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DEVELOPMENT OF AN ICE CORE DRILL FOR LIQUID-FILLED HOLES

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Abstract: Simple tests simulating drilling in a liquid-filled hole were done of an S-type Archimedean core drill, consisting of a drive-unit, a jacket, a shaft with a screw booster and a sweeper, and a barrel. The barrel length was 0.9 m. The tests revealed that the clearance between the jacket and the barrel (which together made up an Archimedean pump) should be a little wider for drilling in a liquid-filled hole than in a dry hole. With the clearance of 7.4 mm, the pump could transport ice chips to the storage space between the booster and the sweeper, where the booster compacted chips by squeezing a large portion of the liquid through the sweeper which was permeable to liquid. The porosity of compacted chips could be as low as 35%.

1. Introduction

As ice is plastic, a hole in ice is ever shrinking due to ice pressure, limiting the depth attainable with a drill system. Though a 900-m hole was drilled in the Antarctic ice sheet without any measure to prevent the shrinking, it is a common practice in a drilling to several hundred meters or deeper to fill the hole with an adequate liquid so as to prevent the shrinkage, requiring a drill workable in liquid. Such a drill is also necessary for shallow drillings in a temperate glacier when melt-water fills the hole.

An electromechanical drill which attains a drilling speed of the order of cm/s in a liquid-filled hole with a power input of a few hundred watts was developed in Denmark and was successfully used in Greenland to drill a 2000-plus meter hole (GUNDESTRUP *et al.*, 1984). In this drill, the mixture of liquid and chips is sucked in three storages by means of a sophisticated mechanism. As no compaction of the mixture is intended, the porosity of chips is perhaps as large as 45%. A large porosity of chips in the drill storage means a large loss of the hole liquid, which is operationally undesirable as the hole liquid is by far the heaviest component in a deep drilling operation.

DONNOU *et al.* proposed a drill which compacted the mixture by centrifugal force to a porosity of about 35%, but the power consumption of their drill was very high (DONNOU *et al.*, 1984).

Recently, we showed that in a dry-hole drilling an S-type Archimedean core drill could compact chips to a porosity of 29% with a power consumption of less than 150% of that when no compaction was attempted, and also suggested that it will achieve similar performance in a liquid-filled hole (SUZUKI and SHIMBORI, 1985). It is worthwhile to confirm the suggestion, as this type is much simpler than the former two drills and contrary to them can work in a dry hole as well.

In this paper, the results of tests simulating drilling in a liquid-filled hole of an S-type drill are presented.

2. General Consideration of an S-type Drill for Use in Liquid

An S-type Archimedean core drill consists of a drive-unit, a jacket, a shaft with a booster and a sweeper, and a barrel, as schematically shown in Fig. 1. The space between the sweeper and the booster serves as a storage for chips. In dry-hole tests, chips, transported by the Archimedean pump, were pushed up by the booster and filled the storage from the bottom. Owing to the friction with the storage wall, the chips were compacted up to 650 kg/m^3 in apparent density (down to 29% in porosity).

In a liquid-filled hole, chips in the storage will be in a state of suspension as the hole liquid is almost as heavy as ice. Hence, the liquid, going out of the storage to compensate the volume of entered chips, will accompany some chips unless the storage has a filter as a few designs shown in Fig. 2.

An electric motor may work in an electrically nonconducting liquid, which is commonly used as the hole liquid. We tested an a.c. commutator motor used in our dry-hole drills in kerosene. Though it rotated, its input current reached almost its

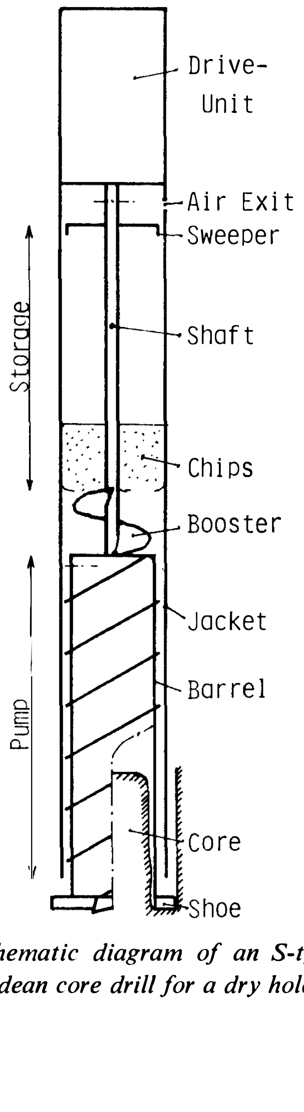

Fig. 1. Schematic diagram of an S-type Archimedean core drill for a dry hole.

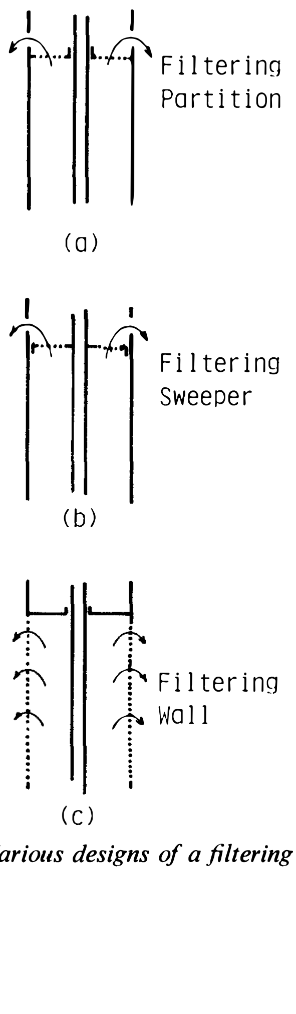

Fig. 2. Various designs of a filtering storage.

rated maximum value. Such a high-rotational motor should be contained in a liquid-tight container for use in liquid.

3. Test Apparatus

In order to test the transport and compaction of chips of a drill in a liquid-filled hole, the liquid level in the hole must be above the storage during the test, that means we must have a hole of a certain depth at the start of drilling. We simulated such a hole by a pipe 1.7 m long, which was fixed on a box containing an ice block, and filled the pipe and the box with liquid. To see the behavior of liquid around the drill and also of chips in the storage, we made the upper 1.2 m of the pipe transparent. As the test drill makes a 134-mm hole, the inner diameter of the pipe must be around 134 mm to simulate the hole. Because of the availability of pipes, the inner diameter was 138 mm for the top 0.2 m, 134 mm for the next 1 m, and 136 mm for the rest. The pipe had a square flange at its bottom for the connection to the box.

The box was 35 cm × 35 cm across and 95 cm deep in inner dimensions. (The depth corresponded to the intended drilling length of less than 0.9 m.) Its bottom and three walls were of plywood while one wall was of transparent plastic so that we could observe the process of drilling. It had a flange to match the pipe flange at its top and a ladder to support the pipe at its back. Pieces of metal angle reinforced it against liquid pressure.

We made the test drill utilizing available components of the ILTS-130 series drills (SUZUKI, 1984). As for the drive-unit, we remodeled the 130-C drive-unit (100 V × 5.5

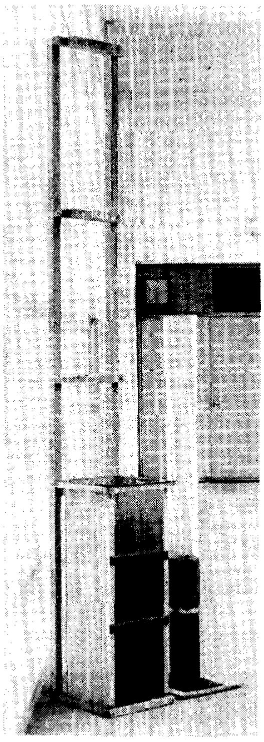

Fig. 3a. The ice box and the hole simulator.

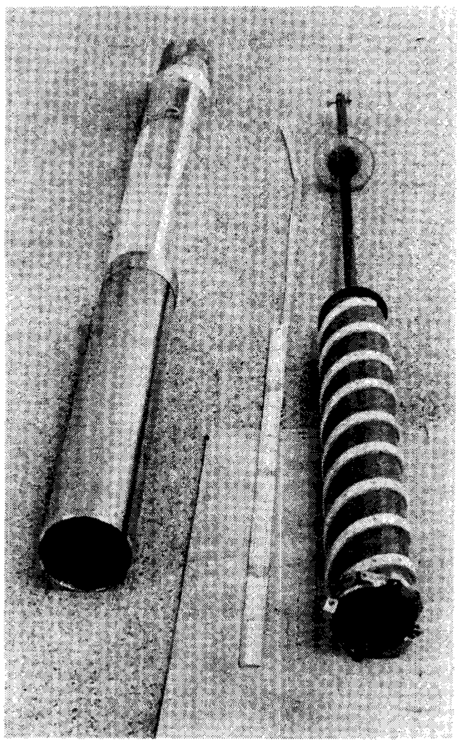

Fig. 3b. The jacket and the Mk-I barrel with the shaft.

A; 160 rpm) by removing its fins and side-cutters (to make it passable through the pipe) and replacing the barrel connector with a shaft connector (to make it suitable to the S-type) and the motor case with a longer one (to keep the motor dry during the test).

To observe the behavior of chips in the storage, we made the middle part of jacket of an acryl pipe 124 mm in inner diameter, while the other parts of a steel pipe 123.8 mm in inner diameter.

For easy tests, we used a short (0.9 m) barrel. Its outer diameter was first chosen as 114.3 mm (Mk-II barrel) since it had made a more efficient pump in dry drilling than 109 mm (Mk-I) did (SUZUKI, 1984; SUZUKI and SHIMBORI, 1985). However, because of the reason described in Section 5, we finally used the latter. The shaft was 1 m long including the booster 0.1 m long. The storage could be as long as 0.8 m.

The pipe, or the (hole) simulator, and the box are shown in Fig. 3a, and the jacket and the barrel with the shaft in Fig. 3b.

4. Test Procedures

As the bottom of the drill (the shoe) was difficult to pass the simulator, the drill was inserted in from the bottom side of the simulator laid down horizontally. The box was also laid down and an ice block about 0.9 m long was inserted in it. Then, the simulator was connected to the box, and the whole system was erected against a wall or a pillar (Fig. 4a). A long handle to work as an anti-torque was inserted into holes at the top of the motor case. Finally, the liquid was poured in through a hole of the jacket to fill the simulator. After drilling a certain length, the drill was pulled up a bit to break core. (Core might not be broken in the present test, as the drill had no pawls. But, the procedure was necessary to prevent possible stacking of the drill

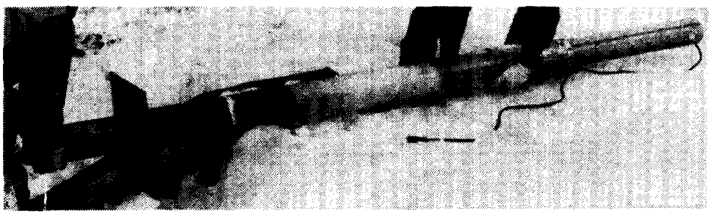

Fig. 4b. The simulator with the drill separated from the box.

Fig. 4a. Preparation of the test.

due to clogged chips.) The connection between the box and the simulator was then loosened to discharge the liquid. The lowering of the liquid level simulated the situation of the drill leaving the liquid surface. The whole system was then laid down and the simulator and the drill were separated from the box (Fig. 4b).

5. Preliminary Tests

We first tested the drill with a Mk-II barrel using water as the liquid. Against the expectation, we could drill only several centimeters. The pump failed to suck the chips.

Means to improve the pump was searched with an ice block and a shortened drill (without the storage). Namely, after drilled the ice block about 0.2 m in dry condition, we filled the drilled hole with a liquid and tested if we could proceed further.

We first changed in vain the liquid from water to kerosene, hoping to reduce the adhesion of chips. Next, we increased the cutting depth from 0.9 to 1.3 mm to make chips coaser. This improved the pump a little and we could drill further but often with abrupt increases in the input current. Lastly, thinking that a wider clearance between the jacket and the barrel might improve the pump, we tried the Mk-I barrel which gave the clearance of 7.4 mm against the Mk-II's 4.85 mm. The cutting depth was 1.3 mm. With this barrel, we could smoothly drill 0.85 m, the possible longest length for the barrel.

6. Results of Simulated Drillings

We did three tests at plus temperatures using blue-dyed water as liquid. We used two kinds of sweeper: One was a 120-mm disk with many 6-mm holes lined with stainless-steel net of 1 mm mesh, and the other a 128-mm circular nylon net of 0.5 mm mesh, sandwiched in between two plastic 120-mm disks with many matched 6-mm holes. We set the former 0.5 m above the booster in the first test, and the latter 0.6 m in the second and 0.65 m in the third. We drilled as deep as possible within the rated current of 5.5 A.

In all the tests, chips appeared in the storage immediately after the drilling began and in due time filled the storage. The chips were then gradually turning white and at the end formed a white (dense) column with blue (less dense) thin layers spacing several centimeters and, in the second and the third tests, with a blue layer about 0.1 m thick above the booster. Chips are also found around the booster in these two tests (Fig. 5).

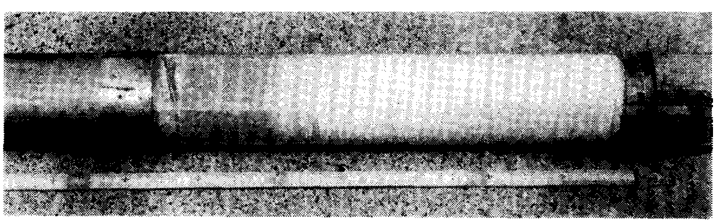

Fig. 5. Chips in the storage.

In the first test, some chips passed around the sweeper, but they never strayed out from the jacket, showing that the outgoing liquid stream was too weak to accompany them. At the end of the test, about 20% of total chips was suspended in liquid above the sweeper. In the second and the third tests, no chips strayed beyond the sweeper because of the oversized nylon net.

We could drill 0.8 m in the first and the second tests and 0.82 m in the third test within the rated input current of 5.5 A. Both the input current and the drilling speed varied little during each test except at the end, when the input current increased noticeably. A typical power input was 80 V × 4.5 A for a drilling speed of 0.01 m/s.

7. Estimation of Compaction

The compaction of chips is described either by the apparent dry density ρ_s or the porosity P, which are related by

$$(1-P)\ \rho=\rho_s,$$

where ρ is the density of ice (917 kg/m³). When the chips fill the storage, we have

$$\rho_s/\rho_d=V_d/V_s=(L_d/L_s)\cdot(d_h^2-d_c^2)/(d_s^2-d_r^2),$$

where V_s is the storage volume, V_d the drilled volume and ρ_d the density of the drilled material (firn or ice), while L_s is the storage length, L_d the drilled length, and d_h, d_c, d_s and d_r are the diameters of hole, core, storage and shaft, respectively.

Substituting the diameters with their respective values of 134, 102, 124 and 25 mm of the test drill and equating ρ_d to ρ, we have for the present tests

$$(1-P)=0.512\ L_d/L_s=\rho_s/\rho.$$

As the chips existed above the sweeper in the first test and around the booster in the second and the third tests, there are some difficulties in the use of the relation.

In the first test, the storage contained about 80% of total chips. Hence, in the relation, we assumed L_s 0.5 m and L_d 0.64 m, 80% of the drilled length. Then, the relation gave P of 34.5% (ρ_s of 601 kg/m³). For the second and the third tests, we added 0.08 m (80% of the booster height) to the storage length and assumed L_s 0.68 and 0.73 m, respectively. In the second test with L_d of 0.80 m, P became 39.8% and ρ_s 552 kg/m³, while in the third test with L_d of 0.82 m, P became 42.5% and ρ_s 527 kg/m³. These were weighted mean values of the dense white part and the less dense blue part (see Fig. 5). The white part might be compacted as dense as in the first test.

8. Concluding Remarks

The tests showed that an S-type Archimedean core drill with a filtering sweeper could take a 0.8-m core in a hole filled with water. However, a drill for a deeper drilling is desired to take a longer core in order to make the total operation time reasonable. Moreover, in a cold region, the hole liquid is not water but some antifreeze. We will consider the ability of an S-type drill under these different conditions.

We first discuss about the compaction of chips. In the second and the third tests, the lower part of column of chips in the storage remained blue. The reason is surely that the upper white part about 0.6 m long blocked the liquid flow. If the liquid could have filtrated the storage wall, for example, as shown in Fig. 2c, we could have drilled further within the rated power until chips had been compacted homogeneously up to 600 kg/m^3 as in the first test. In such a storage, the liquid viscosity may little affect the compaction as the liquid path is short for any part of the column of chips.

In the present tests, there remained a few chips around the barrel when extracted from the jacket. The chips must have been in a state of suspension in the pump during drilling. The liquid viscosity and the pump length will, then, not drastically affect the chip-transportability, though the necessary power to drive the pump is naturally proportional to them.

Thus, even for a longer barrel, we expect the compaction of chips up to 600 kg/m^3 for a storage with filtrating wall of a length satisfying the relation given in Section 6.

The most concerned problem is the suction of chips by the pump, which we solved at present by widening the clearance of the pump. A systematic investigation will be required to find an optimum design of the pump.

Further tests to confirm the above consideration are now in preparation.

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