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Circulation system of an Antarctic electromechanical bedrock drill

Baolin Liu [a], Rusheng Wang [b, c, *], Pavel Talalay [b], Qingyan Wang [a], An Liu [a]

[a] College of Construction Engineering, Jilin University, Changchun, 130026, China
[b] Polar Research Center, Jilin University, Changchun, 130026, China
[c] Polar Research Institute of China, Shanghai, 200136, China

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ABSTRACT

For bedrock core drilling below 3000 m in the Antarctic ice sheet, Jilin University has designed a set of modular electromechanical drills with a local reverse circulation system, which works at the bottom of the borehole to remove the rock powder. Thorough removal of the rock powder is critically important to prevent it from accumulating in the bottom of the hole and eventually blocking the drill or causing other problems. During drilling, rock powder is carried by the drilling fluid, which flows from a down-hole pump to the chip chamber. If drilling fluid in the bottom of the hole cannot overcome the flow resistance or if its velocity is too low, the rock powder will not be carried to the chip chamber, and will remain in the borehole or gather in the clearance of the circulation system. Therefore, the down-hole pump performance characteristics are of vital importance. The selection of the down-hole pump for bedrock core drilling should consider both flow rate and outlet pressure. This paper reports a specific calculating method for the rEquired flow rate of the drilling fluid and the pressure losses in the circulation system.

1. Introduction

Antarctica always offers an unrivaled opportunity for research at the frontiers of knowledge, both for basic scientific and strategic reasons. One of the most amazing and exciting discoveries about our planet in recent years was the unexpected finding of a subglacial Antarctic environment—another world beneath the ice sheet. This subglacial environment can give unique information in various natural and interdisciplinary science fields.

The subglacial environment has become central to our understanding of the formation of the Antarctic ice sheet and past climate change, and also to assessments of possible future climate change (Bell, 2008). Another particularly exciting aspect of the subglacial environment (probably unique to the Antarctic) is the prospect of finding new forms of life inhabiting not only the subglacial lakes but also subglacial till, vents, or cracks in the bedrock (Gilichinsky et al., 2008). In addition, bedrock samples give significant information on subglacial geology and tectonics. The thick ice sheet covering 98% of Antarctica makes it the least geologically explored continent in the world. Recent Antarctic geological mapping has been based on paleo-geological, remote geophysical surveying and modeling (Fretwell et al., 2013; Golynsky, 2003; Satish-Kumar et al., 2008). However, the lack of available rock samples constrains the assessment of the content and age of the subglacial bedrock. The only way to elucidate the origin and structure of rock is direct observation of the ice sheet bed by drilling.

Drilling operations in Antarctica are complicated by the extremely low temperatures at the surface and within the ice sheet, and also by ice flows, the absence of roads and infrastructure, storms, wind, snow, etc. All these reasons have prevented bedrock cores from ever being obtained from inland Antarctica. To recover subglacial bedrock samples, two types of subglacial drilling technologies might be considered (Talalay, 2013): (1) commercial drill rigs with a conventional core barrel, a wire-line core barrel, or coiled tubing, and (2) electromechanical cable-suspended drilling with near-bottom fluid circulation. These drilling technologies have different concepts, limits, performance, and applicable scopes.

To use commercial drill rigs in harsh Antarctic conditions rEquires many components (e.g., hydraulic and fluid processing systems and others) to be principally redesigned to cope with the low temperatures. Commercial drill rigs operate either as outdoor machines or use tents or primitive shelters that provide insufficient protection against the low temperatures and storm winds in Antarctica. Their high weight and power consumption rEquire substantial logistical operations to move and support them, which

* Corresponding author. Polar Research Center, Jilin University, Changchun, 130026, China.
E-mail address: wangrs@jlu.edu.cn (R. Wang).

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make drilling in Antarctica using commercial Equipment not only disadvantageous but also in some cases impossible.

Electromechanical drills with bottom-hole circulation have been proven to be the most reliable systems for ice-core drilling to deeper than 400 m (Talalay, 2016; Appl et al., 1991). The main feature of electromechanical cable-suspended drills is that an armored cable with a winch is used instead of a pipe string to provide power to the down-hole motor system and to retrieve the down-hole unit. The rotor of the down-hole electric motor produces a rotation that is transmitted through the reducer to the core barrel with the drill bit. The use of armored cable significantly reduces power and material consumption, decreases the time of round-trip operations, and simplifies the cleaning of the hole from the cuttings. Recently, the deepest borehole in ice was drilled to 3769.3 m at Vostok Station, East Antarctica, using the Russian KEMS electromechanical in 2012 (Lukin and Vasiliev, 2014).

Unlike conventional rotary drilling, where the fluid is normally pumped to the bottom of the hole from the surface, an electromechanical drill suspended on a cable uses a bottom circulation system with a down-hole pump and chip chamber for filtering the fluid and collecting the cuttings (Talalay, 2006). The circulation flow may be in the normal direction, where the flow is going down the inside of the core barrel and up between the core barrel and the borehole wall, or vice versa in the reverse direction. The latter flow ensures better cleaning of the bottom cuttings and rEquires a lower flow rate.

In our opinion, electromechanical cable-suspended drilling is the most effective method to penetrate subglacial bedrocks. This was confirmed by four successful previous projects carried out by U.S. and Russian specialists (Ueda and Garfield, 1968; Gow and Meese, 1996; Steig et al., 2000). Compared with ice-core drilling, bedrock drilling faces challenges: (1) the drill bits must be able to drill in hard formations with minimal load and acceptable rates of penetration and torque; (2) an antitorque system must provide sufficiently high torque to hold the stator of the electromechanical drill with acceptable axial resistance force (Talalay et al., 2014); (3) a circulation system is rEquired that can remove all rock cuttings from the bottom of the hole and collect them in the down-hole chamber. This paper contains specific recommendations for estimating the rEquired flow rate of the drilling fluid and the hydraulic resistance in the circulation system of electromechanical bedrock drills, which provides a theoretical basis for the selection of the down-hole pump for drilling subglacial bedrock.

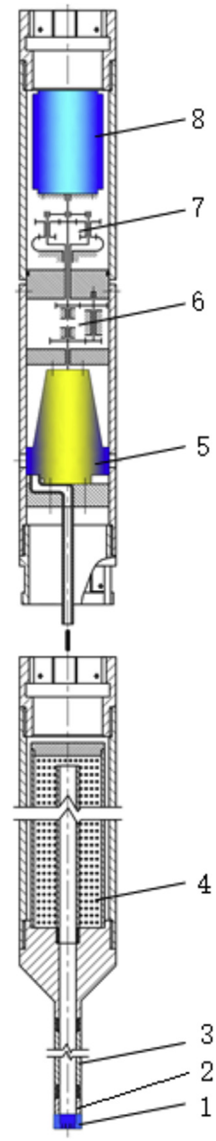

Fig. 1. Schematic diagram of the drill circulation system: (1) drilling bit; (2) core cutter; (3) core tube; (4) chip chamber; (5) down-hole pump; (6, 7) reducer; (8) electric motor.

2. Working principle of the circulation system

Fig. 1 shows the structure of the drill circulation system. Its main components are an electric motor, two reducers, a down-hole pump, a chip chamber, a core barrel, four core cuters, and a drill bit. The down-hole pump is a centrifugal pump, whose flow rate is independent of the operating pressure. The length below the down-hole pump is 2.05 m, and the core barrel is 0.87 m. The diamond drill bit has inner/outer diameters of 41/59 mm.

During drilling, the drilling fluid causes a local reverse circulation flow at the bottom of the borehole as follows. The output shaft of the electric motor drives the down-hole pump through the gear reducer, and the entry of the pump forms a low-pressure region, whereas the annular clearance near the outlet of the pump is a high-pressure region. This pressure difference causes drilling fluid to flow from the annular clearance to the drill bit openings, carrying rock powder into the core tube. It flows upward along the annular clearance formed by the core and core tube wall, and finally through the center pipe into the chip chamber. The rock powder is filtered and deposited in the chip chamber, while the drilling fluid flows upward through the filter into the down-hole pump, through its outlet, and into the annular clearance of the drill and wall of the borehole. The drilling fluid repeatedly forms local reverse circulation at the bottom of the borehole with the suction pump.

3. Calculation of the flow rate

The flow rate of the down-hole pump must be able to remove cuttings. Determination of the theoretical flow rate should consider factors including the structure of the circulation system, the type of drilling fluid (e.g., its density and kinematic viscosity), the temperature, and the size distribution of cuttings.

3.1. Equivalent diameter distributions of the cuttings

The size distribution of cuttings produced by the drill bit is a crucial parameter to calculate the sediment velocity; therefore, it is necessary to determine their Equivalent diameter distribution. This was done through a drilling experiment using a bit composed of diamond particles 30 mesh in size. The resulting cuttings were