Pneumatic Caterpillar Mover for a Light Transport Vehicle

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Abstract. The article discusses the features of construction, design, operation of the mover of a light vehicle with a pneumatic caterpillar track. Unlike multi-cavity pneumatic caterpillar tracks, in the proposed design the number of pneumatic segments is minimized, which can make it possible to even out the diagram of normal reactions on the supporting surface of the vehicle and increase the mobility of the chassis on soils with a weak surface layer and on snow - in conditions typical primarily for regions of the Far North, Arctic and Antarctic. The proposed design of the mover allows for operational repair in the field. The advantages of the proposed design is to reduce the destructive effect on the ground and increase the maneuverability of the vehicle on a weak bearing base, however, the mass and the cost of the mover increase, a slight decrease in energy efficiency and reliability is also expected, especially during systematic operation on hard ground. The relevance of the study is determined by the integrated interest in the development of the territories of the northern regions of the Russian Federation, as well as by the negative experience gained as a result of the operation of tracked carriers with the traditional chassis design in the tundra and forest-tundra regions. The article proposes a method for determining the main structural parameters of the propulsion device, analyzes its operational properties, makes recommendations for possible use. An example of calculation for a tracked vehicle of 3350 kg is given. The mover can be installed on mass-produced chassis of light-weight transport tracked vehicles when upgrading the chassis in the factory using components manufactured in the Russian Federation and technologies developed by the Russian industry.

1. Introduction
A characteristic feature of the caterpillar mover is a pronounced concentration of normal reactions on the supporting surface in the areas where the track rollers are located. The effect is most pronounced when the propulsion unit is operated with a metal chain track on an undeformable base [1].

The flexibility of the soil allows us to involve in the transfer of normal and tangential loads sections of the track adjacent to the area of the track rollers [1,2,3,4,5,6,7]. The use of jointless caterpillar tracks [8,9,10] allows this effect to be developed. Link tracks have the potential to increase the environmental and energy aspects of operation [6], but it seems more radical to apply the principle of expanding the active areas of the supporting surface (involved in the transfer of normal and tangential reactions) to the largest possible area of the supporting surface. The use of pneumatic...
caterpillar tracks gives such prospects in principle. The expressed interest of the leading countries in the practical development of the Arctic and subarctic zones determines the relevance of creating transport vehicles with a contact mover, capable of not only moving effectively on the ground under conditions of work on soils with a weak surface layer in the spring-autumn period or on snow, but also causing minimal harm to unique ecological systems.

In the course of the work, the following main literary sources were considered.

Classical and modern monographs on the theory of movement of tracked vehicles [2,3,11,12]. Particular attention is paid to the analysis of the operation of the caterpillar mover and the mathematical description of the ongoing processes.

Proceedings in the field of design of tracked vehicles [9,13,14,15,16 et al.] - the approaches to the design of the chassis were analyzed.

Modern scientific works on the theory and design of the running gear of transport vehicles and the environmental aspects of the operation of a caterpillar mover [4,6,7,8,10,17,18 et al.] were analyzed with the aim of choosing a strategy for constructing the most reliable and simple mover circuit providing minimal soil impact.

In addition, scientific publications related to the issues of improving the controllability of tracked vehicles by controlling changes in traction on the mover [19,20,21,22,23,24,25,26,27,28] were used.

2. Formulation of the problem
Based on the analysis of the propulsion structure, the features of its interaction with the track, the specifics of the operating conditions, modern and traditional literature in the field of theory and design of tracked vehicles, the following tasks are formulated:

1. To propose the design of a pneumatic caterpillar, which reduces the destructive effect on the soil while improving the patency of the vehicle on soils with a weak surface layer and on snow.
2. To propose a method for determining the main parameters of a pneumatic track.

3. Theoretical research results
The intensification of human economic activity in modern environmental management conditions and the global scale of anthropogenic impact on the biosphere create a situation of acute environmental crisis due to the degradation of environmental objects.

Taking into account current trends in environmental care and minimizing the impact of human life on the biosphere, the problem of creating an environmentally friendly mover is becoming particularly relevant.

The vehicle mover has the most significant damaging effect on soils with a weak surface layer, typical of the tundra and forest-tundra regions. In these areas there is still no developed road network, and only special vehicles with high traffic can work there. These are, as a rule, caterpillar snow and swamp vehicles, which have established themselves as one of the most reliable modes of transport for inaccessible terrain. Distinctive features of these vehicles are high traction and coupling characteristics and low specific ground pressure (0.014-0.025 MPa). However, the operation of existing snow and swamp vehicles (GT-SM, DT-20, Bv-206) often leads to serious damage or even destruction of the land cover. Meanwhile, the natural restoration of flora takes decades. Thus, the need for improving vehicles in order to ensure the environmental safety of their operation is obvious.

One of the steps to achieve this goal is the creation of an "environmentally friendly" mover, which has minimal impact on the soil during operation. An example of such a mover is a pneumatic caterpillar.

A pneumatic caterpillar should be understood as a closed shell (or a combination of such shells) with excessive internal pressure, which functionally replaces the track chain. The pneumatic caterpillar mover, combining the properties of an elastic wheel and a traditional caterpillar, has a number of new qualities unique to it. The use of a pneumatic caterpillar reduces the average and maximum pressure on the ground by increasing the area of the contact spot, and the pressure in the cavity of the pneumatic caterpillar is distributed evenly initially according to Pascal’s law.
By selecting the pressure values in the pneumatic caterpillar, it is possible to reduce the normal load to the level of soil bearing capacity, since to preserve soil vegetation, the maximum value of specific pressure under the caterpillar should not exceed the permissible value for this type of soil. Prospects for the use of pneumatic rubbered tracks on transport vehicles are described in more detail in works [8,29].

In this paper, we consider the issue of designing the track assembly of a transport vehicle using a single-lane air caterpillar based on the ASU-57 airborne self-propelled landing gear chassis (vehicle weight 3350 kg, engine power 55 hp). The use of a pneumatic caterpillar will require a number of changes to the design, in particular the development of a new tension mechanism. However, it is expected to maintain the ability to operate the vehicle with a standard track.

The designed mover is a closed contour consisting of single-lane sections pivotally connected to each other. The principal device is shown in Figure 1.

Each section is made in the form of a closed rubber-cord shell filled with atmospheric air. In the transverse direction, steel fingers are vulcanized with a certain step to increase the uniformity of the caterpillar's work, increase the resistance to twisting and bending. The tensile force is transmitted through the cord threads connecting the fingers. The prototype has a sprocket gear drive wheel located in front. An analysis of the features of the operation of various types of gearing as applied to pneumatic rubber-cord tracks is given in work [8]. It is advisable to maintain the type of engagement, as the most perfect in the kinematic and power relations. To maintain the geometry of the gearing, to ensure high dynamic performance and to prevent the discharge of the caterpillar, the geometry of the prototype caterpillar tracks of the prototype is preserved.

The main tasks in the design of such tracks are: obtaining a uniform distribution of normal pressures under the track; reduction in the intensity of the impact of the mover on the soil; increased traction and coupling properties of the vehicle on soils with low bearing capacity, moreover, not only compared to the wheel (due to the large bearing surface), but also to the metal track (due to a more uniform distribution of specific pressures); improved ride; reduction of vibrational activity of the mover. The expected design flaws are: sensitivity to punctures; decrease in maximum and average vehicle speeds; resource limitation by track wear during operation on soils with pronounced abrasive properties; increase in chassis mass and expected reduction in efficiency (special mention should be made of the expected increase in the rolling resistance of the vehicle); complication and appreciation of the chassis.

Figure 1. Scheme of the section of the tape track:
1 – finger; 2 – bracket; 3 – comb; 4 – cord threads;
5 – outershell; 6 – cavity which is filled with air.
To justify the design decisions being made, the design and verification methods of rubber-cord shells are being applied to the design of a pneumatic mover.

When designing pneumatic caterpillar tracks, many parameters are set during lengthy bench and sea tests. For example, the pre-tensioning force that prevents the caterpillar dropping, the optimal cord closing angles, the number of cord layers, a number of geometric parameters and other characteristics are selected empirically. In our case, in the absence of the possibility of experimental development of design options, we have to confine ourselves to mathematical modeling of the processes that occur when the mover contacts the ground and when the elements between the mover.

Thus, the development of an "environmentally friendly" mover, in view of its obvious need, has great potential for development.

A study of published materials on the theory, calculation and design of transport tracked vehicles leads to the conclusion that if the calculation of a rubber-cord caterpillar for breaking can be carried out according to the methodology used in work [9], then the question of determining the parameters of a pneumatic caterpillar mover is currently not methodologically developed.

Judging by the content of the publications, the main parameters of the pneumatic caterpillar track (working pressure, geometric dimensions, structure of the elastic wall, etc.) are selected by the developers exclusively during the development work.

It seems advisable to try out a technique that allows us to determine the basic parameters of the product by calculation, so as to have the initial data for the experimental testing of samples, not focusing primarily on "production experience" and "human factor".

The cross-sectional diagram of the pneumatic caterpillar is shown in Figure 2.

Initially, it is assumed that for a light tracked vehicle (ASU-57 chassis weighing \( m_t = 3350 \) kg, having 4 track rollers on board, the required dimensions of the elements of the suspension system are taken from [15], or are taken according to the results of measurements on the navigation model located as a prototype at the disposal of the Automobiles and Tracked Vehicles Laboratory, St. Petersburg Polytechnic University), when using a pneumatic caterpillar, it is advisable to replace the standard track roller with a wheel with a pneumatic tire. This will favorably affect the damping properties of the mover, increase the contact area between the track and the tire, improve traction in the contact area, and reduce the likelihood of the vehicle coming off the track. The inevitable consequence of such a replacement is expected to reduce efficiency mover and tire puncture risk.

![Figure 2. The calculated rolling pattern of the track roller with pneumatic tire on a pneumatic caterpillar (cross section): 1 - roller; 2 - section of the pneumatic caterpillar; 3 - base (soil)](image-url)
To simplify the calculations, we assume that the width of the contact patch of the tire with the caterpillar track $2a_y \rightarrow b_w$ (tire width), the width of the contact area of the caterpillar track with the ground is approximately equal to the width of the caterpillar track $b_c$. The load distributions acting on the pneumatic caterpillar from the side of the tire and the normal reaction of the soil can be considered, as a first approximation, as uniform: $\sigma(y) = \text{const}; q_0(y) = \text{const}$. In this case, based on the need for static balance of the track, the areas of the load diagrams $\sigma(y)$ and $q(y)$ are equal to each other. The maximum drawdown of the pneumatic caterpillar and the greatest radial deformation of the tire will be observed when the vehicle moves through a log or similar single obstacle when $p_{km\text{max}} = 0.5 \times m_t g$ [16].

The radial deformation of the tire and the track itself can be estimated by knowing the stiffness of the deformable object $c_w$ and $c_c$: $\Delta r_{\text{max}} = p_{km\text{max}}/c_w$ and $\Delta H_{\text{max}} = p_{km\text{max}}/c_c$. The value $\Delta r_{\text{max}}$ will allow us to go on to determine the length of the contact area between the tire and the caterpillar (we denote it as $2a_x$). The value $\Delta H_{c\text{max}}$ must satisfy (in a first approximation) the condition $\Delta H_{c\text{max}} < H_c$ – otherwise the caterpillar "flattens" when overcoming an obstacle.

The tire selection is made according to the catalog under the action of this maximum static load. The diameter in the free state $D_c$, the width of the profile $b_w$, and the internal pressure $p_w$ are known for the selected tire. If we assume (for evaluative calculations) that the tire is on a solid foundation, the tire stiffness can be estimated by the formula [30]: $c_w = \pi p_w b_w D_c$. kN/mm (the formula is empirical, the values $D_c$ and $b_w$ are, and $p_w$ – MPa). The length of the contact zone will be:

$$2a_x = D_c \sqrt{1 - \left(1 - 2 \times \Delta r/D_c\right)^2}.$$

If there is a need to determine the length of the contact track roller with a massive tire, the calculated dependence and the necessary reference data for the materials used are given in [15].

It is generally accepted that the contact zone of the tire is elliptical. The ellipse area can be found as $S_w = \pi \times a_x \times a_y$.

Then the pressure in the cavity of the pneumatic caterpillar track is: $p_c = p_{km\text{max}}/S_w$. When choosing the pressure, a margin of 10...15% of the value determined at this stage should be kept.

The rigidity of the pneumatic track should be determined experimentally. To estimate this value, to a first approximation, we use the formula from [30], substituting the "equivalent diameter" defined for the section of the pneumatic track rolled into a ring: $D_c^* \approx L_{\text{section}}/\pi$. Thus, $c_c \approx \pi p_c \sqrt{b_c D_c}$, and we get the opportunity to check the condition $\Delta H_{c\text{max}} < H_c$ and, if necessary, adjust the height of the caterpillar track. Other geometrical parameters of the pneumatic caterpillar (wall thickness $h$, rounding radii, etc.), materials, the method of weaving cord filaments, and other technological features can be borrowed from [11], since the loads under the support of the pneumatic caterpillar for the chassis under consideration will not exceed the corresponding loads on the air duct, the design of which was developed in the early 1990s at the All-Russian Research Institute of Transport Engineering (St. Petersburg). For the chassis under consideration (accepted values: $b_c = 200$ mm; $D_c = 500$ mm; $b_w = 70$ mm; $p_w = 2.5$ atm; $L_{\text{section}} = 1$ m) the calculated value of the caterpillar deflection when moving through a single obstacle (log) was $\Delta H_{c\text{max}} = 50...55$ mm. This means that with a wall thickness $h = 8$ mm, the minimum track height will be $H_c \approx 75$ mm.

4. Practical implications and prospects
A prototype of a pneumatic caterpillar can be created and tested on the basis of the existing material and technological base of St. Petersburg Polytechnic University.

After finalizing the design according to the test results, the operation of the mover seems promising on tracked vehicles designed for the transportation of goods, conducting research and exploration work primarily in the regions of the Far North (the Yamal Peninsula and other areas of the tundra and forest-tundra), as well as the Far East.
The increase in mass of the propulsion device and a number of features of its design give reason to expect an inevitable increase in fuel consumption. The mover can be recommended for work on soils with a weak surface layer and on snow, but not on rocky soils and paved roads - in recent cases, in addition to increasing the cost of operation, intensive wear and a decrease in the reliability of the running system are expected. The design of the mover allows for operational repairs in the field, but this requires additional training for the crew.

The mover is oriented toward the use of light category vehicles by weight, it can be used on stand-alone and remotely controlled chassis as well.

5. Conclusion
The performed research allows us to formulate the following main conclusions:

1. The use of the pneumatic caterpillar of the proposed design can reduce the destructive effect on the soil, increase the patency of the vehicle on soils with a weak surface layer and on snow.
2. The caterpillar track of the proposed design is not intended for systematic operation on hard soils and has limited applicability in the ground conditions of forests.
3. The use of a caterpillar track should increase operating costs and increase the cost of the mover.
4. The proposed method allows for the calculation to simply evaluate the main parameters of the track during design.

Thus, the main aspect that determines the interest in the proposed design is the ability to reduce environmental risks associated with the systematic operation of tracked vehicles in the tundra and forest-tundra regions in the autumn-spring period.

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