered by snow with a load capacity of over 0.04MPa [2].

Under these circumstances, getting around is difficult or even impossible.

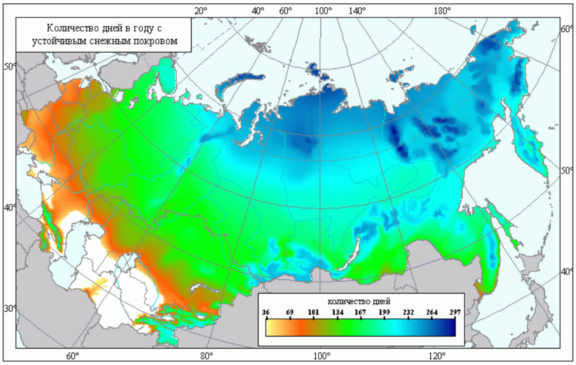

Figure 1. Average duration of seasonal snow cover in Russia and the CIS countries [3]

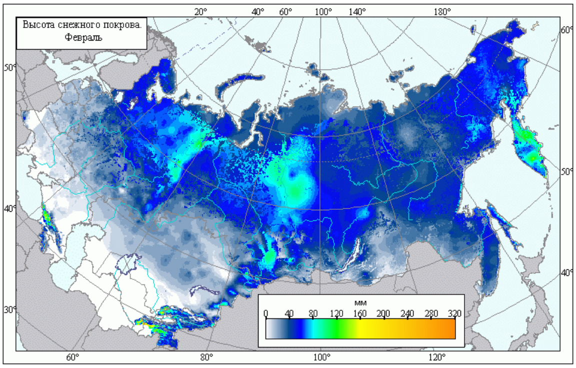

Figure 2. Average depth of snow cover in the territory of Russia and CIS countries [4]

These factors limit the geographical mobility of the population, curb the integrated development of new areas as well as the development of mineral deposits, and reduce the efficiency of emergency services, civil defense, and special services of national security.

Consequently, it is necessary to improve the transport system and create competitive high-quality transport services that will enhance the development of an innovative, and people-centered economy.

One possible way of solving the existing problems is by creating a new generation of off road vehicles. These vehicles would be able to carry out transport operations on deteriorated roads, in poor conditions, and on virgin snow.

Therefore, it is necessary to emphasize the importance of snow studies. The main physical and mechanical properties of snow are density, hardness, cohesion, and internal friction.

There are complex empirically derived dependencies that occur between the discrete properties of snow. It was found that the most critical factor is the snow density. The dependencies between main snow properties and density were developed at the NNSTU (Fig. 3).

The ability to drive on a snow-covered road is determined by traction, which is expressed as the difference between the force applied to the wheel from the motor and the forces resisting this motion (Fig. 4).

The total resistance force is derived from the resistance of motion which is the sum total of: vertical deformation of the snow by the tractive body (F_{fc}) and the trailer ($F_{fпр}$), the excavation-dozing effects ($F_{fэб}$), the crumpling of the snow by the vehicle bottom ($F_{fдн}$), the air resistance (F_{fw}), the rolling resistance (F_f) and the inertial forces that occur during the relative rotation of the wheels ($F_{ин}$). This is defined by the equation (1):

$$F_\Sigma = F_f + F_{fc} + F_{fэб} + F_{fдн} + F_{fпр} + F_{fw} + F_{ин}, \quad (1)$$

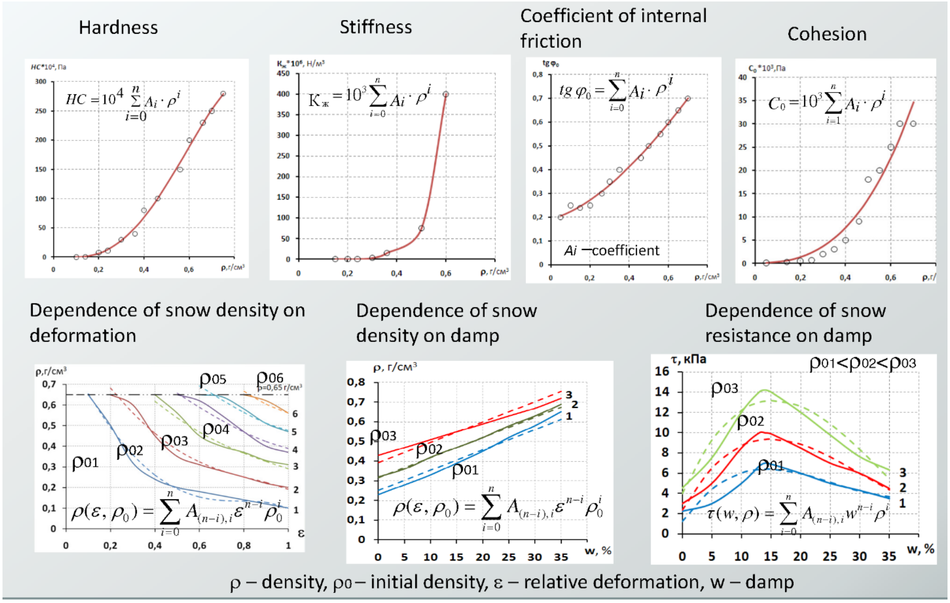

Figure 3. Physical and mechanical snow characteristics

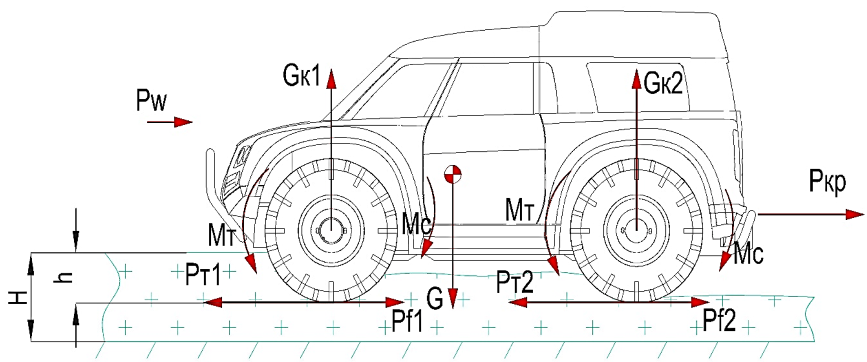

Figure 4. The forces and moments acting on the car driven on a snow-covered road

As the actual properties of snow greatly complicate the process of determining the values of the factors of the resistance force, it becomes necessary to determine not only the theoretical but also the experimental parameters. For example, the rolling resistance force is calculated by the formula (2),

$$F_f = f \cdot G_a, \quad (2)$$

where f – is the rolling resistance coefficient that depends mainly on the properties of the tire and the supporting base as well as the speed. Generally speaking, where f_0 is determined experimentally. Studies have found that when an ***Arktiktrans*** low pressure tire 1300 x 700-24» is when driven over packed snow, the coefficient f_0 = 0.039 when the air pressure of the tire is 0.035 MPa [4].

Snow is a deformable supporting surface that is compacted and destroyed by driving. This is taken into account when calculating the motion resistance forces of compaction (3) and the excavation-dozing effect (4).

$$F_{fc} = 2b\gamma h_{\max}^2 \left(-\ln\left(\frac{\gamma h_{\max}}{\gamma h_{\max} + q_{\max}} \right) - \frac{q_{\max}}{\gamma h_{\max} + q_{\max}} \right), \quad (3)$$

$$F_{f\,\acute{y}\acute{a}} = 2b\gamma h_{\max}^2 \left[\ln\left(1 + \frac{\Delta h}{h_{\max}} \left(1 + \frac{q_{\max}}{\gamma h_{\max}} \right) \right) - \frac{\Delta h}{h_{\max}} \right], \quad (4)$$

where Δh – is the snow depth exported from the contact zone to the cross-axle area as a result of the excavation and bulldozing effects, h_{max} – or snow deformation corresponds to the maximum compaction, and q_{max} – to the maximum pressure of the mover.

Maximum pressures greatly affect the stresses of the contact area between the tractive body and the supporting surface, which in turn determines the motion resistance force. In the calculations the q_{max} is determined using Letoshnev's formula and is limited by tire stiffness.

While calculating the distribution of the normal pressures of the contact area between the snow and the tire, some assumptions were made as to the appearance of the tire: in the longitudinal section it has the shape of a circle with a diameter D, and in the cross-section the surface of the tire that is in contact with the snow has the shape of an ellipse.

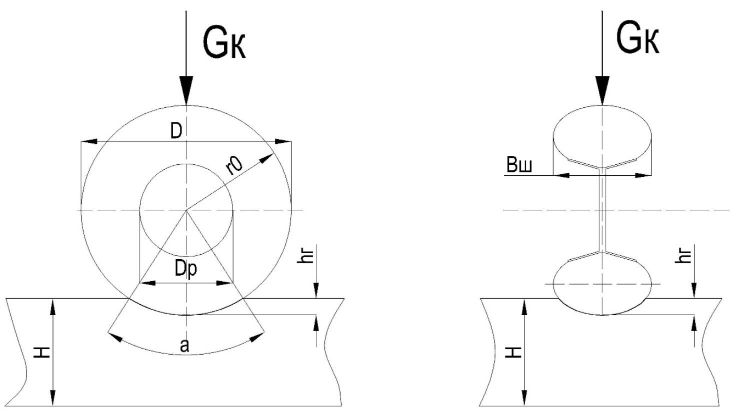

Figure 5. Scheme of the calculation model

The arc length L determines the values of the contact pressure between the tire and the ground according to the driving depth and the cosine law of distribution, taking into account Letoshev's formula. [6]

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$$q_0 = ch^{\mu}{}_{г} cos^2 \varphi$$

The cross-section of the tire, based on the assumption of a sidewall, is shown as an ellipse with axes Ш1 and Ш2 (Figure 6).

$$q = q_0 cos^2 \varepsilon$$

The pressure distribution in the cross-section is taken as in Formula 5.

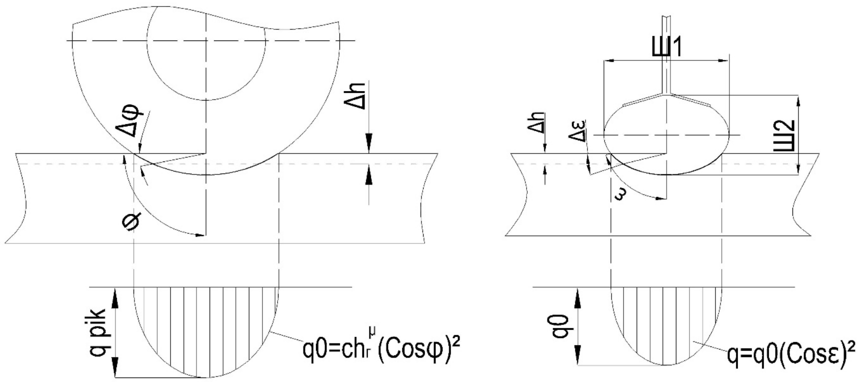


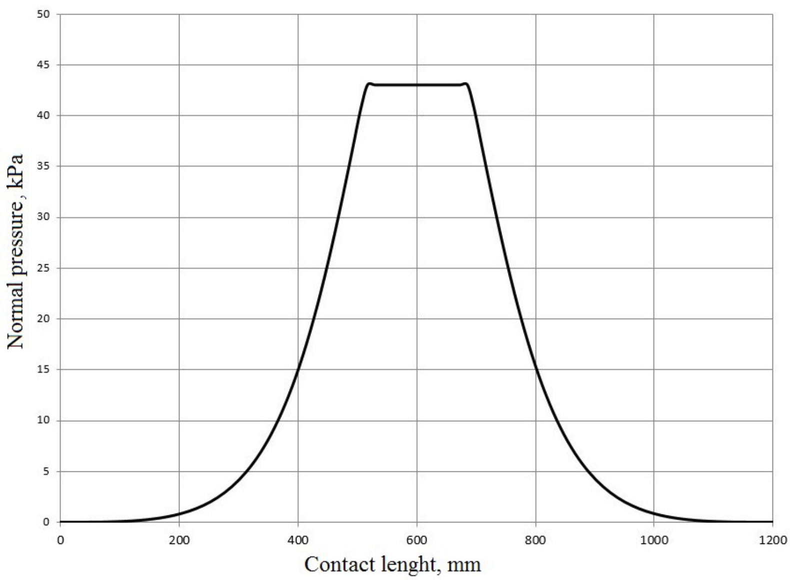
Figure 6. Scheme of pressure distribution of the tire on snow.

Thus, knowing the value of the pressure at each point of the longitudinal, and cross-sections of the tire, we can obtain a picture of the normal pressure distribution of the wheel's contact patch with the snow, and based on the size of the contact patch, are able to calculate the resulting normal reaction. If the pressures from the snow cover exceeds the limit pressure value of the tire, which consists of tire air pressure and tire carcass pressure, [2] they will be restricted by the given value. The result of this restriction is clearly seen in Figure 7. As can be seen, this approach simulates normal tire deformation at the peak point and gives a clear picture of the interaction between the snow and the tire. Furthermore, when the wheel passes over the snow, its physical-mechanical properties change, which must also be considered when determining the forces occurring in the subsequent interaction of the wheels with the surface of motion.

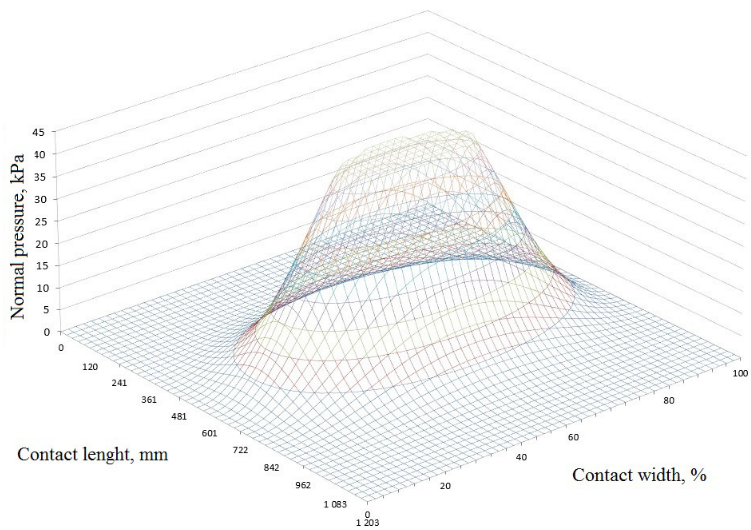
Motion in difficult conditions, even at low speeds, happens unevenly due to wheel spin. Thus, the inertia force of the wheels plays a significant role in motion resistance.

The present research studies the impact of design parameters, such as the size of the tractive body and its clearance.

Based on the data obtained from tractive performance calculation we determined the maximum possible speed of a vehicle under various conditions.



a) Distribution of the normal pressure of the longitudinal central section of the wheel when it is submerged into snow.



b) Distribution of the normal pressure when the wheel is submerged in snow.

Figure 7. Schemes of distribution of normal pressures

Figure 8 shows the result of the calculations for a vehicle with low pressure tires, and a GVW of 3600 kg (weight of cargo is 800 kg) when it is driven on snow that has a density of $\rho_0 = 0.227$ g / cm^3, an initial stiffness of $\gamma = 44.973$ kPa/m, a coherence $C_0 = 0.7836$ Pa, an internal friction angle tg j= 0.3543, and a depth of $H_{сн}$ 60 cm. The diagram shows that when wheel size is increased, but the remaining parameters remain the same (engine power, coefficient of slipping and others), the speed of the vehicle is reduced to a complete stop, as motion becomes impossible.

With an increase in the wheel size, the mass increases in proportion, and thus horsepower inputs to overcome wheel inertia must also be increased. It should be noted that while changing the structure of the tractive body, the power of the resistance structure also changes (Fig. 9). For example, if the width and diameter of the wheel are increased by 1.5 times and 1.9 times, respectively, then the percentage of the power required to overcome the wheel inertia will also need to be increased by 4 times, and the proportion of the power consumed for collapse resistance will then be reduced by 1.5 times.

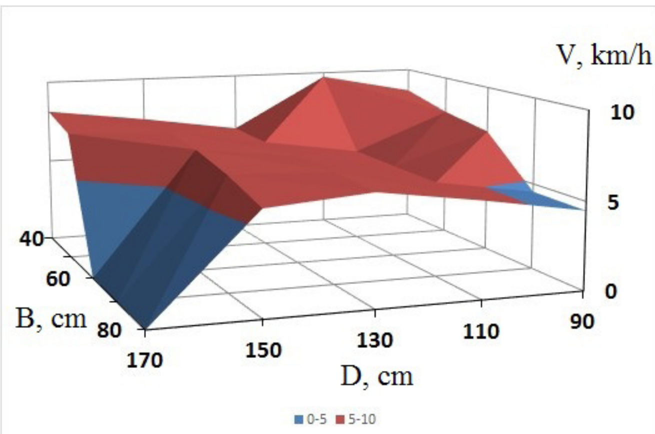


Figure 8. Impact of design parameters of a vehicle at driving speed

The speed of a vehicle is affected by load weight and snow depth (Fig. 10). With the increase in snow depth and load weight the speed diminishes.

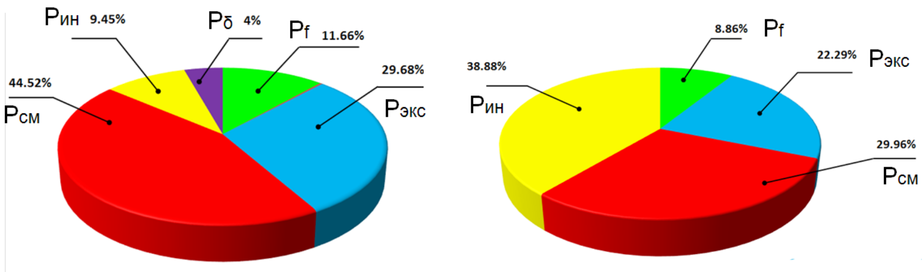


Figure 9. The ratio of resistance powers for the wheels:

a) a width (B) of 40 cm, diameter (D) = 90 cm;

b) a width (B) of 60 cm, diameter (D) = 170 cm.

P_f – the power needed to overcome the rolling resistance; P_{CM} – the power consumed by the support surface deformation; P_δ – the power of the loss due to external sliding of the wheels; $P_{ин}$ – the power caused by uneven rotation of the wheel.

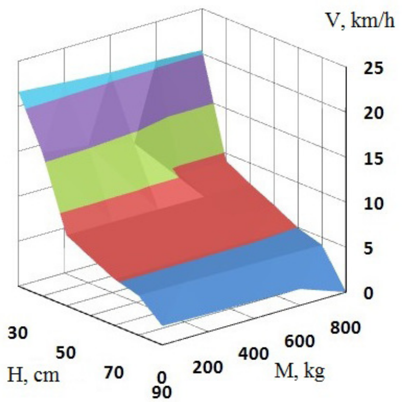


Figure 10. Influence of load weight (M) and snow depth (H) on vehicle speed (V)

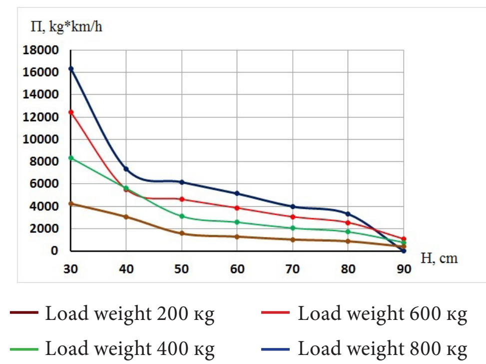


Figure 11. Dependence of vehicle performance (П) on load weight (M) and snow depth (H)

The influence of the load weight on a vehicle's speed is called the capacity of the vehicle. The performance character of a vehicle decreases as the snow depth increases, as shown in Figure 11.

An evaluation of a vehicle's performance demands that certain choices be made in regards to design parameters (design synthesis) at the design stage, which subsequently allows an assessment of the vehicle's motion in specific conditions at the operational stage.

In order to verify the obtained theoretical results, an off-road vehicle fitted with low-pressure ***Rusak*** tires was used to carry out the experiments. The study was made possible by a state contract with the Ministry of Education and Science of the Russian Federation № 16.516.11.6023, and it was carried out jointly with NSTU employees and the ***COM*** Group of Companies (Fig. 12, Tab. 1).

Figure 12. The Rusak All Terrain Vehicle

Table 1. Specifications of the ***Rusak*** All Terrain Vehicle

Axle configuration	4x4
Maximum speed, km/h	60
Gross vehicle weight, kg	3600
Carrying capacity, kg	800
Motor	Diesel Cummins ISF 2.8
Road clearance, mm	450
Wheelbase, mm	2980
Speed of motion on water surface, no less than, km	6
Maximum gradient for climbing, no less	30
Number of seats	4/6, including driver's
Front tires, rear tires	Extra-low pressure
Dimensions (LxWxH), mm	5400x2440x2810

During the tests, the traction speed properties of the off road vehicle were determined. The studies were carried out using high-precision equipment, including: a universal dynamometer ДОУ-3-100И, a multifunctional speedometer VB-20SL3cGPS (the ***Racelogic*** company) and a tensimeter DC-204R (the ***Japanese measurement technologies*** Company).

An example of the data obtained is shown in Figure 13. When driving on virgin snow, the maximum tractive force was (F_{tmax}) 13,657 H, at a speed of (V) 5.94 km/h and a tire pressure of (pw) 0.035 MPa.

Figure 14 shows the results of the theoretical calculations and the experimentally measured values of tractive force when driving a vehicle with a partial load ($m_{авт}$ = 3400 kg) on snow that has a density ρ0 = 0.227 g/cm^3, an initial stiffness of γ 44.973 kPa/m, a coherence C0 = 0.7836 Pa, an angle of internal friction tgj = 0.3543, and a depth of $H_{сн}$ = 40 cm. It follows from the data shows a discrepancy of about 7% on average between the theoretical and the experimental values.

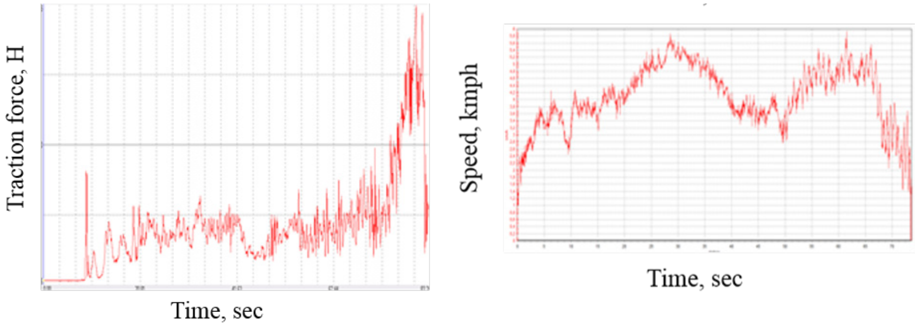


Figure 13. Sensor readings during experiment

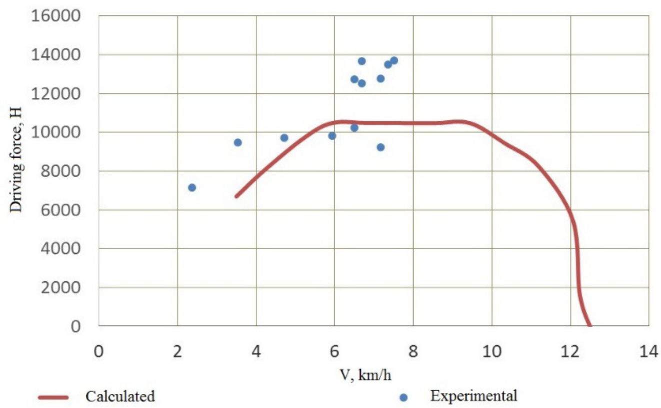


Figure 14. Comparison of experimental and calculated data obtained when driving in first gear

Thus, the experiment sought to find the results of the following:

1. Calculations of the parameters of trafficability and the performance of a wheeled vehicle driven on a snow-covered road.
2. Ascertainment of the influence of the design parameters on the vehicle speed when a vehicle is driven on a snow-covered road.
3. The effect of snow depth and load weight on vehicle performance.
4. An experimental investigation into the tractive properties of a vehicle when it is driven on a snow-covered road. The discrepancy between the actual and the theoretical calculation results did not exceed 15%.

This work was carried out at the Nizhny Novgorod State Technical University. It was named after R.E. Alekseev. Financial support came from the Ministry of Education and Science of the Russian Federation (the unique identifier of the project: RFMEFI57714X0080).

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