A SIMPLE HOT-WATER DRILL FOR PENETRATING ICE SHELVES

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A simple hot-water ice drill capable of making holes 20 cm in diameter through ice at least 50 metres thick was designed at the Defence Research Establishment Pacific and tested on the Ellesmere Island ice shelves. The drill is built primarily with commercially-available equipment, the amount of in-house construction being kept to a minimum. Using readily available fuel, Arctic diesel or turbo fuel, a hole through the 50-metre-thick shelf was drilled at a rate of 11 m per hour. The paper discusses the drill construction and tests, and indicates a number of weak points in the design.

I. INTRODUCTION

A simple hot-water ice drill capable of penetrating the 50-metre-thick ice of the Ice Shelves on Ellesmere Island, has been designed, built and tested by the Arctic Acoustics Group at DREP. Because of the size of the equipment we wished to lower below the ice, it was necessary to develop a technique for drilling holes at least 20 cm in diameter. It was decided that a hot-water drill, although it would not penetrate as fast as a mechanical drill, would be lighter, less expensive and less complicated to operate in the field.

II. THE DRILL

Basically, the drill consists of a water heater, a water pump, a hose to feed the water down the hole and a hose to recover it. In order to reduce the suction head, the hole is kept full of water as long as possible. The ice is quite impermeable, and the head of water is maintained until the drill runs into cracks or porous ice near the bottom of the ice. At that point, the water level in the hole drops to the ambient level of the ocean, the free-board being some 10% of the ice thickness. The diagram in Figure 1 shows a schematic layout of the drill. It indicates that the water may be routed either to the ice hole or to a snow melter, and it may be picked up from either of the two. This flexibility is required because the water to start the procedure is made by melting snow and because it is necessary to top up the water in the hole from time to time.

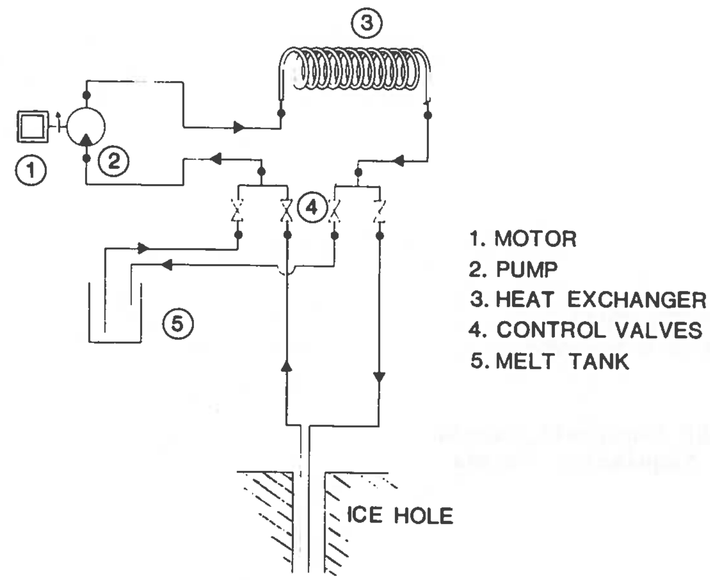

Figure 1. Schematic diagram of the hot-water drill. The pump draws the water from either the ice hole or the snow melter (#5). After the water is heated it can be directed, by means of valve setting, back to either location. The snow melter, which can be heated separately, is used to generate enough water to begin the drilling operation. It is then taken out of the circuit, and the hole drilling begins.

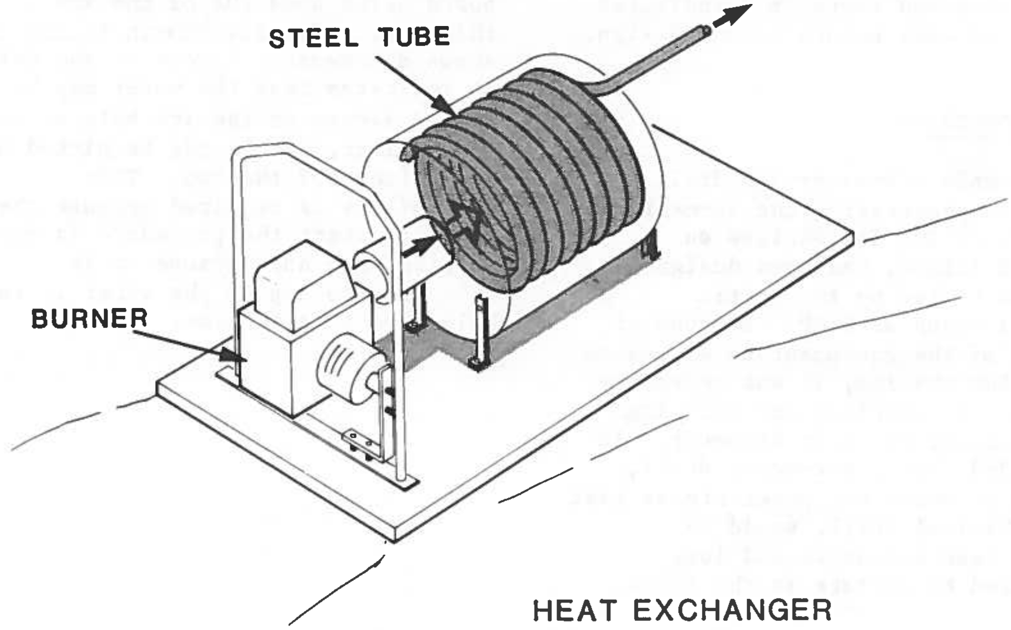

Figure 2. An illustration of the water heater. Either diesel fuel or turbo fuel (JP-4) can be used to supply the heat. The total weight of the unit is about 150 kg.

a. Water Heater

The water heater is a commercial APEX steam generator purchased from Northwest Malsberry, Seattle. It consists of a coil of steel tubing (1/2 in. sched 80), which acts as the heat exchanger, and a burner unit that is similar to those found in a house furnace (Figure 2). It puts 235,000 BTU/Hr (68.9 kW) of heat into the water when a fuel nozzle rated at 3.5 US gal/Hr is used. The actual fuel consumed was 3.2 US gal/Hr (12.1 l/Hr) of turbo fuel (JP-4) which has a heat content of approximately 3.2 x 135,000 = 432,000 BTU/Hr (126.6 kW). This implies the heat exchanger has an efficiency of .54.

A propane-fired water heater was also tested at the laboratory and in the Arctic. It was the 'Nordic' model, made by Edvan Agencies in Vancouver, B.C. Its heat-exchanger coil was copper tubing, and the unit was much smaller and lighter than the steam generator (35 kg vs 170 kg). In spite of this very real advantage, it was not used for drilling holes on the ice shelves. It would produce only 97,000 BTU/Hr (28.4 kW), which is less than half of that produced by the oil-fired unit. Also, propane is a fairly exotic fuel in the Arctic, whereas diesel fuel and JP-4 are very common. Propane fuel tends to be cumbersome because the empty tanks are so heavy. Another objection is that the propane tank must be heated in the cold weather to assure a sufficient flow of gas. (This was done with waste heat from the heater.) However, the unit did work well, and, if a future application demands a lightweight water heater instead of high heat output, and if the heavy propane tanks are not a problem, the propane heater would be the one to choose.

b. Snow Melter

A supply of water is required to fill the hoses and heat exchanger so that the drilling process can begin. The snow melter shown in Figure 3 is simple, light and reasonably efficient. It consists of two concentric barrels. The snow is melted in the central drum, and the flames from the burner rise up the gap between the drums. The water is removed through a plumbing fitting and valve at the bottom. The fuel burner, which was designed for easy attachment, is the same unit as is used on the main heat exchanger.

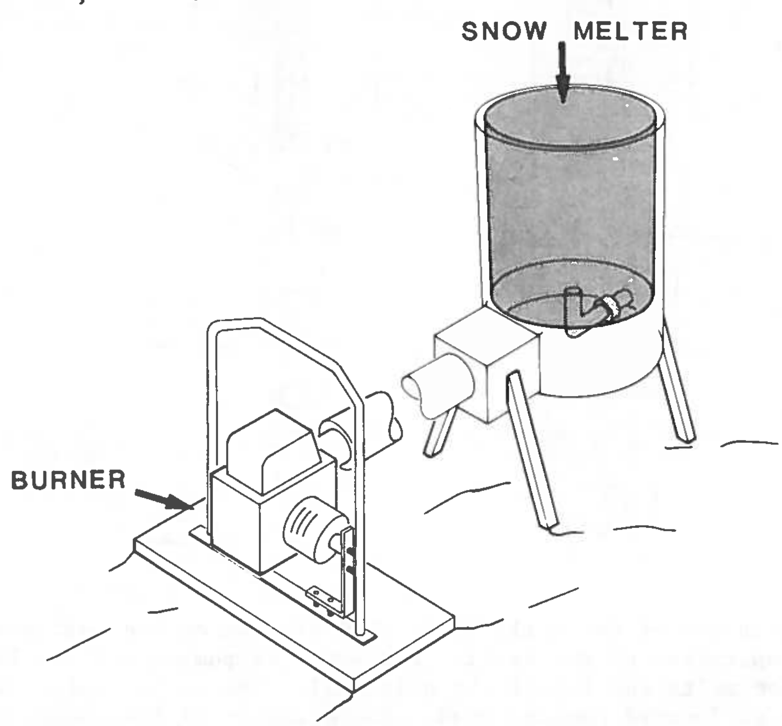

Figure 3. A snow melter for creating the initial water to start the hot-water drill. The snow is melted in the inner tank of two concentric tanks. The outer tank is present to guide the hot air around the melting tank. The burner was the same unit as was used with the water heater.

c. Drilling Head

The drilling head is shown in Figure 4. It consists of a 1.5 metre length of 1 inch plumbing pipe with a 20 kg weight attached to it. Screwed to the top of the pipe is an attachment that picks up the return water and feeds it to the 'return' hose. Also, it prevents the pipe from descending until the ice supporting it has melted; it thus ensures a minimum diameter for the hole.

The simple length of pipe seems to work as well as other more elaborate drilling heads that were designed and tested. A high-speed jet of water is capable of sinking a smaller hole at a greater speed. But, because a fairly large hole was desired, the jet nozzle and associated high-pressure pump were not required. It was found that a shorter length of pipe was not as successful as the 1.5 m length. With a short pipe, the hot water did not have sufficient time to lose its heat to the ice, and the pick-up water was still hot. This caused the temperature of the outlet water to rise to an uncomfortable 90°C, and an excess of heat was lost from the hoses and fittings on the surface. Lengthening the pipe cured this.

When the pipe penetrates the bottom of the ice, the hot water is diluted by cold sea water and is swept away, and the melting action is lost. When this happens, the operator reverses the connections at the surface so that the return hose becomes the feed hose and vice-versa (see Figure 4). The hot water is now blown out the holes in the attachment at the top of the pipe and descends through the ice

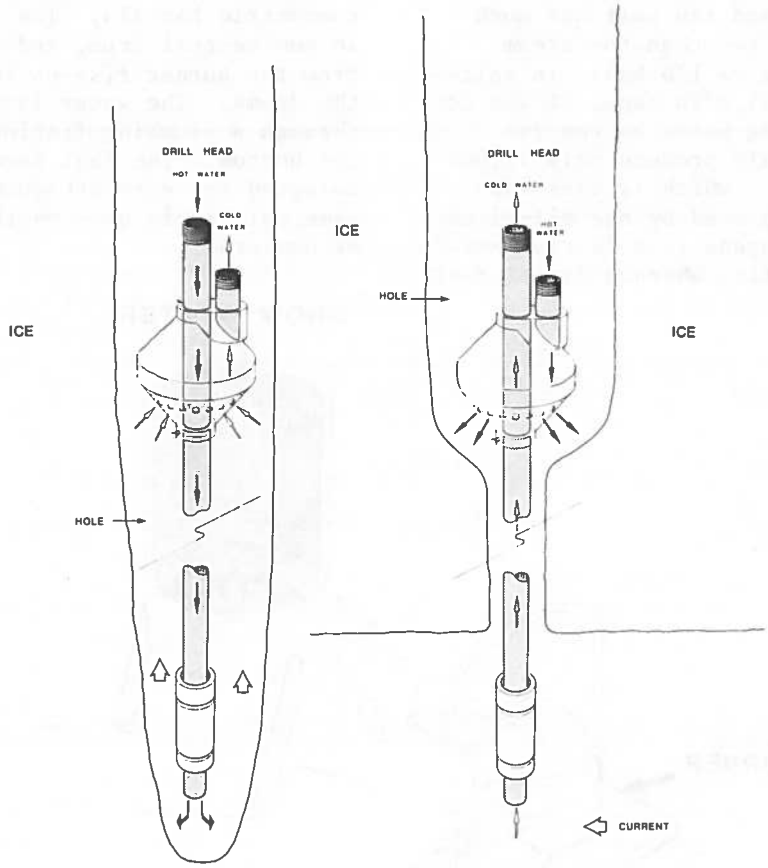

Figure 4. Illustrations of the drill head. The diagram on the left shows the usual operation of the drill. Hot water is pumped out the bottom of the pipe and melts the ice of the hole wall. The cooled water is picked up by the perforated conical head. The diameter of this head sets a minimum size for the hole. The pipe is about 1.5 metres long. The diagram on the right indicates the reversal in water flow once the pipe has dropped below the bottom of the ice. Hot water is ejected from the conical head, and cold water is picked up by the pipe.

to the water below, melting as it goes. Because the sea water picked up by the pipe is colder than the usual return water, the drilling speed drops; however, this is acceptable since only about 1.5 m of ice must be drilled in this way. Once the 'sizing' attachment falls into the water, the hole is complete.

d. Brake Drum

In order to keep the hole plumb, a weight is attached to the drill head and a lifting force is exerted on the hoses at the surface. This produces a pendulum effect. If the drilling head drifts off to the side, there will be a restoring force to bring it back to the plumb. The lifting force is produced by a brake drum, shown in Figure 5. Both hoses are wrapped around the drum at least one and a quarter turns so that there will be no slippage. The braking action is produced by a length of rope wrapped around the drum and attached to the frame. A spring scale in the high-tension side of the rope indicates the braking force exerted on the drum. Since there is virtually no tension in the other end of the rope, the retarding force on the hoses is simply the reading on the spring scale. The braking force is quite constant because the spring in the scale stabilizes the operation. For example, if the rope grabs a little and increases the tension, the spring lengthens, and this extra length causes the rope to slacken off and reduce the tension to its normal value. Usually a force of 7 to 9 kgf is used, and a mass of 20 kg is attached to the drill head. To make it easier to put the hoses on the drum and to take them off, the drum was built to pivot upwards about one end of the shaft. The other end of the shaft is then in the air, and a loop of hose can easily be thrown about the drum. The free end of the shaft is then dropped back onto a yoke support.

The drum is also used as a capstan to bring up the pipe and hoses. The brake rope is removed and an electric drive is attached to the hub of the drum. The hoses are then pulled out onto the ice with the capstan providing most of the lifting power.

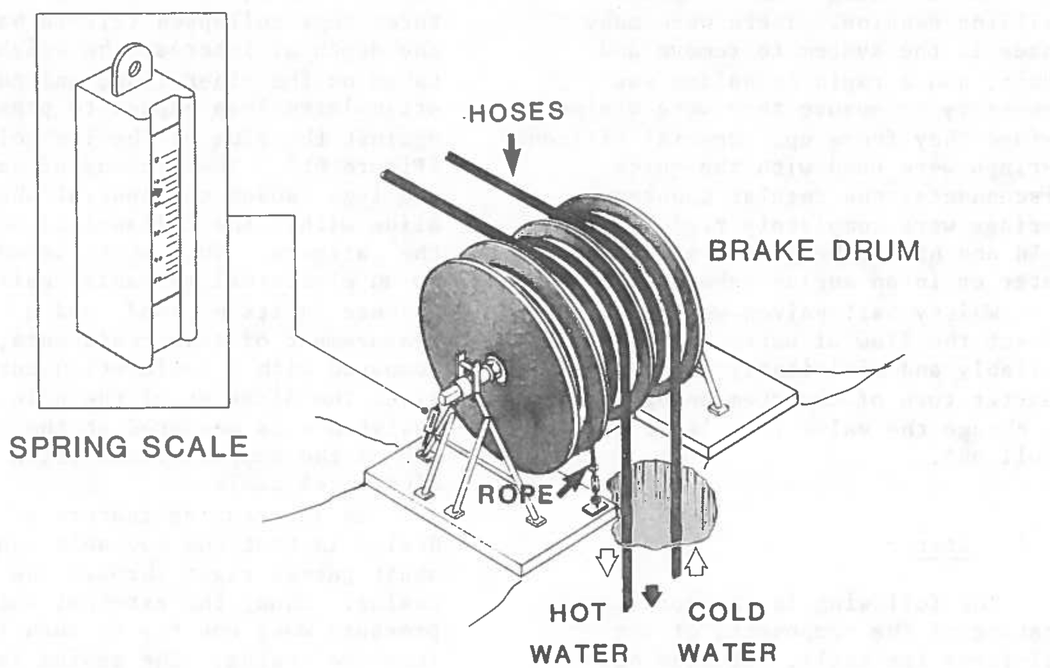

Figure 5. An illustration of the brake drum that is used to provide an upward force on the hoses. This tension, which is less than the weight of the drill head, helps to keep the hoses (and thus the hole) plumb. The inset indicates the spring scale which shows the retarding force. An electric drive can be fit over the square shaft. This turns the brake into a capstan to help raise the drill.

e. <u>Pumps, Plumbing and Motor Generators</u>

A Mann West gear pump (CJN, 1 inch) was used to pump the water out of the hole, through the heat exchanger and down the hole again. It was powered by a 5/8 HP (470 W) electric motor, and the electric power was supplied by a 5 kW Briggs and Stratton motor-generator. The generator also provided power to run the fuel pump on the heater.

The hoses were Gates EPDM (ethylene propylene diene tertolymer) (2.54 cm I.D., 3.61 cm O.D.). They maintained adequate flexibility in the cold weather although they were easier to handle when they were filled with warm water. On the surface, the hoses were coiled in insulated boxes, one box for the feed line and another for the return hose. Before the insulated boxes were used, the hoses rapidly melted their way into the snow. This wasted a substantial amount of heat and made the hoses hard to handle.

All attachments to the hoses were made with 'quick disconnects' (Hansen 'Straight-Through One Inch Brass Couplers'). They greatly facilitated disconnecting and draining hoses whenever anything went wrong or after a drilling session. There were many hoses in the system to remove and drain, and a rapid technique was necessary to ensure they were drained before they froze up. Special silicone O-rings were used with the quick disconnects; the regular neoprene O-rings were completely rigid in the cold and had to be pre-warmed in hot water or in an engine exhaust.

Whitey ball valves were used to direct the flow of water. They worked reliably and efficiently, only a quarter turn of the stem being required to change the valve from 'full off' to 'full on'.

f. <u>Cost</u>

The following is an approximate costing of the components of the oil-fired ice drill. It does not include the shop costs of assembling the parts or of making the snow melter or brake drum. Also, it does not include any spares.

Heater unit (Can)	$3000.
Oil burner	330.
Drill hose ($1.20/foot)	700.
Couplings (10 x $30.)	300.
Valves (5 x $108.)	540.
Electric Motor	180.
Gear pump	60.
Motor generator	370.
Misc. (Hose fittings, spring scale, etc.)	100.
Total	$5580.

g. <u>Hole Calipers</u>

It is very useful to be able to measure the diameter of the completed hole. After the passage of the drill head, heat is continually taken from the water by the surrounding cold ice but slowly added to the water from the warm hoses. Consequently, it is difficult to predict whether the hole will grow or shrink after the head has gone by. This information has a bearing on subsequent modifications of the drill. In order to measure the hole's diameter remotely from the surface, a set of hole calipers was designed and built. It is shown diagramatically in Figure 6. With its weight carried by one of the two support ropes, it is lowered with its three legs collapsed (Figure 6a). At the depth of interest the weight is taken on the other line, and the three articulated legs expand to press against the side of the ice hole (Figure 6b). The process of expanding the legs causes the central shaft to slide within the cylindrical body of the calipers. This shaft is connected to an eleccrical variable resistor (linear in its motion), and a measurement of this resistance, when compared with a calibration curve, gives the diameter of the hole. The resistance is measured at the surface, one of the support lines being an electrical cable.

An interesting feature of the device is that the moveable centre shaft passes right through the main casing. Thus, the external water pressure does not try to push the shaft into the casing. The casing is made of a flexible-walled tygon tubing and is filled with silicone fluid in order to equalize the pressure inside and outside. Since there is minimal pressure difference, the light fitting O-rings act as rod wipers rather than as pressure seals and permit free rod movement at any depth.

III. RESULTS

For the test on the ice shelf in April 1982, turbo fuel was used with the nozzle rated at 3.5 US gal/Hr (13.2 l/Hr), and the hole was sunk at the rate of 11 metres per hour. With a 'sizing' attachment of 17 cm in diameter, a hole was drilled that, in the upper 8 metres, was 23 cms in diameter with a variation of 1 cm. (Problems with the equipment prevented the rest of the hole from being logged. Presumably, the hole decreased in diameter at the bottom.) As far down as could be seen, the hole was very round and the walls were smooth.

During tests at other locations in the Arctic in 1981, it was found that hot-water drills can easily do certain types of jobs that would be very difficult for mechanical drills. For example, a hole was drilled through the ice freeing a cable that had been frozen in place. This allowed a suspended instrument to be recovered.

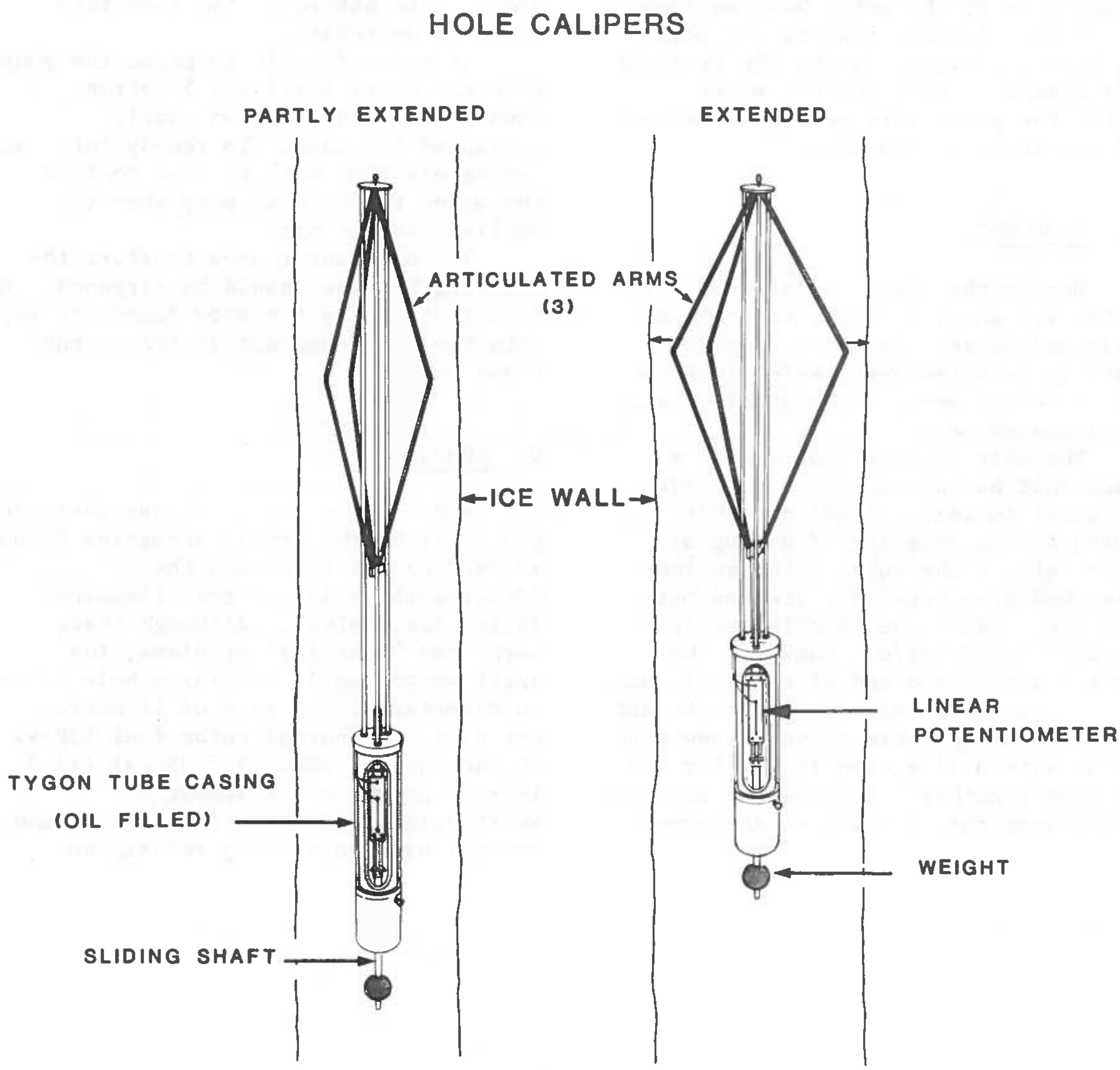

Figure 6. The hole calipers, a device for remotely measuring the diameter of the ice hole. The sliding shaft is connected to the bottom end of the articulated arms. When the weight is taken by a line attached to the framework, the weight pulls the shaft down, and the three arms lie together tightly. When the weight is taken by a line attached to the central shaft, the framework slides down. and the arms expand until the joints meet the walls of the hole. The amount of relative motion, and hence the diameter of the hole, can be inferred from the resistance of the linear potentiometer.

Following the cable through the ice added no extra difficulty to the procedure. Originally, several cable-following mechanisms had been designed, but they were not necessary. It is possible that the heat in the water was conducted ahead by the cable, thus warming the ice and directing the melting action. Another job that could not have been easily done by a mechanical drill was that of freeing wooden posts in the ice and lowering them to a greater depth. These posts, which suspended a small building on the ice, had effectively been lifted by a summer's melt; the water had run down cracks and fissures leaving the posts and building higher in the air by about half a metre. With the hot water drill, the posts were easily melted out and set lower in the ice.

IV. PROBLEMS

During the operation of the drill on the ice shelf a number of problems arose and several failures occurred. Since it is often very useful to know what does not work, these problems will be discussed here.

The most serious problem was a crack that had developed in the heat exchanger tubing. It was probably caused by the freezing of a slug of water left in the tube, although the tubes had been carefully steamed out. This break had to be repaired before the work could begin. Luckily, the break was near one end of the coil, and only a couple of turns needed to be cut off. It was possible to cut a new pipe thread with a file, and the system was put back together. To cure the problem in the long run, a new heat exchanger is being designed. It will be easier to drain and will not be so sensitive to a small amount of left-over water.

A second problem was the overloading and subsequent burn-out of the 5/8 HP electric motor. The flow-rate of the water was quite high and the pressure drop across the heat exchanger rose to over 100 psi (690 kPa), presumably because of the build-up of sediment or scale. Too much power was required to drive the pump, and the motor burnt out. In future, the new heat exchanger will introduce a much smaller pressure drop. Alternatively, the flow rate could be decreased.

It was difficult to prime the pump when the water level was 5 metres down. Also, the suction nearly collapsed the hose. To remedy this, an immersible pump will be used to feed the water to the main pump when the suction head is high.

The melt water used to start the drilling process should be screened. A nail that was in the snow found its way into the gear pump and destroyed the brass gears.

V. SUMMARY

A hot-water ice drill was designed and built by the Arctic Acoustics Group at DREP to drill through the 50-metre-thick ice of the Ellesmere Island Ice Shelves. Although there were some "teething" problems, the drill worked well, melting a hole 23 cm in diameter at the rate of 11 metres per hour. It burned turbo fuel (JP-4) at the rate of about 3.5 US gal (13.3 litres) per hour. A number of shortcomings have been identified, and several parts are being redesigned.