ELECTROMECHANICAL DRILLING IN DRY HOLES TO MEDIUM DEPTHS

by

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ABSTRACT

The maximum depth for ice core drilling in dry holes is limited due to bore hole closure by the action of the hydrostatic pressure and the difficulty to obtain unbroken cores below a certain depth. In this paper we discuss the various sources of stress that act on the core and the consequences for the design of mechanical ice core drills. We present the latest version of our mechanical drill system which has been modified to produce better cores from greater depths.

INTRODUCTION

According to the maximum depth reached by ice core drilling one distinguishes usually between shallow and deep drilling. Shallow drilling comprises operations down to or slightly below the firn to ice transition, i.e. to depths on the order of 100 meters. Due to the short drilling time and the relatively low hydrostatic pressure at these depths bore-hole closure is not a problem and hole fluids are not necessary. Deep drilling to depths over 500 meters however usually go on for several weeks or longer and bore-hole closure must be prevented by filling the hole with a liquid. The use of bore-hole fluid increases the complexity of a drilling system and the logistics considerably. The hole fluid is also a potential source of ice core contamination with trace substances and may even change the gas composition in the bubbles. It is therefore desirable to extend the maximum depth of dry drilling as deep as possible. Bore-hole closure sets a practical limit to the maximum depth can be reached, although this limit can be pushed out with an adequate drill design. Core drilling to intermediate depths was also often not very successful because below a certain depth the ice cores were more and more fractured.

FACTORS LIMITING THE DEPTH FOR THE PRODUCTION OF GOOD QUALITY ICE CORES

- ***Bore-hole closure*** : Since there is essentially no clearence between the cutters and the bore-hole wall already a slight decrease of the hole diameter increases the friction between the drill and the bore-hole wall considerably. Johnsen et al (1980) have calculated the closure rate as a function of depth and temperature. The results are based on measured first year strain rates of two holes (Byrd Station, Antarctica and Site 2, Greenland). For a hole of 100 mm diameter in ice with a temperature of -10°C, for example, a closure rate of a 0.1 mm/day is reached at roughly 80 m depth whereas at -30°C the same closure rate is observed only at 200 m depth. The maximum attainable depth therefore depends on the ice temperature, the drilling speed and the drill design (cutter - wall contact area).

- *Core fracture* : There are several stress components acting on the core during and after drilling. Some of them grow with increasing depth. The sum of them ultimately causes the core to fracture either during drilling, core break or handling. The major stress sources are :

- air pressure in the bubbles,
- drilling (cutting force and other stresses),
- release of hydrostatic pressure,
- core break.

The maximum tangential tensile stress σ in the ice shell around the air bubbles immediately after the hydrostatic pressure has been taken away (after the drill bits have cut the groove around the core) is $\sigma_{max} = p/2$, where p is the bubble pressure at the corresponding depth (Timoshenko and Goodier, 1970). p is in a first approximation close to the hydrostatic pressure. The maximum comparative uniaxial tension around the bubble is then $\sigma_{uniaxial,max} = 3/2\ p$ (Sayir and Ziegler, 1984), which can be compared with the tensile strength of ice. The tensile strength has been measured by various authors. A review is found for ex. in Hobbs (1974). For polycrystalline ice the values increase from about 1.5 MPa at 0°C to 2 MPa at -40°C. For single crystals values of ca. 10 MPa are reported. It is not obvious which case - single crystal or polycrystal - is more appropriate for our considerations. In the worst case we must expect the formation of small cracks around the bubbles already at hydrostatic pressures above 1 MPa, corresponding to a depth of approximately 140 m. This is indeed the depth where usually first problems with fractured cores appear. It is not clear whether or not this can be attributed to crack formation around the bubbles.

Drilling in a dry hole leads to an almost immediate pressure release in the ice core. This causes two kinds of stresses in the ice. (1) The bottom of the core, still attached to the bulk ice, is compressed by the surrounding hydrostatic pressure while the upper part of the core is exposed to atmospheric pressures. This leads to shear stresses near the bottom of the core. (2) Due to the anisotropy of the elastic modulus of ice internal stresses remain in the ice core after the hydrostatic pressure has been taken away.

The drilling itself also exerts forces on the core. All but forces from the cutting of the ice are in principle avoidable since the core when still attached to the bulk ice must not have any contact with the core barrel or any other part of the drill. In reality however it can hardly be avoided that some ice chips get between ice core and barrel and exert a small torque on the core. But with a well designed drill this is a minor problem. The forces on the core from the cutting mainly depend on drill head parameters like pitch, rake and clearance angles, cutting speed, cutter geometry etc. and can be minimized by an appropriate design.

Core catchers have generally a wedge-shaped form in order to break the core when pulling the drill up. This causes a strong stress concentration at the tip of the core catcher and often leads to longitudinal or skew core breaks at depths where other stress sources are already important.

CONSEQUENCES FOR THE DESIGN OF MECHANICAL ICE CORE DRILLS

From the above-mentioned considerations on the stress sources a mechanical ice core drill for dry holes must meet the following essential requirements :

- Overall precision and stability to assure no lateral forces on the core, a straight hole and minimal vibrations for a smooth cutting.
- Self centering drill head design for absolutely centered rotation.
- Minimum cutting force on the core side of the drill head by using a small pitch and sharp cutters with a clearance angle.
- At the end of a run the core should not be broken but cut horizontally.

These requirements have been partly realized in the new version of our electromechanical 4 inch drill. The basic design has been described by Rufli et al (1976). The diagram of the new version is shown in Fig. 1. Description of the drill system :

Power requirements	380 V (3 phase), 15 A
Electronic control	Transistorized pulse with DC control for winch and drill
Winch	DC servo motor with reduction gear 4 kW (8 kW peak) 500 m Kevlar cable (11 mm diameter/7 x 0.6 mm^2 copper conductors) speed : -1 m/sec to +1 m/sec (5 % speed stability at 1 mm/sec)
Drill	core diameter : 105 mm hole diameter : 143 mm speed : -120 to +120 rpm typ. power consumption at 60 rpm : 300 W specific energy consumption : ca. 7 kJ/kg of chips
Tower	9 m high with shaft encoder on top wheel for depth measurement

Concerning the overall stability the drill is equipped with a centered anti-torque section (Fig. 1). The three skates that prevent the drill from rotation are machanically forced to be at the same distance from the drill axis. They are retracted during rising and lowering of the drill. They are driven out to the wall by torque and the release of the cable tension.

The drill head is self-centering in the hole by eight 2 mm wide helical lands, one in front and one behind each chips groove (Fig. 2). One land slightly overlaps with the next so that the drill head touches the hole wall on its whole circumference.

A small drill pitch reduces the stress on the core. However the pitch cannot be decreased to any value because if it is too small the chips are too small to be removed by the auger flights. One way to overcome this problem is to introduce small cutters along the core between the main cutters. We designed a drill bit with four main cutters and four small cutters (Fig. 2). At a pitch of 6 mm per revolution each cutter cuts only 0.75 mm. Along the core side a clearence angle is essential. With no clearence angle "wafered" cores cannot be avoided below approximately 130 m depth. The eight lands of our drill bit yield a rather large contact area with the bore-hole wall and are thus not a good solution in respect to the problem of hole closure. We therefore plan to add additional cutters at the upper end of the drill head to enlarge the hole by a few tenths of a millimeter. This way we create enough clearence to move the drill up and down while maintaining a well centered rotation of the drill bit.

The drill has been succesfully tested at Dye 3, Greenland, in June 1988. A core of very good quality was drilled to a depth of 183 m. Pieces of 1 m length could be recovered with each run. At this depth we encountered considerable problems with hole closure. The lowest 10 meters had to be reamed carefully every day to avoid the drill bit getting stuck in the bore-hole.

CONCLUSIONS

The various improvements to the Swiss Electromechanical Drill considerably increased the quality of the recovered ice cores at medium depths. Although these improvements are based on considerations to reduce stress on the core, the design of a drill that produces good quality ice cores under most conditions requires a profound knowledge of all parameters responsible for possible core fracturing. The relative importance of the various stress factors to the core should be investigated carefully. This would enable us to design a drill bit that exerts minimal forces on the core and would probably allow to recover unbroken ice cores from depths of 500 meters at sites with mean temperatures below -20°C. Completely new drill designs should also be investigated : for example high speed cutting with removal of the ice powder by air stream and filters. The development of a reliable horizontal core cutting system instead of traditional core catchers would be very valuable.

ACKNOWLEDGMENTS

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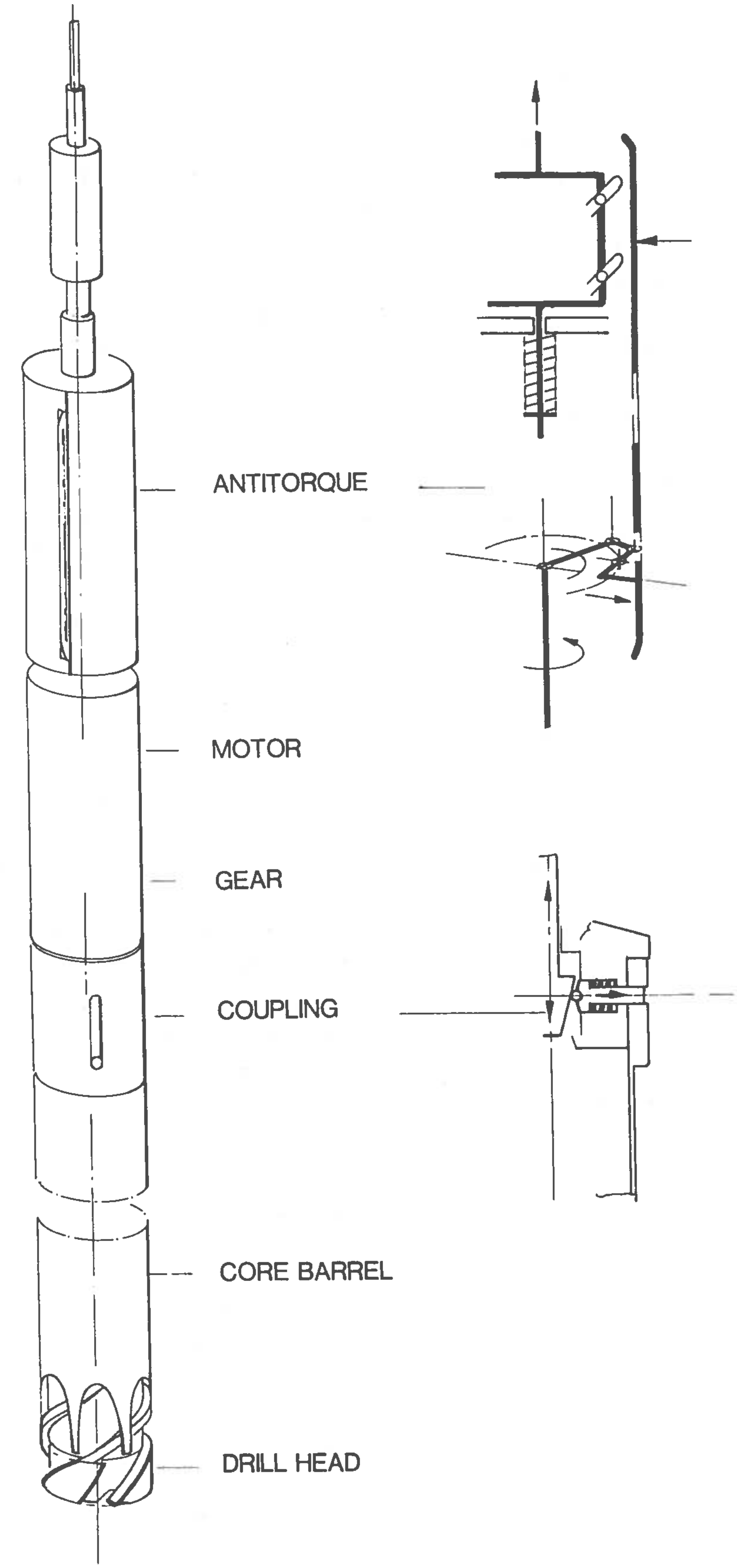

Fig. 1 - The 4-inch electromechanical drill. The operation principles of the antitorque section and the coupling of the core barrel to the drill are shown on the right side.

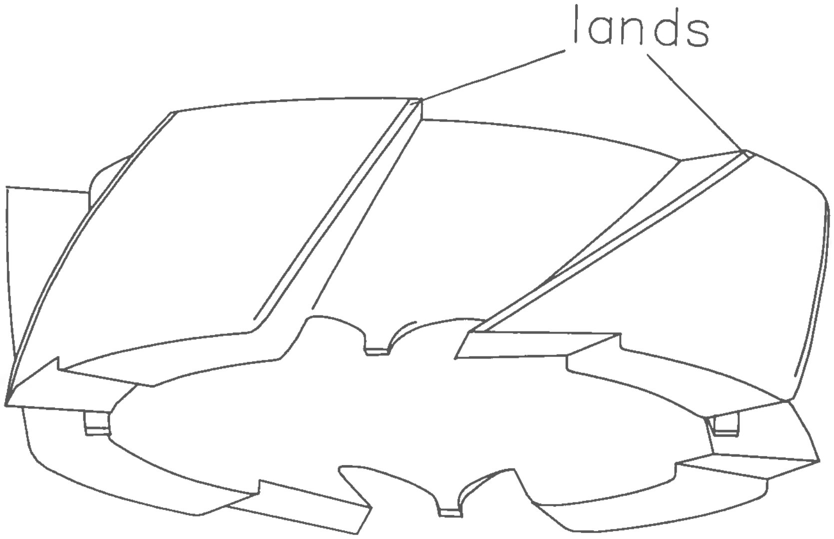

Fig. 2 - The new drill head. It is assembled of three rings (not shown). The cutters are integrated in the lowest ring. The core catchers are fixed to the central part and the upper ring is attached to the core barrel.