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Drilling of Deep Borehole 5G at the Antarctic Station "Vostok" in Ice Layers with the Ice Temperature Close to the Phase Transition Point

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Abstract
The paper provides information about the features of drilling of deep borehole 5G, drilled in ice massif, at the Russian Antarctic Vostok station. Presents the main causes of problems in drilling deep wells at a temperature of the ice close to the phase transition point. The design of the electromechanical drill and discusses the changes made to its design. A new design of the drill head and filter slamboree compartment. The new design of the drill bit enables drilling coarse ice, and the use of a new filter-the possibility of drilling of ice at a temperature close to the phase transition point by regulating the flow of priming liquid from the sludge.

Keywords: Antarctica, Lake Vostok, Borehole 5G, deep drilling, ice layer, ice core.

INTRODUCTION
Works for the development of a technology of the deep drilling in the ice layers in the 57 season of the Russian Antarctic Expedition on 5 February 2012 resulted with the successful unsealing into the relict subglacial lake Vostok in Antarctica at a depth of 3769,3 m, [1].
Drilling of borehole 5G at Vostok station was started in 1990. At the moment the well has a complex multicore design. To a depth of 2755 m drilling was carried out using the heat method, and then mechanical. The mechanical method of drilling in the ice favorably with the heat method is much less power consumption, higher drilling speed, and significantly improve the quality of core. Significant changes in physico-mechanical properties of ice at depths of over 3000 m has demanded major changes in technology and technique of drilling wells at the ice layers on the carrying cable.
Drilling of borehole 5G-2 before the opening of the East lake near the foot of the glacier when the ice temperature close to the phase transition point, was accompanied by a number of problems both during drilling and during expansion of the well bore.
Starting from a depth of 2500 meters, there has been a gradual decline in regular penetrations, and 3000 m depth problems in maintaining a stable drilling process become so significant that the drilling can be just terminated. Analysis of drilling borehole 5G showed that the main reasons of problems during drilling is the change with depth of the crystal structure of the glacier and the increase of ice temperature with depth.
At depths ranging from 2500 m, the size of the ice crystals gradually increase and may exceed the width of the face. At a depth of 3000 m the average size of the crystals exceed 20 mm. After the depth of 3500 m individual crystals have dimensions more than 1 m. As a result, when drilling a series of cores obtained consisted of 1-2 single-crystals [2]. The temperature in the borehole 5G varies from-56 to-2,73° and increases with depth. At depths of over 3000 m, the temperature of the ice close to the phase transition point, resulting in the drilling of mechanically fine particles of sludge having a large free surface, clump together due to the appearance of water on their surface due to heating by friction against each other in the flow of washing fluid, which leads to the formation of sludge in traffic jams.

ELECTROMECHANICAL CORE DRILL ASSEMBLY
Basic electromechanical coring drill KEMS-132 (Fig. 1) includes a crown 1, a core tube 2, lamaslany compartment with a filter for collecting the sludge 3, reducer 4, drive motor 5, pump 6, creating a reverse circulation of flushing fluid, a spacer device 7 for the perception of the reactive torque on the nonrotating part of the projectile, a percussion device 8, 9 electrotek with cable lock 10 to connect the load-carrying cable 11.
Electromechanical drilling Assembly operates as follows. The rotation of the rotor of the electric motor 5 through the reduction gear 4 is transmitted to the coring tube fixed there to a crown 1. The sludge formed during drilling, a flow of washing fluid in the compartment keen on lamaslany 3 and remains in the filter. The washing fluid rising along the central holes of the shafts of the reducer and drive motor, turns out disposing in the annular space of the pump 6. Skates the spacer device 7, contacting the walls of the wells do not allow to rotate the top of the drill during drilling [5].
The sludge formed by the destruction of ice on the bottom of the well, is fond of flow of the washing fluid in the annular gap between the core pipe and the core, where it enters the central filter pipe. Through the holes the filter pipe the filling liquid with the sludge enters the filter cavity, the shell of which is made of wire mesh. Pouring the filtered liquid, after passing through the filter, is directed through the central channel of the drive shaft of the gearbox and the rotor shaft of the electric motor under the action of the pump in the annulus.
A filter element of the chip catcher is a steel mesh with a mesh size of at least 0.2-0.3 mm, which allows the first stage to collect particles with a size exceeding the cell, and in the future-all sludge, as the first layers of the sludge collected in the chip catcher, then act as a filter. Volumetric content and porosity of the slurry in the chip catcher are the most important indicators of the effectiveness of the system of removal. If the sludge does not fall in the chip catcher and accumulate in the annulus, this is a violation of the technological process of drilling, which may lead to filling the bottom zone with an ice chips and sticking the drill. The

denser the sludge in the chip catcher, the more possible regular excavation. The diameter of the chip catcher is determined by the diameter of the core set, and its length based on the planned voyage of sinking. Filter mesh chip catcher is a major source of hydraulic resistance in the circulation system of filling liquids. When you enable rotation, the fluid flow immediately drops about two times, and it is only thanks to the losses in the grid filter.

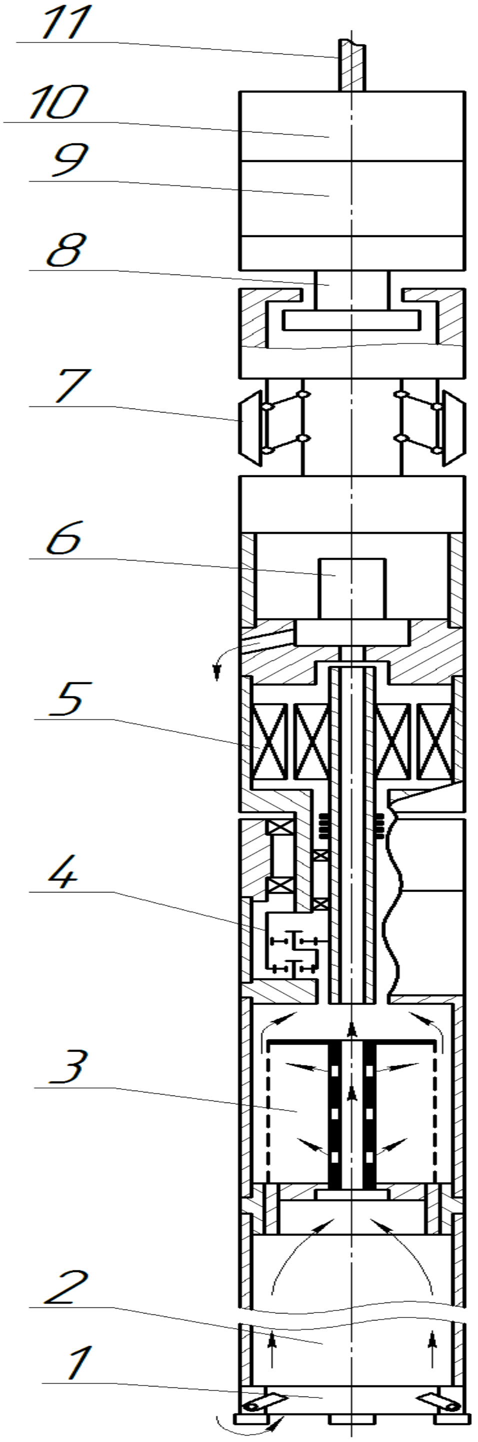

Figure 1: Scheme of the electromechanical coring drill KEMS-132.

Pouring the filtered liquid, after passing through the filter, is directed through the central channel of the drive shaft of the gearbox and the rotor shaft of the electric motor under the action of the pump in the annulus. A filter element of the chip catcher is a steel mesh with a mesh size of at least 0.2-0.3 mm, which allows the first stage to collect particles with a size exceeding the cell, and in the future-all sludge, as the first layers of the sludge collected in the chip catcher, then act as a filter. Volumetric content and porosity of the slurry in the chip catcher are the most important indicators of the effectiveness of the system of removal. If the sludge does not fall in the chip catcher and accumulate in the annulus, this is a violation of the technological process of drilling, which may lead to filling the bottom zone with an ice chips and sticking the drill string. The denser the sludge in the chip catcher, the more possible regular excavation. The diameter of the chip catcher is determined by the diameter of the core set, and its length based on the planned voyage of sinking. Filter mesh chip catcher is a major source of hydraulic resistance in the circulation system of filling liquids. When you enable rotation, the fluid flow immediately drops about two times, and it is only thanks to the losses in the grid filter.

New design of drill bits for drilling ice

Analysis of cutting process of ice and sludge showed that with the increase in the average size of the crystals at a constant speed of rotation of the crown and the mechanical drilling speed (the speed with which increases the depth of the well in the process of breaking down rock or ice) the particle size of the slurry is reduced. During the drilling of fine-crystalline ice slurry is composed mainly of particles larger than 1-2 mm even if mechanical drilling speed less than 5 m/h. When cutting large single crystals (>10 mm) the sludge consists of particles less than 0.5 mm with a large proportion of fine fractions. Once in the filter, finely dispersed slurry forms a filter layer that even with a slight thickness creates a large resistance to flow of the washing fluid. This causes a decrease in fluid flow, which in turn promotes the formation of slurry tubes, the incisors and the stop drilling even with a slight speed of drilling. The process of slurry formation of traffic jams is compounded by the fact that the ice has a relatively high temperature and with a large free surface of sludge particles, which should be the film of water has a great potential for the sticking of individual particles.

The particle size of sludge is affected mainly on the reduction of drilling per flight due to the increase in hydraulic resistance in the filter chip catcher, but the sudden stop drilling arise primarily due to insufficient flow of the washing fluid. In the Russian drilling apparatus and drilling apparatus, which was used in the EPICA, the flow of flush liquid is about 40 l/min When drilling with mechanical speed of 10 m/h, the concentration of sludge in the flow of priming fluid is approximately equal to 2%, and in drilling hard rocks recommended concentration of sludge in it should be below 5%. In practice, when drilling in the ice to a depth of 3000 m mechanical drilling speed can be much larger than 10 m/h, with no problems in the removal of cuttings from the bottom hole does not occur. Thus, the solution to this problem we see in the increase in the flow of wash liquid at least two times.

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These findings were made by the end of seasonal work in 43 minutes of RAE, but because of the shutdown of drilling and the incident in the 52nd RAE crash implemented these decisions were only after the deviation and restore the operating status of the wells in the season of the 56th RAE. After making serious changes in the design of the pump unit the drill string the flow of the washing fluid is increased to 120 l/min Were also made fundamental changes in the design of the drill bit, allowing an increase in the size of the slime three times.

Crown (Fig. 2) is the Union of the three crowns odnorazovyj, [3]. Each cutter forms a bottom, a width of 1/3 overall width of ring face. The thickness of the cutting layer three times more than conventional cutters, which entails an increase of the size of the cuttings and drilling, respectively, per flight. In addition, the larger the sludge is characterized by a smaller total surface, which reduces the risk of sticking of the particles of the slurry, especially at depths greater than 3000 m, where the ice has a relatively high temperature. However, the continuation of drilling at depths of more than 3650 m showed that changes in the design of the drilling of the projectile is not enough. At these depths began to show a temperature rise of ice, and when approaching the lake surface ice temperature was almost equal to the melting temperature. This led to the fact that at the slightest compression of the sludge (for example, at the entrance to the Central sempozyumu pipe and in the filter) formed a compacted tube of the sludge in the result of the continued circulation of the liquid and the crown was filled with ice chips. As already mentioned, the temperature of the ice at these depths is close to its melting point, therefore, the sludge at the slightest influence of power coalesces in the low permeable tube. A similar phenomenon is observed in the formation of snowballs from the damp snow. To cope with this complication was due to the introduction of significant changes in the structure of the filter chip catcher. Most effective get a design that is a combination of a standard filter shell KEMS-132 and filter shell EPICA, allowing to organize the flow of the fluid in the filter that sludge is evenly distributed throughout its volume.

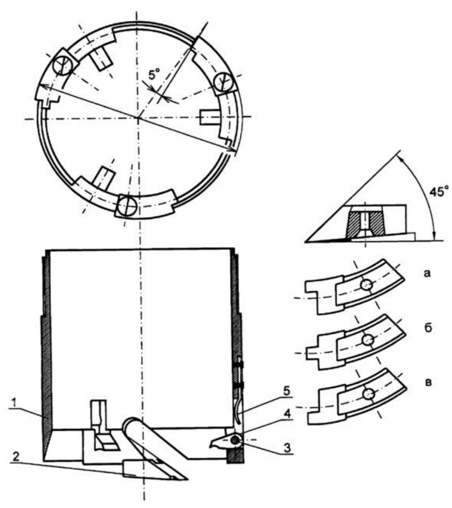

Figure 2: An improved cutter head adapted for drilling "warm" ice: 1-body of the crown; 2-incisors (a, b, C-the modification of individual cutters); 3-axis carnivale dogs; 4-carnivalia dog; 5-coil spring

The result of the changes, the process of drilling a well is fully stabilized. The design was applied for 10 m to the surface of the lake. Managed to ensure even distribution of the sludge in the filter chip catcher, but the excavation for the flight did not exceed 1 m.

The new filter design of the shell for drilling of ice at a temperature close to the phase transition point

In the season of the 57th RAE (November 2011-February 2012.) drilling of borehole 5G-2 was carried out in the interval 3620-3769,3 m. In connection with the above changes in the physical and mechanical properties of ice, had complications in the drilling process, and the extension of the wellbore. Near the foot of the glacier slurry of jams occurred directly at the entrance to the filter, causing the increase in hydraulic resistance in the treatment system and sludge from the bottom and decrease in the penetration per flight. The sinking is terminated when the resistance reaches this value, at which the filling liquid practically does not pass through the filter, and the pump stops.

As a result of complications in the drilling process due to changes in physico-mechanical properties of ice and inaccuracies in the handling of the pipes were caused by the local curvature of individual sections of the wellbore. Was jamming the core barrel and the crank spacer device.

To improve penetration and opportunities ice drilling at temperatures close to the phase transition point, in the season of the 57th RAE has developed a new design of the filter system of bottom hole cleaning from cuttings, [4], is shown in Fig. 3.

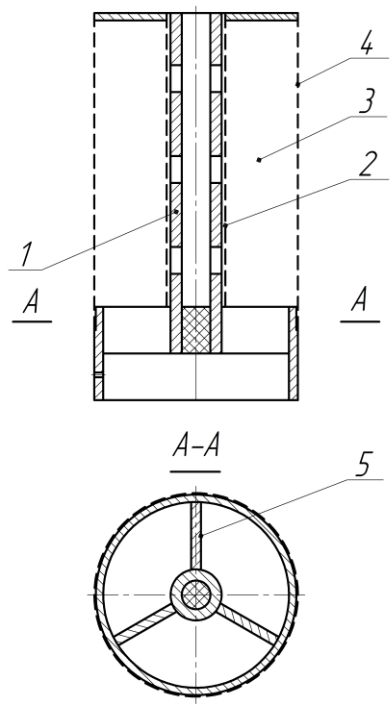

Figure 3: The new filter design of the chip catcher of the drill.

The Central perforated pipe 1 (Fig. 4) the design of the new filter was made with an additional grid 2 over its entire outer surface. Thus, on the upper end of the filter tube is made open, and the cavity of the filter through the annular gap between the outer filter and the inner mesh is made closed. At the lower end of the filter tube is closed, and the cavity is open through the implementation of a removable housing filter through. The liquid with the sludge in this case passes into the cavity of the filter through the annular gap 3 between the outer 2 and 4 internal filter screens unlike the old design, where the liquid from the slurry into the cavity of the filter through a Central perforated pipe, the cross-sectional area which is much less cross-sectional area of the filter. The lower end of the filter has ribs 5 for still attached to its outer mesh of the filter, while the liquid enters the filter through the available cavity in the form of sectors of an annular gap bounded by edges of rigidity.

At the open upper end of the Central tube, the fluid flow is discharged through the outer mesh shell and the other part passes through the Central pipe. There is a possibility of overlap of the holes, which provides the possibility of regulating the flow of fluid sludge and ensures an optimal distribution of the sludge throughout the length of the filter and reduce flow resistance. The openings overlap in the regulation of tube length. Due to the overlapping part of the holes flow of fluid from the slurry passing through the annular gap between the outer and inner filter screens takes the form of a laminar motion. This reduces the probability of contact of the particles with each other being at a temperature close to the phase transition point, sticking them in friction and, consequently, the formation of the slurry tube at the entrance to the filter. Thus, the least contact of ice particles in the cavity filter provides the regular increase of penetration during the drilling of ice being at a temperature close to the phase transition point and provides the possibility of drilling the ice under such physical and mechanical properties.

When drilling wells to depths of 3760 m there was a gradual decrease regular penetrations (Fig. 4). After that, the holes in Central perforated pipe were blocked and has been applied to the possibility of regulating the flow of liquid, which led to the reduction of hydraulic resistance in the filter and increase the regular of sinking.

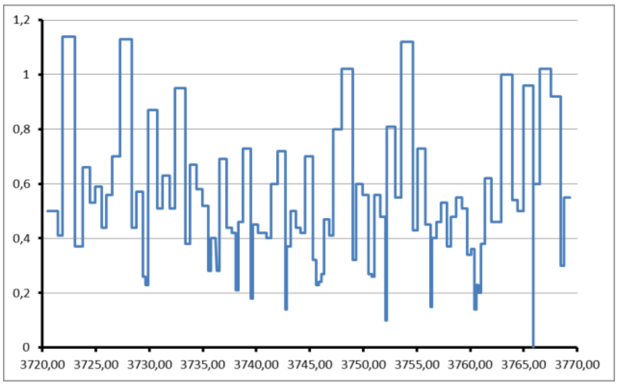

Figure 4: Schedule of penetrations per flight in the season of the 57th RAE

CONCLUSION

Changes made to the design of the projectile, ensured the possibility of drilling coarse ice near the foot of the glacier at a temperature close to the phase transition point. In the season of the 57th Russian Antarctic Expedition in January-February 2012. at Vostok station was continued drilling the borehole 5G-2. The use of this drill string with a new design of the tooth and filters with the possibility of regulating the flow of fluid in screen section compartment of the drill sonde, ensured the passage of the well on the interval 3720-3769,3 m, and execution of penetration into the subglacial lake Vostok.

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