

## Conditions and parameters for a four-track vehicle to overcome obstacles

Vasilii A. Leonov<sup>1</sup>, Mark L. Khazin<sup>2\*</sup>

<sup>1</sup> OOO Ekaterinburg Plant of Specialized Vehicles Kontinent, Ekaterinburg, Russia

<sup>2</sup> Ural State Mining University, Ekaterinburg, Russia

\*e-mail: khasin@ursmu.ru

### Abstract

**Research objective** is to define the parameters and conditions for a four-track vehicle to overcome boulders and stone rivers.

**Methods of research** include the methods of theoretical mechanics and mathematical analysis. Conditions of climbing and tipping are deduced from geometrical relationship, while the conditions of slipping is deduced from the statics.

**Results.** Mining conditions are currently complicated due to the gradual shift of mining to remote northern regions. Road and natural climatic conditions of northern and arctic territories differ from other Russian territories in terms of the low road density and severe climate. Global warming and ice cover depletion have made numerous northern regions accessible and cost-effective for surveying and further mining. Natural climatic and road conditions of northern and arctic regions differ significantly from other territories. Lake and marsh terrain as well as hill and ridged terrain predominate. Ravines and swampy hollows, as well as stone rivers impede vehicles movement during prospecting. For this reason, special technical requirements are imposed on prospecting equipment, namely high cross-country ability on weak soil (snow and swamp) and high transport and adhesion properties with maximum compliance with environmental standards, the ability to overcome stone rivers, etc. A four-track vehicle doesn't cause as much environmental damage to the northern nature, and the tundra in particular, as a two-track vehicle. The research considers and determines necessary conditions for a four-track vehicle to overcome an obstacle.

**Conclusions.** A mathematical model is proposed that describes the movement of a four-track vehicle across the rough terrain and makes it possible to determine the maximum height of the obstacle.

**Keywords:** mining; prospecting equipment; tracked vehicle; obstacle; cross country ability; weak soils.

**Introduction.** Mining conditions are currently complicated due to the gradual shift of mining to remote northern regions [1, 2]. Road and natural climatic conditions of northern and arctic territories differ from other Russian territories in terms of the low road density and severe climate. Global warming and ice cover depletion have made numerous northern regions accessible and cost-effective for surveying and further mining [3]. Lake and marsh terrain as well as hill and ridged terrain predominate. Ravines and swampy hollows, as well as stone rivers impede vehicles movement during prospecting [4, 5].

Specific operating conditions impose special technical requirements on prospecting equipment, namely high cross-country ability on weak soil (snow and swamp) and high transport and adhesion properties, compliance with environmental standards, the ability to overcome stone rivers, etc.

The analysis of operating conditions at mining enterprises in the northern and Arctic regions of Russia shows that the most efficient means of transport is a tracked vehicle

on a single base chassis [6]. Such vehicle provides a large contact area on the ground compared to a wheeled vehicle, allowing more even weight distribution across the soil, which is of major importance when driving on weak soils, swampy and hilly terrain.

Tracked vehicle is the main type of vehicle in inaccessible and northern regions with difficult terrain. When moving, it corrects its course by small adjustments, constantly slowing down the left or right side. This is the characteristic feature of a tracked vehicle. When making a turn or U-turn, it destroys and tears the top layer of the earth with its tracks. It therefore should be noted that, although tracked vehicles are best suited for

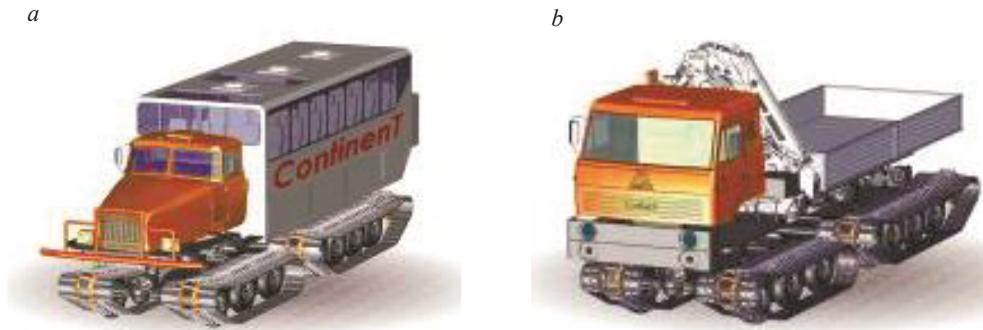


Figure 1. Four-track vehicles of OOO “EZSM Kontinent”:  
*a* – snow and swamp transporter TS AP; *b* – snow and swamp transporter TSK KMU  
 Рисунок 1. Четырехгусеничные транспортеры ООО «ЕЗСМ «Континент»:  
*a* – снегоболотоход ТС АП; *b* – транспортер снегоболотоходный ТСК КМУ

the Arctic and northern regions, they cause significant damage to nature by damaging the tundra’s thin soil. Since the soil surface thaws in summer only to a shallow depth and for a short time, the entire flora is concentrated in a thin surface layer. Each passage of a tracked vehicle over the tundra destroys a thin cover of lichens and mosses, forming a rut and exposing the frozen ground. Scars remain on the soil and are gradually filled with water from the permafrost horizon that has begun to melt. The track swamps under the action of the summer sun and expands in sub-zero temperatures in winter. This can continue for years and decades, because the northern nature does not have enough capability to regenerate. Thus, it is the two-track vehicle that causes the greatest damage to the tundra soil.

In contrast to a two-track vehicle, a four-track vehicle cannot make a U-turn since this is impossible in terms of design. Its motion trajectory can only be straight-line along straight and large arcs. So after a four-track vehicle passage, the tundra’s soil is nearly untouched. The trampled moss of the rut and some water issuing from the inside reveal where the car passed by. After a few hours, the moss straightens out and the rut is almost invisible against the general background of tundra vegetation.

Russian enterprises and foreign companies produce off-road vehicles that differ in purpose, design and parameters. For example, Ukhtysh, Uzola, Unzha (manufacturer: OOO Zavod vezdekhodnykh mashin (All-Terrain Vehicles Plant), Nizhny Novgorod, Russia), Irbis (manufacturer: OAO Zavolzhsky Plant of Caterpillar Tractors), caterpillar all-terrain vehicle-tractor GT-T (manufacturer: JSC Semipalatinsk Machine-Building Plant (Semmach)), two-unit all-terrain vehicle Vityaz DT (manufacturer: JSC Machine-building company “Vityaz”), Nasu (Troll) (manufacturer: Sisu Auto, Finland–Russia), Hägglunds (Moose) (manufacturer: Hägglund & Söner AB, Sweden), Shredder

(manufacturer: BPG Werks, USA) and many others. All vehicles differ in operating characteristics, functional capabilities, design and price-quality ratio.

Machinery by OOO Ekaterinburg Plant of Specialized Vehicles Kontinent (OOO EZSM Kontinent) satisfy difficult operating conditions to the utmost. It compares favorably with analogues in terms of versatility, ease of maintenance, high reliability, and reasonable price. These vehicles are designed to transport goods and(or) people in difficult road and climatic conditions, such as waterlogged (marshy) terrain or virgin snow [7, 8]. Four-track multipurpose snow and swamp transporters by OOO EZSM Kontinent (Figure 1) fully comply with the requirements of TU 4727-008-81765049-2011 “Four-track multi-purpose snow and swamp transporter and its modifications”.

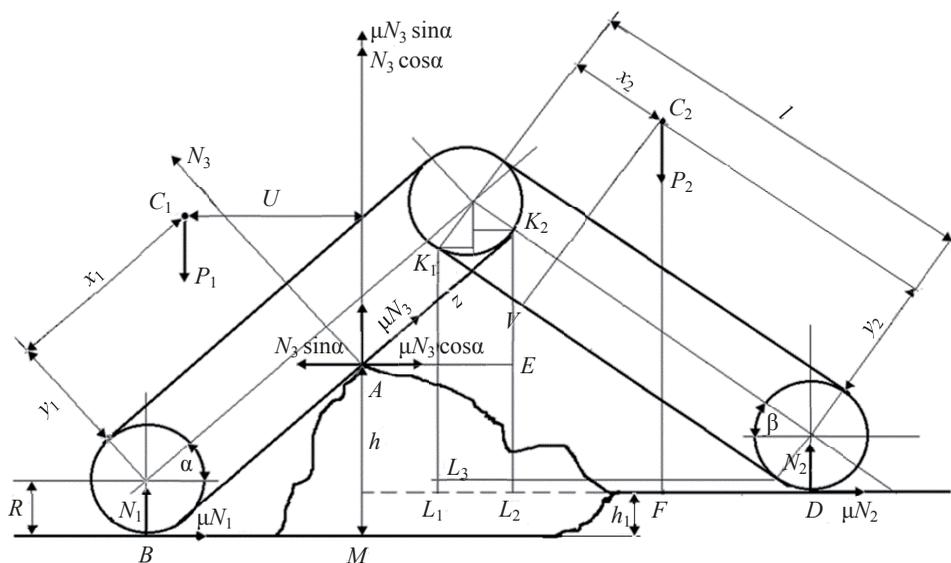


Figure 2. The scheme of obstacles overcoming by a tracked vehicle  
Рисунок 2. Схема преодоления препятствия гусеничной машиной

A two-track vehicle commonly overcomes complex off-road areas due to inertia, while a four-track machine overcomes them due to more uniform distribution of power provided by the transmission to all four tracks owing to the automotive scheme of power transmission in the design. The axles of the all-terrain vehicle are equipped with symmetrical worm gear differentials, which smoothly distribute the torque on both tracks of the front and rear caterpillar tracks. Therefore, a four-track vehicle is closer in design to a 4 × 4 all-wheel drive vehicle.

When driving across the rough terrain, the vehicle has to overcome various obstacles, for example, uneven ground, buried stones, etc. Therefore, a key operational requirement for such transporters is their stability that allows to work in conditions of longitudinal and transverse slopes of complex terrain without tipping over. Stability ensures safe movement for the cargo, driver and passengers and increases operating efficiency of the vehicle. In the conditions of insufficient negotiability, the vehicle will not be able to move across rough terrain [9, 10]. It can lead to the failure of the expedition, and in the worst case, to the loss of the vehicle. To increase the success of prospection, it is important to evaluate the cross-country ability of a four-track vehicle. To create an efficient tracked vehicle, it is necessary to simulate its movement in difficult conditions [11].

The movement of wheeled vehicles across rough terrain is considered in [12, 13]. Overcoming obstacles (stumps and fallen tree trunks) by forestry caterpillar transport is considered in [14, 15] with the zero radius of the track roller.

**Research objective** is to define the parameters and conditions for a four-track vehicle to overcome boulders and stone rivers.

**Methods of research** include the methods of theoretical mechanics and mathematical analysis.

**Results.** The soil of Russian northern and arctic territories in the spring and summer seasons represents pebble with frequent boulder and stone river accumulations, which impede the vehicle’s movement. The most difficult elements in this case are individual stones or boulders representing vertical barriers. The conditions for overcoming individual obstacles by two-track vehicles was studied earlier [16].

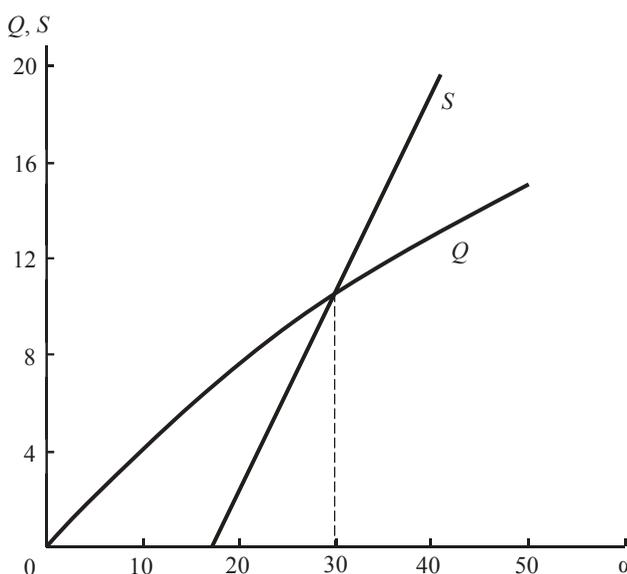


Figure 3. Graphical solution of equation (11)

Рисунок 3. Графическое решение уравнения (11)

Let us consider an obstacle that a four-track vehicle can overcome provided that there is no track deflection inward the contour (Figure 2, where  $P_1$  is the weight of the vehicle on the rear caterpillar track;  $P_2$  is the weight of the vehicle on the front caterpillar track;  $x_1, x_2, y_1, y_2$  are the coordinates of the centers of gravity of the rear and front caterpillar tracks respectively;  $C_1, C_2$  are the centers of gravity of the rear and front caterpillar tracks respectively;  $N_1, N_2, N_3$  are the support reaction forces;  $\mu$  is the coefficient of sliding friction;  $h$  is the obstacle height;  $\alpha$  is the angle between the path and horizontal surface of the rear caterpillar track;  $\beta$  is the angle between the path and the horizontal surface of the front caterpillar track;  $R$  is the roller radius;  $l$  is the distance between the roller centers.

Considering the balance of forces in the horizontal and vertical directions, the following expressions can be written:

$$\sum X: \mu N_1 + \mu N_2 + \mu N_3 \cos \alpha = N_3 \sin \alpha; \tag{1}$$

$$\sum Y: N_1 + N_2 + N_3 \cos \alpha + \mu N_3 \sin \alpha = P_1 + P_2. \quad (2)$$

The tracked vehicle will overcome the obstacle if the sum of the torques in a clockwise direction about point  $A$  is greater than the sum of the torques in a counterclockwise direction, i.e.

$$N_1 BM + P_2 LF \geq \mu N_1 h + P_1 U + N_2 LD. \quad (3)$$

Deducing the values of segments  $BM$ ,  $AF$ ,  $AD$  and  $U$  through known parameters, we get:

$$\begin{aligned} N_1 [R \sin \alpha + (l - z) \cos \alpha] + P_2 [z \cos \alpha + x_2 \cos \beta + y_2 \sin \beta - R \sin \alpha] \geq \\ \geq \mu h N_1 + P_1 \left[ \frac{y_1 - R}{\sin \alpha} \right] + N_2 [z \cos \alpha + l \cos \beta - R \sin \alpha], \end{aligned} \quad (4)$$

where  $z = AK_2$ .

When the vehicle begins to overcome an obstacle, the contact between the rear track and the ground is lost and the reaction force  $N_1$  becomes zero. Then equations (1) and (2) are simplified allowing to find the remaining reaction forces  $N_2$  and  $N_3$ :

$$N_2 = \frac{(P_1 + P_2)(\sin \alpha - \mu \cos \alpha)}{(1 + \mu^2) \sin \alpha}, \quad (5)$$

$$N_3 = \frac{\mu(P_1 + P_2)}{(1 + \mu^2) \sin \alpha}. \quad (6)$$

Segment  $AK_2$ , i.e. the value of  $z$ , can be determined from the scheme (Figure 2) and the geometry conditions:

$$z = l + [R(1 - \cos \alpha) - h] \frac{1}{\sin \alpha}. \quad (7)$$

To establish the relationship between angles  $\alpha$  and  $\beta$ , let us consider segment  $K_2E$ . On the one hand, it can be written as:

$$K_2E = z \sin \alpha. \quad (8)$$

On the other hand,

$$K_2E = K_1L_3 + K_1K_2 + R(1 - \cos \beta). \quad (9)$$

Equating (8) and (9) and taking into account (7), we obtain:

$$\sin \beta = \sin \alpha - \frac{h}{l}. \quad (10)$$

Substituting the values of  $N_2$  and  $N_3$  (from equations (5) and (6)), and  $z$  (from equation (7)) into equation (4), we obtain the expression as a function of variables  $\alpha, \beta, h$  and constants  $P_1, P_2, x_1, x_2, y_1, y_2, l, R, \mu$ :

$$\begin{aligned}
 P_2 \left[ l \cos \alpha + \frac{R(1 - \cos \alpha)}{\sin \alpha} \cos \alpha - h \frac{\cos \alpha}{\sin \alpha} + x_2 \cos \beta + y_2 \sin \beta - R \sin \alpha \right] \geq \\
 \geq P_1 \left[ \frac{y_1 - R}{\sin \alpha} \right] + \frac{(P_1 + P_2)(\sin \alpha - \mu \cos \alpha)}{(1 + \mu^2) \sin \alpha} \times \\
 \times \left[ l \cos \alpha + \frac{R(1 - \cos \alpha)}{\sin \alpha} \cos \alpha - h \frac{\cos \alpha}{\sin \alpha} + l \cos \beta - R \sin \alpha \right]. \tag{11}
 \end{aligned}$$

Equations (10) and (11) determine the necessary conditions for a four-track vehicle to overcome an obstacle. The highest obstacle height that a vehicle can overcome is the maximum value of  $h$  obtained from equation (8) for  $0^\circ \leq \alpha, \beta \leq 90^\circ$ , which satisfies equation (11).

Let's carry out the calculation on the example of TSK KMU snow and swamp transporter (Figure 1, b).

**Main characteristics of the baseline model**

Weight of the haul cargo, kg .....	10,000
Weight of the equipped transporter, kg .....	14,910
Gross weight of the transporter, kg.....	24,510
Gross weight distribution:	
through the front caterpillar track, kg.....	10,370
through the rear caterpillar track, kg.....	14,140
Distance between the centers of the drive sprockets, m.....	2.4
Drive sprocket radius, m.....	0.5

Let us consider the instance when the transporter overcomes the ridge and continues the movement, i.e. when  $h_1 = h$  (Figure 2). In this instance, angle  $\beta = 0$ . Let us denote the left side of equation (11) by  $Q$ , and the right side by  $S$ , and carry out graphical calculation (Figure 3).

The intersection of lines  $Q(\alpha)$  and  $S(\alpha)$  corresponds to the boundary value of  $Q \geq S$ . Thus, the largest angle of the slope to overcome is  $\alpha = 30^\circ$ , and the maximum height of the obstacle to overcome is 1200 mm.

**Conclusions.** A mathematical model has been developed that describes the movement of a four-track vehicle across rough terrain and allows, under known design parameters, to determine the maximum height of an obstacle to overcome.

REFERENCES

1. Heikkinen H. I., Lépy É., Sarkki S., Komu T. Challenges in acquiring a social licence to mine in the globalising Arctic. *Polar Record*. 2016; 52(4): 399–411. Available from: doi.org/10.1017/S0032247413000843
2. Kuznetsov D. V., Odaev D. G., Linkov Ia. E. Peculiarities of technological motor transport selection used for deep north open pits operation. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tehnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal)*. 2017; 5: 54–65. (In Russ.)
3. Tiainen H., Sairinen R., Sidorenko O. Governance of sustainable mining in Arctic countries: Finland, Sweden, Greenland & Russia. *Arctic Yearbook 2015*. 2015. P. 132–158.
4. Andreicheva L. N. Glacial genesis of boulder loam in the north of the bolshezemelskaya tundra. *Vestnik IG Komi NTs UrO RAN = Vestnik of Institute of Geology of Komi Science Center of Ural Branch RAS*. 2018; 1: 3–11. Available from: doi: 10.19110/2221-1381-2018-1-3-11 (In Russ.)

5. Kotiev G. O., Diakov A. S., Sologub S. A. On the necessity to develop the production of specialized wheeled and tracked vehicles for Arctic operation. *Zhurnal avtomobilnykh inzhenerov = Journal for Automotive Engineers*. 2018; 4(111): 27–29. (In Russ.)

6. Tarasov P. I., Zyrianov I. V., Khazin M. L. New special-purpose transport for the Arctic. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal)*. 2018; 3: 136–147. (In Russ.)

7. Kushliaev V. F., Gomonai M. V., Agranovskii A. A., Leonov V. A. Tracked firefighters, rescue and transport-technological machines for the far north. *Avtomobil. Doroga. Infrastruktura = Automobile. Road. Infrastructure*. 2017; 3(13): 7–21. (In Russ.)

8. Kushliaev V. F., Agranovskii A. A., Leonov V. A. Development of crawler wrecking machine terrain to Arctic conditions. In: *Major lines of scientific research in the 21st century: theory and practice*. 2015; 3(4-1(15-1)): 71–76. Available from: doi: 10.12737/13891

9. Sojka M., Čornák Š. Mathematical model of suspension of tracked vehicles. In: *2017 International Conference on Military Technologies (ICMT)*. IEEE, 2017. P. 111–114. Available from: doi: 10.1109/MILTECHS.2017.7988741

10. Yajima R., Nagatani K. Investigation of the tip-over condition and motion strategy for a tracked vehicle with sub-tracks climbing over an obstacle on a slope. In: *2018 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*. IEEE, 2018. P. 1–6.

11. Lu H., Xiong G., Guo K. Motion predicting of autonomous tracked vehicles with online slip model identification. *Mathematical Problems in Engineering*. 2016; 2016 (Art. ID 6375652): 13. Available from: <https://doi.org/10.1155/2016/6375652>

12. Berkemeier M. D., Poulson E., Groethe T. Elementary mechanical analysis of obstacle crossing for wheeled vehicles. *2008 IEEE International Conference on Robotics and Automation*. IEEE, 2008. P. 2319–2324. Available from: doi: 10.1109/ROBOT.2008.4543560

13. Hao W., Xu X., Xu H., Zhou F. Enhancing the obstacle-crossing performance of all-terrain vehicle based on variable-wheelbase chassis. *2019 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*. IEEE, 2019. P. 1329–1334.

14. Kholopov V. N., Labzin V. A. Interaction parameters of the caterpillar vehicle with the obstacle. *Vestnik KrasGAU = Bulletin of KSAU*. 2015; 3: 44–49. (In Russ.)

15. Balakin P. D., Kuznetsov E. A., Prozorov P. A. Modeling of percussion interaction of a track roller of multitask caterpillar vehicle with a single road obstacle. *Omskii nauchnyi vestnik = Omsk Scientific Bulletin*. 2009; 3(83): 68–72. (In Russ.)

16. Leonov V. A., Khazin M. L. Cross-country ability of tracked vehicles. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering*. 2021; 1: 107–114. Available from: doi: 10.21440/0536-1028-2021-1-107-114

Received 29 November 2021

#### Information about authors:

**Vasilii A. Leonov** – engineer, OOO Ekaterinburg Plant of Specialized Vehicles Kontinent. E-mail: [vl@ezsm66.ru](mailto:vl@ezsm66.ru)

**Mark L. Khazin** – DSc (Engineering), Professor, professor of the Mining Machinery Operation Department, Ural State Mining University. E-mail: [khasin@ursmu.ru](mailto:khasin@ursmu.ru); <https://orcid.org/0000-0002-6081-4474>

УДК 629.365

DOI: 10.21440/0536-1028-2022-2-27-35

### Условия и параметры преодоления препятствий четырехгусеничным транспортным средством

Леонов В. А.<sup>1</sup>, Хазин М. Л.<sup>2</sup>

<sup>1</sup> Екатеринбургский завод специализированных машин «Континент», Екатеринбург, Россия.

<sup>2</sup> Уральский государственный горный университет, Екатеринбург, Россия.

#### Реферат

**Цель работы.** Определение параметров и условий преодоления четырехгусеничной машиной валунов и каменных россыпей.

**Методология проведения исследований.** Используются методы теоретической механики и математического анализа. Условия подъема и опрокидывания выводятся из геометрических соотношений, а условие скольжения – из статики.

**Результаты.** В настоящее время условия разработки месторождений усложняются вследствие постепенного смещения горных работ в удаленные северные районы. Дорожные

и природно-климатические условия северных и арктических территорий отличаются от других регионов России низкой плотностью дорожной сети и суровым климатом. Вследствие глобального потепления и отступления ледового покрова многие северные районы становятся доступными и экономически выгодными для проведения разведки и последующей организации горных работ. Природно-климатические и дорожные условия северных и арктических регионов существенно отличаются от других территорий. Преобладающим рельефом является озерно-болотистая и холмисто-грядовая местность. Движение транспорта при проведении геологоразведочных работ затрудняют овраги и заболоченные лоцины, а также каменные россыпи. Поэтому к геологоразведочной технике предъявляются особые технические требования: высокая проходимость по слабонесущим грунтам (снего-, болотоходность); высокие тягово-сцепные свойства с учетом максимально возможного соблюдения экологических норм, возможность преодоления каменных россыпей и др. В отличие от двухгусеничного транспортного средства четырехгусеничная машина наносит значительно меньший экологический ущерб северной природе, в частности тундре. Рассмотрены и определены необходимые условия для того, чтобы четырехгусеничная машина смогла преодолеть препятствие.

**Выводы.** Предложена математическая модель, описывающая движение четырехгусеничной машины по пересеченной местности, а также позволяющая определить наибольшую высоту преодолеваемого препятствия.

**Ключевые слова:** горные работы; геологоразведочная техника; гусеничная машина; препятствие; проходимость; слабонесущие грунты.

#### БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Heikkinen H. I., Lépy É., Sarkki S., Komu T. Challenges in acquiring a social licence to mine in the globalising Arctic // *Polar Record*. 2016. Vol. 52. No. 4. P. 399–411. URL: doi.org/10.1017/S0032247413000843
2. Кузнецов Д. В., Одаев Д. Г., Линьков Я. Е. Особенности выбора технологического автотранспорта для разработки глубоких карьеров Севера // ГИАБ. 2017. № 5. С. 54–65.
3. Tiainen H., Sairinen R., Sidorenko O. Governance of sustainable mining in Arctic countries: Finland, Sweden, Greenland & Russia // *Arctic Yearbook 2015*. 2015. P. 132–158.
4. Андреичева Л. Н. Ледниковый генезис валунных суглинков на севере большеземельской тундры // *Вестник ИГ Коми НЦ УрО РАН*. 2018. № 1. С. 3–11. DOI: 10.19110/2221-1381-2018-1-3-11
5. Котиев Г. О., Дьяков А. С., Сологуб С. А. О необходимости создания производства специальной колесной и гусеничной техники для эксплуатации в условиях арктической зоны РФ // *Журнал автомобильных инженеров*. 2018. № 4(111). С. 27–29.
6. Тарасов П. И., Зырянов И. В., Хазин М. Л. Новые специализированные виды транспортных средств для Арктики // ГИАБ. 2018. № 3. С. 136–147.
7. Кушляев В. Ф., Гомонай М. В., Аграновский А. А., Леонов В. А. Гусеничные пожарные, аварийно-спасательные и транспортно-технологические машины для Крайнего Севера // *Автомобиль. Дорога. Инфраструктура*. 2017. № 3(13). С. 7–21.
8. Кушляев В. Ф., Аграновский А. А., Леонов В. А. Разработка гусеничной аварийно-спасательной машины повышенной проходимости для условий Арктики // *Актуальные направления научных исследований XXI века: теория и практика*. 2015. Т. 3. № 4-1(15-1). С. 71–76. DOI: 10.12737/13891
9. Sojka M., Čorňák Š. Mathematical model of suspension of tracked vehicles // 2017 International Conference on Military Technologies (ICMT). IEEE, 2017. P. 111–114. DOI: 10.1109 / MILTECHS.2017.7988741
10. Yajima R., Nagatani K. Investigation of the tip-over condition and motion strategy for a tracked vehicle with sub-tracks climbing over an obstacle on a slope // 2018 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR). IEEE, 2018. P. 1–6.
11. Lu H., Xiong G., Guo K. Motion predicting of autonomous tracked vehicles with online slip model identification // *Mathematical Problems in Engineering*. 2016. Vol. 2016. Art. ID 6375652. 13 p. URL: https://doi.org/10.1155/2016/6375652
12. Berkemeier M. D., Poulson E., Groethe T. Elementary mechanical analysis of obstacle crossing for wheeled vehicles // 2008 IEEE International Conference on Robotics and Automation. IEEE, 2008. P. 2319–2324. DOI: 10.1109/ROBOT.2008.4543560
13. Hao W., Xu X., Xu H., Zhou F. Enhancing the obstacle-crossing performance of all-terrain vehicle based on variable-wheelbase chassis // 2019 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM). IEEE, 2019. P. 1329–1334.
14. Холопов В. Н., Лабзин В. А. Параметры взаимодействия гусеничной машины с препятствием // *Вестник КрасГАУ*. 2015. № 3. С. 44–49.

15. Балакин П. Д., Кузнецов Э. А., Прозоров П. А. Моделирование ударного взаимодействия опорного катка движителя многоцелевой гусеничной машины с единичным дорожным препятствием // Омский научный вестник. 2009. № 3(83). С. 68–72.

16. Леонов В. А., Хазин М. Л. Проходимость гусеничной машины по пересеченной местности // Известия вузов. Горный журнал. 2021. № 1. С. 107–114. DOI: 10.21440/0536-1028-2021-1-107-114

Поступила в редакцию 29 ноября 2021 года

#### Сведения об авторах:

**Леонов Василий Александрович** – инженер ООО «Екатеринбургский завод специализированных машин «Континент». E-mail: vl@ezsm66.ru

**Хазин Марк Леонтьевич** – доктор технических наук, профессор, профессор кафедры эксплуатации горного оборудования Уральского государственного горного университета. E-mail: khasin@ursmu.ru; <https://orcid.org/0000-0002-6081-4474>

**Для цитирования:** Леонов В. А., Хазин М. Л. Условия и параметры преодоления препятствий четырехгусеничным транспортным средством // Известия вузов. Горный журнал. 2022. № 2. С. 27–35 (In Eng.). DOI: 10.21440/0536-1028-2022-2-27-35

**For citation:** Leonov V. A., Khazin M. L. Conditions and parameters for a four-track vehicle to overcome obstacles. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering*. 2022; 2: 27–35. DOI: 10.21440/0536-1028-2022-2-27-35