EPICA Dome C electronic control system

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ABSTRACT. A new deep drill has been developed within the framework of the European Programme for Ice Coring in Antarctica (EPICA). Several versions of the EPICA drill exist. The version used at Dome Concordia (75°06′1″ S, 123°23′71″ E) was operated with a new electronic control system developed by the Ente per le Nuove tecnologie, l'Energia e l'Ambiente (ENEA) Research Center in Brasimone, Italy. This electronic control system was used for the first time during the 1997/98 Antarctic summer season.

1. INTRODUCTION

The main goal of the European Programme for Ice coring in Antarctica (EPICA) was to drill two deep holes through the Antarctic ice sheet in order to obtain, from the ice cores retrieved, full documentation of climatic and atmospheric changes over the past 500 000 years. At Dome Concordia (Fig. 1) the deep drilling, started in 1997, reached the final depth of 3270.20 m in December 2004. The ice retrieved close to the bottom was ~900 000 years old. Thus the Dome Concordia ice contains the oldest continuous record extending back from the present that has ever been extracted.

2. DESCRIPTION AND COMPOSITION OF THE ELECTRONIC CONTROL SYSTEM

This paper intends to be a general description of how the EPICA electronic control system was designed and implemented. For this reason, some technical aspects are not provided in great detail and diagrams presented are general rather than functional, showing only the principal electronic components used and the general operation logic.

The electronic control system can be divided into two subsystems, physically connected by the drill cable: the 'surface system' and the 'borehole system' (BHS) housed in a pressure tube. These two systems are each composed of several integrated subsystems (Fig. 2).

3. SURFACE SYSTEM

3.1. Computer

The drill console program was written using National Instruments Laboratory Windows 5.1/CVI software. The graphics console allows control of the drilling operation from the surface computer. The data, which are collected during the drilling runs, are stored and can be used for further interpretation of the drill runs. The computer is connected to the other hardware components of the control system by RS232 serial communication ports. Three serial ports are available. COM1 is connected to the surface box by serial port A which is connected to the BHS for transmission of 16 different signals: temperature, inclinometer, pressure and linear variable differential transformer (LVDT) for cutter-load values. COM2 is connected to the shaft encoder via a general converter module for RS232 (GCM232) and provides depth and speed information. COM3 is connected to the load cell via serial port B on the surface box and provides cable load values.

3.2. Encoder

The encoder, mounted on the bottom pulley of the perforation tower, (Leine & Linde, model 09990121, resolution 800 ppe, voltage 9–30 V) is directly connected to the computer COM2 serial port through a GCM232 serial converter module that converts the 4–20 mA current from the shaft encoder into RS232 output. It provides depth and

Fig. 1. Dome Concordia summer camp.

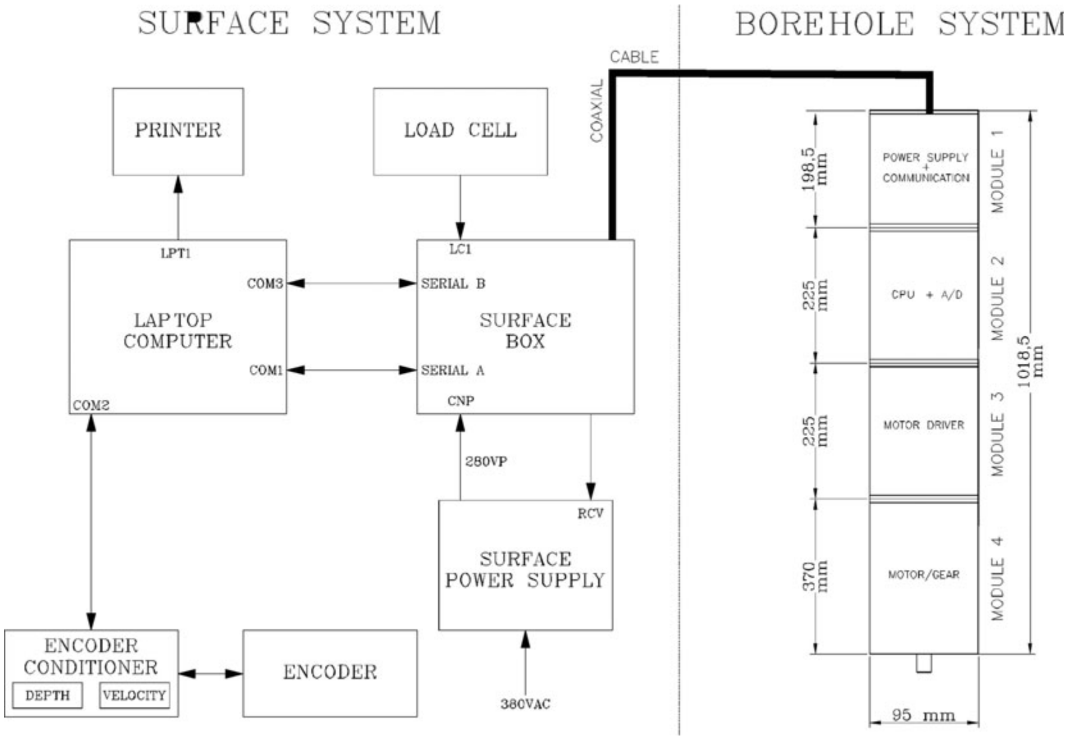


Fig. 2. Overall system, including physical components of the electronic control system: the computer used for the console program; the load cell; the encoder; and the surface box that interfaces all these systems and is connected, through the drilling cable, to the BHS.

speed data during the drill ascent/descent phases. The drilling speed during the ice-cutting process is ~4 mm s^{-1}. It also indicates the drilling depth and the penetrated core length during the run. In the console program, these data are displayed as 'SPEED', in cm s^{-1}, and 'DEPTH', in m.

3.3. Surface box

The surface box (Fig. 3) interfaces the computer running the console program with the load cell and the BHS. It communicates with the computer through two serial ports

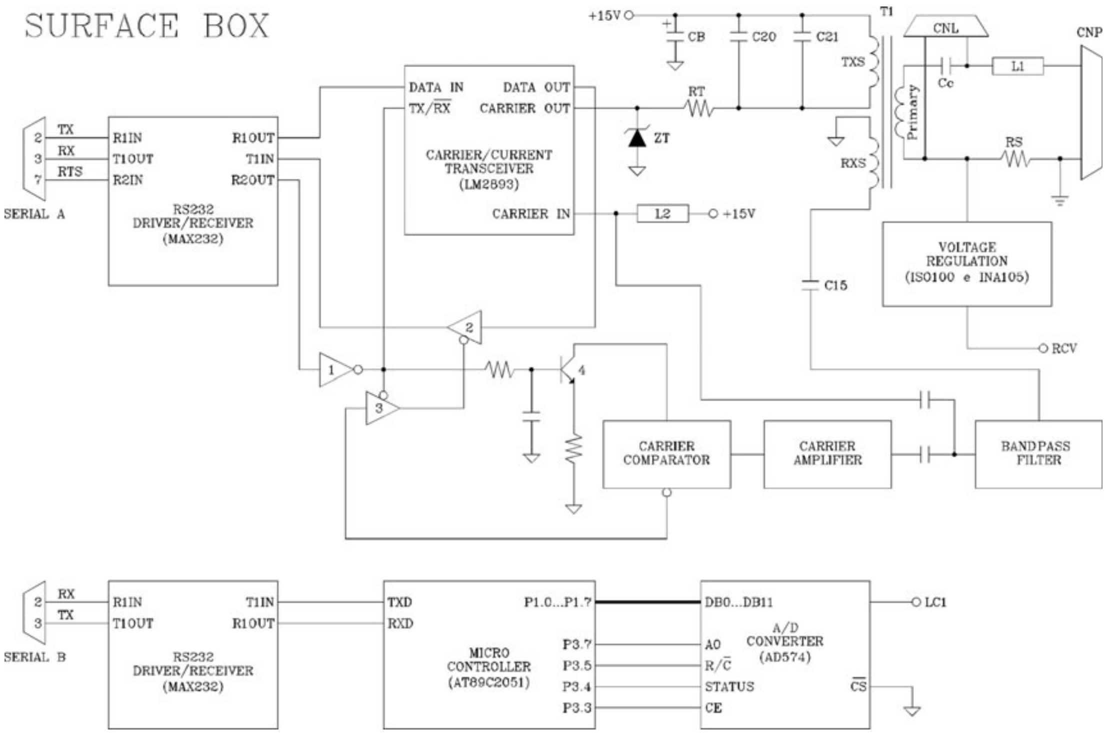


Fig. 3. Surface box outline, including two principal electronic circuits: the first for communication with the BHS, with the LM2893 modem and voltage regulation; the second for the connection to the load cell. Through two serial circuits we have transmission of the remote data to the console program.

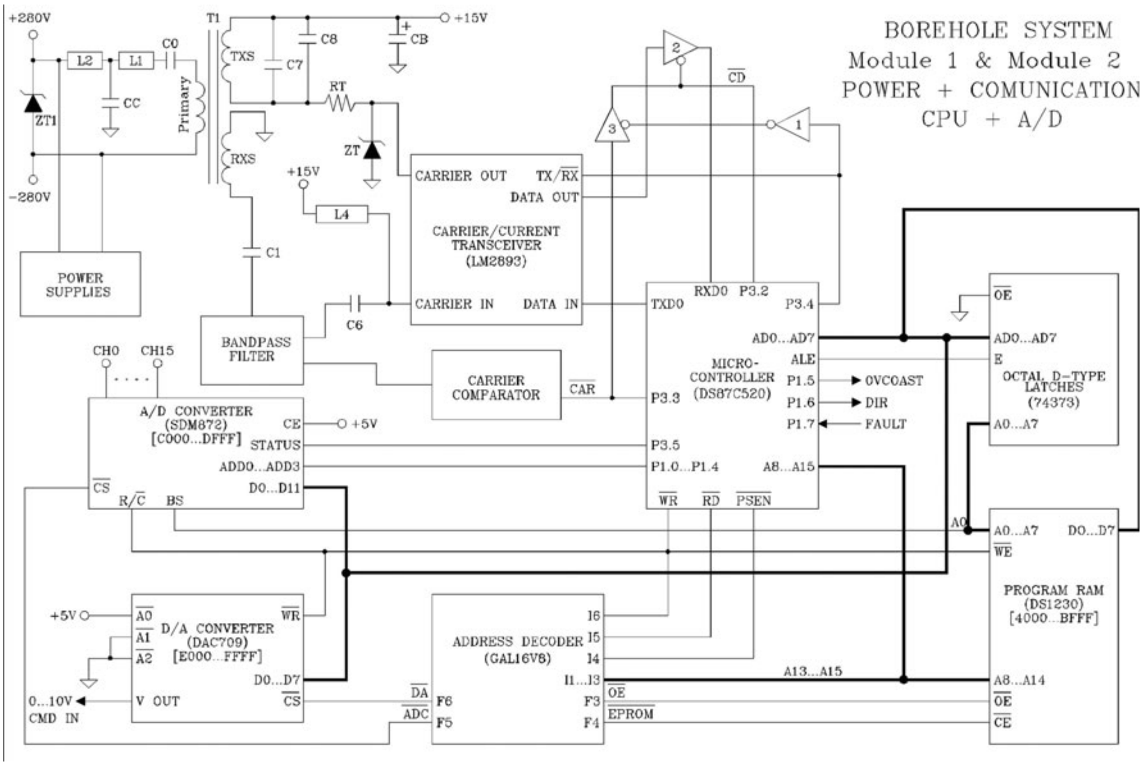


Fig. 4. Modules 1 and 2 outline, including the first two BHS modules, the communication/power module with the LM2893 modem and the power regulation section, and the CPU module that collects and sends remote data. The LVDT circuit is not represented; it is commercially made by H.F. Jensen.

(A and B) and with the BHS through the drilling cable, where the same wires are used for power and communication.

Serial A

Through serial port A (connected to the COM1 computer serial port) the data received from and sent to the BHS are recorded. To communicate with the BHS a power line modem (carrier current transceiver LM2893) is used. The LM2893 is a half-duplex modem, which is designed to operate over power lines by regulating the transmission/reception frequency according to the signal/command sent/received. A corresponding transceiver LM2893 is located inside the BHS power and communication module (module 1). It behaves in the same way, depending on the transmission of BHS data or echoing of console program commands. The program that executes these commands is stored inside the BHS CPU module and works in slave mode. On start-up it sets the LM2893 in RX mode, and waits for the command 'send data' from the console program. Once data are received, it sets the LM2893 to TX mode, and sends the data packet to the surface.

Serial B

Through serial port B (connected to the COM3 computer serial port) the data from the load-cell sensor (MAGTROL, LB210 Series, 0–10 V, 12 bits, with load-monitoring unit LMU117), which is directly connected to the surface box by a BNC cable, are collected. The sensor is located in the pivot of the top pulley of the drill tower and transmits the load on the cable ('CABLE' indicator on the console program). Moreover it displays the maximum force on the cable (also called cable load) needed to break the core ('Max.' indicator on console program). This maximum value is deduced from a high-resolution data sampling during the first 6 s after starting the ascent of the drill. Data acquisition is by a micro-controller (AT89C2051 with its own control program) and an A/D converter (AD574) which converts the analogue reading from the load cell into digital signals (Fig. 2). The digital signal is sent though an RS232 driver/receiver chip to the console program. It provides the data for the displayed graphics.

4. BOREHOLE SYSTEM

The BHS consists of four different modules, each with a specific task. The modules are interconnected through M/F 25 pin connectors and are placed inside the pressure tube.

4.1. Module 1: power supply and communication

The power supply and communication module (Fig. 4), module 1, hosts the circuits that convert the 280 V power from surface into 24, 15 and 5 V and thus supplies the power for the electronic components inside the four modules. It connects through the LVDT printed circuit board (H.F. JENSEN, ICAB LW150GIL) to the LVDT sensor (H.F. JENSEN, XLW16/150 F), which is a linear transducer that measures the length of a spring in the suspension of the anti-torque section of the drill cable. This design improves on former ones, when no load cell in the tower was available and the length of the spring provided a rough estimate of the cutter load ('Cutter' indicator on the console program). Nowadays, the cutter load is primarily used to keep a slight residual load on the cable when dripping in. The module also contains the transmit/receive circuit for communications with the surface modem, which is identical to that in the surface box.

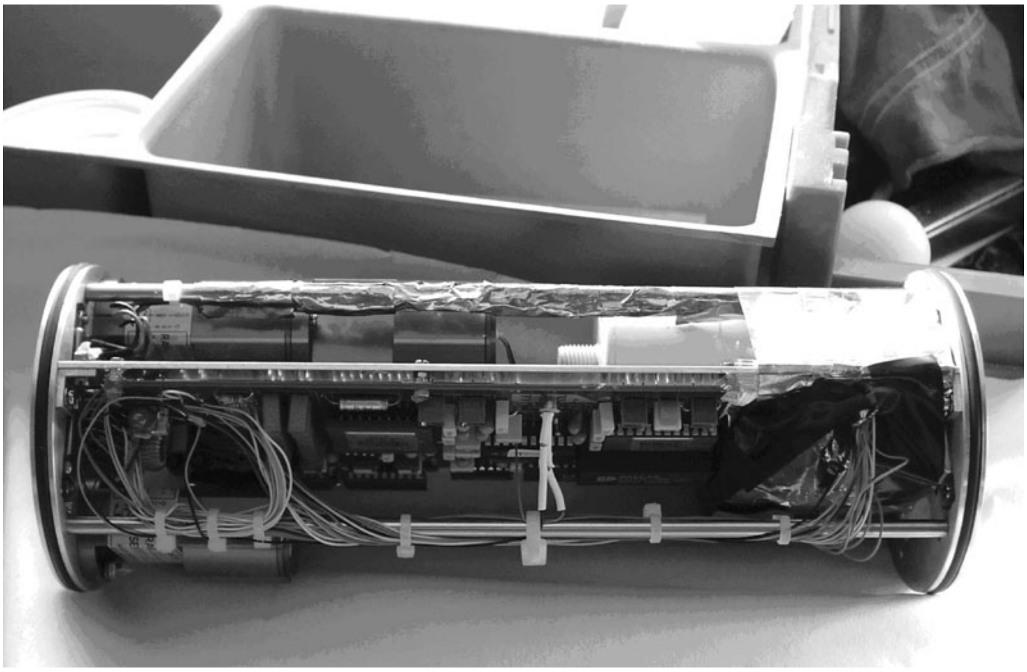


Fig. 5. The CPU module.

4.2. Module 2: CPU and A/D

Module 2 (Figs 4 and 5) is the 'intelligent' module. A programmable micro-controller (Dallas DS87C520) and its external memory (RAM DS1230) control and manage the program. It is possible to update the program from the control computer, using dedicated software. With a specific function of the console program, it is possible to download an updated version of the program to the RAM. The program controls the drill motor (on, off, rotation speed and direction), manages and checks the data-acquisition loop for data stored during the drilling operations and sets the value of the baud rate of the system. This is possible by writing correct hex values in two specific registers of the micro-controller (RCAP2H and PCAP2L). The maximum possible transmission speed of the system is calculated through a formula (by Dallas Semiconductor) that considers the oscillator frequency of the crystal used in the electronics (here 12 MHz) and the desired baud rate (here 2400 bd):

$$\begin{aligned} &\text{RCAP2H, PCAP2L} \\ &\quad = 65536 - \frac{\text{oscillator frequency} \times \text{baud rate}}{32}. \end{aligned}$$

In our case the formula gives 65380, FF64 in hex. We write these values in the correct registers and set the baud rate of the system to 2400 bd.

This module has electronic components (A/D SDM872 and D/A DAC709) for the conversion of analogue signals (temperature, pressure, inclination and motor data) to digital data and digital settings for the motor-to-analogue input to the motor driver. The two *x*-axis inclinometers (located at two diametrical positions and recording in radial directions relative to the cylinder axis of the pressure tube) and the *y*-axis inclinometer (recording in a plane perpendicular to the *x* axis relative to the cylinder axis) are located in this module.

4.3. Module 3: motor driver

This motor driver, module 3 (Fig. 6), contains the motor-driver controller (PWR82505) made by DDC. It controls the drill motor, which drives the drill string with the cutter head and the EPICA drill pump. The motor-revolutions count, which is recorded by a Hall sensor resolver, is fed as a control signal to the motor-driver controller. The drill motor stops automatically in the event of anti-torque blade rotation. Rotation of the anti-torque section is detected if the difference between the two *x*-axis inclinometer readings exceeds a certain threshold.

4.4. Module 4: motor gear and motor

The motor gear and motor, module 4 (Figs 6 and 7) contains a brushless motor (Parvex, model LX320, 4100 rpm) and gear reducer (Mijno MCR 310-02, ratio 1/48). Pressure sensors located inside the pressure-tube plugs indicate the pressure changes in order to track any drilling-fluid leakage inside the electronic pressure tube.

5. THE CONSOLE PROGRAM

The drill console program (Fig. 8) was developed with National Instruments Laboratory Windows 5.1/CVI software. Four different functions are dedicated to the drill control system: (1) functions to set the drill parameters and alarm values; (2) functions for communicating with the drill; (3) functions to control and display the data received from the different remote systems and to store them in ASCII format; and (4) functions to operate the drill motor (command on/off) and drill-motor parameters, speed regulation and sense of rotation. The data acquired by the drill console program are sent from three different remote systems: (1) the encoder, which gives depth reading and cable descent/ascent speed; (2) the load cell, which gives cable load data; and (3) the BHS, collecting 16 different signals including drill-motor signals, temperature, pressure and LVDT sensor signals. All the data are stored, for each run, in a specific ASCII file and can be consulted and checked in detail after the end of each run.

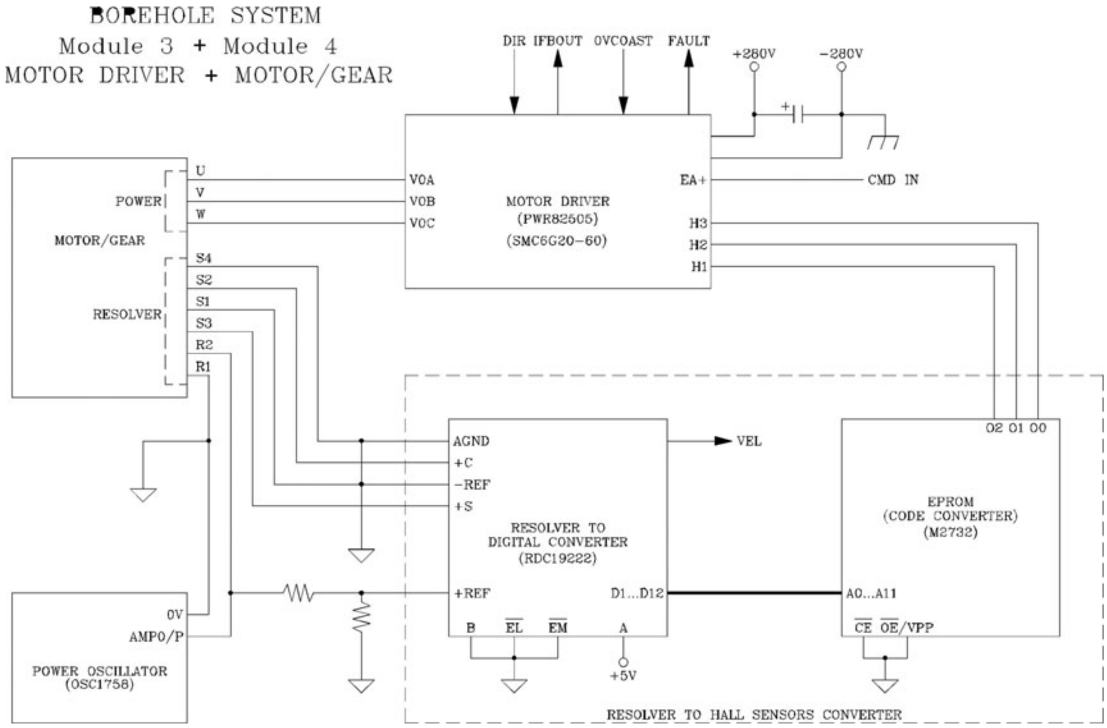


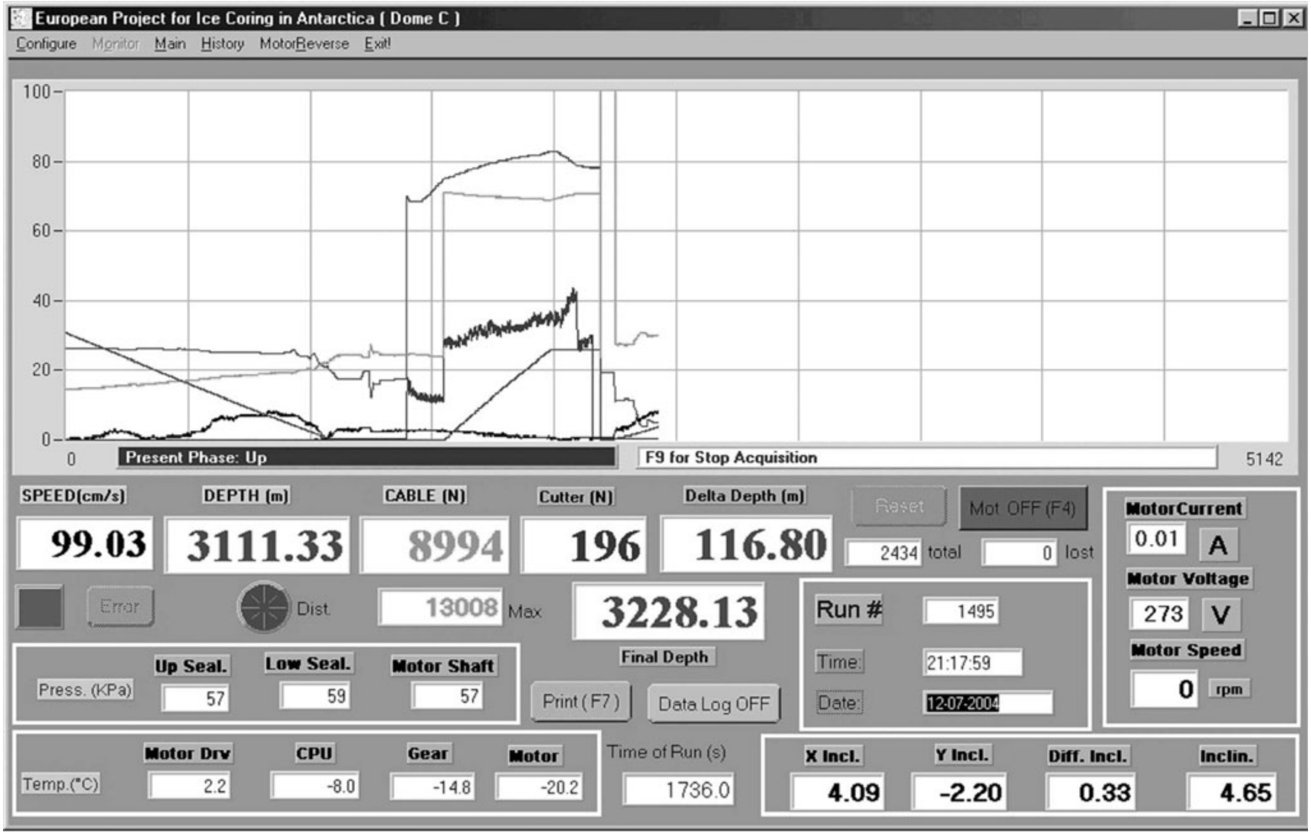
Fig. 6. Modules 3 and 4 outline, including the driver and motor modules. The most important component is the motor driver, which commands and controls the brushless motor.

The computer, with the console program, is connected to these hardware components by three RS232 serial ports. In the initialization phase, the console program needs to know to which serial ports these remote systems are connected. This control is done through the use of a dedicated graphic interface that checks the settings of the three serial ports. It is then necessary to check the communication between the surface box and the BHS. For that we execute, from the console program, the program inside the CPU module. If there are no problems, the remote program sends a confirmation message to the surface, sets remote LM2893 in RX mode, starts to collect data, and awaits new commands from the console program, working in slave mode.

Before commencing data acquisition it is necessary, through two different dedicated panels, to first check the alarm values and to set all parameters necessary to execute the drilling operation. In this phase, it is also possible to choose the sampling rate (0.5–1.5 s) from the three remote systems. We used a sampling rate of 0.7 s. Once the necessary parameters are set, the console program initiates data acquisition from the various systems and provides on-screen graphing of various parameters. From this point, it is possible to start the drill motor and begin the drilling operation.

Three different types of parameters are displayed: (1) information parameters (temperature, pressure, inclination, depth, length of run); (2) control parameters (motor current,

Fig. 7. Motor module.



Present Phase: Up

F9 for Stop Acquisition

SPEED(cm/s) 99.03

DEPTH (m) 3111.33

CABLE (N) 8994

Cutter (N) 196

Delta Depth (m) 116.80

2434 total

0 lost

MotorCurrent 0.01 A

Motor Voltage 273 V

Motor Speed 0 rpm

13008 Max

3228.13 Final Depth

Run # 1495

Time: 21:17:59

Date: 12-07-2004

Press. (KPa): Up Seal. 57; Low Seal. 59; Motor Shaft 57

Temp.(°C): Motor Drv 2.2; CPU -8.0; Gear -14.8; Motor -20.2

Time of Run (s) 1736.0

X Incl. 4.09

Y Incl. -2.20

Diff. Incl. 0.33

Inclin. 4.65

Fig. 8. EPICA screen console.

rotation speed, penetration speed, cable load, cutter load); and (3) graphed parameters (motor current, inclination, delta depth, cable and cutter load).

Every 0.7 s, data are transmitted from the three remote systems (BHS, load cell, encoder) to the console program. The CPU in the BHS collects 16 different signals. Each one takes 2 bytes of storage memory. This means that we have, for each transmission, 35 bytes from the BHS (32 bytes of data + 2 bytes for mistakes + 1 byte checksum). The console program continuously checks the checksum byte, to verify the accuracy of transmitted data. Sometimes noise and cable trouble can compromise communication between the surface box and the BHS. If the checksum is not correct, a wrong-data alarm is displayed ('lost' indicator on console program) and a sound alarm is activated. A similar alarm is activated when any other parameters exceed threshold limits. In both cases, it is the driller who decides whether to continue or stop the drilling operation. The only exception is when the anti-torque alarm is on. The alarm is displayed on the console program, but the program in the BHS CPU module will immediately stop the drill-motor rotation.

6. THE DRILL CABLE AND MODEMS

The cable is one of the main parts of the system and requires particular physical, mechanical and electrical characteristics in order to perform all the functions required. The two big subsystems of the electronic control system are connected through the drilling cable used to operate the drill. The same cable is used to power the drill and to transmit data to the surface. This presents the main difficulty of the electronic system design. During the early drilling seasons we used an unshielded four-conductor cable, model 4H284. To resolve severe communication disturbance at higher frequencies (Gundestrup and Johnsen, 2002) we switched to a custom-made coaxial cable, Rochester 2H287D. This cable was optimized for a sufficiently high wave resistance for high-frequency transmission and a big enough cross-section for electric power transmission (personal communication from F. Wilhelms, 2001). The data are transmitted through the central wire of the cable, while the outer shield is used for the return of the signal. Therefore two powered modems (LM2893 from National Semiconductor Corporation) using the same frequency were installed. One is inside the surface box. The second is inside the BHS. The LM2893 modems are set as follows: tuning frequency 125 kHz; F0 = 125.9 kHz for 0; Fc = 123.2 kHz carrier; F1 = 120.4 kHz for 1 (used during 2001–04 drilling seasons).

Until December 2001 we used a different cable, four wire conductors (Gundestrup and Johnsen, 2002) with different physical and electrical characteristics, that forced us to set the LM2893 modem with a frequency outside its correct working range (50 and 300 kHz). The LM2893 modem was set as follows: tuning frequency 35 kHz; F0 = 36 kHz for 0; Fc = 35 kHz carrier; F1 = 34 kHz for 1 (used during 1997–2001 drilling seasons). This caused many communication problems between the BHS and the surface box during the first drilling seasons.

7. CONCLUSION

The EPICA drilling seasons can be broken into two main periods: 1996–2000 and 2000–04 (Augustin and Antonelli, 2002; Augustin and others, 2007). During the first period we had problems with the electronic modules, many of them due to lack of field experience. The electronic system behaved differently in field tests than it had during laboratory tests in a cold room. At that time the electronic system was a preliminary prototype. The first three seasons were very fruitful, with much experience gained through the problems encountered. The problems discovered in the field were solved later, back at the laboratory. The electronic system became increasingly reliable.

When the drilling cable was changed (season 2001/02) from a four-conductor unshielded cable to a custom-made coaxial cable, which was optimized for transmission of higher frequencies for communication and supply of sufficient power to the drill, the communications improved significantly between the BHS and the surface box using the new communication module. Since then, no more data have been lost, the electronic reliability has been excellent and the drilling operation has become much smoother. The final depth of 3270.20 m was reached in four drilling seasons. We learned a lot from the EPICA field experience, working in Antarctica under extreme environments: the simpler electronic modules are, the easier they are to repair in the field and major modifications can only be performed in the laboratory between drilling seasons.

This experience will be very useful for the development of the new electronic system we plan to use for the IDRA (Italian Drill for Research in Antarctica), a new drill developed by ENEA Brasimone for the Talos Dome Ice Core Project (TALDICE).

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