ICE SHEET DRILLING BY SOVIET ANTARCTIC EXPEDITIONS

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ABSTRACT

Scientists of the Leningrad Mining Institute and of the Arctic and Antarctic Research Institute have developed fundamentals of the theory of the process of drilling by melting of open holes. A series of electrothermal core drills used with a cable has been manufactured. Two drilling rigs have also been developed and manufactured: a stationary one for deep drilling, and a mobile one for drilling to 150 m.

The deepest borehole at Vostok Station is 952 m. Core recovery was 99 per cent. The core diameter is 125 mm, and the borehole diameter is 180 mm.

Geophysical and geochemical studies in the boreholes have been made together with observations of ice-sheet dynamics and ice rheology.

The Arctic and Antarctic Research Institute has developed and successfully used lightweight electrothermal core drills for sinking boreholes in warm mountain glaciers without pumping out the water. In addition, thermal drills for drilling without core removal in warm and cold glaciers have been developed. Depths of boreholes in warm glaciers (with and without core removal) and in cold glaciers (without core removal) are 200 m and 80 m, respectively.

At the present, an electromechanical core drill is being tested in laboratory and field conditions, thermal core drills for a non-freezing fluid-filled hole are being developed, effective fluids are being selected, a system of removing ice chips and meltwater from the borehole is being developed, and the equipment for drilling to 4000 m is being designed.

Preparation is underway for drilling a deep borehole at Vostok Station in the 1977-1978 season.

Electrothermal drilling devices for coring and non-coring melt penetration of holes are used for ice-sheet studies in Soviet Antarctic Expeditions (Barkov, 1960; Barkov *et al.*, 1973; Bobin and Fisenko, 1974; Korotkevich, 1973; Kudryashov and Yakovlev, 1973; Kudryashov *et al.*, 1973; Morev, 1972a, 1972b; Sekurov, 1967).

A method for calculation is developed which enables us to select optimum variants of construction elements and regimes of drilling by melt penetration. On the basis of the theory of moving sources of heat (Rosenthal, 1946) and the theory of heat conductivity of the bodies with dispersed heat sources by means of conjugation of one-dimensional temperature fields, a stationary process of melt penetration drilling is analytically outlined, with the heat exchange between the heater and the ambient liquid and gaseous medium being taken into account.

A general formula of the rate of melt penetration drilling of open holes is obtained (Kudryashov and Fisenko, 1973).

$$V = \frac{2ka\lambda_1 m\,(1 - nL^2)\,L}{a\rho\gamma - (T + \sigma H)\,\lambda_2}$$

where

$$m = \frac{1}{2\lambda_1}\left[\frac{1096N}{(D_2^2 - D_1^2)\,L} + \alpha\pi\,(D_1 + D_2)t\right] \qquad \text{Eq. (1)}$$

$$n = \frac{\alpha\pi}{2\lambda_1}(D_1 + D_2)\ ;\ k = \frac{F_1}{F_2}$$

D_1 and D_2 – inner and outer diameters of the annular heater

F_1 and F_2 – areas of the hole bottom and heater cross section

L – height of the heater

T – mean annual temperature of the ice surface

t – mean temperature of the ambient liquid and gaseous media

N – electric capacity of the heater

λ_1 and λ_2 – heat conductivity of the heater and ice materials

a – temperature conductivity of the ice

ρ – melting heat of the ice

γ – ice density

α – coefficient of heat exchange between the heater and ambient liquid and gaseous medium

σ – ice temperature gradient

H – depth of the hole

Eq. (1) considers major factors that determine the process of melt penetration drilling. Its analysis makes it possible to assess the influence of these factors upon the effectiveness of

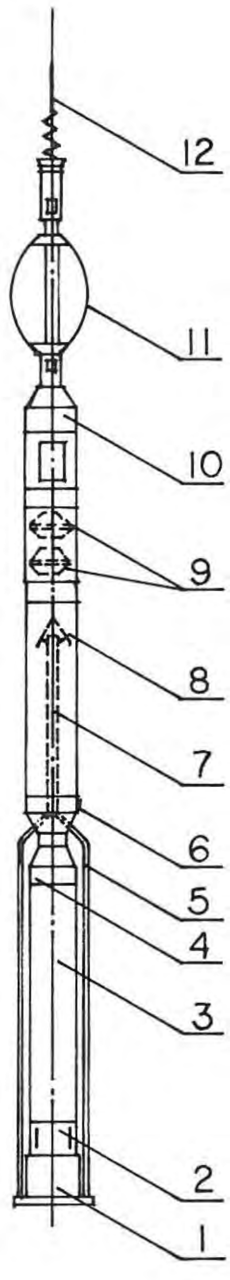

Figure 1. Schematic diagram of the electrothermal drill TELGA (see text for explanation of numbered areas).

the process. The calculated values of the rate of melt penetration drilling have proved to be close to the observed ones (Barkov *et al.*, 1973; Bobin and Fisenko, 1974; Kudryashov *et al.*, 1973; Kudryashov and Yakovlev, 1973).

The electrothermal drill TELGA used in the Soviet Antarctic Expedition is shown schematically in Fig. 1. The thermal drill has an annular heater consisting of a copper body which contains a nichrome heater element in a ceramic insulation. Air insulation between the wall of the hole and the heater is provided by ring-shaped protrusions on the bit bottom. Above the heater there is a core catcher (2). Along the core barrel (3) there are drainage pipes (5), the lower ends of which are close to the bit bottom and make it possible to control water ejection.

The upper ends of the pipes (5) are fixed on the assembly adapter (4) which connects them with the inner pipe (7) of the water tank (8). The adapter (4) has a valve (6) to drain water after the drill is raised. In the upper part of the tank (8) there is a vacuum-pump section with a pair of two-stage turbo-pumps (9) joined in sequence. The armor of the cable-wire (12) is fixed to the upper adapter (10). Above the adapter (10) there is a spring centering device (11).

The outer and inner diameters of the annular heater are 178 mm and 130 mm, respectively. The electric capacity of the heater is 3.5 kW, the length of the core barrel is 2 m, and the total length of the drill is 7.5 m.

The TELGA electrothermal drill operates as follows. After lowering the drill in the hole the heater (1) and vacuum pumps (9) are switched on. Due to vacuum in the tank (8) the water that forms on the bottom is ejected by the air flow and transported through the pipes (5) and (7) into the tank (8).

After the core barrel (3) is filled, the power supply is switched off, the hoist raises the drill from the bottom of the hole and the core catcher (2) automatically grips and retains a core. At the surface the core is retrieved, the water drains from the tank and the drill is prepared for the next run.

A test drilling was made at the 50th kilometer from Mirny, Antarctica, in October-November 1969. During 36 days a hole 250 m deep was completed and a core was recovered (Kudryashov *et al.*, 1973).

In 1970, with the help of the TELGA electrothermal drill, a deep hole was started at Vostok Station. In four months a depth of 507 m was achieved and a core was recovered (Barkov *et al.*, 1973; Kudryashov, *et al.*, 1973). A schematic diagram of the drilling equipment is given in Fig. 2, where

1– electrical switchboard

2– control board

3– window aperture

4– oil furnace

5– auxiliary hoist

6– rig

7– tower rings

8– installation of the drill over the hole

9– supporting framework
10– bench and instruments
11– fire prevention capacity
12– steel sledge
13– hoist motor
14– two-speed gear reducer
15– main hoist
16– cable wire
17– generator-motor system
18– lathe
19– collapsible balance-block
20– drill in the hole
21– conductor

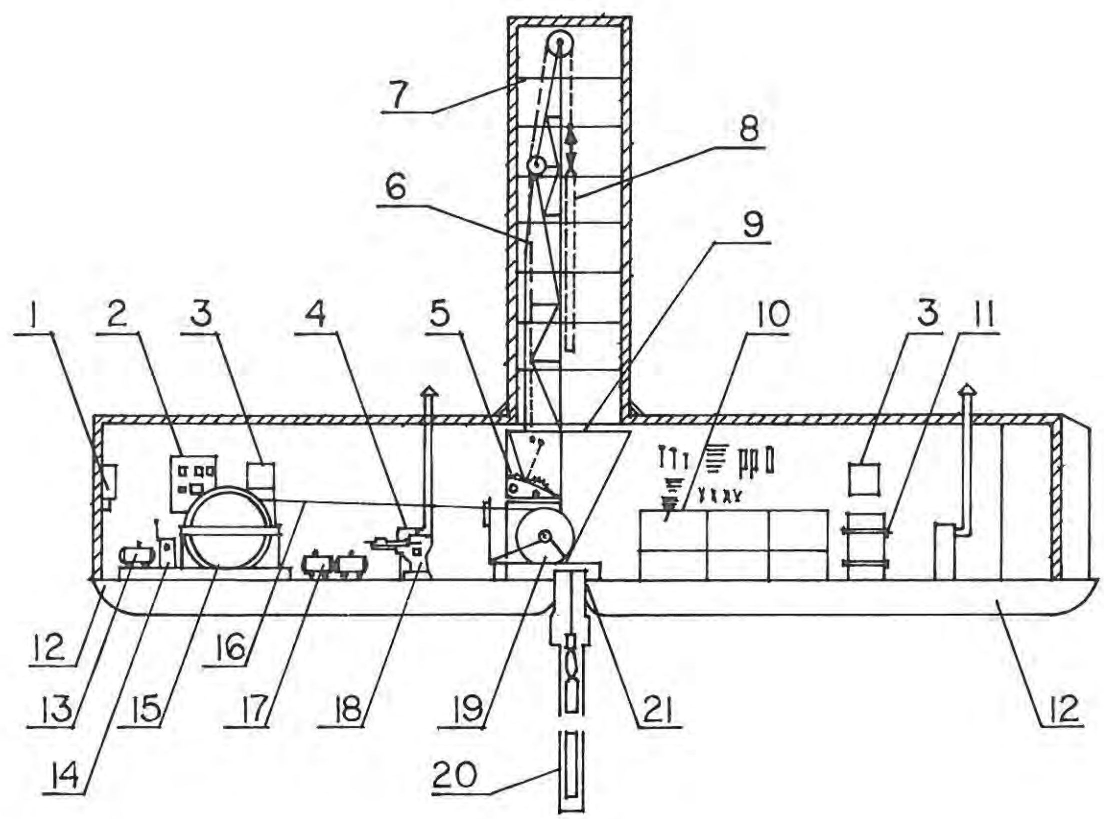

Figure 2. Schematic diagram of the electrothermal drilling equipment at Vostok Station (see text for explanation of numbered areas).

In 1971 complications occurred in the course of drilling due to lack of reliability of the control system for the performance of the drill.

In May 1972 the depth of the hole was 952 m, and a core was recovered.

In 1973 an attempt to continue drilling by melt penetration of a deeper open hole failed because of hole closure. As a result of this failure a part of the hole was left uncompleted and a new hole was started at a depth of 350 m. At present there is an open hole 905 m deep at Vostok Station. In this hole observations on temperature, deviation from the vertical, and the rate of deformation of the wall of the hole are being made.

For field conditions a mobile drilling unit, installed on a sledge, with a mobile version of the TELGA drill has been used (Bobin and Fisenko, 1974). During research traverses along the route Mirny-Pionerskaya three core holes to 70 m in depth were completed. The total depth of the holes completed by the TELGA drills was about 3000 m, with a depth of 952 m as a maximum.

For non-coring drilling of shallow holes lightweight electrothermal drills have been developed. These drills have conical heaters 40 and 80 mm in diameter (Morev, 1972b). During drilling in cold snow, water percolates into the wall of the hole, and during drilling in warm mountain ice with ice temperature about 0° C, the hole remains filled with water.

A coring electrothermal drill with an annular heater (Morev, 1972b) was also tested in mountain ice.

The conical heater (Morev, 1972b) is shown in Fig. 3. Its main feature is as follows: part of the heat from an electric heater coil (1), wound on a copper core (2), is transferred to the heater point; the remaining part, in a quantity needed to expand the area of the bottom of the hole to a given extent, is transferred to the ice through the outer wall of the heater (3). The distribution of heat over the surface of the heater depends on the thickness of the copper core and side insulation (4). The heater is designed to operate in a borehole filled with water or non-freezing liquid. The heater connections (5) are sealed with rubber (6).

Core bits are of the same construction, but the copper core and the walls are ring-shaped. The coring electrothermal drill tested in warm ice has an annular heater, a core barrel, core catchers, a centering device and a cable joint. It was lowered in the hole on a single-core cable 12 mm in diameter. The steel armor of the cable was used as a second conductor. The total depth of the holes completed by this drill was about 4000 m; a maximum depth was 200 m. The core drill ran about 250 m, with a maximum depth of 120 m.

At the present, surface drilling equipment and cable-suspended electrothermal and electromechanical drills for drilling 4000-m-deep holes filled with a non-freezing liquid are being developed.

At the same time apparatus and techniques for glaciological, geophysical and thermophysical research, as well as instruments for recovering sterile ice samples for microbiological studies are being developed.

It is being planned to begin the development of a device for recovering CO_2 samples from the ice for radiocarbon dating.

Table 1

Specifications of Electrical Heater Bits

In Electrothermal Drills

		TYPES OF HEATER BITS			
		Conical working surface			Flat working surface (TELGA)
		continuous		annular	annular
Diameter, mm	heater	48	80	112/88	178/130
	hole	48-50	82-85	116-120	180-185
	core	-	-	82-85	120-125
Ice temperature, ^{o}C		0	-19 to -28	0	-28 to -57
Power, kW		1-2	3-4	1.5-2.2	3.5
Voltage, V		150	200	160	250
Drilling rate, m/hr		7-9	7-10	3-4.5	1.5-2

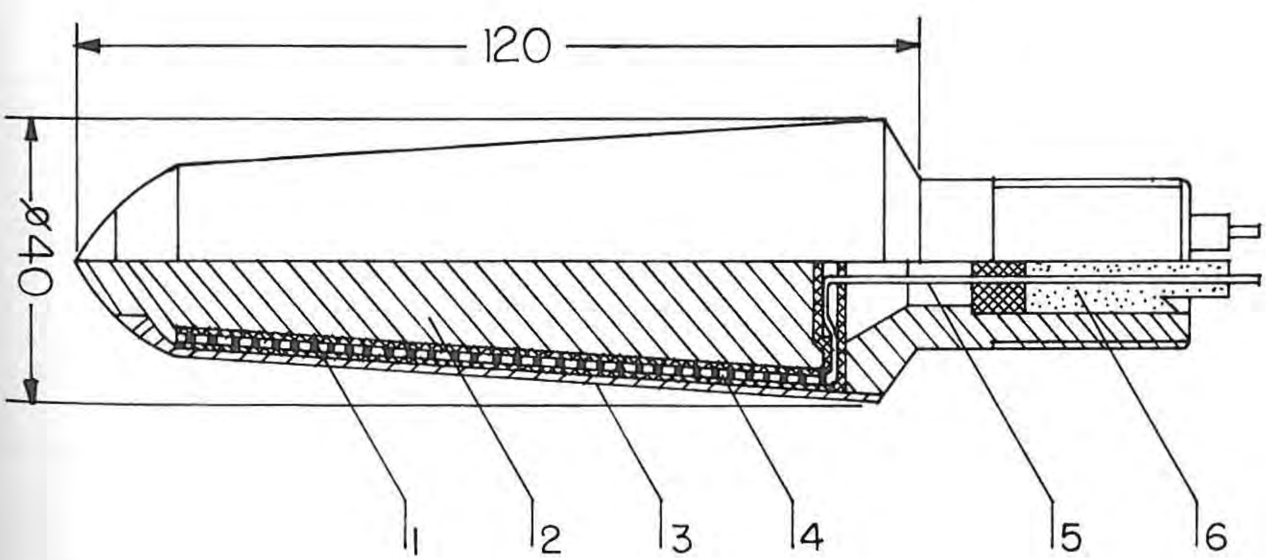

Figure 3. Schematic diagram of a conical electrical heater bit (see text for explanation of numbered areas).

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