Enhancement of inertial mechanical reamer for borehole 5G conditioning to penetrate into subglacial lake Vostok

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Abstract. The paper reviews challenges associated with designing of equipment required to implement the selected technology of penetration into Subglacial Lake Vostok in Antarctica. It describes the design process of inertial mechanical reamer, which is required for one of the stages of the proposed penetration technology. The initial design of the reamer was developed, manufactured and tested in Borehole 5G during the seasonal shift period of the 62nd Russian Antarctic Expedition (December 2016 – January 2017). Based on the test results the reamer design was critically reviewed, enhanced and subsequently tested in Borehole 5G during the seasonal shift period of the 63rd Russian Antarctic Expedition (December 2017 – January 2018). Tests of the improved design of the mechanical reamer confirmed that the adopted design solutions are correct.

1. Introduction
Further investigation of Lake Vostok that was penetrated on February 5th, 2012, by specialists of the St. Petersburg Mining University and the Arctic and Antarctic Research Institute [1] involves sampling of the lake water and bottom sediments. Being the largest subglacial lake in Antarctica, Lake Vostok is a unique natural system [2, 3, 4], thus, first of all, the survey procedures have to satisfy the environmental safety requirement. This can be achieved only if all the employed mechanisms and arrangements operate in a safe and faultless way.

2. Well preparation technology
Specialists of the St. Petersburg Mining University developed a borehole conditioning technology for sampling lake water and bottom sediments [5] from Borehole 5G that envisages the following six stages (Fig. 1).

The second stage consists in reaming the bottom section of the borehole up to 300 mm in diameter within the depth interval of 10 meters from the borehole bottom (Fig. 1, b). It is intended to perform this operation using a mechanical reamer mounted on the mechanical drilling assembly [6]. Originally, the following design of the inertial mechanical reamer was suggested (Fig. 2) [6].

The inertial mechanical reamer consists of a hollow housing (1) which walls have three continuous axial slots (2) located at 120° relative to each other.

A support (3) is fixed inside housing (1). The support is designed as a 118-mm disk with a centrally located square hole (10 mm x 10 mm) and four 30-mm openings to evacuate the drill cuttings formed in the reaming process. Support (3) has a yoke (4) with eye ends (5) located at the same angles as the
axial slots (2) of the housing, i.e. 120°. The pin (6) of yoke (4) is square in cross section with the side width of 10 mm, which prevents its axial rotation against the support (3). The cutting tool holders (7) are hinge-mounted in the eye ends (5) of the yoke and can freely rotate relative to the hinge axes. The reamer assembly has three cutting tool holders (7), which secure its self-alignment in the hinge axes. The cutting tool holders (7) are rectangular in cross-section (18 mm x 12 mm).

Figure 1. Technology of borehole conditioning before penetration into Lake Vostok

a – borehole drilling with a mechanical drilling assembly; b – borehole reaming with a mechanical reaming assembly; c – borehole reaming with a thermal reaming assembly; d – ingress of lake water into the reamed section of the borehole; e - deployment of the delivery vehicle in the reamed section of the borehole; f - running of the research module into the lake.

The upper ends (8) of the cutting tool holders (7) are located at 33° relative to the lower part and are fitted with adjustment screws (9) that limit the opening angle of the cutting tool holders (7) during the drill string rotation. The cutting tools (10) are fixed at the lower part of the holder levers and have two cutting edges that secure ice cutting in vertical and lateral directions. The cutting tools are fitted with guards (11) that prevent the tool slapping while drilling.

The reamer is fixed instead of the drill bit at the end of the drilling tube of the mechanical drilling assembly. Screws (9) are adjusted so as to reach the required opening angle of the cutting tool holders (7). In the transport position all the cutting tools are located inside the housing (1).

The drilling assembly is run into the borehole until the bottom edge of the housing (1) reaches the borehole bottom. Then, the drill string rotation is started and the angular velocity of the reamer reaches ω = 13.6 – 23 c-1. The resulting centrifugal inertial force makes the cutting tool holders (7) deviate from the rotation axis by angle φ and extend out of the housing (1) through the axial slots (2) in the housing until the cutting tools (10) rest against the borehole walls.

The borehole is reamed when the drilling assembly starts rotating and simultaneously lifting up the
Once borehole reaming is completed, the drill string rotation is stopped. When this happens, the cutting tool holders (7) are closed by the gravity force. The drilling assembly with the reamer can be pulled from the borehole.

Subsequently, reaming can be repeated with the adjustment screws (9) set to obtain the required opening angle of the cutting tools as consistent with the attained borehole diameter.

![Figure 2. Inertial mechanical reamer in transport (a) and operating (b) positions](image)

This design of the inertial mechanical reamer was tested in Borehole 5G during the seasonal shift period of the 62nd Russian Antarctic Expedition (December 2016 – January 2017) (Fig. 3).

![Figure 3. Inertial mechanical reamer mounted on the drilling assembly](image)

3. **Test results**

Test results showed that the reamer performed its main function, i.e. hole enlargement, quite well. However, the following three disadvantages were revealed.

The first one is high labour intensity of adjusting the opening angle of the cutting tool holders (7) with adjustment screws (9) due to the need to remove the reamer from the drilling tool (Fig. 2).

Another disadvantage is lack of reliability in conversion of the cutting tool holders from the transport into the operating mode if they miss the axial slots (2) in the housing (1) (Fig. 2). No failures have been observed in conversion from the operating into the transport mode, which proves that reamer jamming
in the borehole is highly unlikely during its lifting up the borehole. The third disadvantage is concerned with hindered passing of the cuttings produced in the borehole reaming process due to insufficient area of openings in the support (3) (Fig. 2).

The following modifications have been made in the reamer design to eliminate the identified deficiencies.

1. An external limiting device to control the opening angle of the cutting tool holders was introduced. This limiting device represents a tube which inner diameter is equal to the outer diameter of the reamer (Fig. 4). The limiting device is fixed in the specified position with locking screws.

2. Two designs of the guides were suggested: one solid for three cutting tool holders simultaneously and the other one independent for each tool holder individually (Fig. 5).

The shape and the number of openings in the support was changed resulting in a larger cross-sectional area to improve drill cuttings throughput (Fig.5).

**Figure 4.** Inertial mechanical reamer with the external limiting device to control the opening angle of the cutting tool holders

**Figure 5.** Inertial mechanical reamer with solid guide for cutting tool holders (a) and individual guides for tool holders (b)

The enhanced design of the inertial mechanical reamer was tested in Borehole 5G at Vostok Station during the seasonal shift period of the 63rd Russian Antarctic Expedition (December 2017 – January 2018).
4. Conclusion

The tests were performed at the depth of 3650 m which is characterized with complications of the borehole reaming and drill cuttings removal processes due to a high temperature of the cut ice. It is possible to draw the following conclusions based on the test results:

Firstly, introduction of the external limiting device that controls the opening angle of the cutting tool holders helped to significantly decrease the labour intensity of the tool holders angle adjustment, which can now be done without removing the reamer assembly from the drilling tool.

Secondly, the use of the guides secured conversion of the cutting tool holders from the transport position into the operating mode and backwards. The solid design of the guides proved to be easier to assemble and more accurate in terms of centering the internal parts of the reamer inside the housing.

Thirdly, changing the shape and the number of openings in the support that resulted in larger cross-sectional area failed to eradicate problems with removing the drill cuttings from the cutting tools and the reamer housing (Fig. 6).

![Figure 6. Drill cuttings on housing of inertial mechanical reamer](image)

Further activities aiming to enhance the inertial mechanical reamer will be focused on eliminating the last design deficiency, i.e. inefficient removal of drill cuttings from the cutting tools and housing of the reamer. Tests of the new reamer design are planned to be performed in Borehole 5G at Vostok Station during the seasonal shift period of the 64th Russian Antarctic Expedition (December 2018 – January 2019).

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