Journal of Glaciology, Vol. 32, No. 111, 1986

INSTRUMENTS AND METHODS

A NEW INSTRUMENT FOR DETERMINING STRENGTH PROFILES IN SNOW COVER

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ABSTRACT. The Digital Thermo-Resistograph is a portable microprocessor-based data-probe system for quick and accurate field collection of snow-cover strength. This was accomplished by constructing a probe with a load cell, a small snow platform for probe-position information, and a Z-80 microprocessor-based data acquisition system. A 64 × 240 dot matrix LCD graphic display unit is used to show immediately complete strength profiles in the field. Sufficient memory for the storage of 25 profiles is provided. Temperature and temperature-gradient collection is also planned as a part of the instrument but as yet this work has not been completed.

The results of winter 1984 field tests are presented. The Digital Thermo-Resistograph proved to be fast and reliable in collecting snow-strength information. Comparisons with the ram penetrometer are shown and suggestions for future developments are discussed.

RÉSUMÉ. *Un nouvel instrument pour la détermination de profils de résistance du manteau neigeux.* Le thermo-résistographe digital est un système basé sur un micro-processeur et une sonde pour l'obtention rapide et sure de données sur la résistance du manteau neigeux. Ceci a été réalisé en construisant une sonde avec une jauge de contrainte une petite plate forme pour donner la position de la sonde dans la neige, et un système d'acquisition de données à l'aide d'un microprocesseur Z-80. Un écran graphique 64 × 240 points est utilisé pour visualiser immédiatement le profil de résistance sur le terrain. La mémoire est capable de stocker 25 profils. On envisage aussi la collecte de la température et de son gradient, mais cette adjonction n'a pas encore été faite.

Les résultats des tests de terrain de l'hiver 1984 sont présentés. Le thermo-résistographe digital s'est avéré rapide et sûr pour collecter les données de résistance de la neige. On expose des comparaisons avec le pénétromètre ram et on présente des suggestions pour des développements futurs.

ZUSAMMENFASSUNG. *Ein neues Instrument zur Bestimmung der Festigkeit in Schneedeckenprofilen.* Der Digitale Thermo-Resistograph ist ein tragbares Datengewinnungssystem auf Mikroprozessorbasis für schnelle und genaue Feldbeobachtungen der Schneedeckenfestigkeit. Diese Sonde ist aus einer Ladezelle, einer kleinen Schneeplattform für Daten über die Position der Sonde und einem Datenaufnahmesystem auf der Basis eines Z-80-Mikroprozessors konstruiert. Ein graphischer LCD-Bildschirm mit einer Matrix von 64 × 240 Punkten zeigt unmittelbar im Feld komplette Festigkeitsprofile. Der Speicher reicht für 25 Profile. Die Aufzeichnung der Temperatur und ihres Gradienten ist als Teil des Instruments vorgesehen, aber noch nicht verwirklicht.

Die Ergebnisse von Feldbeobachtungen im Winter 1984 werden vorgelegt. Der Digitale Thermo-Resistograph erwies sich als schnelles und zuverlässiges Gerät zur Feststellung der Schneefestigkeit. Vergleiche mit der Rammsonde werden gezogen und Vorschläge für die künftige Entwicklung diskutiert.

INTRODUCTION

One snow-cover property which is of considerable interest to scientists and avalanche personnel is strength. There are several conventional methods of measuring the strength of snow. The standard instrument found in ski areas and research institutes worldwide is the rammsonde, or ram penetrometer. A relative strength index, or ram number, with the dimension of kilograms, is determined with the rammsonde (Perla and Martinelli, 1976). Gubler (1975) discussed the relationship between the ram number and other snow properties. A device which gives similar information more conveniently is the snow resistograph (Bradley, 1966). It measures the reactive force exerted by the snow on a pair of 60 degree cones attached to a spring. The force is recorded directly on a strip chart.

Another widely used device is the shear frame. It can be used to measure the shear strength between two layers, but it is cumbersome and requires a large number of measurements (Sommerfeld, 1973; Conway and Abrahamson, 1984).

DESCRIPTION OF THE DIGITAL THERMO-RESISTOGRAPH

The Digital Thermo-Resistograph (DTR) is a successful microprocessor-based data acquisition system that digitally records snow strength. The DTR uses a semi-conductor strain gage load cell with a 60 degree cone in the end of a probe for strength measurement. A position-detector platform contains a position sensor which provides a signal every time the probe moves one millimeter. An instrumentation case houses the microprocessor, the interface circuits, and the operator controls and displays. In its current configuration, the DTR can take a strength profile in 1 min and provide immediate graphic display in the field on a 64 × 240 dot matrix LCD graphic display unit built into the control unit. Permanent paper records can be obtained later with an ordinary X–Y recorder, since the strength profiles are stored digitally in memory.

The strength transducer utilizes an isolated hollow aluminum column load cell as shown in Figure 1. A nylon bushing isolates the load-cell column from the cone shaft to

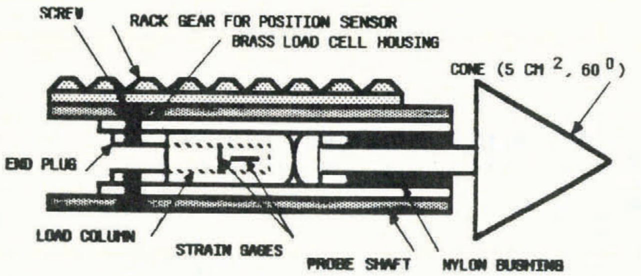

Fig. 1. Schematic of DTR probe showing the cone and load column with semi-conductor strain gages.

guarantee that the load cell is to be subjected only to axial forces. The axial strain incurred by the strain gage under a cone loading of 0.250 MPa is only 68 micro-strain. To measure this small strain, semi-conductor strain gages with a gage factor of 155 were used. The result of this design is excellent linearity and good temperature stability. There are some problems with the shaft icing up, but proper cleaning and preparation has reduced those problems markedly. The strength recorded by the DTR has units of stress and is merely the load measured by the load cell divided by the projected area of the cone.

To measure depth, a round film disk with 90 alternating light and dark sections on the perimeter is used with a source sensor array to create a signal when the sensor shaft is turned. The probe shaft was fitted with a rack gear such that the position sensor receives a signal each time the probe is advanced 1.0025 mm, thereby providing excellent position resolution.

MICROPROCESSOR DATA-ACQUISITION SYSTEM

Hardware

The heart of the data-acquisition system (Fig. 2) is the Z-80 microprocessor (CPU) made by Mostek Corporation (1979). An LM24002G 64 × 240 graphic display unit is used for showing snow-strength profiles in the field. To transfer the profiles to paper in the laboratory, an HP7005B *X–Y* recorder is used.

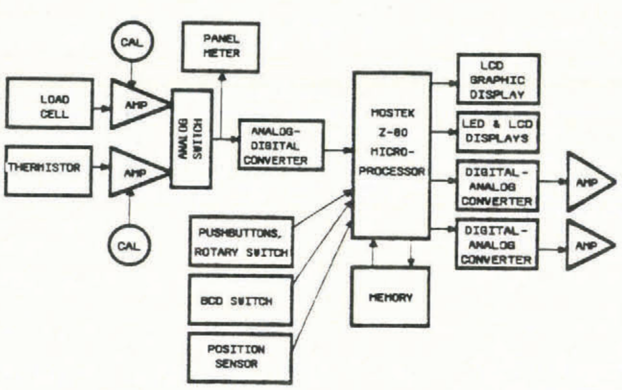

Fig. 2. Block diagram for the Digital Thermo-Resistograph.

To store analog voltage signals, an interface circuit and an eight-bit analog-to-digital convertor (ADC) are used. This device converts a voltage range (in this case 0–4 V) to a number which is proportional to the voltage (e.g. 0 V = 0, 2.2 V = 140). With the 0–4 V range corresponding to zero to a snow strength of 0.250 MPa, there is no round-off involved in displaying the snow strength digitally.

An eight bit digital-to-analog convertor (DAC) is used for the *Y*-axis drive of the *X–Y* plotter with an accuracy of $\pm 10^{-3}$ MPa for strength. A twelve-bit DAC is used for the *X*-axis drive for maximum flexibility in programming. It is usually set for a full-scale range of 2.048 m of depth.

The control panel is illustrated in Figure 3. For operator control, one rotary-function switch, four push-buttons (PB1, PB2, PB3, and PB4), and a two-digit BCD switch are provided. These are interfaced directly to the microprocessor which allows each switch to perform several functions. Two four-digit LCD numeric displays are used for operator prompting. The first (DIS1) displays depth information only, whereas the second (DIS2) displays different variables depending on the function in use. For convenience, an edge-reading panel meter enables the operator to see the strength change faster than a digital display could be read and understood. It also allows for simple checking of transducer operation.

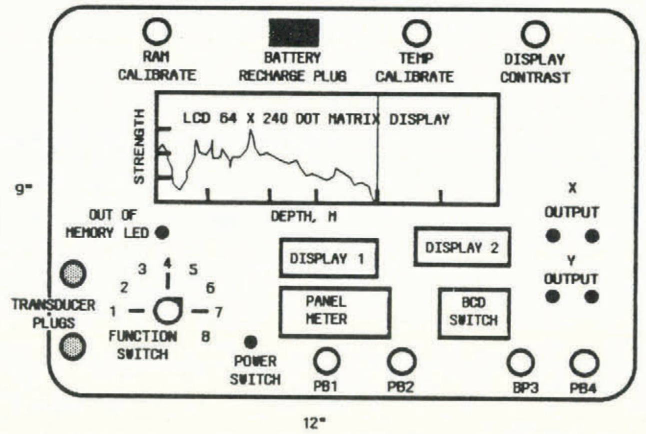

Fig. 3. Control unit lay-out for the DTR.

2k bytes of read-only memory (ROM) are provided for program storage. Data storage is in the form of 10k bytes of low-power CMOS random-access memory (RAM) which is never disconnected from the power supply. The stand-by current drawn from the battery for data-storage memory is low enough so that the battery retains a charge for 2 months without data loss. With 10k bytes of RAM, 25 strength profiles of 2 m depth could be stored. In practice, rarely more than ten profiles were kept at once.

The control unit is housed in an aluminum instrumentation case. The battery charger is an external unit, which is plugged in when needed.

Operation of the Digital Thermo-Resistograph

In its completed form, the DTR will be capable of both strength and temperature profiles. However, since the software for the temperature measurements is not yet completed, only the strength measurements will be described.

Once a site is chosen, the instrumentation case is opened, the position-sensor frame is placed in the snow, and the probe is assembled and connected to the instrumentation case (Fig. 4). The strength transducer is then quickly calibrated and zeroed, which requires only a few seconds to accomplish. The probe is then inserted in the position-sensor frame, the position is zeroed, and with the control unit now ready, button PBI is pushed and the probe is thrust all the way to the ground. The CPU records and stores position and strength. When the ground is reached, button PB2 is pushed to separate this profile from any others which have been or may be taken. The probe may now be withdrawn and the procedure repeated for a new profile.

To display any strength profile, the operator merely switches the function switch to display mode (No. 5), dials in the desired profile number with the BCD switch, and presses PB3. To compare profiles, the operator can dial in a new profile number and again press PB3. Figure 5 shows five profiles superimposed over a ram profile. To clear the screen, PB4 is pushed. At a later time the profiles can all be plotted directly on to paper with an *X–Y* plotter. This procedure is also quite simple and fast. Typically about 3 min are required to generate a 2 m strength-profile plot complete with *X* and *Y* scales.

Evaluation of performance

Figure 4 shows the DTR being used in the field and Figure 5 shows direct comparison of the ram penetrometer with the DTR. In general, they follow each other closely. The blockiness of the ram profile is caused by the nature of the ram-penetrometer data-collection method; i.e. penetration is estimated to the nearest centimeter, and being off by 1 cm can result in a 25% difference in ram number.

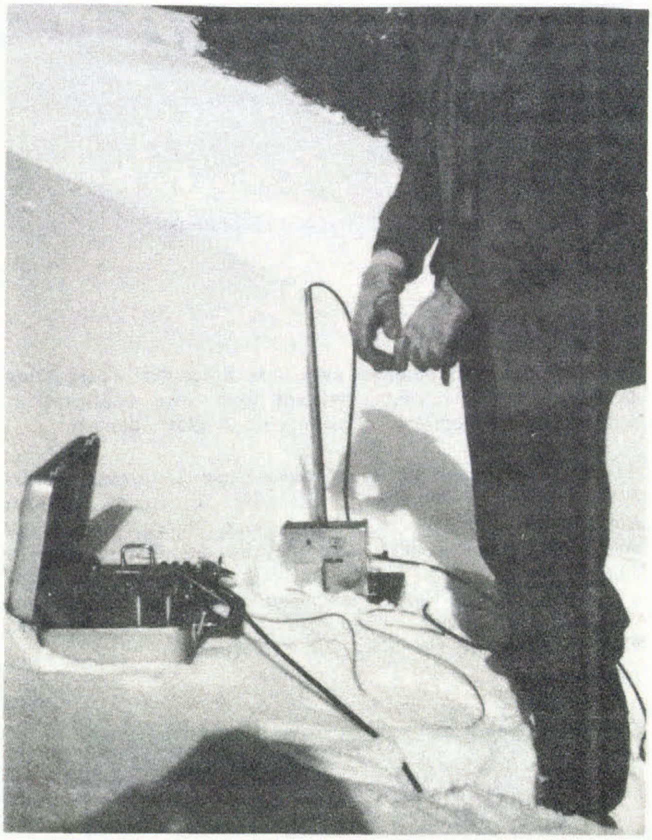

Fig. 4. The DTR in use in the field. The control unit is in the foreground, and the probe has just been inserted into about 1.6 m of snow cover.

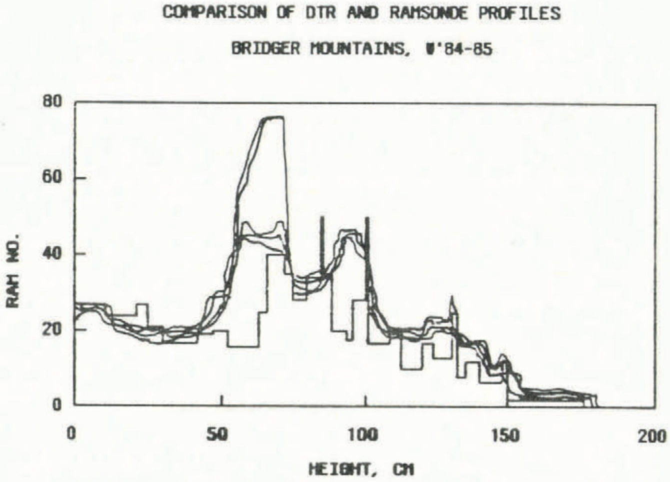

Fig. 5. Comparison of a number of DTR profiles with a rammsonde profile. The smooth curve is from the DTR.

The DTR is capable of fast rise times as evidenced by the steep slope when running through an ice crust as shown in Figure 5.

The DTR generally shows peaks in the same spots but the area in the center shows some wide variation. This was caused by a ski track buried in the snow, since the test area was known to be heavily traveled by Nordic skiers. A ski track would set up a local hard layer, and probing near it would produce the pattern shown in the figure. This figure shows that repeatability between DTR profiles is good.

A number of improvements could be made. One area involves the mode of operation of the position-sensor frame, which could readily be reduced in size, thereby producing a weight saving of about 50% over the current frame. The probe shaft itself could be made much lighter. The present 2.4 kg of probe mass could be reduced in two ways. First, a nylon rack gear could replace the steel rack gear now in use. Also, an aluminum shaft could replace the steel shaft now in use. A weight saving of 70% for the probe would result. With these weight savings, the DTR could prove to be a very compact, light and portable instrument which would fit into a small back pack.

One area that needs to be studied is the effect of varying the rate of probe insertion down into the snow. Bradley (1966) found the optimum with his device to be 10 cm/s. Since these two devices work on essentially the same principle, a study would likely indicate an optimum rate of the same order of magnitude. A preliminary investigation indicated that the response was not very rate sensitive at this value of 10 cm/s, which would require only about 20 s to probe a 2 m deep snow cover. However, a more thorough investigation is needed before final conclusions can be reached.

ACKNOWLEDGEMENT

The work reported here was supported by the National Science Foundation grant No. CEE-8318476 and ARO grant No. DAAB19-92-K-0127.

REFERENCES

Bradley, C.C. 1966. The snow resistograph and slab avalanche investigations. *Union de Géodésie et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Commission pour la Neige et la Glace. Division Neige Saisonnière et Avalanches. Symposium international sur les aspects scientifique des avalanches de neige 5–10 avril 1965, Davos, Suisse,* p. 251-60. (Publication No. 69 de l'Association Internationale d'Hydrologie Scientifique.)

Conway, H., *and* Abrahamson, J. 1984. Snow stability index. *Journal of Glaciology,* Vol. 30, No. 106, p. 321-27.

Gubler, H.U. 1975. On the Rammsonde hardness equation. [*Union Géodésique et Géophysique Internationale. Association Internationale des Sciences Hydrologiques. Commission des Neiges et Glaces.*] *Symposium. Mécanique de la neige. Actes du Colloque de Grindelwald, avril 1974,* p. 110-21. (IAHS–AISH Publication No. 118.)

Mostek Corporation. 1979. *1979 microcomputer data book.* Carrollton, TX, Mostek Corporation.

Perla, R.I., *and* Martinelli, M., *jr.* 1976. *Avalanche handbook.* Fort Collins, CO, U.S. Department of Agriculture. Forest Service. (Agriculture handbook 489.)

Sommerfeld, R.A. 1973. *Statistical problems in snow mechanics.* Fort Collins, CO, U.S. Department of Agriculture. Forest Service, p. 29-36. (General Technical Report RM-3.)

MS. received 9 September 1985 and in revised form 31 January 1986