ICE CORE DRILLS USABLE FOR WET ICE

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Abstract: Ice core drills which stored cuttings above the core barrel were tested. Cuttings were pushed up by one short booster screw. For a constant drilling speed, the necessary power increased with the amount of cuttings, being less than 110% of initial value (power for cutting only) for a 1.2-m drilling and about 150% for a 2.6-m drilling. The drills could core wet ice as efficiently as cold ice. The method of storing cuttings is also adequate for a drill used in a liquid-filled hole.

1. Introduction

Double-tube auger drills are now widely used because of their simple and reliable cuttings-transport mechanism, in which an Archimedean pump consisting of a rotating inner tube (barrel) with augers and an outer tube (jacket) lifts cuttings to the top of the barrel. There, cuttings are either deflected into the barrel and stored in its upper part (RUFLI *et al.*, 1976; RAND, 1976) or further pushed up and stored above the barrel (THEODÓRSSON, 1976; ÁRNASON *et al.*, 1974) as schematically shown in Figs. 1a and 1b respectively. We will call the former the U-type (unit storage for cuttings and core) and the latter the S-type (separate storage for cuttings and core). Clearly, the necessary power to push up cuttings in an S-type increases with increasing amount of cuttings. As it was difficult to push up cuttings more than 1 m when an S-type drill was first introduced (THEODÓRSSON, 1976), U-type drills have become common in later development (JOHNSEN *et al.*, 1980; LITWARK *et al.*, 1984; SUZUKI and SHIRAISHI, 1982; SUZUKI, 1984; SUZUKI and SHIMBORI, 1984).

In the course of development, we found that the efficiency of the Archimedean pump depends strongly on the clearance between the jacket and the barrel, the optimum value being about 5 mm. (This fact might have been recognized by ÁRNASON *et al.* (1974). Their S-type drill, which required a large lifting power, had the clearance of 5.5 mm when that of early U-type drills was 10 mm or more.) For a drill used for cold ice, we are now using the clearance of 4.5 to 5.2 mm, with which we can transport cuttings easily for 4 m or more (SUZUKI and SHIMBORI, 1984). However, in drilling warm ice, wet cuttings transported through such a narrow clearance often consolidate too firmly to be deflected into the barrel by simple deflectors. Though not systematically studied, it seems that the longer the barrel, the wider the necessary clearance for wet cuttings to be easily deflected.

A wider clearance means a wider cutter and in turn a larger amount of cuttings and a larger power for cutting. Together with a less efficient Archimedean pump, this makes a drill with a wider clearance less atractive. Without the deflection of cut-

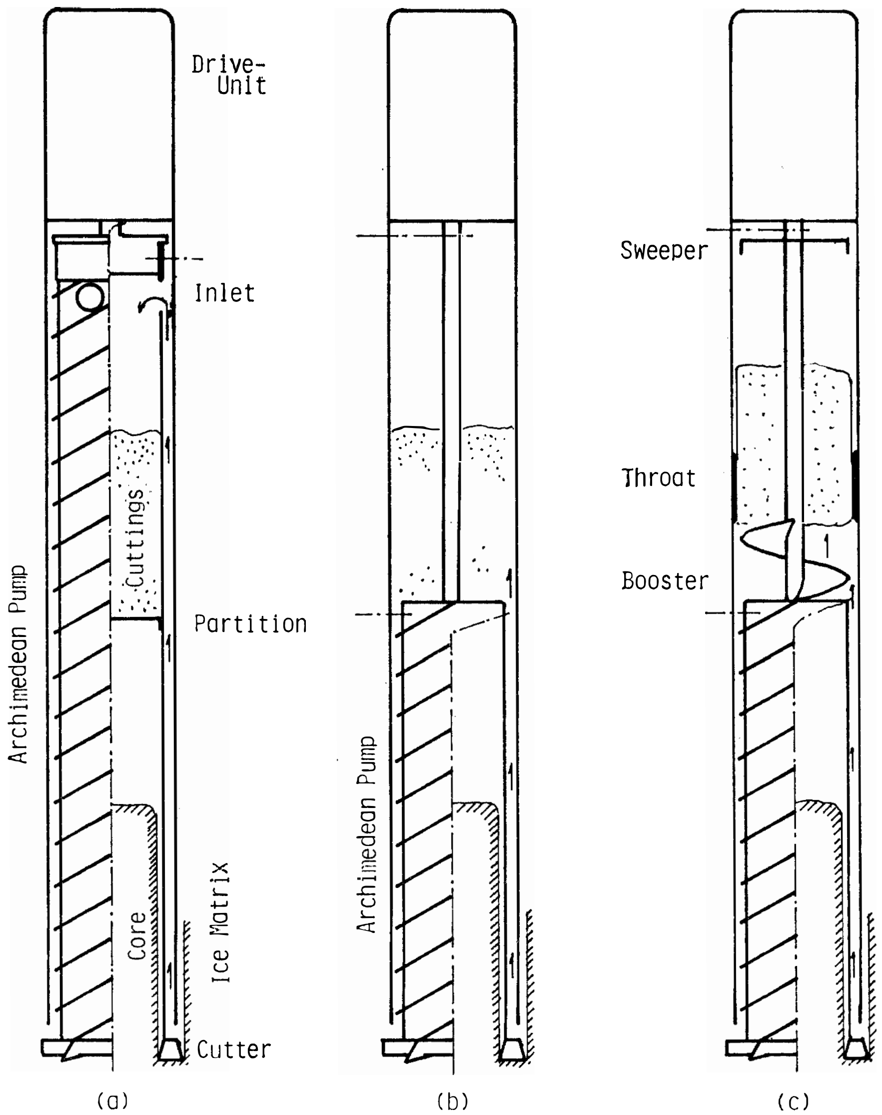


Fig. 1. Schematic diagrams of double-tube auger drills. (a) U-type; (b) S-type; (c) Improved S-type introduced in this paper. (Throat was not yet tested.)

tings, an S-type drill can use a narrow clearance. Hence, it will be worth to reconsider an S-type drill, though it has had difficulties in pushing up cuttings as mentioned before. In this report, we show that a simple improvement can overcome the difficulties and make an efficient drill usable for warm as well as cold ice.

2. Description of the Drill and Results of the Test

The drill is the same as a U-type drill, ILTS-100A, taking a 80-mm core and drilling a 107-mm hole (SUZUKI and SHIMBORI, 1984), except that the barrel length is shortened from 1.5 to 0.7 m while a long shaft is added between the drive-unit and the barrel and the length of jacket is properly adjusted. The shaft has a booster just above a barrel connector at the bottom and a sweeper near the top. The booster is a 100-mm (one pitch) long single spiral slightly inclined inward and the sweeper a disk (see

Fig. 1c). Cuttings transported to the top of the barrel are given additional upward momentum by the booster and fill the space between the sweeper and the booster from bottom. At the end of a drilling run, the shaft is disconnected from the drive-unit and pulled out together with the barrel from the jacket so as to sweep out cuttings. Then the barrel and the shaft are disconnected so that core can be taken out upward.

The necessary length L_s of the storage space is given by

$$L_s(d_3+d_s)(d_3-d_s)\rho_c=L(d_5+d_0)(d_5-d_0)\rho\,, \tag{1}$$

where L is the core length, d_3, d_s, d_0 and d_5 are the diameters of storage (99 mm), shaft (19 mm), core (80 mm) and hole (107 mm), respectively, while ρ is the density of ice (917 kg/m^3) and ρ_c that of cuttings. With the values given above, we have

$$L_s/L=490/\rho_c(\text{kg/m}^3)\,. \tag{2}$$

For expected values of ρ_c of 400 kg/m^3 and L of 0.65 m, L_s becomes 0.8 m. As cuttings were expected to fill the booster, the distance between the sweeper and the bottom of booster of the drill was taken 0.8 m.

The drill was tested at environmental temperatures of +25 and −10°C. In both cases, the drill drilled ice 60 cm in 60 s with an input of 320 W (80 V, 4A), which was by 10% larger than the input power for a U-type drill, ILTS-100A, to drill cold ice at a similar speed. Contrary to the expectation, ρ_c reached 670 kg/m^3 for warm ice and 600 kg/m^3 for cold ice, showing that the friction between the jacket and cuttings was high. The increased power over the U-type drill was consumed by the booster to push and move cuttings against the friction. The higher density for warm ice was certainly due partly to the melting of cuttings in contact with the warm jacket.

It must be noted that while cuttings made a solid column above the booster they are discontinuous around the booster so that the Archimedean pump had no effect on the compaction of cuttings. Also, the effective length of the storage should be taken as the distance between the sweeper and the top of the booster.

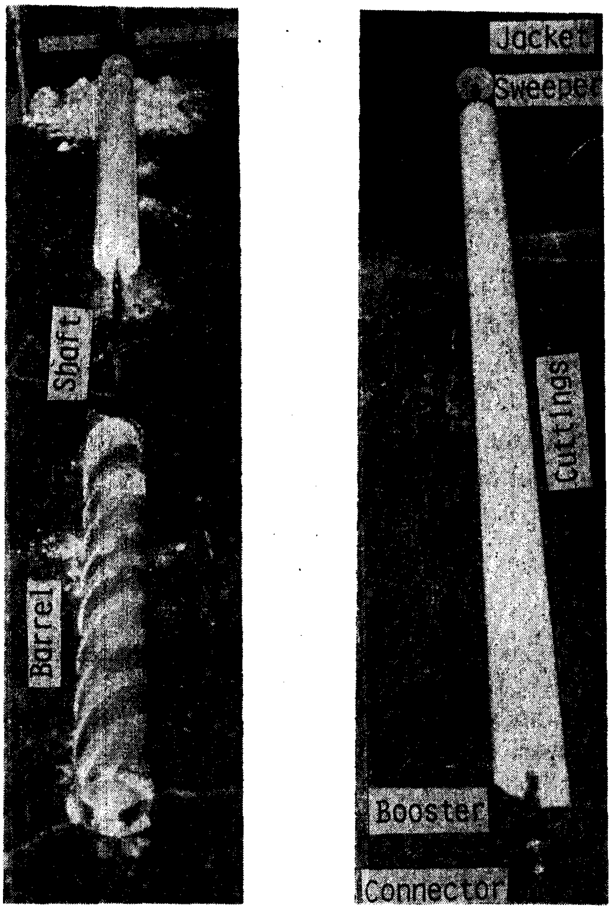
3. Results of Test with an Elongated Shaft

In order to see how high the booster can push cuttings, we then extended the shaft so that the effective length of the storage was 1.8 m. With ρ_c of 600 kg/m^3, this corresponds to the core length of 2.2 m. As the drill with a 2.2-m long barrel and a 1.8-m storage was too long to be laboratory-tested, we used the same 0.7-m barrel without catching paws, and the test was done by drilling ice 0.45 to 0.7 m successively, leaving core in ice and cuttings in the drill. The transfer of the drill from one hole to the next was done as quietly and rapidly as possible. A preliminary test at −10°C showed that the required power increased rapidly after 0.9 m drilling and we could drill only to 1.8 m within the rated input of 100 V, 5.5 A of the drive-unit. To take a core longer than 1 m, we should decrease the friction between cuttings and the jacket.

Two methods were conceived to decrease the friction: (1) Line the inside of jacket with less frictional material and (2) Make a short throat just above the booster (Fig. 1c) so as to prevent cuttings above the throat from contacting the jacket. The second method was conceivable, because cuttings had already become a solid core when they passed an observation hole on the jacket about 10 cm above the top of the booster.

We tried the first method and lined the jacket with teflon film. Results of tests at $-10°C$ with a drilling speed of 0.7 to 0.8 cm/s were as follows:

Test #1. Successive lengths of drilling were 0.68, 0.63 and 0.61 m with the maximum input (at the end of each drilling) of 279 W (90 V, 3.1 A), 315 W (90 V, 3.5 A) and 369 W (90 V, 4.1 A), or 116, 131 and 154% of the initial value of input (80 V, 3 A), respectively. As the length of cuttings was 1.3 m for the total drilling length of 1.92 m, the density of cuttings calculated from eq. (2) was 724 kg/m^3 (Fig. 2a). Actually, more than 10% of cuttings were lost during the transfer of the drill, and the density would be 650 kg/m^3 or less. The cuttings could be easily pulled out.



(a) (b)

Fig. 2. (a) The elongated shaft with the barrel pulled out after 1.9-m drilling (test #1). The length of cuttings including the lower broken part, which scattered near the mouth of jacket, was about 1.3 m.

(b) The elongated shaft pulled out by warming the jacket after 2.6-m drilling (test #2). The length of cuttings was 1.7 m. No cuttings were seen around the booster.

Test #2. Successive lengths of drilling were 0.6, 0.6, 0.6 0.6 and 0.2 m with the maximum input of 240 W (80 V, 3 A), 248 W (80 V, 3.1 A), 280 W (80 V, 3.5 A), 400 W (90 V, 4.5 A) and 360 W (90 V, 4 A), or 100, 103, 117, 167 and 150% of the intial value of input, respectively. The cuttings were too compacted to be pulled out by the sweeper. Hence, they were pulled out after the drill was warmed at 20°C for

1 hour. The length of cuttings was 1.7 m for the total drilling length of 2.6 m, giving the density of 750 kg/m^3 from eq. (2) (Fig. 2b). The measured values were 651 kg/m^3 near the top, 678 kg/m^3 at the middle and 658 kg/m^3 near the bottom. Some 12% of cuttings were lost during the transfer.

4. Conclusion

It seems that cuttings are easily sweeped out when their density is less than 650 kg/m^3, which corresponds to the power of about 150% of the initial value. Within this limit, the S-type drill can take a 1-m core even when no measure to decrease the friction between the jacket and cuttings is taken and a 2-m core when the jacket is teflon-coated. Though not yet tested, the throat seems very promising. After cuttings have passed the throat, the friction will increase little as the contact area is constant. Hence, there may be no limit of core-length due to the friction for an S-type drill with the throat. Besides, the necessary power will decrease as the compaction of cuttings to 600 kg/m^3 will be enough to make them a solid core.

An S-type drill could considerably be shorter than a U-type drill, where cuttings are packed by gravity only to 400 kg/m^3 or so. Because of its shortness and its ability to drill both warm and cold ice, an S-type drill will be preferable to a U-type one in spite of an increase in the necessary power.

An S-type drill does not use gravity for storing cuttings. Hence, it can be used in a liquid-filled hole. The fact that cuttings can be compacted to 650 kg/m^3 by a simple booster means that the separation of liquid and cuttings is easily achieved without a complicate mechanism, such as a centrifugal device (DONNOU *et al.*, 1984). We are now designing an S-type drill for use in a liquid-filled hole.

References

ÁRNASON, B., BJÖRNSSON, H. and THEODÓRSSON, P. (1974): Mechanical drill for deep coring in temperate ice. J. Glaciol., **13**, 133–139.

DONNOU, D., GILLET, F., MANOUVRIER, A., PERRIN, J., RADO, C. and RICOU, G. (1984): Deep core drilling; Electromechanical or thermal drill? CRREL Spec. Rep., **84–34**, 81–84.

JOHNSEN, S. J., DANSGAARD, W., GUNDESTRUP, N., HANSEN, S. B., NIELSEN, J. O. and REEH, N. (1980): A fast light-weight core drill. J. Glaciol., **25**, 169–174.

LITWARK, J., KERSTEN, L. and KUIVINEN, K. (1984): The PICO intermediate drill system. CRREL Spec. Rep., **84–34**, 41–44.

RAND, J. (1976): The USA CRREL shallow drill. Ice-Core Drilling, ed. by J. F. SPLETTSTOESSER. Lincoln, Univ. of Nebraska Press, 133–137.

RUFLI, H., STAUFFER, B. and OESHGER, H. (1976): Lightweight 50-m core drill for firn and ice. Ice-Core Drilling, ed. by J. F. SPLETTSTOESSER. Lincoln, Univ. of Nebraska Press, 139–153.

SUZUKI, Y. (1984): Light weight electro-mechanical drills. CRREL Spec. Rep., **84–34**, 33–40.

SUZUKI, Y. and SHIMBORI, K. (1984): Mechanical drill systems for the 25th Japanese Antarctic Research Expedition. Mem. Natl Inst. Polar Res., Spec. Issue, 34, 188–196.

SUZUKI, Y. and SHIRAISHI, K. (1982): The drill system used by the 21st Japanese Antarctic Research Expedition and its later improvement. Mem. Natl Inst. Polar Res., Spec. Issue, **24**, 259–273.

THEODÓRSSON, P. (1976): Thermal and mechanical drilling in temperate ice in Icelandic glaciers. Ice-Core Drilling, ed. by J. F. SPLETTSTOESSER. Lincoln, Univ. of Nebraska Press, 179–189.

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