AN IN-SITU SAMPLING THERMAL PROBE

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Abstract

Philberth's thermal probe concept and Aamot's pendulum steering technique have been incorporated in a new design which passes a portion of the meltwater formed at the tip of the probe through its interior where various parameters such as conductivity can be continuously monitored in high pressure cells. The telemetry system and probe design will permit the addition of other in-situ measurements.

A simple DC measurement system provides precision measurement of the ice temperature and changes in the inclination of the probe during freeze-in periods at selected depths in the ice sheet.

Introduction

In 1979, the Polar Ice Coring Office (PICO) undertook the development of an in-situ sampling thermal probe the design of which would: minimize the possible occurrence of the difficulties encountered by previous probe users, include a telemetry system to permit measurements while advancing under power, provide means for making various measurements on the meltwater flowing from the tip of the probe through high-pressure sample cells within the probe, and provide a simple DC measurement system and the transducers necessary to measure changes in the orientation of the probe due to the flow of the ice sheet during freeze-in periods while the cooling curve of the probe is being measured.

The probe is pendulum stabilized; its center of gravity is below the 16.5 cm diameter upper hotpoint which controls the advance rate (Figure 1). The lower hotpoint and the body of the probe have a diameter of 12.7 cm. The overall length is 3.45 m and the weight of the probe in air is 150 kg.

The lower 2.11 m segment of the probe is a hermetically-sealed, thick-walled, non-magnetic stainless steel chamber at atmospheric pressure which is designed to withstand an external pressure of $5\text{x}10^7$ N/m^2 or "pascals" caused by the overburden of 4000 m of ice plus a peak over pressure which exists temporarily during the refreezing of the meltwater. This chamber contains the two hotpoints, transducers, high-pressure sample cells and the telemetry equipment.

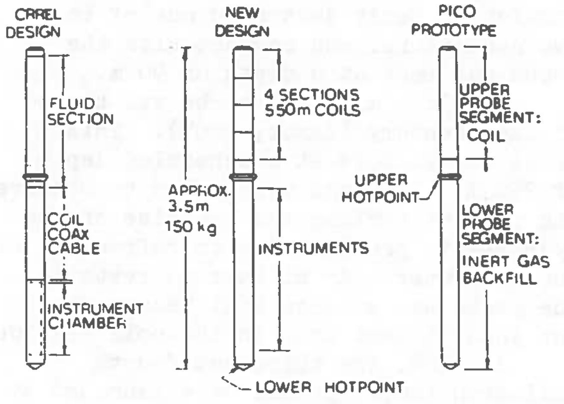

Figure 1. Thermal probe designs

The upper 1.32 m segment of the probe contains about 3 km of miniature coaxial high-voltage cable tested to withstand 3000V DC immersed in water; this segment is open to the ice/water environment.

Most of the exterior cylindrical surface of the probe is covered with a Nichrome V ribbon heating element sandwiched between fiberglass-reinforced epoxy layers. The purpose of this heating element is to melt the ice around the probe when starting up after a freeze-in period. It provides a power density of 0.3 watt/cm^2 of exterior surface area. Tests have shown that it melts the probe free in ice of -40°C temperature in approximately one hour, the interior chamber temperature at melt-out being about 20°C.

History

In 1962, Karl Philberth (1962) described the concept of he and his brother Bernhard for a thermal probe to measure the temperature inside of an ice sheet. The outstanding characteristic of this probe was that the wire for the transmission of electrical power to it and signals from it payed out of the advancing probe and became fixed in the refreezing meltwater above it.

In 1962, Philberth's (1964) concept of a mercury steering-ring to stabilize the vertical course of the thermal probe was successfully tested at Jungfraujoch, Switzerland.

In 1964, the development of the Philberth thermal probe was undertaken at USA Cold Regions Research and Engineering Laboratory (CRREL) with the assistance of K. Philberth.

In 1965, the first Philberth probe built at CRREL was tested at Camp Century, Greenland (Aamot, 1967). An insulation fault destroyed one of the two conductors, and contact with the probe was lost at a depth of 90 m.

In 1966, a second probe was tested at Camp Century (Aamot, 1967). This probe was stopped at a scheduled depth of 259 m. Readings were taken to observe the rate of cooling and the rise of the hydrostatic pressure due to refreezing of the meltwater. An attempt to restart the probe was unsuccessful because there was insufficient heat in the coil section.

In 1968, the third and fourth Philberth (1976) probes were launched at Station Jarl-Joset, Greenland. The cartridge heaters in the third probe short-circuited at a depth of 218 m, and again in the fourth probe at a depth of 1005 m. Temperatures were measured at depths of 218, 615 and 1005 m. The fourth probe was successfully stopped at 615 m, allowed to freeze-in for the temperature measurement, and then restarted on its way.

Two thermal probes with pendulum vertical stabilization have been launched in Antarctica (Aamot, 1970).

In 1971, a CRREL pendulum probe was launched at South Pole Station by John Rand (1971). It failed at a depth of 6 m, probably because the coil was inadvertently overheated by operating at too high a power level in the porous firn.

In 1973, the Australians (Morton and Lightfoot, 197-) launched their thermal probe at a site 80 km south of Casey Station where it reached a depth of 112 m when it failed, probably due to inadequate insulation on the stepping switch. The temperature at that depth was measured.

Design Features

To minimize the possible occurrence of the difficulties encountered by previous probe users, PICO undertook the analysis and design of a hermetic seal for the cartridge heaters, which previously were not hermetically sealed and could have caused moisture to enter in the insulation around the heating element and/or the oxidation of this heating element itself, resulting in a reduction of the wire diameter.

Two approaches were investigated: (a) hermetically-sealed cartridges were fabricated and tested with very satisfactory results -- their production was difficult to achieve and very expensive; (b) normal off-the-shelf cartridges were purchased -- after insertion in the hotpoints, these assemblies were baked out at 120°C for approximately one hour prior to final assembly of the lower segment of the probe. Since the interior of the probe is evacuated and refilled with an inert gas the heaters need not be hermetically sealed. Test results have indicated a sufficiently acceptable performance.

The cartridge heaters in the upper and lower hotpoints are operated at 50 percent of their rated wattage. At a maximum operating voltage of 1325V DC and a current of 4.07 amperes, the total heating power of 5400 watts is so divided that 1350 watts are dissipated in the upper hotpoint and 4050 watts in the lower hotpoint.

The entire 2.11 m lower segment of the probe is hermetically sealed by a combination of a U-type Variseal and a pair of O-rings; this provides redundancy but also the needed assurance of adequate sealing (Figure 2).

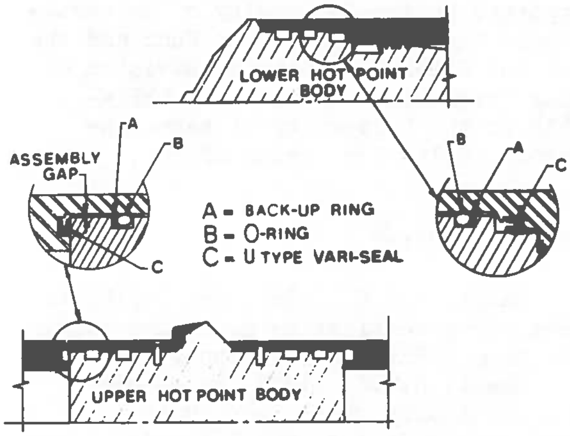

Figure 2. Hermetic sealing method of the instrument chamber

The miniature coaxial high-voltage cable consists of a solid center conductor insulated with an extruded copolymer of ethylene and tetrafluoroethylene (DuPont's TEFZEL) covered with a braided silver-plated outer conductor.

The center and outer conductors are dead-soft annealed copper. This should permit a 20 percent elongation due to movement of the ice before the cable ruptures.

The dielectric strength is tested by immersing the complete coil in tap water at room temperature and applying a difference of 3000V DC for four hours between the center conductor (cathodic = negative) and the surrounding water -- any breakdown constitutes a failure.

The specified cable diameters and values measured on a sample are shown in Table 1. The maximum DC resistance of the center and outer conductor at 20°C are 0.0334 Ω/m and 0.0295 Ω/m, respectively. The maximum specified loop resistance of 0.0629 Ω/m exceeds the 0.057 Ω/m measured on a 50-m sample.

The characteristic impedance, Z_o, and propagation constant, γ, were calculated at frequencies of 100, 1000, 10,000 and 100,000 Hz to confirm the capability of transmitting a continuous stream of data to the surface while advancing the probe under power.

The telemetry system is powered by a string of Zener diodes in series with the heating elements. The DC output voltages of the transducers are converted into pulses in the audio frequency range. These variable-frequency pulse trains are sequentially transmitted over the coaxial cable to the surface monitoring station which consists of a Hewlett-Packard 1222A oscilloscope and 5316A universal counter, a Fluke 1720A controller-computer, a Fluke 2020A printer and signal processing electronics. The data is gathered, analyzed and then stored on floppy disks (5¼-inch diameter) for future use.

This probe, like all of its predecessors, contains a rotary selector switch, but the significant difference is that this switch has a much higher dielectric strength of 3000V DC and a current carrying capacity of 17 amperes. The switch is actuated by reversing the polarity of the DC voltage feeding the coaxial cable. Its use permits:
(a) the application of power to any one or selected combination of heating elements, (b) measurement of the resistance of the heating elements or various thermistors, (c) measurement of the voltage or charging of the battery pack used to energize the transducers for DC measurements, (d) measuring the

Table 1. Specification of Miniature High-Voltage Coaxial Cable with TEFZEL Insulation

	Specified Cable Diameter	Measured Diameter
Center Conductor	0.805-0.823 mm ($0.0320^{+.003}_{-.0004}$ inch)	0.823 mm (0.0324 inch)
Over Insulation	1.245-1.321 mm (0.0505 ± .0015 inch)	1.245 mm (0.0490 inch)
Overall	1.727-1.829 mm (0.070 ± .002 inch)	1.748 mm (0.0688 inch)

DC voltage outputs of the inclinometers, compass and pressure transducers.

The pressure transducer, a Schaevitz P763-0001A, measures the pressure of the meltwater. A conductivity cell of in-house design measures the conductivity of the meltwater as it advances through the probe.

The inclinometers, Schaevitz LSRP-14.5, are calibrated at -30°C for operation over the range of 0°C to -55°C. They are in a 90° x-y axis offset stack with a Z-axis alignment.

The compass is a Norwegian-made Aanderaa Model 1248 rotating, permanent magnet unit.

The coil section which contains the coaxial cable, unlike all previous probes, is placed atop the upper hotpoint (Figure 1). The PICO prototype thermal probe uses a CRREL coil section, but future probes will use a customized coil section. This consists of individual sections, each of which contains 550 m of coaxial cable and is 29.2 cm long. The advantage of the sectioned coil segment is the reduction in cable cost and winding cost. A specially-designed, collapsible mandrel is available for the orthocyclic winding of the coaxial cable (Lenders, 1962).

Performance

The performance of the prototype probe has been tested at the PICO laboratory in ice conditions ranging from -50°C to -25°C.

The penetration rate in ice at a temperature of -25°C is 1.6 m/hr. The penetration rate is controlled by the upper hotpoint. The calculated power distribution of 1/4 to the upper hotpoint and 3/4 to the lower hotpoint ensures the proper vertical pendulum steering of the probe. The Australian probe also utilizes a similar power distribution (Morton and Lightfoot, 197-).

The CRREL coil to be used on the prototype was frozen in ice at a temperature of -40°C. The coil was freed after one hour at a current of 4 amperes.

The wall heaters on the exterior of the probe's instrument and coil sections are designed to provide sufficient heat for a complete melt-out after the freeze-in period. The designed flux density of 0.3 watt/cm^2 , at a current of 3 amperes, melts the probe free from the -40°C ice in approximately one hour.

Tests which must be completed before launching the prototype include: (a) overall systems pressure, (b) flowrate of meltwater through the probe when penetration is controlled by the upper hotpoint, and (c) calibration of the conductivity cell.

Acknowledgements

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