Snow movers overview

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Abstract. Arctic exploration requires good transport accessibility to all its areas. Scientists need transport to support their scientific research, vehicles are also required for recreational purposes. Use of different vehicles depends on weather, snow and ice conditions. In the article are reviewed different types of snow movers and given possible prospects for the development of this area.

1. Introduction

A large part of the Russian Arctic Zone and several other countries are covered with snow during the most part of the year. These areas are rich in minerals, but have weak road networks, which make the development of subsoil and the extraction of natural resources very difficult. Besides, the improvement of the indigenous peoples living standards is directly related to transport accessibility. Serially produced all-wheel drive vehicles are not suitable for operation in the extreme natural and climatic conditions of the Arctic, where the temperature can drop below -50 °C and the snow depth reaches 2 m. In this regard, the urgency of creating safe and energy efficient Arctic snowmobile vehicles is undoubted. Since the XX century, Russian inventors have developed various designs of special vehicles and snowmobiles to solve this problem.

In 1900, the Russian inventor F. Dergint patented a sled driven by a screw rotor propeller [1]. In 1905 the journal "Vozdukhovatel" published an article about the invention of S.S. Nezhdanovsky - propeller-driven sled, the features of which were a large air screw and ski support-undercarriage movers, later airships were equipped with a combustion engine [2]. The first caterpillar for snowmobiles was suggested by A. Kegress. In 1909, he introduced the "Nepir" car with a caterpillar instead of the rear wheels and short wide skis instead of the front wheels [3]. The above-described inventions started the evolution of snowmobile engineering. Further development and improvement of designs led to the appearance of thousands of patents and widespread distribution of snowmobile equipment among the northern regions' people.

Today a snowmobile is the most common transport for working in the Arctic zone conditions. This type of vehicle is the most universal and accessible for traveling on snow as a roadbed. A snowmobile is called "a vehicle designed for off-road movement, mainly on snow, with its own weight not exceeding 450 kg" [4]. Caterpillars are used as a mover, and direction of movement is set by turning the skis. Splitting are utilitarian, tourist, mountain and sports snowmobiles.

The most commonly used types of snowmobile vehicles in the Arctic and adjacent areas are: utilitarian snowmobiles, all-terrain low-pressure tire vehicles and tracked all-terrain vehicles. The main disadvantage of each type of vehicle is the impossibility to cope with their tasks both on hard road surface or ice cover, and in deep snow conditions due to the peculiarities of the movers. Let's consider...
different designs of movers and support-undercarriage movers, which are used in snowmobile vehicles. Among the main support and running modules that allows to move on the snow cover, stand out: caterpillar, wheel, rotary screw, combined, wheel walking mover, ski support-undercarriage movers, and an air cushion as part of aero-sleeper.

2. Wheel Mover
Despite the underdeveloped road network in the northern territories, movement can take place on common roads. In this case, the wheel mover is the most appropriate solution. A large number of scientists have studied the interaction of wheel mover with snow: Y. S. Ageikin, L. V. Barakhtanov, V. V. Belyakov, V. S. Makarov, and others.[6-13] and various scientific schools: R.E. Alekseev NSTU (Nizhny Novgorod), BMSTU (Moscow), NAMI (Moscow), NTU (Kiev), etc.

On the cross-country ability of vehicles with wheel mover primarily affects: tire design and average track pressure. The usage of tires with universal or all-terrain protector [5] is a common solution when using vehicles with wheel mover in winter conditions. The tread pattern, as well as the height of the lugs should ensure high performance qualities of the equipment. Analytical dependences of the influence of the height of the lugs and the saturation of the tread pattern are given in the works of Ya. S. Ageykin [5], [13]. Tires with improved tread design can be equipped on the wheels of SUVs such as "Niva", UAZ "Patriot", Land Rover Defender and many others. They are equipped with ATVs RM800 DUO, STELS 800D, BRP Outlander (figure 1) and others. The pressure on the ground of the wheel mover with flat tires on the example of off-road vehicle VAZ-2121 "Niva" is 0.48 (kgf/cm²).

![Figure 1. BRP Outlander quad bike equipped with all-terrain tyre treads.](image)

It should be noted that the tread pattern and the lug size of the tire depends on the conditions in which the vehicle is operated. The same construction can not be equally effective on all types of base surfaces. This has to be considered during operation and a compromise have to be sought.

The work of Ya.S. Ageikin [5] also describes movers with arch, wide profile tires and pneumatic rollers. All these tires are united by the fact that due to a larger contact area they exert less pressure on snow than ordinary tires. However, the way in which they interact with the support base is strongly dependent on the tread pattern and the density of the tread elements. In the snowy ground, pneumatic rollers have proven to be the most effective. It is explained by the largest profile width and smaller diameter, which allows increasing the profile height in comparison with other considered solutions [5]. Such type of engine was developed in the 50-60s in the USSR and nowadays can be found on foreign chassis, for example, pneumatic rollers are installed on a tractor Catterpillar, used in the Antarctic (figure 2). The average pressure of pneumatic rollers on the supporting surface is 0.2-0.5 (kgf/cm²) [5].
The disadvantages of this type of mover include increased tire wear due to higher compression deformations of the sidewalls and membrane deformations of the treadmill [5]. In addition, their dimensions do not allow the use of this type of mover on more compact vehicles than tractors and trucks.

Representatives of wheeled vehicles that can move in snowy conditions include VPK233114 Tiger-M (Figure 3), EAGLE IV (MOWAG, Switzerland), Iveco LMV M65 (IVECO, Italy), and others. They are equipped with a wheel mover with all-terrain tires with adjustable pressure. They are slightly inferior to conventional tires on public roads, but at the same time they are more effective in case of off-road driving [5].

In the operation areas of the considered vehicles the snow height often exceeds 1 meter [13]. Carrying capacity of snow in this case is very low. All-terrain vehicles on ultra-low-pressure wheel movers can effectively cope with transport tasks in these conditions, providing the necessary cross-country ability. The representatives of such wheeled vehicles, equipped with this mover and produced as a serial model, are "Viking"-2992, TRACOL 39295, Sherp PRO (figure 4) and others. The model of interaction of ultra-low-pressure pneumatic wheel mover is presented in [16]. According to the manufacturer's data, the average pressure on the supporting surface of such vehicles can reach 0,1 kgf/cm².
During driving on paved roads, the handling of these vehicles is impaired by the failure to reduce vibrations caused by the tires, which leads to tiredness of the driver. Also disadvantages of this type of mover are low load capacity [11], which puts significant limitations in the design and operation. The problem can be solved by increasing the number of axles.

The choice of the axis arrangement depends on the capabilities of the all-terrain vehicle: to overcome possible obstacles, stability of its movement and weight distribution on the wheels, etc. Often used schemes are "1-1-1" and "1-1-1-1" [13], their application provides the most uniform distribution of load on the ground. Such scheme is used on all-terrain vehicle "Rusak K-8" (figure 5), the average pressure on the supporting surface of which is about 0.13 (kgf/cm²).

In case of low efficiency of the wheeled mover it is possible to use tools that increase its cross-country ability on snow. There are constructive solutions to increase the cross-country ability of the wheeled vehicle by using a removable tracked mover [18-21]. In all presented cases the increase of cross-country ability is provided due to the extension of the mover contact area with his supporting surface and reducing the pressure on it. Figure 6 shows the design of the company "Stalker-Trak" [22]. Its advantages include simple mounting on the vehicle hub without special equipment and low load on hub bearings. Ground pressure of "Niva" vehicle on such tracks is 0.16 kgf/cm².
3. Tracked movers
Tracked mover is the most popular in off-road conditions. In the Arctic zones, snow and swamp-going vehicle are especially popular. Their advantage is the possibility of moving on snow covered lands, melted and soft snow high cross-country ability and possibility to move on public roads due to special design of the track [14,23]. At NSTU developed a range of especially light tracked vehicles, which include snow and marsh vehicles "Ukhtysh" (pressure on the supporting surfaces is 0.15 kgf / cm²), "Uzola", "Unzha" [24]. There are also representatives of all-terrain vehicles "Rusak" (figure 7).

![Figure 7. Snow and swamp-going vehicle "Rusak".](image)

For snowmobiles, the combination of tracked movers and ski guides is most often used. The most common is the skating-sliding system (figure 8). It is installed at the rear of the snowmobile and consists of guides and road wheels, as well as plastic "skis" resting on the bottom of the track. The snowmobile is rotated by front-mounted skis. Among the vehicles with this type of mover, the Buran snowmobiles can be distinguished (its specific pressure on the supporting surfaces is 0.046 kgf / cm².), Taiga 500 as well, Alpina Sherpa and others.

The disadvantages of a such mover are destructive effect on the road surface and limited service life. Due to the fact that the track grouser is a rubber band which reinforced with a cord and equipped with lugs, it is possible to move not only in the snow, but also on solid support bases without increased wear and damage to the roadway.
The most common configurations are "two tracks - one ski" and "one track - two skis" [25]. Similarly to tires track geometry and its pattern have an impact on cross-country ability. The most important parameters are track width and length. With reducing the track width and length, controllability and maneuverability of snowmobile vehicles is improved. When these parameters are raised, an increase of cross-country ability is noted. Such an example is a wide track of the most famous utilitarian snowmobile "Buran".

![Figure 8. Tracked mover with skating-sliding system.](image)

The disadvantage of the skating-sliding system includes the necessity of regular lubrication with snow which goes inside the track when the snowmobile is in operation. It can negatively affect the possibility of long travel on solid support bases such as ice.

4. Combined mover
It is a type of movers which provide the possibility to change design parameters in the process of transport task performance. They include multi-axle wheeled machines with the ability to change the number of axles in the process of operation, wheel-track and roller-tracked, wheel-wheeled thrusters, etc. Feature of the combined wheeled mover with an assistant tracked mover is the ability to use the tracks instead of the front axle wheels. This design enables to increase cross-country ability when driving on soils with low bearing capacity. In conditions of short-term movement on such soils, it seems reasonable to use a lightweight track mover, which positively affects the vehicle mass characteristics. Such developments were conducted in the 80's by R.N. Ulanov, their result was an all-terrain vehicle BVSM-80 based on GAZ-53 (figure 9a). Currently, similar designs can be found in small-batch European projects based on MAN trucks (figure 9b), DAF and others.

![Figure 9a. BVSM-80 with a combined mover](image)

![Figure 9b. Truck by «Ingenieursbureau» with a combined mover](image)

The disadvantages of such propulsors include the complexity of design, an increase of total weight and vehicle cost, the inability to use on small snowmobile equipment.
5. Rotary-screw mover
In contrast to the tracked mover, rotary screw drive modules increase cross-country ability when they are immersed in snow and soil due to the larger contact area between the base cylinder and screw blades. This type of mover has found an application not only on large snow and swamp-going vehicles such as Marsch Screw, Dorothy L, ZIL-29061 (figure 10) and similar, but also on more compact motorcycles and motor-launches GPI-05 and GPI-15. Average value of ground pressure by rotary-screw mover is 0.004 (kgf/cm²) [27].

![Figure 10. ZIL-snow and swamp-going vehicle on a rotary-screw mover.](image)

In spite of the unique possibility of moving both in snowy and marshy areas, snow and swamp-going vehicle is not suitable for moving on solid support bases and damages vegetation [13].

6. Air-cushion vehicle
Air-cushion vehicles (HCVs) can demonstrate their efficiency in operating conditions in areas with underdeveloped road networks [15]. Air-cushion can be either a complete support-undercarriage movers, or it can partially unload the mover. The advantages of an air cushion include high speed and minimal ground pressure. However, it is important to note the big overall dimensions, low dynamic properties and low controllability of HCV.

7. Metal-elastic wheels
There is no practical implementation of this type of wheeled propulsor for snowmobile motor vehicles, but it is worth noting this design as promising for the solution of transport problems in the Arctic zone. Metal-elastic (airless) wheels are technical devices based on elastically deformable thin-walled structures (26). Practical application of this type of mover was found in the composition of mobile vehicles exploring the planets' surfaces. Such wheels cannot be punctured, they can operate in any environmental conditions, and metal-elastic wheels have small unsprung mass and low ground pressure.

For a long time the wide application of metal-elastic propellers was hindered by the lack of effective calculation methods. The appearance of modern works in this scientific field can change the current situation, providing designers with appropriate design tools [26]. The appearance of anticrorosive alloys, new polymeric and composite materials provides new opportunities for the design of new metal-elastic wheeled movers with better performance characteristics.

The advantage of such a design can also be the simplicity installation on a wheeled unit, such as a cross-country vehicle (figure 11). Development of the design with the ability to change the stiffness of the metal-elastic wheel in a wide range will increase the vehicle cross-country ability. This technological solution will make this type of transport equally effective when moving on snow and solid support bases. That may be possible due to the transformation of the mover from sliding to rolling mode. In the first case, ground pressure will be low (about 0.015 kgf/cm² [28]) and the movement resistance will be
comparable with the ski module. Rolling mode in driven mode will allow you to move on such supporting bases as ice and roadbed.

![Figure 11. Sketch of a snowmobile with a metal-elastic track module.](image)

8. Conclusions
The review of snowmobile movers [29-35] showed a great variety of design solutions in this area. Many of them are designed only for use in large-sized vehicles. The most perspective and preferable direction of development of movers is development of a universal adaptive design which integration is possible both on individual small-sized vehicles, and on large cross-country vehicles. Such construction can become an airless track module, which is a metal-elastic wheel, due to automatic transformation will switch from sliding to rolling mode. The adaptability of the structure will make it possible to set the optimal ground pressure depending on the condition of the snow cover and its depth. The values of average ground pressure given in the article enable to speak about efficiency of the suggested technical solution.

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