A new 122 mm electromechanical drill for deep ice-sheet coring (DISC): 4. Drill cable

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ABSTRACT. The deep ice-sheet coring (DISC) drill developed by Ice Coring and Drilling Services (ICDS) under contract with the US National Science Foundation requires a drill cable capable of transmitting high amounts of electrical power as well as high rates of data. The DISC cable was designed and manufactured by the Rochester Corporation to core ice to depths of 4000 m. In addition to the steel strength members to support the drill, the cable has copper wires for conducting electrical power for the drill sonde cutter, pump motors and the sonde electronics and an optical fiber core for data transmission. The outer steel layers are filled with a special compound to minimize fluid penetration of the cable.

INTRODUCTION

An ice-drill cable serves three functions: to physically support the drill, to supply power to the drill, and to enable communications between the sonde and the surface. Following the design requirements of the science and engineering communities for the new deep ice-sheet coring (DISC) drill, the University of Wisconsin, working in collaboration with the Rochester Corporation of Culpeper, VA, produced a design for a new and unique cable to satisfy these requirements. This new cable is capable of supporting ice-core drilling to depths of 4000 m (Shturmakov and others, 2007).

History

Throughout the history of deep ice-core drilling, most drill cables have been of similar design, primarily varying in breaking strength and number of conductors. A comparison of some cable parameters used in deep ice-core drilling over the past 32 years is shown in Table 1. In the past, almost all drills have used the power conductors to also provide communication to the surface. This strategy has worked successfully, but has limited the bandwidth and quality of the data retrieved. Other variations of cables include a Kevlar strength member and also conductors in non-coaxial configurations. The drilling community has been most successful using a coaxial configured cable with steel strength members. For the DISC drill, six multimode optical fibers were added for dedicated communication channels, resulting in much more data throughput to the surface, with no noise caused by the power system. There is enough bandwidth in the fibers to communicate eight temperature, four pressure, inclination, orientation and other sense lines at ten times per second.

Science requirements

Primary science requirements related to the drill cable include the length of the cable required to reach the bottom of the ice sheet at the drill site and accurate depth determination derived from cable payout. At West Antarctic Ice Sheet (WAIS) Divide, the first drilling site for the new drill, the depth to the ice-sheet base has been measured at 3465 m (Morse and others, 2002; http://www.waisdivide.unh.edu/about/sitedetail.html). A length of 3800 m of cable was determined as being sufficient to provide a comfortable depth margin.

The payout accuracy requirement for the cable is 0.02% or 0.8 m at the full length of 4000 m. The actual payout accuracy of the DISC drill system depends not only on the cable elongation characteristics, but also on the sheaves, encoders, temperature and cleanliness, among others. The accuracy of the system is still being measured and analyzed and is not the purpose of this paper. A piece of the cable was sent to the Tension Member Technology (Huntingdon Beach,

Table 1. History of drill cable parameters

Drill (year)	Diameter mm	Breaking strength kN	Weight in air $kg\,km^{-1}$	Conductors	Source
JARE XV (1974)	11.8	29.4	450	4 copper	Suzuki (1976)
ISTUK (1980)	6.5	25.0	153	4 copper	Gundestrup and others (1984)
PICO (1982)	10.0	59.6	420	7 copper	Litwak and others (1984)
ISTUK (1990)	7.2	33.4	201	4 copper	Johnson and others (2007)
PICO GISP2 (1993)	20.6	89.0	354	4 copper	Wumkes (1994)
JARE Dome F (1993)	7.7	37.4	246	7 copper	Tanaka and others (1994)
EPICA (2000)	7.3	35.6	230	7 copper	Augustin and others (2002)
DISC (2006)	15.2	142	885	8 copper 6 fibers	

Notes: JARE: Japanese Antarctic Research Expedition; ISTUK: Danish–Greenlandic ice drill; PICO: Polar Ice Coring Office, USA; GISP2: Greenland Ice Sheet Project 2; EPICA: European Project for Ice Coring in Antarctica.

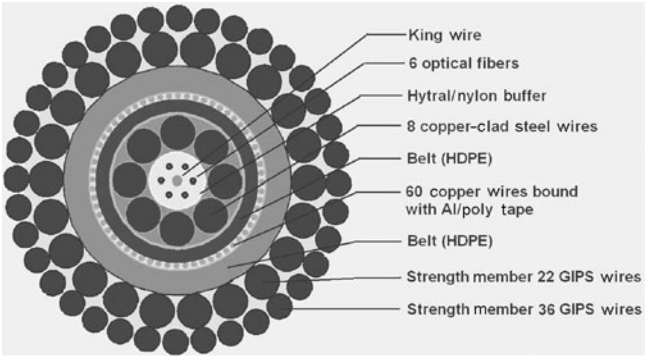

Fig. 1. Cable cross-section as designed.

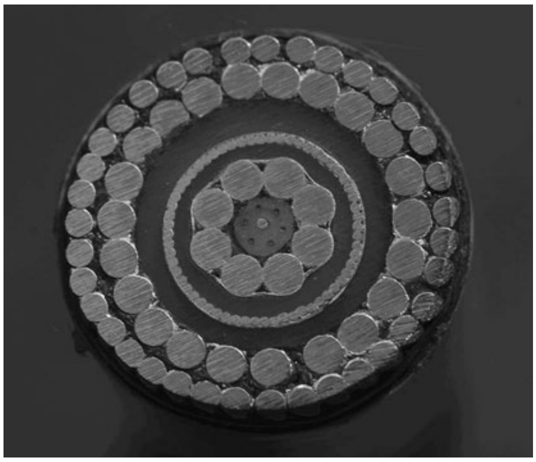

Fig. 2. Cable cross-section as built.

CA, USA) laboratory and all the cable specifications were verified. Tests included an elongation vs tension test.

Engineering requirements

Engineering requirements for the cable include the physical weight and size of the cable, breaking strength, and imperviousness to the drill fluid. The cable must fit on the winch spool and not weigh more than the cranes and shipping will allow. The breaking strength must be higher than the mechanical fuse at the top of the sonde and lower than the total winch pulling power. The breaking strength of the cable depends mainly on the diameter of the cable and the number of wires in the outer diameter. This cable has 36 wires on the outer surface, with 22 smaller wires just inside the outer layer. The breaking strength is specified at 142 kN. The drilling fluids used at WAIS are Isopar K and HCFC-141b. The cable is designed with void filler and outer layers that are impervious to these fluids.

The cable has an operational life of 5 years, assuming that the same cable is used throughout the entire WAIS Divide campaign. This will not be the case for the DISC drill at WAIS Divide because the initial 2800 m long cable will be swapped for the full-length cable at the end of the January 2009 drilling season. In order for the cable to last 5 years, a flexibility specification for 25 000 bends is required. This assumes 1000 drill runs where the cable travels through four sheaves on the way down or up. With a safety factor of 3, 1000 drill runs yields a result of 24 000 bends in the cable life. The DISC drill cable successfully passed a fatigue test performed by Rochester Cable in which a 30 m piece of cable was wrapped around a sheave for 25 000 cycles at –55°C. The most important cable requirements are summarized in Table 2.

Table 2. Cable requirements

Requirement	Value	Note
Length	3800 m	Estimated bottom of WAIS Divide is 3540 m
Cable diameter	15.2 mm	Cable must fit into winch spool
Total elongation	0.02%	4000 m × 0.02% = 0.8 m maximum
Longitudinal temp. coefficient	0.003% °C^{-1}	0°C to –40°C operating range
Bending radius	0.3 m	Winch spool size
Flexibility	25 000 bends	4 sheave bends each pass
Sonde weight	4181 N	Typical load (940 lb)
Cable weight	3500 kg	885 kg km^{-1}
Maximum load	57.8 kN	
Breaking strength	142 kN	
Shock rating	2000	Number of core breaks at maximum load
Operating temp.	–40 to 30°C	Working season
Storage temp.	–80 to 80°C	Over winter and shipping
Cable life	5 years	One hole

Communications

Optical fibers were chosen as the best engineering solution to ensure the highest signal quality with good noise rejection over the length of the cable. The fibers are multimode 62.5/125 μm graded index. This type of fiber does not have the distance capability of single-mode fiber but it is more forgiving during cable termination. In addition, the bandwidth of a single-mode fiber exceeds the requirement. The sonde is configured to have one full duplex channel for each of two microcontrollers. There is a redundant fiber for the two upwards fibers to handle extra data traffic going to the surface. This extra data traffic comes from all the sensors in the sonde which provide temperature, pressure and accelerometer data. This allows full use of the six fibers in the cable with some redundancies. Because of the optical signal loss in the fibers, special optical transceivers are used. They

Table 3. Cable materials

Part	Diameter mm	Note
King wire	0.9	Starter wire
6 optical fibers		62.5/125 μm multimode
Hystral/nylon buffer	2.6	Holds fibers together
8 copper-clad steel wires	3.7	Supply conductors 1.6 mm
Belt of HDPE	7.0	High-density polyethylene
60 copper wires	7.8	Return conductors 0.34 mm
Belt of ETFE	9.9	Ethylene tetrafluoroethylene
Void filler		Proprietary filler based on PTFE pipe sealant. Impervious to the drill fluid in use
22 GIPS wires 1.5 mm	12.9	Layer 1 strength member
36 GIPS wires 1.1 mm	15.1	Layer 2 strength member

Note: GIPS : galvanized improved flow steel.

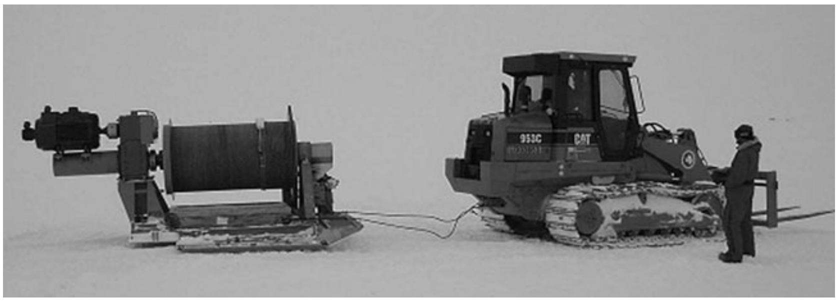

Fig. 3. Cable on winch at WAIS divide.

have very good optical sensitivity but are limited to only a 38 400 baud rate. This baud rate is fast enough to handle low-bandwidth signals.

Cable design

The cable materials are given in Table 3. To allow the cable to be properly assembled, a king wire was used as a starter. The optical fibers are wrapped around this king wire and isolated by a buffer. Then the eight copper wires are wrapped around this core. A belt material of high-density polyethylene (HDPE) is then wrapped around this. This is followed by 60 smaller copper wires and an HDPE belt. The first layer of strength steel is then added along with a void filler. This void filler is a proprietary mixture that is similar to the pipe sealant used on pipe threads in the oil-drilling field. The filler must completely adhere to the area between the steel layers to prevent drill fluid from attacking the inner belt. Finally, the last layer of the strength steel is added. The completed cross-section diagram is shown in Figure 1. The final, as-built cable cross-section is shown in Figure 2. The final cable is cleaned and tensioned when it is placed on a drum.

Measurements

Each component of the drill cable was tested as it went through the manufacturing process. First, the optical fibers were verified for attenuation to check for breaks. Then the fibers were wrapped by both Hytrel (Dupont) and nylon belts. After both copper-wire layers were added, the resistance of the cable was measured. The cable resistance measured 3.53 $\Omega\,km^{-1}$, meeting the specification of $<3.9\,\Omega\,km^{-1}$. Thus the specification for insulation resistance and leakage current was met with a generous margin. Finally, the finished cable was tested for concentricity and diameter. The breaking strength was measured at 144 kN compared to the specification of 142 kN.

Field testing

A 1200 m drill cable was tested during ice-core drilling at Summit Camp in Greenland during the summer of 2006 (Johnson and others, 2007). The cable performed well. The 1200 m cable was removed and replaced with a 2800 m cable for the Antarctic field season at WAIS Divide. Figure 3 shows the winch and cable being transported to the final drill site. This cable successfully completed the first ice-core season at WAIS Divide, in the 2007/08 season. Some flaking of the outer void layer did occur but this was expected.

CONCLUSIONS

The cable met the science and engineering requirements of the DISC drill. Possible future enhancements to the cable system include extra optical fibers for more bandwidth and redundancy and a better way to clean the outside of the cable to reduce the contamination caused by cable filler falling off around the drill system.

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