MECHANICAL DRILL SYSTEMS FOR THE 25TH JAPANESE ANTARCTIC RESEARCH EXPEDITION

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Abstract: Two light-weight mechanical drill systems, one capable of drilling down to 250 m and the other to 60 m, were developed for the use by the 25th Japanese Antarctic Research Expedition during its inland traverse. Also developed was a mechanical drill to back up 800-m thermal drilling at Mizuho Station. The design and specifications of the drills and winches are described.

1. Introduction

Glaciological activities of the 25th Japanese Antarctic Research Expedition (JARE-25) included two 200-m and many 10-m drillings during a traverse survey over East Queen Maud Land. Though the winch W-9-150 of JARE-21 (SUZUKI and SHIRAISHI, 1982) is still in use in Antarctica, its cable length is only 150 m. Hence, for the 200-m drillings, a new winch with 250-m cable, W-6-250, was designed. This is a component of the new light 250-m drilling system with the ILTS-130E drill of JARE-24 or the new ILTS-130F drill. On the other hand, the ILTS-100A drill was developed to replace the ILTS-140B, which had been used for 10-m drillings since 1981 (JARE-22). For use in 10-m drillings, the drill was suspended by a rope and powered through an independent electric wire. However, we provided a new winch with 60-m cable, W-5-60, in order to make a very light 60-m drill system.

Another important drilling operation by JARE-25 is the 500-m drilling at Mizuho Station. In 1983, using an 800-m thermal drill system, JARE-24 reached 414 m depth where the contraction of the bore-hole due to ice pressure became so strong that they were obliged to stop drilling for fear that the drill might be stacked. JARE-25 may be able to drill deeper with the thermal system by increasing the power supply and/or decreasing drilling speed so as to drill a larger hole*. However, an electromechanical drill is preferable to a themal drill at such a depth because the former has self-reaming ability. The ILTS-150A drill, to be suspended by the existing 800-m winch, is intended to drill a new deeper hole 152 mm in diameter taking a core 930 mm long in each run. It can also be used to ream the contracted 414-m hole to recover the original diameter of 172 mm or more in order to let the thermal drill start operation from the bottom of the 414-m hole.

In this paper, the design and specifications of three new drills and two new winches are described. Necessary references are made to other equipment.

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* Note added in proof: JARE-25 reached 700.63 m on August 1, 1984 with the thermal drill only.

2. Drilling Equipment Available for JARE-25

All drilling equipment available for JARE-25 is listed in Table 1. An individual code is given to every piece of equipment. In the code, the letter(s) stand(s) for the kind of equipment, the next two digits indicate the JARE number which procured it and the third is a serial number. A drill (a drive-unit with a suitable barrel and jacket set) may be referred by the code of the drive-unit like D231, D221, D251 etc. in the text.

The load capacity of the winches increases in the order of W252, W221, W251, W211 and TW. Any drill can be suspended by a stronger winch than the one originally assigned for it. For this purpose, suitable connectors were provided. The drill D253 can be suspended by either W211 or TW.

Table 1. List of available drilling equipment for JARE-25.

Item	Code	Type	Specification/Remarks
150-m system (Std. generator: 2 kW)			
Winch/Controller	W/C211	W-9-150	200V/1 kW: load 100 kg
Drive-unit (Drill)	D231	JARE-140C	200V/1 kW
Barrel/Jacket	B/J231		Std. core/hole dia. 105/146 mm
30-m system (Std. generator: 1 kW)			
Winch	W221		Manual: load 50 kg: cable 30 m
Drive-unit (Drill)	D221	ILTS-140B	100V/550W
Barrel/Jacket	B/J22		Std. core/hole dia. 105/146 mm
New 250-m system (Std. generator: 1.2 kW)			
Winch/Controller	W/C251	W-6-250	d.c. 100 V/600W: load 50 kg
Drive-unit (Drill)	D251	ILTS-130F	200 V/350 W
Barrel/Jacket	B/J251	Mk II	Std. core/hole dia. 107/133 mm
Drive-unit	D241	ILTS-130E	200 V/350 W
Barrel/Jacket	B/J241	Mk II	Std. core/hole dia. 107/133 mm
Barrel/Jacket	B/J242	Mk III	Std. core/hole dia. 109/133 mm
New 60-m system (Std. generator: 0.75 kW)			
Winch/Controller	W/C252	W-5-60	d.c. 100 V/300 W: load 25 kg
Drive-unit (Drill)	D252	ILTS-100A	100 V/350 W
Barrel/Jacket	B/J252		Std. core/hole dia. 81/107 mm
New large mechanical drill			
Drive-unit (Drill)	D253	ILTS-150A	d.c. 100 V/300 W
Barrel/Jacket	B/J253		Std. core/hole dia. 132/158 mm
Thermal 800-m system (Std. generator: 3ϕ 10 kW)			
Winch/Controller	TW/TC	W-12-800	3ϕ 200V/3.7+0.4 kW: load 150 kg
Large drill	TDL24/25		Heater O.D. 168 mm
Small drill	TDS24/25		Heater O.D. 140 mm

3. Description of the Drills

Several pioneering drills such as the U.S.A. CRREL drill (RAND, 1976) and the Swiss drill (RUFLI *et al.*, 1976) have established the basic design of a small electro-mechanical drill. The double tube type has a characteristic design in which the inner tube (a barrel) has drag cutters at its bottom and augers on its outer wall. The auger rotates inside the outer tube (a jacket) fixed to the drive-unit. Cuttings are transported upward by the augers through the clearance between the jacket and the barrel to the inlet at the top of the barrel and then are contained in the upper part of the barrel.

The first Japanese drill of this type was the JARE-ID-140 of JARE-20. The development from this unsuccessful drill to the successful 150-m system of JARE-21 (W211 and the drill JARE-140B) through the ILTS-140T drill (later reformed to D221) has already been published (SUZUKI and SHIRAISHI, 1982), in which the details of D231 (the improved version of the JARE-140B) were also described. Also briefly introduced in that paper were the ILTS-130 series drills with Mk I barrel and jacket. The details of them and of the improved barrels Mk II (B/J241) and Mk III (B/J242) (hence the drill D241) were presented at the International Symposium on Ice Technology, Calgary, Canada, 1982 (SUZUKI, 1984). The D251 drill is similar to the D241 while the D252 and D253 drills are its scaled-down and -up versions, respectively. However, as the publication of the proceedings of the Symposium is delayed, we summarize here the designs of the new drills again, describing their specifications in Table 2.

Table 2. Specifications of the drills.

Drive-unit					
Code	D231	D221	D251	D252	D253
Type	JARE-140C	ILTS-140B	ILTS-130F	ILTS-100A	ILTS-150A
Weight (kg):	44	20	10	6.2	13.2
Input (V)×(A):	200×9	100×9	200×3	100×6	100×6 d.c.
Output (kW/rpm):	1/10000	0.5/4000	0.35/20000		0.3/3000
Reducer Type:	Harmonic	Cyclo	Planetary		Planetary
Ratio:	100:1	40:1	5×5×5:1		5×5:1
Barrel and Jacket					
Code	B/J231	B/J232	B/J251(242)	B/J252	B/J253
Weight B/J (kg):	11/10	7/7	10/9(4/10)	2.2/5	12/11
Length B (m):	1.5	1	1.8(2)	1.5	1.8
Core length (m):	0.55	0.35	0.80(0.95)	0.60	0.93
Auger slope :	25	25	40(45)	45	35
No. of augers :	2	2	2	3	3
No. of paws :	4	2	4	3	6
Cutters, No. of :	4	2	4	3	3
Protrusions (mm):	2	2	0.96(1.07)	1.32	0.87
Std. rotation :	100	100	160	160	120
Speed (m/min):	0.8	0.4	0.61(0.66)	0.63	0.31
Basic diameters					
Std. core (mm):	105.0	105.0	107.0(109.0)	80.6	132.0
Barrel; inner :	110.1	110.3	111.1(113.0)	85.0	136.6
outer :	114.3	114.3	114.3(116.0)	88.0	139.8
Jacket; inner :	136.6	135.8	123.8	99.2	149.8
outer :	139.8	139.8	127.0	101.6	152.4
Std. hole :	146.0	146.0	133.0	106.6	158.0
Drill length (m):	2.3	1.6	2.2(2.4)	1.9	2.3
weight (kg):	65	34	29(24)	13.4	36.2
gross wt. (kg):	74	40	39(36)	18	53

Each drill consists of three parts: a drive-unit, a jacket and a barrel. The jacket is fixed to the drive-unit by screws, while the barrel is connected to the drive shaft of the drive-unit. One can quickly disconnect them for taking out a core and cuttings from the barrel.

The role of the drive-unit is to give adequate rotation (100 to 200 rpm) and necessary torque T (see later) to the barrel. For this purpose, the drive-unit has guide fins to counter the torque T* due to the reaction. The guide fins fit in four grooves cut on the hole wall by side cutters attached to the drill-unit to counter the torque (SUZUKI, 1978). It must be noted that while T is equal to the sum of three terms, T1 (the torque exerted by the barrel on the jacket), T2 (that on the wall of the hole) and T3 (that on the bottom of the hole), T* is the sum of T2 and T3 only. Though its main role is to secure the smooth transport of cuttings, which results in the decrease in the sum of T1 and T2, the jacket itself reduces T* because it reduces T2 by decreasing the exposed part of the barrel. To make T2 negligible, the jacket for all Japanese drills except the unsuccessful ID-140 was straight-ended and covered the barrel almost entirely.

The bottom of the jacket was apart from the top of the cutter holder by only 15 to 18 mm (see Fig. 1). This short distance proved enough for cuttings to enter smoothly into the clearance between the jacket and the barrel. For the upward motion through the clearance, the cuttings must slip against the augers, in other words, the jacket must hinder the rotation of the cuttings. For this purpose, a few aluminum tapes 0.3 mm thick and 10 mm wide were fixed with adhesive tapes on the inner wall of the jacket to form ribs of a finished height of about 0.7 mm.

The pipe clearance, or the difference between the inner radius of the jacket and the outer radius of the barrel, strongly affects the transport of cuttings. Its value for ILTS-130 Mk I (the outer diameters of the jacket and the barrel being 127.0 and 109.0 mm respectively) was around 7.5 mm depending on the thickness of the jacket. As can be seen from Table 2, the older drills have larger values while the new ones have smaller values of pipe clearance than that of the Mk I. In laboratory tests of drilling cold ice (-5 to -15°C) with the old drills including Mk I, cuttings filled the space between the barrel and the jacket and were hardly transported to the height of 1.5 m. On the other hand, cuttings from the new drills were transported so fast, probably either by air stream or by collision, that they did not remain between the barrel and the jacket. In a recent test, a standard 130 drive-unit (similar to the D241/251) with an elongated version of the Mk II 4 m long drilled ice as easily as with the standard the Mk II, showing that T1 was only a fraction of T3. In the test, the drilling speed of 0.01 m/s (corresponding to the barrel rotation of 160 rpm) was achieved by a power input of less than 400W to the drive-unit. The power input to the barrel was estimated to have a maximum of 250W, which corresponds to the 15 Nm torque for a rotation of 160 rpm.

The jackets and the barrels were made of the most easily available steel pipes in nominal inch sizes, except B241 and 252 which were made of aluminum pipes.

The augers were formed by fixing a high-density polyethylene belt (Solidur, made in West Germany) 3 mm (planed to 2 mm for B242) thick and 15 mm wide on the wall of the barrel pipe with adhesive tape, which was proven withstand water and also cold down to $-40°C$. The slope of the augers was 35° to 45° for the new drills, 25° to 30° for the old drills. After the augers were fixed, the remaining exposed part of the outer barrel wall was lined with adhesive film of Teflon 0.08 mm thick to improve the transport of cuttings.

The cutter holder at the bottom of the barrel was designed to hold three or four cutters to cut ice and three to six paws to break and retain the core. The cutter holder of B251 is shown in Fig. 1, in which the standard cutter (for B241/251/242/253) is also shown. As seen from the figure, for the edge angle of 35° of the standard cutter, the clearance is 25° and the rake 30°. The cutter holder of B242 has cutters of different shapes, with different values for those angles. The cutters are made either of sintering alloy, whose main ingredients are tungsten, cobalt and carbon (K-20: made by Mitsubishi Kinzoku Kogyo K.K.) or of high-speed steel with adequate heat treatment. The alloy cutters are less abrasive than the steel ones which are as

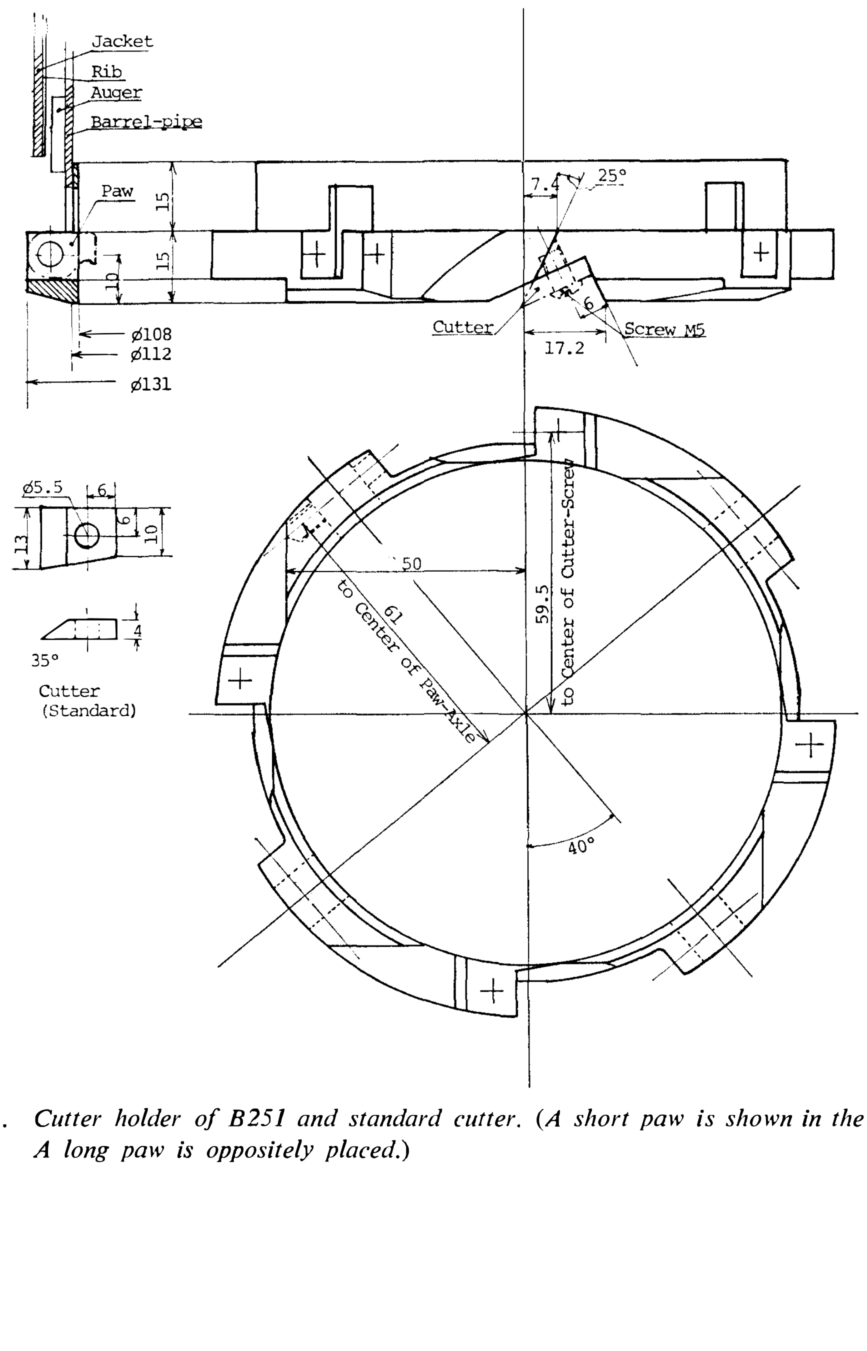

Fig. 1. Cutter holder of B251 and standard cutter. (A short paw is shown in the figure. A long paw is oppositely placed.)

efficient as the former while they are new. The 20-mm wide steel cutters were also provided for the B253 to ream the thermal hole.

The necessary strength of the drill, cable and winch depends on the necessary tension to be given to the drill to break the core. The tension, in turn, depends on the core diameter and the design of paws. Though we have not yet found any satisfactory design of paws, three paws 11 mm wide for the B252 (the core diameter: 82 mm), four for the B251 (108 mm) and six for the B253 (132 mm) seem to have reduced the necessary tension to less than 600, 1000 and 1500 N, respectively.

4. Winches and Controllers

Important characteristics of the winch cable to be used for a drill system are the tensile strength and the number and resistance of conductors. The first must be several times as large as the core breaking tension and the second must be enough to power and control the drill.

In the case of the JARE-140B drill (the original type of D/B/J231), the tension was assumed to be as large as 10000 N while the drive-unit required four conductors each for 10-A current and another two for control. Hence, for the W211 we used 9.53-mm cable with 7 conductors (Rochester Corporation 7-H-374A: sp. wt. 357 kg/km, breaking strength 52.5 kN: sp. resistance of each conductor 34.1 Ω/km). Because of the decrease both in tension and power for the D251 and D252 drills, we chose a 5.54-mm 4-conductor cable (4-H-218A: 122 kg/km; 19.6 kN; 84.3 Ω/km) and 4.65-mm cable (4-H-185A: 85 kg/km; 12.9 kN) for the W251 and W252, respectively.

The weight of 250-m of 4-H-218A is 30.5 kg while the gross weight of the D251 (core and cuttings included) is 39 kg. Hence, the W251 must hoist 69.5 kg at the maximum. The W251, driven by a 600-W d.c. motor, was designed to have a load capacity of 70 kg and a hoisting speed of 0.4 m/s. On the other hand, the weight of 60 m of 4-H-185A is 5.1 kg and the gross weight of the D252 18 kg. The W252 winch, driven by a 300-W d.c. motor, was designed to have a maximum load of 30 kg and a hoisting speed of 0.5 m/s.

Both of the winches were made as compact as possible. A harmonic drive reducer (CS-40-160 for W251 and CS-32-100 for W252) is incorporated in the cable drum. The reducers must withstand only the hoisting torque, because the core is broken by directly rotating the drum with a torque wrench.

The mast is made of FRP pipe 80 (W251) or 70 mm (W252) in outer diameter. As the mast can swing back, its effective height is the length of the drill.

The winch specifications are given in Table 3.

The circuit diagram of the C251 is given in Fig. 2, in which T1 is a variable transformer (output 0 to 130V) and T2 a 2 : 1 step-up transformer. In case of the C252, which is exclusively used for the 100-V drill D252, the transformer T2 and the switch S1 was omitted. When the switch S3 is in the stop position, the winch motor serves as a brake. One may control the lowering speed by switching S3 between the down and stop positions. The brake resistance should have been variable. Then, one can control the lowering speed more easily. For slow feed in drilling (0.01 m/s or less) by the C251/252, it must be done mannually.

Table 3. Winch specifications.

		W211	W251	W252	TW
Code	:	W211	W251	W252	TW
Type	:	W-9-150	W-6-250	W-5-60	W-12-800
Cable: Type	:	7-H-374A	4-H-218A	4-H-185A	
No. of conductors	:	7	4	4	1/7
Sp. resistance	(Ω/km):	34.1	84.3	84.3	20/65
Armor resistance	(Ω/km):	5.58	15.4	22.3	2.5
Diameter	(mm):	9.53	5.54	4.65	11.8
Strength	(kN):	52.5	19.6	12.9	400
Sp. weight	(kg/km):	357	122	85	500
Length	(m):	150	250	60	800
Motor: Input	(V):	200	100 (d. c.)	100 (d. c.)	200 (3φ)
Output power	(kW):	1.0	0.6	0.3	3.7+0.4
Drum: Dia. (m)×width	(m):	0.36×0.32	0.26×0.2	0.24×0.14	
Load	(kg):	150	70	30	100
Hoisting speed	(m/min):	25	24	30	60
Weight: Cable	(kg):	54	31	5	400
Main frame	(kg):	96	25	15	800 (est.)
Mast ass.	(kg):	31	10	7	300 (est.)
Total weight	(kg):	181	66	27	1500

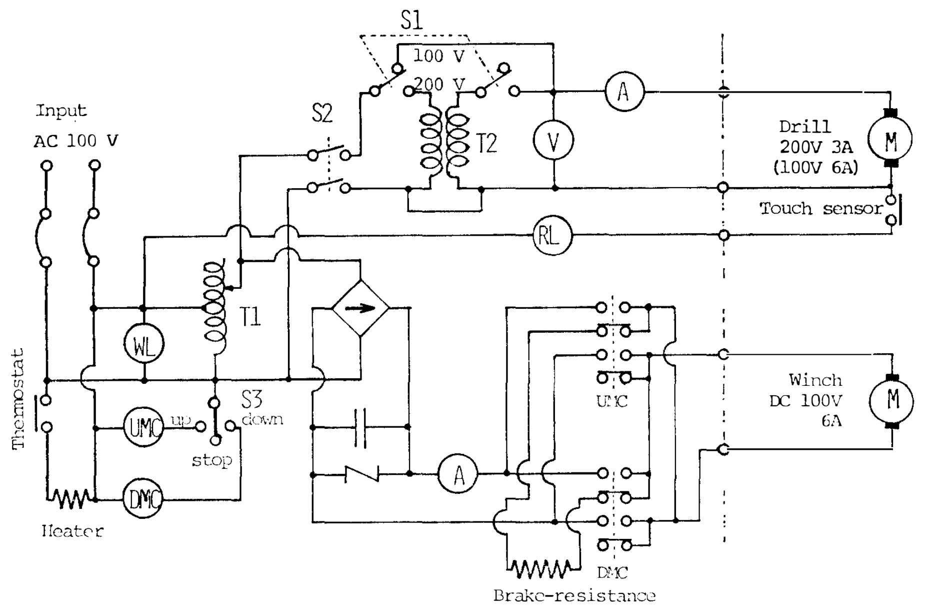

Fig. 2. Circuit diagram of C251.

5. Concluding Remarks

The new drills can drill ice with less power and take longer cores than the 130 Mk I and other old drills. The improvement has been achieved mainly due to the narrower pipe clearance and may be partly due to the steeper slope of the augers and the Teflon lining.

In the laboratory tests, an elongated version of the B/J251, 4-m long, successfully drilled ice at a speed of more than 0.01 m/s, transporting cuttings as easily as the standard D/B/J251. An 8-m long barrel, capable of taking a 4-m long core in one run, is now quite feasible.

Hitherto, in drillings deeper than 300 m, a thermal drill has been favored over a CRREL-Swiss type drill because the former can take a longer core. Now, with a

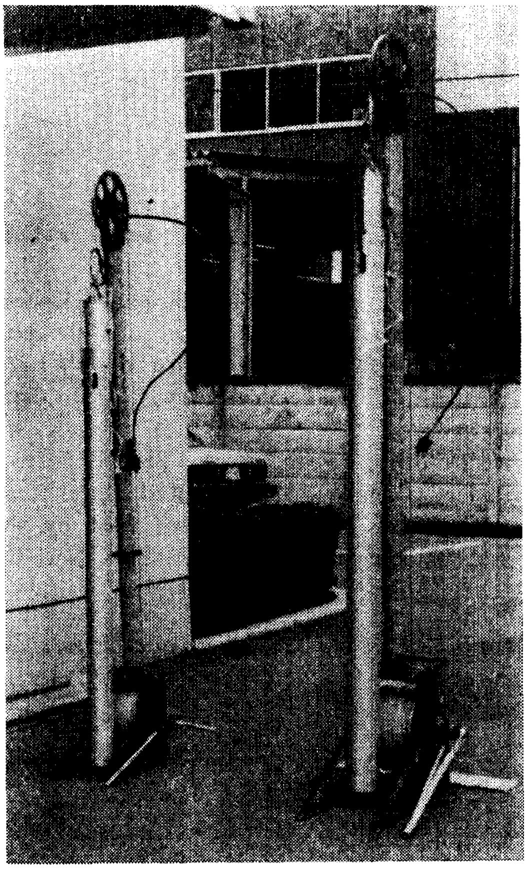

Fig. 3. Drills suspended by winches: D/B/J/W252 (left) and D/B/J/W251.

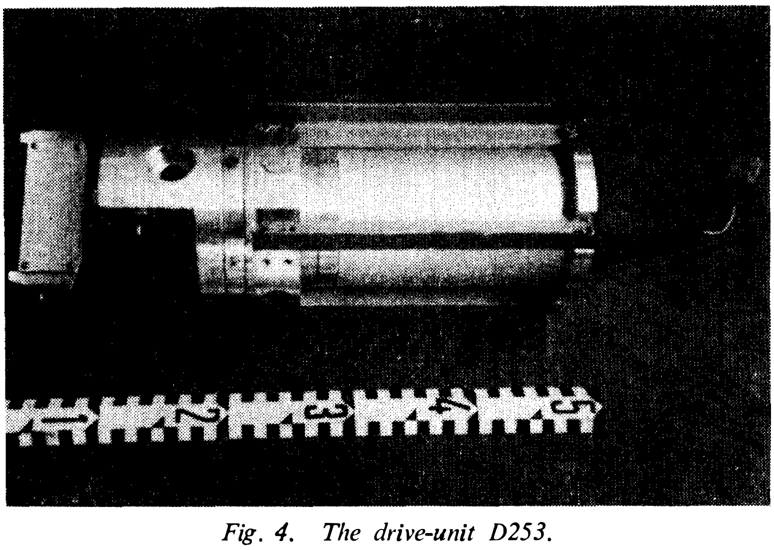

Fig. 4. The drive-unit D253.

4-m core having become feasible and a 2-m one quite practical, the light mechanical drill described above will compete with a thermal drill in dry drillings at any depth. Augers may transport cuttings even in a liquid-filled hole. We are now planning to test the drills in a kerosene-filled hole.

The winches are not yet developed so satisfactorily as the drills. Their lightness and compactness sacrifice durability and capacity.

According to Dr. H. NARITA of JARE-24, the D241 suspended by the W231 successfully drilled several holes deeper than 100 m. We are waiting for the report on the performance of the new systems.

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