INSTRUMENTS AND METHODS

A SIMPLE THERMAL ICE DRILL*

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Abstract. A thermal ice drill using a silicon carbide electrical resistance element has been developed. The silicon carbide element is operated bare in water, permitting a very simple and efficient drill design. Maximum operating power density in these elements is limited to 400 W./cm.[3] by the tendency of wet silicon carbide to deteriorate rapidly at high current levels. The elements are readily replaceable and have a drilling life of 40 to 70 m. of hole. Normal drilling rates in ice of 5 to 6 m./hr. can be consistently maintained with 220 W. power input to the drill.

Résumé. On a développé une foreuse thermique à glace utilisant un élément de résistance électrique au carbure de silicium. L'élément au carbure de silicium est utilisé à nu dans l'eau, ce qui permet un projet très simple et efficient. Le maximum de densité de la puissance utilisée dans ces éléments est limitée à 400 W par cm[3] par suite de la tendance du carbure de silicium humide à se détériorer rapidement pour des niveaux de fort courant. Les éléments sont aisément remplaçables et ont une vie de forage de 40 à 70 mètres de trous. Les vitesses normales de forage dans la glace sont de 5 à 6 mètres par heure et peuvent être en conséquence maintenues avec une puissance de 220 W à l'entrée de la foreuse.

Zusammenfassung. Ein thermischer Eisbohrer mit einem elektrischen Silicon-Carbid-Heizwiderstand wurde entwickelt. Der Silicon-Carbid Widerstand wird ungeschützt in Wasser eingesetzt, sodass das Bohrverfahren sehr einfach und wirksam ist. Die höchste erlaubte Leistungsdichte beträgt 400 W cm^{-3}, da bei höheren Leistungen das nasse Silicon-Carbid schnell zerfällt. Die Heizwiderstände sind leicht auswechselbar und haben eine Lebensdauer von 40 bis 70 m Bohrlochtiefe. Bei einer Leistung von 220 W können normale Bohrleistungen von 5–6 m hr^{-1} ohne Unterbrechung aufrecht erhalten werden.

Introduction

In recent years many deep holes in temperate glaciers have been bored for the purpose of lining them with a pipe casing to measure the ice deformation at depth. Equally valuable are holes drilled simply to determine ice thicknesses and map the bedrock beneath. Such a drilling program was initiated as part of the Blue Glacier studies in 1960, and has been carried out there intensively in 1962. The object of this work was to determine total ice mass in the glacier accumulation zone, delineate ice thickness profiles along principal flow channels and thus contribute to a study of ice flow characteristics, and to map sub-glacial topography. Preliminary results have been reported informally (LaChapelle, 1960, 1961) and a report on the 1962 results is in preparation. This present note describes the simple thermal ice drill which was developed to carry out the drilling.

After numerous field tests in 1961 and 1962, an electrically powered thermal ice drill 1·8 cm. in diameter has been perfected which utilizes silicon carbide as a heating element. During the 1962 summer field season twenty bore holes were drilled in the Blue Glacier accumulation zone, the combined length totalling 983 m. Of these, 718 m. were bored with the new silicon carbide ice drill; the balance were bored in surface firn layers by a conventional thermal drill with resistance-wire heater. Of the twenty holes, six were abandoned at depths from 5 to 27 m. when englacial crevasses or cavities were struck which were too wide to permit spanning with an aligned bore hole. Five holes were abandoned at depths from 2 to 58 m. owing to technical difficulties associated with test and development of the drill design (on three occasions the drill stuck in the hole and was lost). The remaining nine holes, mostly bored following the development of a satisfactory drill, reached presumed bedrock at depths ranging from 38·6 to 142·0 m.

A thermal ice drill does not give absolute assurance that bedrock has been reached, for it cannot distinguish between bedrock and englacial debris, hence the depths at which the drill

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ceases to penetrate must always be recognized as minimum values for ice thickness. In a simple glacier accumulation zone uncomplicated by tributaries or avalanche-fed areas, it is reasonable to assume that most of the rock debris will be found close to the glacier sole, but in one case on the Blue Glacier, debris zones in the ice were positively identified (dirt adhered to the drill tip) at depths of 30 and 49 m. in a hole 112·4 m. deep. Avalanches or rock falls up-stream from this point were a possible debris source. The drill was brought up from the bottom coated with mud in three of the 1962 bore holes, and these holes are strongly presumed to have reached the glacier sole if not actual bedrock.

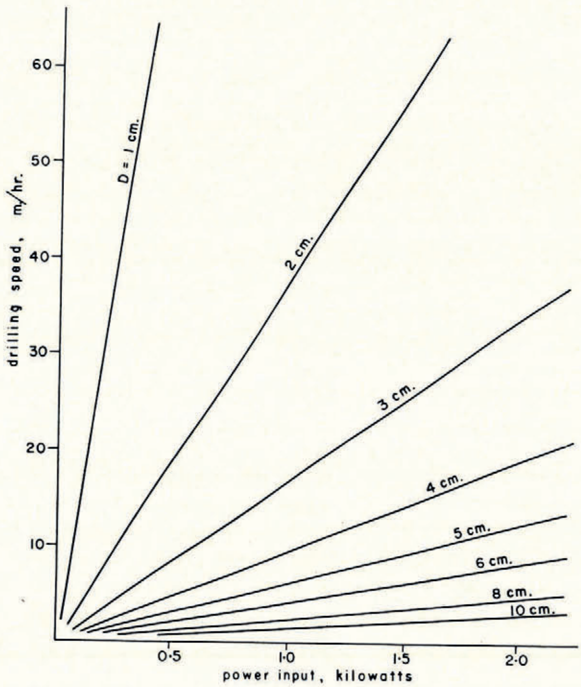

Fig. 1. The dependence of drilling speed on power input and drill diameter for a one hundred per cent efficient thermal drill working in ice of density 0·9 g./cm.[3]

Design Criteria

A drill design was sought which had the following characteristics:

1. Low power input, and consequently an easily portable power supply.
2. Sufficiently low current demand that a reasonably small-gauge, and hence light-weight, power cable could be used.
3. Operation of the heating element bare in water, thus eliminating completely the possibility of failure due to leaks in a water-tight seal.
4. Simplicity of construction which would permit ready repairs and heating element replacement in the field.

Conditions 1 and, in part, 2 can most easily be met by utilizing a small-diameter drill. Power input for a given drilling speed varies as the square of the hole diameter (see Fig. 1). This makes a small drill highly attractive when it is not necessary to case the bore hole with a large pipe.

Melted glacier ice normally has a very low ion content, and for practical purposes is an electrical insulator as long as it remains uncontaminated. There is no reason why wire-wound electric heating elements cannot be operated bare in the water if they are self-supporting (see for instance Ward (1961); Nizery (1951) has described such a bare-wire element which drilled successfully at the expense of an operating current of 120 A.). Unfortunately, requirements of stiffness and adequate circuit resistance for low operating current are incompatible for ordinary heating-wire alloys. Supporting materials, high operating temperatures, and configurations for efficient heat transfer require introduction of a water-tight seal. In the present instance, a heating element material was sought that had sufficiently high resistivity to be used bare, and in bulk rather than as a wire. Silicon carbide appears to be the only readily available substance suitable for such an element. It has the proper range of resistivity, withstands high operating temperature and a reasonable amount of thermal shock, and is readily available. Under the limitations described below, operating power densities approaching 400 W./cm.^{3} may be achieved.

Design Problems

One deficiency of silicon carbide is brittleness, but this has not proved to be a handicap in practice. A more serious defect in this application is a tendency to deteriorate at the negative terminal when heated by an electric current under water. Surmounting this obstacle has been the principal source of design difficulties in the drill described here. A wide variety of element configurations and terminal designs have been tested in the laboratory and field; the most effective design to date, for which operating data are given below, is illustrated in Figures 2 and 3. There is considerable difficulty in securing reliable terminal connection to the very high resistance silicon carbide. The mechanically most secure terminals were formed by molding silver amalgam (dental modeling alloy) against the carbide under pressure, but in actual practice these terminals proved to have no particular advantage over simple aluminum foil for extending element life. Terminals of the silver amalgam, of copper, and of aluminum, alone and in various combinations, were tested for influence of connector metal on carbide deterioration, but no such influence was apparent. Aluminum foil was used in the final design because it was the most convenient; a single layer of aluminum foil was pressed firmly against each end of the carbide element until it adhered, and then additional layers of foil were added until the element could be seated in the drill tip. Gold foil for the first layer probably would provide superior performance, but has yet to be tried in the field. There is a marked acceleration of carbide contact erosion when water in the bore hole becomes contaminated, and element life is then short. This occurred in the 1962 Blue Glacier bore hole where the drill passed through zones of dirty ice 30 and 49 m. beneath the surface. Below these zones the heating elements had to be replaced frequently and the copper drill body suffered electrolytic corrosion. Operating life of the silicon carbide elements equipped with silver amalgam terminals was more than doubled by soaking them in hot motor oil prior to use. Apparently the motor oil excludes water from the silver-carbide contact long enough to inhibit deterioration.

On the basis of two summers of such laboratory and field tests, it is concluded that the simplest way to extend silicon carbide heating element life is to maintain operating current below the critical level at which deterioration becomes rapid. This critical current density at the metal–carbide junction appears to be in the neighborhood of 7·0–7·5 A./cm.^{2} for the type of silicon carbide used. The successful design sketched in Figure 2 reduces current density by offering the increased contact surface of a cone instead of a plane, and allows maximum length of element and hence maximum circuit resistance. It normally operates at a contact current density of 6·0–6·5 A./cm.^{2}. The untreated silicon carbide elements with plane silver terminals (contact current density around 8·0 A./cm.^{2}) seldom drilled more than 5 to 8 m. of ice before failing. Treated with motor oil, in many instances they drilled 15 m. or more. Carbide elements with the configuration shown in Figure 2 drilled from 40 to 70 m. before failing. Failure usually occurred when gradual contact erosion reduced the effective contact area and thus raised the current density above the critical level.

Operating Characteristics

This drill differs fundamentally from the more familiar style of thermal ice drills in its mode of operation as well as in the resistance element material. In the solid-nose electric drill point, heat reaches the ice from a wire resistance element through insulation, through a copper tip, and thence through a thin layer of water which is removed by a laminar flow as the ice melts (Shreve, 1962). In the present silicon carbide thermal drill the heat is communicated directly from the resistance heating element to water, and then is transferred to the ice by turbulent flow of water in the space surrounding the silicon carbide. This is a far more

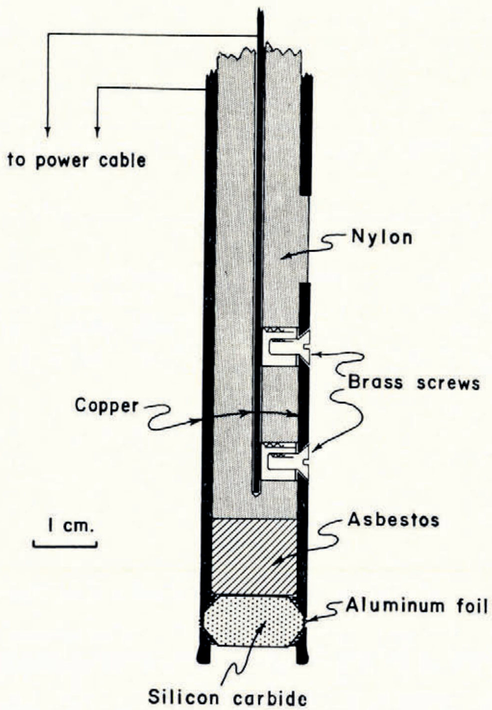

Fig. 2. Cross-section through the silicon carbide ice drill, showing construction and electrical connections

effective heat transfer mechanism, as demonstrated by the efficiency achieved in the simple pilot model in spite of substantial heat losses upward and to the sides. Design improvements probably can result in even higher efficiency. Construction of the drill sheath (the outside tube) from a suitable thermal insulator instead of copper might be one such improvement. This heat transfer method does limit the drill to use in impermeable ice where water remains standing in the hole; the drill is very quickly destroyed by over-heating in permeable firn. Above the glacier firn line it is necessary to provide an auxiliary "firn drill" to reach impervious ice. This was done during the Blue Glacier field work, and a simple thermal firn drill was constructed from copper tubing and a high-density, 165 W. electric cartridge heater. This drill, the same diameter as the carbide drill, penetrated firn at 6 to 8 m./hr. to reach ice in this locality at depths of 15 to 20 m.

The construction of the thermal drill is illustrated in Figures 2 and 3. A length of thick-walled copper tubing is electrically insulated from the tube body by a nylon plug which in turn is thermally shielded from the heating element by a layer of asbestos. Electrical connections are made through the copper tube and its insulated section. The latter can be removed easily with a small screwdriver for quick replacement of the heating element. A 2·5 m. length of galvanized steel pipe behind the copper drill tip provides alignment in the bore hole and weight to insure uniform drilling.

The silicon carbide heating element is a short section of standard electric furnace heater marketed by the Carborundum Company of America under the trade name "Globar". The Type A-8 rod, 8 in. (20·3 cm.) long and a nominal $\frac{5}{16}$ in. (0·8 cm.) diameter, was used. This heater is rated at 4·3 A. on 115 V., but there is considerable factory variation in the silicon carbide and the normal operating current at 115 V., as calibrated by the manufacturer for

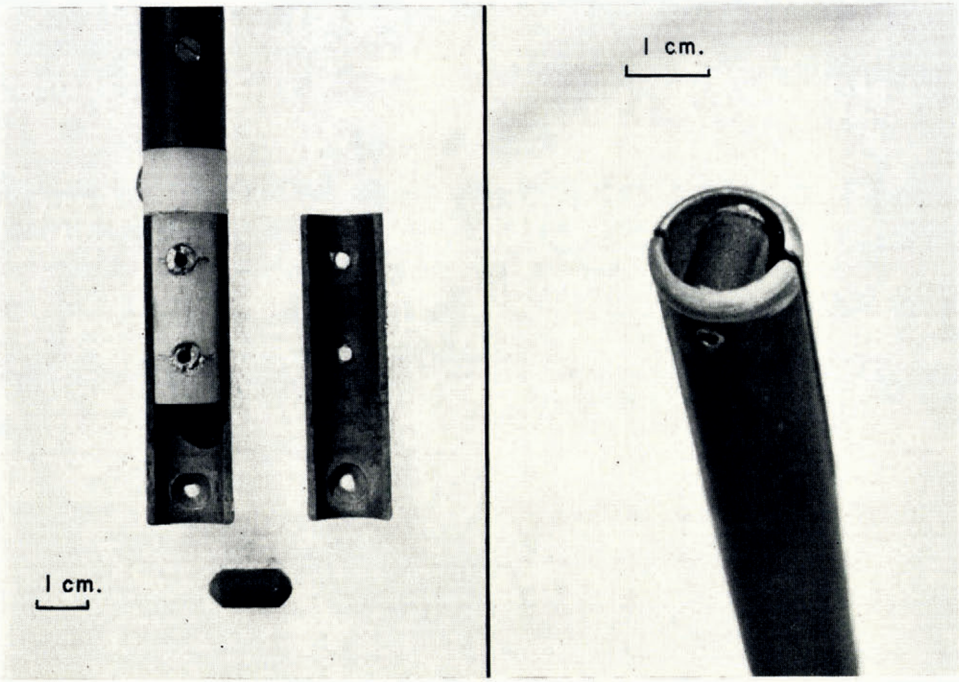

Fig. 3. The thermal ice drill with silicon carbide electric heating element. The asbestos shield mentioned in the text is not shown in the left-hand illustration

each individual rod, varies from 4·3 to 5·0 A. The visible granular character of the carbide also varies from rod to rod, as does the operating life of the lengths used for the drill heating elements. There appears to be no way to select the more desirable rods except by trial. This manufacturer also produces a higher-resistance heater for use on 220 V., but drill elements made from such silicon carbide have very short operating lives.

The maximum operating power of the drill is about 220 W. if the current limitation mentioned above is observed. This yields a drilling speed of 5·5 to 6·0 m./hr. As the carbide element ages, rise in the contact resistance enables slightly more power to be applied, and drill performance actually improves with element use up to the point of failure. Consistent operation above 5 m./hr. drilling speed is practical. Efficiency of the drill, computed as the ratio of the cross-sectional area of the drill to that of the hole, is 55 per cent. The ratio of the actual drilling speed to the theoretical drilling speed in ice of density 0·9 g./cm.^{3}, in effect the same ratio as above but easier to estimate in the field, gives an efficiency of 59 per cent. The 500 ft. (152·4 m.) power cable used with the drill dissipates 40 to 50 W.; the demand on the generator is thus less than 300 W. at all times. The normal operating voltage delivered to the cable varies from 50 to 75 V., depending on the condition of the carbide element. A control panel with meters is needed to enable the generator field current to be controlled as required in order to achieve the desired input power to the drill. The rather large negative temperature coefficient of resistivity found in silicon carbide requires good current overload protection to prevent drill damage if the water is lost from the bore hole.

ACKNOWLEDGEMENTS

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