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INSTRUMENTATION FOR THE PICO DEEP ICE CORING DRILL

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Abstract: An electronic data collection and control system has been developed for the PICO 13.2 cm deep ice coring drill. It monitors a variety of drilling parameters including inclination, depth, temperature, pressure, RPM, weight and others. It also displays this data for the drill operator and allows the operator to control speed and direction of the drill motor. The display program allows setting limits on all parameters so an alarm sounds if anything goes wrong. This instrumentation package will be described and some of the data collected with it will be discussed.

1. Introduction

The first version of this Instrument Package was reported on at the Ice Drilling Workshop which was held at Grenoble, France in 1988 (HANCOCK and KOCI, 1989). It has gone through several redesigns and updates in the intervening 5 years. Three of the mechanical relays have been replaced by solid state devices and we are in the process of designing out the last one. New lower power devices have been incorporated to decrease the power draw of the electronics by a factor of three. Container redesign has eliminated O-Ring failures (so far). And, a total of four microprocessors in the system have allowed a simultaneous real time readout of all drilling parameters on the operator's computer screen as well as alarms to warn him of problems.

2. System Description

Due to the great length of cable (≈ 4 km) used with this drill, and the limited size and number of electrical conductors in the Kevlar reinforced cable, it is difficult to get the required power (≈ 3 kW) to the drill. Figure 1 shows a block diagram of the electrical and electronic systems. The resistive losses in the cable are reduced by transforming our AC power up to as much as 1120 vac to put into the cable, and then transforming that down to 120 vac in the drill. This is rectified in the instrument package to provide DC power to the drill motor. The problem with AC power is that it does not allow for reversing the rotation of the drill motor. A reversing relay is included in the instrument package (I.P.) and is controlled by a microprocessor which switches the direction of rotation of the drill upon commands from the control panel at the surface. This microprocessor is also used to collect a great deal of data concerning the operation of the drill and communicate this data back to the surface. The conductors in the cable that are used for this serial data link had to be shielded to minimize the interference due to the high voltage power being carried by other conductors in the same cable.

The pulley at the top of the tower has a shaft encoder attached which measures the amount of cable payout to determine the depth of the drill.

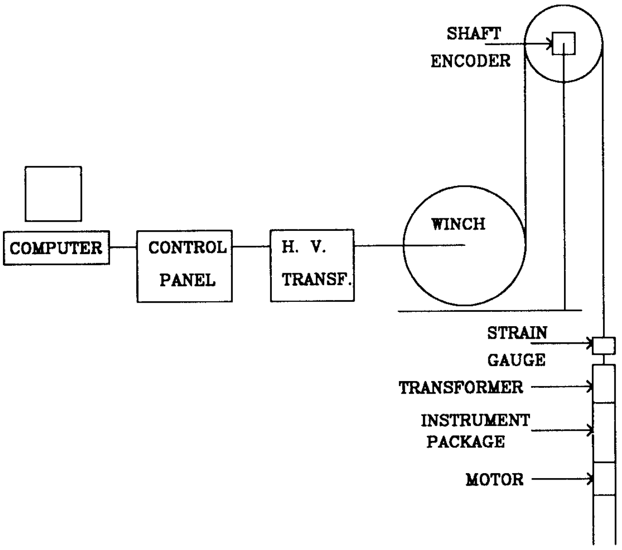


Fig. 1. Block diagram of the electrical and electronic systems in the drill.

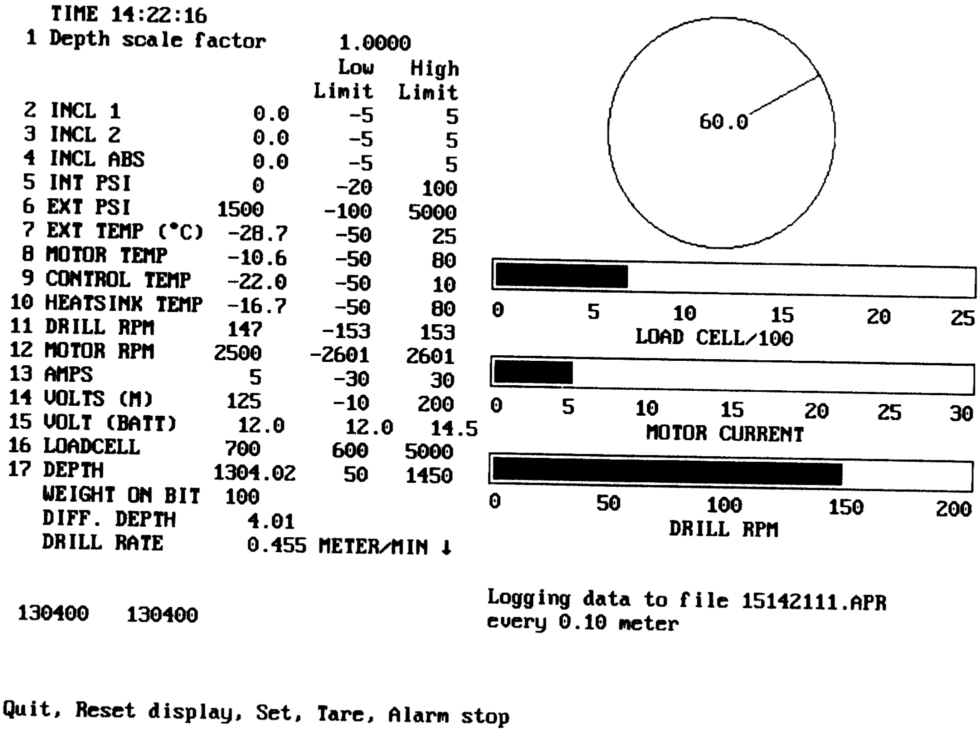
The I.P. container is a structural part of the drill and is approximately 1.7-m long. It is made of 1.58-cm thick aluminum to withstand downhole pressures which may reach 31 MPa in Greenland. The electrical feedthroughs are made of fiberglass reinforced epoxy and are rated to withstand 138 MPa. The microprocessor in the drill is a variant of the 8051 made by Intel Corporation. It controls, in addition to the motor reversing relay, a solid state relay that can shut off power to the drill motor while leaving power available to charge the battery and run the sensors and data acquisition circuitry. The speed of the drill motor is controlled by the operator at the surface using a variac to vary the AC voltage going to the drill. Since this voltage can vary all the way down to zero, a battery is required in the I.P. to provide continuous power to the circuitry. When the AC voltage is set above approximately forty percent of maximum, there is enough voltage to provide the needs of the electronics circuitry while also recharging the battery. There is a circuit that automatically controls a solid state relay to prevent overcharging the battery. To minimize battery drain, the microprocessor can turn off power to the sensors and data collection circuitry when no data is required by the operator at the surface. The solid state relays that can control the DC currents to charge the battery and power the sensors are recent developments that are made possible by the low resistance power mosfets that are now available.

The data collection system is made up of low power cmos versions of the industry standard type 574 twelve bit analog to digital converter and type DG506 sixteen channel multiplexer. The microprocessor steps to each of the 16 input channels, initiates an A/D conversion, stores the resulting data and when all channels have been read, it transmits the data to the control panel at the surface.

The program in the drill microprocessor is comparatively simple. All it has to do is wait for a command or interrogation from the control panel, execute the command to stop or reverse the drill motor, collect the data from the sensors, and send it back to the control panel.

The control panel is built around the same 87C51 type microprocessor that is in the drill but the program in the control panel is much more complex. It has to count every pulse from the shaft encoder so it can calculate depth. It has to monitor all the switches on the control panel to execute the operator's commands. It has to do all the timing to execute the simplex bidirectional communication with the drill as well as store the most recent data from the drill. Since it was designed to be a stand alone control panel, it also has to do the calculations on the raw data from the drill to convert it to useful numbers that it can display on its LED readout. It also is able to send the raw data out over a serial link to a microcomputer for permanent storage for use in future calculations.

The problem with the display on the control panel is that it can only show one parameter at a time. This last year, a computer was purchased which had the speed required to do these calculations in real time. So a program was written which both stores the data for future reference and provides a readout on the monitor of all the various drilling parameters at the same time. The more important ones such as motor current and drill weight are also presented graphically in analog fashion for quicker interpretation by the drill operator. Figure 2 is a printout of the monitor screen showing simulated data. The circle in the upper right corner is the compass readout and is showing a 60 degree magnetic heading. The program also allows for setting limits on each of the parameters so that an alarm will sound if any limit is exceeded. The display for the one that caused the alarm also changes color and flashes on the screen so the operator can determine which one it is more quickly.



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   TIME 14:22:16
 1 Depth scale factor        1.0000
                             Low   High
                            Limit  Limit
 2 INCL 1             0.0     -5      5
 3 INCL 2             0.0     -5      5
 4 INCL ABS           0.0     -5      5
 5 INT PSI            0      -20    100
 6 EXT PSI         1500     -100   5000
 7 EXT TEMP (°C)  -28.7      -50     25
 8 MOTOR TEMP     -10.6      -50     80
 9 CONTROL TEMP   -22.0      -50     10
10 HEATSINK TEMP  -16.7      -50     80
11 DRILL RPM       147      -153    153
12 MOTOR RPM      2500     -2601   2601
13 AMPS              5       -30     30
14 VOLTS (M)       125       -10    200
15 VOLT (BATT)      12.0     12.0   14.5
16 LOADCELL        700       600   5000
17 DEPTH          1304.02     50   1450
   WEIGHT ON BIT   100
   DIFF. DEPTH       4.01
   DRILL RATE        0.455 METER/MIN ↓

 130400   130400                         Logging data to file 15142111.APR
                                         every 0.10 meter


Quit, Reset display, Set, Tare, Alarm stop
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Fig. 2. Drill operator's data display (using simulated data).

3. Sensors and Data

The future calculations referred to above mean that the data can be easily imported into a spreadsheet and plotted verses depth or time in order to analyze what was happening in the drill. This analysis may allow for improvements in drill operation or for presentation in papers such as this. All of the figures that follow were created using data from one logging run done on July 2, 1992 at the GISP II site in central Greenland.

The sensors include a load cell (strain gauge) that is placed at the point where the cable connects to the drill. This allows measurement of the variation in drill weight caused by different situations encountered in the drilling process (Fig. 3). For example, the decrease in weight while drilling indicates how much force is being put on the drill bit. Or the increase in weight after drilling indicates how much core was recovered. The change in weight can also indicate how fast the drill is traveling through the fluid in the borehole or where the drill enters the fluid. In Fig. 3, for example, the drill enters the fluid at 200 m, the rate of descent is increased at 650 m, variations in borehole diameter cause variations in drag on the antitorque system, and at the end the drill touches bottom and is drawn back up slightly.

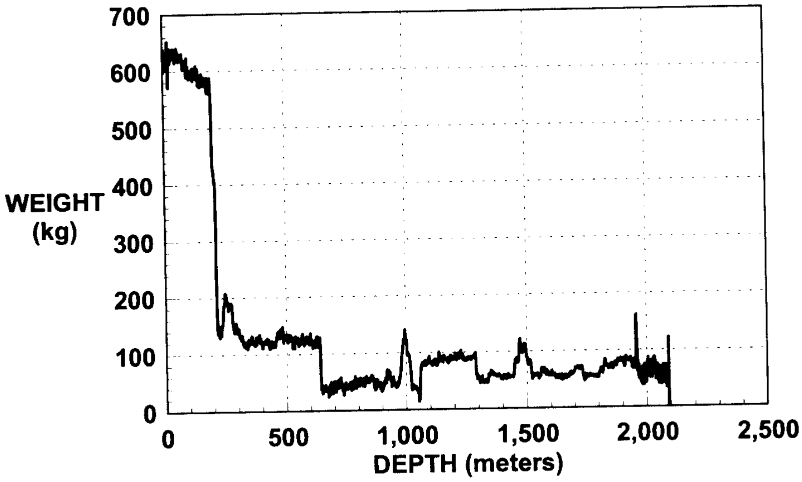

Fig. 3. Loadcell readout versus depth.

Four thermistors are included as temperature sensors. One measures the internal air temperature of the instrument package to see if any of the circuitry is overheating. Another measures heatsink temperature of power transistors or relays that are used in the I.P. The DC motor has a thermistor mounted on it to watch for overheating as well as checking on any leakage in the rotating seals since the "liquid cooled" motor would run cooler than normal. The fourth thermistor is used to measure the temperature of the fluid in the borehole. Figure 4 shows the temperature of the fourth thermistor as the drill goes down the borehole. It shows the air temperature at zero m, a gradual cooling as it passes through the casing and then a sudden cooling when it enters the fluid at 200 m. Having a good plot of borehole temperature allows the glaciologists to predict what temperatures will be encountered at the bottom of the glacier, *i.e.* whether we will find ice or water there.

A hall effect probe provides isolated sensing of the motor current. This replaces a

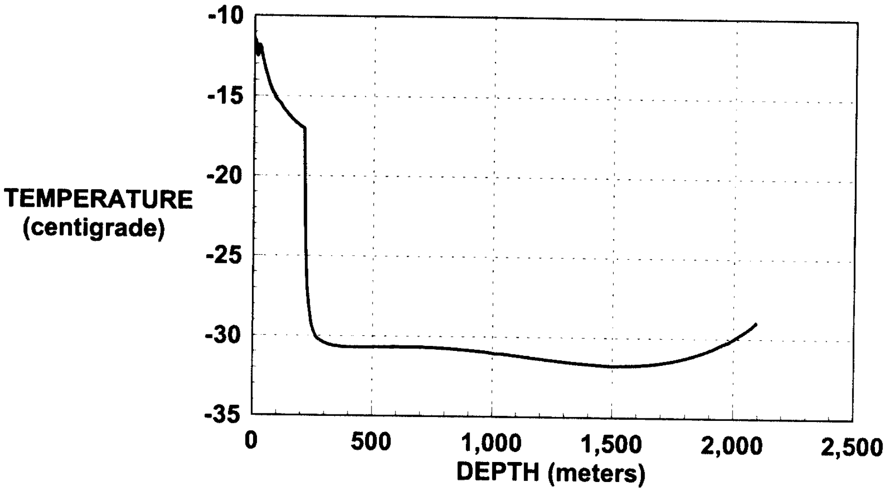

Fig. 4. Temperature in the borehole.

resistor that was used in the earlier design, and doesn't cause any voltage loss to the motor. The motor current is the most sensitive indication of when the rotating drill first starts cutting ice when it touches the bottom of the borehole. The voltage to the motor is measured as is the tachometer output to record motor RPM. Figure 5 shows these parameters during the descent. The RPM of the drill, which is scaled and offset to fit the graph, is zero until 1950 m and then increased to about 2500 RPM. The voltage is kept at 45 V during most of the descent to maintain the battery charge in the instrument package, and then increased to control the motor speed when the run/stop relay turns on the motor at 1950 m. The amps are very low during battery charging but increase when the motor is turned on. When the drill touches bottom, the amps increase sharply, and the rpm and voltage both drop due to the resistance of the conductors in the cable. The battery voltage (not shown) is monitored to be sure that it is being properly charged and is providing sufficient power to the data collection circuitry.

Two pressure transducers are installed. One measures the pressure of the fluid in the borehole which gives a good indication of where the top of the fluid is being maintained.

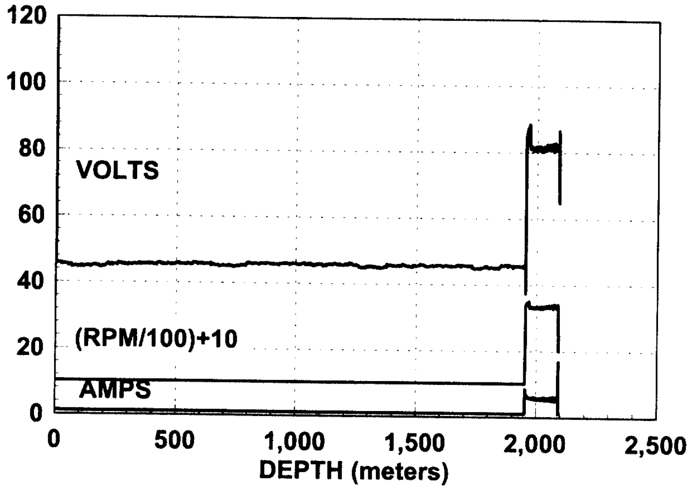

Fig. 5. Drill motor voltage, amps, and rpm (rpm scaled and offset).

In Fig. 6, pressure verses depth, and the other figures, the depth is always indicated relative to the bottom tip of the drill whereas the pressure sensor and other sensors are located at the top of the drill 25 m up. The other pressure sensor is located inside the instrument package to warn the operator of any leakage of the seals allowing fluid inside the I.P.

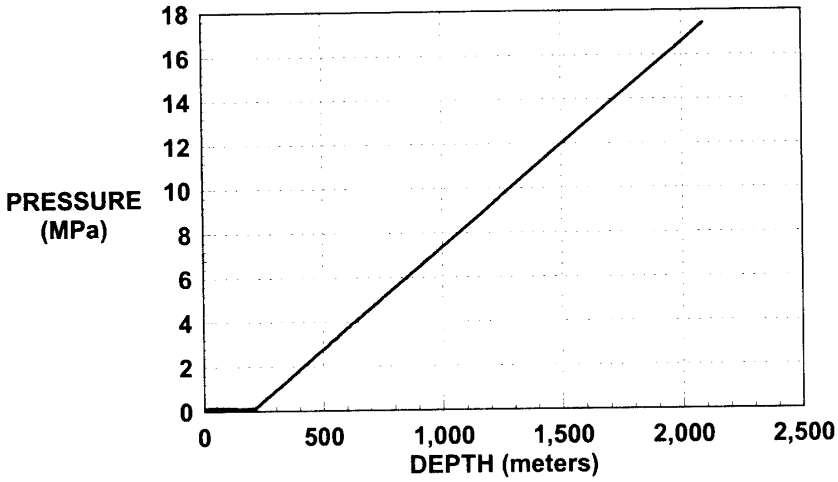

Fig. 6. Borehole fluid pressure versus depth.

Two inclinometers are mounted orthogonally in the instrument package and are used to tell the operator whether the borehole being drilled is vertical. In Fig. 7 it is seen that as the drill randomly rotates during its descent, the 90 degree phase relationship causes the output of one inclinometer to be zero when the other is at a maximum. In Fig. 8, the two outputs are combined mathematically to indicate the absolute inclination at any point in the borehole. It can be seen that the proper combination of techniques for keeping the borehole vertical was worked out at about 1600 m.

A compass was added to the instrument package this past year. This compass is based

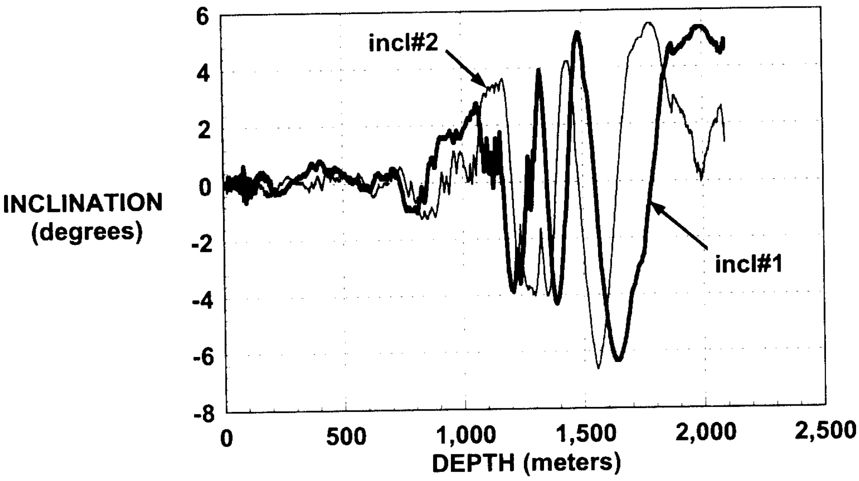

Fig. 7. Plot of the two inclinometers versus depth.

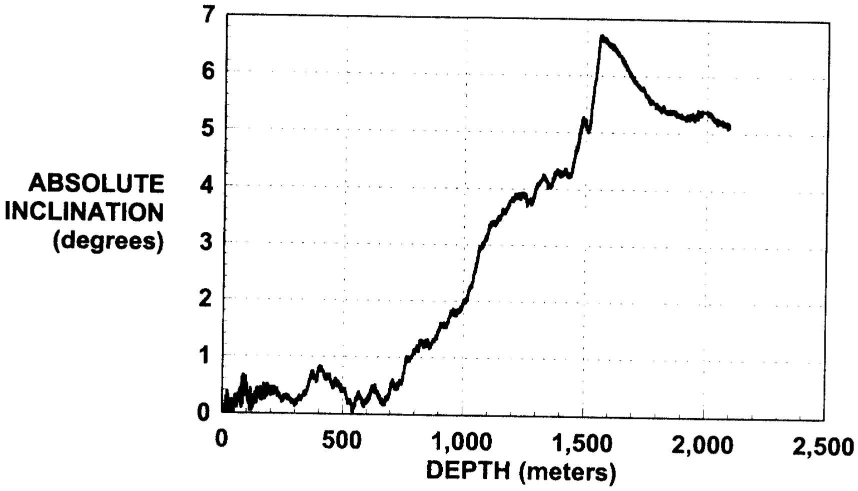

Fig. 8. Calculated borehole inclination versus depth.

on a 2-axis fluxgate magnetometer and has a liquid type gimbal action to correct for tilt. It has its own microprocessor to calculate actual magnetic heading. This allows the operator to check for slippage of the drill's antitorque system and also provides the possibility of determining the core's orientation relative to magnetic north. Figure 9 shows the compass heading of the drill as it randomly rotates during its descent. The antitorque system does not touch the sides of the casing during the first 100 m thus the relatively rapid rotation during that part of its trip. A small oscillation in heading which caused the compass output to cross the 360 to 0 degree transition several times near 2000 m caused what look like several rotations there.

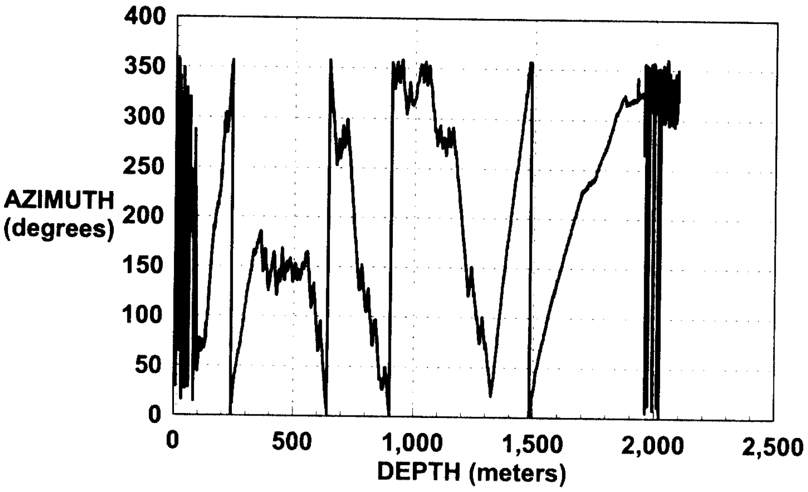

Fig. 9. Compass heading versus depth (see text).

By combining various information from these sensors, calculations can reveal more information about the drilling process. For example, by combining the incremental depth readings with the two inclinometers and the compass readings, the shape of the borehole can be calculated as seen in Fig. 10. Notice that the scales of the three axes are different and that the thick line represents the borehole while the thin lines are the projections of the borehole onto their respective planes.

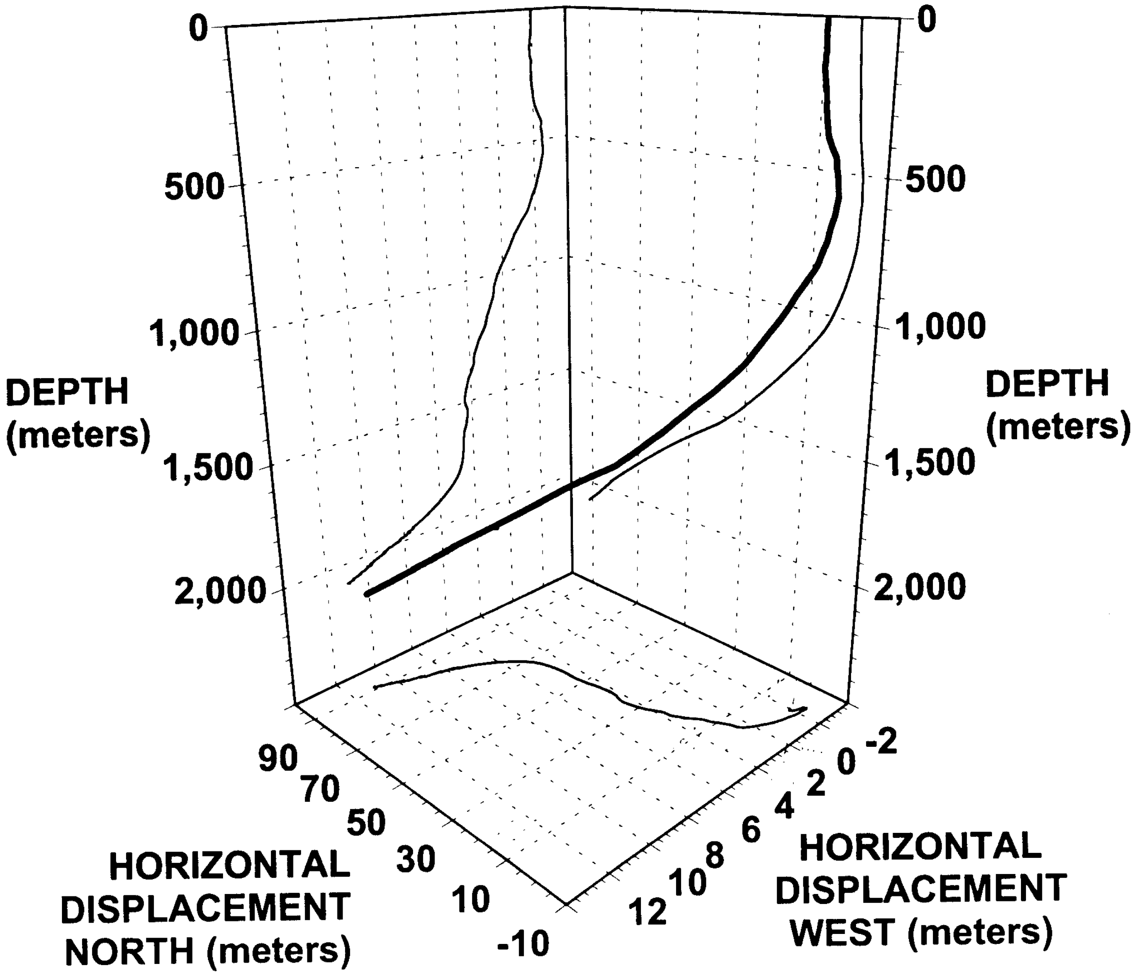

Fig. 10. Borehole shape. Scaled for illustration, thinner lines are projections onto their respective planes.

4. Future Developments

A brushless motor system will be tested this year. By eliminating brushes in the motor, it is hoped that the motor can be run wet (in the drilling fluid) thereby eliminating the need for rotating seals which are a problem in the high pressures encountered at 3000-m depth. The electronics in the brushless motor controller easily allow reversing the direction of the motor, thus the last mechanical relay could be removed from the system.

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The electrical power circuitry and the data collection circuitry for the PICO Deep Drill were designed and constructed at the University of Nebraska, Lincoln, Nebraska, under a contract from the Polar Ice Coring Office, University of Alaska, Fairbanks, Alaska.

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