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Analysis of the cutting tool for the destruction of snow–ice formations on road pavement

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Abstract. The paper presents an analysis of the cutting tool structures for the destruction of frozen soils and snow-ice formations. The basic parameters (geometry and material) taken into account when creating cutting tools are revealed which are as follows: the influence of cutting speed on the durability of the cutting tool and cutting force, the optimal cutting angles and the layout of the cutters. The main advantages of using disc cutters in the design of ice-breaking equipment are presented. They allow you to replace the sliding friction of the cutting edge with the traditional rolling friction tooth (the disc rolls along the face). As a result, the tool life is increased, dynamic loads on the working body are reduced when meeting with the inclusions, since the contact of the cutting edge with the inclusions at the initial moment will be point, and the speed will decrease as it is immersed in the array, therefore, the load on the cutting tool will increase slowly.

For the Russian economy, the role of roads is especially great, as–the foundation of socio–economic development. In the North, winter roads (snow–ice roads) are the only way of transport between settlements and industrial facilities, ensuring the livelihoods of the population. The construction of the winter road is a time-consuming process requiring the use of specialized equipment (milling, loosening equipment, etc.) for the preparation of the route (alignment of frozen soil, cutting ice).

Improving the quality of winter maintenance of roads can increase the productivity of vehicles, the volume of traffic, reduce wear and tear of cars and tires, fatigue of drivers, reduce the consumption of fuel and lubricants, reduce losses from road accidents. The greatest expenses on the winter maintenance of city roads fall on removal of the freshly fallen and condensed snow. Insufficient snow removal equipment and high intensity of snowfalls are the main reasons for the appearance of snow and ice formations on the road.

In Siberia and the Arctic regions, snow averages 26.30% of annual precipitation in winter, and at least 75.80% of snow is removed by snow ploughs directly from roads. Russia is covered with snow on 60–70 % of its territory (the Arctic, the Far North, Siberia and the far East) for at least six months, in the presence of snow–ice formations on the road surface, the grip of the car wheels decreases, which leads to an increase in the braking distance and safe turning radius by 3–9 times. The duration of the winter period is 5.5 months, and in the Northern regions of the country up to 9 months, during which regular snow removal work is organized, the cost of winter snow removal reaches 70–75% of the total cost of maintaining roads.

The destruction of snow and ice formations is an energy–intensive process that requires the use of several units of various equipment, specialized ice–breaking equipment or the use of specialized blades for dumps, which increases financial costs.

The question of increasing the efficiency of destruction of frozen soils and snow–ice formations in the construction of winter roads and maintenance of roads is relevant.

One of the modern directions of increase of efficiency of destruction of the developed environment by earthmoving and mining machines both in the Russian Federation and abroad is retrofitting of the working equipment with highly effective teeth and disk cutters and installation of the equipment taking into account optimum parameters providing decrease in power consumption of process.

It is necessary to investigate the design of cutting tools for the destruction of frozen soils, in order to use effective tools in the construction of snow removal equipment as there are reserves to improve the performance of ice–breaking machines.

The main cutting tool used in the working bodies for the destruction of frozen soils are the teeth Cutting tools, schemes of arrangement to the working bodies of the cutting conditions subject of many studies [1 – 8]. On the basis of these works it can be concluded that the choice of cutting tools designed for the development of frozen soil should be justified by technical and economic calculations, based on such indicators as minimum energy consumption, maximum process performance and sufficient tool life. These indicators in the earthmoving machine depend on the geometric parameters and the material of the tool, the schemes of its arrangement on the working body, the parameters of the soil cut, cutting speed, etc.

The main value in the creation of the cutting tool is the choice of rational geometry and tooth material [9 – 12]. As follows from these works, for the manufacture of teeth used steel 45, 40Х, 40ХФА, etc., and for tips rippers – steel 110Г13Л. The cutting part of the tooth is strengthened by wear–resistant surfacing.

B [13] it is recommended, based on the condition of sufficient strength of the cutter and the minimum cutting force, the cutting angle to choose 30 – 40º, rear angle, excluding friction of the rear face of the ground – 5 –10º. The authors [14, 2] consider the optimal cutting angle for frozen soils to be 45º, and the back angle is recommended to be 15º.

Cutting angle α according to the works of V.I. Balovnev is determined by the formula

$$\alpha = 90^\circ - \beta - \mathrm{arctg}\,(V_F / V_C), \quad (1)$$

where β – rake angle, deg.;
V_F – feed rate;
V_C – cutting speed,

a back angle **γ** the formula

$$\gamma = 90^\circ - \beta - \delta - \mathrm{arc\,tg}\,(V_F / V_C), \quad (2)$$

where δ **–** taper angle, deg.

The width of the cutting part of the tooth of trench excavators varies from 16 to 60 mm, tips rippers–from 66 to 114 mm. Recommended by the researchers of the rational angles of cut 30–45º is not embodied in the structures of teeth. The angle of sharpening in most of them is about 70o. The energy intensity of destruction by such teeth is overestimated [15]. Between the width of the tooth *b*, step *t* and depth of cut *h* there is a certain relationship.

When cutting frozen soil with a single cutter it was established [7] that the most rational is the ratio (t–b)/h = 1,3–2,0. Taking into account the optimal combination of cutting speeds and feed, size, number of teeth and schemes of their arrangement on the working bodies of trench excavators, the ratio (t–b)/h is recommended to be 0.5–0.9 [7]. With a cutting edge width of up to 15 mm, the best cutting conditions are those that provide a chip thickness of 15–20 mm.

Wedge–shaped plates of hard alloy VK15 have a semicircular cutting edge. The choice of the edge shape and the length of the carbide insert, which is approximately twice the expected average maximum chip thickness, is justified in [16]. Rotary cutters successfully applied by domestic and foreign firms on working bodies of earthmoving, coal–mining, mountain, snow–removing, etc. machines deserve attention (figure 1).

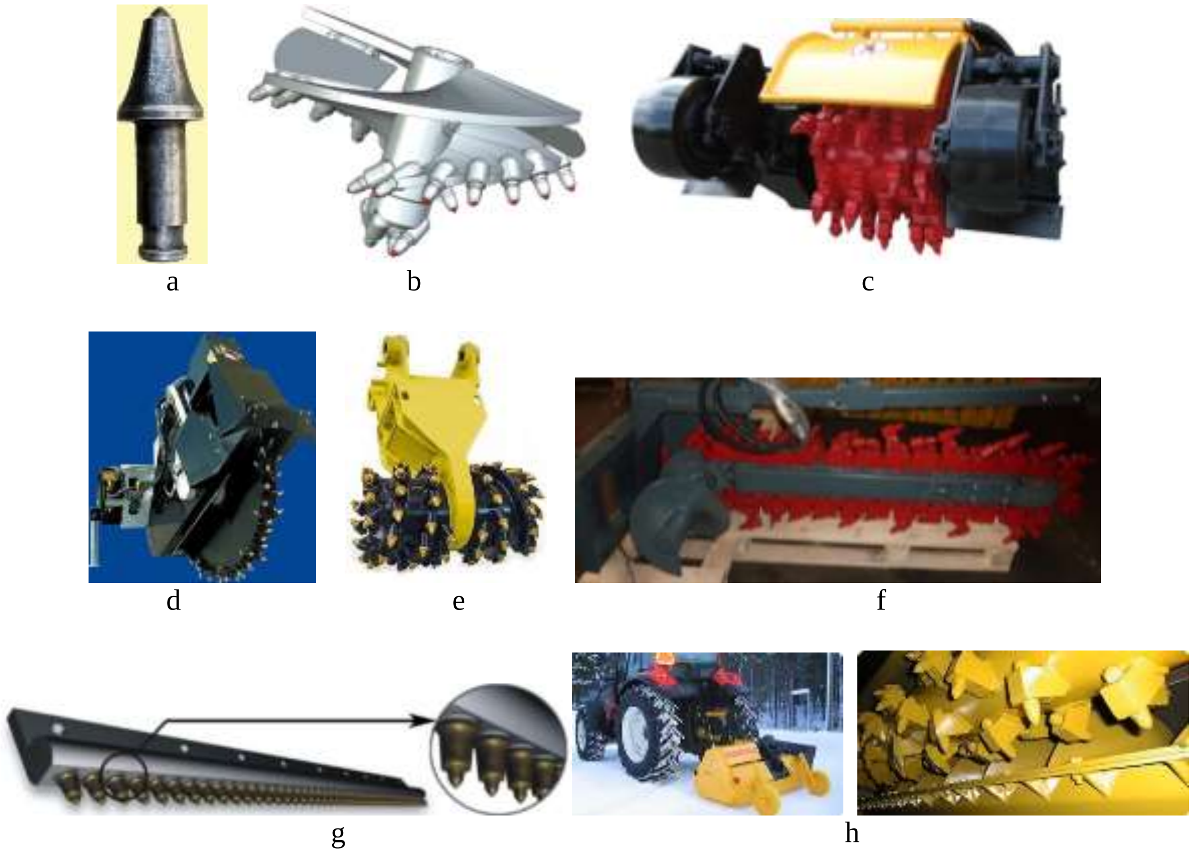

Figure 1. The use of rotary cutters in the working bodies of drilling and earthmoving machines: a – rotary cutter; b – drill cone; c – road cutter; d – milling trencher; e – milling and loosening equipment; f – chain trencher; g – blade grader; h – ice breaker SASNOMAC KT–2.

Advantages of rotary cutters: minimum metal consumption, low consumption of carbide inserts, increased resistance to impact loads, uniform wear on the diameter and self–sharpening of the cutter in the process of destruction of durable material. Disadvantages: the minimum width of the cutting edge, reducing the remote ability of the soil from the face, a significant reduction in the installation step and an increase in the number of cutters on the working bodies, rapid wear of the conical part of the cutter holder, leading to the exposure of the carbide insert and its cleavage.

Cutting speed has a great influence on the durability of the cutting tool and the ability of the working body to remove from the face of the destroyed soil. In machines designed for the development of frozen soils, the cutting speed is different. In rotary and chain trench excavators it varies from 0.6 to 1.74 m/s, in rippers – from 0.4 to 1 m / s [18, 19]. However, continuous machines manufactured by individual departmental organizations have a cutting speed of up to 10 m/s [14, 15].

About 40% of operating costs are related to tooth replacement. To ensure the development of frozen soils, it is necessary to increase their wear resistance by 30–50 times [20] compared to the wear resistance sufficient for the development of a homogeneous melt soil. This can be achieved in two ways: hardening the cutting edge with a carbide solder or reducing the friction path.

Recommended cutting angles 30–45º and a back angle of 10–15º are rational in terms of cutting forces and energy intensity of the process, but at such angles and reinforcing the cutting edge with a carbide soldering, the cross section of the holder is weakened, and when meeting with inclusions, there are chips of the soldering or breakage of the tooth holder. In this regard, some researchers [21] have opted to increase the cutting angle to 80–90º, so that during the cutting process, the soldering worked in compression. But at the same time, cutting forces increase by 1.75 times [22], therefore, the energy intensity of the process increases. With existing structures of the tool, reducing the friction path of its cutting edge is not feasible, since each point of it rubs against the face from the beginning of the penetration to its exit from the face. At the same time, intensive wear of the edge is inevitable.

A promising tool used in tunneling combines for rock with a coefficient of strength f<8, are disc cutters, which will later be called disc cutters. The prospects of this tool is due to the fact that it makes it possible to reduce the friction path tenfold, since each point of the cutting edge when rolling the disk along the straight face is immersed in the soil mass along the cycloid only by the value of the cutting depth. The points located closer to the axis of rotation of the disk are immersed in an array of shortened cycloids, and their friction path on undisturbed soil is reduced.

The use of disc cutters allows you to replace the sliding friction of the cutting edge with a traditional rolling friction tooth (the disc rolls along the face), this increases the durability of the tool, makes it possible to reduce the dynamic loads on the working body when meeting with inclusions, since the contact of the cutting edge with inclusions at the initial moment will be point, and the speed will decrease as it is immersed in the array, therefore, the load on the cutting tool will increase slowly. Because the dynamic load and the road friction is reduced and the durability of the tool is increased, there is a possibility to increase cutting speeds and dramatically improve performance.

The use of this tool will replace in some cases the usual teeth on the disc cutters or work with them in different versions of their installation on the working bodies of earthmoving machines. Also, disc cutters can be used in the construction of snow removal equipment in order to reduce the energy consumption of the process of destruction of snow and ice rolling on the road surface.

Figure 2 shows a one–sided and two–sided sharpening cone disc cutters made by machining on a lathe used for the destruction of snow–ice formations. Discs with double–sided sharpening (figure 2 a, b) are designed to be located only at right angles to the destroyed array, resulting in a frontal cutting, more energy–intensive than tangential [18], and discs for increased wear resistance can be equipped with carbide inserts along the perimeter of the cutting part (figure 2 b) [23]. Drives with one–sided sharpening (figure 2) provide the reduction of energy intensity compared to the disks with double–sided sharpening.

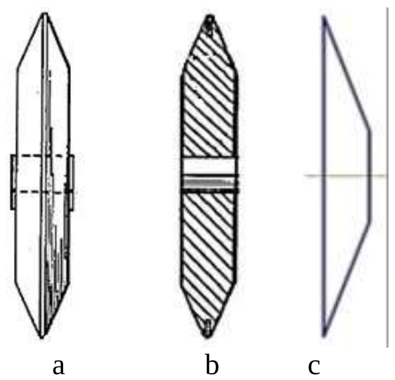

Figure 2. Discs for the destruction of snow–ice formations: a – cutting disc with double–sided sharpening; b – disc with double–sided sharpening; c – disc with one–sided sharpening.

In [24, 25] described snow removal equipment in the design, which used disc cutters made in the form of a truncated cone with an angle of 40–45º mounted on the axes with the possibility of passive rotation, which makes it possible to reduce the friction path tenfold and reduce cutting forces. The optimal angle of installation of the working bodies snow plows providing the overlap between adjacent discs and the interaction of drives with the developed array populacional scheme except for the extreme.

Figure 3 shows the design of the working body to remove snow–ice rolling from the road surface in the design, which used disc cutters [24].

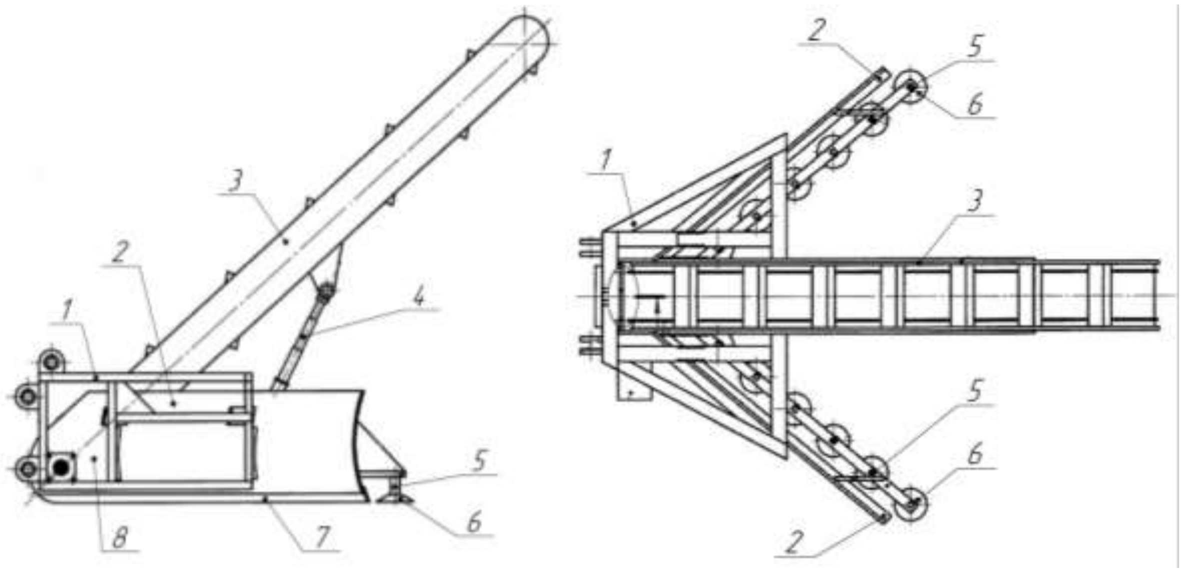

Figure 3. Working body to remove snow and ice rolling from the surface of roads and airfields: 1 – frame; 2 – two blades; 3 – bucket conveyor; 4 – hydraulic cylinder; 5 – axis; 6 – disc cutters; 7 – blade grader; 8 – plate.

The cutters are installed at an acute cutting angle (no more than 10°) to the surface of the snow–ice rolling figure 4 a shows a Bobcat scraper equipped with a disk (diameter 457, 559 mm.) with a spherical surface, passively rotating on the axis and having a self–sharpening cutting edge, figure 4 b scraper with a disk diameter 560 mm. spherical shape with semicircular cutouts along the perimeter, figure 4 in the ice picker with a disk diameter 550 mm. cone–shaped with replaceable cutters, which in the case of blunting or breakage can be replaced. Scraper allows you to align (cut) the soil of different hardness, to destroy strong snow and ice deposits on road surfaces up to 40 mm thick, at a speed of 2–10 km / h.

a b c d

Figure 4. Bobcat Scraper: a – Bobcat scraper with a round disk; b – Bobcat scraper with a disk with semicircular cutouts along the perimeter; c – ice cleaver with replaceable cutters; d – destruction of strong snow–ice formations with a scraper.

Studies have shown that the use of a disk tool well proven in tunneling machines for rock. The prospects of this tool is due to the fact that it makes it possible to reduce the friction path tenfold, since each point of the cutting edge when rolling the disk along the straight face is immersed in the soil mass along the cycloid only by the value of the cutting depth. The points located closer to the axis of rotation of the disk are immersed in an array of shortened cycloids, and their friction path on undisturbed soil is reduced. The use of disc cutters in the construction of snow removal equipment will significantly reduce the energy consumption of the process of destruction of snow and ice rolling on the road surface.

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