



A New instrument for determining strength and temperature profiles in snowpack
by Timothy Francis Dowd

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Engineering Mechanics
Montana State University
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Abstract:

The purpose of this thesis project was the development of a new field instrument for determining strength and temperature profiles in snowpack. The standard tool now used for strength determination is the ram penetrometer, which is slow, cumbersome, inaccurate, and does not provide immediate results. Temperatures are generally taken with a dial stem thermometer in a snowpit wall, which is difficult to do accurately at specific intervals. The Digital Thermo-Resistograph was designed and built in an attempt to improve field snowpack data collection.

The Digital Thermo-Resistograph is a portable microprocessor-based data acquisition system for quick and accurate field collection of snowpack compressive strength and temperature data. This was accomplished by building a probe with a load cell and thermistor, a small snow platform for probe position information, and a Z-80 microprocessor-based data acquisition system. The system provides information in digital form for every sampled point. A 64 x 240 dot matrix LCD graphic display unit is used to show complete strength and temperature profiles in the field. Provision is made to transfer these profiles to paper via an ordinary X-Y recorder for a permanent record of field data. Sufficient memory for the storage of 25 profiles is provided.

The results of winter 1984 field tests are presented. The thermistor could not be made- to work accurately, and so was not integrated into the system. The Digital Thermo-Resistograph proved to be fast and reliable in collecting compressive snow strength information, which is measured from 0.0 to 2.55 kg/sq cm at five mm increments through the snowpack. Comparisons with the ram penetrometer are shown. Ideas for future developments are discussed.

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MONTANA STATE UNIVERSITY
Bozeman, Montana

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ABSTRACT

The purpose of this thesis project was the development of a new field instrument for determining strength and temperature profiles in snowpack. The standard tool now used for strength determination is the ram penetrometer, which is slow, cumbersome, inaccurate, and does not provide immediate results. Temperatures are generally taken with a dial stem thermometer in a snowpit wall, which is difficult to do accurately at specific intervals. The Digital Thermo-Resistograph was designed and built in an attempt to improve field snowpack data collection.

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Chapter I

Introduction

The mountain snowpack is of interest to ski areas, winter mountaineers, climbers, hydrologists, scientists, and others. From the first day that snow falls, the mountain snowpack is a dynamic ground cover that often presents a hazard in the form of avalanches. Naturally occurring snowpacks generally exhibit a complex stratigraphy composed of individual layers of snow with different properties (Perla, 1975). This layering is caused by changing weather and snowstorm conditions. For example, an ice layer or hard crust can result from wind action or sun-induced melt-freeze cycles. Surface hoar and graupel are examples of thin, weak layers which are caused by very different meteorological conditions. Additionally, once the snow is on the ground, it metamorphoses due to temperature gradient induced vapor transport in the snowpack itself.

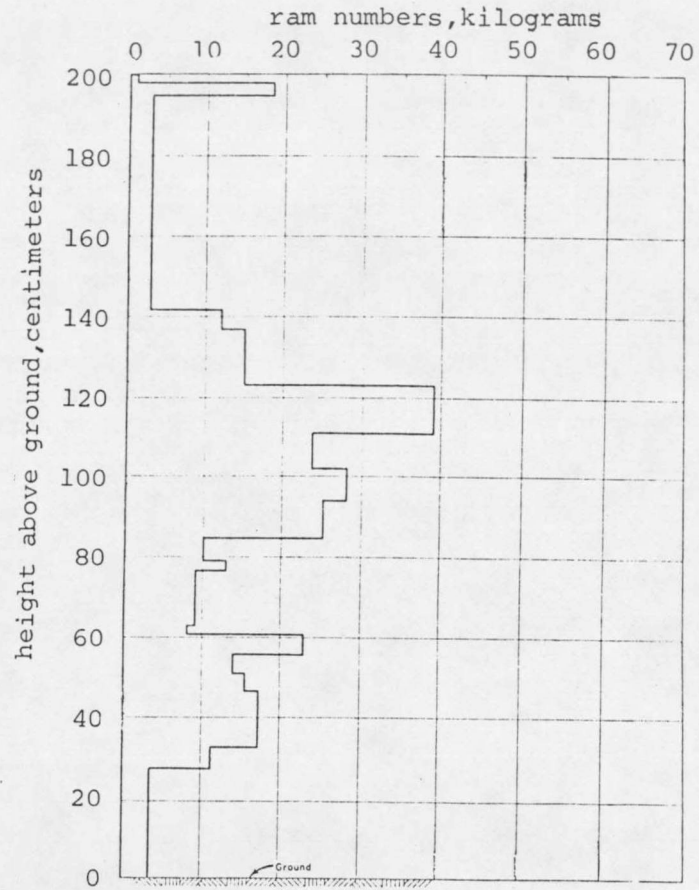
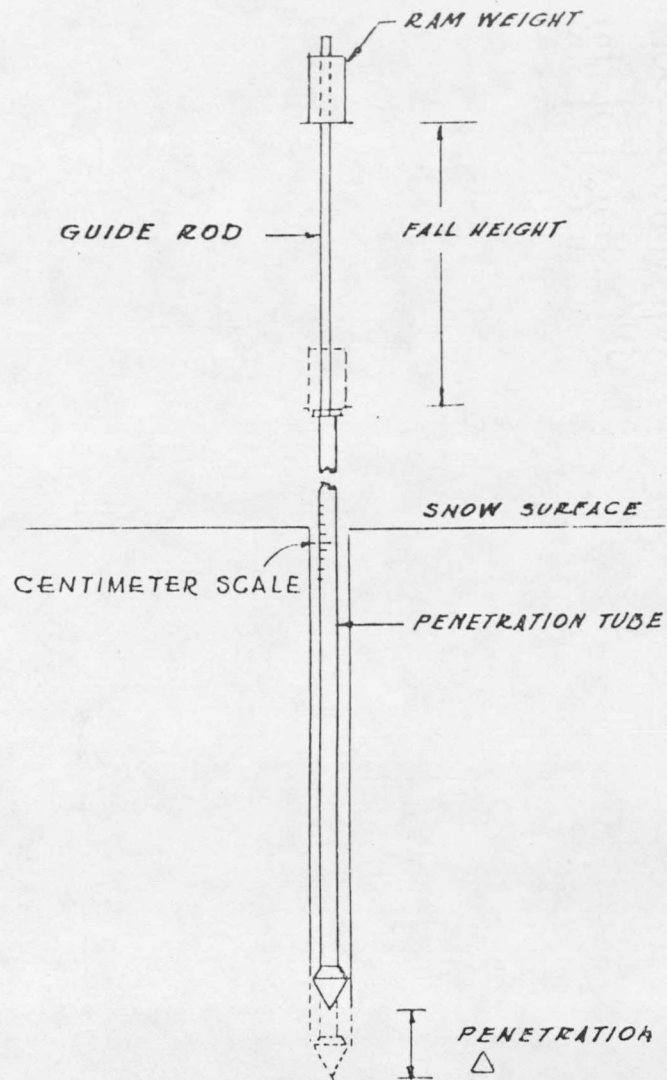
One snowpack property which is of considerable interest to scientists and avalanche personnel, and the subject of this thesis, is strength. The three types of strength that can be measured in snow, as in most materials, are compressive, tensile, and shear strength. There are several conventional methods of measuring the compressive strength of snow, which is of great interest. The standard instrument found in ski areas and research institutes worldwide is the Rammsonde, or ram

penetrometer (Figure 1). This device consists of a tube with a 60 degree cone on the end, a centimeter scale down the shaft, and a ram weight on a guide rod used in a slide hammer fashion. The cone angle of 60 degrees is standard for use in compressive snow strength measurement. A relative strength index, or ram number, with the dimension of kilograms, is determined by the equation shown in the figure. The ram number is plotted on graph paper to illustrate the relative strength profile of the snowpack.

The problem with the ram penetrometer method of strength measurement is the high error content of information taken from the snowpack. This problem results largely from the tedious nature of the process, which can take fifteen minutes for a single profile. There is an ever-prevalent tendency to drop the ram weight from a greater height than necessary, resulting in deeper penetrations per drop and consequent lower resolution. Also, reproducibility of a ram penetrometer profile is low.

Another problem with using the ram penetrometer is the lack of provision for an immediate strength profile in the field. It must be drawn up later, after the operator has returned from the field, typically after several hours. It is generally considered that a ram penetrometer profile takes an hour from data collection to final graphic preparation. A faster method is needed in order to collect better, more useful data in the time available.

Dr. Charles Bradley, a geologist at Montana State University, developed a strictly mechanical device that produces strength profiles quickly in the field (Figure 2; Bradley, 1966). It measures the reactive



$$\text{Ram number} = Q + R + \frac{N \times H \times R}{\Delta}$$

Q = weight of tube(s), KG

R = weight of ram, KG

N = number of blows

H = fall height of ram, CM

Δ = penetration in N blows, CM

Figure 1. The ram penetrometer, the ram number formula, and a sample ram profile.

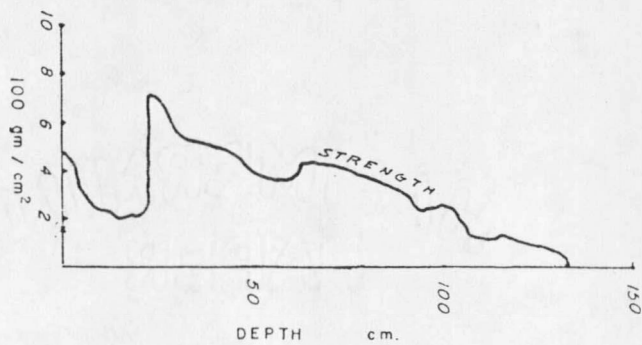
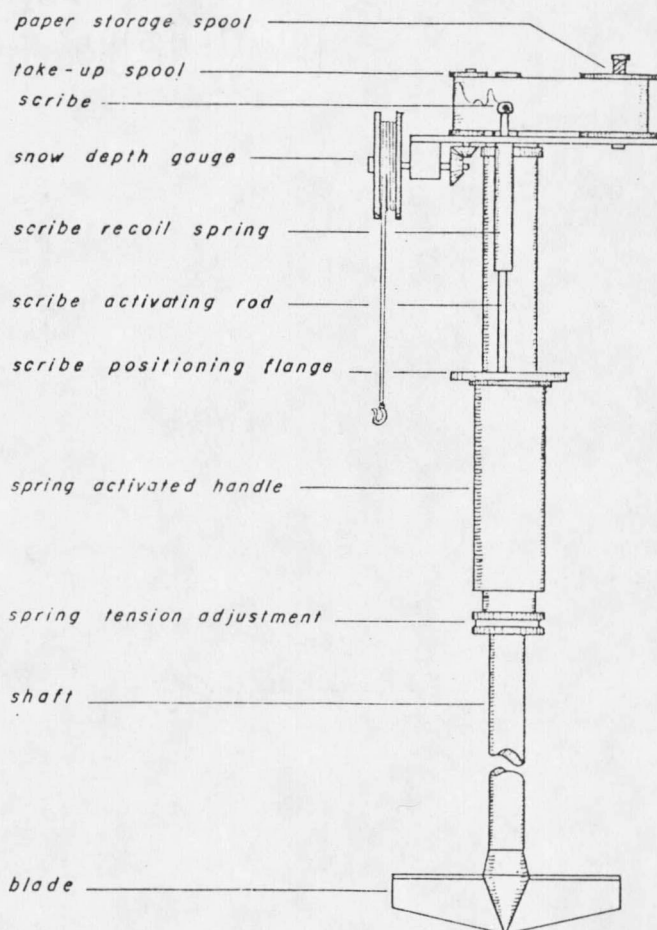


Figure 2. The Bradley Resistograph, with sample Resistogram.

force exerted by the snow on a blade (later a pair of 60 degree cones) attached to a spring. The machine is used by pushing the blade down to the bottom of the snowpack, rotating it 90 degrees about the vertical axis, then retracting the assembly back up through the snowpack. The spring deflection is recorded on paper which is driven by a cord attached to the boot of the operator, which turns a drum while the device is being pulled up through the snow. The paper is then read directly by the operator to find the compressive snow strength in units of kg cm^{-2} .

Since only five Bradley Resistographs were sold by MSU, the device was apparently not well received. The pressure sensitive paper used is narrow, hard to read, and the markings are easily obscured by rough handling. The requirement that the probe be pushed to the bottom of the snowpack and twisted before being retracted for measurement meant that the snow sample under consideration was often disturbed before the instrument could be used. Also, the strength of the bottom layers (often up to five centimeters thick) is not recorded on steep slopes.

A number of other obscure devices have been designed and built for measuring snow strength. The most widely used of these devices is the shear frame. It can be used to measure the shear strength between two layers, but is cumbersome. At MSU some have tried to use a handheld hardness guage with an oversize tip for use on a snowpit wall. None of these methods has gained wide acceptance.

Clearly, a new approach to snow strength measurement was needed. Duain Bowles, a technician at MSU, made the first attempt at constructing a device that would take a continuous electronic

measurement of the snow compressive strength profile (Figure 3). He used a load cell built into the end of a probe with a 60 degree cone for force measurement. A position detector platform was built with a hand crank and ten-turn potentiometer for position sensing, which attached to a roller that ran against the shaft of the probe. This potentiometer provided the horizontal axis drive for a storage oscilloscope. The vertical beam deflection was to indicate strength, and permanent records were to be taken with a camera.

While a step in the right direction, this device never made it to the field. The design of the load cell was too responsive to off-axis forces, and the roller used against the probe was unable to track position accurately. What was needed was the development of the idea of continuous strength measurement, as this device attempted, into an accurate and reliable lightweight field instrument. This early device was the basis for the Digital Thermo-Resistograph, the subject of this thesis.

The Digital Thermo-Resistograph (DTR) is a successful microprocessor-based data acquisition system that digitally records compressive snow strength. The DTR uses a semiconductor 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. Temperature measurement with a thermistor in the probe end was attempted, but there was insufficient time to develop this idea. In its current configuration, the DTR can

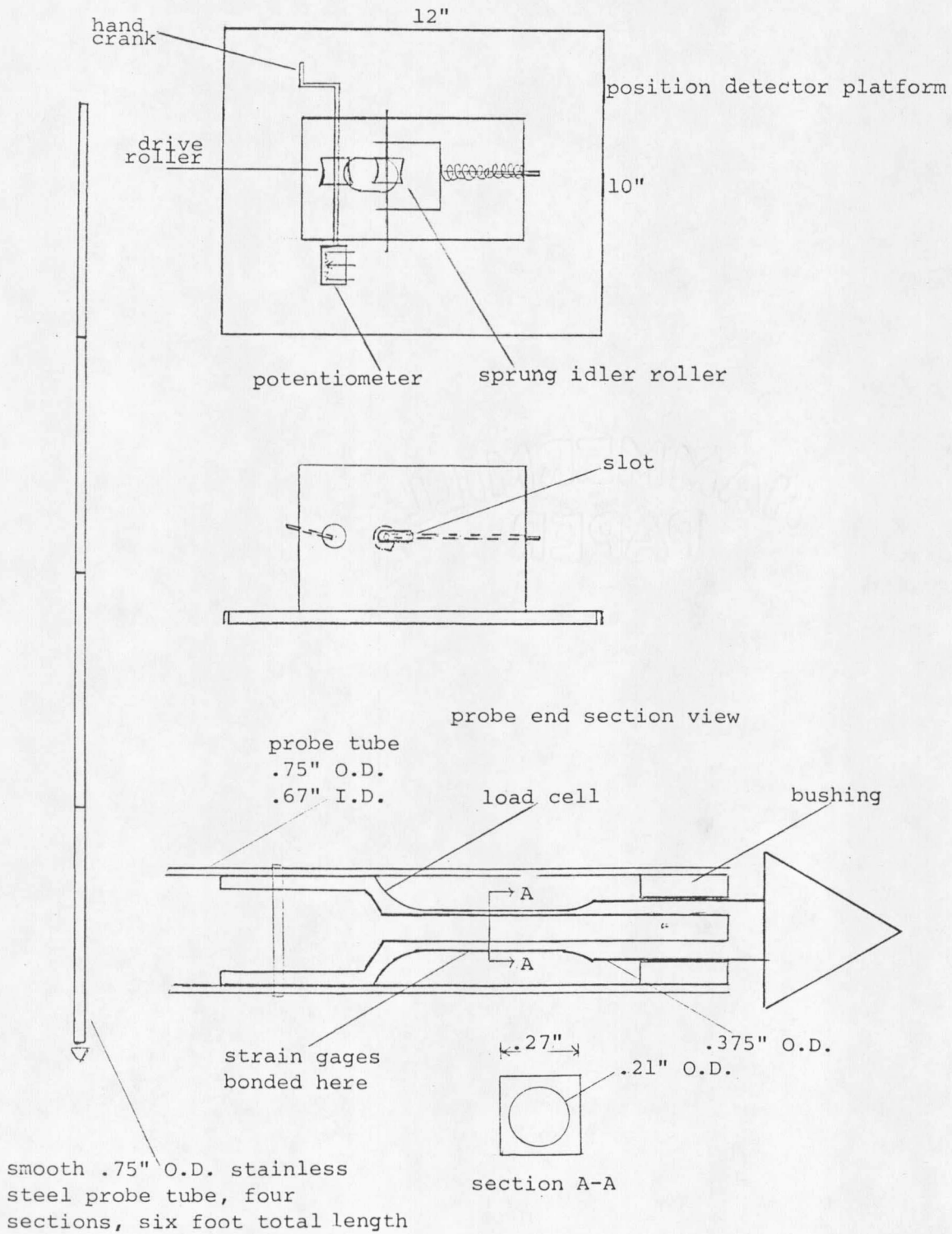


Figure 3. The Duain Bowles snow strength device.

take a strength profile in one minute and provide immediate graphic display in the field on a 64 x 240 dot matrix LCD Graphic Display Unit built into the control unit. Permanent paper records can be kept with the use of an ordinary X-Y recorder.

The organization of chapters loosely follows the chronological development of the DTR. In order, they are: transducer development, microprocessor data acquisition system development, results and conclusions (ideas for future developments are discussed here), and summary.

Chapter II

Transducer Development

The first part of the DTR development was the design and construction of the transducers. The three devices required were a load cell to measure force on a 60 degree cone at the probe end, a position sensor to measure the vertical penetration of the probe into the snowpack from the snow surface, and a device to measure the temperature of snow. Development of these transducers represented 50 percent of the time invested in the project since the first several transducers which were tried proved to be unworkable.

Strength Transducer

The first transducer to be developed was the load cell to measure the snow reactive force on a 60 degree cone with a projected area of five square centimeters. The device that Duain Bowles built did not work well for two reasons. First, the load column where the strain gages were bonded was not isolated from bending moments that could be introduced by transverse loads applied to the cone (Figure 3). Second, the material and shape of the load column caused problems. The use of stainless steel combined with the large column cross-sectional area meant that very little straining of the column would occur at the force levels expected. High amplifier gain was required with a resulting

extremely low signal-to-noise ratio. This load cell arrangement never made it to the field.

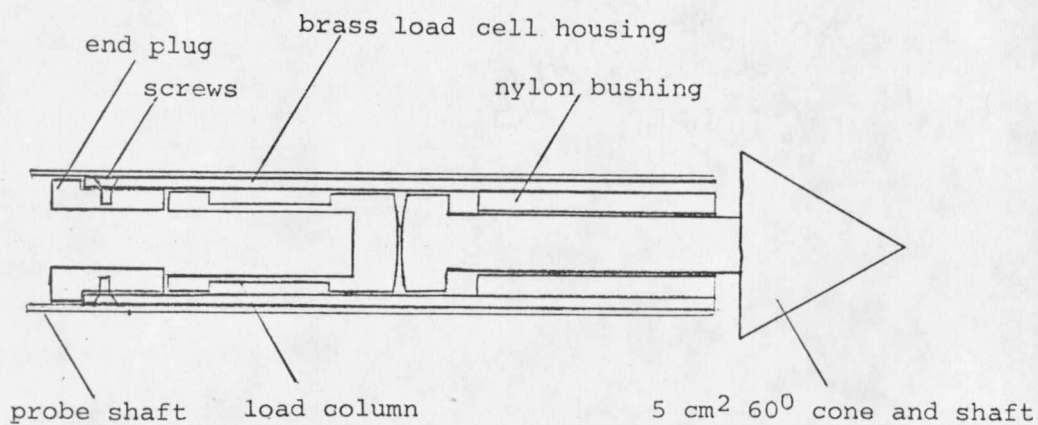
The first attempt at acquiring an appropriate load cell for the strength transducer was in the commercial marketplace. Over 100 letters were sent to manufacturers, resulting in 25 responses of which two were positive. One firm's offer was extremely expensive. It involved a \$3400 design fee and purchase cost of \$3500 per unit, while the other product included an unusable change to the design. The design feature of the DTR which was difficult for commercial devices to fill was that it must fit inside the 0.750" O.D. tubing at the probe end and work in a cold, wet environment.

Since the commercial market could not provide a suitable device affordably, the next attempt was with pressure transducers. Dr. R. L. Brown at MSU had successfully used an Endevco 8510-1000 pressure transducer with the diaphragm filled with silicone rubber to measure shock waves in snowpack. Using this transducer, an attempt was made to install a piston and cylinder so that the pressure transducer was measuring a true fluid pressure by the cone shaft acting on the fluid in the cylinder. These devices invariably leaked. Another configuration attempted was a shaft running into the pressure transducer directly with silicone rubber as an intermediary. A reasonable load cell was made this way, with a non-linear force to voltage transfer function. This load cell was used three times in the field with the incomplete data acquisition system until it was found broken. At this point, the idea was dropped.

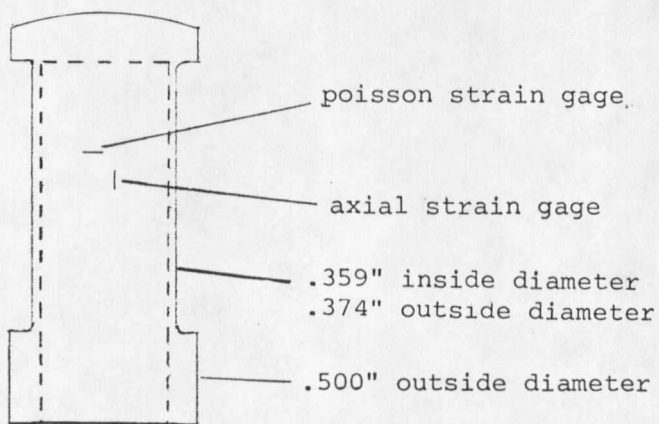
The next design attempted was an isolated hollow aluminum column load cell, similar in several ways to the Duain Bowles device (Figure 4). Isolating the load cell column from the cone shaft guaranteed that the load cell would be subjected only to axial forces. The column dimensions shown were picked as a compromise to fit several constraints. It had to be large enough in diameter for the poisson gage to be bonded to it. The wall thickness was as thin as could be practicably machined and yet withstand overloads from abuse of the probe. It was made of aluminum which will strain three times as much as a similar steel device with the same load. Even with these features, the axial strain incurred by the strain gage under a cone loading of 2.55 kg cm^{-2} was only 68 microstrain. To measure this small strain, semiconductor strain gages with a gage factor of 155 were used. The result of this design was an excellent linear transfer function and good temperature stability (Figure 5). There are some problems with the shaft icing up, but proper cleaning and preparation has reduced those problems markedly.

Position Detection Transducer

The system Duain Bowles used for position detection suffered from several flaws. The first and most important was that the potentiometer shaft experienced slip relative to the probe shaft while the probe was being cranked into the snow. This loss of accuracy was on the order of 50 percent. The second problem was that the potentiometer had a free run of ten turns, after which it had to be turned back to zero for snowpacks deeper than 0.8 meters. For use with the screen of an oscilloscope this was reasonable, but a better device which would have



section view of probe tip



load column
6061-T6 aluminum

Figure 4. Digital Thermo-Resistograph load cell.

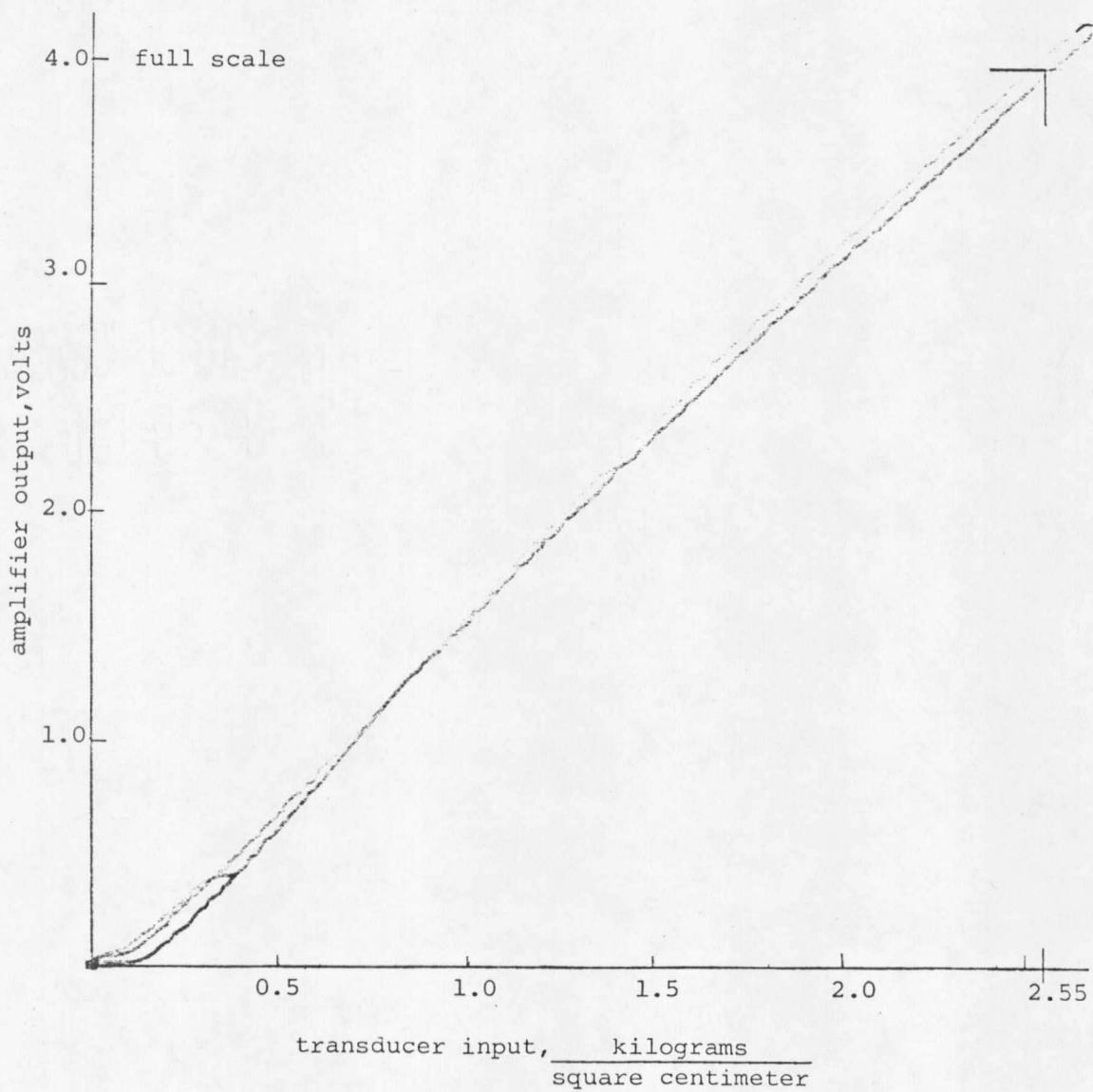


Figure 5. Digital Thermo-Resistograph load cell transfer function.

no limitation on snowpack depth other than the probe length was needed.

For position detection the DTR uses a round film disk with 90 alternating light and dark sections on the perimeter with a source sensor array to create a signal when the sensor shaft is turned (Figure 6). The probe shaft was fitted with a 1/4" x 24 rack gear, and the position sensor shaft had a 24 x 27 spur gear such that one signal from the source sensor array was 1.0025 millimeters. The rack gear was the difference that solved the friction and accuracy problem. The system occasionally fails to measure any depth when the source sensor array or film disk presumably becomes covered with water vapor or ice due to unfavorable climatic conditions. It has, however, generally worked reliably.

Temperature Transducer

The last device to be built was the temperature transducer. A linear thermistor was fitted into the probe end outside of the shadow of the cone. The idea was that the probe would be put at a particular position in the snowpack, and then the operator would wait for thermal equilibrium to be established before storing the measurement. The problem with this idea was that there was so much thermal mass in the probe itself that thermal equilibrium with the snow would take ten to 20 minutes or more, an unreasonable length of time. This part of the DTR was not finished.

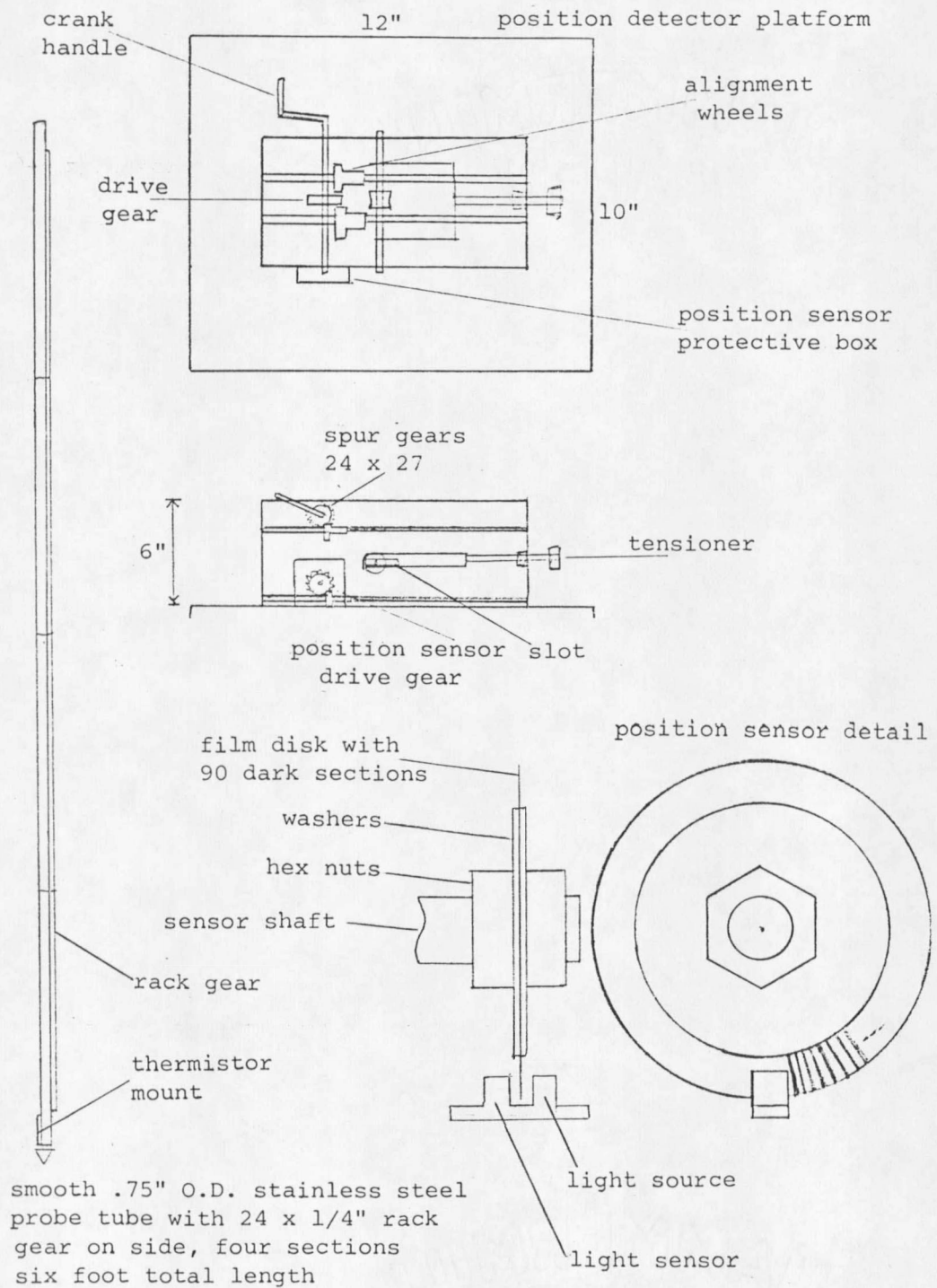


Figure 6. Digital Thermo-Resistograph probe and position sensor.

Chapter III

Microprocessor Data Acquisition System

Once the transducers were providing useful information, a system was required to effectively store, display, and distribute this information. The Duain Bowles device employed a storage oscilloscope for this purpose. This oscilloscope is heavy, requires AC power or a large battery pack, and can only store snow strength profiles with a camera. A data acquisition system was needed to provide immediate graphic snow strength data, and to create a permanent record. It was decided to use a microprocessor in the DTR to carry out these functions due to its low cost, ease of programming, and an available variety of devices which are compatible with such a system.

Hardware

The heart of the data acquisition system (Figure 7) is the Z-80 microprocessor (CPU) made by Mostek (Mostek, 1979). It is an eight bit device with up to 64k bytes of addressable memory, up to 256 I/O ports, and a good reputation for reliability. A significant factor in the decision to use this CPU over others is the software support of the HP64000 development system available in the Electrical Engineering Department at MSU. The HP64000 provides file editing, assembly, PROM programming, emulation, and debugging utilities all in one console. Software development is covered in the next section.

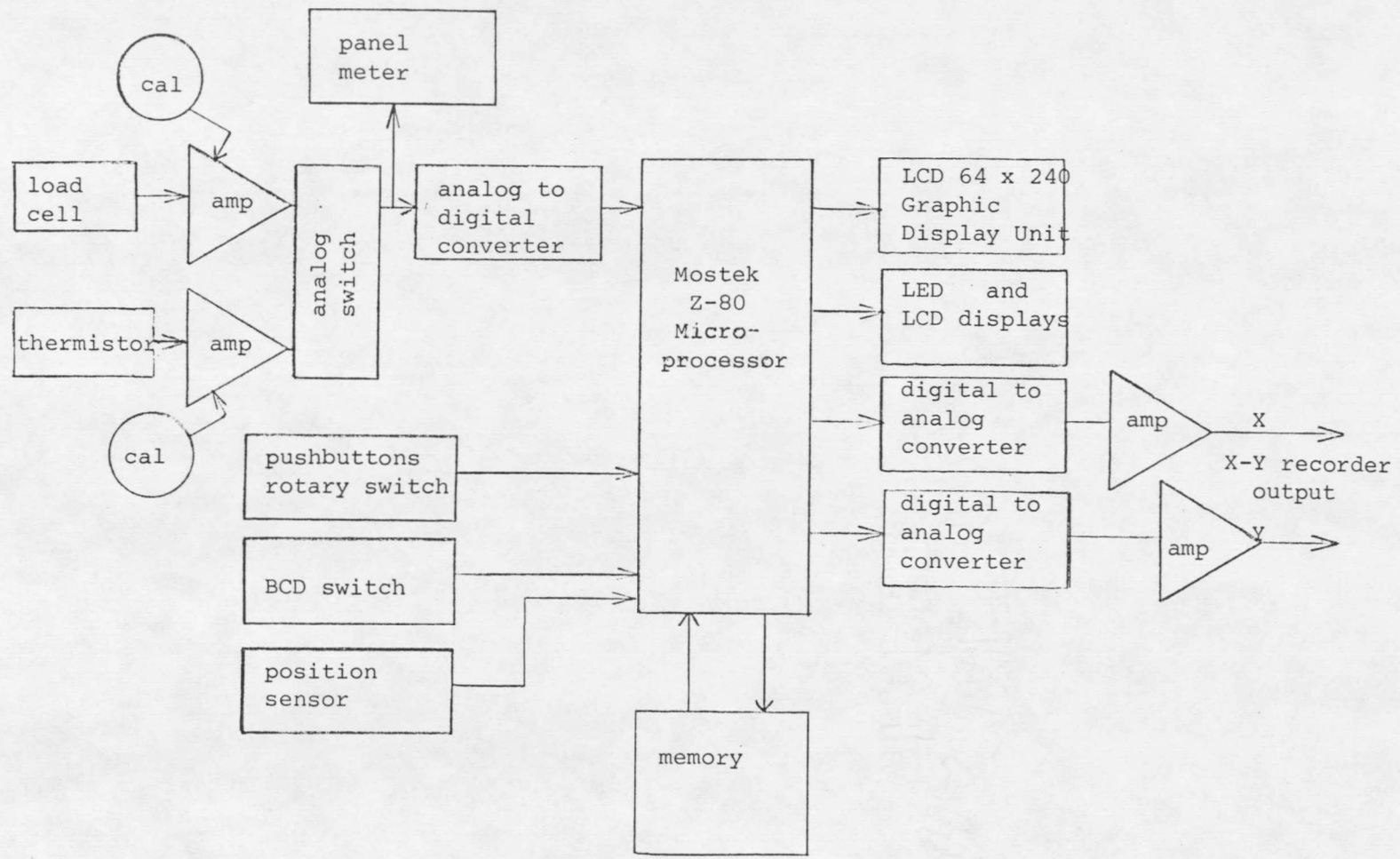


Figure 7. Digital Thermo-Resistograph block diagram,

To meet the criterion of having immediate graphic output in the field for snow strength profiles, a search was made for a field strip chart or X-Y recorder. Due to the environmental conditions of the winter mountains, ink pens used in such recorders proved to be unworkable since the ink does not flow well at low temperatures. Another problem is frost buildup on moving parts, and the capacitive displacement transducers used in many units freeze below zero degrees Celsius. One field X-Y recorder, the Allen Datagraph Model 600, was found to be capable of handling these conditions and more down to -30 degrees Celsius. It would have cost \$1800, weighs 24 pounds, and blowing snow would still have resulted in wet recorder paper and other complications.

The DTR program was stalled at this point until a random input led the author to Sharp Electronic Corporation's new line of large scale LCD dot matrix displays. It was then decided to use an LM24002G 64x240 Graphic Display Unit (\$220) for showing snow strength profiles in the field. To transfer the profiles to paper in the laboratory, an HP7005B X-Y recorder already owned by the Department of Civil Engineering and Engineering Mechanics was used. The LCD Graphic Display Unit was a new product, was poorly documented, and was difficult to interface to the DTR. In addition, the company ignored the author's letter requesting help. However, the unit worked perfectly once these difficulties were overcome. It was rated to -20 degrees Celsius and since it used no moving parts, it had none of the problems of the previously proposed field recorder or the paper used in the Bradley Resistograph.

To use a digital microprocessor system to store analog voltage signals, an interface circuit and an analog-to-digital converter (ADC) are required. The simplest ADC for use in an eight-bit microprocessor is one with the same eight bit resolution. This device will take a voltage range (in this case 0 to 4 volts) and assign a number to the input voltage from zero to 255, the range of numbers in eight bits, based on the proportion of the voltage to the range (e.g. 0 volts = 0, 2.2 volts = 140). With the zero to four volt range corresponding to zero to 2.55 kg cm⁻² snow strength on the transducer, there is no roundoff involved in displaying the snow strength digitally. Temperature was handled much the same way, with the zero to four volt range corresponding to a +1.0 to -24.5 degrees Celsius temperature range.

To drive the X-Y recorder, two digital-to-analog converters (DAC), with associated amplifiers, were used. An eight bit DAC was used for the Y axis drive for strength and temperature, which amounts to total loss of accuracy of one least significant bit, or 0.01 kg cm⁻² of strength or 0.1 degree Celsius (1/256 of full range). A twelve-bit DAC was used for the X axis drive for maximum flexibility in programming. It was usually set for a full scale range of 2.048 meters of depth.

For operator control, one rotary function switch, four pushbuttons (PB1, PB2, PB3, PB4), and a two-digit BCD switch were provided. These are interfaced directly to the microprocessor which allows each switch to perform several functions depending on how the program resident in the system looks at it. Two four digit LCD numeric displays were used for operator prompting. The first (DIS1) displayed depth information only, whereas the second (DIS2) displayed different

variables depending on the function in use. For convenience, an edge reading panel meter was provided to be able to see the strength or temperature change faster than a digital display could be read and understood. It allowed for simple checking of transducer operation.

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

The control unit is housed in a Zero Corporation Centurion Elite Model 100X (9"x 12"x 5") aluminum instrumentation case (Figure 8). The battery charger was an external unit, which was plugged in when needed. The integrated circuits were placed on two wire wrap boards, each with a 44 pin edge connector on one side. The entire circuit was wire wrapped together, consuming approximately 400 feet of wire. It was later found that this construction method was the cause of several problems, and any future version of this device should have printed circuit boards made for it.

Software

The software for the DTR transforms a box of parts into a useful instrument with some intelligence to carry out tasks as programmed. The program in the DTR uses about 500 lines of Z-80 assembler language. The

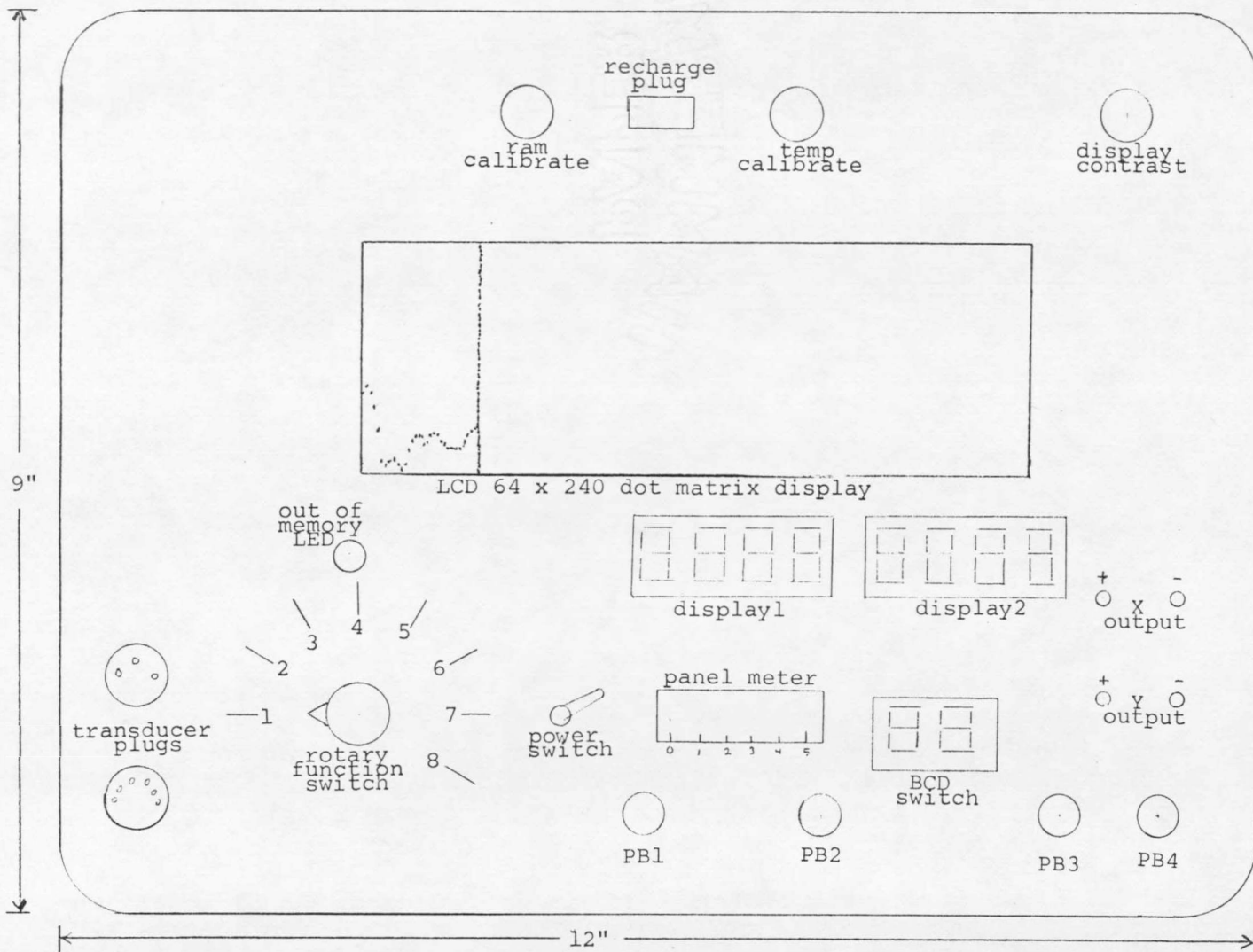


Figure 8. Digital Thermo-Resistograph control unit layout.

total program length is only 1k bytes, which speaks both for the efficiency of assembler language and for the magnitude of the programming effort required for larger systems. The DTR microprocessor system operates in a real time environment and therefore runs continuously while the power is on. It responds to operator instructions and so is generally looking to certain switches for prompting. The program is organized into eight sections of which five are written and running. The other three were to be involved with temperature measurement. The program section to branch to is determined by the position of the main function switch. If the switch is changed in the middle of a function, that function is aborted. The program is written so that the main function switch can be rotated at will and nothing will be disturbed, since further action of some sort is always required to carry out a function.

The data is stored in memory as one long sequential file of numbers starting at address 1800 (Figure 9). The first two bytes (the header) at the top of the data storage memory form the number of bytes used in that first strength profile. This is followed by the stored actual snow strength data starting with the surface on down, with a stored reading corresponding to each five millimeters of depth. At the end of this set of numbers, which is found only by counting down to it, the next profile header is kept with the number of readings kept for it. Profile number is implied by the number of profiles preceding it. In this way the full capacity of available memory is utilized, and virtually any depth strength profile can be recorded. Free space is found when a header of zero is found, which is where the next profile

| Address | Bit | Function |
|------------------------------|-------|---|
| 0000 ↓ 07FF | | Program read only memory |
| 0804 0805 0806 0807 | | Display 2 least significant digit second digit third digit most significant digit |
| 0808 | | Eight bit analog to digital converter input |
| 0810 | | Eight bit digital to analog converter output for Y axis X-Y recorder drive |
| 0820 0840 | B0-B3 | Twelve bit digital to analog converter output for X axis X-Y recorder drive, upper four bits Lower eight bits for above |
| 0880 | | Eight bit output latch |
| | B0 | LED (unused) |
| | B1 | LED (unused) |
| | B2 | LED (unused) |
| | B3 | LED out of memory |
| | B4 | relay load cell or thermistor input to ADC (unused) |
| | B5 | (unused) |
| | B6 | Position increment for Display 1 |
| | B7 | Position clear for Display 1 |
| 0900 | | Eight bit input latch |
| | B0-B2 | Rotary switch |
| | B3 | Pushbutton 1 |
| | B4 | Pushbutton 2 |
| | B5 | (unused) |
| | B6 | Pushbutton 3 |
| | B7 | Pushbutton 4 |
| 0A00 | | BCD switch input |
| 1000 17FF | | LCD graphic display unit transparent random access screen memory |
| 1800 ↓ 37FF | | Strength and temperature profile random access memory storage |

Figure 9. Digital Thermo-Resistograph control unit memory map.

will be put. When memory space is filled up, the out-of-memory LED is lit, and no more data will be stored.

Section one of the program is calibrate strength mode. In this mode the panel meter indicates the voltage from the strength transducer, and DIS2 displays the strength value updated every 2/3 of a second. The DIS1 display shows depth read from the position sensor, and can be zeroed by pushing PB2. This is useful for checking for proper operation and setting the zero point of the strength transducer. It also allows the operator to see how deep the snowpack is if desired. Memory is never written to in this mode.

The next section is temperature calibration mode. It works much the same way as section one, except that temperature information is displayed instead. This mode was used to determine that the first attempt at measuring temperature needed work, since the thermistor and amplifier response was erratic and extremely slow.

Section three is strength profile collection mode. When first switched to this mode, DIS1 is zeroed and DIS2 shows the number of strength profiles already taken. When the operator is ready to take a new profile, he pushes PB1. Now DIS2 displays the profile number assigned to the profile now being taken, DIS1 shows the depth constantly updated as the probe goes down, and the meter shows the output from the transducer. The operator at this time is pushing the probe down into the snowpack through the position sensor set on top of the snowpack. The CPU is counting each millimeter, and every time five millimeters have gone by it polls the ADC for a reading from the strength transducer. This reading is then stored in the next available

space in memory, and the two byte number in the profile header is incremented by one. When the probe reaches the ground, the operator pushes PB2 or turns the function switch. When this action is done, data collection stops, DIS1 is zeroed to indicate that the switch was successfully pushed, and the program reverts back to the same place as at the beginning of this paragraph.

Section four was to be temperature data collection mode. This function was to work by the operator running the probe down through the position sensor to where the temperature was to be measured, wait for the transducer to settle out, and then an LED was to prompt the operator to move the probe down for a further reading. This section has not been written.

Section five is review and display mode. One method of strength profile review is to display actual digital values of position and strength on DIS1 and DIS2, respectively. The profile number of interest is dialed into the BCD switch whence DIS1 displays position and DIS2 displays strength at that position. These displays show strength starting at the ground which is shown as 0.000 meters. Higher positions are reached by alternately pushing PB1 and PB2 to move by five millimeter increments (e.g. push PB2 to reach 0.005 meters, PB1 for 0.010 meters, PB2 again for 0.015 meters, etc.). If both PB1 and PB2 are held down simultaneously, the displays are continuously incremented through that profile at the rate of 0.050 meters per second. When the end is reached, it wraps around to the beginning of the profile at 0.000 meters.

The second method of profile review is to display the complete strength profile graphically on the LCD Graphic Display Unit. When first switched to review/display mode, the display shows a random pattern of dots, so the operator needs to push PB4 to clear it completely. As above the profile number of interest is dialed into the BCD switch. When PB3 is pushed, the strength profile indicated on the BCD switch is displayed on the screen. Since there are 64 dots in the Y direction and the strength data is in the form of an integer number from zero to 255 inclusive, the strength number is divided by four to determine its Y value. In the X direction, left screen is considered the ground, and every dot right represents ten millimeters so that every other data point collected is displayed. At the end of the line drawn, at right, a vertical line is drawn to accent the top of the snowpack. To directly compare profiles, all the operator needs to do is to dial up another profile number on the BCD switch and press PB3. This can be done for any number of profiles, but after about three profiles are displayed simultaneously, it becomes rather confusing as to which profile is which. Anytime the operator wants to clear the screen to start over, he pushes PB4 again.

The next section is plot mode wherein the profile dialed into the BCD switch is transferred to paper via an X-Y plotter. The LCD screen display is on with what was left after review/display mode was last used. To calibrate the plotter, the X and Y drives are set to their zero position with 0.0 volts. For the operator to set the maximum X and Y deflection for the paper size in use in the plotter, PB3 and PB4 are used. When PB3 is pushed, the X axis drive is set to its maximum of 2.0

volts, with same procedure holding for the Y axis drive and PB4. When PB1 is pushed, the program assumes that the operator has calibrated his plotter, has installed paper and the pen is down, for now the axes are drawn. First the X axis is drawn, with tick marks every ten centimeters of depth. The pen comes back to zero and draws the Y axis with tick marks every 0.5 kg cm^{-2} strength. The pen goes back to the first strength value and proceeds to plot the strength profile. When the end is reached, everything stops to wait for the operator to lift the pen. The operator then pushes PB2, which sends the pen back to the origin. Plot mode is the one and only mode where once it is started, all switches are ignored until the function is done. Three minutes are typically required to plot one strength profile.

Section seven was to be used for plotting temperature gradients. The program would have performed the computation from its own database and plotted the result. This section has not been written.

Section eight is used to erase the memory. Due to the serial form of data storage, individual erasures and saves could not be carried out. When it is needed, the entire memory is cleared by being filled with zeros. Due to the importance of this function, the program requires that both PB1 and PB2 be pushed simultaneously for erasure to occur.

There are an infinite number of ways to program a CPU to manipulate devices such as are found in the DTR. The method of operation arrived at here was found by trial and error with consideration given to user friendliness and efficient use of resources, along with talking with potential users to get their ideas on how best to use the machine.

Chapter IV

Results and Conclusions

The first several weeks of DTR operation were beset with what appeared to be fatal problems. A problem that defied solution for several weeks was to go out into the field, collect some interesting data, and then for the control unit to lose all of that data because of some real time CPU problem before plotting could be accomplished. After much investigation of the software looking for errors, none could be found. It was decided, on speculation, to divide the one megahertz CPU clock rate by two, yielding a 500 kilohertz clock rate, to see if there was any difference. This action solved all of these previously observed problems. The cause appears to be due to the use of wire wrap circuit construction, which introduces extra capacitance into the data and address buses. Excessive capacitance increases the settling time of those lines. If there is insufficient settling time allowed, a digital one can be read as a zero and vice versa, which immediately sends the CPU into an unknown state.

Another problem was strictly mechanical in nature. The machine shop that installed the nylon bushing in the load cell (Figure 4) did not restrain it well enough at first. When the probe was pushed down into the snow and retracted, the bushing, cone, and shaft were lost at the bottom of the snowpack. Installation of a set screw solved this

problem: Correcting the mechanical problem delayed the DTR development by two weeks while new parts were manufactured.

When these problems were resolved, too little time remained for the collection of sufficient data for a serious statistical study of the capabilities of the DTR. Figures 10 through 13 show all of the snow strength comparisons between the DTR and ram penetrometer that were taken, presented in chronological order.

Figures 10 and 13 show three direct comparisons 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 ram penetrometer data collection method; i.e. penetration is estimated to the nearest centimeter, and being off by one CM can result in a 25 percent difference in ram number. The DTR is capable of fast rise times as evidenced by the steep slope when running through the supposed ice crust as shown in Figure 10, top. Figure 10, bottom, shows a "garbage oscillation" of the ram profile at the bottom of the snowpack which the DTR did not see. This type of layering is not observed in the bottom of a late season snowpack, and shows the problem of reading the centimeter scale on the ram penetration tube accurately.

Figure 11 is a comparison between a single ram profile and multiple DTR profiles taken in a close area. The DTR generally shows peaks in the same spots, but the area in the center shows some wide variation. This has been hypothesized to have been 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 show the pattern shown in the figure. This

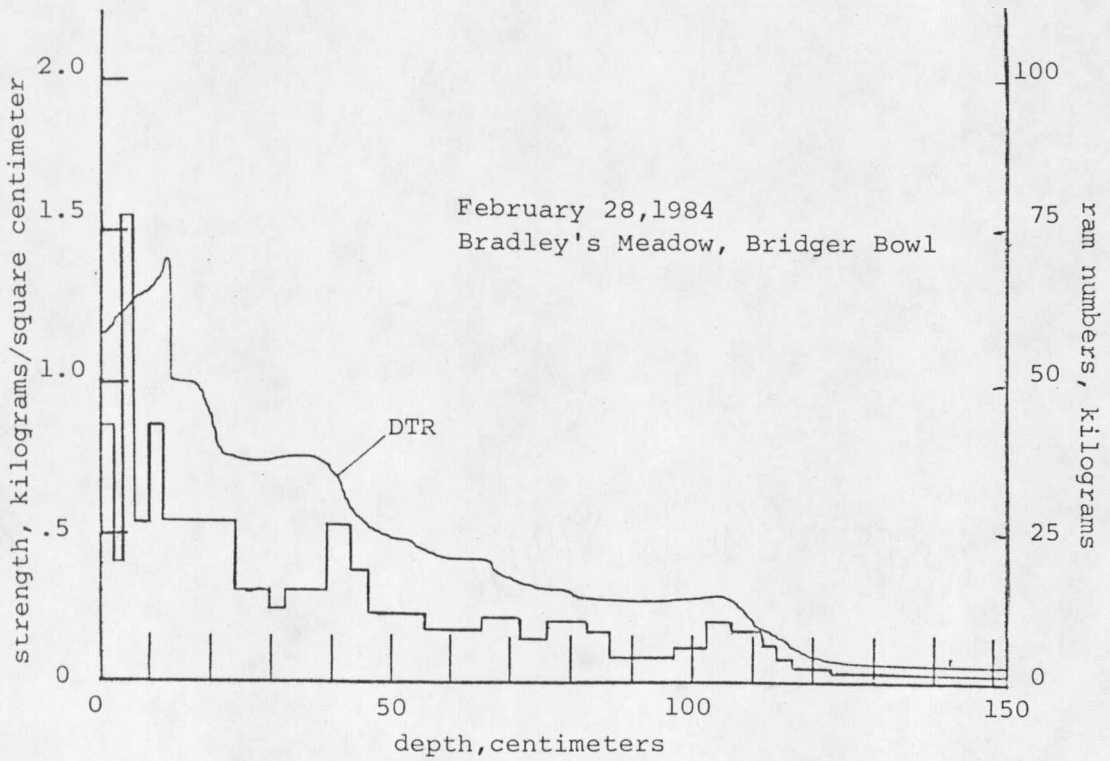
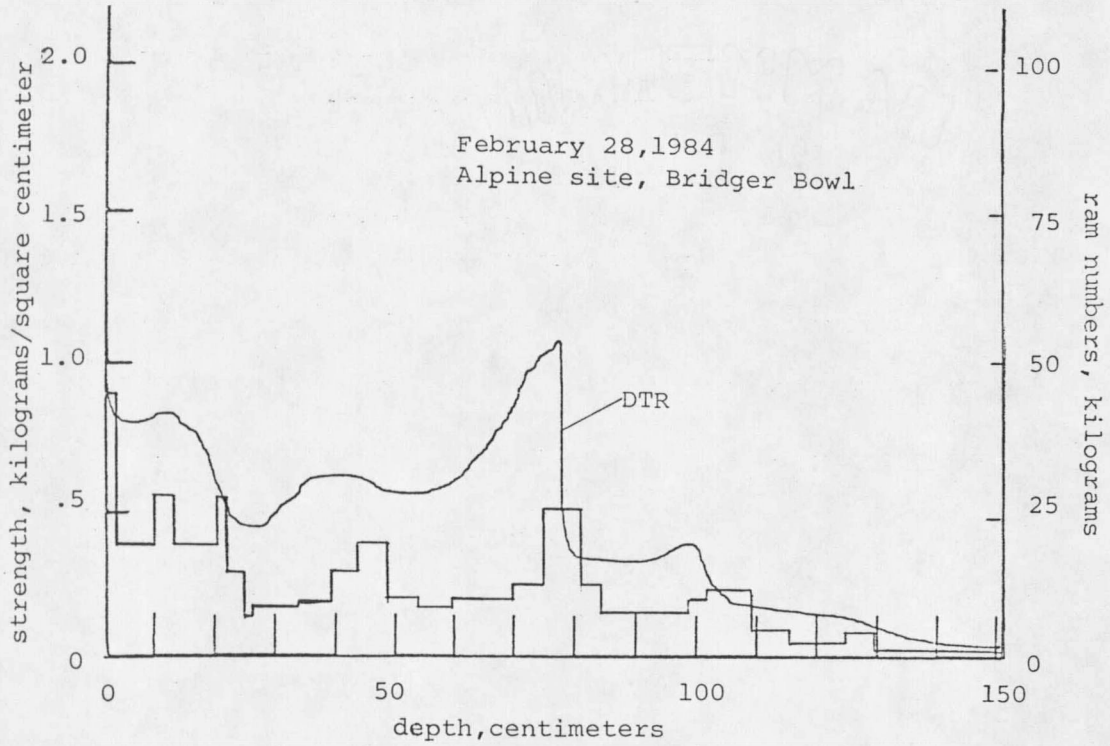


Figure 10. Snow strength measurement comparisons.

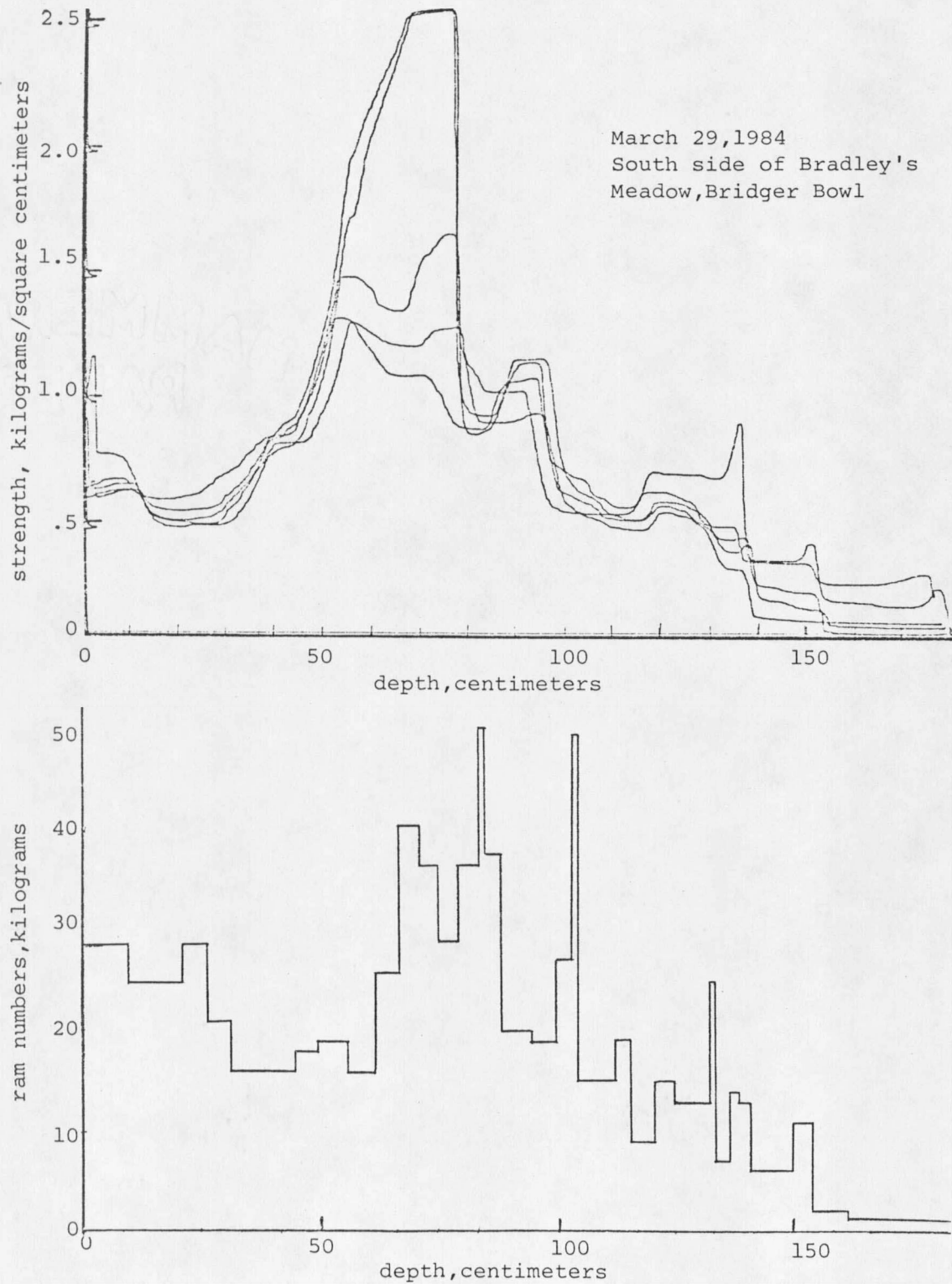
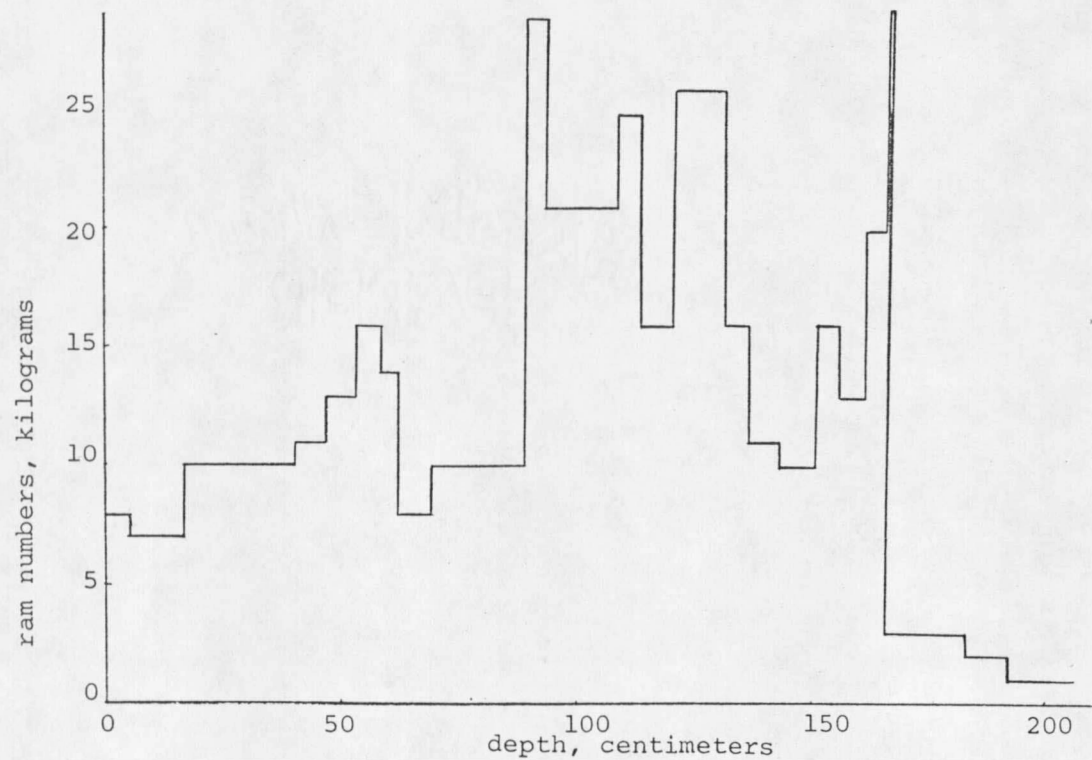
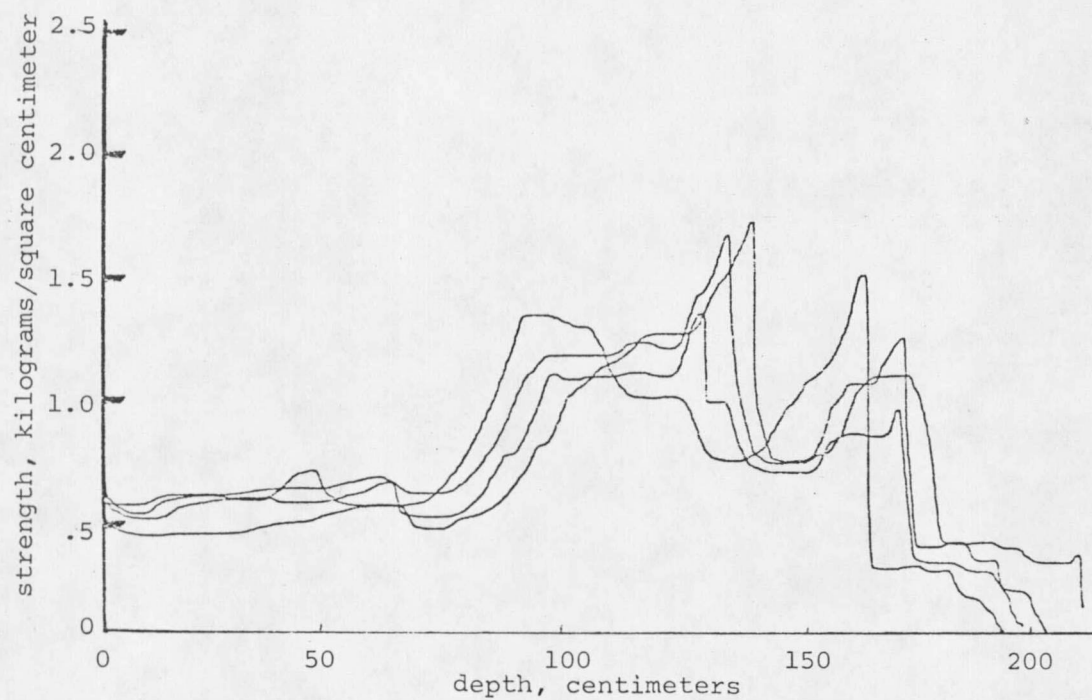


Figure 11. Snow strength measurement comparisons.



April 3, 1984
Alpine site, Bridger Bowl

Figure 12. Snow strength measurement comparisons.

April 5, 1984
North of North Meadows run
Bridger Bowl

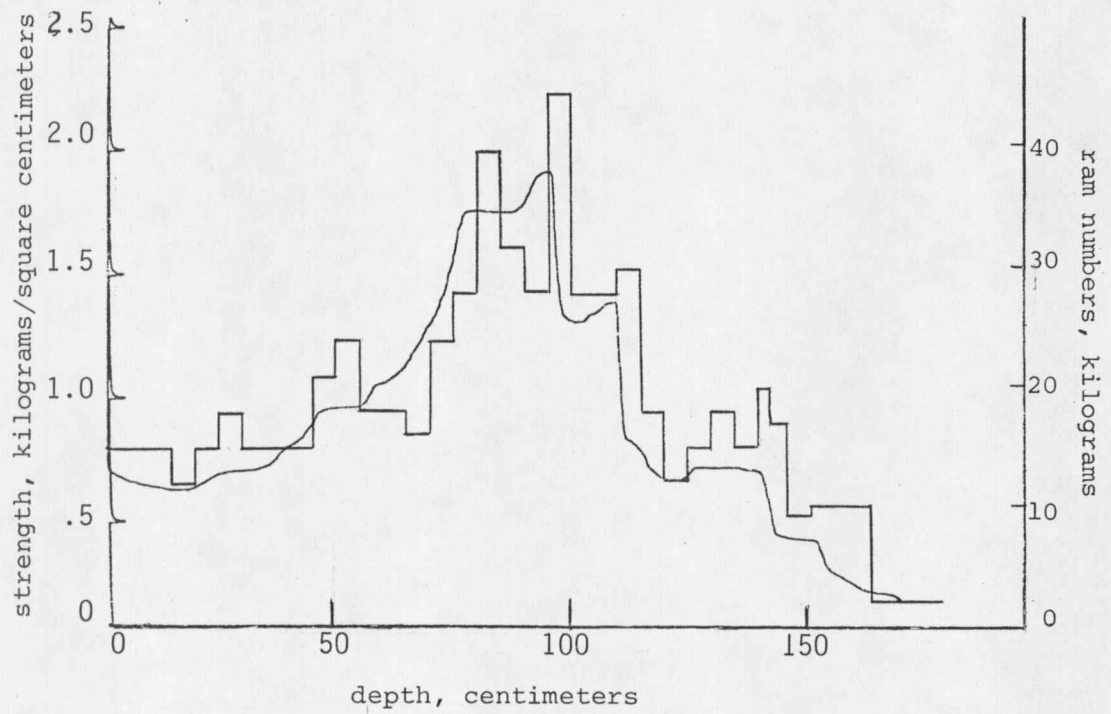


Figure 13. Snow strength measurement comparison.

figure shows that repeatability between DTR profiles is good, as long as the snow is consistent.

Figure 12 is a similar test to the one profiled in Figure 11. This test site was near a tree, so that close alignment is not to be expected due to uneven ground underneath. There is more variation in the magnitude of the peaks, but being close to a tree in and of itself can cause this phenomenon. This phenomenon is caused by the increased heat flow due to the presence of the tree, increasing the rate of metamorphic processes, which results in large random variations in strength nearby.

In general one can say that the profiles are similar, with strong and weak layers in the same places in the snowpack. To arrive at more significant conclusions, more investigation is needed. One line of thought would follow Dr. Bradley's ideas (Bradley, 1966). In that paper he was correlating strength in the units of kg cm^{-2} to the snow load above that point in the same units to check for avalanche possibilities. The failure mechanism proposed was that when the snow load above a layer exceeds its strength, the resulting collapse causes an avalanche.

The HP7005B X-Y recorder that the Department of Civil Engineering and Engineering Mechanics had for use with the DTR was out of calibration and had problems with drift and inadequate small-deflection response. This could be seen in the irregularities of the DTR profiles. The tick marks are uneven, the pen does not rezero accurately, and other problems occurred, all of which affected the accuracy of the final profiles as can be seen in the figures. A different recorder

without these problems, or rebuilding this recorder, would deliver the accuracy the DTR is capable of.

One possible solution to the X-Y recorder problem would be to add a serial interface onto the data acquisition system so that the information in the memory could be transferred directly to a mainframe computer. This could then be plotted on a high quality plotter, such as are available on the VAX computer used by some in the department. This possibility requires a minimum of electronics but could consume a substantial amount of program space that may not be available in the present configuration of the DTR.

A number of other improvements could be made. One area involves the mode of operation of the position sensor. In the present configuration, there is a crank with a spur gear to drive the probe into the snow, with two sets of alignment wheels, along with the position sensor and related shaft on the platform. At first, the instrument was used by setting up the probe in the platform, setting up the control unit, and then cranking the probe down. When the probe hit a hard crust, the platform would rise instead of the probe going down. Since it was hard to keep enough pressure on the platform to prevent upward motion without pushing it further down into the snow, this mode of operation led to inaccuracies. The mode of operation that evolved was to push directly on the probe, with the position sensor dragging on the probe a small amount. This drag is much more easily supported by the snow. The platform therefore needs only to support the position sensor and one smaller set of alignment wheels. The weight could be reduced by 50 percent.

The probe shaft itself could be made much lighter. The present 2.4 kilograms of probe mass for two meters of length could be reduced in two ways. The first involves the rack gear, since it is made of steel, which was chosen for both availability and strength required to drive the probe down into the snow as mentioned above. Since the rack gear now only turns the position sensor, a lighter nylon or plastic rack and spur gear set could be used. This would also eliminate the rust problem. The probe could also be lightened by using a thinner shaft such as the aluminum tubing used in ski poles. Several ski pole ram penetrometers are in use that are strong enough and weigh 70 percent less, such as are available from Life-Link Inc. of Jackson Hole, Wyoming.

The electronic circuitry itself needs to be improved by the design and installation of printed circuit boards instead of the wire wrap construction now used. One failure involved the loss of one-half of the LCD Graphic Display Unit screen. This was traced back to an integrated circuit that was no longer conducting from its pins to the wire wrap socket. The solution was to clean the pins and socket, and reinsert the chip. Soldered connections as found in printed circuits would have prevented this problem.

The method for review of actual digital values of strength is cumbersome. The present system requires the operator to alternately push buttons to ascend through the profile memory. It would be more convenient to have one button ascend at some rate, and the other button descend. This way, an operator could find the local maximum and minimum strengths much more easily. This requires a hardware change, since DIS1 is not interfaced directly to the CPU as an addressable

memory location such as DIS2. DIS1 is driven by an up only counter, which simplified the counting and display of the position sensor input. The change would be to make DIS1 similar to DIS2, and some software to carry out the counting function would have to be written. The position sensor output now goes to both the counter and the interrupt line of the CPU. With a suitable program it only needs to go to the CPU.

One area that needs to be studied is the effect of varying the rate of probe insertion down into the snow. Dr. Bradley found the optimum with his device to be ten centimeters per second. Since these two devices work on essentially the same principle, a study would likely indicate an optimum rate of the same order of magnitude.

Naturally, the temperature sensor needs work. A thermistor which is more thermally isolated from the probe shaft would help a great deal in improving the response time.

Chapter V

Summary

The Digital Thermo-Resistograph is a successful portable microprocessor-based data acquisition system for collecting compressive snow strength profiles in the field. It is capable of taking and graphically displaying snow strength profiles from snow cover in a few minutes. Later, when the operator has returned to his laboratory, permanent paper records can be made with the use of an ordinary X-Y recorder.

A brief history of previous devices for collecting snow strength information is presented. The ram penetrometer, the conventional tool for use in the field, is tedious to use, inaccurate, and takes a great deal of operator time. It does not provide immediate graphic output, which must be prepared by hand later, out of the field. The Bradley Resistograph is fast, portable, and provides immediate graphic output, but was not a complete success. The paper output was hard to read and smudged easily, and other complications made it not completely satisfactory. The device Duain Bowles worked on was a step in the right direction, but was not completed.

A detailed look at the hardware and software in the DTR is presented. A load cell in the end of a probe uses high performance semiconductor strain gages to measure the small forces involved in snow

strength measurement. The position of the probe relative to the top of the snowpack is found with an optical source-sensor array and a film disk on a shaft running against the probe. Temperature information was to be collected with a thermistor mounted in the probe end, but it could not be made to work well in the time available.

The software in the DTR transforms a box of parts into a working system. The details of internal operation of the system is presented. Operator interaction with the various buttons and switches determines the mode of operation of the DTR at any given time. Instructions for DTR use are discussed.

The results from Winter 1984 field tests at Bridger Bowl, Montana are presented. Difficult development problems prevented a serious statistical study of the capabilities of the DTR. Qualitative comparisons are made with the ram penetrometer, the standard tool found worldwide today. There is also a short discussion of the repeatability of the instrument.

While the DTR works well in its present configuration, changes could be made to improve operation and reliability. Printed circuit boards to replace the present wire-wrap construction should be designed and built. A number of smaller details, such as the use of I/O ports instead of the memory-mapped I/O should be considered. Reworking the temperature probe to decrease the settling time and noise needs to be done. When a successful temperature probe is made, the appropriate software could then be written.

The potential uses of the DTR are many and varied. Accurate correlated strength and temperature information will allow better

studies of temperature gradient metamorphism of snow in the field. For avalanche personnel, more accurate records of the snowpack through the season would improve snowpack stability evaluations. An interesting project would be to keep a detailed record of snowpack conditions with the DTR of an avalanche area, and see if reliable predictions of avalanche activity can be made from a statistical analysis of several season's results.

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