# DEEP CORE DRILLING
# BY JAPANESE ANTARCTIC RESEARCH EXPEDITIONS

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*ABSTRACT*

*Deep drilling by Japanese Antarctic Research Expeditions in 1971 during JARE XII began at Mizuho Camp (70°42.1' S, 44°17.5' E) with a 400-m winch, a 2.4-kW thermal drill and a 100-W electrodrill. In 1972, JARE XIII reached 147.5 m with a new thermal drill. Plans were made in 1973 to reach 800 m by February 1975, so JARE XV installed a new 800-m winch at Mizuho in May 1974. Drilling will start in October 1974 with a 3-kW thermal drill. In January 1975, two people from JARE XVI will join the operation with another 3-kW thermal drill. A thermal drill similar to JARE XV's and a 400-W electrodrill were tested in November 1973 at Ice Island T-3 by a party from Nagoya University, who successfully obtained 30 m of 250-mm-diameter cores using those drills and a large 6-kW thermal drill. JARE programs have thus made two winches, five thermal drills and two electrodrills, and one thermal drill is now in preparation.*

## Introduction

Despite active participation of glaciologists in JARE, no deep drilling project had been proposed by Japan until 1969. One of the reasons was that JARE had no base on the continent or on an ice shelf. Also, until JARE IX, Japan's main concern had been directed toward a traverse between Syowa Station and the South Pole by JARE IX in 1968-69.

Prior to JARE IX's departure from Japan in 1967, a long-range glaciological research plan covering JARE X, XI, XIV and XV had been approved, in which extensive oversnow traverses were scheduled over an area from 35° E to 52° E, requiring a permanent depot at about 71° S, 45° E.

Soon after JARE X departed Japan, several glaciologists, including the author, proposed to use the depot as a drilling site by JARE XII, XIII and XVI. In May 1969 the drilling project was approved and incorporated with the traverse project to form the Mizuho Plateau-West Enderby Land Project covering JARE X through XVI.

The transportation capability of JARE limited the total weight of drilling equipment to 1000 kg. Based on available information (Patenaude *et al.,* 1959; Shreve and Kamb, 1964; Ueda and Garfield, 1968, 1969a, 1969b), plans were made to reach 400 m with a thermal drill by 1972, and JARE XVI was to reach 1000 m with an electrodrill, yet to be developed. With the courtesy of CRREL, a full set of blueprints of a winch and a drill, CRREL Mk II, was obtained, and feasibility studies of making them in Japan were started in August 1969.

A budget of about $10,000 was allocated to the drilling project in fiscal 1970. A 400-m cable made in accordance with CRREL specifications and a 1.5-kW winch were ordered. Because of difficulties in obtaining thick aluminum and plastic pipes, the drill design was greatly changed and a small 2.4-kW drill, JARE 140, was made. As a trial, a 100-W electrodrill was also made. Meanwhile, JARE XI opened a depot, Mizuho Camp, at 70°42.1′ S, 44°17.5′ E in July 1970. The ice thickness there was reported as 2095 m.

JARE XII personnel arrived at Mizuho on June 28, 1971, and stayed for two weeks to install a 12-kVA generator and to construct living quarters. They returned to Mizuho at the end of September with the drilling equipment. After installing the winch in a 4-m pit, they began drilling on October 16 with the electrodrill, which stuck at 38.8 m on November 1. Recovery efforts failed on November 6, when the cable slipped out from the clamp of the drill. Drilling of a new hole began the next day with the thermal drill, which was lost at 71 m on November 17.

It had been hoped to develop a practical electrodrill for JARE XIII, but because no motor with an appropriate gear reducer was found, a thermal drill was adopted again. A new drill, JARE 140 Mk II, designed for easy disassembly, was used by JARE XIII personnel, who started drilling in July 1972. Despite many problems, they reached 104.5 m on September 14, when the drill stuck. By pouring 60 liters of antifreeze into the hole they recovered the drill, but only with severe damage to the pump. A new pump was sent from Syowa and they restarted drilling on November 6, reaching 147.5 m on November 14, where the drill again stuck and was abandoned.

Because low ambient temperatures in the drilling operations of JARE XII and XIII caused many problems, it was decided that the operation of JARE XVI should be done in January-February 1975, with personnel being flown to Mizuho from the ship. Equipment had been transported by JARE XV in the previous year. Since it would only be possible to work a maximum of 40 days, the target depth was lowered from 1000 m to 800 m. Preparation was begun of a winch with 800 m cable, two 3-kW thermal drills (JARE 160), and an electrodrill.

Failures in JARE XII and XIII to reach the target depths were partly attributed to the lack of field tests of the drills. Fortunately, Nagoya University was planning to take large ice cores from T-3 in October, so it was decided to test the new drills there.

The Nagoya party arrived at Barrow, Alaska, in September 1973 with one of the JARE 160 drills, the electrodrill and a large thermal drill, Type 300. Poor weather prevented them from getting to T-3 until the end of October, but by the end of November, they succeeded in getting 30 m of 250-mm-diameter cores and 31 m of 132-mm-diameter cores with the thermal drills.

Based on the interim report from T-3, the other JARE 160 drill was modified into the JARE 160A, which, together with the 800-m winch, was sent on JARE XV. The winch was installed at Mizuho in May 1974. The test drilling is due to start in October. In January 1975, two people from JARE XVI will join the operation with a new thermal drill, JARE 160B, which is now in preparation.

The Japanese ice-drilling activities to date are summarized in Table 1.

**Table 1**

**Japanese Ice-Drilling Activities**

| Party | Year | Equipment | Performance |
|---|---|---|---|
| JARE XII | 1971 | 12-kVA 200-V 3-phase generator<br>1.5-kW winch with 400 m cable<br>2.4-kW thermal drill (JARE 140)<br>100-W electrodrill | 38.8 m by electrodrill<br>71 m by thermal drill |
| JARE XIII | 1972 | 2-kW thermal drill (JARE 140 Mk II) | 147.5 m |
| Nagoya University | 1973 | 6-kVA 200-V 1-phase generator<br>50 m electric cable<br>Gasoline-powered 100-m winch<br>3-kW thermal drill (JARE 160)<br>400-W electrodrill<br>6-kW thermal drill (Type 300) | 30 m of 250-mm-diameter cores<br>31 m of 132-mm-diameter cores |
| JARE XV | 1974-75 | 12-kVA 200-V 3-phase generator<br>Transformer and rectifier to supply DC 0-230 V 30A<br>1.5-kW winch with 800 m cable<br>3-kW thermal drill (JARE 160A) | |
| JARE XVI | 1975 | 3-kW thermal drill (JARE 160B) | |

## Description of the Components

(A) *Power Sources:* A 5-kW 200-V single-phase AC generator was considered as a power source in the early stage of planning, but it was later decided to install a 12-kVA 200-V three-phase AC generator at Mizuho for general use. While a three-phase generator allows the use of an easily-obtained three-phase induction motor for a winch, it presents difficulties in powering a drill through a cable which is intended to transmit single-phase current (see below). Namely, to draw a large power load from one phase of the generator causes a severe imbalance, thus requiring dummy loads on other phases and increasing fuel consumption considerably. As a remedy, JARE XV brought a rectifier which converts three-phase AC into DC current, possibly solving the problem. At T-3, a 6-kW 200-V single-phase AC generator was used.

(B) *Cables:* Specifications of the 400-m cable made in 1970 and the 800-m cable made in

1973 are shown in Table 2. Both are CRREL-type cables, having seven control conductors and one power conductor, the latter together with armors being intended to transmit DC or single-phase AC current. Extensive laboratory testing of the 1970 cable showed it to be weak in radial impact. When a 20-kg weight was dropped on the cable from a height of 0.5 m, the insulation broke down on some of the control conductors. Such a radial impact can occur during drilling when the cable slips off a sheave. To prevent this, the groove of the sheave must be deep enough. Because the cable undergoes repeated bending during drilling, repeated bending tests were carried out in low ambient temperatures (Fig. 1).

Table 2

Specifications of Cables

| | JARE XII (400 m) | JARE XV (800 m) |
|---|---|---|
| Plain Copper: Number/dia. | 7/0.23 mm | 7/0.23 mm |
| Thickness of Nylon Insulation | 0.23 mm | 0.23 mm |
| Diameter of One Conductor | 1.15 mm | 1.15 mm |
| Diameter of Seven Conductors | 3.45 mm | 3.45 mm |
| Thickness of Mylar Tape Layer | 0.15 mm | 0.15 mm |
| Plain Copper: Number/dia. | 12/1.18 mm | 15/0.9 mm |
| Diameter up to Power Conductor | 6.1 mm | 5.55 mm |
| Thickness of Polyethylene | 0.85 mm | 0.8 mm |
| Thickness of Braid | 0.3 mm (Nylon) | 0.3 mm (Polyester) |
| Galvanized Steel: Number/dia. | 12/1.0 mm | 14/0.8 mm |
| Tinned Hard Copper: Number/dia. | 12/0.99 mm | 14/0.8 mm |
| Diameter up the First Armor | 10.4 mm | 9.35 mm |
| Galvanized Steel: Number/dia. | 27/1.20 mm | 25/1.20 mm |
| Diameter of Cable | 12.8 mm | 11.8 mm |
| Resistance: Control Conductor | $< 65\Omega$/km | $< 70\Omega$/km |
| Power Conductor | $< 1.4\Omega$/km | $< 2.0\Omega$/km |
| Armor | $< 1.9\Omega$/km | $< 2.5\Omega$/km |
| Tensile Strength | $>$ 4000 kg | $>$ 3000 kg |
| Weight | 650 kg/km | 450 kg/km |

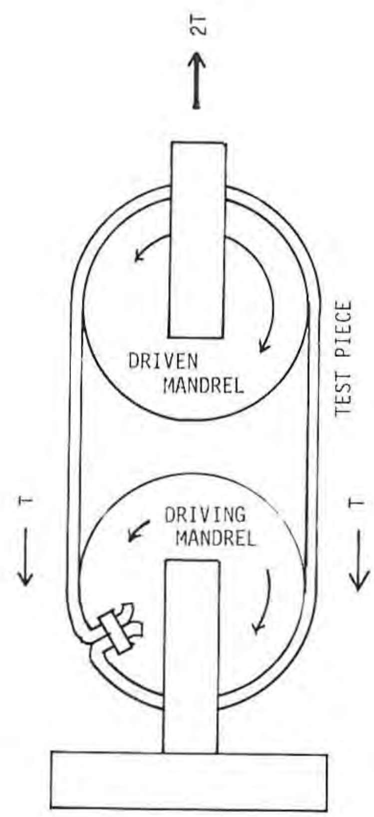


**Figure 1.** Schematic diagram of the bending test of the cable.

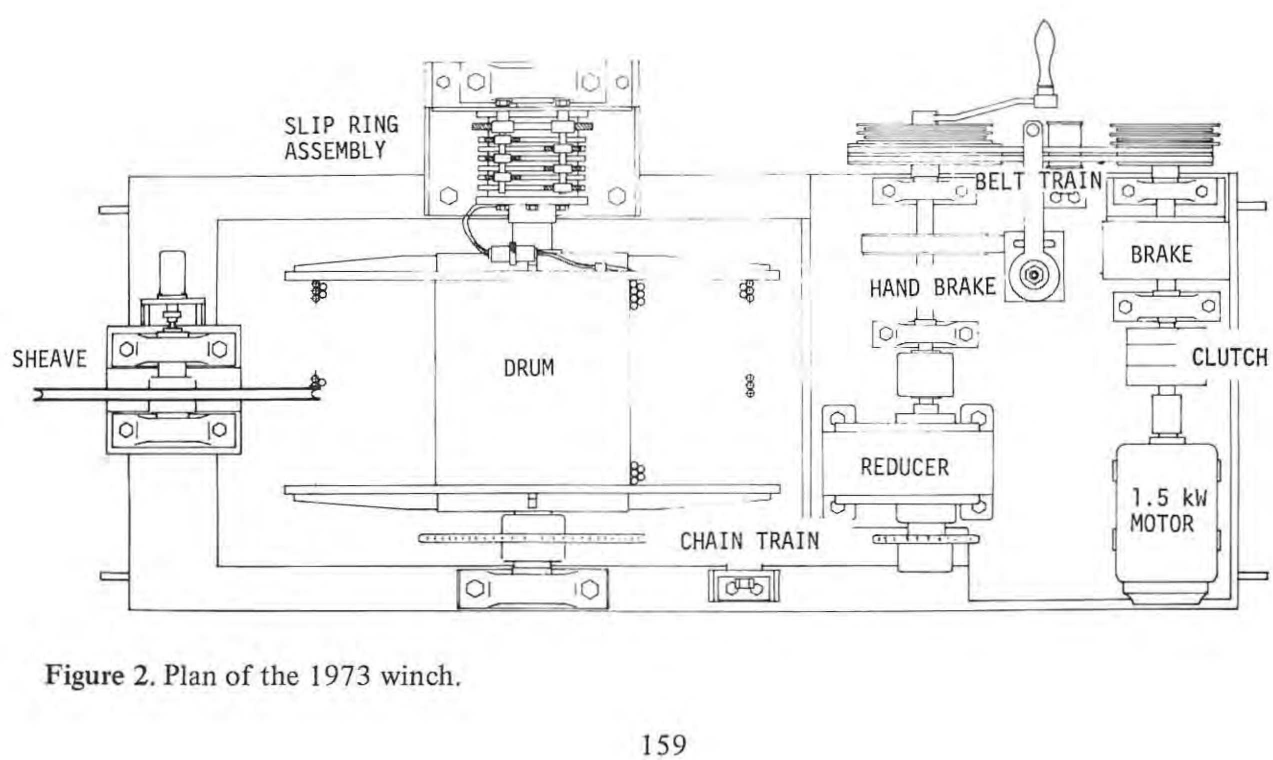


**Figure 2.** Plan of the 1973 winch.

The test piece of the cable, half-way wound on a mandrel of 320-mm diameter, is forced to move back and forth while tension is applied to the cable. With a 1000-kg tensile force, -25$^{o}$ C ambient temperature and 33 cycles per minute reciprocal movement, the cable showed no serious damage at 2000 movements while at 3000 movements some copper wire in the inner armor broke and pierced the polyethylene layer, causing a short circuit to the power conductor. The tensile strength of the cable was over 4800 kg, enough to hold the weight of the cable itself, 260 kg, plus that of the drill, about 50 kg, and the breaking strength of the ice core, estimated at several hundred kilograms.

In order to ensure the minimum winding speed of 20 m/min of the winch, the weight of the 1973 cable was considerably reduced at the sacrifice of the tensile strength and the conductivity of the power conductor. The designed value of 3000 kg of the tensile strength seems enough for breaking ice cores, and the lower conductivity can be overcome by use of high voltage, if necessary.

(C) *Winches:* The 1970 drum was similar to the CRREL model with 7 elements of plane ring slip rings, which was replaced by cylindrical ones in the 1973 drum, because the latter is easy to make and to maintain. The 1970 drum with 400 m of cable weighed about 450 kg, while the 1973 drum with 800 m of cable weighed about 550 kg.

The power trains are similar for both winches (Fig. 2). A 1.5-kW three-phase motor was used, which might be better replaced by a DC motor, if the rectifier mentioned above works well. The electromagnetic clutch and brake were adopted in anticipation of automatic control by such signals from the drill as cable tension, water level in the tank, etc., but no automatic control was actually used.

The frame and mast were made of steel instead of aluminum alloy. The height of the mast was shortened to 3.5 m for both winches.

(D) *Thermal Drills Other than Type 300:* Specifications are given in Table 3, including the Type 300 drill and the CRREL drill (Ueda and Garfield, 1969a, 1969b). The working principle is the same as the CRREL drill. Each consists of five blocks: spring suspension block, vacuum pump block, water tank block, core barrel block and main heater.

(D-1) *Spring Suspension Block* (Fig. 4): The cable was fixed to the inner cylinder with a screw clamp instead of with plastic (epoxy) cement or low-temperature alloy (white metal). The screw clamp was adopted for easy reattachment of the cable in case it breaks. The actual clamping force was not measured. Specifications of the suspension spring and the load-indicating system were the same for all drills. Three ranges of the load—small, normal and large—were indicated on the surface control panel by signals from a microswitch assembly at the suspension block. The load in normal range was between 14 and 18 kg.

(D-2) *Vacuum Pump Block:* A diaphragm-type 20-W vacuum pump, IWAKI AP 220, capable of producing a vacuum of -450 mm Hg, was used throughout, with modifications to fit in a 130-mm-diameter (for the 140) or 150-mm-diameter (for the 160) cylinder. In low ambient temperatures, the diaphragm often stiffened, making the pump difficult to start. A heater (Fig. 3) was added to warm the pump for the 160A and 160B.

The pump housing of the JARE 140 was a stainless-steel cylinder with a cover on top and a female screw thread at the bottom. The suspension was bolted to the top cover, while

Table 3

Specifications of Thermal Drills

| Type | Length, mm | Weight, kg | Core Capacity Dia./Length, mm | Heater Ring O.D./I.D./Height, mm | Heater Elements | Estimated Melting Area, $cm^2$ | Power Per Unit Area, $W/cm^2$ |
|---|---|---|---|---|---|---|---|
| 140 | 2500 | 30 | 103/1000 | 142/105/75 | 100 V 1.2 kW x 2 | 80 | 30 |
| 140 Mk II | 3050 | 40 | 105/1200 | 142/108/75 | 100 V 1.0 kW x 2 | 75 | 27 |
| 160 & 160A | 3420 | 50 | 132/1500 | 168/134/70 | 200 V 1.5 kW x 2 | 90 | 33 |
| 160B | 4000 | 60 | 132/2000 | 168/134/65 | 100 V 1.5 kW x 2 | 90 | 33 |
| 300 | 2080 | 140 | 250/1500 | 285/252/100 | 200 V 2.0 kW x 3 | 180 | 33 |
| CRREL Mk II | 4600 | 80 | 122/1500 | 162/124/51 | 215 V 625 W x 18<br>Used at 115 V<br>ca. 3.2 kW | 90 | 36 |

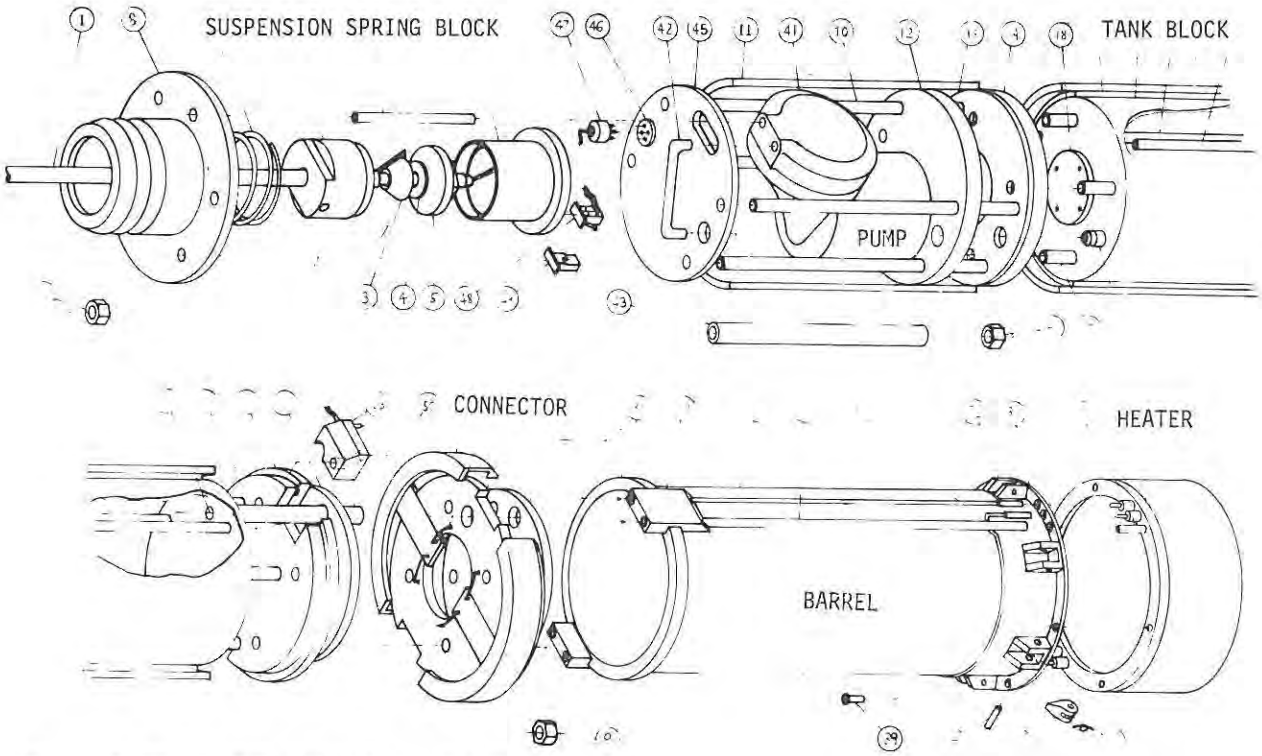


**Figure 3.** The JARE 160A thermal drill.

a male coupler, glued to an FRP casing of the tank and barrel block, fitted in the female screw. The housing of every other drill was a "cage" made of four long bolts planted on a basal disk with an FRP casing which was not a tensile structural member. The suspension was fixed to the bolts and the disk was fixed to the tank (see below).

(D-3) *Water Tank Block* (Fig. 5): Every tank was made of a 2.1-mm-thick stainless-steel pipe, of either 114.3 mm O.D. (the 140) or 139.8 mm O.D. (the 160). A simple water gauge using a buoy was mounted in every tank. The 160B tank will have an electromagnetic valve to recover its inner pressure quickly so as to make water in the suction tubes flow down rapidly (see next paragraph). Every tank was covered with foam plastic, and inserted in 4.5-mm-thick FRP pipe of either 139 mm O.D. (the 140) or 159 mm O.D. (the 160), except for the 160A tank, which was covered with thin sheet steel lined with a rubber sheet heater. The heater is intended to be used if the drill freezes in the hole. Every tank except the JARE 140 was a structural member with four bolts fixed on each end panel. The upper four bolts fastened the base of the pump housing on the tank, while the lower four fixed a connector (Fig. 6) for the barrel block on the tank. The connector of the 140 Mk II was a simple disk with six holes. That of the 160 was a sophisticated device with two semi-circular arms, which, when closed, gripped the flange of the barrel so as to fix the barrel to the tank.

(D-4) *Core Barrel Block* (Fig. 7): The barrel of the JARE 140 was an extension of the FRP tank casing. A core-cutting ring was glued to its lower end. A special feature of the ring is its catcher-releaser, whose turning can instantly release all catchers from the core so that the core is easily taken out downward.

The structural member of the JARE 140 Mk II barrel block was six 6-mm-diameter shafts with a male screw threaded on both ends. The shafts were fixed on a core-cutting ring similar to the 140. An inner case was inserted between the shafts. Water piping and electrical wiring were fastened to the inner case, as were the shafts. A 139-mm-O.D. FRP pipe covered them for protection. The shafts were fastened with nuts on the holes of the disk of the tank block. The above construction made it easy to disassemble the barrel block for inspection of water piping and electrical wiring.

The barrel of every 160 series drill (Fig. 3) was a 2.1-mm-thick stainless-steel pipe, 139.8 mm O.D., with core-catchers welded at the lower end and a flange at the upper end. The flange was for the connection of the barrel to the tank block (see previous paragraph). The barrel had no catcher-releaser. Core was taken out by detaching the barrel from the tank block and turning it upside down.

Water tubes for all the drills were stainless steel (6 mm or 8 mm O.D.). A silicone-rubber lead heater of 2-mm diameter was used for warming the tubes, except for those of the 160B, which were hoped to have no freezing problem because of the pressure release valve of the tank.

(D-5) *Main Heaters:* To avoid the fine machining required by the CRREL design, where cartridge heaters were inserted in an aluminum ring, we adopted molded heaters throughout. The heating elements were made of stainless-steel sheath heater of 8-9 mm diameter.

(E) *Type 300 Thermal Drill:* The drill consisted of a core barrel with a heater and a side pilot pipe with a core cutter. Meltwater was allowed to flow in a pilot hole previously drilled by the JARE 160, and was occasionally taken out with a bucket. A possible version is to use the lower part of the pilot pipe as the water tank.

(F) *Electrodrills:* The 1970 drill consisted of four blocks: a cable suspension, an anti-torque device, a power unit, and a barrel. The suspension was common with the JARE 140 thermal drill. The anti torque device was of the pantagraph-type with four pairs of arms expanded outward by four adjustable springs. The power unit was a 100-W 100-V single-phase 4-P induction motor with a 15:1 gear reducer. Thus, at 50 Hz the drive shaft rotated at 100 rpm. The barrel was 1.5 m long and was made of 114.3 mm O.D. steel pipe. At the lower end of the pipe was welded a cutter shoe of 150 mm O.D. and 105 mm I.D. on which three cutters were fastened with hexagonal bolts. Triple spiral fins were welded all over the barrel. The pitch was a uniform 150 mm. Hence, two adjacent fins were 50 mm apart vertically. The upper half of the barrel was the reservoir for ice chips. In actual operation, the drill revealed many defects, the most serious one being the ineffectiveness of the spiral fins to move ice chips upward. Often only 20 or 30 cm of drilling caused ice chips to cling between fins and the wall of the hole, overloading the motor. The loss of the drill at 38.8 m was due directly to this defect. Another defect was the difficulty of adjusting the anti torque spring. This might be overcome by adding "skates" to the arms. The power was felt to be slightly insufficient.

The 1973 drill was primarily made for the test at T-3. The drill had no complicated suspension devices, but rather a simple hook on its top. A 200-V 400-W single-phase 2-P motor (3000 rpm by 50 Hz) was mounted on the upper base while a 39:1 gear reducer was fixed at the lower base of an anti torque device. The motor and the reducer were coupled by a spline mechanism to accommodate the change of the height of the device, which was of the pantagraph-type with three pairs of arms. "Skates" were not added, though later they were felt necessary. The weight of the motor was considered enough to expand the arms, but in actual test it was not. The barrel

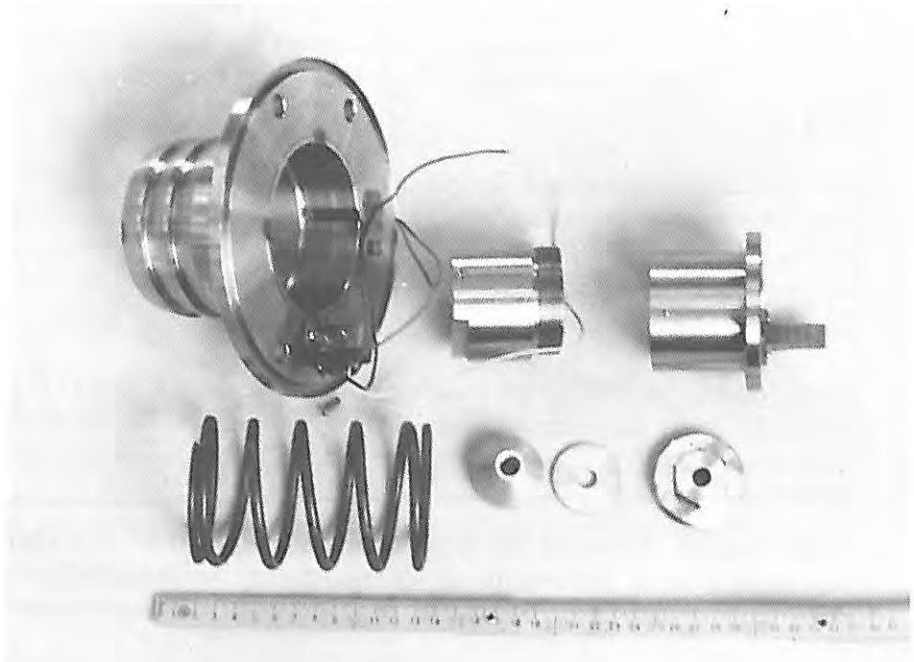

**Figure 4.** Suspension block.

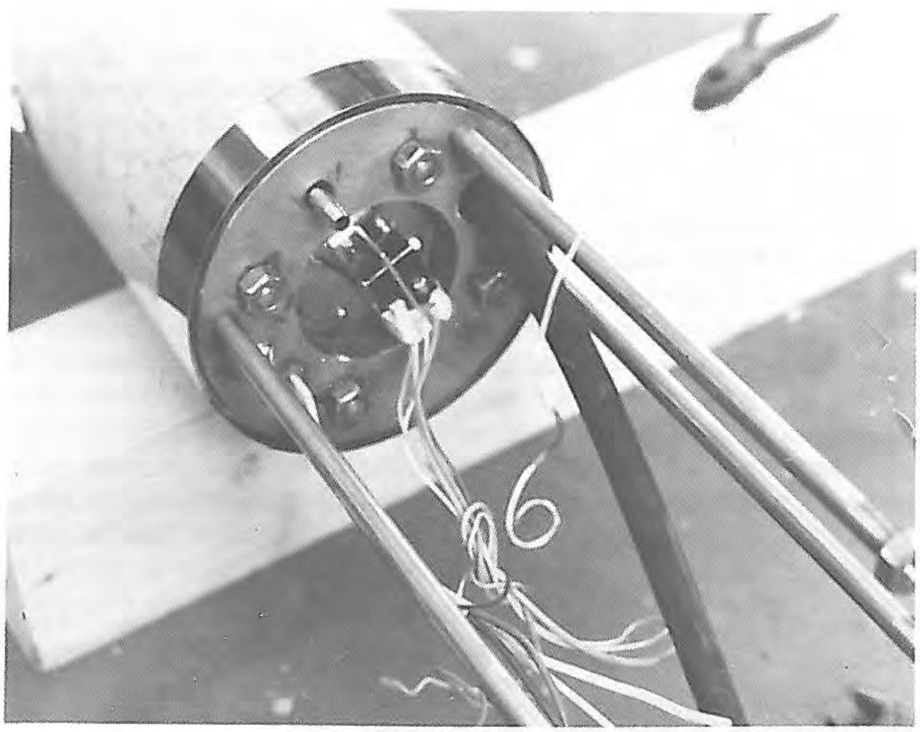

**Figure 5.** Upper end of tank block and frame of pump housing. Two limit switches are for monitoring vacuum and water level.

Figure 6. Lower side of connector.

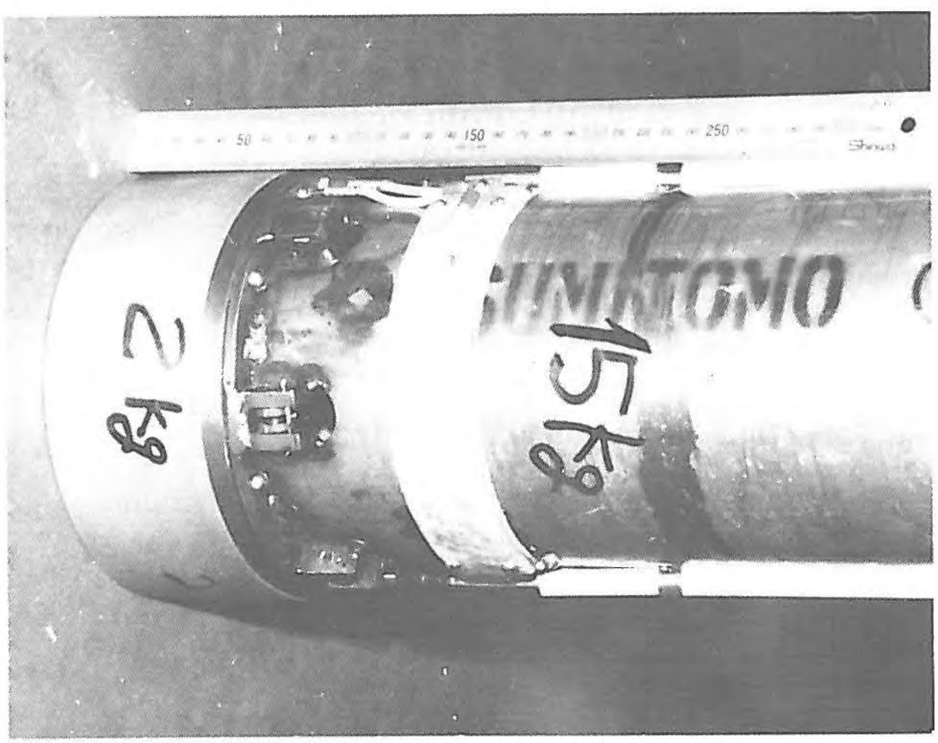


Figure 7. Lower part of core barrel and heater.

was made of stainless-steel pipe of 139.8 mm O.D. and 134 mm I.D. The cutting shoe was of 165 mm O.D. and 131 mm I.D. Two cutters were fastened on the shoe, each by one hexagonal bolt. A special feature of the shoe assembly was that it had two claws for core-breaking. When the drill rotated in reverse, the claws caught and struck the core to make it break. Double spiral fins of a uniform 240-mm pitch were welded onto the barrel, which was 2.2 m long with the upper 1 m being a chip reservoir. Some results from the test at T-3 were that (1) the drill usually stuck after proceeding 50 to 60 cm, requiring improvement of the chip-removing mechanism; (2) as long as the drill proceeded smoothly, the input current was less than 2 A, showing that the motor had enough power for chipping ice; (3) a drilling speed of up to 15 cm/min was obtained.

### Concluding Remarks

Up to now, mostly thermal drills have been used in JARE ice-drilling projects because they are more easily made and more stable in operation than electrodrills. But it is evident that a thermal drill is far less effective than an electrodrill. While the drills 140, 140 Mk II and 160 have never reached a drilling speed of 1.5 m/hr, a primitive 400-W electrodrill easily reached a speed of 10 m/hr. This means that if the electrodrill could take the same length of core in one cycle as the thermal drills, it would shorten the overall drilling time of 450 m by more than 250 hours. Thus, the development of a reliable lightweight electrodrill is desirable, especially if an effective way can be found of removing ice chips. As for cutters, those of the CRREL mechanical drill seem successful as was recently shown by the performance of the drill made in Iceland (Árnason *et al.*, 1974).


### Acknowledgments

Thanks are expressed to those who operated the drills in Antarctica and the Arctic, especially to Dr. H. Shimizu, Mr. T. Kimura, Mr. H. Narita and Mr. O. Watanabe, the leaders at Mizuho of JARE XI, XII, XIII and XV, respectively. Mr. T. Kimura designed the 1971 electrodrill. Special thanks are due to CRREL and ANARE for supplying the photographs and blueprints of the CRREL drill and the photographs of its Australian version, respectively, and also to Dr. K. Kizaki of Ryukyu University for obtaining them. Finally, thanks are due the Japan Polar Research Association for financial support to attend this symposium.


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