LIGHTWEIGHT 50-METER CORE DRILL FOR FIRN AND ICE

Heinrich Rufli, Bernhard Stauffer, and Hans Oeschger
Physics Institute
University of Bern
Sidlerstrasse 5
3012 Bern, Switzerland

ABSTRACT

The increasing interest in ice-core analyses has made it apparent that new drills need to be developed for coring in firn and ice.

To close the gap between the range of the SIPRE coring auger and that of the CRREL thermal drill an electromechanical drill has been constructed which will core to 50 m in firn and ice.

The drill is suspended from a cable, and consists of a coring system, a driving system and an antitorque system.

The drill was tested successfully in Greenland in 1974, where it was possible to drill to 50 m in a few hours.

Introduction

With the SIPRE coring auger it is relatively easy to drill to 20 m in firn or 10 m in ice. Drilling deeper is possible but difficult. Holes with depths between 100 and 500 m have usually been made using thermal drills (Ueda and Garfield, 1969).

Attempts have been made to close the gap between the ranges of the two drills by modifying the SIPRE coring auger. The modifications consist of an electrical drive for drilling and electrical and mechanical means for raising and lowering the auger. They allow deeper drilling but the equipment is heavier and the drilling is time-consuming because of the need to handle the numerous extensions. Furthermore, with deeper holes more chips are lost in the hole and the cores are shorter.

Because of these problems the development of a new drill to close the gap seems desirable. The penetration of meltwater into thermally drilled cores in firn makes the cores unacceptable for certain analytical studies. To overcome this problem the new drill should be electromechanically driven.

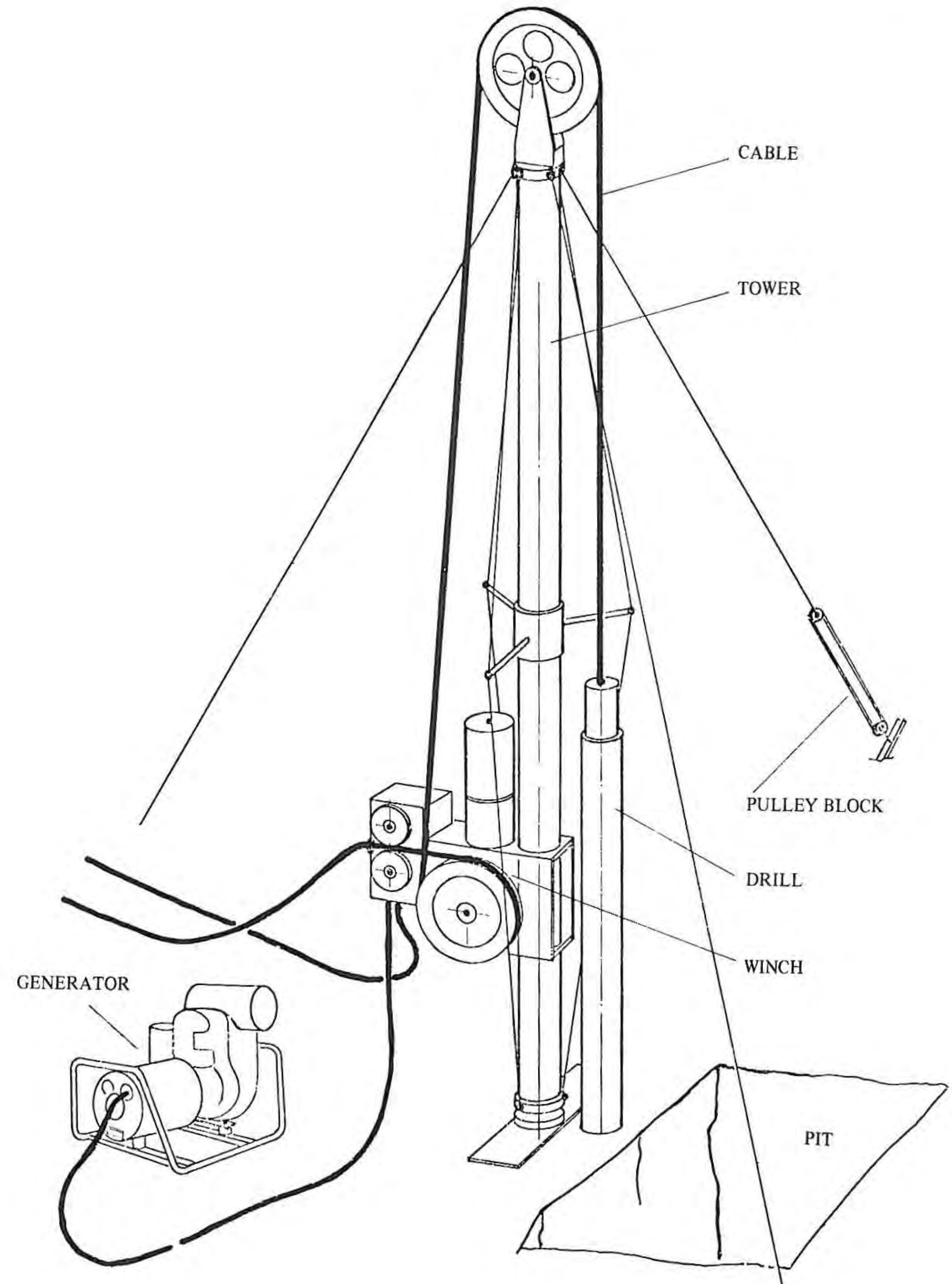

Figure 1. The drill unit.

In the last few years such a drill has been developed at the Physics Institute at the University of Bern, incorporating experience from the SIPRE coring auger and the Icelandic electromechanical drill (Árnason *et al.*, 1974). The prototype was tested and used in the Greenland Ice Sheet Program in 1974 to obtain cores at Summit Station (19 m), Crête (23 and 50 m), and Dye 2 (25 and 45 m).

Description of the Drill Unit

The drill unit consists of four parts (Fig. 1): drill with cable, tower, winch, and generator.

No single part is heavier than 50 kg, so that the equipment can be transported in any type of helicopter or on a small sledge. The total weight of the complete unit is 150 kg.

The Drill (Fig. 2)

A core barrel, similar to the SIPRE coring auger but about 2 m long with an auger flight over the total length, rotates inside an outer (jacket) tube. Four holes in the upper half of the core barrel provide inlets for the ice chips which are transported up by the auger flights between the core barrel and the outer tube and get packed behind the core. After each run (70 to 90 cm long) the core barrel is separated from the rest of the drilling unit and the core and the chips are removed.

The drill has the following parts, each of which is described in detail: cable and cable connection, antitorque system, driving section, and coring section.

Cable and cable connection:

A reinforced electrical rubber-jacketed cable with a load capacity of 300 kg is used. It consists of seven electrical conductors (cross section 1.5 mm^2) and is reinforced with three hemp ropes. The cable is covered with a special rubber which remains flexible down to -35^{o} C. The cable diameter is 17 mm and the weight is 39 kg per 100 m with a bending radius of 120 mm. The cable is fastened in a cable termination with epoxy (cast) resin.

The antitorque system (Fig 3):

This system prevents the rotation of all parts of the drill except the core barrel and its driving mechanisms. This system has to work in loose firn as well as in hard ice. To accomplish this two devices are used. In the first device 4 knives (skates) which are retracted during the lowering or raising of the drill are pressed radially against the wall of the borehole as soon as the drill reaches the bottom of the borehole. This device is effective in hard firn or ice but the knives (skates) are not long enough for soft firn. The second device consists of 2 plate springs which press against the wall of the borehole at all times. They provide the additional restraint required in the soft firn.

The driving section:

The drill is driven by an air-cooled electric commutator motor which uses 500 W, 200 V AC

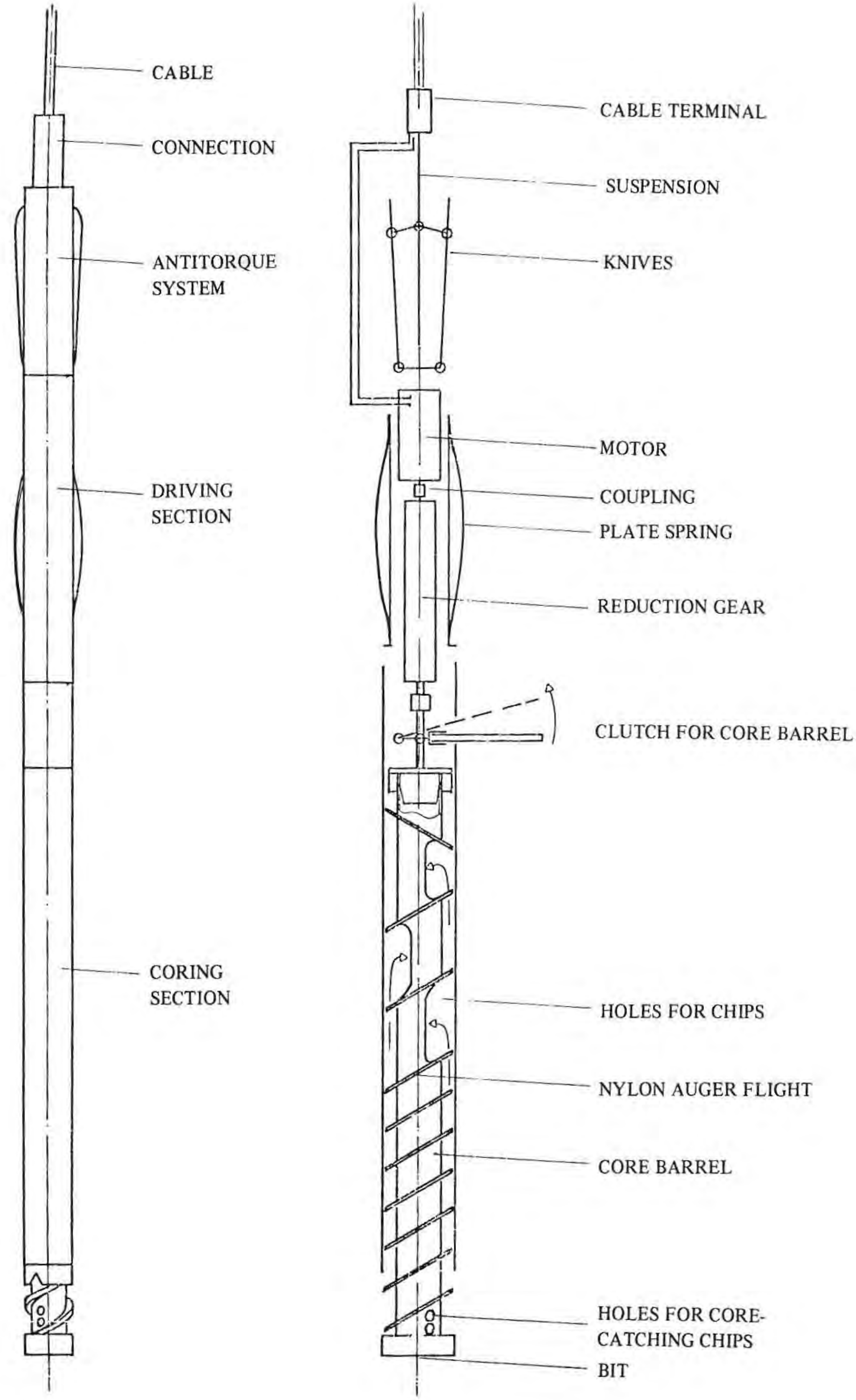

Figure 2. The drill.

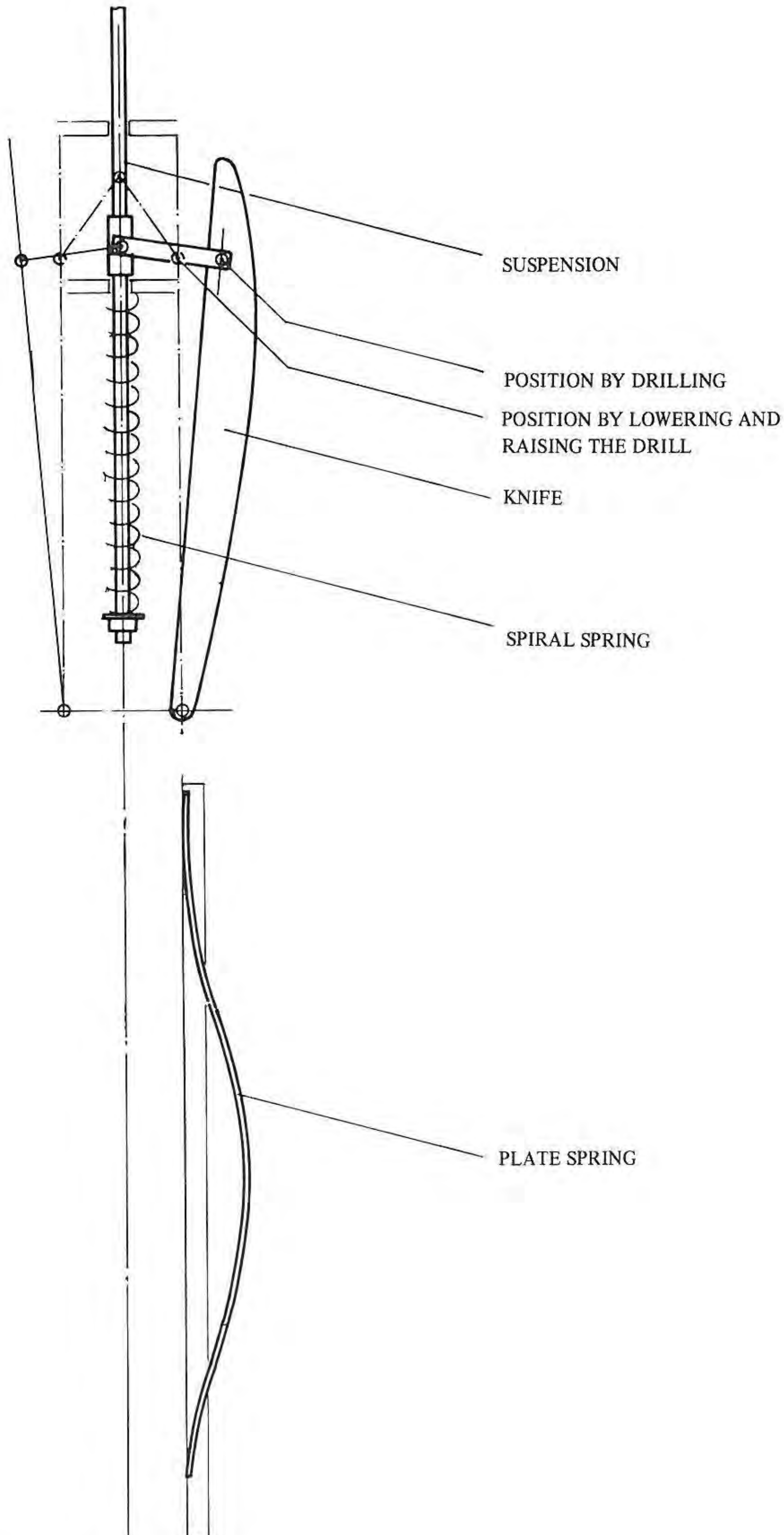

Figure 3. The antitorque system.

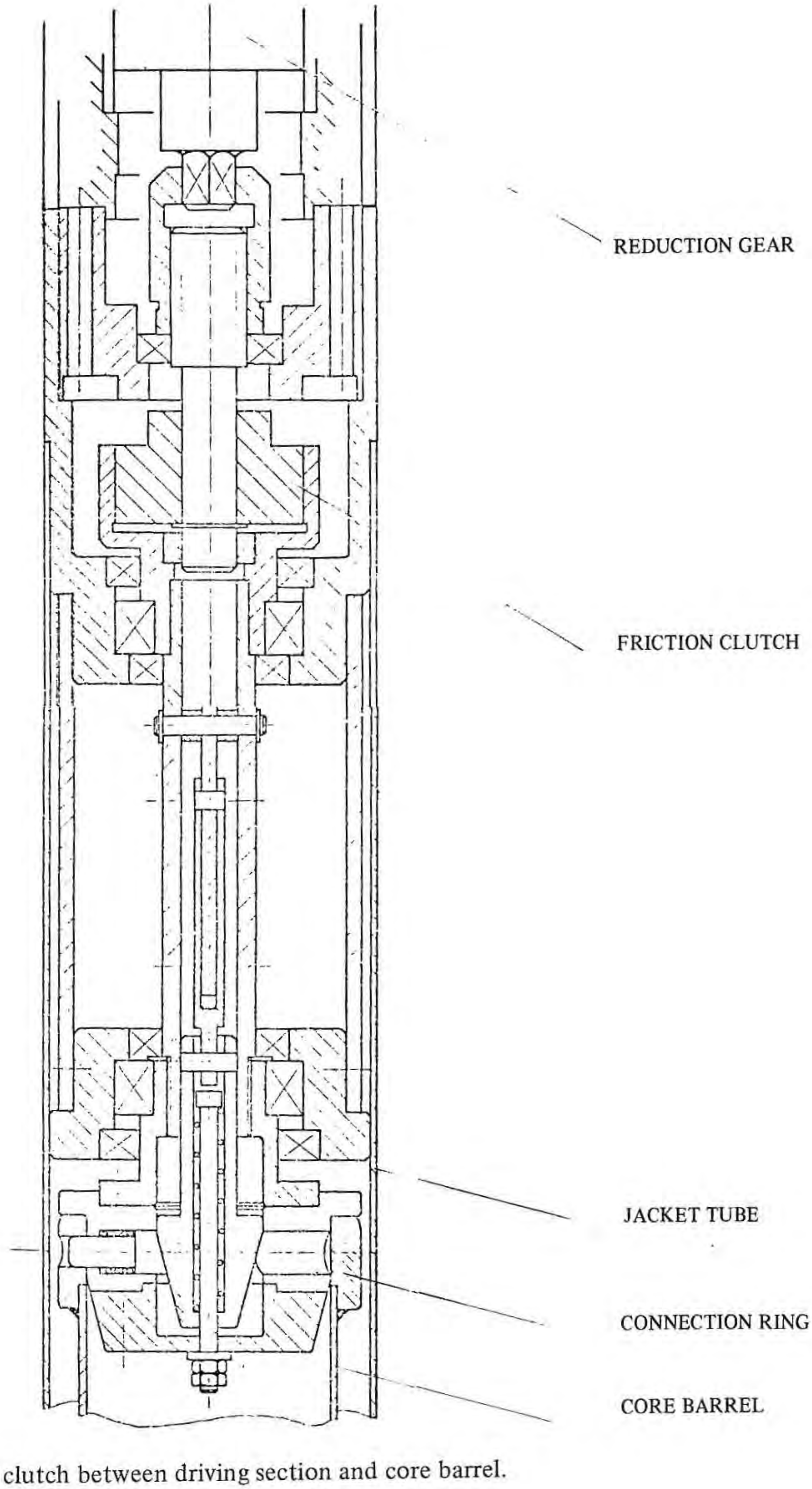

Figure 4. The clutch between driving section and core barrel.

with 50 or 60 c/s. The mechanical power at 23,000 rpm is 320 W. The high speed of the motor is reduced by planetary gears to 90 rpm. Between gear and core barrel a friction clutch (Fig. 4) prevents overloading of the gear reducer and motor.

The coring section (Figs. 5 and 6):

The coring section consists of a core barrel (Fig. 5) which fits inside the non-rotating jacket tube (Fig. 6). The core barrel, a 2-m-long steel tube, has an inside diameter of 80 mm. The lower half of the core barrel has a double-auger flight which raises the chips and serves as a bearing for the core barrel in the jacket tube. The auger flights are made of nylon attached to the core barrel with screws. Only one flight goes over the upper half of the core barrel which has four holes to admit chips to the space above the core. A steel ring is welded to the top of the core barrel to connect it to the driving section. The drill bit is attached to the core barrel with screws. It is fitted with two replaceable knives similar to those on the SIPRE coring auger but adjustable in diameter. The inner diameter, 75 mm, is also the core diameter; the outer diameter, 114.5 mm, cuts a hole whose diameter is 115 mm. Four 2-cm-diameter holes above the bit allow chips to enter the tapered space between the core and the bit where they provide a core-catching action like that used on the SIPRE coring auger. A movable styrofoam disc was placed in the middle of the core barrel after each run to separate the core and the chips.

The jacket tube (Fig. 6) covers the entire length of the core barrel except the lower 15 cm. Three ribs along the inner side provide the frictional resistance between the spinning chips and the non-rotating jacket tube that is required for the auger flights to elevate the chips to the inlet at the top of the core barrel. The bottom of the jacket tube has an inlet ring with three triangular notches. Its outer diameter, 113 mm, is just 2 mm less than the diameter of the borehole.

The Tower (Fig. 1)

The tower consists of two aluminum tubes, each 2.3 m long, 130 mm O.D. and 124 mm I.D. On the top is the sheave for the cable. The bottom has a ball joint (Fig. 7) which provides a movable platform for the tower. The tower is 5 m high and is held erect by three guy-wire cables. All three cables have a pulley block with a nylon rope at the ground anchor end. Using the pulley blocks and the ball joint of the tower, it is easy to bring the tower into a vertical position, even in steep terrain.

The Winch (Fig. 8)

The winch is fixed to the tower. The cable on which the drill hangs goes over the sheave on the top of the tower, then down through the winch and is spread out on the surface because there is no cable drum. The winch has no reel, but works similar to a capstan. An electric motor, single-phase 220 V/550 W, drives a double-gear system (variable reduction gear and then a worm gear). The first gear is variable between 0 and 1100 rpm, and the maximum speed after the second gear is 38 rpm. The winch also includes the control panel. An ammeter guards against an overload of the drill motor and the winch motor.

The Generator

A two-stroke gasoline engine drives a single-phase 2-kW generator. The unit is fixed on a

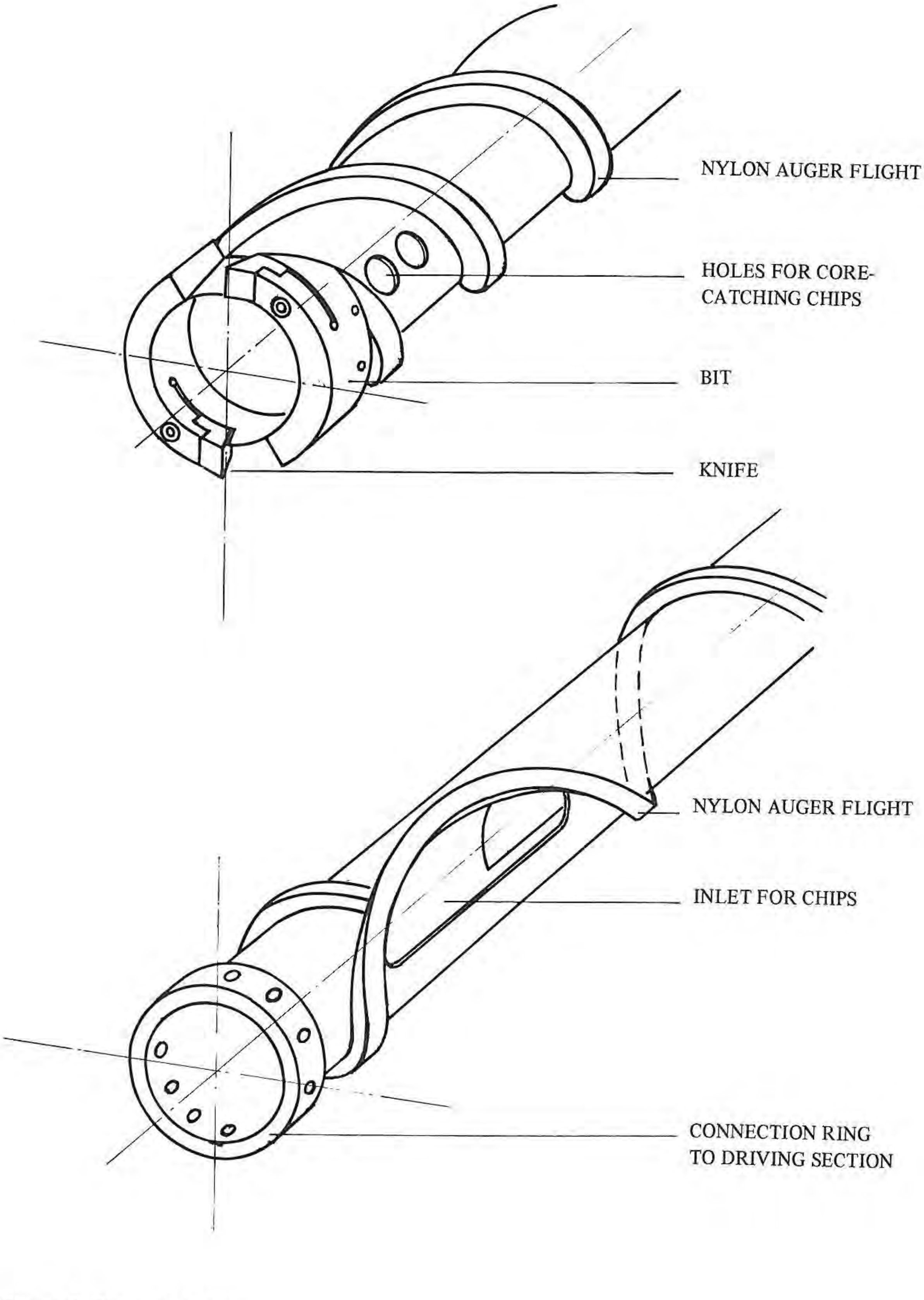

Figure 5. The core barrel.

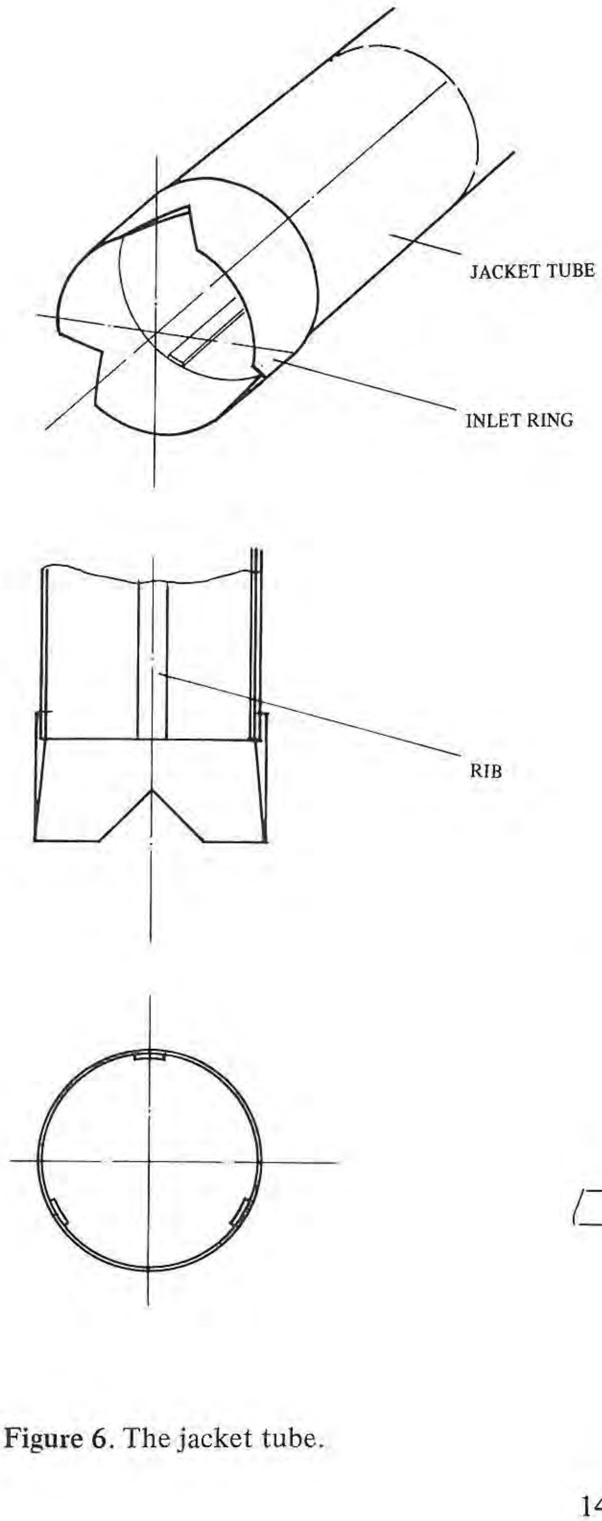

Figure 6. The jacket tube.

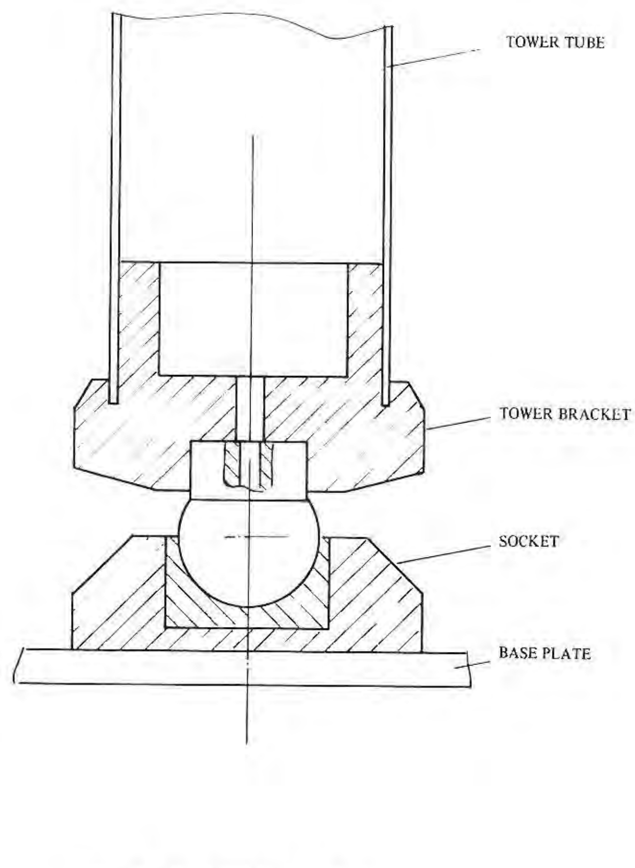

Figure 7. The ball joint.

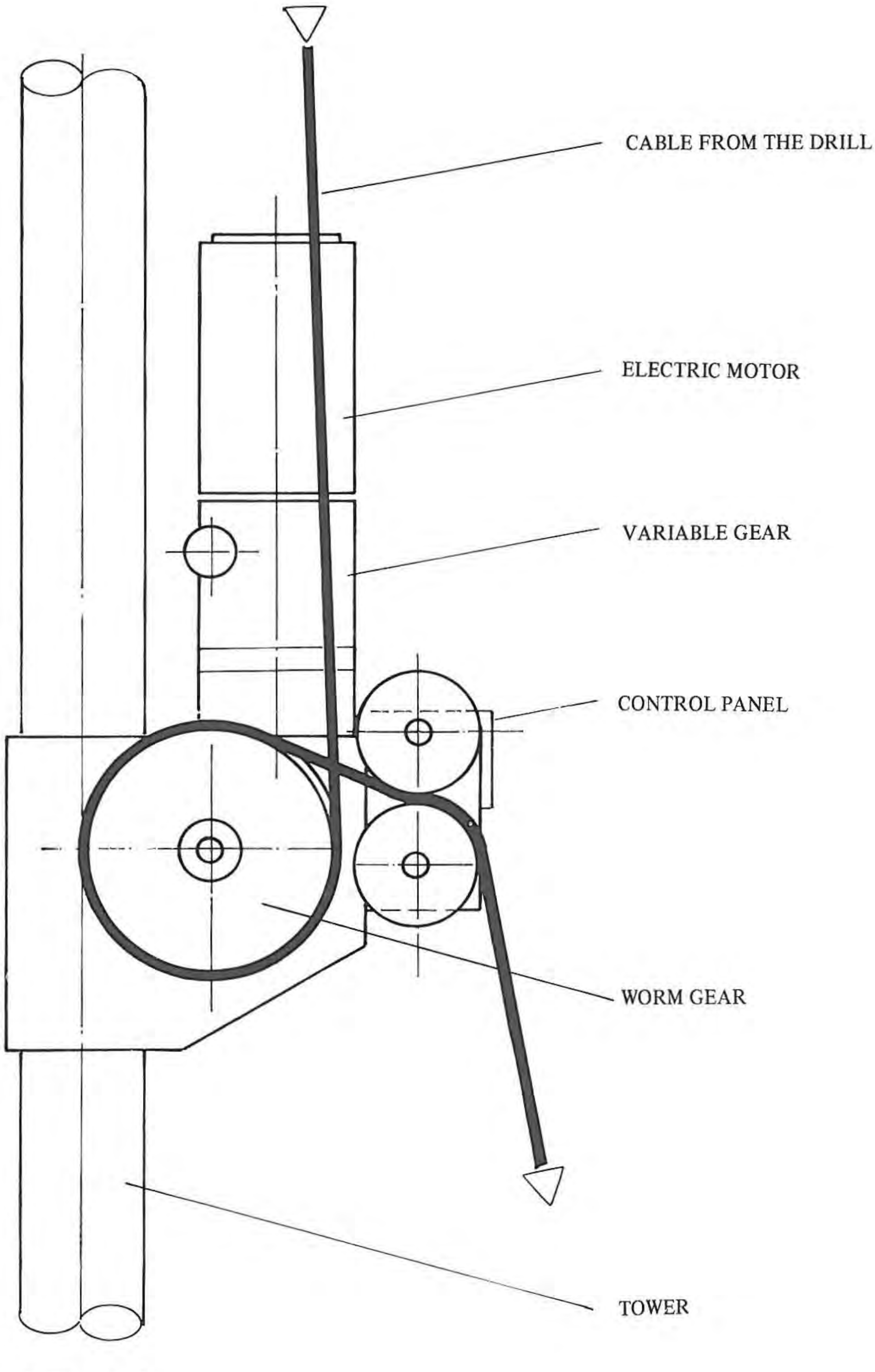

Figure 8. The winch.

frame and its weight is 38 kg. The fuel consumption is about 5 gallons of gasoline for a 50-m borehole.

Drilling Preparation

For transportation the complete drill unit is packed in three boxes with a total volume of 0.85 m^3. It takes two men about two hours to assemble the drill and to get it ready for drilling. One man digs a pit about 1.5 m on a side and 1.5 m deep to provide room to pull the core barrel down from the drill, while the other man assembles the tower, the winch, and the cable. To raise the tower, one man holds the ball joint firmly on the surface and the other raises the tower like a long ladder. While one man holds the tower vertical, the other fixes the anchors in the snow and adjusts the pulley blocks. When the drill is connected to the cable it serves as a plumb to bring the tower into its final perpendicular position.

The generator is normally located about 10 to 15 m from the drill tower.

Drilling Operations

At the beginning of drilling, it is very important to maintain a vertical hole. Therefore for the first 3 to 5 cores the drill feed is kept very slow. After the first 5 m of drilling, it is helpful to dry the drill on the outside and let it sit in the hole for awhile, allowing it to cool to the temperature of the firn.

The complete run involves the following steps:

1. Lower the drill down the hole at the full speed of the winch.
2. Begin decelerating a few meters above the bottom of the hole and touch the bottom very slowly.
3. Give slack on the cable corresponding to the length of the new core to be drilled.
4. Stop the winch and start the motor of the drill.
5. Hold the cable over the hole by hand. This gives the best feeling for the feed of the drill.
6. After the desired length is drilled, switch off the drill motor.
7. Start the winch to raise the drill with very low speed.
8. Pull on the cable by hand to break the core.
9. Increase the speed of the winch and raise the drill.
10. Disconnect the core barrel.
11. Push the core out.

12. Replace the disc which separates the core barrel into a core and chips section, and clean the barrel with a brush.

13. Re-connect the barrel.

14. Check the drill function with the motor.

A run at 40 m depth takes about 5 to 6 minutes.

Drilling Experience and Tests

Tests were made in 1973 at Dye 2, Greenland, in February and March 1974 in the Swiss Alps on Jungfraujoch and Plaine Morte, and in 1974 in Greenland at Summit, Crête, and Dye 2. In 1973 we had a complete drill unit except for the electric winch. After some trouble with the coring section, we changed it and used the SIPRE auger together with the driving section. This allowed us to get some experience with the driving system and the drill tower. With this combination we drilled to 24 m. To move the drill up and down we used a hand-driven winch.

In the 1973-74 winter we built a new coring section and an electric winch. We tested the new core barrel on Jungfraujoch in February 1974 by hand driving, just to find out how the new principle was working.

Alpine Glacier

In March 1974 the new core barrel, together with the driving unit, was tested on Plaine Morte, a glacier in the Alps 2700 m above sea level, and got the first proper experience in snow and glacier ice with the new drill. We still used the hand-driven winch. Several short holes were drilled through the 3-m snow layer on the ice and down to 5 m into the ice. One of the most important considerations was to determine the best diameter for the bit. For this purpose we had different sets of cutters with us. We also modified the inlet ring of the jacket tube and made some torque measurements to find out the power required to drill in ice. The drilling speed we got in snow was 2 cm/sec, and in glacier ice 1 cm/sec. With a core barrel length of 210 cm, we got 100- to 120-cm cores in snow, and 60- to 70-cm cores in glacier ice. The inlet ring of the jacket tube was modified by cutting notches (Fig. 6) so that the chips would enter the jacket tube while drilling in ice. Without the notches the chips were merely rotating with the core barrel on its open end and would get packed in front of the jacket tube, giving us trouble in raising the drill. The free part of the core barrel was 25 cm at that time, but we later made it shorter. The rest of the new coring section did not have to be changed.

Greenland Firn (1974)

Summit (Fig. 9):

Except for some trouble with the inlet ring, the drill worked well in principle. At a depth of 19 m the coupling between the motor and the reduction gear broke and could not be repaired in the field.

Figure 9. Drill unit assembled at Summit Station, Greenland.

Crête:

After a complete overhaul of the drill we tried to reach 50 m depth at Crête Station.

Antitorque system:

At a depth of 23 m the entire drill began to rotate. With the increasing density of ice the friction increased between the core and the bit because the cutters were exactly flush with the inlet diameter of the bit so as to guarantee good core catching. To reduce the friction we moved the cutters about 0.1 mm each to the inside and got better results. We also fixed a helical spring behind the plate springs of the antitorque system (Fig. 3) to give them more pressure against the wall of the borehole.

Even after these changes we still could not penetrate beyond 23 m depth. We then started a new hole and succeeded to reach the desired depth of 50 m.

Cooling the drill before drilling:

On the surface the drill is normally warmer than the firn in the borehole because it is warmed by the air and the solar radiation. The warm drill gets wet in the borehole and becomes covered with ice, and the chips freeze to the core barrel. To avoid this it is best when beginning a new hole to drill only the length of the drill. Then dry the drill including the core barrel, lower it into the hole and let it cool well below the melting point of ice before resuming drilling. When there is a lull in the drilling always leave the drill in the hole.

Core catching:

When drilling the second hole we had trouble at a depth of 30 m with core catching. The cutters made the core surface too smooth and the chips too fine (almost powder). A change in the angle on the inside of the cutters produced grooves in the surface of the cores, and we could catch them again, even at a depth of 50 m where the firn has a high density.

Winch:

The winch was not as strong as it was planned to be. The maximum speed of 25 m/min was never reached in raising the drill.

Drilling techniques:

One of the most important results was the drilling technique outlined above (Drilling Operations). The total drilling time at Crête for the 50.50-m hole was about 10 hours.

Dye 2:

Because Dye 2 is in the percolation zone, we had different firn conditions from those at Crête.

We drilled to 25 m in 3 hours, when the drill stuck downhole and we were unable to raise it with the winch. We tried to raise it with glycol, but after 2 days without results we made a final effort. A 200-liter drum of glycol was heated to 80° C with an electrical heater and the hot glycol was put into the hole. The drill was freed very easily, and we could see the reason why it stuck. Two pieces of wood that were placed on the inside of the plate springs at Crête absorbed meltwater and swelled, so the springs could not move in.

After a complete overhaul of the drill, it was seen that nothing was damaged by the glycol, but we had to start a new hole. We drilled 45 m in 7.5 hours without any trouble. No cores were lost, and the average length of the cores was 80 cm.

Conclusions

The drill unit described seems to work well for shallow-hole drilling in firn and ice down to 50 or 70 m, but some modifications to the drill and the winch are necessary. To drill in temperate glaciers the drill needs to have a submergible driving section. The antitorque system will require longer skates instead of the present plate springs.

Acknowledgments

This work was supported by grants from the Swiss National Science Foundation and the U.S. National Science Foundation. We thank Mr. B. Lyle Hansen and Mr. John Rand from CRREL for their advice concerning the design; Mr. P. Domke, his apprentices, and Mr. W. Bernhard for constructing the prototype; Dr. John Röthlisberger for his help on Plaine Morte; and Dr. Sigfus Johnsen for his help in GISP-74.

REFERENCES

Árnason, B., H. Björnsson, and P. Theodórsson, 1974, Mechanical drill for deep coring in temperate ice: *Journal of Glaciology,* v. 13, no. 67, pp. 133-139.

Ueda, H.T. and D.E. Garfield, 1969, The USA CRREL drill for thermal coring in ice: *Journal of Glaciology,* v. 8, no. 53, pp. 311-314.

Note added in proof: A new and modified drill was built in 1975 and used to drill four holes for the Greenland Ice Sheet Program-1975: a 94-m hole at Dye 3, an 80-m hole and a 30-m hole at South Dome (about 190 km south of Dye 3), and a 60-m hole at Hans Tausen Ice Cap. The new drill is designed for drilling to 100-m depth and the complete unit weighs about 350 kg, including tool box. The drill and tower are packed in one box (2.4 m long, 0.28 m^3, 90 kg), and the remaining components (less tools) in four boxes (each 0.14 m^3, 60 kg). Two winch systems were made for the drill: one is a capstan winch with 120 m of rubber cable, and one is a conventional winch system with a drum and a steel cable with three conductors. Both winch systems use the same motor and gear box. The winch speed is about 40 m/min and the motor has a thyristor driving unit for the speed variation.