Mem. Natl Inst. Polar Res., Spec. Issue, 49, 113-123, 1994

# DEVELOPMENT OF A JARE DEEP ICE CORE DRILL SYSTEM

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***Abstract:*** The final design of an electro-mechanical drill is very simple both in shape and in mechanism. It is a straight tube consisting of an antitorque section, motor and computer section, chip chamber and core barrel. Three cutters (rake angle : 30 to 40 degrees, pitch : 5 to 7 mm) are attached to cut an ice core 94 mm in diameter and bore hole 135 mm in diameter. The maximum core length is 2.1 m long. Chips are transported between the core barrel and the outer tube by spiral rim attached to the core barrel. No motor for sucking chips up to the chip chamber is installed. The chips are separated from liquid by the filter at top of the chip chamber, and are compacted to the density of 500 kg/m$^3$. In the pressure tight electronics section, a computer, DC brushless motor (270 V, 600 W, 12000 rpm) and reduction gear (1/170) are installed. The antitorque section has three leaf springs. A steel cable 7.7 mm in diameter has been chosen. The actual drilling operation is easy, for in response to the cutter load, a switching signal (go or stop) can be sent from the relay computer to the winch controller. What an operator has to do is, before drilling, to set the winch speed at the proper value and set the threshold value of the cutter load, and, while drilling, check the motor current if it increases rapidly.

## 1. Introduction

Japanese Antarctic Research Expedition (JARE) plans to start drilling at Dome F in the field season 1994-95.

For the past 20 years, a Japanese electro-mechanical shallow drill that has characteristic side cutters for antitorque has been used for drilling at many sites from Antarctica to the Himalaya. In 1983, a thermal drilling system was developed to make a dry hole 700 m deep at Mizuho Station, Antarctica. We have, however, never developed a deep ice coring system.

Considering energy consumption and transportation load, we decided to develop an electro-mechanical drilling system for Dome F. The system has been developed since 1988. Based on the experience of ISTUK (GUNDESTRUP *et al.*, 1984), five different types of electro-mechanical drill were manufactured as pre-prototypes. In these drills, differences were in the antitorque (leaf spring or skate), chip chamber (with or without pump) and core barrel (double tube or single tube with chip channel).

Experiments have been carried out using the domestic facilities shown below, and field tests were carried out in Antarctica (1988 and 1989), and at Dome GRIP, Greenland, (1991 and 1992).

After the field test at Dome GRIP in 1991, the drill, with leaf spring antitorque, without pump in chip chamber and double tubed core barrel, was selected as the final prototype. The final drill system was designed and manufactured in 1993.

## 2. Experiments

### 2.1. Cold chamber

A tower 20 m high with a cold chamber has been constructed at Tachikawa, Tokyo (see Fig. 1). A block of commercial ice (0.2 m × 0.6 m × 0.9 m) can be set in the chamber in which cooled kerosene is circulated from the cooling container. The temperature of ice and liquid is usually –5°C or even higher because of limited ability of the cooling system. One ice block provides three runs of test drilling. As shown in Fig. 2, through the window, one can see how the drill is cutting ice in the liquid and how chips are being collected.

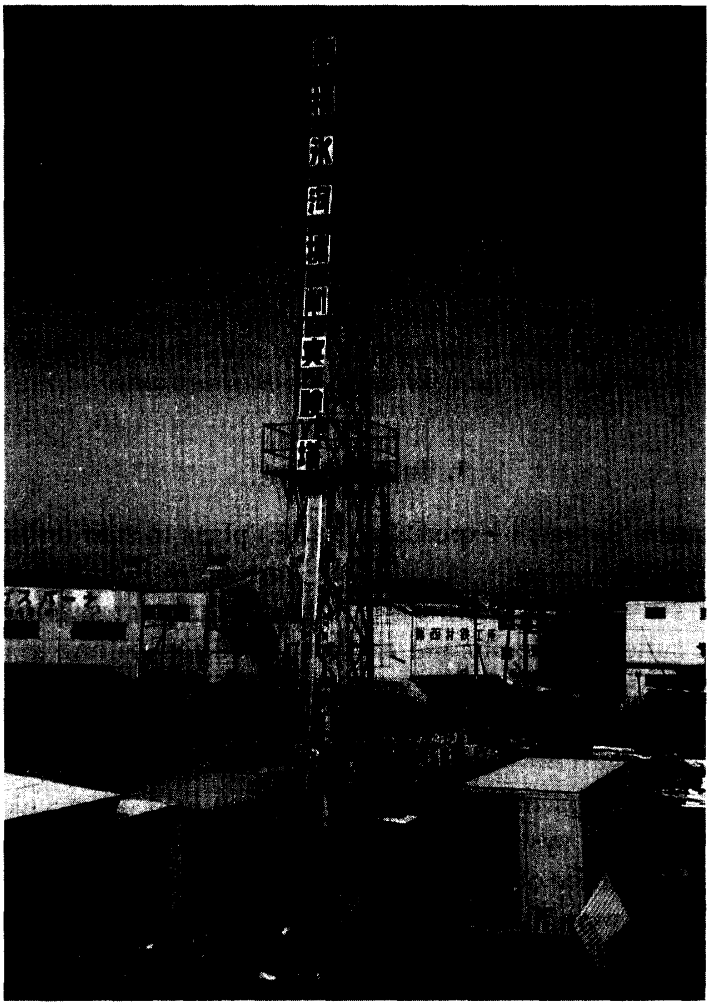

*Fig. 1. A tower and a cold chamber (under foot of the tower) for elementary experiments.*

Experiments are focused on cutting ice, on collecting and transporting chips, on electronics and on ancillary features such as ease of handling. Experiments have been carried out here since 1988.

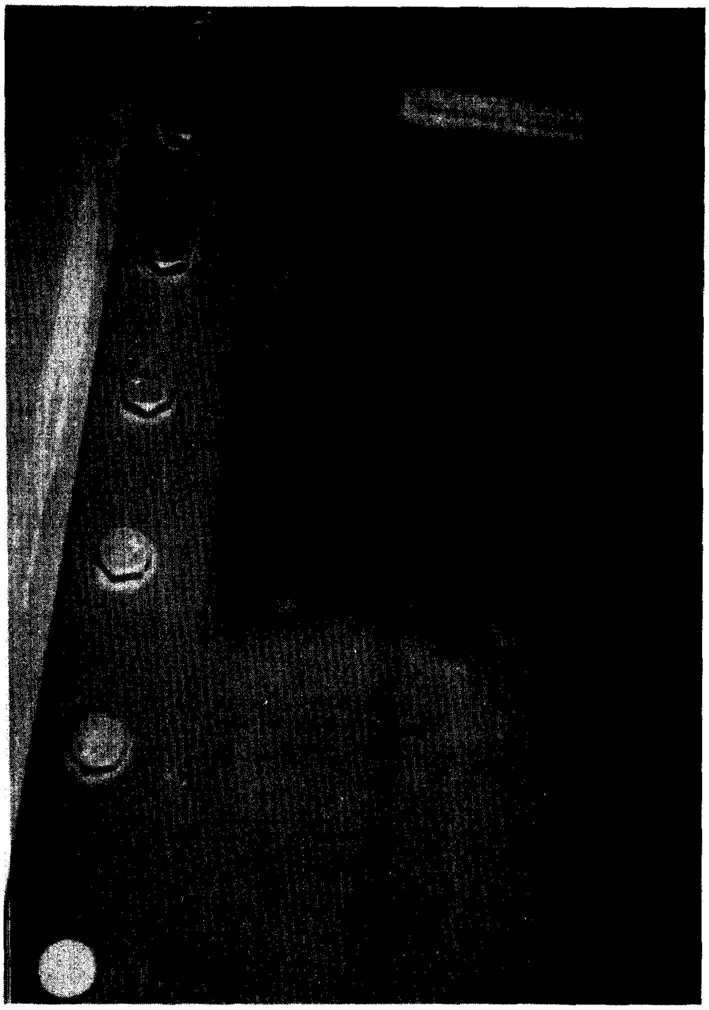

*Fig. 2. Liquid filled cold chamber. Through a window, one can see how the drill is cutting ice.*

### 2.2. Ice tower

For experiments focused on total performance of the drill system in a cold environment, a temporary ice tower 15 m high (see Fig. 3), was constructed at Rikubetsu town, eastern Hokkaido, where the lowest air temperature (lower than –25°C) in winter in Japan is often recorded. Although the town is one of the coldest places in Japan, it is still not cold enough to check all items we need to check for Dome F where mean annual temperature is –60°C.

After making pilot holes 8 m deep for the prototype drill, 7 m liquid filled drilling was carried out in each hole. The cross section of the ice tower was 1.0 m × 1.0 m. So it had enough space to make 9 holes of 63 m of total drilling length (see Fig. 4).

Using the final prototype drill, experiments, including measurement of drag force for drill moving in the liquid filled borehole, were carried out in 1992 and in 1993.

### 2.3. Prototype drill

Two candidates for the prototype drill were selected during the first three years of development. As shown in Fig. 5, one of them is a double tube type without pump. The other is the chip channel type with pump. The pump in this case is of the whirlpool type.

In the latter, the pump should be installed at the bottom of the chip chamber to generate and to maintain efficient liquid flow for transportation of chips. Two reduction gears are used in this case. The upper one is for the pump, and the lower one for the core barrel. In order to rotate the pump with enough speed by one motor, the shaft that runs through the chip chamber should be rotated at high speed. Here are some defects. Several bearings have to be attached to protect the long shaft from vibrating unstably in high speed rotation. This causes energy loss, or motor power loss. As seen in Fig. 5, the path of chips is complicated at lower gear reduction. This is not good for the smooth flow of chips.

After the field test at Dome GRIP in 1991, the former type was selected as the final prototype. This is because of its lower consumption of driving energy, simpler mechanisms to transport chips and easier handling at the surface. In addition, Japanese technicians and researchers are familiar with this type of drill, for it is similar to their shallow drill.

The final design of the JARE deep ice core drill system was improved after the field test at Dome GRIP, 1992, and experiments at Rikubetsu, 1993.

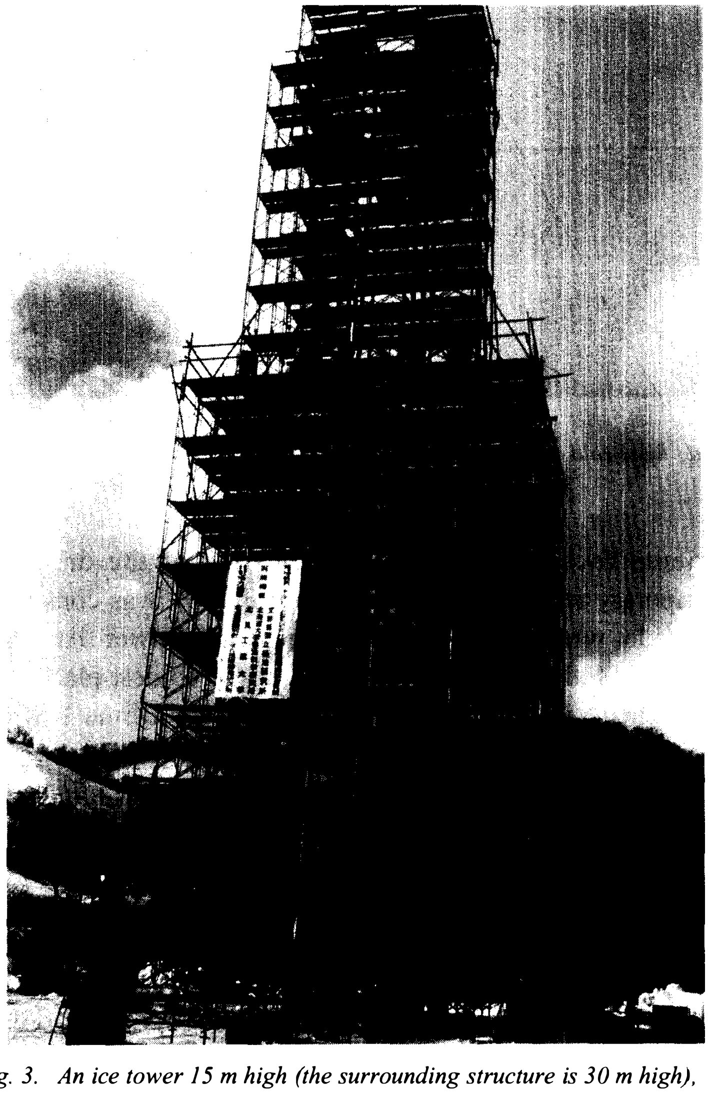

*Fig. 3. An ice tower 15 m high (the surrounding structure is 30 m high), at Rikubetsu, Hokkaido, for experiments in a cold environment.*

*Fig. 4. Experiment using the ice tower. The cross section of ice is 1 m × 1 m.*

## 3. Final Plan

The design concept is similar to our shallow drill, particularly in its chip transportation mechanism.

The drill consists of 4 major sections : antitorque section, pressure tight electronics section, chip chamber and core barrel, as schematically shown in Fig. 6. The total length is 8.1 m.

### *3.1. Antitorque section*

The length of this section is 805 mm. There are three leaf springs, 25 mm wide and 2.5 mm thick. The original shape of the spring is according to REEH (1984). In the section, there is a slip ring and a knocker which weighs 12 kg.

### *3.2. Pressure tight electronics section*

The computer, the motor and the reduction gear are installed in a pressure tight tube

(Fe-Cr-Mo alloy) with an inner diameter of 90mm and length of 1423 mm. It is designed to be tight at pressures up to 29.4 MPa. A leakage sensor, the electrical resistance of which changes rapidly when the surface of the sensor touches liquid, is attached at the bottom of the tube. The resistance is always monitored to warn of failure of the pressure seal.

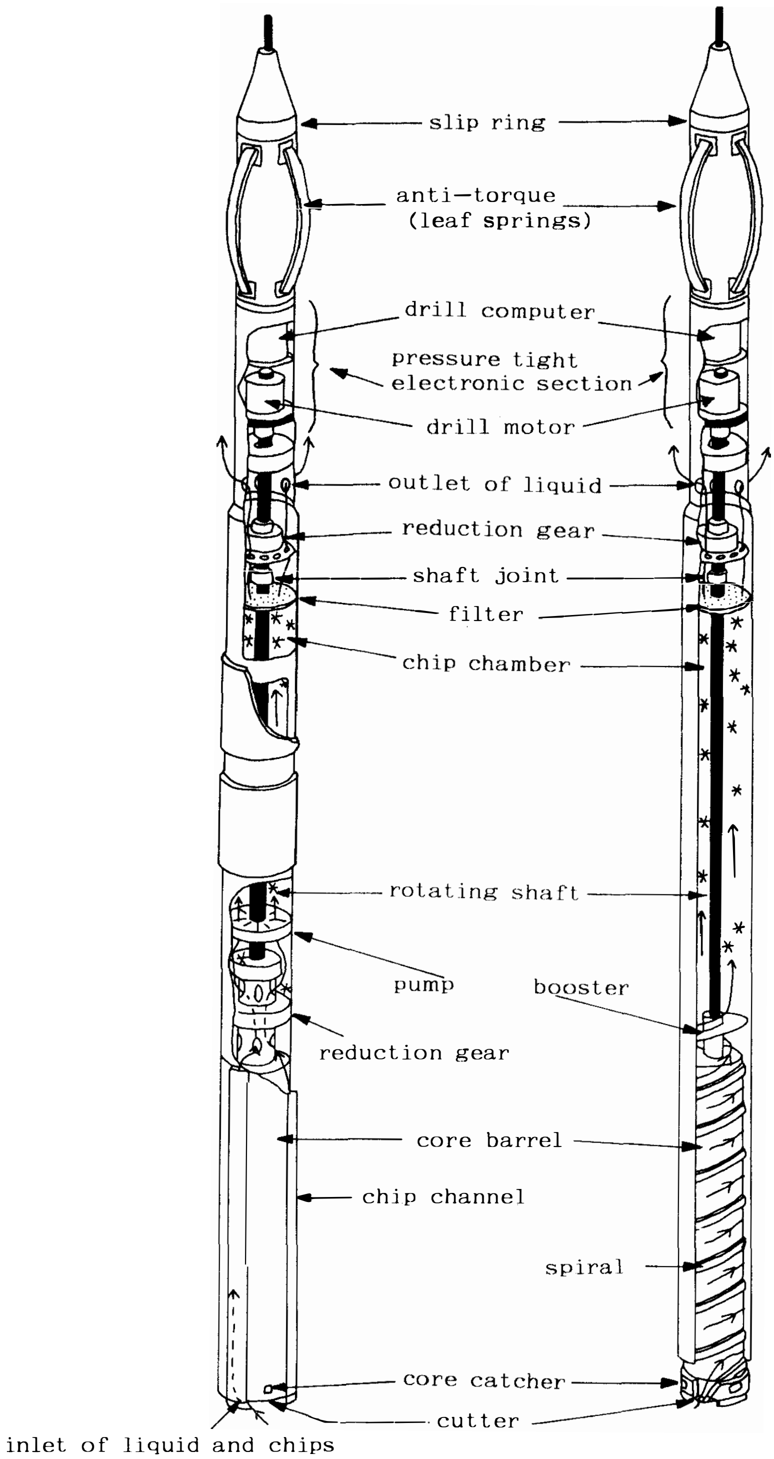


*Fig. 5. Two prototype drill candidates: with chip channel and pump (left) and with double tube and no pump (right).*

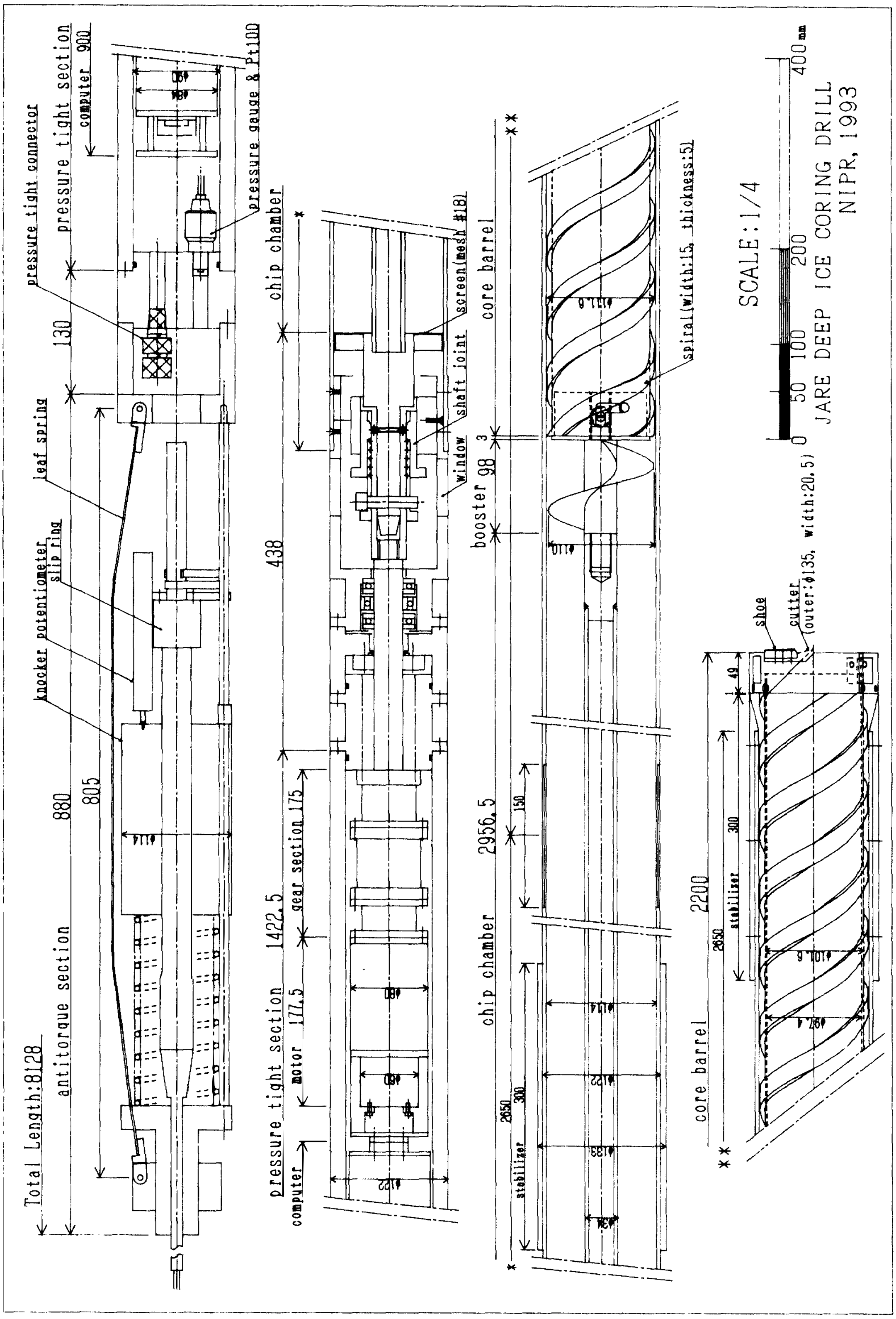


*Fig. 6. Schematic drawing of the JARE deep ice coring drill.*

### 3.3. Chip chamber

The measured density of chips in the prototype drill chamber varies from 500 to 620 kg/m$^3$. Using this density value together with the cutter width and cross section of the chip chamber, calculation shows that the chip chamber has to be at least 1.46 times longer than the maximum core length. Since the maximum core length is 2.1 m, the chip chamber is designed to be 3.0 m long.

Through the center of the chamber, there runs a shaft to rotate the core barrel. To separate chips from liquid, screen (mesh size #18) is attached around the shaft at the top of the chamber. At the bottom of the chamber, a screw-like fin is attached around the shaft for boosting chips into the chamber.

One can easily remove chips by pulling the shaft after releasing the shaft joint above the screen. The inside of the chamber can be easily cleaned by using hole liquid and/or pressurized air.

### 3.4. Core barrel

This consists of outer and inner barrels. The maximum length of the core is 2.1 m. The core diameter is 94 mm. A spiral 15 mm wide and 5 mm thick, of high density polyethylene, is attached by small screws to the outer surface of the inner barrel. The spiral angle is 40 degrees. The core barrel with the spiral can work as Archemedian pump to transport chips upward while the barrel is rotating (maximum 70 rpm).

One can detach the core barrel from the shaft each time an ice core is removed from the barrel.

### 3.5. Cutters

Tests have been carried out under the particular combination of temperature and pressure encountered in the ice at Dome F.

The drill has three cutters made of high speed steel (Rockwell hardness is 63). Several cutters with different configurations were designed. Rake angles, measured from the vertical, are 30, 40 and 45 degrees. The angles between the ice surface and bottom cutter surface are 10 and 15 degrees. Pitches are 4 mm and 7 mm. The cutter width is 20.5 mm, which provides a clearance of 6.5 mm between the outer barrel and borehole wall. This large clearance is needed for smooth faster movement of the drill during its travel between the surface and bottom of the hole, because our drill has no channels for liquid to escape through.

Drilling speed is expected to be 20 cm/min at least, or 12 m/hr. Then, at Dome F, 3000 m deep, actual cutting from the surface to the bottom would be within 250 hrs or about 11 days.

### 3.6. Electronics

Figure 7 shows the electronics of the final plan.

The drill motor is DC brushless, 270 V, 600 W, and normally 12000 rpm. Electricity is supplied from the surface by using 5 of the 7 cable conductors. Voltage varies 0 to 500 V at the surface.

The computer drives the motor and it also transfers sensor signals to the surface after converting analogue signals to digital ones. One conductor is used for supplying electricity

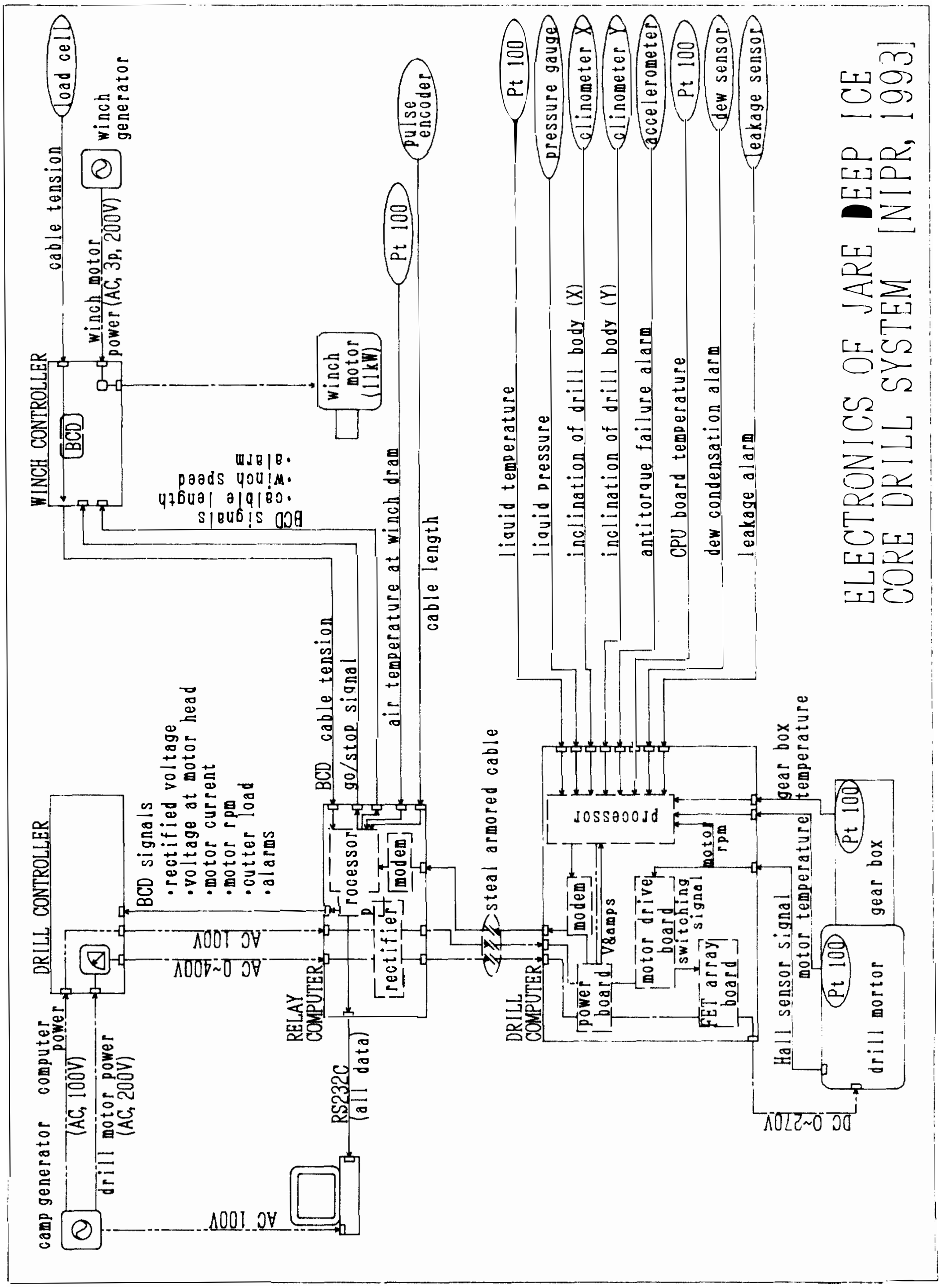


*Fig. 7. Schematic diagram of electronics of the JARE deep ice core drill system. Two motors to hinge and to tilt the tower are excluded.*

to the computer (voltage is 24 V at the computer head), and one is for signal transfer. Ten elements such as cutter load, liquid temperature and pressure, drill inclination (X, Y), motor current, motor voltage, and temperatures at gear, motor and CPU, are monitored.

A computer (relay computer) at the surface receives signals from the drill and from the sensors at the surface, including cable tension and cable length.

For communication between these computers, a CCITT V.23 600 bps compatible modem is used.

All sensor data are sent from the relay computer to a personal computer and displayed numerically and/or graphically on a CRT. They are saved on a hard disk.

### 3.7. *Cable*

Here we show the nominal specifications. A steel armored cable of 7.72 mm diameter with 7 conductors is chosen. Weight in air is 246 kg/km. The DC resistance of one conductor is 54.5 Ω/km and of armor is 9.5 Ω/km. The cable breaking strength is 37.4 kN, and the working load is 14.7 kN.

### 3.8. *Winch*

A maximum winch speed of 1.0 m/s is required. While cutting ice, the winch has to be controlled at slow speed such as $3.3\times10^{-3}$ m/s (or 20 cm/min).

Since the weight of 3000 m of cable in the borehole liquid is about 660 kg and the expected drill weight is 180 kg, the maximum static load is 8.2 kN. On the basis of the ice tower experiments, the dynamical force or the friction force between the drill and borehole liquid (viscosity 5.0 MPa·s) when the drill is pulled upward at a speed of 1.0 m/s is roughly estimated as 2.2 kN. Then the total winch load is 10.4 kN.

The final specifications are : maximum load 10.8 kN; speed range $1.7\times10^{-3}$ (or 10 cm/min) to 1.0 m/s; winch dram 410 mm in diameter and 801 mm wide with Lebus grooving system; winch motor 11 kw, 200 V, 3-phase driven by an inverter.

The winch speed can be controlled to be so slow that the cable can be fed to keep the cutter load constant and stable while the drill is cutting ice. To keep the cutter load constant, there is a switching circuit within the relay computer. If the cutter load becomes higher than the threshold value, the switching circuit acts to stop the winch; if lower, it acts to restart the winch. The cable tension detected by the load cell at the tower sheave can be alternatively chosen as the threshold. In this case, the switching circuit acts to start or stop the winch, depending on the cable tension. These threshold values are set manually by a drill operator.

### 3.9. *Tower*

The tower is a steel truss 10 m long with cross section 0.4 m × 0.4 m. On the tower, the drill is supported by a gutter with short pillars. The tower is hinged and tilted at a point 4 m from the top end, for drill site ceilling height is determined to be 4 m by logistic requirement. Using a small winch to pull a cable whose end is fixed at the lower part of it, the tower can be hinged. To tilt the tower up to 7 degrees from the vertical, a tilt motor is placed at the hinge point.

The operation of this drill is expected to be very easy. An operator can set the cutter load threshold at the surface. He can also set the winch speed slow enough to keep constant cutter load or cable tension. The optimum combination of the winch speed and the threshold depends on cutting speed. Once the optimum combination is set the switching circuit helps to drill automatically. This combination is easily found by experiments or field tests. Also, on the job it is easy to adjust for different ice hardness.

## Acknowledgments

Our thanks are due to the Rikubetsu town office and Shibare-Gijutsu-Kaihatsu-Kenkyusho (or Rikubetsu Institute of Cold Technology) for their cooperation and logistic support to construct and maintain the ice tower. Thanks are also due to the GISP team for their technical suggestions and discussion of the drill system when our members visited the GISP camp, 1991 and 1992.

None of the authors can imagine that our drill system could have been improved without field testing and experience in operating the ISTUK at Dome GRIP, 1991 and 1992. We would like to express our great appreciation to the GRIP team for their permission, logistic support, technical advice, operational suggestions, and heartfelt encouragement.

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*(Received June 30, 1993; Revised manuscript received August 18, 1993)*