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Controller for portable intermediate depth ice core drilling system

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Abstract: The primary objective of ice core drilling is to obtain the highest quality core while minimizing the effort needed. This requires a control system with precision control and convenient operation. An intermediate-depth portable ice core drilling system designed and constructed at the Byrd Polar Research Center (BPRC) has been tested during four expeditions under different working conditions. Several design options were tested to both control and monitor performance of the winch, thermal and electro-mechanic drills.

An attempt has been made to develop a universal controller that can be used with either thermal or electro-mechanical drills and with various power sources, ranging from a conventional alternating current (AC) portable generator, custom high voltage direct current (DC) generator or an array of solar panels. Currently, controller system built in two configurations: (1) to operate a 500 m winch, dry hole electro-mechanical (EM) drill and fluid electro-thermal (ET) drill at low (1 kW) power, and (2) to operate a 500 m winch, EM and ET drills at high power (400 Vdc and 6.0 kW). To allow the use of different power sources and different drills a modular design was chosen. The control system includes three modules: (1) for measuring and indicating drill depth, drill rate, and cable tension, (2) for driving reversible winch and drill motors at the same time (225 Vdc, 2.25 kW), and (3) for driving a high power (400 Vdc, 20 kW) drill or winch motor. The controllers are built around industrial servo-amplifiers (SA) for DC brush motors and have over-voltage and over-current protection. This design permits convenient positioning of each module on the winch frame. This paper describes the details of the design and functional options of an ice drill control system.

1. Introduction

Ice drills can be divided into two broad categories: operated (1) with an AC or (2) a DC power. Portable ice core drilling systems are usually powered with DC motors. These motors are smaller and lighter compared to the AC motors of the same power and their speed can be varied with simple controllers. The speed of a DC motor is proportional to the supply voltage and its torque is proportional to the supply current. AC motors require complex electronics to control speed. The 120/240 Vac portable power generators are inexpensive and commonly used to power shallow and intermediate depth ice core drilling systems. The EM and ET ice drills and winches have been controlled with either variable auto-transformers (variacs) or thyristor systems (Taylor, 1976; Jessberger and Dorr, 1984). Rectifiers convert variable AC power to variable DC power. This

is a very simple and robust design. Electronic frequency controllers are used to vary the speed of AC motors (Litwak *et al.*, 1984).

There are two functions of a drill controller: (1) gradually reach desired speed and (2) change direction of rotation. Often controllers have a current limiter to protect the controller, power source and drill motor against overheating and damage. Voltmeters and amperemeters indicate drill and winch power and changes of the load during a drilling run.

The lowering and raising of EM or ET drills is an important operation of the drilling process. The controller for a winch motor includes the same functions as the drill controller plus fine speed control at slow raising and lowering rates. This function is necessary for precise positioning of the drill at the surface and at the borehole bottom during raising or lowering a borehole tool and for cable feeding during a drilling run.

The variable autotransformer (Variacs) power adjustment devices are frequently used in ice drill controllers. These devices are simple, more or less economical, and relatively lightweight controller permits to vary up to 1.0–1.5 kW power. It is rather complex to achieve automatic speed control with this type controller and it cannot be used with a DC source of power.

The BPRC intermediate depth portable ice core drilling system (Zagorodnov *et al.*, 2000) includes a dry hole cable EM drill (0.6 kW), an ET drill (1.0–4.0 kW), a hoist system (1.5 kW), a controller, power system and shelters (Zagorodnov *et al.*, 2002). Two power sources have been used with this system: (1) conventional 120/240 Vac portable generators, and (2) 200 Vdc array of solar panels. Currently a custom high altitude, 400 Vdc portable generator is ready for field-testing (Zagorodnov *et al.*, 2002). The new controller has been designed to operate from either an AC or a DC power source.

Variacs, industrial thyristor systems, SA, analog meters and digital read-out units have been tested in cold polar environments and under bright tropical sun and high altitude. Enclosures, switches and power connectors were investigated. This paper summarizes our experience and presents some design options and future improvements.

2. General considerations

Shallow and intermediate depth ice drilling requires intensive physical and mental activity for both drilling and ice core processing. The lack of oxygen at high altitude (5000–7000 m) makes these tasks more difficult. Lightweight parts, simple assembly and convenient operation procedure reduce operator errors. A modular controller system was found to be practical for transportation, operation, repair and modifications. The BPRC ice drill controller has two modules: (1) depth, rate and cable tension monitors and (2) drill and winch variable controllers with voltage and amperage meters. The modules are housed in 240 × 185 × 180 mm off-the-shelf fiberglass boxes. They are fixed on the drilling mast with worm-drive clamps at convenient heights.

Analog meters have an advantage on digital meters because they do not require power and are less expensive. However, digital meters permit more accurate measurements. Digital meters with bright 12 mm high light emitting diodes (LEDs) are readable inside of a drilling shelter or in the bright sun.

DC controllers require switches with snap action. Conventional toggle switches can burn out when operated at a high altitude, even at low voltage. Common twist-lock

Table 1. Specifications of control units.

Control unit	Weight, kg /Power, kW	Power IN	Power OUT	Options	Cost, \$US
Variac	4.6/1.4	120 Vac	0-140 Vac	rectifier, doubler	154
Variac	16.5/4.2	120/240 Vac	0-240 Vac	rectifier, doubler	600
Industrial, AC*	2.7/1.0	120 Vac	0-90 VDC	reverse, brake, current limit	250
Industrial, AC*	2.7/1.8	240 Vac	0-180 VDC	reverse, brake, current limit	350
Servo- amplifier A	0.267/2.25	24-225 Vdc	0-225 VDC**	reverse, current limit, feedback	425
Servo- amplifier B	3.4/20.0	80-440 Vdc	0-400 VDC**	reverse, current limit, feedback	1200

*complete controller.

**output voltage proportional to the input voltage.

connectors have been found to be the most robust, economical and reliable way of electrical power connection.

Specifications of voltage adjustment devices are presented in Table 1. Conventional 50/60 Hz variacs are durable and relatively cheap. They can be used only with an AC power source and cannot be used for the automatic control of penetration rate or cable tension. They are heavier compared to other devices.

Industrial thyristor type DC motor controllers built in weatherproof, cast aluminum boxes and equipped with switches and knobs. Usually they do not have meters. These controllers include an adjustable current limiter. Industrial controllers are lightweight and cheap but must operate from an AC power source only. The weak side of these controllers is the switches. If on/off or reverse switches are operated with a load they can burn out.

Industrial SA can accept DC or rectified AC power and they are lightweight. Their cost is about that of variacs. They have the highest specific power and the lowest specific cost parameters. These devices include an adjustable current output limiter, protection from over-voltage and they can be operated by automatic feedback control systems. More details will be discussed in the Drill/winch power controller section.

In our controllers we use off-the-shelf electronics that were specified for a temperature range from 0 to +30°C. Although most of our drilling operations have been conducted at air temperatures below the melting point, only one of two counter/rate meters (depth monitors) malfunctioned repeatedly at low temperatures.

3. Cable tension and depth module

This module's function is to monitor cable tension, drill position and drill velocity in the borehole. Two load cells support the pulley mounted on top of the mast. A digital

load cell meter permits to measure up to 250 kg of load with a resolution of about 0.1 kg. This resolution was achieved during laboratory tests without the drill or winch motors running. During the drill operation the vibration from the winch motor and drill limits practical resolution to about 1 kg. This is about 2% of the drill and cable weight and 3–10% of the cutter's pressure. There were episodes of the weight readout malfunction that attributed to low temperature.

Two identical 6-digit micro-controller based counters/rate meters are coupled to a two-phase optical encoder (1054 cycles/revolution) on the pulley. When programmed they show position (depth) of the drill in the borehole with a resolution of 1 mm and repeatability of 30–50 mm in a 300 m borehole. One push-button switch alternates between depth and rate without losing either value. The last position is also stored if the power is turned off. The counters are reset at the surface to show the depth in the borehole, then at the bottom to show the penetration depth during this particular run. Usually both counters are set to zero at the surface and, when the drill reaches the bottom, only one counter is reset to zero. Counters are wired in parallel so a malfunction of one counter will only be an inconvenience and will not affect the precision of the measurements. This meter usually performed well (up to -7°C), but sometimes it malfunctioned without obvious reasons. The most likely reason for malfunction is low operation temperature. Since extended temperature range counters and load cell readouts are not available we plan to incorporate low power heaters inside of each meter.

The load monitor and counters have an optional isolated RS232 interface or an analog 0–10 Vdc output. The RS232 interface provides an opportunity to record depth and cable tension data on a computer. The computer monitor can then display the drilling parameters in digital or graphical format. A history chart of the cable tension permits monitoring the dynamics of the drill penetration and manual correction of the cable feeding rate if the feedback is not available or is malfunctioning. A continuous record of depth provides an objective documentation of drilling progress. The module is powered by a standard 120 Vac or 12 Vdc power supply.

4. Drill/winch power module

Field operation of the EM drill in Greenland and on Mt. Kilimanjaro (Zagorodnov *et al.*, 2002) provides convincing data that a better quality ice core can be obtained when penetration of the EM drill is controlled with the winch. For that purpose the BPRC drilling system is equipped with an auxiliary slow DC motor that feeds the cable at a constant speed during the drilling run. This drilling procedure requires separate control of the drill and winch motors. In order to achieve simultaneous control of drill and winch motors, a power module incorporates two identical variable DC sources (servo-amplifier A, Table 1), one for the drill and one for the winch motor. One set of voltage and amperage meters is switched between the two outputs. Industrial servo-amplifiers are lightweight, economical and reliable DC/rectified AC power control devices. SA based controllers have been field tested for winch and EM drill control at low temperatures (-20°C) and high altitude (6.200 m above sea level). More than 850 m of ice cores were obtained during four expeditions at 9 drilling sites without a malfunction of the SA.

To control the thermal drill at high power an experimental unit was developed. This

unit consists of a high voltage SA (servo-amplifier B, Table 1), volt- and amps meters, switches and power connectors. The advantages of this controller are high power and lightweight. The disadvantage is high cost. That unit has not been field tested, yet.

Another experimental controller drives the winch motor at a very slow rate. With this controller, the auxiliary slow motor can be excluded and a very precise winch speed can be maintained with only one winch motor. Control of the winch motor with an SA at very slow speeds (0.5–2 rpm) requires feedback from the shaft encoder on the pulley. The same driver circuit can be switched to high-speed mode when retrieving or lowering the drill.

5. Conclusions and future development

SA based controllers have been used in four polar and high altitude field operations and have never malfunctioned, they are robust and provide reliable protection for motors and power generators. Further development of this type of controller permits precise slow speed control of the winch without an auxiliary motor.

Industrial of-the-shelf digital counters required additional heaters for reliable function at low temperatures. Digital LED displays are reliable at low temperatures and readable in bright sun light.

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