Prospects for development of a drilling tool for producing minerals in frozen soils

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Abstract. This article reveals importance and relevance of exploration and development by drilling tools of minerals in frozen soils. The problems that arise during operations of drilling tools are considered. Existing types of drilling tools for mining are described. The advantages and disadvantages are listed, the principles of action and the type of soil deformation during the interaction of a tool with frozen soil are considered. The necessity of developing a drilling tool that implements a less energy-intensive production process and does not destroy the structure of solid minerals is considered. A comparative analysis of the drilling speed and energy intensity of soil destruction by drilling tools is carried out. Conclusions are drawn about the effectiveness of the proposed drilling tool.

1. Introduction
Minerals are critical in industry. [1-3]. More than 80% of all industrial reserves of minerals in the world are located in the northern part of Russia. These include some of nickel and platinoids (one third of the world's reserves), cobalt (15% of the world's reserves). All Russian diamond deposits, about 80% of oil and almost all of the produced gas, 90% of tin, gold, mica, apatite and many other types of raw materials. Prospects for exploration and mining in the Arctic zone are determined by need to replenish reserves and develop the economic potential of the country [4-7].

The production of such work requires, as a rule, the use of machines with increased power and correspondingly increased energy costs. Despite the huge variety of mechanization tools, methods and technology improvements, the mechanization of winter earthworks remains unresolved [8].

There are a number of problems encountered when drilling frozen and permafrost soils, one of which is increased tool wear due to the fact that frozen soils have strong properties and belong to the V-VI category of drillability soils. It also has high abrasiveness, which corresponds to 66-100 mg. In addition, drilling process is negatively affected by the fact that the soil has a complex layered structure (from frozen sandy soil layers - whose strength is comparable to concrete, to plastic, thawed soil layers with a high content of moisture, clay and peat particles). In some layers, the tool behaves highly efficiently, while in others this design is inoperative [9-10].

Mechanical strength of frozen soils depends on the type of deformation. The relative ratio of the resistivity of frozen soil corresponds to the different types of deformation shown in Table 1. Indentation is the most energy-intensive type of deformation, and rupture is less energy-intensive.
Table 1. Relative ratios of resistivity of frozen soil to various types of deformation.

| Deformation pattern | Break | Compression | Shift | Bend | Cutting | Indentation |
|---------------------|-------|-------------|-------|------|---------|-------------|
| Relative average    | 1     | 3           | 1.7   | 2    | 7       | 21          |

2. Material and methods

Currently, for drilling frozen soils, various types of drilling tools are used that implement various types of deformation.

2.1. Wing bit

One of the most commonly used drilling tools is a wing bit, which carries out the process of soil destruction by deformation of cutting and scraping action. This type of deformation is energy-intensive and corresponds to a relative index of 7 according to Table 1 of the relative ratios of the resistivity of frozen soil to various types of deformation. This type of drilling tool is mainly used on I-III categories of drillability soils. However, when used on more durable categories, performance decreases. This happens due to the constant contact of working surface with the soil, which leads to increased wear of the working edges and, therefore, makes the well uneven and with a reduced size.

2.2. Cone bit

Drilling tools that implement a less energy-intensive process of soil destruction include cone bits. Chisels are equipped with multi-cone cones, on the surface of which concentric rows (crowns) are weapons (teeth, teeth). The crown located at the base of the cone is called peripheral. To increase the wear resistance, the teeth are hardfaced. Soil deformation occurs from the indentation of cones and their rolling [12-13]. The type of compression deformation predominates to a greater extent. Since frozen soil is susceptible to brittle fracture, the cone bit is effective, but when lamellar soils appear, drilling becomes ineffective due to the fact that plastic soils cannot be crushed.

2.3. Cutting cone bit

To solve the problems of roller cone and blade bits, of interest is a combined cutting cone bit [14]. The bit includes a body, paws with cones mounted on a free axis of rotation, equipped with rock cutting elements in the form of teeth, forming a peripheral, with a calibrating edge, and central weapons.

There is a movable blade with a cutting part located between the cones, which is spring-loaded so that the elastic force is always less than the axial force attributable to the cones. The essence of this invention is as follows, in the development of frozen soil a cone bit is used and the cones are pressed in and the rock is chipped to form microcracks, and when melt rock appears, a paddle bit is turned on and the soil is cut. The main disadvantage is the complexity of the design, as well as the difficulty of using on lamellar soil, since there is sticking and further freezing of the soil.

2.4. Detonator capsules

Other methods of deformation of frozen ground, which also require attention, include methods using dynamic action of gases, leading to the formation of microcracks, and further drilling.

One of these types of development of frozen ground is the use of detonator capsules. Explosive is supplied through the pipe cavity after a certain period of time. During the explosion, microcracks are formed, thereby facilitating the further work of the working tool [15]. The same principle of destruction only with compressed air is a device for the development of frozen soils, including a tubular hollow body with a screw tip, with a conical sealing plug and exhaust holes. A check valve is installed above the cork, located in the cavity of a sealing cap, which communicates with the cavity of a tubular body. The cavity of a tubular body by means of a switching valve can periodically communicate with a source of compressed gas or with a vacuum pump [16]. Deepen the tubular body with a tip to a predetermined depth. Then the valve is switched and the cavity of the tubular body is
connected to a source of compressed gas. Compressed air bursts into the zone of reduced pressure and opens pores and cracks, which causes the destruction of the soil mass. Due to this deformation, further drilling process with a helical tip occurs in a more simplified form.

2.5. Screw working bodies
Of particular interest are screw working bodies for drilling frozen soils. When these types of working tools are working, shear deformation occurs, which corresponds to lower energy consumption compared to other types of drilling tools.

These include a screw working body for development of frozen soils. A drive rod has a tip equipped with a screw blade. The screw blade is associated with a screw blade of the tip and is its continuation. A pitch of the blade gradually increases away from the tip and from a value equal to the pitch of a tip of the blade. The tip cuts a helical blade in the soil mass, then a screw blade is introduced with a gradually increasing step, an upward force arises, which leads to separation of the soil.

Similar principle of soil destruction in the face is carried out by a helical drill. A working body of which contains a drive rod with a tip equipped with a screw blade, which above goes into a screw blade. The upper turn of the auger blade is equipped with a shearing element made in the form of a wedge mounted on the periphery of the blade. In addition, it ensures the destruction of the soil by its layer-by-layer separation from the array, which significantly increases the speed and reduces the energy consumption of drilling. A similar principle of soil deformation is carried out by a screw working body.

Design of the screw working body for formation of wells contains a conical core with a helical blade, consisting of a conical section with a constant pitch of turns and a cylindrical section with a pitch of coils having a constant increment relative to the pitch of the turns of a conical section of the blade. When using such a working body, the process of soil destruction occurs in the following sequence, first the traction part with a constant step creates screwing, and when the destructive part is introduced into the soil with an increasing step, spallation occurs.

3. Theory
A more effective method of soil destruction during well drilling, in comparison with existing types of drilling tools, is realized by a screw drill. The idea of using a screw drill is to increase the radius of the screw blade on the destructive part for the separation of frozen soil.

A helical drill is a core with a helical blade located on it, which is divided into a lead-in and destructive part.

An entrance part is designed to create traction ability of the screw drill and implement its immersion without the action of axial crushing force.

A destructive part contains a helical blade with variable geometric parameters. In the first section, the blade has a constant step and a variable radius, which changes when the radius is rotated by a certain angle (ψ), in the second section, the screw blade has a constant radius and an increasing step, while the inclination of the upper forming surface of the screw blade to the axis of rotation varies from sharp to right angle.

Theoretical studies were carried out on three types of drilling tools: roller cone bit, paddle bit and screw drill. Investigated parameters such as the drilling speed and the process of energy consumption during the operation of these types of drilling tools.

4. Results and discussions
The criterion for the efficiency of the workflow of any drilling tool is energy intensity. The main parameters that affect the energy intensity of the drilling process are the geometric parameters of the drill, which affect the magnitude of the torque during operation of the drilling tool and the rate of penetration of the well.
Studies were carried out to compare the dependences of the energy consumption of the process of drilling wells with various types of drilling tools with a diameter of 300 mm on the ultimate strength of soils for uniaxial soil compression is shown in Figure 1.

With an increase in the uniaxial compression strength of the soil, the energy intensity of the drilling process for all types of drilling tools increases. However, the greatest energy intensity is observed during the operation of the blade bit. 1.8 times less energy consumption is observed during operation of a cone bit. The smallest energy consumption of the drilling process among the listed is carried out by a helical drill. The energy intensity value is 3.3 times less than that of a blade bit and 2 times less than a cone bit.

An important indicator of the drilling process is the drilling speed. The time required for drilling a well depends on the speed of drilling the bit and on the duration of its operation to wear. Based on the ratio of the cost of driving one meter, investing in a properly selected drilling tool will significantly reduce the drilling time and the number of tripping operations.

Experiments were carried out and the speed of the drilling process for different types of drilling tools with a diameter of 300 mm is presented in Figure 2.

With an increase in the uniaxial compressive strength of the soil, the value of the drilling process speed decreases for all types of drilling tools. However, the highest drilling speed is observed when the screw drill is in operation. 3.8 times faster drilling speed with a screw drill than with a roller cone bit. The lowest speed of the drilling process among the listed ones is carried out by a blade bit. The speed value is 8.75 times faster than the paddle bit.

The greatest efficiency of the studied screw drill is manifested on frozen soils, which have more fragile properties - sandy and sandy loam. This represents the greatest value since it is these soils that cause great difficulties in their drilling due to their high strength and abrasiveness.

5. Conclusions

The proposed drilling tool is a drilling process. This type of soil deformation is the less energy intensive and most effective way of tillage. This is of great importance for the process of drilling frozen soil. The use of drilling tools allows the drilling of frozen soils with less energy consumption compared to existing types of drilling tools and greater efficiency.
The carried-out studies have shown the need and expediency of further studies aimed at determining rational geometric parameters and operating modes that contribute to the achievement of maximum efficiency of drilling in frozen soils.

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