Estimating method of efficiency of wheel chassis driving on snow

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Abstract. The method of an estimation of efficiency of a wheeled chassis during movement on snow is considered in the article. The change in snow parameters – height and density - during the winter period and the probability of a combination of these parameters is considered. Analytic dependences are given to calculate the height and density of the snow cover, depending on the duration of snow lying. An empirical coefficient is given allowing taking into account the increase in the spread of snow heights, depending on the duration of the winter. The concept of a criterion for the loss of mobility as a probability of the possible time of movement of the chassis during winter time without loss of passability has been introduced. A technique is proposed for estimating the mobility and efficiency of special chassis along the snow canvas of the track, taking into account variability of characteristics during the winter period.

1. Introduction

The efficiency of transport and technological machine driving on snow in winter is determined by parameters of chassis and characteristics of snow cover. The greatest difficulty is the performance of transport operations in areas where there is no snow removal, including when driving on virgin snow. During the winter period, characteristics of the snow cover are not constant, namely, in the initial period there is a constant growth of snow depth with a constant increase of the average density, then there is a smooth increase in the depth of the snow and also the smooth increase of snow density, the last stage is accompanied by a sharp decrease in the height and significant increase of snow cover density. These stages are typical for each winter, there will be different time of snow lying and its maximum height.

For such variable characteristics, it is necessary to correctly assess the possibility of using vehicles. This can be done if you use the evaluation of the efficiency of the wheeled chassis when driving on snow, characterized by the probability of the possible time of movement of the chassis during the winter time without loss of passability.

2. Methods and Discussion

Researches of snow cover were started by Voeikov A. I. [1], Kuzmin P. P. [2], Richter G. D. [3]. Today in Russia the leading positions in questions of transport snow science are taken by «Nizhny Novgorod scientific and practical school of transport snow science».

First of all the work by Veselovsky M.V., Rukavishnikov V.S. [4], Nikolaev A.F., Kuleshov
A.P.[4], Barakhtenov L. V. [4], Belyakov V. V. [5], Shapkin V. A. [6] and their students are dedicate
to this topic. Such scientists as Lee J., Shop S. [7], Bekker M. [8], Melloh R. [7], Pytka J. and others in
different times made a research of a snow cover.

The main conclusion from the analysis of the work of these researchers is that the necessary factors
are sufficient to assess the vehicle passability and mobility on snow, its height \( H \), density \( \rho \), stiffness
\( K_r \), connectivity \( c \) and the angle of internal friction \( \phi \).

The most convenient model of snow cover as a roadbed for transport and technological machines
describing it from the viewpoint of statistical characteristics is the model proposed in the works of
Makarov V.S. [9, 10], which allows one to describe the nature of changes in the height and density of
snow during winter, as well as to determine the probability of these parameters.

In general the average value of the snow cover height can be determined by dependence:
\[
\bar{H} = \sum_{i=0}^{4} a_i t_i^c ,
\]
where \( a_i \) – empirical coefficient; \( t_i^c \) – the current conditional duration of the winter season with a
steady snow cover in ten day periods \( t_c = (0,15) \).

For convenience of use of these dependences, it is expedient to calculate changes of height of snow
during the winter period on dependence:
\[
\Delta H = \sum_{i=0}^{4} a_i H_t^i ,
\]
where \( H_{\text{max}} \) – average maximum snow height during the period; \( a_i^H, t_i^c \) – empirical coefficient.

Dependences for determining the boundaries of 5 and 95% of the probability of snow cover heights
is determined by the formula:
\[
H_{5(95)} = \bar{H} \pm e^{0.5 \, \zeta \, \sigma_H} ,
\]
where \( \zeta = T_c^{-1}(e-2)t_c +1 \) – empirical coefficient; \( \sigma_H \), - mean-square deviation for the observed
area; \( T_c \) - conditional duration of the winter season with the steady snow cover (\( T_c=15 \)).

Average values of snow cover density are determined by dependence:
\[
\bar{\rho} = \sum_{i=0}^{4} b_i t_i^c ,
\]
where \( a_i^b, t_i^c \) – empirical coefficient.

Dependences to determine the boundaries of 5 and 95% probability of snow cover density is
determined by the formula:
\[
\rho_{5(95)} = \rho \pm e^{0.5 \, \sigma_{\rho}} ,
\]
where \( \sigma_{\rho} \), - mean-square deviation for the territory under consideration.

For the real and conditional time occurrence of the steady snow cover conditional dependence:
\[
t_c = T_c (t-1)/(T-1) + 1 ,
\]
where \( t \) - the current ten day period; \( T \) - number of the ten-day period, duration of snow cover.

Figure 1 shows examples of changes in the height and density of snow cover during the winter
period.

Generalizing equations for determining the stiffness \( K_r \), connectivity \( c \) and the angle of internal
friction \( \phi \) of snow depending on the duration of the snow cover, are calculated on the basis of the
approach [4] for the following dependences:
\[
K_r(t_c) = e^{\sum_{j=1}^{4} b_j \rho(t_c) y_j} , \quad c(t_c) = e^{\sum_{j=1}^{4} c_j \rho(t_c) y_j} , \quad \phi(t_c) = \sum_{j=0}^{t_c} d_j \rho(t_c) y_j ,
\]
where \( b_j, c_j, d_j \) - empirical coefficients.
To calculate the traction force and resistance force, one must know the normal and shear stresses, the most convenient mathematical model for the snow way is the dependencies [5]:

\[ q = h \gamma (1 - hh_{\text{max}}^{-1})^{-1}, \]  
\[ \tau = 0.8e^{-K \delta_i} \left[ c_0 A + Bq \tan \varphi_0 \right]. \]  

Figure 1. Examples of changes of the height (left) and density (right) of the snow cover during the winter period

For calculating the parameters of the movement of wheeled vehicles on snow, the model of the interaction of the wheel with the canvas of the way was proposed by V.V. Belyakov [5].

To calculate the passability, mobility and efficiency of vehicles in the snow in a stochastic setting, you must first set the parameters of the snow at each time. To describe the occurrence of a joint event, namely the combination of all possible values of height and density, it is necessary to introduce a snow cover matrix of dimension \( n \times n \), where the \( ij \)-th element is represented in the form \( [\rho_i; H_j; p(\rho H)_{ij}] \) (\( \rho_i \) – density of \( i \)-th element; \( H_j \) – height of \( j \)-th element, \( p(\rho H)_{ij} \) – combination probability \( \rho_i \) and \( H_j \), defined as the product of the probabilities of the corresponding elements). Defining the parameters of the vehicle, let us explore the possibility of its movement and power factors.

The basic algorithm-scheme of the method for estimating the efficiency of wheeled chassis motion when driving on snow is shown in Figure 2.

The criterion for mobility loss can be defined as the probability of a possible time of movement of the chassis during the winter time without loss of passability: \( K_{TA} = \sum_{T=0}^{\infty} \frac{[P(\rho H)^+)]_{ij}}{T+1} \), where \( [P(\rho H)^+]_{ij} \) – the accumulated probability at time \( T \) is determined on the basis of the possibility of movement with the given parameters \( \rho_i \) and \( H_j \). In fact, it can be determined from the following considerations:

\[ P(\rho, H)^+ = \sum_{ij} [p(\rho H)_{ij}, \begin{cases} 0, & \text{if } \Delta P \leq 0, \\ 1, & \text{if } \Delta P > 0. \end{cases} \], \]  

where \( \Delta P \) is the traction power reserve [4], is defined as the difference between the possible tractive effort and the resistance to movement.

In accordance with this method, we calculated the probability of motion for a special wheeled chassis on a snow virgin land. Calculations were carried out for the characteristics of the snow cover corresponding to Fig. 1. The analysis showed that its efficiency in terms of the possibility of movement in winter is \( K_{TA} = 0.34 \). The probability of movement by ten day periods is shown in Figure 3.
Figure 2. The basic algorithm-scheme of the method for calculating the efficiency of a wheeled chassis moving along a snow canvas, taking into account variability of characteristics during the winter period

3. Conclusion
An analysis of the work on the research of the snow cover as a roadway was carried out. It is concluded that the necessary factors sufficient for assessing the passability and mobility on the snow cover are its height $H$, density $\rho$, stiffness $K$, connectivity $c$ and the angle of internal friction $\varphi$.

Analytic dependences are given to calculate the height of the snow cover, depending on the duration of snow lying. An empirical coefficient is given allowing one to take into account the increase in the spread of snow heights, depending on the duration of the winter. Dependencies are shown to determine the boundaries of 5 and 95% of the snow cover heights.

Analytic dependencies are given for calculating the average density and also for 5 and 95% of the boundaries of snow cover density probabilities. The methodology for estimating the mobility and efficiency of special chassis on the snow cover has been developed, taking into account variability of characteristics during the winter period.

It is established that for the wheeled vehicle in the study, the efficiency in terms of the ability to move in winter is 0.34. At the same time, 25% of the winter period (under the conditions considered, with an average maximum snow height of about 0.85 m), the special wheeled chassis can move less than 5%.
Figure 3. The probability of movement by ten-day period

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