Future Technical Developments For The Polar Ice Coring Office 13.2 cm Ice Coring Drill

by

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Abstract

Engineering development of the PICO 13.2 cm ice coring drill has been hampered by the fact that the drill was always expected to be in the field and in use on projects even during its technical developmental stage. Since the size and site-specific nature of the drill precluded a proper systems test, the system has nearly always experienced significant unexpected teething problems during its first few years of project use. Most of these problems have been successfully eliminated. It is now time to address the final developmental stage of the drill system in the forms of simplification, maximum reliability and minimal logistical requirements. This paper will explore potential design solutions for accomplishing these goals. Areas to be covered include minimizing tower height, simplifying the surface handling procedures, minimizing system set-up and tear-down time, minimizing overall logistical weight, minimizing the drilling fluid requirement and flexibility-tailoring of the system to specific project field conditions. Future system design and procedural modifications toward these ends and others will be examined and evaluated.

Introduction

Deep ice core drilling is often carried out under the worst environmental conditions nature has to offer. Thus the engineering design involved must be the most reliable and efficient available. To these ends the Polar Ice Coring Office has developed the 13.2 cm drill system for retrieval of deep, large diameter ice cores.

The developmental program for the 13.2 cm drilling rig has been essentially concurrent with its first ice core recovery project. Since this was the case, a proper experimental systems test and evaluation was never carried out on the rig prior to field operations. Managing an engineering development program in this fashion invites disaster, but circumstances dictated that the system be readied as quickly as possible.

While the drill rig has been successful operationally, it has experienced unexpected problems in the field due to its lack of a complete developmental test program. There has never been time or opportunity available to analyze the system design and operations for maximum efficiency, minimum logistics requirements, and maximum project flexibility.

Though the first field project has served as the design's operational test, all of the problems that the 13.2 cm drill system has experienced have been successfully solved to date. It is now time to re-examine the system for design optimization. The areas of equipment weight, surface operations, set-up and tear-down time requirements, drilling fluid needs and system project flexibility will be investigated for possible improvements. Potential design solutions will be evaluated.

Existing Design of the PICO 13.2 cm Ice Coring Drill

A description of the downhole portion of the drill will be provided for purposes of comparison. The surface handling equipment will then be described as well.

The cutting head is the extreme lower end of the downhole system (refer to figure 2). It is attached to the inner core barrel by means of bolts. The head is also the rotational stabilizer for the lower end of the inner core barrel. This is accomplished by a brass bushing on the head which runs against the outer core barrel inner diameter. The head also carries the ice cutters and shoes and provides the actual shaving action which removes ice chips and carves out the ice core to be retrieved. The drilling head serves as a mount for the core dogs and core dog springs as well. These are used for core breaks and for retaining the core in the barrel during the trip back up the borehole.

Ice cutters used with 13.2 cm drill so far have been of both the chevron-shaped and the flat cutting edge variety. It has been found that the flat cutter provides a coarser ice chip which is more easily trapped by the screens for retrieval. This cutter also seems to provide a stable drilling action with lighter bit weights. Less bit weight enhances drill stability and minimizes vertical deviation of the borehole. Typically the cutting face of the cutters are angled at 45 degrees or less. Shoes are provided which allow either a 0.8 degree, 1.0 degree or 1.2 degree angle of cutter penetration into the ice. A typical penetration rate is 1.0 cm per revolution. The cutters are usually made of tool steel. Carbide has been used also, but tool steel provides a good cutting edge, is easier to fabricate and is less expensive. The cutting head is usually driven at a rotational speed of 100 RPM during drilling.

The inner core barrel is fabricated from steel. Filament-wound carbon fiber has also been used successfully. The naturally low friction coefficient of a carbon fiber barrel can be used to enhance core quality. The design change to steel was made in order to minimize problems with the head attachment bolts enlarging their holes through the composite. This design change also shifts the operational center of gravity of the drill down nearer the head. This action serves to stabilize the drill longitudinally.

At present two inner core barrel lengths are used with the 13.2 cm system; a three meter barrel and a six meter barrel. The six meter barrel provides the standard ice core length.

The outer core barrel is also steel. It does not rotate, but serves to channel the drilling fluid flow carrying the chips up to the screens. The lower end of the outer barrel also serves as a bearing race for the rotation of the drill head on its bushing. Like the inner barrel, the outer barrel is made in six and three meter lengths, with six meters being the standard.

Immediately above the core barrels in the drill string is the pump section. A progressive cavity type pump with a Teflon liner is utilized to pump the drill fluid in a flow cycle which would be considered reversed in most drilling applications. Drilling fluid flows through the pump upward into and through the screens, then back down between the O.D. of the outer core barrel and the borehole annular wall to the head. It then flows upward between the two concentric core barrels and back through the pump. The ice chips (or cuttings) are carried on this flow cycle from the head and are trapped in the screens. The type of pump used is heavy but handles the ice chip flow through its pumping cavity well. The pumping rate is typically about 135 liters per minute at 100 RPM and about 0.75 HP is absorbed by the pump.

Immediately above the pump is the screen section. This simple device serves as a strainer to catch the ice chips that flow up through the pump. It consists of a hollow cylindrical tube whose wall is fabricated of screen material. The screen mesh will only allow ice chips of smaller than 0.02 cm width to escape. Two screens are typically used with the six meter barrel while a single screen is used with the three meter barrel. Each screen is six meters in length. A drive shaft from the motor section above the screens runs the length of the screens through their center and drives the pump.

Rotary torque is supplied to the cutting head and pump from the motor and gear reducer section above the screens. A 5 HP DC motor provides the torque through a 17:1 gear reducer. The motor usually runs at 2,500 RPM. Excellent success has been realized with the gear reducer, but substantial problems have been encountered with the motors. They provided very poor field performance when immersed in the n-Butyl Acetate drilling fluid. Each motor provided only about 14 hours of running time. To eliminate this problem, a high pressure seal package was designed to prevent the drilling fluid from entering the motor canister. The seal package is meant to prevent drill fluid from entering the motor canister at pressures as high as 300 atmospheres.

Measurement of downhole drilling conditions is provided by an instrument section mounted just above the motor canister. Parameters measured include temperature, pressure, bit RPM, drill motor current and amperage, two-axis inclination, azimuth reference, bit weight and depth. These outputs are displayed on a CRT at the surface drill control station. Display software includes adjustable parameter limits with alarm settings and real-time analog bar graphs.

Immediately above the instrument section is the transformer canister. For purposes of efficiency, power for the drill is transmitted down the drill cable in the form of alternating current. It is transformed to DC prior to powering the instrument section and drill motor.

In order to hold the entire 25 meter length of the drill against the rotational torque of the motor, anti-torques are installed above the transformer section. There are two in-line sets of these with four springs each. They are made from spring steel flat stock. As the drill enters the hole, these springs are radially compressed and take a grip on the borehole wall. They allow ascent and descent but not rotation of the drill body. Initially problems were encountered with the springs not being able to hold against full motor torque and with occasional spring fracture. This situation was overcome by strengthening the springs and by making their pre-set tension adjustable. No further problems have been encountered since the anti-torques were re-designed.

An S-type strain gage weight indicator is attached to the drill above the anti-torques. Read-out from this instrument provides bit weight and winch load readings to the instrument data panel.

The drill cable itself is a state of the art device capable of doing several things at once. It provides four power leads downhole to the drill as well as carrying six data channels back to the surface for drilling parameter read-out. It is sheathed in Kevlar 29 which provides it with an ultimate pull strength of about 106,750 Newtons (see figure 3). Other advantages of this type of cable are its minimum elongation under load, its minimum thermal coefficient and its very high resistance to chemical attack. Tensile tests of the Kevlar 29 material soaked for extended periods of time in n-Butyl Acetate showed a one time reduction of tensile strength of 4%. This cable is also substantially lighter weight for its strength then would be a steel cable of the same length.

The surface handling equipment for the 13.2 cm drill system is fairly straightforward (see figure 4). A diesel-hydraulic winch has 4 km of cable spooled on its drum. The winch is capable of pulling up to 50,000 Newtons of cable tension. A thirty one meter tower allows the full 27 meter length of the drill to be hoisted from the hole. Depth encoders are attached both on the winch itself and on the tower crown blocks for redundant depth readout. A second weight-indicating load cell is also installed on the crown blocks.

Since the drill is designed in such as way as to allow it to be broken into approximately six meter sections, a rotating carousel has been provided on which to hang these individual parts. The carousel has eight stations. After a drilling run, the drill is hoisted completely free of the hole. Then the core barrel with included ice core sample, which is the lowest section, is removed and hung on the carousel. Following this operation, the two screen sections with their loads of ice chips are hung individually on the carousel. Two empty screen sections already hung on the carousel are then rotated into position and placed in the drill string. Finally an empty core barrel is attached and the drill is ready to make another trip downhole. As the drill is descending, the chips are cleaned from the two screen sections just retrieved and the ice core sample is carefully removed from the inner core barrel.

Removal of the ice core from the inner core barrel entails gently winching the six meter barrel down from its vertical position in the carousel to a horizontal position on a specially designed tray. The outer core barrel is then winched off, and the ice core is carefully pushed out of the inner barrel with a long "swabbing" rod. The core is pushed out of the barrel on to a roller tray. Sawing of the ice core into approximately one meter sections for handling then takes place. The inner and outer core barrels are then reassembled within one another, the cutting head, shoes and cutters are inspected and serviced, and the core barrel assembly is re-hung on the carousel. The surface handling system is now ready for the arrival of the drill on the next coring run. All of this activity typically takes place in about twenty minutes as the drill is descending on its next trip.

When the ice chips are cleaned from the screen sections, a vibrator is used to shake the compacted cuttings free and cause them to fall out of the open bottom end of the cylindrical section. The chips are soaked with n-Butyl Acetate and are carrying a fairly large amount of the drill fluid with them. In order to prevent any spillage and to recycle the butyl, a drip pan is provided beneath the carousel. It serves to catch all of the drips and spills as the drill exits the borehole. All liquid butyl is funneled back into the borehole. In addition, an auger system is installed at the bottom of the drip pan. Its function is to carry the loose ice chips outside the drill shelter to a large centrifuge. There the cuttings are centrifuged until approximately 95% of the n-Butyl Acetate with which they are soaked is removed and recovered. This butyl is then funneled back down the borehole as well. Approximately 5% of the drilling fluid is lost to evaporation during these operations.

n-Butyl Acetate is certainly not a traditional drilling fluid for use in ice coring. The commonly used fluids in the past have been such things as Diesel Fuel Arctic weighted with fluorocarbons and LVT-200 weighted with bromoil. After a rigorous and thorough search by PICO, n-Butyl Acetate was selected as the best drilling fluid for its benign environmental effects, low viscosity, low freezing temperature, minimum toxicity and its autodense properties.

The entire surface portion of the 13.2 cm drill is typically enclosed in an unheated wind shelter. Depending on conditions though, use of the shelter is not a requirement.

Possible Downhole Drill Design Modifications

Minimal Use of Drilling Fluid-

The drilling fluid in use in the present drill system design is n-Butyl Acetate. This fluid has a number of advantages as a drill fluid. It also has the disadvantage of requiring that the same volume of drill fluid must be brought to the drill site as is required to fill the bore hole volume. The possible use of one of the various alcohols as a drill fluid has the potential to minimize the drill fluid volume (and thus the logistical requirement) brought to the drill site. Use of alcohol can minimize this requirement since a large percentage of the drill fluid would then be made up of melt water mixed with the alcohol.

A number of questions remain to be answered concerning this concept however. They involve thermodynamic, chemical, safety and environmental concerns. A significant amount of research would need to be done in order to justify a change of drilling fluids. The potential savings in logistical requirements (principally weight into the remote camp) certainly justifies the investigation however.

Thin Kerf Bit Design-

Another area in which design changes could be made in order to maximize efficiency is in the design of the drill head. The volume of ice cuttings recovered on each drill run is determined by the depth drilled and the kerf width cut by the head. If the cuttings volume is minimized through reduction of drill head kerf width, surface handling problems to the centrifuge or chip melter would also be minimized. Drill retrieval cable loads would be reduced as well. This would allow slightly faster drill retrieval speeds and an overall improvement in efficiency.

The potential problems involve design of the core dog mountings within the thinner drill head wall.

Number of Screens In Use-

With the present 6 meter core barrel length, about one and one third of the available two screens are filled on each drill run. With minimization of the kerf width, the ice chip volume can be reduced to the point that only one screen would be needed in the drill string. This situation would reduce not only overall system weight and downhole weight, but surface handling time requirements as well.

Use of Brushless DC Motors in the Drill-

Operational problems have been encountered with the brush-type DC motors presently in use in the drill. It has been found that if the n-Butyl Acetate drilling fluid leaks into the motor canister, the motors can only be expected to continue operating for another 14 hours on average. The drilling fluid chemically attacks the motor winding varnish, the wiring insulation and the magnet attachment resin. It also dissolves the bearing lubricant and washes it out of the bearings. The motor brushes themselves tend to mechanically wear down very quickly.

This problem has been solved by redesign of the motor canister seal package to prevent leakage at high pressures.

However a better solution might be the use of a brushless DC drill motor capable of running immersed in n-Butyl Acetate. The advantages are that the winding varnish will be made from epoxy (which is essentially immune to chemical attack from butyl), the wiring insulation will be of butyl rubber and the magnets will be mechanically retained. There are no brushes to wear. This design change has already been implemented and will undergo test.

Elimination of Outer Core Barrel Strips and Inner Core

Originally the inner core barrel was fabricated from carbon fiber and was designed with spirals attached to its outer diameter. These spirals were meant to serve two purposes. They acted as an Archimedes screw with respect to the drilling fluid and ice chip mixture and helped to pump this mixture to the screens. In addition to this function the spirals also served as a centering device for the inner core barrel within the outer core barrel. Three longitudinal metal strips were attached to the inner diameter of the outer barrel. Each strip was approximately one centimeter in width and a few millimeters in thickness. The spirals attached to the outer diameter of the inner core barrel rode on these strips and used them as a bearing surface. These strips were also intended to provide vertical shear to the drill fluid-ice chip mixture and aid in mixture transport to the screens. Field experiments with a smooth steel inner barrel have demonstrated that the flow capability of the pump is sufficient to carry the chips to the screens without the use of spirals or strips.

Possible Surface Handling Equipment Design Modifications

Tower Height-

At present the 13.2 cm drill system requires a 31 meter tower in order to hoist the downhole portion of the drill completely clear of the borehole (refer to figure 1). The drill must be hoisted clear of the hole in order to access the core barrels and change out other components between drilling runs. The tower is lightweight and mechanically simple, but requires substantial time to erect and disassemble. Since the tower projects above the drill shelter, this configuration is also subject to high wind effects when the drill is hanging on the tower. Wind can cause the drill to sway which can make surface operations in the drill shelter difficult.

A method of dealing with these problems is to reduce the tower height requirement to that required for one section of the drill assembly (refer to figure 4). This change will minimize tower set-up and disassembly time and also reduce the overall system logistical weight. It would no longer be possible to hoist the full length of the drill clear of the borehole. Disassembly of the drill sections would require that the drill be disassembled from the top down instead of from the bottom up. The entire drill length would be hung in the borehole and taken apart by sections; top section first. Slips would be needed to safely hold the uncoupled drill sections as they hung in the borehole awaiting disassembly. The transformer, instrument, motor and pump sections would be removed from the drill string as one section. These parts of the drill string comprise approximately an 8 meter length. The two screen sections and the core barrel would then be removed one at a time for cleaning and core removal, respectively.

A convenient side effect of this concept would be the elimination of the catwalk now required for reaching the drill string joints. All drill crew work for making and breaking connections would be done at grade level. Drill system weight would also be reduced.

The only drawback to this concept is the time requirement for making and breaking the extra drill string connection. This is expected to add about 5 minutes to the current surface handling time of approximately 20 minutes.

Elimination of the Carousel-

The transformer, motor and pump sections would not be hung on a carousel. Instead, once disconnected, these three sections would be hung as one piece in a plastic pipe installed in the firn at a slight angle to the vertical. The sections would be positioned in this "rathole" with the use of the main winch. The winch would also be used to retrieve these sections for making up the drill string. The full screen section and core barrel just retrieved from the borehole would be similarly hung one at a time in two more "ratholes" with an auxiliary winch. An empty screen and core barrel would be pulled from two more of these holes and the drill would be re configured for the trip downhole. Once the drill is on its way down, the full screen and core barrel would be emptied of ice. Elimination of the carousel in this fashion would reduce overall system logistical weight and set-up and disassembly time.

Auger and Centrifuge-

Drill fluid recovery is certainly enhanced with the use of the ice cuttings auger and centrifuge system presently in place. These are expensive and heavy pieces of equipment however.

An often expressed scientific viewpoint suggests saving the ice cuttings from each drill run and melting them for analysis. If a chip melter were built, this process could be accomplished relatively easily. The drilling fluid could then be recovered as it separated from the melted chips. It would then be poured back into the borehole. In terms of procedure, the chips would be caught in a large container as the screens were emptied. They would then be carried to the melter by snow machine. Thus both the auger and centrifuge requirements would be eliminated. The weight of the melter would be added to the equipment list, but overall a systems logistical weight reduction should occur.

Drill Shelter-

The unheated drill site dome as it is used now is a very useful item. It acts as a wind break, clear working area and a storage building for tools and spares. It does not allow snow drifting to occur around the drill equipment. The main problem is the time requirement for setting it up and taking it down. There is also a long term drift accumulation problem around the structure over a period of years. The shelter's weight constitutes a substantial addition to the system's overall logistical weight.

Elimination of the shelter is being considered for those drill projects which are not expected to run more then a season or two. Drifting will be minimized by erecting the drill structure on a platform of snow slightly above the surrounding grade. Temporary wind breaks would serve to protect the drill crew from the worst of the weather. Most of the wind will be allowed to blow right through the lowest part of the drill surface structure. A warm-up shelter in the form of a Jamesway or Weatherport will serve as a crew rest area, shop and equipment maintenance area. An added advantage of this concept is the excellent ventilation provided by the absence of a shelter. Drilling fluid fumes at the work site will be minimized.

Number of Drill Crew Personnel-

It is possible that the surface handling procedural and equipment changes described here might reduce the number of drillers required per shift. Conceivably the rig could be run with a single field engineer and two drillers rather than the three drillers presently used. This situation would advantageously impact the logistical requirements for such a remote camp.

Efficient and safe procedures for operating the rig are already in place for the present design. Careful ergonomic and safety studies would have to be done before this crew reduction idea could be practically implemented.

Main Winch design-

At present the winch in use is an electro-hydraulic type. It provides plenty of overall torque and sufficient drill retrieval RPM, but cannot provide the finely controlled low speed RPM needed for drilling. Precise control of bit weight must be maintained, and this can only be done with precise winch control. Generally speaking, this type of precision is not available with hydraulic drive and control systems. It was necessary to add an electric penetration drive to the existing winch for purposes of fine low speed control. An additional problem with hydraulic systems in this application is that they do not handle extremely cold temperatures as readily as pure electronic systems.

It is possible to drive a winch of this size electrically and have fine low speed control built in to the system. This can be accomplished relatively easily with an electronic drive and controls. Higher reliability and an overall simplification of the drill equipment would result from this modification as well. An additional advantage to be had is precise winch control for safely making and breaking drill string connections. A slight reduction in system weight might be available also.

Drill Control Room-

The drill control room in the existing design is built on a level with the catwalk about 6 meters above the rig floor. The height is necessary in order for the drill operator to see the connections being made or broken in the drill string by the drillers. Safety dictates that the drill operator must have a clear view of these activities while running the winch.

Since the conceptual design calls for the catwalk to be eliminated and for these activities to be performed at grade level, the control room can be positioned at grade level as well.

The single disadvantage to this idea is the probability of snow drifting downwind of the control room. Careful positioning of the rig with respect to the prevailing winds would be a necessity.

Optimization of the Drill Cable Design-

The experience gained on the first deep coring project for the 13.2 cm drill system has pointed out a problem with the existing drill cable. For purposes of light weight, an electro-mechanical cable with a Kevlar 29 strength member was selected. The n-Butyl Acetate drilling fluid was proven to not chemically attack the Kevlar strength member. Another problem was overlooked however. The strength member is fabricated in a woven configuration within the cable. This weave requires a lubricant in order to prevent the Kevlar from abrading itself as the cable is flexed. It was found that after a period of approximately two years of field use, the drilling fluid had dissolved and washed out all of the cable lubricant. This resulted in the cable strength member weaves abrading one another until the cable was damaged beyond safe use.

Research into available cable types has determined that electro-mechanical cables are available which utilize a uni-directional lay of Kevlar. This design does not abrade itself under load and requires no lubricant. This cable design is also sheathed externally in Spectra fiber which requires no lubrication and serves to protect the Kevlar from sheave abrasion. Overall cable diameter is actually reduced while cable working strength increases somewhat. Change to this type of cable will allow a larger cable capacity on the winch.

Conclusions

The PICO 13.2 cm ice coring system has been quite successful to date, though it has never been experimentally field tested. This is true even when the developmental difficulties discovered during its first operational project are taken into consideration.

There is certainly room for improvement however, and the conceptual design changes set forth in this paper are intended to provide access to these possibilities.

Most of the potential improvements fall into two categories; faster drill rig set-up and tear-down time and reduced logistical weight requirements. Some mechanical simplification of the drill system is also available.

The first of these areas of improvement translates into more drilling time for a given season length. This is very important when the drill site is Greenland or the Antarctic, where only a five month and a three month drilling season are respectively available. The quick recovery of a complete ice core to bedrock might mean the difference between one drill season and two or more, depending on the depth requirement.

The second area translates directly into money. Reduced logistics requirements means a project that costs less. More funding is therefore available for the scientific aspects of the project. Given the vagaries of polar weather, simplified logistics also means a project that is more likely to succeed.

The third area of improvement comes down to a drill rig that is simpler, safer and more ergonomically efficient. Mechanical reliability of the system is also enhanced.

All of the conceptual design changes listed are intended to provide a shorter drilling season with an enhanced potential for project success at less cost.

Captions for the four figures in the technical paper; "Future Technical Developments for the PICO 13.2 cm Ice Coring Drill"

Figure 1: Tower and surface equipment for the PICO 13.2 cm ice coring drill

Figure 2: Cross-sectional drawing of the existing PICO 13.2 cm ice coring drill

Figure 3: Tensile strength of various drill cable materials

Figure 4: Possible future design of surface handling equipment for the PICO 13.2 cm ice coring drill