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STABILIZING THE COURSE OF A THERMAL PROBE

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13. ABSTRACT
For thermal drilling in ice, probes are used which sink into the ice as an independent mechanical system. However, such drills tend to lose their vertical direction and slant toward the horizontal. Satisfactory drilling can only be obtained if the drill is stable, i.e., if the direction of its axis returns to the vertical once it has been diverted from it. Various probe shapes are discussed in terms of maximum stability. Flat-headed probes are stable but not suitable for penetrating ice because they push small pebbles and other impurities in front of the device which heat the meltwater, thus decreasing the efficiency. Cone-shaped probes can be stabilized by increasing the heat flux emitted by the end of the cone. A probe with a constant temperature created by a heavy copper head has a large flux at its lower end and is so thermally controlled. Such probes are simple and sufficiently stable in temperate ice. In cold ice, a mercury heat-controlled probe should be used.

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NOTICE

STABILIZING THE COURSE OF A THERMAL PROBE

[Paper by Mr Karl Philberth, presented by Mr Jean Coulomb at the 10 January 1966 session of the French Academy of Sciences; Paris, Compt. Rend. Acad. Sc., French, 7 February 1966, 262 (6), pp 456-459]

SUMMARY

For thermal penetration into a glacier cap (Islandsis) one can use probes which burrow into the ice as an independent mechanical system. Such probes tend to level out onto the horizontal. This instability is discussed, a standard for (course) stability is given, and stable construction designs are suggested.

For thermal boring in ice, a probe (1) has been suggested whose cable -- an insulated wire for transmitting the necessary electrical power -- is paid out from inside the probe and remains frozen into the ice. The energy required for paying out the cable is so slight that it can be disregarded in relation to the weight of the probe. The probe in the ice thus forms an independent mechanical system. The question which arises is whether such a probe will lose its vertical direction to follow a curvilinear path moving closer and closer to the horizontal. Cable probes of the ordinary sort have a tendency to turn around if the cable bears only a portion of the weight of the probe proper, or if the cable rests on the probe.

The probe (1) is very long in proportion to its diameter (say 200cm to 10cm), but its path is extremely long (several kilometers); a curving of this path is geometrically possible, but a regular curve -- even a minimal one -- would give rise to an intolerable inclination. Hence we cannot expect a reliable probe unless the probe itself is stable, in other words, if the direction of its axis returns to the vertical after it has been shunted off it.

In dealing with the stability of free probes in ice, we shall confine ourselves to the rigid revolving forms, and consider the important case, practically speaking, of a length far greater than the diameter. The heat flow (power per unit of surface of the probe) is assumed to derive from revolution. We shall disregard the heating of the water melting beneath the probe (see [2]). G is the center of gravity, H is the center of hydrostatic thrust in the melting water. In Figure 1, the forces are indicated by the dotted arrows, the movement by solid arrows.

We can show (Figure 1) each infinitesimal shift of the probe by an axial displacement $\vec{da}$ of the base and of the tip by a radial displacement $\vec{dR}$ of the base and by a radial displacement $\vec{dr}$ of the tip. $\vec{dR} = +|\vec{dR}|$, if $\vec{dR}$ is tilted downward, $dR = -|\vec{dR}|$, if $\vec{dR}$ is tilted upward. We shall define $\vec{dr}$ analogously. The probe rights itself, if the angle α between its axis and the perpendicular diminishes; then $d\alpha = (dr - dR)/l < o$, (l being the length of the probe); $dR > dr$ is the condition of stability.

More detailed research indicates that there are probes which are stable for small α and stable for large α. Between these two cases there is a boundary angle to which the probe does not respond. This boundary angle must be as large as possible. Because it may happen that the probe is shunted off course by small pebbles, meteorites, or some technical accident.

Using the stability criterion, let us talk now about the behavior of a few theoretical types in tempered ice. The probe in Figure 1, with unheated lateral walls, has $dR = dr = 0$ (indifference). The probe in Figure 2 has heated lateral walls, hence $dR > 0$, $dr > 0$; if the heating of the walls is constant along the entire length of the probe, you get $dR = dr$ (indifference); if it is hotter in the lower part, you get $dR > dr$ (stability). Figure 3 shows a probe with no heating in the lateral walls; it is stable because of $dR > dr = 0$ (3). A pointed tip with a revolution flow moves exactly in the direction of the axis ($dR = 0$). In Figures 4 and 5 you have $dr > 0$ (in Figure 4 because of the heating of the lateral walls, and in Figure 5 because of its conic form); and so you have $0 = dR < dr$, or instability.

However, a probe with a flat bottom will push little pebbles ahead of it, thus adversely affecting contact between the probe and the ice. In this manner it produces warm water, which cuts down on efficiency and endangers stability.

H. Aamot (U.S.A., C.R.R.E.L.) has suggested a design which is stable, despite its pointed bottom and its revolution flow (Figure 6). The heating is dosed, so that the load of the probe rests on the symmetrical edge, whose center of curvature C is above G; the couple tends to diminish the tilt $(0 < dR > dr < 0)$.

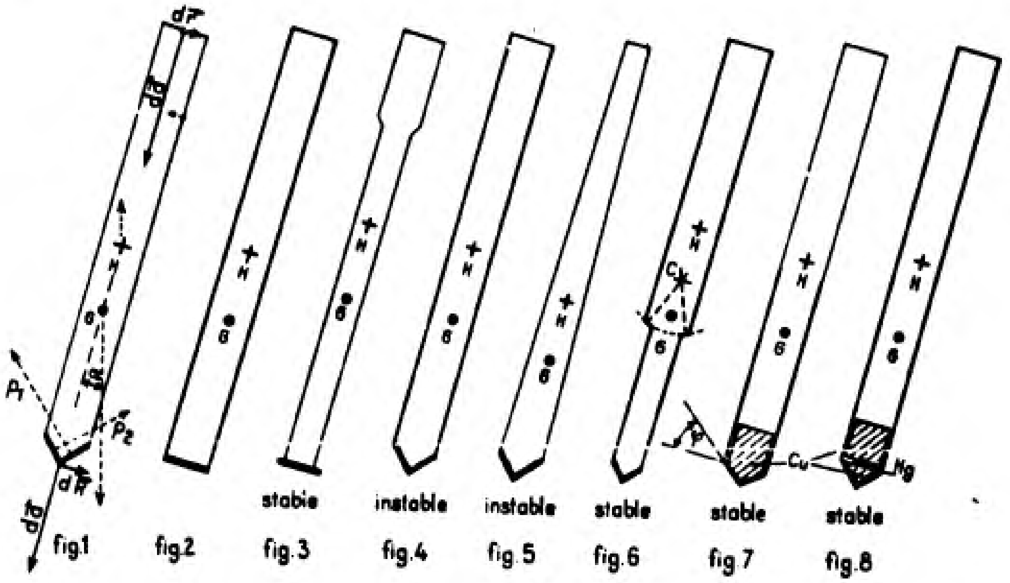
We said earlier that cylindrical probes with pointed tips (Figures 1 and 4) are not stable. This is true only if the flow around the tip is revolving. You can stabilize a cylindrical probe with a pointed tip by increasing the flow from the lower part of the tip ("thermal regulation"). The relative difference dc/c between the flows on the two sides is equal to the relative difference dg/g between the quantities of ice melted per unit of time. These quantities of ice are proportional to the projections from these two sides on the direction of movement. We find that $dc/c = dg/g$ approximately equal (for $dR/a \ll 1$) to $(4/\pi)\,(dR/a)\,\mathrm{tg}\,\varphi$, where φ is the base angle of the tip; hence:

$$\frac{dR}{a} \approx \frac{\pi}{4}\,\frac{dc}{c}\,\mathrm{cotg}\,\varphi$$

In the boundary-case of $\varphi=0$ (flat bottom; figures 2 and 3), we have $dR > 0$, even though the flow around the bottom is circular ($dc/c=0$). The point can shift only if the lower portion of the probe can follow that shift by reason of its geometrical form (Figure 3) or has a sufficient flow along the lateral walls (Figures 2, 7, and 8).

Normally, a cylindrical probe rests on the lower side of the tip (Figure 1: $p_1 > p_2$). The water film is thinner and the thermal contact between tip and ice is better than on the other side. For this reason, a tip with constant temperature -- which can be achieved approximately at least with a solid copper (Cu) head -- has a high flow on the lower side; there is thermal regulation. Such probes are simple and sufficiently stable in tempered ice (Figure 7). To simplify our quantitative thinking about such regulation, we shall assume that the point of application of all the tip forces is its extremity. The relative difference between p_1 and p_2 is then equal to $8/\pi \cot^2\varphi$ multiplied by the ratio between the radial and axial forces of the tip (Figure 1). This latter ratio is proportional to $\mathrm{tg}\,\alpha$. If the relative difference between p_1 and p_2 is small, it is approximately proportional to $\mathrm{tg}\,\alpha\,\mathrm{cotg}^2\varphi$. For $\varphi > 30'$ the setting is low. The probe comes close to a constant angle α, which is $\neq 0$ for $dr > 0$.

In cold the lateral walls must either have a conical form (Figure 5) or be heated. (Figures 2, 4, 6 and 8) We might consider the conical form of the lateral wall as a kind of "outside heating," because of the heat of freezing of the melted water. This heat produces a flow, whose minimal value -- to protect the lateral walls against freezing -- is proportional to the negative temperature of the ice: it is also a function of the speed and diameter of the probe and of the distance from the base of the probe. When the lateral flow goes beyond the minimal value, it causes the ice to melt; when this happens, you have $dr > 0$. In practice, such "overheating" is inevitable. To make up for this, dR must be big enough so that, even under unfavorable conditions, you have dR > dr. In the case of a pointed-tip probe, this calls for efficient heat regulation. You can regulate the heat power flowing through the tip by means of a groove running perpendicular to the axis and partially filled with mercury. The mercury (Hg on Figure 8) flows to the lower part and forms a unilateral heat transfer bridge. This stabilization method has been tested under working conditions (3).



These two methods of heat control show important differences: the constant-temperature method requires that the point at which radial force is applied (Figure 1) to the lateral wall be situated above G; this is a drawback, because it means that almost the entire lower half of the lateral walls be overheated. This method is more efficient as ϕ is smaller. The mercury method works better if ϕ is fairly large (for example, 45'); the point at which the radial force is applied may be located lower than G, and the bigger ϕ is the lower it can be.

FOOTNOTES

[*] Session of 10 January 1966.

[1] K. PHILBERTH: Comptes rendus, 254, 1962, p 3881.

[2] R.L. SHREVE: *J. Glaciol.*, 4, # 32, 1962, pp 151-158.

[3] K. PHILBERTH: *Polarforschung*, 34, 1964, pp 278-280.