LIGHT WEIGHT ELECTRO-MECHANICAL DRILLS

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ABSTRACT

The ILTS-130 series, light weight electro-mechanical core drills, have been operated in various locations. Some are as short as 1.4 m and as light as 20 kg, yet capable of taking a 0.4 m length ice core in one minute, with a power input of 400 W. They are suitable for drilling to 30 m depth.

An extended version, 2.4 m in length and 28 kg in weight, took a 1 m length ice core in 2 minutes, during a laboratory test. This drill will be used in 1983 in Antarctica to replace the JARE-MID-140B drill, which, in 1980, cored a 100 m hole in 44 h and another 143 m hole in 81 h.

The basic design of the ILTS-130 series is described. Suggestions for further improvement and comments on planning a drill system are also included in the paper.

INTRODUCTION

For a drilling operation to be carried out by a small party with limited logistics, an electro-mechanical drill is superior to a thermal drill, because the former consumes much less energy than the latter. Several pioneering drills such as the Icelandic drill (Árnason, *et. al.*, 1974), the USA CRREL drill (Rand, 1976) and the Swiss drill (Rufli, *et. al.*, 1976) have established the basic design of the small electro-mechanical drill.

The Japanese Antarctic Research Expedition (JARE) had a requirement for a drill system to core a 150 m hole. For this,the basic electro-mechanical drill unit was selected.

Although the first drill unit only reached 64 m (Ikami, *et. al.*, 1980), the second system was successfully used by JARE-21 to core a 100 m hole in 44 h and another 143 m hole in 81 h in 1980 (Suzuki and Shiraishi, 1982).

The second drill system consists of the following components: the core drill (JARE-MID-140B; 65 kg), a winch with a 150 m armored cable (W-9-150)(195 kg), a 2.8 kW generator (70 kg) and a controller unit (20 kg). The winch and the generator are mounted on a sled towed by an over-snow vehicle. The complete system may be set up and operated by 3 persons.

In the course of developing the two systems, a short test drill, 1.6 m in length and 30 kg in weight (ILTS-140B) was made. Slightly modified, it was later used in Antarctica to bore holes down to 30 m. The drill was suspended by either a manual or an electric winch and tower system with steel wire, while power was fed through an independent power cable via a controller from a 1.2 kW generator (35 kg). The total weight of the system, including a tripod, was less than 100 kg.

The ILTS-130 series, light weight drills were designed when the Water Research Institute of Nagoya University required a drill to be used on the Himalayan glaciers. Primarily intended for use in high mountains, they are short and light. Of the four drills (ILTS-130A,B,C and D) equipped with the Mk I (1 m) barrel, model D is only 1.4 m long and weighs 19.8 kg. Combined with a commercially available light winch (300 Watts, 4 mm ϕ x 30 m cable), a 650 W generator, a tripod and a 30 m electrical cable, it is a light weight system, that may be back packed by three people.

Various field tests have proven the practicability of the drills. Model A has been used on a Himalayan Glacier, where a depth of 33 m was reached. Model B was used at Halley Bay, where a depth of 22 m was reached. Model C was used to core to a depth of 22 m in silty ground ice at Tuktoyaktuk, N.W.T.

These drills transported chips so easily, that an improved 2 m long barrel and corresponding jacket was fabricated. This Mk II barrel was laboratory tested. It took a 1 m core in under 2 minutes.

A fifth drill, ILTS-130E, will be equipped either with the Mk II barrel, or a Mk III to be made. This unit, with the W-9-150 winch, will be used in the Antarctic in 1983.

A 200 m drill system weighing less than 100 kg will be made for use in Antarctica in 1984.

The ILTS-130 series drills have the same basic structure, consisting of the drive unit, the barrel and jacket. They are derived from the earlier drills already described by Suzuki and Shiraishi, (1982). Table 1 summarizes the specifications of the different drill series.

DRILL STRUCTURE

Drive Unit

The center piece of the drive unit is the main shaft housing, which also houses the side cutter assembly. The jacket is fixed to the housing, while the barrel is connected to the lower end of the main shaft by an adapter. The power unit is mounted directly onto the housing, except in the MID-140B, which has an independent base for its power unit. The shaft is capable of sliding 30 mm relative to the housing, thus allowing the power section to hammer the housing when breaking core, in a similar way to the Danish drill (Johnsen *et. al.*, 1980).

Side Cutters

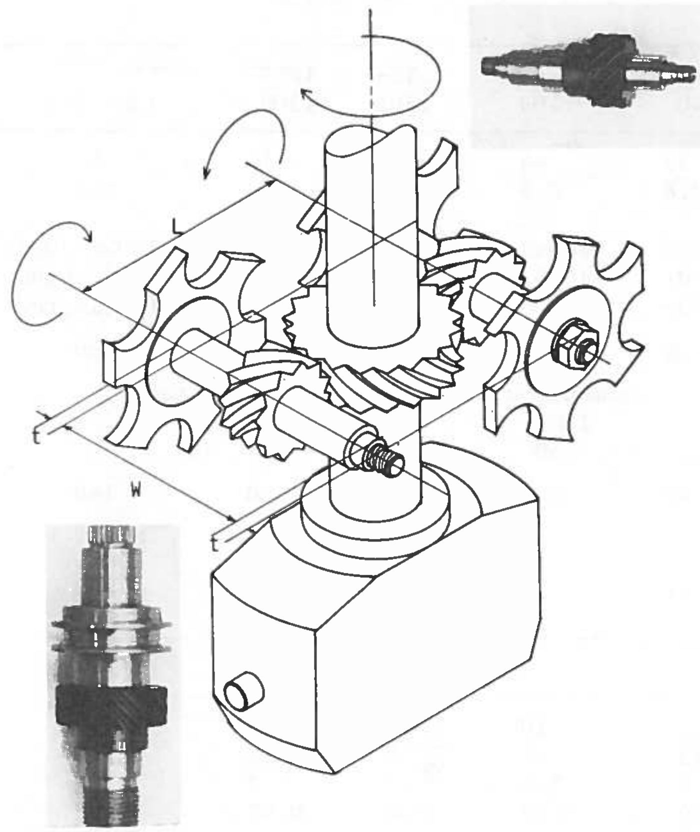
An electro-mechanical drill must counter the torque exerted by the action of its cutters. Two anti-torque devices were proposed: the side drills and the side cutters (Suzuki, 1978). Tests showed the former to be impractical, but the latter to be very effective. This device was then installed in all later drills.

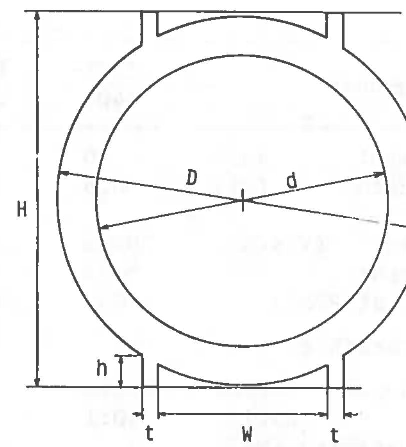
As shown in Fig. 1, three 45° spiral gears, transfer the main rotation to two horizontal axes of the side cutters, to make four grooves on the hole wall.

The guide fins placed in alignment with the side cutters, fit the grooves with a bottom clearance of 1 mm and a side clearance of 0.25 mm. The guide fins help the side cutters counter the torque. Some typical dimensions of the grooves are shown in Fig. 1. The cross-sectional area of the grooves is only a few percent of the main annular area. The short (10 cm long) guide fins of the ID-140 failed once in the JARE-20 operation when both the guide fins and the cutters were in a very weak depth-hoar layer. The guide fins lost alignment with the grooves and the drill became stuck. As a result of this. the fins were lengthened on later drills. In addition, the MID-140B was equipped with free-wheeling safety cutters behind its guide fins. These would cut new grooves for escape when a mis-aligned drill was pulled up. However, with its long fins, the MID-140B never mis-aligned in the JARE-21 operation, so for simplicity, the safety cutters were eliminated on the ILTS-130 series drill. The guide fins improve the straightness of the hole, while the side cutters either increase (by the use of the left-handed gears, as shown in Fig. 1) or decrease (by the use of the right-handed gears), the thrust on the barrel. For the ILTS-130 series drills the left-handed gears are appropriate.

Quick Barrel Releaser

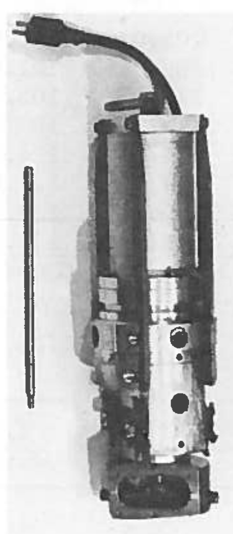
The MID-140B and the ILTS-130 series drills were equipped with a quick barrel releasing mechanism (in the same manner as the Swiss drill) to allow barrel release irrespective of barrel orientation. A release ring, which can slide over the main shaft, is linked to a release shaft inside a center hole of the main shaft by a pin, through slits on the main shaft. The release shaft, in turn, is linked to joint pins in the connecting plug through a pantograph mechanism. A spring inside the main shaft pushes the release ring to its lower position, so that the joint pins pro-





		MID-140B	ILTS-140T	ILTS-130A	ILTS-130C	ILTS-130E
L	(mm)	82.8	82.8	70	70	70
W		73	74	64	64	64
t		6	6	5	5	5
H		142.8	162.8	130	134	132
h		12.0	22.4	9.7	11.7	10.7
D		146	146	133	133	133
d		105	105	101	101	107
A_g	(mm^2)	243	491	164	204	184
A_r		8083	8083	5881	5881	4901
A_g/A_r	(%)	3.0	6.1	2.8	3.5	3.8

Figure 1. Drive mechanism for side cutters and the cross-section of the hole for the different drill series. A_g and A_r are the areas of the grooves and the annulus.



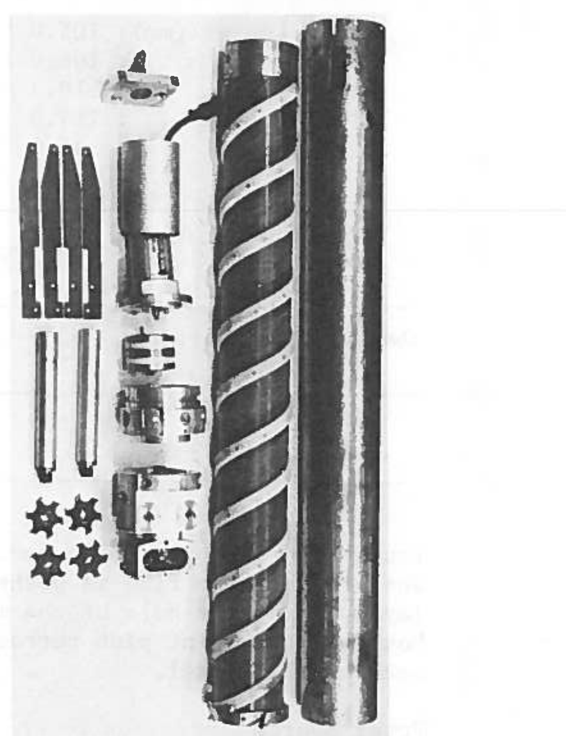


Figure 2. Left: MID-140B drive unit.
Center: ILTS-130C drive unit, and barrel quick-release lever (bar).
Right: Main components of the ILTS-130C drill unit.

Table 1. Specification of the drills

Drive-unit	ILTS-140T	ID-140	MID-140B	ILTS-130A	ILTS-130B	ILTS-130C/D,E
Weight (kg):	20	55	44	19	10	9
Length (m):	0.6	0.8	0.8	0.5	0.5	0.4
Input (V)x(A):	100x9	200x4	200x9	200x9	100x4	100x6/200x3
Output (W/ at RPM):	500/ 4000	450/ 10000	1000/ 10000	450/ 10000	220/ 15000	350/20000 (estimated)
Reversible?	no	yes	yes	no	no	no
Reducer Type:	Cyclo		Harmonic drive		Planetary	
Ratio:	40:1		100:1		5x5x5:1	
Capacity (Nm):	n.a.		50		30	
Main rotn. (RPM):	100	100	100	100	120	160
Cutters(Number):	2	2	2	4	4	4
Protrusion (mm):	2	4	4	2	0.9	0.9
Drill rate (m/h):	24	48	48	48	26	36
Barrel and Jacket				Mk I A/B/C/D	MK II	MK III
Jacket weight (kg):	7	12	10	4/6/4/5	10	10
Barrel weight (kg):	7	13	11	7/7/7/6	10	4
Barrel length (m):	1	2	1.5	1	2	2
Core length (m):	0.35	0.80	0.52	0.40	0.92	0.96
Auger slope (°):	25	30	25	30	40	45
Number of augers :	2	2	2	2	2	2
No.of vert. pawls :	2	2	2	4	4	4
No. of horiz. pawls:	0	2	2	0	0	0
Core diameter (mm):	105.0	107.0	105.0	101.0	107.0	109.0
Holder I.D. :	106.0	108.0	106.0	102.0	107.6	109.7
Barrel I.D. :	110.3	110.1	110.1	105.0	111.1	113.0
O.D. :	114.3	114.3	114.3	109.0	114.3	116.0
Jacket I.D. :	135.8	131.0	136.6	124.6*	123.8	123.8
O.D. :	139.8	135.0	139.8	127.0	127.0	127.0
Holder O.D. :	142.0	137.0	140.0	129.0**	130.0	130.0
Hole diameter :	146.0	140.0	146.0	133.0	133.0	133.0
Overall dimension				A(B)	C,D	E with Mk II (III)
Length (m):	1.6	2.8	2.3	1.5	1.4	2.4
Weight (kg):	34	80	65	30(23)	20	29(23)

*B: 123.0, D: 123.8 ** C, D: 130.0

trude from the plug to connect the barrel. When the release ring is pushed up by a lever, through a hole of the main shaft housing, the joint pins retract, disconnecting the barrel.

Power Source

Because of their light weight, series commutator motors of high revolution were used on all the drills, together with a high ratio reducer, to give a barrel rotation of about 100 RPM. The power source specifications are shown in Table 1.

The poor performance of the ID-140, due to its very poor chip transportation was wrongly interpreted as being due to the weakness of its 450 W motor. The MID-140B was then equipped with a 1 kW motor. However, the reducer (CS-25-100-GSPS, manufacured by Harmonic Drive Systems, K.K.) with a maximum output torque of 50 Nm, was unchanged, because no stronger reducer of the right size was available. The reducer was broken twice in the JARE-21 operation. The motor activated the horizontal pawls (described later) and the allowable torque on the reducer was exceeded. In drilling normally, a power of 450 W is adequate, so the 450 W motor was reused for the ILTS-130A unit without horizontal pawls. Motor power was further reduced on the later drills because they produced lower drilling rates, which gave improved core quality. Three 5:1 planetary reducer components (LUG-75-5MAD, -5MLD and -5MLG8: made by Matex K.K.) were used to get a final ratio of 125:1 at an output torque of 30 Nm. The combined dimension of the three components and the three spacers is a height of 53.2 mm. The diameter is 75 mm and the weight 923 g. A single 128:1 harmonic component (CS-20-128), with the same output torque, is 70 mm in diameter, 45 mm in height and 400 g in weight. Though a little bulkier and heavier, the planetary reducer was chosen because of its high efficiency (90 % in three stages, against 70 % for the harmonic reducer) and its ease of coupling to the input axle with a D-shaped shaft end and to the output axle with a serrated end.

Because of its small diameter (80 mm OD) and weight (1.2 kg) and easy availability, a motor taken from a disc grinder (PDA-100B; made by Hitachi Koki, K.K.) is now used on the ILTS drills. The motors are rated at 600 W at 100 V or 200 V. Its rotation is so high, that the main shaft rotation of the ILTS-130C with the 100 V motor, reached 160 RPM at 70 V, without the barrel and 145 RPM at 90 V when drilling in ice. The input current was about 4.5 A. It is recommended that the current be kept below 70 % of the rated value.

In order to activate the horizontal pawls, the JARE drill motors can be reversed by surface control. The ILTS-130 drills have no such function.

Jacket and core barrel

Clearances. The chip transport ability of a drill seems to depend strongly on (1) the clearance between the jacket and the core barrel (the barrel clearance) and (2) the clearance between the hole and the core (the cutter width). The clearance between the core and the inner barrel (the core clearance) and that between the jacket and the hole (the hole clearance) must be sufficient to ensure smooth entrance of core into barrel and jacket into hole, respectively. Their values may be calculated from Table 1.

The barrel clearance and the cutter width on the ILTS-140T were chosen as near to those of the USA CRREL drill as possible: 10.75 mm and 20.5 mm respectively, while the core clearance and the hole clearance of the former are 2.6 mm and 3.1 mm respectively, both larger than the CRREL drill.

In order to decrease the cutting torque, the barrel clearance was reduced to about 7.4 mm on the ILTS-130 A to D drills (Mk I barrel and jacket). Since the chips were still easily transported, a further reduction of the barrel clearance is being tried on the ILTS-130E: to 4.75 mm in the Mk II and to 3.9 mm in the Mk III barrel and jacket. In laboratory tests, the Mk II easily transported chips along its 2 m length for cold ice but some problems exist if the ice is wet.

For the ILTS-130 drills, a core clearance of 2 mm is sufficient, but the hole clearance must be at least 3 mm for a jacket of seamed steel that has not undergone special shaping treatment.

Jacket. The two important roles of the jacket are to reduce the torque exchange between the barrel and the hole wall, and to secure smooth transport of chips. For the first role, the jacket should cover the core barrel as completely as possible. The jacket of the ID-140 had a few deep notches at its base, as they had been considered necessary for preventing chips from packing there, and straying into the hole clearance. Such prevention is a prerequisit condition for the second role. As the tests with the ILTS-140T drills showed the notches to be unnecessary, the later jackets are straight ended. The length of the ILTS-130 jackets is such that its base is about 3 cm above the upper surface of the cutter shoe. The distance of 3 cm, or ten times the hole clearance, seems necessary to prevent chips from straying into the hole clearance.

For chips travelling into the barrel clearance to be transported upwards by the auger flights, the jacket should prevent their rotation. For this purpose, either ribs were attached to the inner jacket wall (as on the CRREL and Swiss drills) or grooves were cut on the inner wall (as on the Danish drill). Three steel ribs were welded onto the inner wall of the MID-140B jacket, resulting in large distortions of the jacket, which had to be straightened. On the Mk I and the Mk II jackets, aluminum strips, 10 mm wide and 0.3 mm thick were fixed with 0.5 mm thick adhesive tape, making the ribs of finished thickness 0.7 mm. From three to six strips were installed. The tape, a type used in carpet joining, was found to withstand water and temperatures as low as -40°C. On the Mk III jacket, with a tube clearance of only 3.9 mm, strips will be replaced by grooves.

Core barrel. The cutter shoe is attached to the lower end of the barrel. This assembly for the ILTS-130C and the MID-140B is shown in Fig. 3. The latter cutter shoe assembly would occasionally jam in ice, produce bad core quality and fail to break or hold core (Suzuki and Shiraishi, 1982). Anti-torque failure was attributed to sticking of chips at the base of the shoe. Its shape was therefore changed in order to have a lower diameter at the base of the shoe. The horizontal pawls were abandoned because of their ineffectiveness. In comparison, the available force for activating vertical core breakers is about 30 times more. The much improved ILTS-130 shoe has four cutters and four core breakers. The latter successfully broke core at forces less than 2000 N. However, for holding firn cores, longer pawls of modified shape are needed. These have been fitted on the ILTS-130E shoe.

Only two auger flights are used, even with the four cutters. No difficulties were encountered with this arrangement. On the Mk I barrel, two polyethylene spiral strips (Somarite; manufactured by Somar Kogyo K.K.) 20 mm wide and 6 mm thick, were fixed to the barrel by screws. Their slope angle was 30°. The barrel was then machined to 120 mm OD, to make the clearance between the auger and the vertical strips about 0.8 mm to 1.5 mm. On the Mk II and Mk III

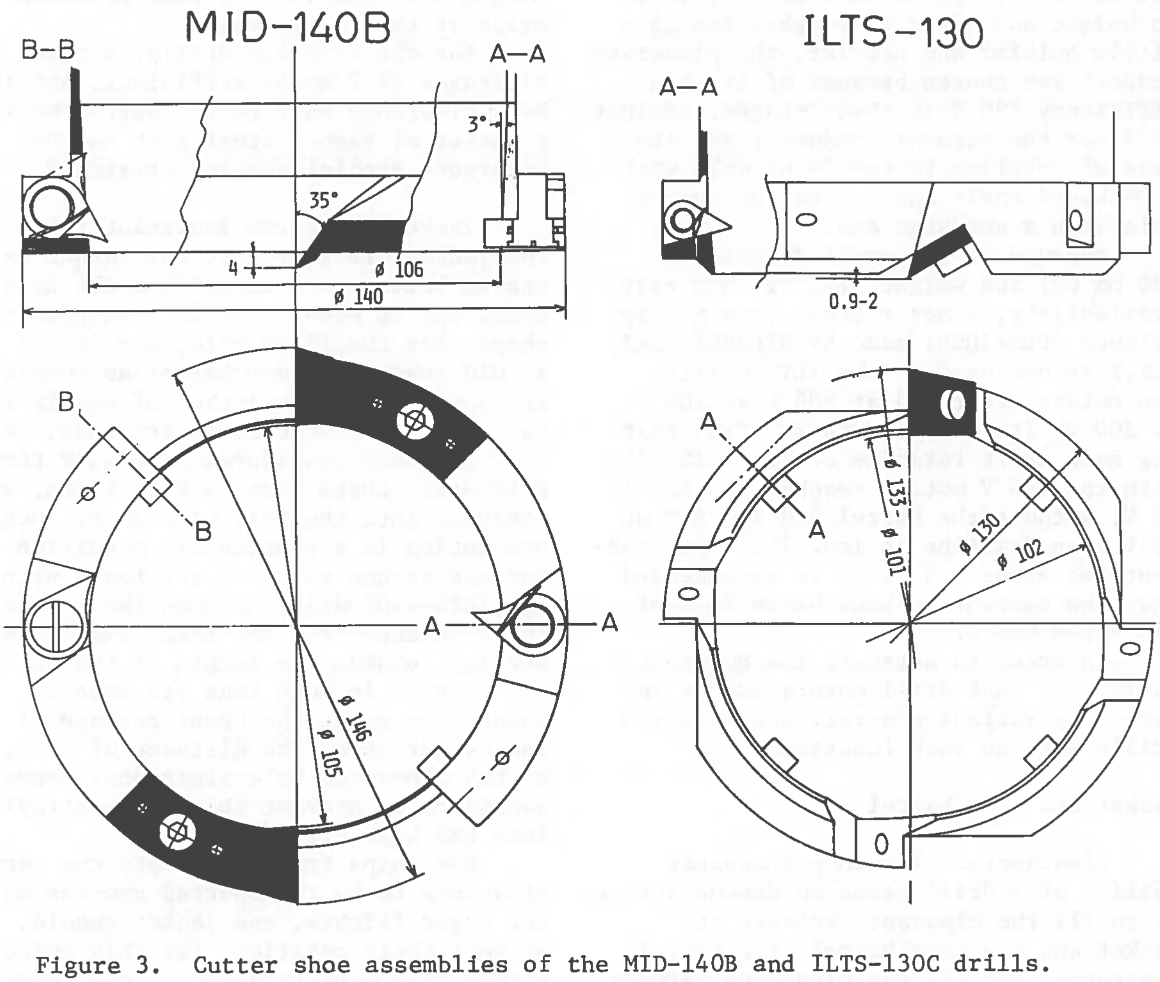


Figure 3. Cutter shoe assemblies of the MID-140B and ILTS-130C drills.

barrels, polyethylene spiral strips made of Solidur (manufactured in West Germany) 19 mm wide and 3 mm thick, were fixed in place with the adhesive tape used for attaching the vertical strips. Various auger slope angles up to 60° will be tried as fabrication is simple.

Cutters. The standard shape of the ILTS cutter is very simple: a flat, almost rectangular piece with one edged side as seen in Fig. 3. The Mk I and Mk II holders determine the bottom clearance angle as 30° and 25° respectively, while the Mk III holder, to which the cutters are reversely fixed, determines the back-rake angle as 40°. Cutters of hardened steel with various included angles varying from 30° to 50° have been supplied for the Mk I holder. The 45° cutters worked well for cold ice and firn but for drilling in wet ice, 30° angle cutters were necessary. Steel cutters are completely useless when drilling in ground ice with only a few percent by weight of silt present. Special cutters with a tungsten carbide tip were effectively used there. The clearance angle used was 15°.

Recently, tungsten-cobalt-carbon cutters with edges shaped by sintering have become available (K-20, made by Mitsubishi Kinzoku Kogyo K.K.). Cutters with included angles of from 30° to 50° are now being laboratory tested.

DESIGN SUGGESTIONS

The Anti-torque System

Escape device. When a drill with this system is to be used in an area where the drill may jam, it must have an escape device, such as the free wheeling safety cutters of the MID-140B. Motor driven safety cutters, not yet tested, may also be employed. A better solution is to make the guide fins retractable.

Extension unit. When passing through a thick weak layer of snow, where the drill rotated during the preceding run, the anti-torque system must be extended to bridge the thickness of the layer. (This idea was originally suggested for the Swiss drill by H. Rufli). Auxiliary fins may also be temporarily placed above the guide fins.

Deep drilling. Where a cased hole is used, the pipe must have appropriate grooves for the guide fins.

Gravity drive. For a heavy drill, gravity driven side cutters (an application of the free wheeling cutters) may be worth consideration.

Drill Strength

Because it has been established that with the proper core breaker design, tensile forces of less than 2000 N are required to break core and torques less than 30 Nm are sufficient to cut the ice, the design strength values, especially of the barrel, may be reduced accordingly. The 2 m, Mk III, barrel will be made of 1.5 mm thick aluminum tube (1.46 kg/m). The 1.2 mm thick steel jacket of the ILTS-130A and C might not be sufficiently rigid, and could be replaced by an aluminum tube 2 to 3 mm thick.

Load Sensor

Because of their simple construction and reliable anti-torque system, the drills were not fitted with any monitoring devices. The torque and barrel rotation speed were estimated from the input current and voltage observed at the surface. A simple load sensor will be installed on the ILTS-130E unit. The signal will be frequency modulated and transmitted through conductors in the cable.

Hole and Core Size

Small sized core is attractive, because of its ease of breaking after a run. However, larger core may be necessary for reasons related to analyses to be made on the core. Some adopted (and suggested values) for the core, hole, inner barrel, and jacket diameters (in mm) are: (70, 95, 76.2,88.9); (82, 107, 88.9, 101.6); (95, 120, 101.6, 114.3). A drill with the second set of values has been made and tested.

Armored Cable

The cable should be able to sustain a load of 2000 N and supply to the drill a current of 3 A (at 200 V) or 6 A (at 100 V). Suggested cables are Rochester 1-H-126K (3.18 mm ϕ, 41.7 kg/km, 6.67 kN tensile strength) for a 50 m system, and a 1-H-181K (4.72 mm ϕ, 95.4 kg/km, 15.8 kN tensile strength) for a 200 m system.

DESIGN OF A DRILL SYSTEM

The following equations will provide a guide for the design of the drills.

The time, t, required to drill to a depth D is

$$t = (D/L)(L/v + D/V + t_o) \quad (1)$$

where L is the core length, v is the drilling rate, V the winching rate and t_o is a time constant dependent on the system design and the ability of the drillers. For a small system, a value of t_o of several minutes is possible.

The barrel length, L* and the core length, L are related by the equation:

$$k\, L\, (h^2 - c^2) = (L^* - L)\, d^2 + P \quad (2)$$

where k is the ratio of the density of ice against that of stored chips, h is the hole diameter, c is the core diameter, and d is the barrel inner diameter. P is a correction term for chips stored in the clearances. Putting $2w = (h - c)$ and $2(r + d) = (h + c)$, taking $k = 2.5$ and neglecting small terms, the following simple and reliable relationship is derived:

$$L^*/L = 1 + 10\, w/d \quad (3)$$

where w is the cutter width. For usual values of w and d, L*/L has a value of 2 to 3.

For decreasing t, L is usually increased, but one must be sure that the drill can transport chips to a height L*.

The necessary motor power output, P*, of the drill is estimated from

$$P^* = E\, A\, v \quad 4)$$

where E is an energy per unit volume (taking typical values of from 5 to 7 MJ/m^3) and A is the cutting area (m^2). A very efficient drill may be associated with a value of E as low as 1 MJ/m^3 (Mellor and Sellmann, 1976).

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