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A BUOYANCY STABILIZED HOT POINT DRILL FOR GLACIER STUDIES

Haldor W.C. Aamot

October 1968

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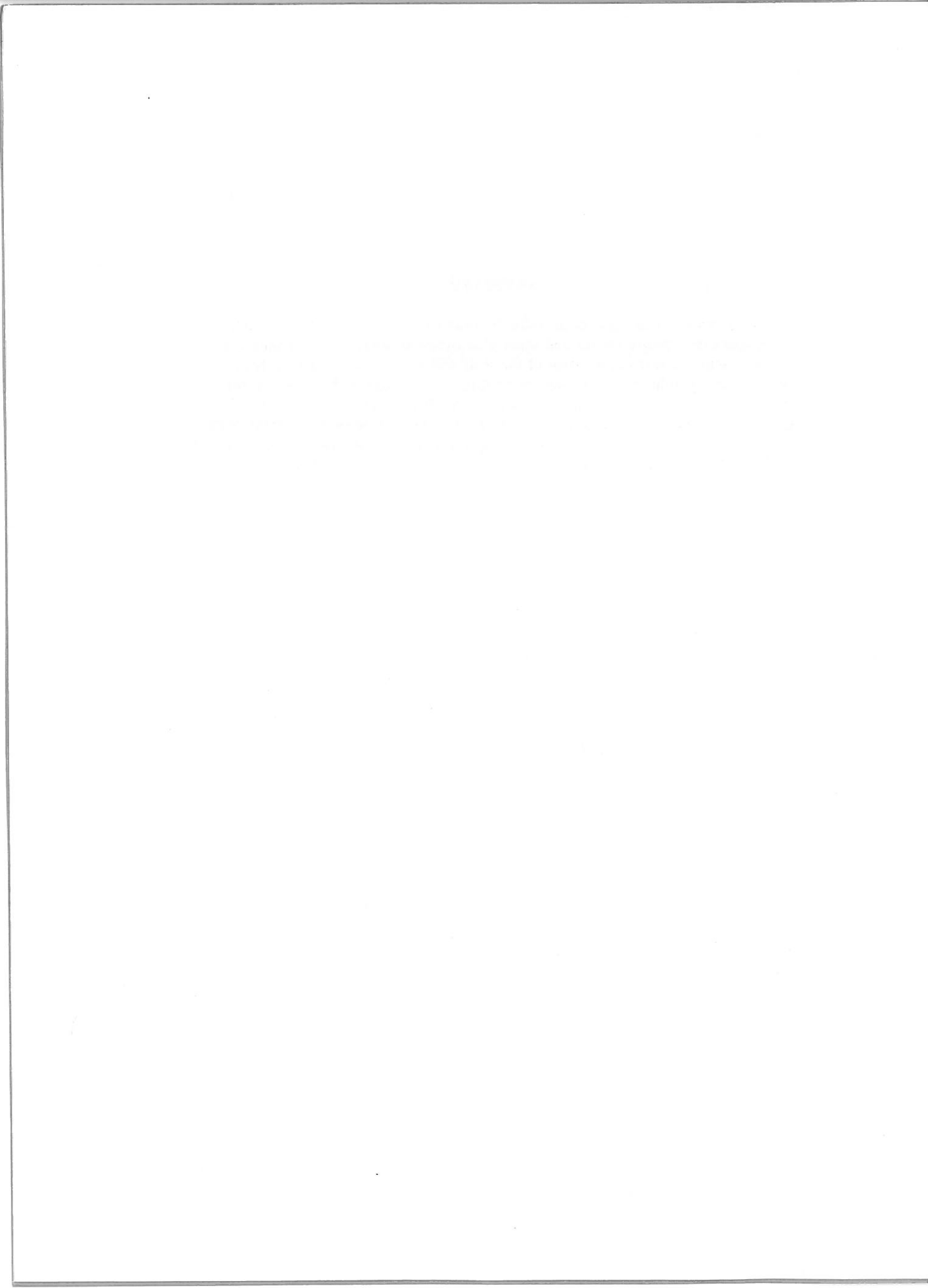
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PREFACE

The hot point drills described in this report were developed to fill the need for a light, simple drill for penetration of ice sheets and direct ice thickness measurements. Messrs. Malcolm Mellor and Charles M. Keeler of the Cold Regions Research and Engineering Laboratory (CRREL) expressed a need for this type of drill for use in glacier studies. The buoyancy stabilization system was conceived in an effort to assure vertical penetration of the drill. The drills were fabricated in the Measurement Systems Research Branch (Mr. William H. Parrott, Chief) of the Technical Services Division (Mr. B. Lyle Hansen, Chief), CRREL, U.S. Army Terrestrial Sciences Center (USA TSC). This report was prepared by the project engineer, Mr. Haldor W.C. Aamot, Research Mechanical Engineer. The author wishes to express his appreciation to Mr. Mellor for his constructive review of the manuscript.

USA TSC is a research activity of the Army Materiel Command.

ABSTRACT

Hot point drills are practical tools for penetrating glaciers for ice thickness and temperature measurements and other glaciological studies. *Buoyancy stabilization* ensures a vertical attitude of the drill and a plumb hole using a heavy hot point and a light upper section which floats in the surrounding melt water. The buoyant force is less than the weight of the drill in air but its rectifying moment about the fulcrum (the tip) is greater than the tilting moment of the drill weight. Two methods to prevent refreezing of the melt water are proposed to permit drilling in cold ice and to assure continued access to the hole.

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by

Haldor W.C. Aamot

INTRODUCTION

The need of the glaciologist in the field for a practical drill to penetrate mountain glaciers for ice thickness measurements and other uses has been satisfied by development of electrically powered, cable-suspended hot point drills. La Chapelle (1963)* reports on such a development. A cable-suspended drill, however, requires a means of attitude stabilization if a plumb hole is to be assured for depths of 100 m and greater (Philberth, 1966†; Aamot, 1967**).

The purpose of the work reported in this paper was to develop a small practical drill capable of producing plumb holes. The report describes the drill and the buoyancy stabilization feature proposed by the author for use in temperate ice where refreezing of the melt water is not a problem. Methods of drilling in cold ice are also suggested. The performance of several prototypes in the field is reported. Such drills can produce plumb holes of any diameter for ice thickness measurements and for insertion of instrument packages and mechanical devices.

BUOYANCY STABILIZATION

While penetrating the ice a cable-suspended hot point drill is completely immersed in melt water. It has a heavy tip (hot point) which is heated to produce melt penetration. Buoyancy stabilization is accomplished by a lightweight section above the hot point whose upward force keeps the drill erect. The drill is always heavier than water so that it rests on its tip. The contact force S (Fig. 1) is necessary for effective melt penetration. Consequently, the buoyant force B must be less than the weight of the drill in air (W). Nevertheless, the drill is positively erect and plumb when the rectifying moment (buoyant force times distance of the center of buoyancy from the tip) is greater than the tilting moment (weight of the drill times distance of the center of gravity from the tip).

For analysis the drill will be considered a prismatic (cylindrical) body. The hot point is of a homogeneous heavy material such as copper. The buoyancy section is a hollow sealed tube, e.g. of a laminated plastic. The following nomenclature is defined:

L_1 = length of hot point
L_2 = length of buoyancy section

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* LaChapelle, E. (1963) A simple thermal ice drill. *Journal of Glaciology*, vol. 4, no. 35.

† Philberth, K. (1966) Sur la stabilisation de la course d'une sonde thermique. *Comptes Rendus 262*, February 7, p. 456-459.

** Aamot, H.W.C. (1967) Pendulum steering for thermal probes in glaciers. *Journal of Glaciology*, vol. 6, no. 48. Also U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Special Report 116.
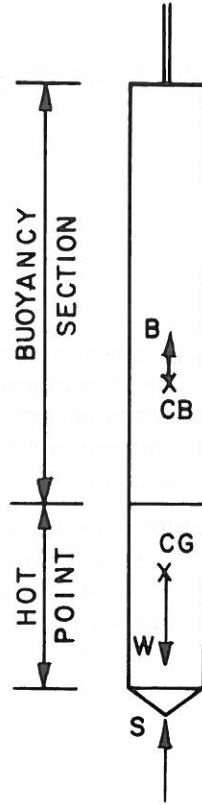
Figure 1. The buoyancy stabilized drill stands vertically on its tip, the hot point, when immersed in water. The center of buoyancy, CB, is above the center of gravity, CG. The leverage of the buoyant force B (equal to the weight of the displaced water) keeps the drill erect. The contact force of the hot point on the ice, S, is equal to the weight of the drill in air, W, less B.

W_1 = weight of hot point before immersion

W_2 = weight of buoyancy section before immersion

ρ_1 = density of hot point

ρ_2 = density of buoyancy section

ρ_3 = density of water or other fluid.

The required length of the buoyancy section will now be determined. For equilibrium conditions, the sum of the moments in Figure 2 is zero:

$$\left(\frac{L_1}{2}\right)W_1 + \left(L_1 + \frac{L_2}{2}\right)W_2 - \left(\frac{L_1 + L_2}{2}\right)B = 0 \tag{1}$$

$$\left(\frac{L_2}{L_1}\right)^2 \left(\frac{\rho_2 - \rho_3}{2}\right) + \left(\frac{L_2}{L_1}\right)\left(\rho_2 - \rho_3\right) + \left(\frac{\rho_1 - \rho_3}{2}\right) = 0$$

$$\left(\frac{L_2}{L_1}\right) = \frac{-(\rho_2 - \rho_3) \pm \sqrt{(\rho_2 - \rho_3)^2 - (\rho_2 - \rho_3)(\rho_1 - \rho_3)}}{(\rho_2 - \rho_3)}$$

$$\left(\frac{L_2}{L_1}\right) = -1 \pm \sqrt{1 - \left(\frac{\rho_1 - \rho_3}{\rho_2 - \rho_3}\right)} \tag{2}$$
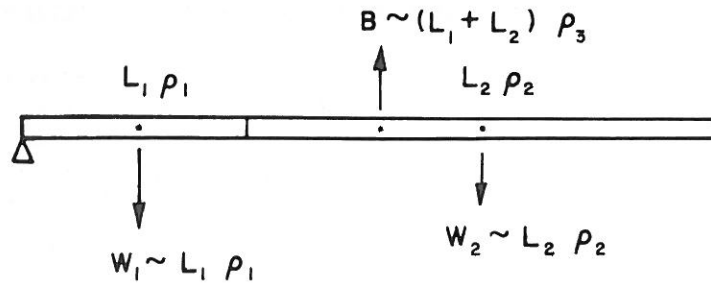
Figure 2. When the rectifying moment of the buoyant force about the pivot point is greater than the sum of the tilting moments of the various parts, the drill assumes a vertical attitude.

The following values are selected for the solution of a practical example:

$$\rho_1 = 8.0 \text{ g/cm}^3 \qquad\qquad \rho_2 = 0.1 \text{ g/cm}^3 \qquad\qquad \rho_3 = 1.0 \text{ g/cm}^3$$

$$\left(\frac{L_2}{L_1}\right) = +1.96 \text{ or } -3.96. \tag{3}$$

The negative value is not applicable. For positive stability, the length of the buoyancy section must be greater than 1.96 times the length of the hot point:

$$L_2 > 1.96 L_1. \tag{4}$$

The magnitude of the buoyant force at equilibrium is:

$$\frac{B}{W} = \frac{(L_1 + L_2)\rho_3}{L_1\rho_1 + L_2\rho_2} = 0.361. \tag{5}$$

For positive stability

$$B > 0.361 W. \tag{6}$$

The resulting contact force with the ice is

$$S < 0.639 W.$$

It is desirable to maintain a large contact force with the ice to achieve efficient melt penetration. The designer has little control over ρ_1 and ρ_3 but ρ_2 can be kept to the smallest practical value, thus keeping L_2 and B small. The buoyancy section can be made from a sealed thin wall tube. The hydrostatic pressure which tends to collapse the tube is not great at the ice depths encountered in mountain glaciers and thus permits a very light-weight design. The cable should be as light as possible to reduce the disturbing effect on the drill stability and to preserve the operator's feel of the cable tension.

Figure 3. Buoyancy stabilized drill.

DESCRIPTION OF THE DRILL AND FIELD TEST RESULTS

The design used for the first drills tested in Alaska is illustrated in Figure 3. The solid copper hot point is long to achieve a large contact pressure of the tip with the ice. The electric resistance cartridge heating element is heated only in the lower half. It is completely soldered into the copper with tin-lead solder for effective heat transfer. The buoyancy section consists of a tube of laminated plastic (glass cloth with epoxy resin). It is bonded and sealed against the hot point and cap with an epoxy resin adhesive. The cable has a push-on connector to permit recovery at least of the cable if the drill cannot be retrieved.

Power is transmitted through a 100-m length of RG 58 A/U coaxial cable. The resistance of the cable is about 5 ohms, the heater resistance is 50 ohms, the generator voltage is 117 v ac and the power requirement about 250 w. The diameter of the hot point is 2.03 cm and the drill length about 50 cm.

Messrs. Malcolm Mellor and Charles M. Keeler used five of these drills for ice thickness measurements in Alaska on 21 and 22 August 1967. Their work was on an east-facing tributary to the Black Rapids glacier south of Fort Greely (63°25'N, 146°10'W) at an elevation of about 1500 m (5000 ft). There was surface melt water runoff on the glacier.

The first and second holes were 51 and 53 m, respectively. The third hole reached an empty cavity at a depth of 22 m; the drill made contact again with solid material at 60 m. The fourth hole was started near the third and reached a depth of 62 m. On the fifth hole the drill froze in place at 10 m after having been stopped over night.

The penetration rate was about 5 m/hr. The efficiency, based on a minimum melt penetration power requirement $P_M = 12.1 \, v \, a^2 \, (79.71 + 0.5T)$, watts, is about 61%. Typical values are between 60 and 70%. T = ice temperature below the freezing point in degrees Celsius; a = radius of the hot point in centimeters; v = rate of penetration in centimeters per second.*

None of the drills were recovered, but the cable was pulled back out of each hole. The subsurface ice temperature could not be measured in the water-filled holes but the temperatures in the "winter cold wave" a few meters below the surface were probably several degrees below the freezing point.

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* Aamot, H.W.C. (1967) Heat transfer and performance analysis of a thermal probe for glaciers. USA CRREL Technical Report 194.

DRILLING IN COLD ICE

Cold ice presents a special problem. The melt water refreezes at a rate directly proportional to the temperature difference between the original ice temperature and the freezing point. The drill itself functions well while penetrating fast enough but before any great depth can be reached the cable becomes anchored in the refrozen melt water which closes the hole beginning near the top and following the drill. Refreezing must be prevented.

The freezing point of the melt water can be lowered by adding a suitable amount of ethylene glycol as an antifreeze mixture to keep the hole open. This is the least expensive approach. Tests are still necessary to confirm that reliable mixing occurs over the full length of a long slender fluid column when the glycol is added at the top.

The melt water can also be removed from the hole by pumping or by displacement. Pumping is not as practical as it may seem at first because a submersible pump must be used and the flow lines must be prevented from freezing. An immiscible, non-freezing liquid with a greater density than water, such as trichlorethylene, will lift the water out of the hole very effectively. The drill works efficiently under this solvent and the water rises in small droplets. Tests are still necessary to determine whether the water will rise without wetting and freezing to the hole walls, building up and constricting the hole gradually, or whether slushing will occur. Most likely the water will freeze into ice droplets which will then rise more reliably, making their removal at the surface easier. The material cost of this approach is greater than that of the antifreeze method.

By preventing hole closure due to refreezing the drill can probably be recovered. In that case the cost of the antifreeze or the solvent will be offset, at least in part.

CONCLUSIONS AND APPLICATIONS

The cable-suspended hot point drill is capable of penetrating glaciers and producing vertical holes reaching beyond the limits of hand augers to depths of 100 m and more. In temperate ice the drill can be retracted by the cable. In slightly colder ice similar depths can be reached without special measures to prevent refreezing provided the drill speed is sufficient; recovery is not possible. Very few glaciers are really temperate. Therefore, the drill is considered expendable and the design is simple to keep the price low.

In cold ice refreezing must be prevented. Access to the hole and probably even the recovery of the drill are thus assured as long as ice movement does not produce large deformations.

First of all, the drill permits effective measurement of ice thickness. The hole is then available for ice temperature measurements. In a plain melt water filled hole the temperature sensors must be left to freeze in place. If the hole is filled with a non-freezing liquid the temperature relaxes much quicker because less heat has to be dissipated in the ice and the cooling curve and final ice temperature are obtained sooner than if there is refreezing. Inserting pipe casing into the hole can ensure access for a long time, even following significant ice movement.

An open hole (filled with antifreeze or a solvent), especially if it is cased, permits other glaciological measurements and studies, such as ice movement with an inclinometer or acoustic and dielectric properties with instrument packages inside the glacier.

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13. ABSTRACT

Hot point drills are practical tools for penetrating glaciers for ice thickness and temperature measurements and other glaciological studies. Buoyancy stabilization ensures a vertical attitude of the drill and a plumb hole using a heavy hot point and a light upper section which floats in the surrounding melt water. The buoyant force is less than the weight of the drill in air but its rectifying moment about the fulcrum (the tip) is greater than the tilting moment of the drill weight. Two methods to prevent refreezing of the melt water are proposed to permit drilling in cold ice and to assure continued access to the hole.

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