A new 122 mm electromechanical drill for deep ice-sheet coring (DISC): 2. Mechanical design

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ABSTRACT. The deep ice-sheet coring (DISC) drill consists of four major mechanical drilling subsystems and four subsystems supporting on-surface activities. The mechanical drilling subsystems are a drill sonde, a drill cable, a tower and a winch. The drill sonde is the down-hole portion of the drill system and consists of six distinct sections: (1) the cutter head, (2) the core barrel, (3) the screen section, (4) the motor/pump section, (5) the instrument section and (6) the upper sonde, which includes anti-torques and drill cable terminations. The drill cable not only provides the means of supporting the drill sonde in the borehole, but also provides conduits for electrical power and data transmission. The tower tilts to allow the drill sonde to be serviced in the horizontal position without removing it from the tower. The winch provides a means of quickly raising the sonde from the borehole and providing the fine control necessary for coring operations.

INTRODUCTION

The deep ice-sheet coring (DISC) drill developed by Ice Coring and Drilling Services (ICDS) under contract with the US National Science Foundation is an electromechanical drill designed to take 122 mm diameter ice cores to depths of 4000 m (Johnson and others, 2007; Mortensen and others, 2007; Shturmakov and Sendelbach, 2007; Shturmakov and others, 2007). The DISC drill consists of four major mechanical drilling subsystems and four subsystems supporting on-surface activities. The mechanical drilling subsystems are a drill sonde, a drill cable, a tower and a winch. Other critical on-surface subsystems consist of core-handling equipment, a screen-cleaning station, and a drill-fluid handling system. DISC and other coring-drill specifications are presented in table 5 of Augustin and others (2007).

DRILL SONDE

The DISC drill sonde is the down-hole portion of the drilling system and consists of six distinct sections: (1) a cutter head, (2) a core barrel, (3) a screen section, (4) a motor/pump section, (5) an instrument section and (6) an upper section that includes an anti-torque mechanism and drill cable terminations.

Cutter head

The cutter head (Fig. 1) holds four cutters for cutting an annular ring of ice to produce an ice core. It also holds four interchangeable core-dog cages that support four core dogs. Core dogs are sharpened teardrop-shaped pawls used to break the core off at the end of the drilling run and support it from slipping out of the bottom of the core barrel as it is carried to the surface. Four buttons called shoes, located on the bottom face of the cutter head, limit the penetration of the cutters. The vertical distance between the bottom surface of the shoes and the cutter tips sets the pitch or rate of penetration of the drill. The pitch used on the DISC drill is 3–10 mm maximum. The rake of the cutters or angular tilt from a vertical plane is 40°. Their relief angle is 15°. The cutters cut a 24 mm wide annulus, creating a 170 mm diameter hole with a 122 mm diameter core. A set of four cutters, core dogs, shoes and stabilizers are equally spaced in the cutter head in a radial array at 90° intervals. With this spacing, there is always an identical and opposing component at 180°, and small horizontal movements of the cutter head caused by unwanted vibrations are dampened. The cutter head is mechanically attached to the core barrel. Rotational velocity and torque for cutting the ice is imparted to the cutter head from the cutter motor through the screen barrel and core barrel. In the DISC drill both the screen barrel and core barrel rotate.

Core barrel

The function of the core barrel (Fig. 1) is to protect, support and carry the core intact throughout the drilling operation, from drilling of the core, core break, tripping out of the hole, lay-down of the drill on the tower, removal and turning of the core barrel and pushing of the core from the core barrel to the core handlers. Smooth, vibration-free operation of both rotating core and screen barrels for all speeds is critical to quality drill performance. Five geometrical criteria are

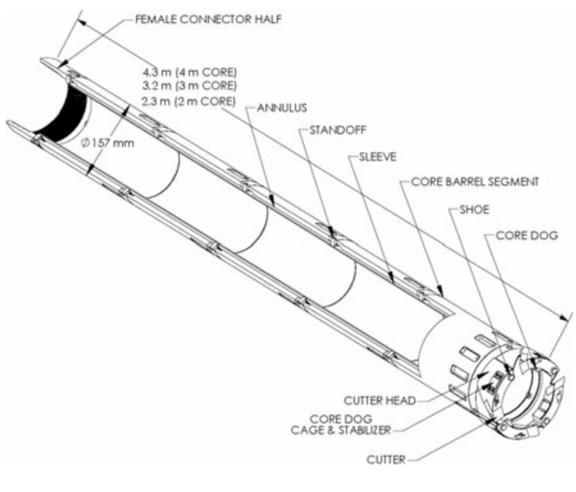

Fig. 1. Core barrel and cutter head.

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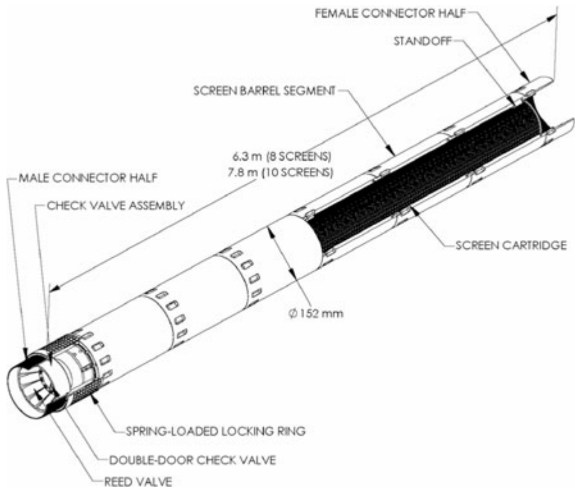

Fig. 2. Screen section.

required to ensure successful barrel design to guarantee quality performance: (1) an accurate and constant inside diameter, (2) an accurate and constant outside diameter, (3) concentricity of both inside and outside diameters, (4) roundness at any cross-section along the length of the barrel, and (5) exceptional straightness for the full length of the barrel. A commercial tubing manufacturer could not be found in the USA to produce barrels for the DISC drill having all five of these geometrical attributes in the lengths desired. Consequently, a modular concept was developed for the design of both the screen barrel and core barrel. Each complete barrel is comprised of multiple short segments mechanically fastened together to make barrels of the required length. This concept allows for adaptability and convertibility of barrel lengths, a wider selection of available materials, and replacement of one or more segments if damaged. A standard barrel segment length of 253.6 mm was determined so that three connected barrel segments would equal the finished length of one screen cartridge (see below). Three sample barrel sections were manufactured and tested to ensure that the segmented barrel met all five criteria. Furthermore, tensile testing showed that the mechanical connection between barrel segments will resist axial forces greater than 178 kN. One drawback was that the mechanical connection required a minimum wall thickness of 10 mm. This results in a wider kerf which generates more ice chips. The thicker wall, however, created a core barrel with more thermal mass having a longer thermal time constant. The barrel was less likely to be deformed, damaged or prone to sag. This allowed longer unsupported length, and the added weight closer to the bottom of the drill sonde was desirable.

The core barrel can be fitted with a sleeve to support the core. The sleeve is 2 mm thick, constructed of fiberglass filaments wound on a 123 mm diameter mandrel. The sleeve is supported by intermediate stand-offs at each core-barrel segment along the full length of the core barrel. In addition to supporting the core, the sleeve provides some thermal insulation of the core. The stand-offs allow a 5.5 mm wide annulus between the outside surface of the fiberglass core sleeve and inside surface of the core barrel. The annulus provides a pathway for the drill-fluid–ice-chip slurry to be pumped upward from the cutters through the core barrel into the screen section. Clear, screen-filtered drilling fluid expelled from the pump above the screen section circulates downward between the wall of the borehole and the outside surface of the screen and core barrels to the tip of the cutters.

The female half of a custom-designed connector assembly consisting of an internal-tapered, American Petroleum Institute (API) stub-ACME, four-lead, threaded collar is used to couple the core-barrel section to the screen section above. It is mechanically attached to the top of the core barrel. The other half, the male threaded collar of the custom-designed connector assembly with a locking ring designed to limit the potential for unscrewing, is mechanically attached at the bottom of the screen section. The complete connector assembly provides a rigid, straight connection between the core and screen barrels. The connector permits quick uncoupling and coupling so that the core barrel can be removed and an empty one reconnected; this feature helps shorten the time between drill runs. The modularity allows core barrels to be assembled in a number of lengths.

Screen section

The screen section (Fig. 2) provides a means to filter ice chips, produced by the cutters, from the drilling fluid circulating through the drill. It also provides a compartment in which to collect and store the ice chips for transport to the surface. The filter selected for the screen section is a commercial well screen with 0.17 mm wide internal circumferential slots. The well screen is designed for maximum filter area and minimum pressure drop. A modular, interchangeable screen cartridge concept was developed for speed and ease of cleaning during drill operations. Each screen cartridge has an internal diameter of 108 mm and is 0.76 m long, with three polyethylene stand-offs equally spaced in a radial configuration at each end. Their purpose is to center the screen cartridge in the screen barrel and provide a 5 mm wide annulus between the outside of the screen cartridge and the inside wall surface of the screen barrel. Screen cartridges are inserted into the barrel in a long stack. The DISC screen-barrel design is modular so that any number of screen cartridges can be used. Normal drilling requires eight to ten screen cartridges.

A check-valve assembly, consisting of two concentric unidirectional valves, is used to control the direction of drilling-fluid flow. The assembly is inserted at the bottom end of the stack of screens. Its body slips into the screen barrel and locks with a quick turn and click of its bayonet-latch mechanism. The check-valve assembly supports the weight of the screen cartridges above and employs a set of commercially available one-way double doors to allow the fluid–chip slurry pumped up from the cutters to enter the inside of the screen cartridge stack where chips are filtered from the drilling fluid and collected. The one-way double doors will quickly close, trapping the collected chips in the screen if the pump is stopped or if there is any tendency for back flow (e.g. when the drill is tripping upward out of the hole). A concentric array of 12 openings with reed valves located in the check-valve housing outside the double doors will allow one-way back flow of clear fluid to drain and bypass the screens in the opposite direction down through the drill as the drill is tripping out of the borehole. Allowing a back flow of clear fluid through the inside helps to reduce the resistance of the drill moving upward in the borehole, as drilling fluid has a pathway inside as well as around the drill.

A female half of the custom connector assembly is used to couple the screen section to the pump above and is

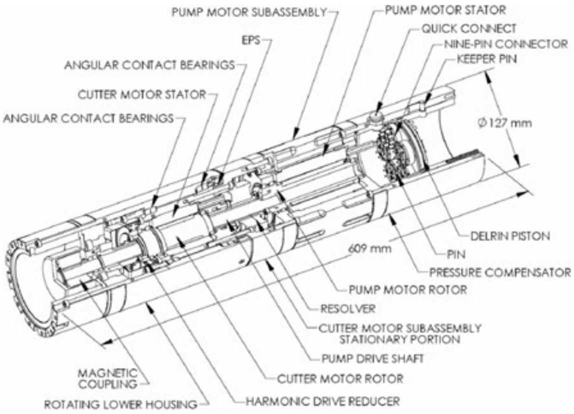

Fig. 3. Motor section.

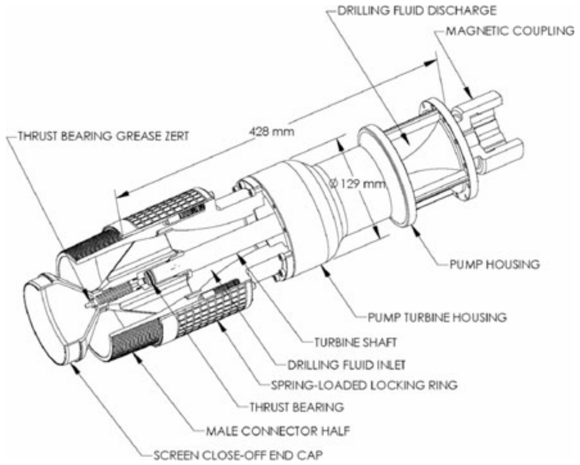

Fig. 4. Pump section.

mechanically attached to the top of the screen barrel. A male half of the connector assembly used to couple to the core-barrel section below is mechanically attached at the bottom of the screen barrel. The connectors are designed for uncoupling and coupling the screen section so that a screen barrel can be removed and replaced by another screen section.

Motor/pump section

The motor/pump section (Figs 3 and 4) is a highly integrated, self-contained, pressure-compensated, three-piece, oil-filled sub-assembly capable of operation to –50°C and 40 MPa external pressure. This section contains two independently controlled, tandem-mounted brushless d.c. motors. One motor is used to drive the barrels and the cutter to cut the ice. The other is used to drive the pump to circulate drilling fluid to collect the ice chips. Smooth, vibration-free operation of both motors at all speeds is critical to quality drill performance.

At the top of the motor/pump section is a pressure-compensator assembly. It mechanically attaches the motor/pump section to the lower bulkhead of the instrument section. Basically, it is a large piston with 25 mm of axial travel designed to compensate for changes of the volume of the oil in the oil-filled motor cavity. Electrical power, commutation signal, resolver signal and thermal couple wires for motor operation enter through five custom-manufactured, flat-faced, nine-pin connectors integrated into a DuPont Delrin® piston. Each pin, connected to a wire, is designed to be removable from the connector body in order to change out a motor if necessary. The oil level in the motor module can be visually inspected quickly by observing the position of a keeper pin in a slot on the pressure-compensator outer housing. An oil-type grease gun is used to pump oil in through a quick-connect fitting when necessary.

The pump-motor sub-assembly is mechanically attached to the bottom of the pressure-compensator assembly. Electrical power, commutation signal and thermal couple wires for pump-motor operation terminate in the pump-motor stator winding. Electrical power, commutation signal, resolver signal and thermal couple wires for the cutter motor pass through a channel in the housing of the pump-motor sub-assembly and continue downward until they terminate in the cutter-motor stator winding. The pump motor is an Emoteq hollow-bore frameless model rated to 2.5 kW at a maximum speed of 3500 rpm. DISC drill-fluid circulation requires 0.7–1.0 kW at 2100–2400 rpm. The pump motor drives the pump through a magnetic coupling located at the bottom end of the pump-motor module. The magnetic coupling is keyed at the bottom end of a bearing-supported shaft extending downward from the pump motor through the hollow-bore resolver, cutter motor and reducer. The magnetic coupling is used to eliminate a high-speed pump shaft seal, accommodate small axial and radial misalignment of the pump shaft, provide vibration isolation and facilitate quick change of the pump. Pump-motor rotation is counterclockwise when viewed from the top.

The cutter-motor sub-assembly is mechanically attached to the bottom of the pump-motor sub-assembly. The cutter motor is an Emoteq hollow-bore frameless model rated to 1.8 kW at 7500 rpm maximum. DISC drill cutter operation requires 0.6 kW at 2400 rpm. The motor rotates the lower housing and pump housing of the motor/pump section and screen and core barrels through a 30 : 1 Harmonic Drive Products reducer. This reduction imparts a rotational speed of 80 rpm to the rotating housing for a cutter-motor speed of 2400 rpm. Its rotation is clockwise when viewed from the top. The rotating lower housing is supported by duplex tandem REALI-SLIM® angular-contact bearings on the bottom, and a duplex tandem pair of REALI-SLIM® angular-contact bearings on the top. These bearing sets are designed to carry the full vertical static and dynamic load of the drill. A resolver is located in the cutter-motor sub-assembly at the top end of the cutter motor and is driven from the rotating housing. The resolver is used to monitor the position of the rotating housing with respect to the motor/pump section. The resolver output along with the azimuth output from the instrument section is used to determine core orientation just prior to breaking the core. A single Parker energized polymer seal (EPS) is used to prevent the oil from leaking between the rotating housing and the stationary portion.

Much consideration was given to the material for construction of the motor sub-assembly. There are many custom machine parts with precision bores, so a free-machining and stable material was desirable. Internal corrosion from condensation was a concern, with potential for formation of small abrasive particles that could shorten the life of the precision bearing sets. Materials with a dissimilar coefficient of thermal expansion would not accommodate large thermal changes without potentially stressing or binding the rotating components. Two motors running simultaneously

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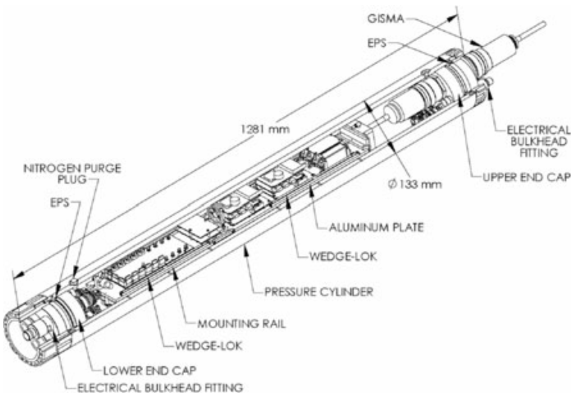

Fig. 5. Instrument section.

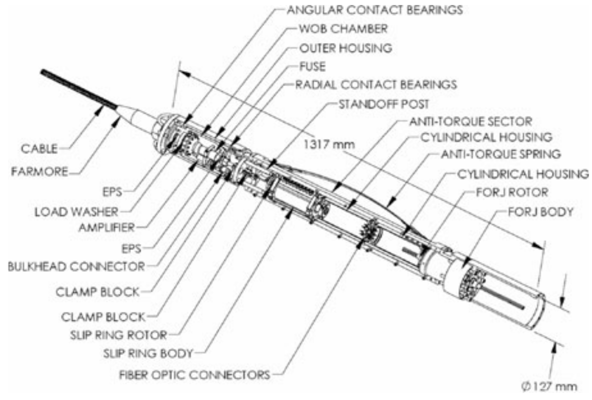

Fig. 6. Upper section.

will generate heat that must be dissipated quickly, so good thermal conductivity is important. The ideal material would have a coefficient of thermal expansion less than the steel motor components and bearings, be free-machining, stable with low distortion potential, and transfer heat well. The material selected was martensitic 416 stainless steel for optimum machinability, high stability, low distortion, low corrosion and low coefficient of thermal expansion. This material does not have as good a thermal conductivity as desired, but still could be used for the motor sub-assembly.

Oil filling with hexafluoroacetone (HFA) was accomplished using a simple apparatus employing a vacuum bell jar large enough to fit over the entire motor sub-assembly standing vertical. Air was evacuated and HFA oil was allowed to backfill the evacuated motor-module internal cavity through a fill hole in the center of the pressure-compensator piston. Oil flow was regulated with a needle valve.

The pump circulates drilling fluid to transport ice chips upward from the cutter into screens where they are collected. The DISC drill does not use a fixed displacement pump. Instead, a modified Gould 5CNHC single-stage turbine pump with one balanced rotating part is used. It was necessary to modify the pump-housing and thrust-bearing arrangement to ensure it could be attached to the drill. As with all rotating components of the DISC drill, smooth, vibration-free operation of the pump at all speeds is critical to quality drill performance. Normal pump operation during coring is 2100–2400 rpm. This produces a flow of approximately 280 L min^{-1}. Operation of the pump at 3500 rpm will produce a flow that, in theory, gives the potential to increase the descent speed of the drill into the fluid-filled hole. This is accomplished by running the pump at high speed to increase drill-fluid displacement upward through the center of the drill as it descends through the borehole. The idea has not been tested and will be attempted in the next drilling season at the West Antarctic ice sheet (WAIS) divide. Since the pump is not a fixed displacement type, small changes in the pressure drop through the drill have a large impact on the volume of fluid it can displace. This fact played a large role in the choice and design of the screens described in the previous subsection.

The male half of the custom-designed connector assembly and locking ring is mechanically attached at the bottom of the pump housing. The connector assembly provides for a rigid, straight connection of the motor/pump section to the screen section.

Instrument section

The instrument section (Fig. 5) is a 1.15 m long, 133 mm outside diameter, pressure-rated, sealed cylindrical compartment designed to keep all the internal electrical components dry and protected from the harsh, fluid-filled borehole environment. The instrument section houses high-voltage power electronics, motor power supplies with signal electronics, instrumentation components with electronics, and surface-to-drill high-speed communication electronics. Primary sealing of the instrument section is accomplished by tandem expanded polystyrene (EPS) located in each upper and lower end cap. Wires for high-voltage power and signals from the weight-on-bit (WOB) sensor enter through two pressure-rated electrical bulkhead fittings on the upper end cap. Power and signal wires for operation of the motors in the motor/pump section exit through three pressure-rated electrical bulkhead fittings on the lower end cap. Fiber-optic communications from the surface enter through a large pressure-rated bulkhead connector on the upper end cap. A set of mounting rails, thermally coupled and attached to the sides of the inside bore of the instrument module, provide a pathway to transfer heat out through the drilling-fluid cooled wall. All the electrical and electronics components (Mortensen and others, 2008) inside the instrument module are mounted on a 6 mm thick aluminum plate locked into the mounting rails by Wedge-Lok® assemblies. This aluminum plate picks up heat from the electronics and transfers it to the cold mounting rails. The aluminum plate slides out of the instrument module at either end, with removal of one or both end caps to facilitate service of electrical and electronics components. The top of the instrument section mechanically connects to the bottom of the upper section. The bottom of the instrument section mechanically connects to the top of the motor/pump section. These connections carry the full vertical static and dynamic load of the drill. Small fittings are located in the wall of the instrument section to facilitate back-filling its internal volume with dry nitrogen.

Upper section

The upper section (Fig. 6) is the portion of the sonde where the torque reaction of cutting ice is transferred to the wall of the borehole. It is also the assembly where the drill cable's interfaces to carry the mechanical load, electrical power and fiber-optic communication for the drill are located. The drill cable not only provides the means of supporting the drill sonde in the borehole, but also provides conduits for electrical power and data transmission. The mechanical connection of the cable's two outermost strength layers of galvanized improved plow steel (GIPS) is made by separating, cleaning, fish-hooking and potting of the strands into a Farmore connector. The Farmore connector is threaded onto a hollow-bore, necked-down mechanical fuse link designed and calibrated to separate at 66 kN so that the cable may be salvaged if the drill becomes impossibly stuck. The mechanical fuse passes top to bottom through a small sealed pressure-rated WOB chamber where it is shouldered with a step on its outer surface to a Kistler quartz load washer. This load washer, sandwiched between the load-carrying mechanical fuse and the upper surface of the WOB chamber, provides WOB information for the drillers. The load washer and its high impedance amplified are kept out of the drilling fluid and dry in the WOB chamber. Sealing of the WOB chamber is accomplished by the use of identical Parker EPS located between the outside surface of the mechanical fuse and the top and bottom surfaces of the bore in the WOB chamber. This way the EPS balances the hydrostatic pressure between the mechanical fuse and the load washer.

With its GIPS stripped back and potted into the Farmore connector, the inner portion of the cable can freely pass through the hollow bore of the mechanical fuse. Below the mechanical fuse, the next two layers of insulation are stripped back from the cable in two steps appropriately spaced apart to reveal its outer and inner high-voltage conductor. A copper clamp block is fastened around each of the two conductors. Here the high-voltage conductors leading to the rotor of an electrical slip ring are electrically connected. In addition, the wires from the Kistler amplifier pass out through the bottom of the WOB chamber by means of a high-pressure bulkhead connector and are electrically connected to the rotor of the electrical slip ring. The rotor of the electrical slip ring has a hollow bore to allow the remainder of the cable, the jacketed optical fibers, to pass through and connect to the optical fibers in the rotor of a sealed and pressure-compensated fiber-optic rotary joint (FORJ) via a set of intermediate fiber-optic connectors which are employed to facilitate assembly and disassembly.

The rotor of the electrical slip ring is mechanically connected to the bottom of the WOB chamber with three stand-off posts in a radial array extending down from the bottom of the WOB chamber. The three posts permit open access to attach the two copper high-voltage clamp blocks and yet provide direct mechanical coupling to the electrical slip-ring rotor. The electrical slip-ring rotor is mechanically connected to the rotor of the FORJ through tandem cylindrical housings. The cylindrical housings are separated in the middle by a plate on which the intermediate fiber-optic connectors are mounted. Each of the tandem cylindrical housings is designed in two pieces so that one half stays attached and the other half can be opened up or 'clam-shell' to facilitate connection of the optical fibers from the cable to the bulkhead and from the FORJ to the bulkhead. The clear internal volume of each cylindrical housing permits the optical fibers to be coiled within each housing at a maximum bend radius. This technique imparts maximum reliability, as it reduces stress on the fiber-optic connections and optical fibers. If the cable rotates by virtue of the mechanical design, so must the WOB chamber, the electrical slip-ring rotor and the FORJ rotor.

Two sets of Kaydon radial ball bearings are concentrically mounted around the outside of the WOB chamber. One set shouldered at the top of the WOB chamber is a duplex tandem pair of REALI-SLIM® angular-contact bearings, and the other set at the bottom of the WOB chamber is a pair of REALI-SLIM® radial-contact bearings. An outer housing of 127 mm outside diameter fits over both of the Kaydon bearing sets and is shouldered on the outer race of the top duplex tandem pair of angular-contact bearings. This bearing set carries the full vertical static and dynamic load of the drill. On the lower end of this outer housing are four anti-torque sector plates configured and attached to make an internal volume with a large square internal cross-section and a 127 mm outside diameter with four flat areas for mounting the anti-torque spring assemblies. The square internal cross-section of the assembled anti-torque sector plates is used to impart rotary motion to the body of the electrical slip-ring assembly while permitting it limited free axial movement to accommodate small axial variations due to thermal effects. The body of the FORJ is rigidly fastened at the lower end of the anti-torque sectors. The connection of the lower cylindrical housing to the FORJ rotor has limited free-floating axial movement, also necessary to accommodate small axial movements due to thermal changes. Much care was used to negate the possibility of binding or excessive loading of the electrical slip-ring assembly and the FORJ for temperature effects, as their rotors must operate freely.

The anti-torque sector plates are designed to be opened in a 'clam-shell' manner to facilitate access to all mechanical and electrical components held within. This idea is much like opening the hood of a car to service the engine rather than removing its entire body. Electrical conductors from the body of the electrical slip-ring assembly pass around the outside of the tandem cylindrical housings through channels in the FORJ body and terminate in two connectors in the internal volume at the very bottom of the anti-torque module where they can be plugged into the pressure-rated connectors on the top of the instrument module. Fiber-optic conductors from the body of the FORJ terminate in the same internal volume in a pressure-rated connector. Ample internal volume at the bottom of the anti-torque section was allowed to facilitate mating the electrical connectors and the connector in the field and to coil the excess wire and fiber-optic conductors.

The anti-torque section has a relatively large enclosed volume flooded by drilling fluid. Fluid is permitted around the high-voltage connections on the cable and electrical slip-ring body. For safety reasons, a quick-connect fitting and proper venting was incorporated to facilitate purging with nitrogen to avoid an oxygen atmosphere in these areas.

TOWER

The tower tilts to allow the drill sonde to be serviced in the horizontal position without removing it from the tower. It is also the reaction framework for suspending the drill sonde on the drill cable in the hole during raising, lowering and drill operations. The tower consists of a base with wide stance, vertically adjustable feet for leveling, modular truss framework with drip pans and adjustable roller cradles for supporting the sonde, and a hydraulic-driven ball screw actuator for tilting. The tower uses a crown sheave instrumented for cable payout, cable tension and cable load. Modular truss sections fold flat to reduce their volume for transport.

Adjustable arms of the roller cradles are designed to be aligned with the sonde on the tower by a precision jig

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transit. They require a one-time precise adjustment, so the rigid sonde barrels can be freely rotated during drilling operations to assemble and disassemble the tapered threaded connectors on the screen and core barrels. Seven roller cradles support the sonde on the tower.

The tower pivot is located approximately 8 m above the bottom end of the truss such that a 10 m deep, 1.2 m wide slot is used to accommodate the lower part of the tower as it tilts to its vertical position. Actuation of the tower to tilt it into either position is done with a radio-controlled, manual joystick that provides variable speed capability and frees the operator to walk around and observe the tower in motion. Hydraulic fluid with a pressure of 7.6 MPa and a flow of 64 L min^{-1} for running the ball screw actuator is provided by a separate hydraulic power unit located adjacent to the tower. A spring-actuated pressure release brake holds the tower in any desired position when the operator stops the motion with the joystick.

WINCH

The winch provides a means of quickly raising the sonde from the borehole and providing the fine control necessary for coring operations. It is capable of pulling 36 kN at 2.8 m s^{-1} and has controllable low-speed resolution for drilling of 0.1 mm s^{-1}. The winch drum has capacity to hold 4000 m of 15.2 mm diameter cable. The physical layout of the winch is unique in that its drum axis is parallel to the drill cable as it runs between the winch and tower. The winch level wind traverses back and forth across the width of the drum in line with the cable. This layout allows the winch to be close-coupled to the tower base.

High-speed operation of the winch for raising and lowering the drill sonde through the hole utilizes a 1790 rpm, 112 kW inverter duty motor with an integrated shaft encoder coupled to the drum through a 30 : 1 primary gear reduction. The low-speed operation of the winch for drilling of the core utilizes a 2.2 kW inverter duty motor coupled to the 30 : 1 primary gearbox on the end opposite to the 112 kW motor via an electrically actuated clutch and 120 : 1 secondary gearbox. This gives an overall ratio of 3600 : 1 for the low-speed drive. The clutch permits the secondary gearbox to be decoupled from the primary gearbox when the 112 kW motor is powered. Decoupling the secondary gearbox is necessary to avoid exceeding the recommended pitch-line velocity of the 120 : 1 ratio gear train. The 112 kW motor always remains coupled to the primary gearbox. When drilling a core, the clutch is engaged and the 2.2 kW motor is powered to provide the torque and speed to drive the drum. At the same time, the 112 kW motor is not powered and is being back-driven by the 2.2 kW motor. This way the pulse output from the 112 kW motor shaft encoder is utilized no matter which drive motor is being operated.

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