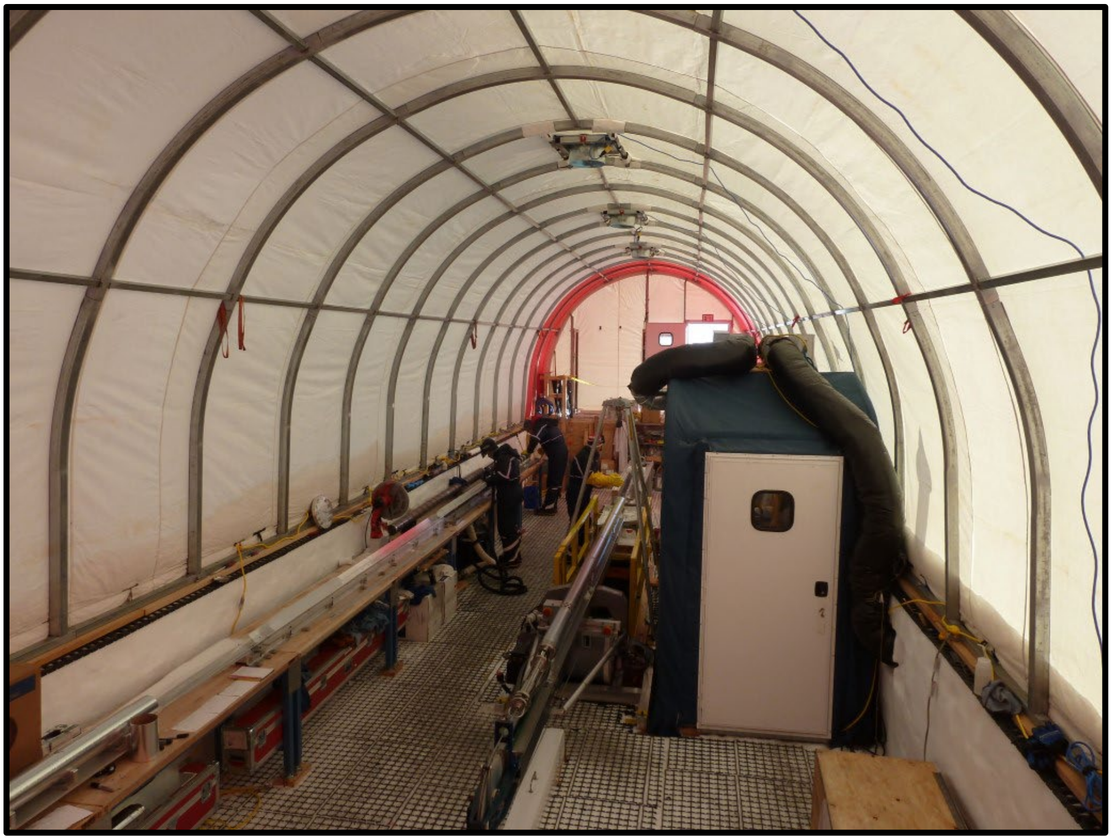

FORO 3000 DRILL

Operations and Maintenance Manual

July 13, 2026

NSF Ice Drilling Program
University of Wisconsin-Madison Space Science & Engineering Center
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Table of Contents

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1.0 PURPOSE

This document describes the operations and maintenance of the Foro 3000 Drill system.

2.0 SCOPE

This document applies to the operations and maintenance of the Foro 3000 Drill system including all major field-deployable sub-systems.

3.0 REFERENCES

- 1008-0014 SSEC Project Safety Plan
- 8399-0003 Foro 3000 Science Requirements
- 8399-0004 Foro 3000 Engineering Requirements
- 8399-0005 Foro 3000 Failure Mode and Effects Analysis – Summary
- 8399-0008 Foro 1650 Failure Mode and Effects Analysis – Table
- 8399-0012 Foro 3000 Equipment Manuals
- 8614-0110 IDP Intermediate & Deep Drill Safety Training
- 8614-0112 Foro Drill Bulkhead Seal Installation and Maintenance
- 8614-0113 Foro 1650 and Foro 3000 Drill Cable Termination
- 8501-0019 IDP Drill Slot Confined Space Training
- 8501-0024 Casing Fusion Welding Procedure
- Note: Referenced drawings can be found in the IDP SolidWorks PDM vault.

4.0 DEFINITIONS

IDP – NSF Ice Drilling Program

NSF – National Science Foundation

QAS – Quality Assurance and Safety group

SSEC – University of Wisconsin-Madison, Space Science & Engineering Center

5.0 RESPONSIBILITIES

IDP Engineering is responsible for the generation and maintenance of this document.

SSEC QAS is responsible for ensuring that this document is created, reviewed, approved, maintained and changed per applicable SSEC processes.

Project personnel are responsible for understanding this document.

6.0 RECORDS

None.

7.0 SAFETY NOTICE

The SSEC Project Safety Plan, 1008-0014, describes in detail the processes used to define, evaluate, mitigate, report, and communicate potential and real safety concerns for equipment and field projects. Document 8614-0110 contains safety training specific to the Foro 3000. This section highlights key safety concerns for the Foro 3000 Drill system and is not meant to replace the SSEC Project Safety Plan. Only trained personnel should operate the Foro 3000 Drill. All drillers and those operating or assisting with operations of the Foro 3000 Drill must read and understand the following safety precautions prior to operating this device.

Personal Protective Equipment (PPE)

- Personnel shall wear appropriate PPE during drilling operations, including:
    - Safety glasses
    - Footwear – safety toe and liquid-proof
    - Hearing protection
    - Gloves – liquid-proof and cut-resistant
    - Appropriate clothing – avoid loose clothing, jewelry, and loose long hair. Liquid-proof outerwear is recommended.
    - Hard hats – required when working near suspended loads or when working below other personnel.

Mechanical Safety

- Cutters – The ice cutting bit is extremely sharp. Operators should wear protective gloves and take care whenever handling cutting bits.
- Pinch Points – There are several areas on the drill where a finger, hand, arm or clothing could be pinched. Operators should identify all pinch points prior to operation and should be mindful of all such points during operation.
- Suspended Loads – Users shall never stand under suspended loads. Injury may result from moving, rotating, falling or unbalanced loads.
- Rotating Components – The drill head may be rotated under power while servicing the drill on the tower. Keep hands, limbs, loose clothing, and hair away from any rotating components. The drill operator must make sure it is safe to rotate the cutter head and that others working with the drill are made aware it will be turning before it is turned on.
- Eye Protection – Must be worn whenever handling fluids or fluid-soaked cuttings.
- Cold Hazard – Drill components may be extremely cold when pulled from the borehole. Always wear appropriate gloves when handling.
- Slippery Surfaces – The drill trench floor and handrails may become slippery when wet with drilling fluid. Use caution whenever walking on the wet floor or grabbing handrails.

Electrical Safety

- Electrical shock – Extreme care shall be taken when assembling, disassembling and servicing electrical equipment. Always disconnect power before servicing equipment. Proper lockout tagout procedures shall be followed and only qualified people should be working on electrical equipment.
- Grounding – Because the drill sits upon a large thickness of ice, a common earth ground cannot be established. Workers shall ensure that all drilling equipment is bonded together to a common ground back to the generator(s).

Chemical Safety

- Safety Data Sheets are provided to staff and shall be available at the work site. All staff should review the SDS's before handling chemicals.
- Use fluid resistant gloves and eye protection when handling drilling fluid or other chemicals.
- Use care and observe all safety warnings when handling chemicals.
- Combustibles – This system uses combustible fuel for the generator and may be supplied with ethanol for freeing a stuck drill. Take care to properly store all combustibles away from all major heat sources.
- Secondary Containment – Fuels and other fluids should be stored in secondary containment to prevent spills and unplanned release. Secondary containment devices must be requested from the logistics provider.
- Drilling Fluid Hazard – If used, review the SDS for any potential of combustion or potentially present health hazards. Proper PPE must be worn when handling and using drilling fluids.

Environmental Safety

- Cold – This drill will be deployed to extremely cold climates. Operators shall wear outerwear suitable to protect themselves from the cold and should monitor their own and fellow workers' activities for exposure to cold.

Confined Space for Slot Entry

- Retrieval equipment – Including a harness, retrieval line (lifeline), and tripod for lifeline
- Hardhat or climbing helmet
- Belt O2 Monitor – For detection of lack of oxygen due to dangerous levels of gasses from drill fluid
- Radio
- Gloves

8.0 OVERVIEW

The Foro 3000 Drill is the next generation of the Danish Hans-Tausen Drill and Danish Deep Drill, with the capability of producing 3-meter-long cores. This manual primarily focuses on the setting up of the Foro 3000 drill system. The operations guide, preventive maintenance checklists and drill log templates are provided in Appendices A-C.

The Foro 3000 Drill is sufficiently portable for coring at a wide variety of sites, and capable of retrieving 98 mm diameter core from the surface down to 3000 meters depth in four typical field seasons.

In addition to the drill itself, the Foro 3000 system includes the following ancillary items:

- Core Processing System: core barrel puller, trays, vacuum, saw, and tables
- Chip melter to recover the drill fluid from the chips created by drilling the core
- Drill fluid handling system
- Vacuums to clean the drill cable and the core
- Pilot hole system
- 7” and 9” diameter reamers
- A 4.9 m (16 ft.) x 19.5 m (68 ft.) x 3.5 m (11.5 ft.) high un-insulated fabric shelter for housing the drilling and core processing operations.
- A 1.5 m (5 ft.) x 2.5 m (8 ft.) x 2.5 m (8 ft.) high heated hard-sided structure located inside the drill tent serving as the drill control room.

The Foro 3000 Drill is designed and constructed to be transportable by heavy lift aircraft or overland traverse. The drill tent can remain set up over multiple seasons and most equipment is left onsite to "winter-over". To drill to 3000 meters depth in four field seasons, a minimum of 40 working days each season with a 10-person field-team operating 24 hours per day is required. This includes seven drillers and three core handlers.

9.0 DRILL SYSTEM LAYOUT

A plan view of the drill system layout is shown in Figure 1. See drawing 8399-0245 *Foro 3000 Site Layout* for additional views and details.

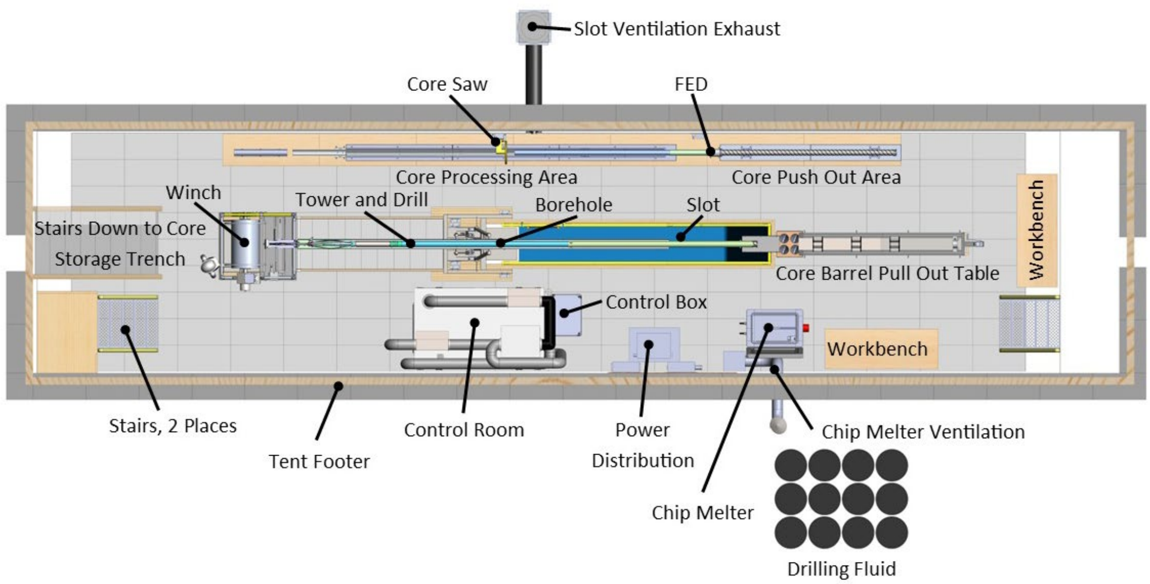


Figure 1. Foro 3000 Drill System Layout with major components labeled.

The drilling floor inside the tent is recessed 1.5 m (55”) to permit the use of a lower height tent and to help keep the building cooler by having less wall area exposed to the sun. A set of stairs is located inside the door at either end of the tent to access the drilling floor. A smaller structure within the drill tent, which is heated and ventilated, serves as the control room for operating the drill and as a warming area. Windows on two sides of the control room provide a good view of the drill floor and the room is large enough to comfortably hold four people.

10.0 TENT SITE PREPARATION AND CONSTRUCTION

10.1 Drill Trench

The drill site should be laid out with the prevailing wind direction in mind. To minimize drifting, the drill tent should be positioned with one of the end walls pointing into the wind. Cargo lines should also run lengthwise with the wind, and rows should be spaced out enough so equipment can get between them to clear snow drifts. Empty pallets, low boxes, and all electrical runs should be well marked with flags so they can be found if they get buried and to prevent them from getting damaged by equipment.

The base layer of the drill tent footing is 1.0 m x 0.5 m sections of Geoblock Porous Pavement tiles. They are installed directly on a level snow surface with the smaller grid openings facing up, Figure 2. This allows the drill tent, which will be assembled off the end of the trench, to easily slide over the footer.

Figure 2. Orientation of Geoblock, side-view, for use under the tent footings.

Install two lines, consisting of 23 sections (75.5') each, of Geoblock that are spaced 15' apart, Figure 3. Level and backfill the tiles with snow as they are installed. The two lines should create a level plain for the tent to sit on. Drawing 8399-0245 *Foro 3000 Site Layout* shows the location of the footings in relationship to the borehole and trench. Note, the borehole is not centered in the tent. This must be considered if the borehole must be in a specific location and if the drill system is being set up in reference to it. The drawing also shows only 21-1/2 tiles are required for the length of the tent. Place the extra tiles off the end of the trench layout that the tent will be constructed on. Assembling the end of the tent frame on these tiles keeps the frame from digging into the snow when it is sliding into place. Wait to place the two short lengths of footing that will be under the tent end walls until after the trench excavation has been completed.

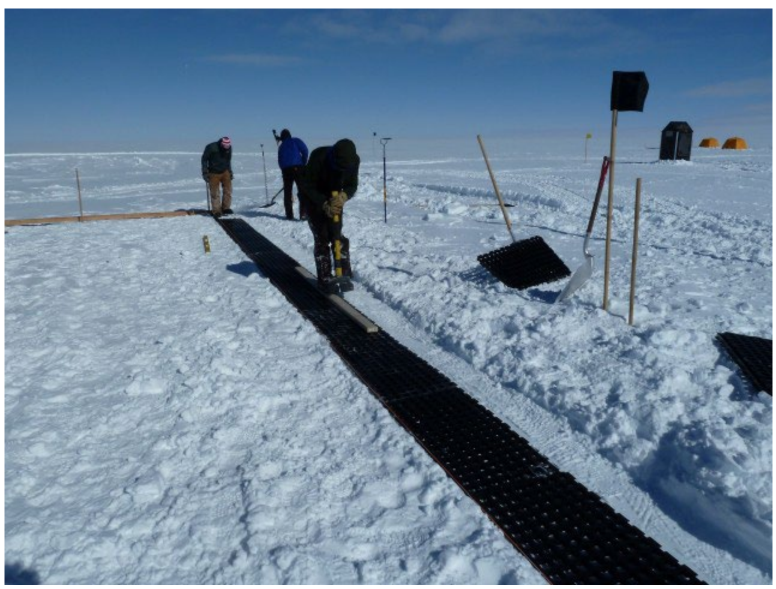


Figure 3. Installing the Geoblock tent footing

Drawing 8399-0326 *Trench & Slot* provides the dimensions for the trench excavation. Lay the two side footings before excavating the trench. This establishes the width of the trench and provides a level surface to measure the depth from. Depending on equipment available, the trench could be excavated with heavy equipment such as a bucket loader or bulldozer or could be done by hand with chain saws. If heavy equipment is going to be used, first cut along the inside edge of the footing with a chain saw. This will provide a clean edge along the footing and help prevent the snow under it from being disturbed. These cuts may need to be repeated a few times as the trench is deepened. After excavation, end walls will need to be built and then backfilled, Figure 4. Either wood or snow block wall will work. Before building the end walls, it is a good time to place the heavy items like the tower base, winch drum, and chip melter crates in the trench while there is a ramp.

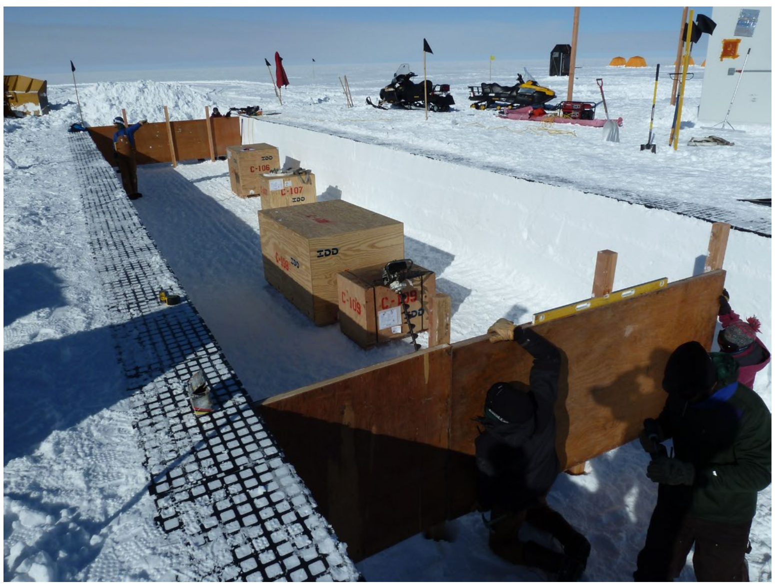


Figure 4. Excavated trench with large cargo pieces in place and wood end walls being built. Note, this picture is from setting up Foro 1650. The procedure for Foro 3000 is the same with the trench being 4’ longer.

10.2 Tent Construction

Assemble the drill tent off the end of the trench that the Geoblock footings run long on, following the instructions for assembling the tent in 8399-0012 *Foro 3000 Equipment Manuals*. The tent should be built with the first few feet of the tent frame on top of the Geoblock footing to facilitate with sliding the tent into place.

Lag bolt the base rails to 2x6 wood lumber, see drawing 8399-0330 *Tent Footer*, for the footing dimensions, making sure the joints of the boards are offset from the joint in the base and that the lag bolts don’t protrude out the bottom of the lumber. Place straps at each arch to keep the base from spreading until it is secured over the trench. Diagonal straps should also be installed to keep the building square while being moved. These steps are shown in Figures 5 and 6.

Figure 5. Tent frame being assembled off the end of the trench and on the Geoblock footing tails. Note: this picture is of the Foro 1650 tent, but the assembly process is the same for Foro 3000.

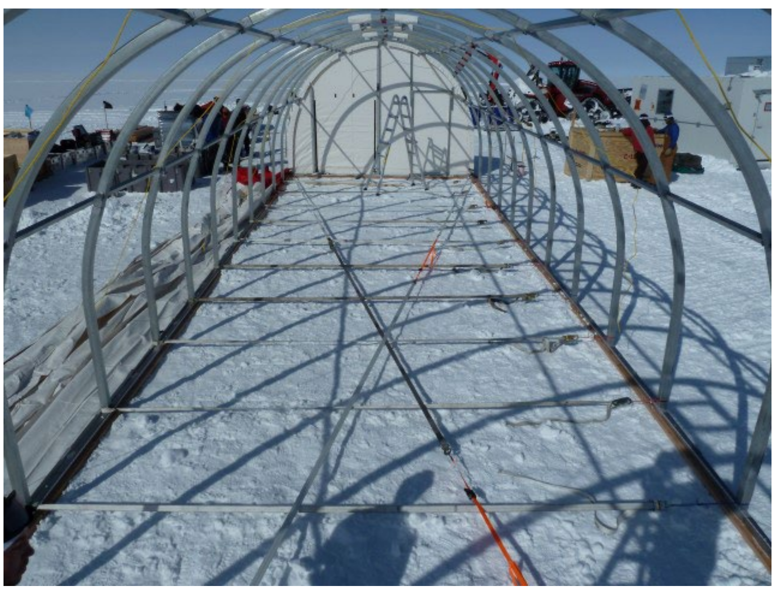


Figure 6. Assembled tent frame with straps to keep the base from spreading. Note: this picture is of the Foro 1650 tent, but the assembly process is the same for Foro 3000.

Install the cover as described in the tent manual. However, after centering the body cover, bunch up one side and install the roof vents, Figure 7. This is also a good time to install the 12” powered fans. They mount from the inside of the tent, Figure 8.

Figure 7. Installing the roof vents. Note: this picture is of the Foro 1650 tent, but the assembly process is the same for Foro 3000.

Figure 8. Installing the roof vent fans. Note: this picture is of the Foro 1650 tent, but the assembly process is the same for Foro 3000.

Finish installing the cover, but do not tension the cover contour ropes at this time. Once the tent assembly is complete, pull it over the trench using a vehicle, tractor or winch. Be careful to keep the tent centered as there will be only a few inches on either side between the tent base and the inside edge of the Geoblock. Snow pickets are provided to secure the tent base to the snow. As the tent is being pulled over the trench, drive a picket in every 4' on each side. This will act as a guide and keep the tent centered. If these are placed properly, they will line up next to each arch once the tent is in its final position. Once the tent is in its final position, drive the pickets in until they are flush with the top of the 2x6 to prevent them from damaging the fabric cover. Remove the internal straps and let the frame push against the pickets. Run deck screws through the picket and into the 2x6. Finally, finish tensioning the cover per the manufacturer's instructions and install the stairs at either end.

11.0 DRILL SYSTEM INSTALLATION

11.1 Winch and Tower Footer and Slot Excavation

Assemble and install the slot and tower footing assembly, 8399-0238 *Slot and Tower Footer Assembly*, and winch footing, 8399-0173 *Winch Footer*, in the trench floor before excavating the slot. The slot footing will serve as a guide and prevent the snow edge from eroding as the slot is cut. Figure 9 shows the slot being excavated with an electric chain saw and shovels.

The Foro 3000 slot is considered a permit required confined space which falls under the 29CFR1910.146(c)(5) exemption. See the SSEC Project Safety Plan, 1008-0014, for confined space requirements. Entry into the slot requires training, PPE, and a signed entry certificate; details are outlined in the IDP Drill Slot Confined Space safety training, 8501-0019.

Figure 9. Slot excavation after the winch footing has been installed. Note, the picture is of assembly of the Foro 1650 system, but the process is the same for Foro 3000.

Depending on the duration of the project and condition of the snow, a floor should be laid to stabilize the snow and prevent the work area from getting slippery. Geoblock Porous Pavement grid sections are provided for this. The grid sections are placed with the larger grid openings facing up, opposite that for the tent footing, to provide the best traction. The grid sections should be backfilled with snow to lock them into place and to create a smooth walking surface, Figure 10. The panels are made of polyethylene, so they can easily be cut with standard woodworking tools. It is recommended to not start placing the flooring until the winch footing has been set, as the flooring needs to be set around this equipment. Flooring also does not need to be placed under the control room if it is being used. However, it is a good idea to lay flooring under the core processing line to provide good footing for the tables. Drawing 8399-0327 *Geoblock Flooring_Foro 3k* shows the recommended Geoblock layout for the floor. It is recommended to run all cables, hoses, and duct work that will run under the floor before installing the floor. However, the floor panels can be removed after installation to bury utilities as necessary.

Figure 10. Installing the Geoblock flooring.

11.2 Control Room

The control room is a 5’ x 8’ heated and ventilated hard-sided structure. Assemble the control room per drawing 8399-0377 *Control Room Assembly*. Rope pulleys are included for placing the roof. After the floor is laid, the roof is assembled on top of it. Rig the pulleys off the tent frame and raise it up high enough to assemble the walls. Then lower the roof into place. The heating/ventilation system, which includes an Energy Recovery Ventilator (ERV) to preheat the incoming fresh air, is then assembled on the roof as shown in 8399-0377 and Figure 11. Warm air, which is turned over 53 times per hour, is supplied at the ceiling level and returns to floor level under the operators’ desk to create a down-draft air flow. Manuals for the ERV and heaters can be found in the 8399-0012 *Foro 3000 Equipment Manuals*. The intake and exhaust duct should be run outside the drill tent and terminated with vertical ducts that are at least 3’ high and fitted with wind directional caps.

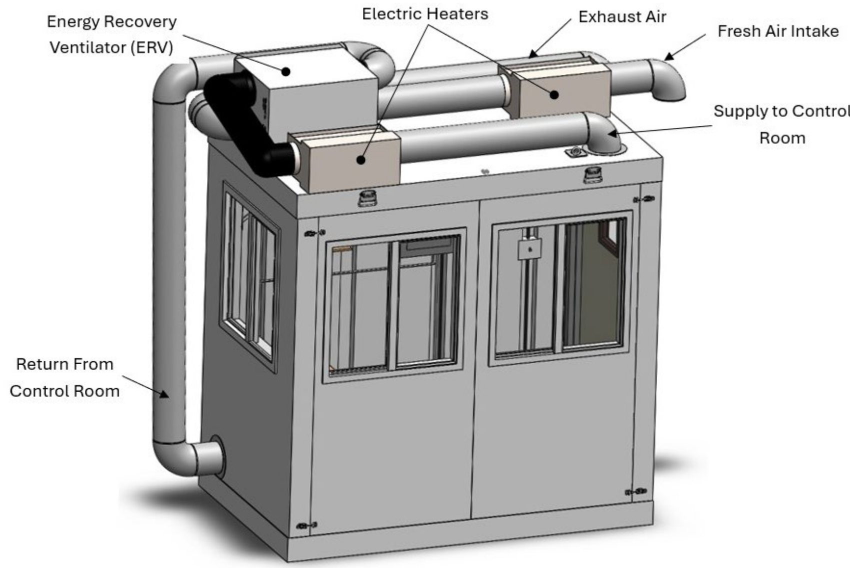


Figure 11. Control Room with heating/ventilation system.

11.3 Power System

The Foro 3000 Drill system requires a 480V 3-phase power feed with a minimum generator sizing of 35kW at sea level. The two electrical distribution panels and step-down transformer are included as part of the system along with all the interconnect cables. Install a 4' x 8' sheet of plywood to the left of the control room, Figures 1 and 12. Place the 480V panel on the left and 208V panel on the right with the transformer centered below them. Make sure the panels are mounted high enough so the doors will clear the top of the transformer. The system is plug-n-play, so no hard wiring is required. For further details, see drawing 8614-0585 *Power System Wiring Diagram* for complete system specifications and 8399-0012 *Foro 3000 Equipment Manuals* for information on the two panels and transformer. The feeder cables for the vacuum system, slot ventilation fan, and multi-tap outlets located on the other side of the drill tent will need to be buried beneath the Geoblock flooring. The 480V panel is also equipped with a 60A breaker and receptacle that can be used to feed camp power.

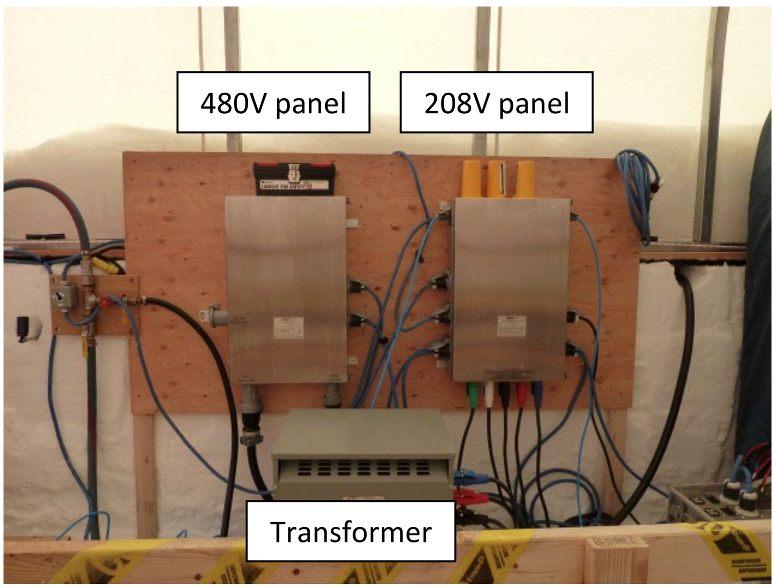


Figure 12. Electrical distribution panels with transformer.

11.4 Control System

The drill system is operated via electronic controls distributed throughout the system, Figure 13. Emergency stop buttons (E-stops) are present at the winch, control box, on the slot hand railing near the end of the slot, and console – these can be used to stop winch and tower motion at any time. All E-Stop buttons in the system must be released for the drill system to be used. The control box, console, and sonde contain the most complex and sensitive electronics in the system. These assemblies should not be opened or modified except under the clear guidance of IDP electrical engineers.

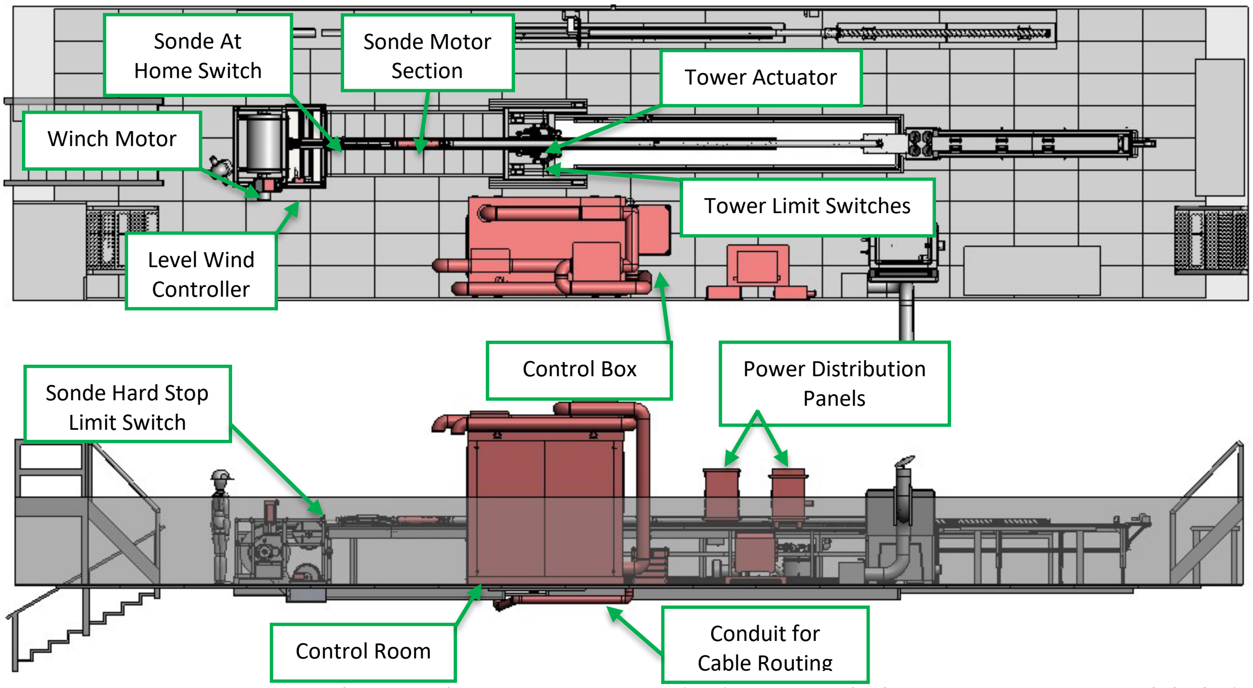


Figure 13. Foro 3000 control system layout, top view and side view with the major components labeled.

11.4.1 Control Box

The drill system requires a 208V 3-phase supply and a 480V 3-phase supply, both connected to the control box, Figure 14.

The Control Box contains:

- 600V DC power supply that powers the drill
- 24V DC power supply for control voltages across the drill system
- Two motor drives that operate the winch motor and tower actuator
- A microcontroller to translate the signals from the tower pendant to the tower actuator motor drive
- Connections to various limit switches and other peripheral devices associated with the winch and tower motors
- An E-Stop button
- Connections to the Console

The power supplied to the drill is controlled by opening a lid on the top of the control box to directly access the controls on the front of the Sorensen power supply.

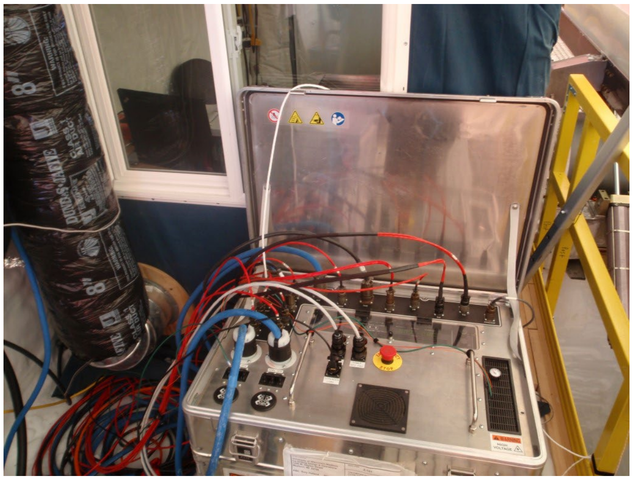


Figure 14. Control box.

11.4.2 Console

The Console allows the operator to control:

- The winch motor
- The drill motor, if the Drill Control Interface is configured appropriately

The Console also includes an E-Stop button, and an indicator light that is illuminated when any E-Stop in the system is activated. The indicator will also illuminate if a cable carrying an E-Stop signal is disconnected.

11.4.3 Winch Assembly

The winch motor is powered and controlled by the motor drive in the control box, but the level wind is only powered from the control box – it contains a closed loop control of the cable guide based on the cable position.

11.4.4 Drill Tower

The Drill Tower can be tilted via the buttons on the Tower Pendant, which controls the tower actuator.

The red button on the pendant is NOT an E-stop. It is used to enable the other pendant controls – when not in use, the red button should be left pressed in to disable the pendant controls.

When the red button is pulled out, the knob on the Tower Pendant can be pulled down to drive the tower towards the vertical position or pushed up to drive the tower towards the horizontal position. Tower motion will stop when either of the tower limit switches are actuated, corresponding to the vertical or horizontal tower positions. The tower should not be left in any position other than horizontal or vertical – operating the winch with the tower in other positions may result in unexpected movement and/or hazards to personnel and equipment.

11.4.5 Sonde

The control system elements on the sonde are concentrated in the motor section. These include the circuit boards mounted to a heatsink within the motor section, the drill motor and drive, inertial measurement unit, aka navigation module, and borehole pressure sensor.

11.4.6 Drill Control Interface

The Drill Control Interface, Figure 15, is a program developed in NI LabVIEW 2020, with the following features:

- Displays all the data communicated to or from the Sonde electronics
- Allows the operator to control the operation of the drill motor
- Displays data associated with cable tension and payout, including an estimate of the weight on the bit and whether the drill is floating in the drill fluid

If desired, the Interface includes a feature whereby the operator can pass control of the drill motor to the console. It is typically run on a laptop located in the control room, near the console.

Figure 15. Drill control interface inside the control room tent. Note: This picture is from the Foro 1650 system, with the Foro 3000 system being similar.

11.4.7 Power Up Procedure

1	Visually confirm that grounding wires link all exposed metal to the control box
2	Visually confirm that the following cables are connected:

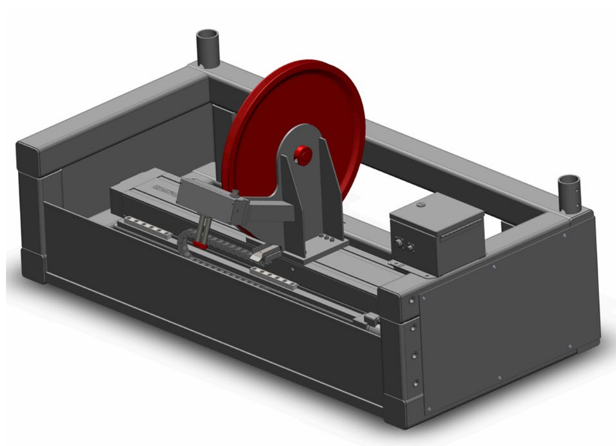
Cable Tag	Cable Description	From Control Box To:
WM	Winch Motor power cable	Winch Motor
WMR	Winch Motor Resolver cable	Winch Motor
WB	Winch Brake cable	Brake Resistor
TAM	Tower Actuator Motor cable	Tower Actuator
TMR	Tower Motor Resolver cable	Tower Actuator
DP	Drill Power cable	Winch Drum
LW	Level Wind power	Level Wind
SLS	Sonde Limit Switches	Crown Sheave
TLS	Tower Limit Switches	Tower Horizontal/ Vertical Limit Switches
E-STOP	E-Stop cable	E-Stop Button
C1, C2, C3, C4	Console cables 1, 2, 3, and 4	Console
TP	Tower Pendant	Tower Pendant

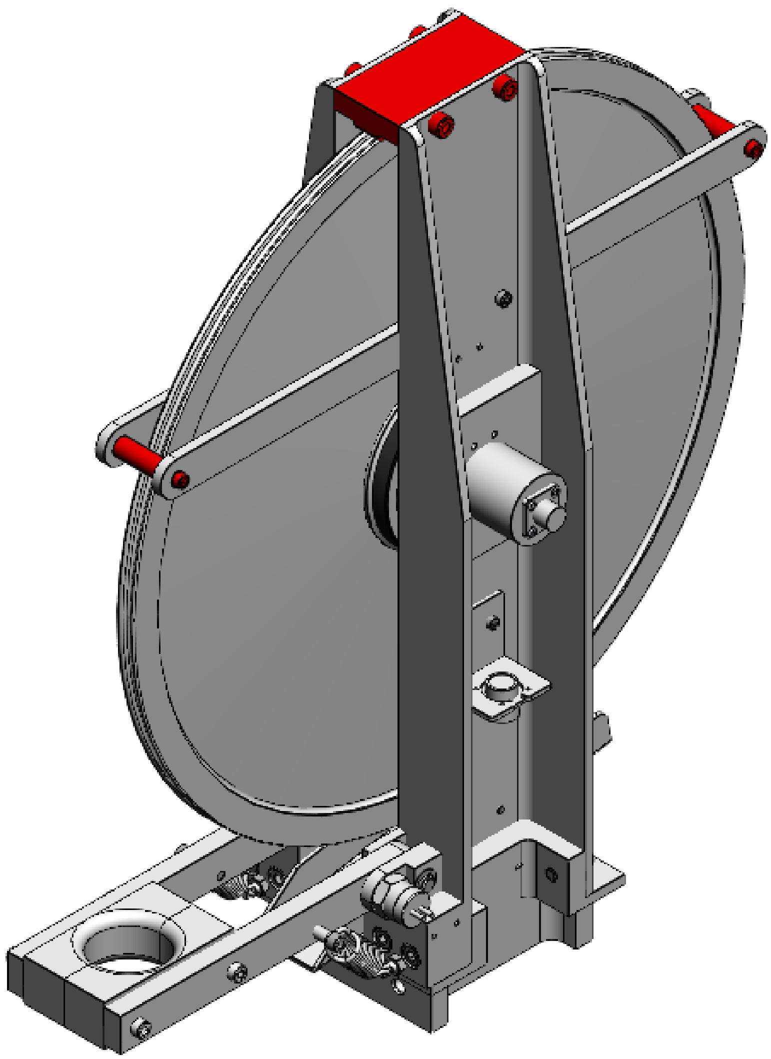
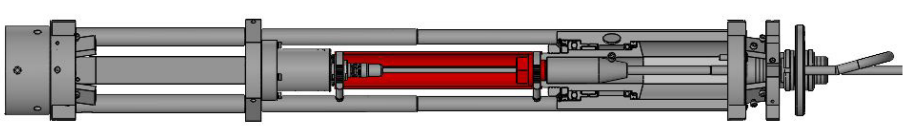
3	Confirm that the 208V and 480V breakers on the Drill Control Box are in the OFF position
4	Confirm that the Sorensen power supply in the Drill Control Box is switched off and disabled
5	Confirm that the controls from the Drill Console are as follows: • Winch motor set to Stopped • Winch motor Coring and Tripping speeds set to zero • Drill speed set to zero
6	Confirm that all E-stop buttons are in the inactive (up) position
7	Connect the 208V and 480V plugs to the Drill Control Box
8	Notify any nearby personnel that power is being applied by saying “Power On”
9	Switch the 208V and 480V breakers on the Drill Control Box to the ON position
10	Wait 30 seconds to allow for system initialization

11.4.8 Power Down Procedure

1	Switch off and disable the Sorensen power supply in the Drill Control Box
2	Switch the 208V and 480V breakers on the Drill Control Box to the OFF position
3	Disconnect the 208V and 480V power cables from the Drill Control Box
4	Wait 10 minutes for the system to completely de-energize

11.4.9 Assembly Procedure: Sonde and Winch Cable

1	If the system is powered down, execute the **Power Up Procedure** (11.4.7)
2	Confirm that the Sorensen power supply in the Drill Control Box is switched off and disabled
3	Remove the straps from the Winch Drum to release the Winch Cable
4	Use the Drill Console to provide slack as necessary by paying out the winch cable
5	Assemble the Winch Cable with the Level Wind by removing the components highlighted below in red, then threading cable between the rollers and through the sheave mount and replacing the removed components. 

6	Assemble the Winch Cable with the Tower crown sheave by removing components highlighted below in red, then threading cable onto crown sheave, and replacing the removed components. 
7	Remove the protective cover from the end of the Winch Cable
8	Assemble the Winch Cable with the Sonde by removing components highlighted below in red, then securing the cable strain relief head to the antitorque, mating the cable connector with the slip ring, and replacing the removed components. 

11.4.10 Disassembly Procedure: Sonde and Winch Cable

1	If the system is powered down, execute the **Power Up Procedure** (11.4.7)
2	Confirm that the Sorensen power supply in the Drill Control Box is switched off and disabled
3	Execute the steps of the **Assembly Procedure: Sonde and Winch Cable** (11.4.9) in reverse order

11.4.11 Drill Control Interface Initialization Procedure

1	If the system is powered down, execute the **Power Up Procedure** (11.4.7)
2	Connect the USB cable from the Drill Console to the PC to be used for running the Interface
3	Open the Device Manager (Win+X then M), expand the Ports (COM & LPT) tree, and take note of the COM port associated with the Drill System
4	If the Drill Control Interface has not been run before, use the InstaCal program from Measurement Computing to configure the input channels of the USB-1808-OEM, such that all channels are single ended (SE), except for channel 0 which is differential (DIFF); set the Encoder Z input mode to Active high level
5	Start the Drill Control Interface application
6	Use the COM port dropdown to select the COM port identified in step 3 above
7	Run the program by selecting Operate > Run
8	Confirm connection to sonde, then select State > Initialize
9	Use controls at left of screen to set drill speed

11.5 Winch and Tower

A tilting tower design is used for the Foro 3000 system so the drill can be positioned horizontal for ice core and cuttings removal and for servicing. The tower is 7 m in length and is designed to work with a drill that has a 3 m long core capacity. The tower will also accommodate reamers or other tools up to 12 inches in diameter, if the sonde rests are removed. Specifications for the winch are shown in Table 1.

Pulling Capacity	9.8 kN (outer layer) – 13.3 kN (first layer)
Line Speed	1.2 m/s (first layer) – 1.6 m/s (outer layer)
Gearbox	57:1 helical bevel gear
Motor	17 hp, 2,400 rpm, 460 V
Cable	Rochester 4-H-281A, 4 x #22 AWG conductors, 34.7 kN breaking strength
Cable Capacity	3,100 m nominal

Table 1. Winch specifications

The crown sheave is instrumented to measure cable tension and speed. The sheave also includes a cable guide to prevent the cable from coming off the sheave in the event cable tension is lost. A hard stop switch that stops the winch is also integrated into the cable guide if the sonde-at-home switch fails. Below the hard stop is the sonde-at-home switch. This switch is used as a home reference for the drill and stops the winch and lights the sonde-at-home light on the console when the drill contacts it. The crown sheave assembly is shown in Figure 16.

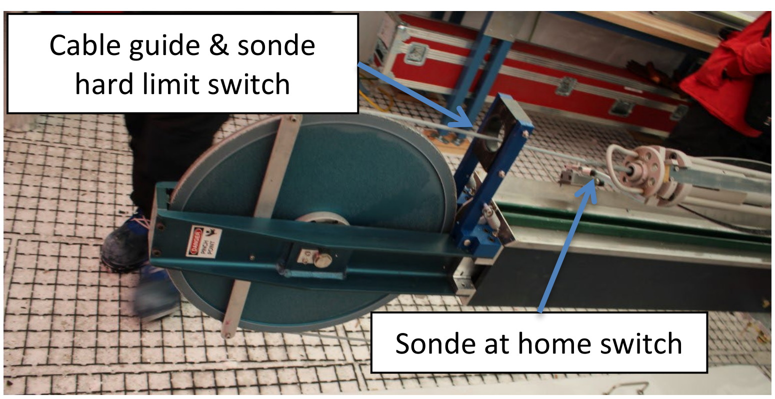


Figure 16. Crown Sheave assembly

The tower breaks down into 1 and 2 m long sections for easy transport. The tower base pivot features a four-bar linkage to compensate for change in winch cable length as the tower is tilted so the drill remains stationary. The winch and level wind are structurally connected to the tower base by two wood beams recessed in the floor, effectively creating a path for the winch cable to route below the floor surface, Figure 17. Removable aluminum panels cover the cable way for safety and so personnel can walk through this area when the tower is in the vertical position. Handrailing around the winch and level wind protect personnel from the rotating and moving components.

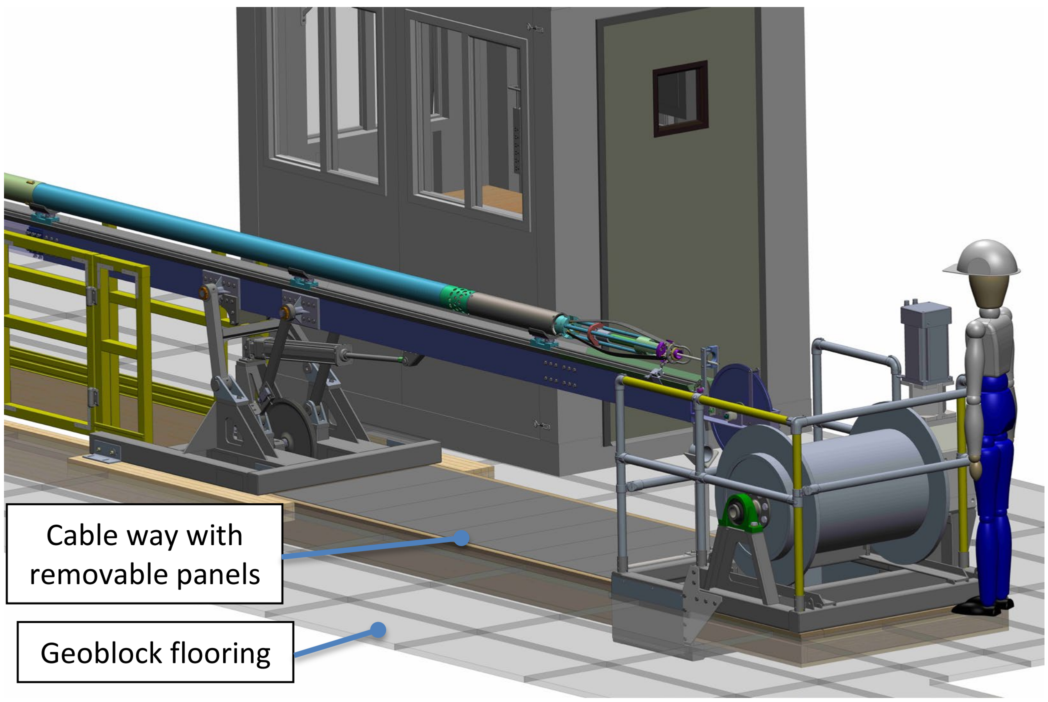


Figure 17: Tower base and winch connected with sub-floor cable way. The Geoblock flooring is shown transparent to show the tower base and winch footing structures connected with the cable way.

The winch was designed so to the drum can be removed without the need for special lifting equipment. A spare winch drum, loaded with pre-tensioned winch cable, is shipped with the system in a special crate designed for swapping the winch drums. Figure 18 shows the winch drum sitting on its shipping pallet behind the tower base.

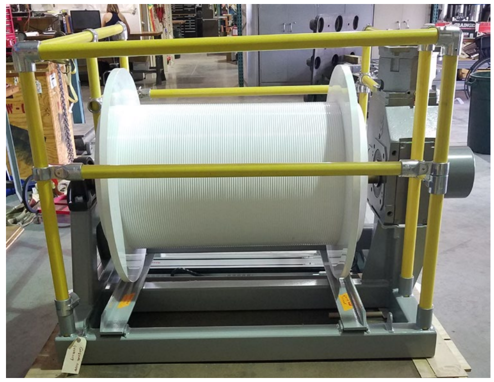


Figure 18. Adjustable rails installed under the winch drum flanges are used to support the drum for swapping drums without the need for lifting equipment.

An electric linear actuator is used to tilt the tower and is controlled with a handheld pendant. The pendant provides full variable speed control for tilting the tower. The vertical and horizontal limits of the tower are set with adjustable limit switches. In the vertical position there is also a hard stop to counter high cable tension loads. The vertical limit switch should be set so the tower contacts the adjustable stops. If this is not done, the tower could move until it hits the stops during core breaks. To set the stops, first set the limit switches with the hard stops lowered out of the way. Then raise the hard stops until they just make contact. This will ensure that the actuator is being stopped by the switches and that it is not excessively loading the tower base frame, Figure 19. The tower has four adjustable height sonde rests that can be placed anywhere along the tower. It is recommended to place one at the base of the anti-torque, one under the motor section, one around the midpoint of the chips chamber, and the last one near the end of the tower. Adjust the height of the rests so the drill is straight and contacts them at all four points. Details of the tower assembly are covered in drawing 8399-0176 *Tower Assembly*.

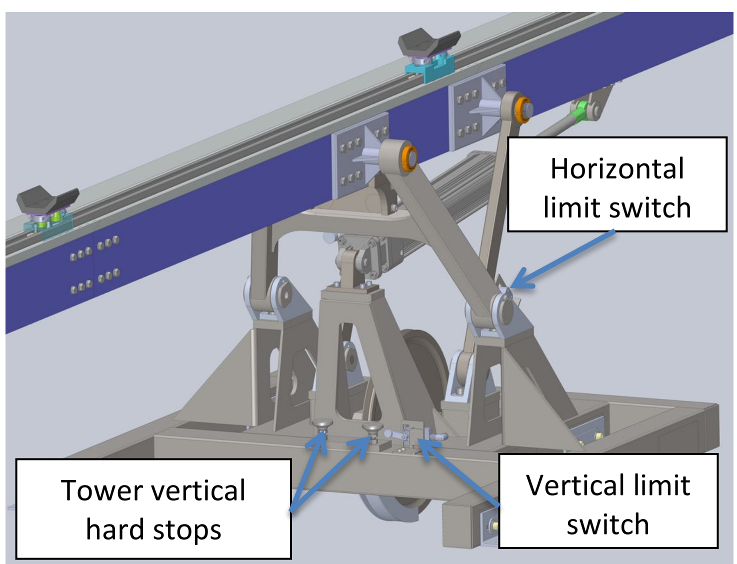


Figure 19: Tower vertical hard stops and tower vertical and horizontal position limit switch locations.

11.6 Level Wind

To ensure even cable winding, the Foro 3000 winch is equipped with a level wind. The level wind operates fully independent of the winch and maintains position and speed by measuring the angle the cable is coming off the winch drum. The system is designed to always keep the cable near perpendicular to the winch drum axis. The level wind assembly ships separate from the winch and the two components are bolted together once in place in the drill trench, Figure 20.

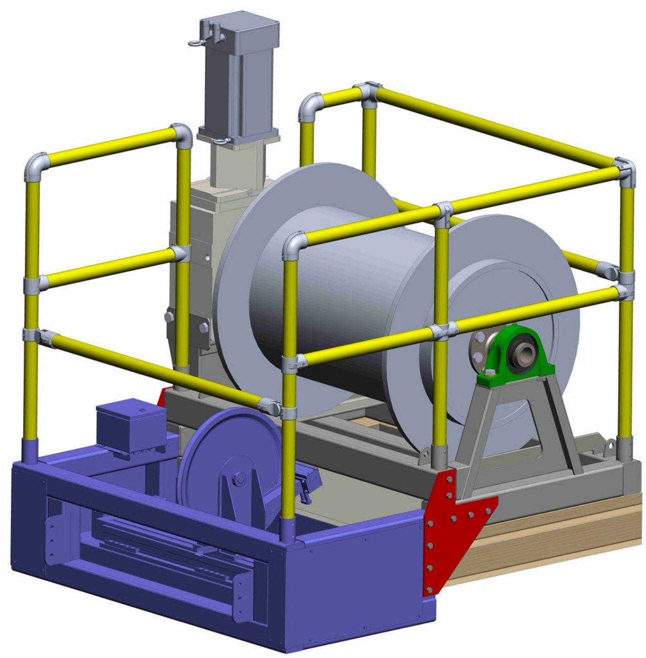


Figure 20: The level wind, highlighted in blue, is secured to the winch assembly with the plates highlighted in red.

The level wind is powered by the control box, and the attached electrical enclosure contains the motor controller. Under a cover strip on the side of the linear slide are two magnetic non-contact limit switches, one for either end of the travel. They should be set to stop travel about one cable diameter before reaching either drum flange. This will prevent the cable from stacking up at the flanges and ensure a smooth turnaround. Operators should keep a close eye on the level wind when the winch is first run after the level wind has been installed and adjust the limit switches as necessary. Use the following procedure to install or remove the winch cable.

Procedure for installing or removing the winch cable, Figure 21.

1. Loosen the clamp screw and unthread the nut on one end of the level wind sheave axle.
2. Remove the level wind sheave axle and sheave.
3. Remove the two M4 screws and keeper plate on the end of the cable position sensor rollers. Note: The rollers are retained so they will not fall off when the M4 screws are removed.
4. Route the cable through the level wind sheave frame.

5. Place the cable between the cable position sensor rollers and reinstall the keeper plate and two M4 screws.
6. Put the sheave back in place and install the axle shaft.
7. Install the threaded axle nut and tighten the clamp screw.

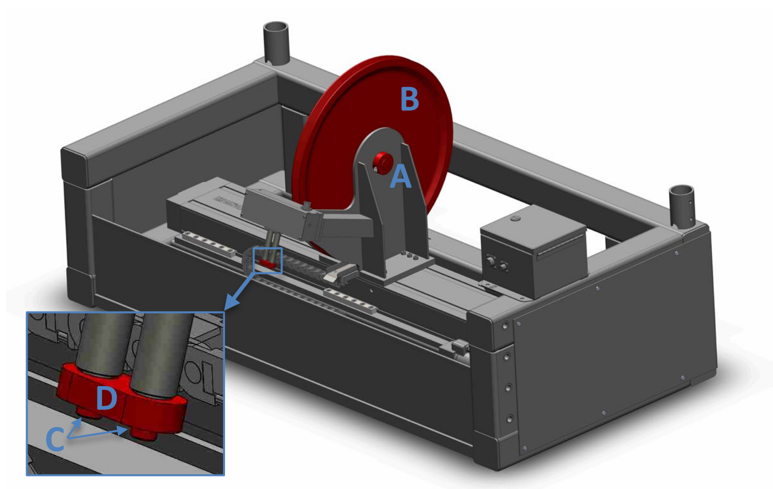


Figure 21. Level wind assembly. Parts that need to be removed for installation or removal of the cable are highlighted in red. They include the sheave axle (A), sheave (B), two 4 mm screws (C), and cable keeper plate (D).

11.7 Winch Cable

The winch drum contains 3,100 meters of cable. The winch cable is 9/32" diameter with four internal #22 AWG conductors. Full specifications for the cable can be found in 8399-0012 *Foro 3000 Equipment Manuals*. The cable is mechanically attached to the drill using an EVERGRIP 118-30-L termination. The cable termination and electrical connector should be installed following the instructions in the 8614-0113 *Foro 1650/3000 Winch Cable Termination Procedure*.

11.8 Core Pullout Table

Located at the end of the drill slot is the core pullout table. The table separates at the midpoint and the hand winch and frame assembly is removable in one piece for ease of assembly and shipping. Drawing 8399-0264 *Core Pullout Table* shows the complete assembly. The table mounts to the slot and tower footing assembly shown in drawing 8399-0238 *Slot and Tower Footer Assembly* to keep it from moving when using the hand winch to pull out the core barrel. The table height is adjustable so the core barrel can be aligned with the sonde rests on the tower. Three movable core barrel holders that slide the length of the table are provided for placing the core barrel or hollow shaft on when removing or installing them in the drill. A drip tray runs the full-length of the table to contain the drilling fluid and cuttings and direct them to the chips bucket that sits between the core pullout table and the slot. A head clamp, which attaches over the drill head, is provided to facilitate pulling out the core barrel and hollow shaft. It also covers the cutters to prevent operators from contacting them when handling the barrel. In most cases the core barrel can be pulled out by hand, but if it becomes stuck the hand winch at the end of the table can be used to assist with pulling.

11.9 Core Processing System

After the core barrel has been pulled from the drill onto the Core Pullout Table, the barrel is transferred by hand to the core pushout station at the end of the Core Processing System. The ice core is then pushed from the core barrel through the Fluid Evacuation Device (FED) to remove fluid from the core if wet drilling. After the FED is a 6 m long section of tray with an ice core saw mounted at the midpoint for measuring and cutting the cores into 1 m lengths. At the end of the tray is a station for putting the core into layflat tubing and then into 1 m ice core tubes. Drawing 8399-0246 *Core Processing Table Assembly* and Figure 22 show the complete assembly.

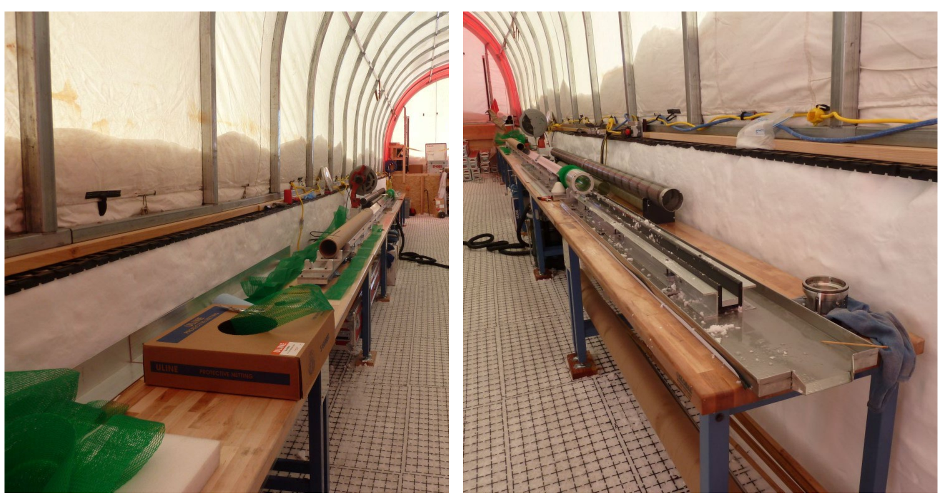


Figure 22. Core processing system. Note: this photo is of the Foro 1650 system. The Foro 3000 system is nearly identical and just has a longer section to receive the 3m long core barrel.

The base of the system is comprised of seven butcher block topped tables. After they are assembled and leveled, the FED, Figure 23, should be mounted in place, followed by the three drip trays to the left of the FED and two trays to the right.

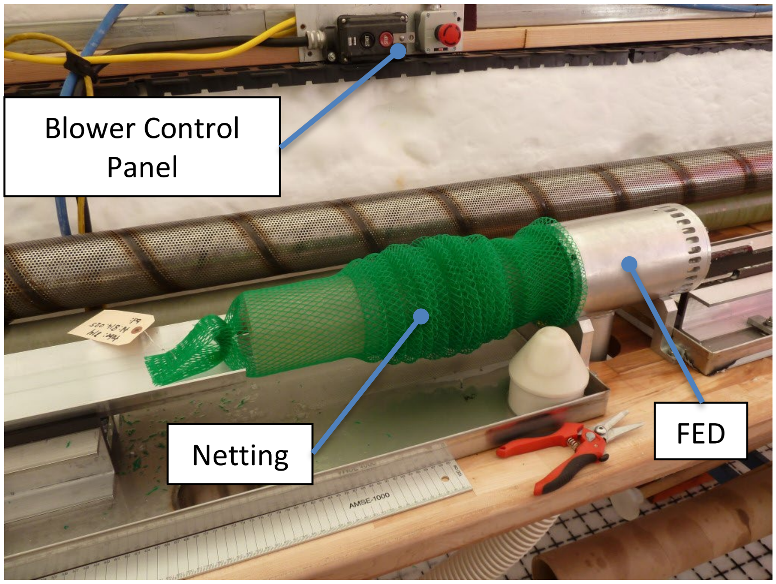


Figure 23. FED assembly loaded with netting for brittle ice. Note: this picture is of the Foro 1650 system. The FED for the Foro 3000 system is very similar.

Three nearly identical 2 m long rail assemblies mount on the tables next to provide a rigid, height adjustable base for the core trays. The only notable difference is that the core tray between the FED and core saw is not fixed to the rails so it can slide and the core trays to the left of the saw are fixed to the rails. Two short rail assemblies go to the right of the FED to support the core barrel. The drip trays, rail assemblies, and tables are marked with letters to indicate the location of each unit. The fixed core trays attach to the rails using flat head screws. The movable tray is free to slide so it can be positioned close to the FED for receiving the core and then moved to the left to transfer the core to the other trays. The tray was made to slide so it can be moved out of the way to load the green ice core netting, used when drilling brittle ice, on the FED netting sleeve, Figure 23. Loosely install the rail assembly mounting clamps, but do not fully tighten them until the core trays are aligned. At this time also install the layflat installation fixture at the left end of the core trays. Fiberglass tubes, 1 m and 2 m long with the same 98 mm OD as the ice core, are provided to aid in aligning the core trays with the FED and core barrel. Lastly install the metal cutting chop saw with 14” diameter blade used for cutting the cores to length.

11.10 Vacuum System

Located under the core processing table to the left of the FED is a vacuum system, Figure 24, that is used to provide suction for the FED and the winch cable cleaner. The system consists of two major components: a regenerative blower and fluid catch canister. On the side of the fluid canister is a fluid level sight tube. Be sure to empty the canister before the fluid level reaches the filter or fluid will get sucked into the blower. The outlet to the blower also has a filter to prevent debris from entering the blower. The blower outlet should be plumbed to the branch fitting on the slot ventilation hose recessed in the snow wall right behind the core processing table. The lid of the canister is removable and all hose fittings on the canister have quick connect fittings so they can be easily removed for servicing or emptying of the canister. When the canister is full, it can be emptied directly into the open tank next to the chip melter. The starter contactor for the blower mounts to the underside of the table and the blower control panel, containing the E-stop and start/stop buttons, should be mounted to the tent footing above the FED, Figure 23. The starter contactor requires both 120V and 208V power. The 120V cord should be plugged into a multi-tap outlet cord running along the tent footing and the 208V power is fed from a dedicated breaker on the 208V panel. The feeder cord, which ships with the panels, should be buried under the Geoblock with other cables that are coming across the building from the power distribution panels. Be sure to remove and lock-out and tag-out both power sources before performing any maintenance or service on the blower.

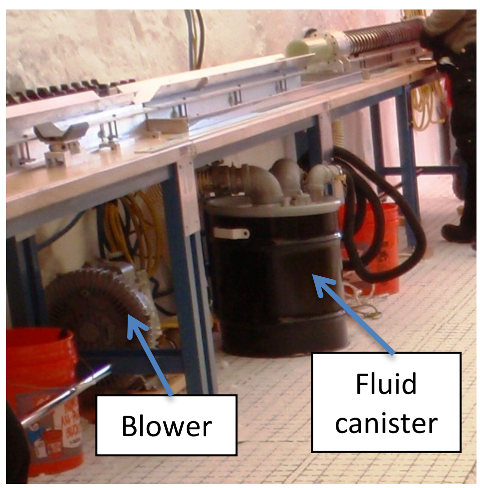


Figure 24. Vacuum system. Note: this picture is of the Foro 1650 system. The Foro 3000 system is very similar.

The smaller black hose can be used for vacuuming fluid off the ice core, general clean up, or connected to the cable cleaner. When using this hose, close the blast gate on the suction hose going to the FED for best suction. The cable cleaner, Figure 25, is effective at removing drilling fluid from the winch cable when tripping out of the hole. It should be used whenever wet drilling to minimize fluid loss. The black hose connects directly into the side of the attachment which fits around the winch cable. When the cable cleaner is not in use, it is stored on brackets under the core processing table.

Figure 25. Cable cleaner. Note: this picture is of the Foro 1650 system. The Foro 3000 system is very similar.

11.11 Fluid Handling

Drilling fluid is delivered to the site in either 55-gallon drums or 275-gallon International Bulk Container (IBC) totes. Fluid should be staged close to the building as called out in Figure 1 and shown in Figure 26. A drum pump is used to transfer fluid from the drums directly to the borehole.

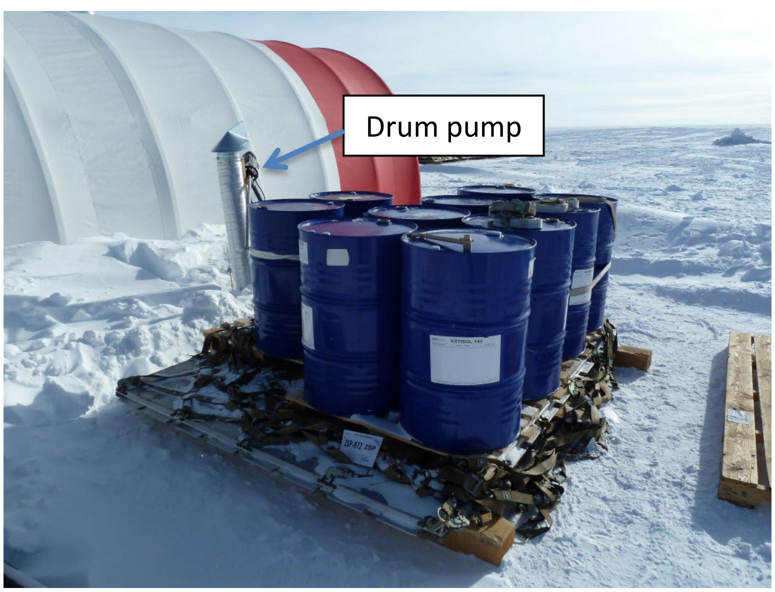


Figure 26. Pallet of drilling fluid outside the drill tent

The control switch for the pump and hose valve is preassembled on a board that should be mounted to the left of the electrical panels, Figure 12 and Figure 27. The 120V power cord should be plugged into a dedicated outlet on the 208V panel. The blue hose with the quick connect goes between the pump and the control board. Connect a second hose below the valve and run it to one of the fittings on the side of the hole cover. To transfer fluid to the borehole, first insert the drum pump into a full drum. Then open the valve on the control board and turn the pump on. With the hole cover open, the operator should be able to see fluid coming in. When the pump sound changes pitch, the drum is empty, and the pump should be turned off and the valve closed. A gallon or two of fluid will remain in the drum. Each drum will have to be tipped and emptied into a bucket to recover the remaining fluid.

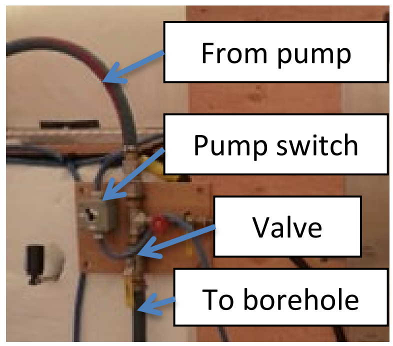


Figure 27. Fluid handling control board.

11.12 Chip Processing

The slurry of ice cuttings and drilling fluid, which is recovered from the chips chamber on the drill, is processed in a chip melter to separate the drilling fluid from the cuttings. Figure 28 shows the major components of the chip processing system. With the tower horizontal, and before the core barrel and hollow shaft are pulled out, a tray is lifted into position between the end of the drill, and the slurry pan to prevent the slurry from going into the slot.

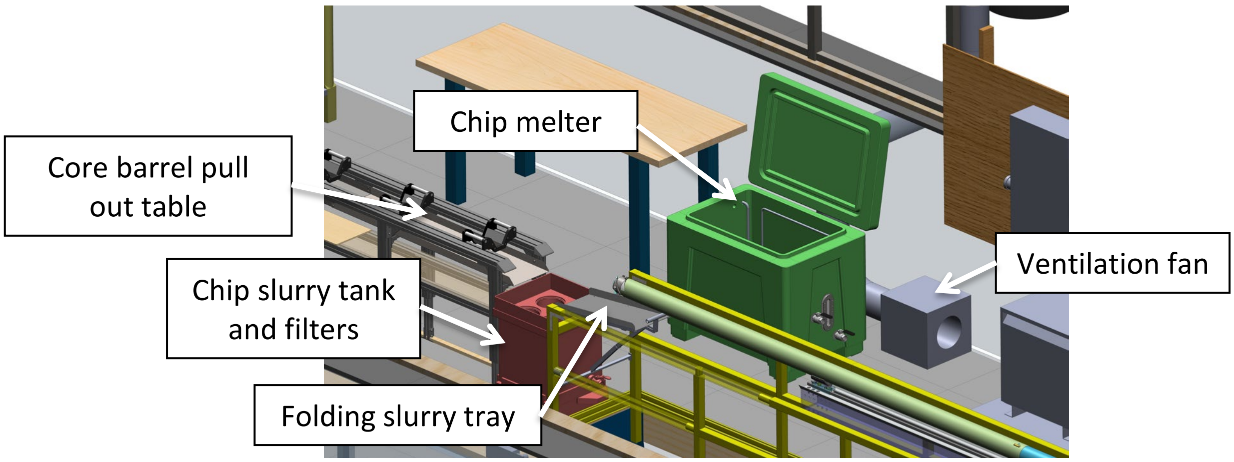


Figure 28. Chip processing equipment includes the slurry tray, slurry tank with bag filters, chip melter, and ventilation.

As the core barrel and hollow shaft are pulled from the drill, the folding slurry tray and the core barrel pull out table collect the cuttings slurry and direct it to the chip slurry tank. The slurry tank, Figure 29, contains four filter bags to separate most of the drilling fluid from the cuttings. Once drilling fluid has drained from the filter bags, the slurry tank is slid over to the chip melter where the filter bags are removed and emptied into the chip melter. Drilling fluid is removed from the tank using the fluid drain valve and transferred into an open head drum located next to the chip melter (not shown).

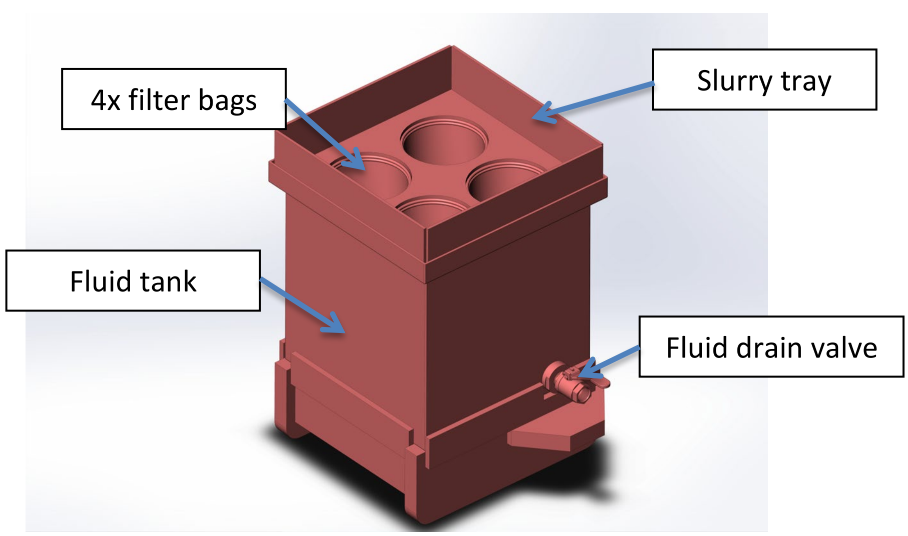


Figure 29: Slurry tank.

The chip melter incorporates a 2-kW electric heating element to warm the chip slurry above freezing so the water and drilling fluid will separate by density. The heater has a built-in thermostat that should be set as low as possible to minimize drilling fluid vapors. Note the fluid level must be maintained above the heating element to prevent damage to the heater. Keep the lid closed as much as possible to minimize heat loss and vapors from escaping. A small submersible pump circulates fluid in the tank to speed up the melting process. Before draining fluid from the tank through either valve, the pump should be turned off and the fluids let rest for several minutes until fully separated with drilling fluid on top and water on the bottom. The sight window is used for viewing the transition between water and drilling fluid. Be sure to lower the water level to below the drill fluid valve before draining drilling fluid. Drilling fluid should be transferred to an open head drum and allowed to cool below freezing before being returned to the borehole. Figure 30 shows the chip melter valves and sight window.

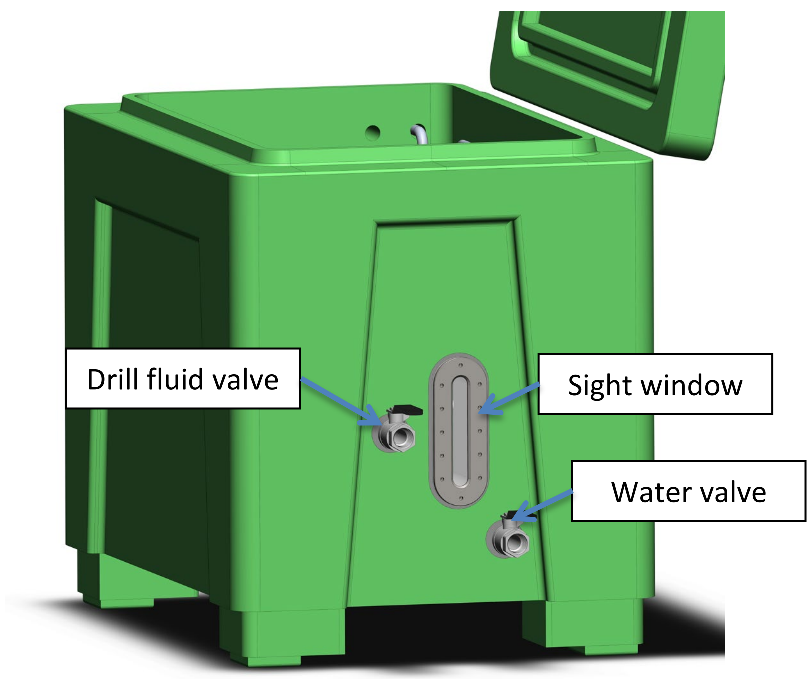


Figure 30: Chip melter.

11.13 Ventilation

To reduce the smell associated with using the Estisol 140 and other drilling fluids, the drill tent has been fitted with three ventilation systems. The first system is the four 12" diameter roof mounted ventilators shown in Figure 8. They are easiest to install at the time the tent is being set up. The second system is the Chip Melter ventilation. This fan should be located behind or next to the chip melter, Figure 28. The external portion of the duct work with directional wind cap is visible in Figure 26 next to the drum pump.

The third system is the slot ventilation. The ventilator is placed outside the drill tent and a flexible 12" hose runs under the floor in the building and down the slot wall in a recessed notch. The slot ventilation system is shown in Figure 31.

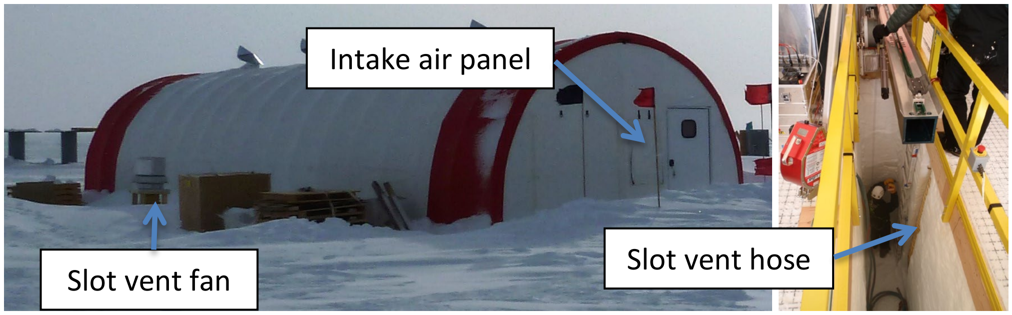


Figure 31. Slot ventilation system. Note: this picture is of the Foro 1650 system. The Foro 3000 tent is very similar.

The makeup air for all three ventilation systems comes from the mesh vent panel on both end walls of the tent. Both vents should be kept open whenever the ventilation systems are running.

Vent location	Air flow
Roof	4 x 900 cfm
Slot	1054 cfm
Chip Melter area	400 cfm
Total air flow is 5054 cfm, which provides 22 air exchanges per hour.	

12.0 DRILL SONDE

12.1 Sonde overview

The Foro 3000 sonde, Figure 32, is a longer version of the Foro 1650 sonde. It is configurable to drill 3 m long, 98 mm diameter cores in either dry or fluid filled boreholes. Drawing 8399-0111 *Foro 3000 Drill Assembly* shows the complete drill assembly. The winch cable terminates in a three-bladed anti-torque at the top of the drill. Next in line is the motor section, which includes the motor and gearbox to provide cutter rotation, as well as an electronics package that provides communication with the surface and feedback on parameters such as voltage, current, pressure, temperature, and inclination all within a pressure tight tube. Following the motor section is the chips chamber with internal hollow shaft. The hollow shaft transmits the cutter rotation to the core barrel while the annular space between the hollow shaft and chips chamber tube collects the cuttings generated while drilling a core. The core barrel and outer tube are next in line. The outer tube connects to the chips chamber while the hollow shaft connects to the core barrel. Flights on the core barrel work in conjunction with grooves on the inside of the outer tube to transport the cuttings from the head to the chips chamber. Last in line is the cutter head with replaceable cutters, core dogs, and penetration shoes.

Figure 32. Foro 3000 sonde assembly. The chip chamber and core barrel outer tube are shown transparent to show the internal components.

12.2 Anti-Torque

The Foro 3000 Drill utilizes a three-bladed anti-torque section, Figure 33, to centralize the top of the drill and prevent the upper portion of the drill from rotating. See drawing 8614-0030 *Anti-Torque Section* for the full assembly. The anti-torque assembly attaches to the drill cable with a modified EVERGRIP cable termination. This termination allows the winch cable, which has been pre-terminated with a connector, to be easily installed and removed from the anti-torque. The termination is housed within a bearing assembly that allows the anti-torque and winch cable to spin freely of each other. The components of the bearing assembly and cable termination are called out on drawing 8614-0040 *Cable Bearing Assembly*. The curve of the three blades is adjusted with the nut assembly, shown in yellow in Figure 33. To set the curve, measure from the OD of the torque tube to the highest point on a blade and set the distance to 58 mm if cutting a 126 mm borehole and 60 mm if cutting a 129.6 mm borehole. This should be a good starting point and may need to be adjusted depending on the firn conditions.

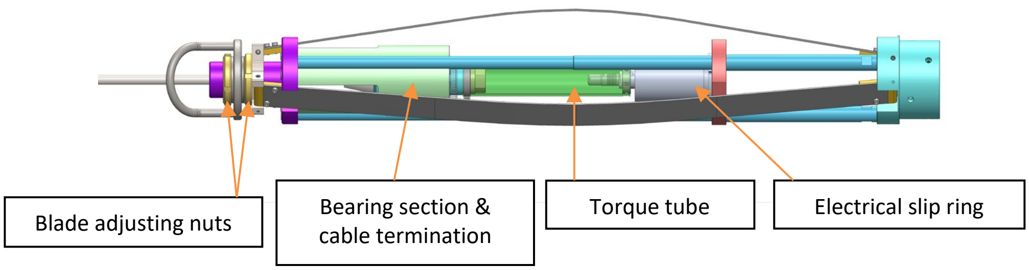


Figure 33: Anti-Torque section.

12.3 Motor Section

The motor section, Figure 34, consists of a pressure tube with sealed top and bottom plug assemblies that isolate the internal components from the borehole fluid. Internal components include a brushless DC servo motor, harmonic drive reducer, and electronics. Drawing 8614-0078 *Motor Section Assembly* details the motor section components. The motor section mechanically connects to the anti-torque section with shoulder screws. An electrical cable with pressure-rated connectors connects the anti-torque slip ring to the bulkhead connector in the top plug assembly. 8614-0112 *Foro Drill Bulkhead Seal Installation and Maintenance Procedure* describes the process for maintaining and replacing the upper and lower bulkhead seals.

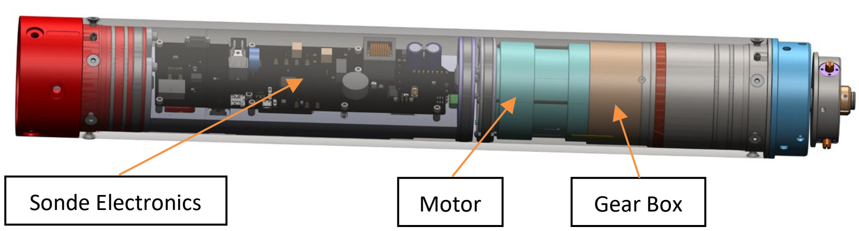


Figure 34: Motor Section

12.4 Chips Chamber

The chips chamber is a stainless-steel tube between the motor section and the outer barrel of the sonde. The chips chamber connects to the bottom plug assembly of the motor section with six retaining pins that also stabilize the sonde in the borehole. Chips from the cutter head/core barrel assembly are transported into the chips chamber during the coring process and stored there until emptied on the surface.

12.5 Hollow Shaft

Torque from the motor section is transferred to the core barrel/cutter head assembly via the hollow shaft, Figure 35. The hollow shaft top coupling connects to the motor section drive plate via three quick-lock pins. Valve assemblies at the top and bottom of the hollow shaft open to allow fluid to flow through the chips chamber and speed sonde descent. The valves should be rotated to the open position manually while the drill is being prepared on the surface. The valves will automatically close when forward cutter rotation starts to keep chips from washing out of the chips chamber during drilling and sonde ascent. One or more helical boosters can be added to the hollow shaft to aid in chip transport up the chips chamber. They attach to the hollow shaft with clamp nuts on the top and bottom. A booster is always used at the bottom of the hollow shaft running inside a housing with axial strips on the inside to increase chip transport efficiency. Additional boosters can be placed on the hollow shaft at any location, but generally only one additional booster is needed directly above the chips valve assembly. If a booster is not needed in the mid area of the hollow shaft, a central support is provided to keep the shaft centralized and prevent whipping when rotating. A fine cylindrical metal screen fits over the hollow shaft to allow fluid to pass through the large holes in the hollow shaft and up through the center while keeping the cuttings in the chips chamber. Drawing 8399-0100 *Hollow Shaft Assembly* details the hollow shaft assembly components.

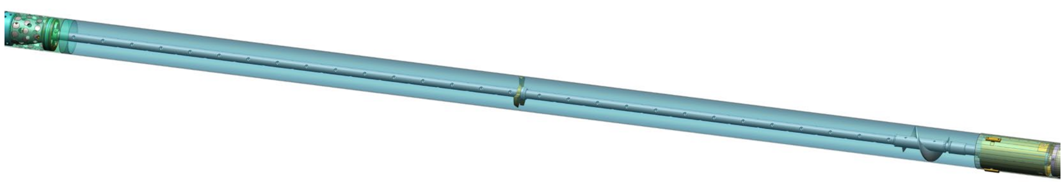


Figure 35: Hollow Shaft Assembly.

12.6 Core Barrel

The core barrel assembly transfers torque from the hollow shaft to the cutter head, accepts the ice core as it is drilled, and transports chips from the cutter head to the chips chamber via helical flights, Figure 36. The core barrel connects to the hollow shaft drive plate with three quick-lock pins. This core barrel is used for both dry and wet coring.

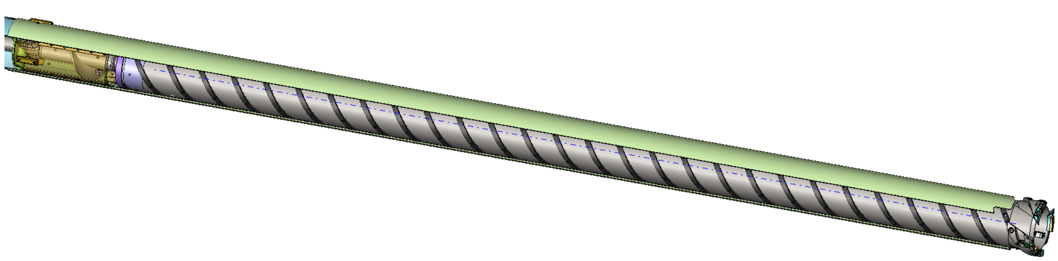


Figure 36: Core barrel and outer tube assembly.

12.7 Outer Tube

The fiberglass outer tube attaches to the bottom of the chips chamber tube with a slip-joint retained with three custom locking pieces that also act as stabilizers in the borehole. The core barrel rotates within the outer barrel, and the chips transport upward via the helical flights in the annulus between the barrels. Axial grooves on the interior wall of the outer tube provide a reaction surface for the chips on the helical flights which helps to impart vertical motion to the chips. Drawing 8399-0113 *Outer Tube* details the part.

12.8 Cutter Head

The cutter head attaches to the bottom of the core barrel with three custom screws/nuts and serves as a mount for the cutters and core dogs, Figure 37. Two types of cutter heads exist: dry and wet. The wet cutter head has a smaller outer diameter to allow the chip slurry to circulate around the head. IDP has had the best success using the dry cutter head for both dry and wet coring. See drawing 8614-0341 *Cutter Head Assembly_Dry drilling* for cutter head, cutter, shoe, and core dog assembly details.

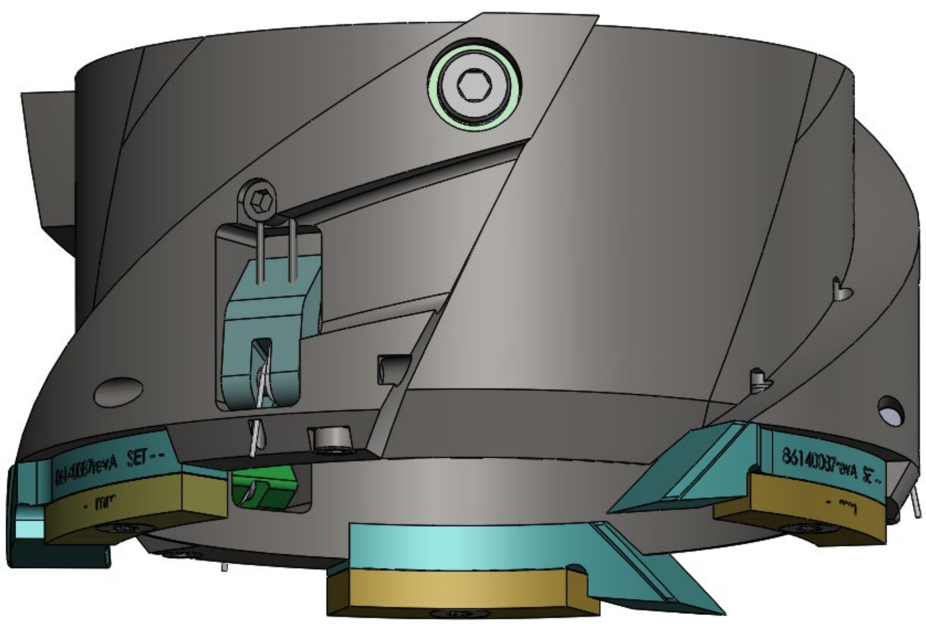


Figure 37: Cutter head assembly configured with standard cutters and long core dogs.

Several types of cutters can be used with the Foro 3000 Drill, Figure 38. Dry coring is generally done with standard cutters that cut a 126 mm diameter borehole. Wet coring can be done with regular cutters that cut a 126 mm or 129.6 mm diameter bore. IDP has generally had better success using 126 mm diameter cutters for both wet and dry drilling, although the narrower borehole can decrease ascent/descent speeds in deep holes. Step cutters, which have geometry that allows each cutter to cut one-third of the annulus, are also available. Step cutters create larger chips at low cutting pitch (axial distance per revolution), which can improve chip transport in challenging coring conditions. Step cutters do, however, have a larger depth-of-cut at a given pitch compared to regular cutters which can cause poor core quality in stressed/brittle ice. Step cutters are available in both 126 and 129.6 mm borehole diameters. Scoop cutters, where the inner cutting edge is radiused to decrease point stresses on the ice core, are available for use in challenging ice conditions. Varying success has been achieved with scoop cutters in the past, and they are hard to sharpen to a keen edge, so use of them is cautioned. Insert cutters, with carbide or steel inserts, are another option. They are particularly useful in dirty ice conditions where the cutting edge gets damaged or wears out quickly and needs to be changed frequently. Traditionally, it was challenging to make the cutting edge on carbide as sharp as was possible on steel cutters. This would cause increased weight on bit while cutting and poorer finish on the cores. However, manufacturing techniques and materials are improving, so the carbide inserts now perform nearly as well as the steel inserts.

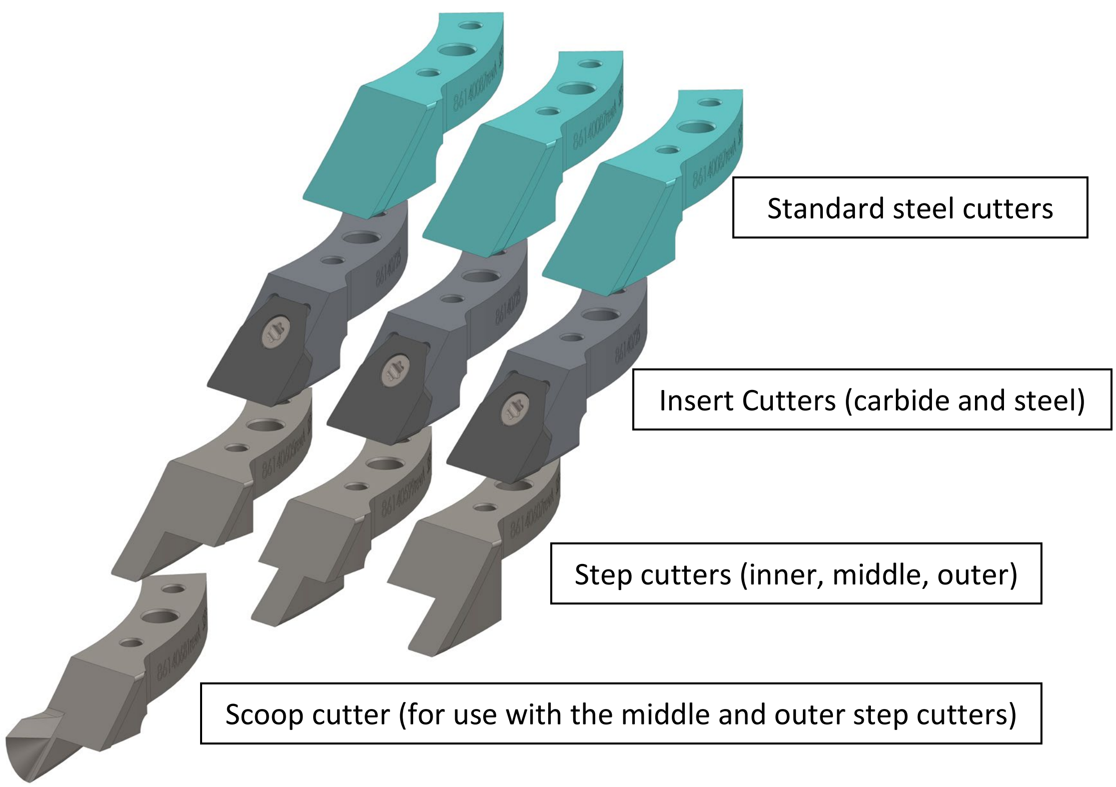


Figure 38: Cutter types for the Foro 3000 Drill. From top to bottom, standard steel cutters, insert cutters, step cutters, scoop cutter for use with middle and outer set cutters.

Cutter shoes are necessary to control the depth-of-cut of each cutter, which also sets the pitch. Specific shoes are used with regular, step, and scoop cutters, respectively. Shoes are available for common pitch depths, and shims can be used to refine the cutter pitch, as necessary. Consult the Foro 3000 Drill Shoe Height spreadsheet to set the appropriate pitch as coring conditions dictate.

The cutter heads have mounts for three core dogs which are used to break and hold the core in the core barrel at the completion of each coring run. Each core dog rotates around a pin that retains it in the cutter head. The normal configuration is for each core dog to be energized by a leaf spring keeping the core dog edge in contact with the core and a light torsion spring pushing the core dog back into the leaf spring. This arrangement can improve core quality in fully dense ice, however, in soft firn this set-up usually reduces the core diameter and makes core recovery difficult. Use of only a light-to-medium strength torsion spring, with no leaf spring, pushing the core dog against the ice core is recommended in firn. Long, short, and tear-drop core dogs are provided. Long core dogs are used in soft formations, short core dogs are used as the ice densifies, and tear-drop core dogs can be used in place of short core dogs and reduce core spalling, i.e. long narrow pieces of ice that break off the outside of the core, in some ice conditions.

Using the correct cutters, pitch, and core dogs for the ice formation being cored is critical for good core quality. Most sites suitable for the Foro 3000 Drill will drill well with regular cutters and a pitch between 5 mm (soft firn) and 0.5 mm (brittle/stressed ice). Penetration shoes are available for these pitches, and shims can be used to fine-tune the pitch further. Step cutters are a good option if chip transport has deteriorated, but the core quality is still acceptable. Scoop cutters can be tried if core quality is unacceptable. Make sure to use the applicable shoe for each type of cutter. Cutter sharpness is extremely important. Cutters should be changed frequently and resharpened/honed if core quality is deteriorating. A used cutter that still appears sharp can negatively affect core quality. Ice that is colder and/or dustier (Greenland, etc.) will dull cutters faster.

In summary, correct core dog length, sharpness, and spring strength can affect core recovery as well as core quality. In general, use longer core dogs in firn and transition to shorter core dogs as the ice densifies. Poor core recovery and/or extensive ice spalls on the core are signs that the core dogs are too long, dull, and/or the spring is too light. Use only a light torsion spring on core dogs in soft firn. Changing to a leaf/torsion spring set-up can improve core quality in fully dense ice that is brittle/stressed. A tapered collet, if available, can improve core recovery and quality in firn and extremely brittle/stressed ice.

12.9 Chip Bailer

A chips bailer tool can be attached to the motor section in place of the chips chamber and used to remove unrecovered chips from the borehole, Figure 39. The bailer tool consists of a perforated tube with a filter sock inside, a butterfly valve, and a brushed plunger assembly. Bailer plungers are available for 126 and 129.6 mm borehole diameters, both using the same perforated bailer tube and butterfly valve. Bailer tubes are 2-meters long but can be combined with a coupler to make a 4-meter-long tube. See drawing 8614-0369 *Chips Baler Assembly* for details.

Filter socks are available in 400- and 800-micron mesh. In general, use the coarsest mesh that adequately cleans the borehole. Fine meshes and felt liners significantly slow the downward travel of the bailer tool through the borehole fluid column. Filter socks are attached by removing the butterfly valve housing and retaining the metal ring of the filter sock between the housing and the perforated tube end.

When descending the bailer downhole, watch the cable tension closely to ensure that the bailer sonde does not float in the fluid column. At the end of the bailer downhole run, the butterfly valve will close, and the plunger assembly will actuate to let fluid bypass around the outside of the bailer sonde. On the surface, remove the butterfly valve housing and pull out the full filter sock. If the filter sock sticks inside the perforated tube, use light vibration (light taps with a rubber mallet) to loosen the chips enough to pull the filter sock out without ripping it. Dispose of the chips in the hopper to be run through the chips melter. Clogged filter socks can be melted out in a hotbox, chips melter tank, or allowed to sublimate in the sun.

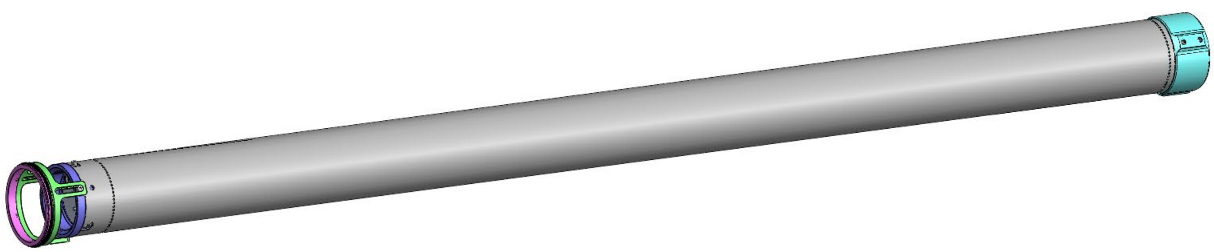


Figure 39: Chips bailer.

12.10 Reamers

Reamers are used to increase the diameter of the borehole through the firn for installation of a casing, Figure 40. Two-stage reaming, 7-inch and 9-inch, is necessary to enlarge the diameter of the borehole to fit the 8-5/8” diameter HDPE casing. The reamer assembly attaches to the bottom of the motor section in place of the hollow shaft, chips chamber and core barrel/outer tube assemblies. See drawings 8614-0141 *Reamer_7 inch Assembly* and 8614-0146 *Reamer_9 inch Assembly* for details on the reamer assemblies.

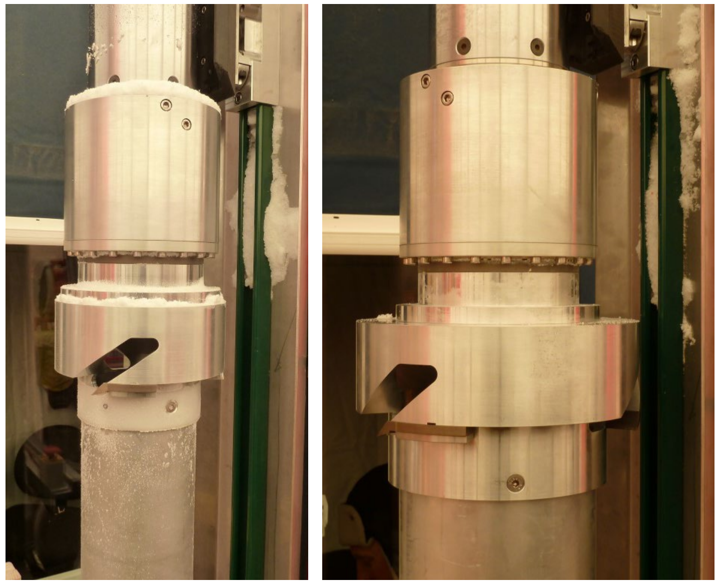


Figure 40: 7-inch and 9-inch reamers.

The reamer cutter head is at the top of the assembly followed by a tube that collects the cuttings. The cap at the bottom of the tube is retained with a pin that is easily removed without tools for emptying the cuttings, Figure 41.

Figure 41: Reamer assembly sitting on the drill tower. Note: this photo is of the reamer in use with the Foro 1650 system.

The chip collection tube on the 7-inch reamer is designed to fit the 126 mm diameter borehole (pilot hole), and the 9-inch reamer chip collection tube is designed to fit in the 7-inch reamed hole. Any cuttings that are not collected in the chip collection tube will end up in the pilot hole and must be collected later with the coring drill. Based on past use, the reamers are about 98% efficient at collecting cuttings. Therefore, the borehole should be drilled at least 10 m beyond the final depth for the 7-inch reamer so there is depth for the missed cuttings and the length of the chips collection tube. It is important that the full length of the coring drill is in the pilot hole before reaching the chip pack. Otherwise, the Anti-Torque (AT) blades will start in the reamed portion of the hole, making it challenging to collect chips while having to adjust in the AT blades at the same time. Note, the sonde rests will have to be removed from the tower to allow enough room for the reamer head.

Reamer Size	AT Blades	Shoes	Reamed depth to fill chips tube
7-inch	Standard	2 mm	1 to 1.3 m
9-inch	Long	2 mm	1.4 to 2 m

Both reamers have worked well running 2 mm shoes (2 mm depth of cut per cutter) and rotating at full speed (about 60 rpm). The depth that can be reamed until the chips tube is full will decrease with depth. Be careful not to overfill the chips tube otherwise cuttings can get packed around the head and lead to getting stuck. Cuttings are removed from the reamer with it hanging vertically. Since the tower is not tall enough to raise the end of the reamer up to floor level, an operator will be required to work in the slot to empty cuttings. To empty the cuttings, place a bucket under the reamer and remove the bottom cap. With a light tap on the side of the tube with the end cap, the chips will fall out into the bucket. Once the end cap has been reinstalled, the reamer is ready for another run. The bucket full of cuttings can be lifted out of the slot using a rope.

NOTE: The reamer MUST be kept rotating as it is being raised at the end of a reaming run until the end of the chip collection tube is above the run end depth and fully in the larger diameter that was just created. Failure to do this may result in the reamer getting stuck. The drill motor can then be turned off while tripping to the surface.

After reaching the final depth with the 7-inch reamer, switch back to the coring drill setup and clean any lost cuttings from the pilot hole before moving on to the 9-inch reamer. The cuttings sinter together enough so that they can be drilled and recovered as “firn cores”. When switching to the 9-inch reamer, the anti-torque blades must also be replaced with a longer set to work in the larger borehole diameter. After completing the 9-inch reaming, switch back to the coring drill again and collect the lost cuttings from the pilot hole. The borehole is now ready for installation of the casing.

13.0 BOREHOLE CASING INSTALLATION

Boreholes for multi-season projects are normally cased down to the firn-ice transition to minimize drilling fluid loss and because the drilling fluid level must be brought up to the transition to properly pressure compensate the borehole to prevent borehole closure. The 9-inch diameter reamed hole is sized to work with DR 17 High Density Polyethylene (HDPE) pipe, which has an OD of 8.625” and ID of 7.549”. It can be purchased with threaded ends, which require a sealant to make joints fluid tight, or with cut ends, requiring the pipe sections to be welded together as they are being lowered into the borehole. The procedure for fusion welding casing sections together is covered in 8501-0024 Casing Fusion Welding Procedure. Specialized clamps have been built for lowering and holding the casing as it is being installed, Figure 42. A lifting ring is mounted to the bottom of the anti-torque section so the drill winch can be used for lifting and lowering the casing sections.

Figure 42: Installing a casing with threaded connections. Left; section of casing being lowered with the drill winch. Center; upper casing clamp. Right; lower casing clamp.

The hinged clamps have a toggle clamp closure with adjustable U-bolt. Twelve adjustable grub screws with serrated faces stick proud of the ID of the yellow clamp body and bite into the casing. The screws and clamp must be adjusted properly so the full depth of the serrated face of all twelve screws are engaged into the casing surface. This prevents the casing from slipping in the clamps under full load. To achieve this level of clamping force, the nuts on the toggle clamp U-bolt must be tightened and loosened using a socket wrench, Figure 43.

Figure 43: Loosening the toggle clamp U-bolt nuts with a socket wrench to remove the upper casing clamp.

After the casing is installed, cut it to the finished depth of the drill slot. Note, first install a foam plug below the level at which the casing is going to be cut to prevent plastic bits or other objects from falling into the borehole. Do not remove the plug until after the casing cover has been installed. Backfill around the casing, as needed, to bring the snow level flush with the top of the casing. Next, place the stainless-steel drip pan over the casing and pilot drill the holes for mounting the casing hole cover assembly and then install the casing cover. To contain fluid coming off the drill and tower as it is tilted, the slot wall and floor are covered with flexible liner material. Mount it to the rim board at the end of the slot with screws, lay it down the end wall and floor, and lap it over the edge of the casing drip pan. Secure the sides of the slot liner to the slot wall with the provided metal stakes. The finished drill slot is shown in Figure 44.

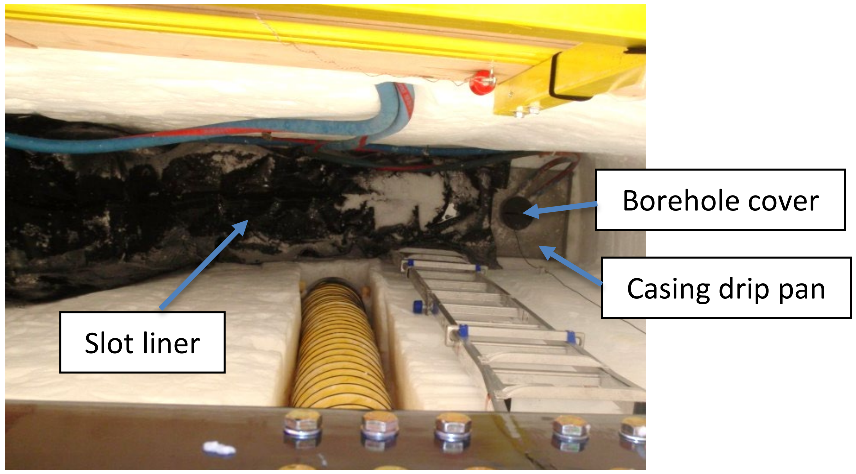


Figure 44: Drill slot showing the slot liner, casing drip pan, and borehole cover.

14.0 WINTERIZING FOR MULTI-YEAR PROJECTS

With some preparation, most of the drill system can safely remain on site and winter over for multiple season projects. Any equipment that will not be able to handle extreme winter-over temperatures should be removed and shipped out for warm storage. Items that must be removed include the following:

- Winch/tower control box
- Console and laptop
- Level wind controller
- Drill motor sections
- Control room ERV control boards
- Cordless tools and batteries

Any equipment requiring maintenance or repair should be shipped back to IDP. This often includes cutters and core dogs and motor sections. Spare parts kits for the components being returned should also be sent with them.

It is recommended to add internal anchors between the tent frame and ice to ensure the integrity of the tent during the winter months while no one is around to check on it. Eight screw-in ground anchors are supplied with the system for this. Evenly space and install four anchors along each side wall and in line with one of the tent frame arches. Attach the hook end of a cargo strap to the tent frame with a loop of rope or webbing, Figure 45 A. Attach the ratchet end of the cargo strap to the ground anchor, Figure 45 C. Evenly tension the eight cargo straps once they are all in place, Figure 45 B.

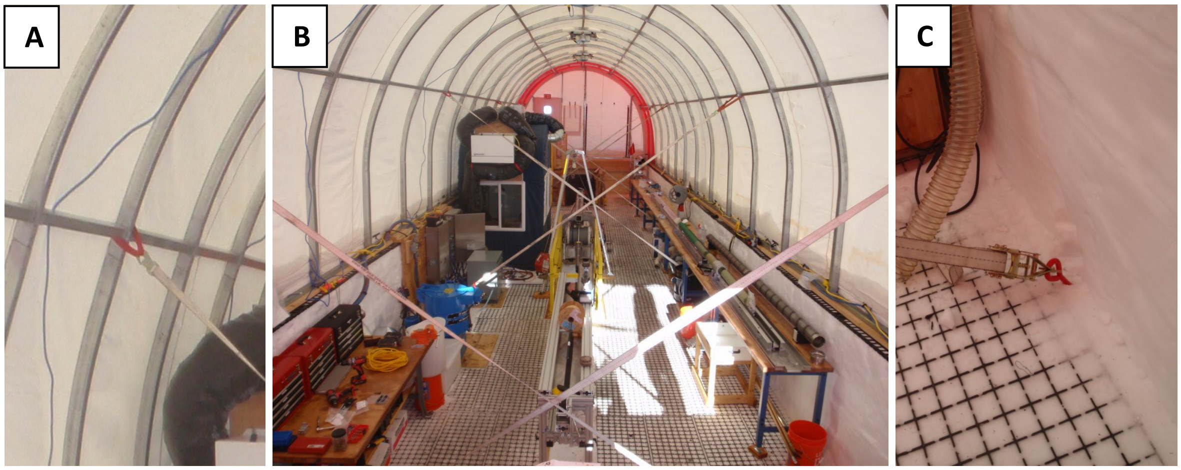


Figure 45: **A –** Strap connection on the tent frame. **B –** Drill tent secured from the inside for the winter. **C –** Strap attached to a ground anchor. Note: These pictures are of the Foro 1650 Drill system. The procedure for securing the Foro 3000 Drill tent is the same.

Cover the slot ventilation fan with an empty shipping crate and secure it with a strap and snow pickets, Figure 46. Brace or secure the two entry doors on the inside to ensure they won't blow open during high winds, Figure 47. After bracing the doors, exit through the zippered cargo door and secure it closed and bury the snow flap. The four wind directional roof vents do not need to be removed or sealed for the winter. On past projects, little to no snow has entered through the vents during the winter. Make sure all shipping cases and crates are well flagged and secured by strapping them together and to the pallets.

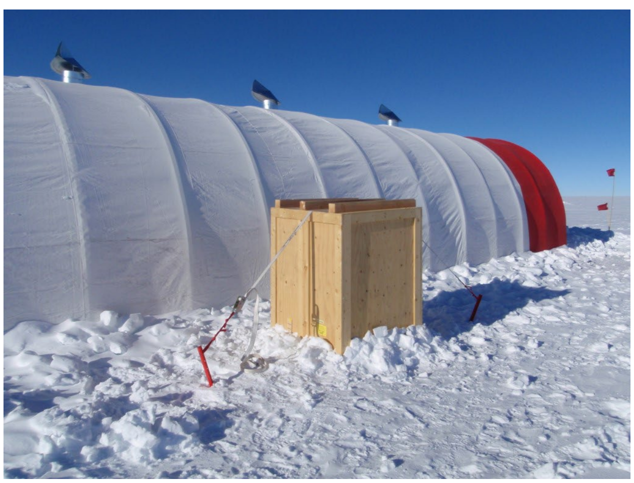


Figure 46: Cover over the slot ventilation fan.

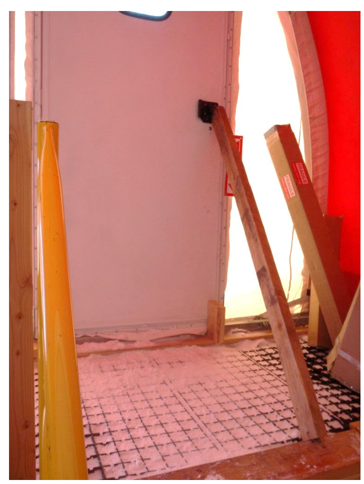


Figure 47: Bracing at the bottom and mid-point of the entry door.

15.0 Shipping and Inventory Lists

Copies of the current packing and inventory lists are available on the IDP SharePoint site at IDP – Documents\Shipping\Proformas\Foro 3000.

16.0 APPENDIX A: FORO 3000 DRILL RUN OPERATIONS – REFERENCE GUIDE

Please complete all fields on the Drill Run Log and take detailed notes to document drill performance or changes made to the drill configuration, Appendix C.

Note: The computer has speed limits set for when the drill is near the surface or bottom of the hole. If the speed limits are exceeded, the screen background will turn yellow, and the speed display will flash red. This is only a warning indicator; it is up to the operator to slow down.

Note: All distances denoted in (m) or (mm) refer to cable payout distances.

1) Ensure 'WOB limit' is set to 600 N on the computer.

2) Start new drill run in the logbook and press **New Run** in LabView.

3) Make sure the floor operator has opened the hole cover.

4) Set the winch to pay-out and lower the sonde until sonde-at-home light goes out.

5) Set winch to pay-in and slowly raise the sonde until the sonde-at-home light turns green; the winch will automatically stop when the switch is engaged.

6) Press the reset button twice on the LCI-90i to **ZERO PAYOUT DEPTH.**

7) Zero WOB by pressing the **WOB RESET** on the computer screen.

8) Set the winch to pay-out and lower the drill no faster than **0.15 m/s** while the drill is on the tower and entering the casing.

9) Ensure the floor operator checks that the cable bearing rotates freely.

10) Close the hole cover.

11) Trip down at **0.50 m/s** to 130 m, or until the drill is below the casing.

12) When you see the WOB increase as the drill enters the drilling fluid, click **RECORD FLUID LEVEL** on the computer; record the fluid level in the logbook.

13) Increase speed to **1.0 m/s**, keeping your EDW (Effective Drill Weight) above 100 N. The background on the computer screen will turn red and the EDW display will flash red if the EDW is in alarm; **it is up to the operator to slow down!** The control system will not do it for you.

14) Start gradually slowing descent around 20 m from bottom.

15) About 1 m above the previous end depth, slow down to 0.03 m/s and trip down slowly while watching WOB; either stop 0.02 m from the displayed bottom or stop payout when WOB increases and you touch bottom; if you touch off bottom, be sure to raise the drill until all of the WOB comes off before turning the cutter on.

16) Set drill toggle switch to forward and set the input voltage to **500 Volts.**

17) Turn the A-T slip siren on (toggle switch on console).

18) Set the winch payout speed, using the coring knob, to **3.0 mm/s**; **adjust as needed according to previous drill run speeds noted in logbook.**

19) When the cutter current spikes, you are now cutting ice; press **DIFF RESET** on the console and/or **RESET DELTA** on the computer to reset delta Depth.

20) Adjust speed feed rate as needed (i.e. if cutter current is jumpy or if WOB is climbing significantly, slow your speed by a few tenths; if the cutter is dropping out, increase your speed by a few tenths.

21) Stop paying out if the cutter current spikes, WOB spikes, or if other adverse events are witnessed; otherwise, stop at your desired core length.

22) Stop the cutter if the A-T siren starts going off at a rapid interval.

23) Stop Payout, when the current drops and Tension/WOB stabilize (~20 seconds) turn off the cutter and set the direction switch to stop.

24) Turn off A-T Slip siren.

25) Record end depth and delta depth in the logbook.

26) Set winch direction to pay-in; quickly turn tripping knob halfway (pointer at 12 o'clock) and break core.

27) Record Max Tension in the logbook.

28) Continue your ascent after the core break and slowly increase ascent speed up to **1.4 m/s** (max speed of the winch) or as conditions permit.

29) Approximately 10 m before you exit the recorded fluid level, slow to **0.5 m/s.**

30) Further decrease speed to **0.3 m/s** while the drill is in the casing.

31) Open the hole cover.

32) When the drill begins to come out of the casing, decrease speed to **0.15 m/s.**

33) When the sonde engages the sonde-at-home switch, the light on the console will turn green and the winch will automatically stop.

34) Set the winch speed knob to zero and the direction switch to stop.

35) Complete the drill run entry in the logbook.

36) Begin surface operations.

17.0 APPENDIX B: PREVENTIVE MAINTENANCE CHECKLISTS

Foro 3000 Drill Preventive Maintenance Checklist			
WEEKLY CHECKS	**WEEK OF: ________**		
ITEM	**ACTION**	**DATE**	**INITIALS**
CHIP MELTER			
Chip melter tank and fittings	Inspect for damage/leaks		
Heater power cable	Inspect for damage		
Heater element	Inspect for damage		
CONTROL SYSTEM			
Hard stop switch on tower	Verify function		
E-Stops (5)	Verify function		
Control box heater	Verify function		
Data	Perform data archiving		
FLUID HANDLING SYSTEM			
Drum pump	Inspect for wear/damage/leaks		
Hose and valves	Inspect for leaks		
CORE PROCESSING			
Fluid Evacuation Device (FED)	Verify operation and air passages are free of chips		
Core saw	Verify operation and inspect for damage		
TOOLS			
Tools	Inspect for damaged/missing tools		
POWER DISTRIBUTION			
Power cabinets/equipment	Inspect for damage		
Cables	Inspect for cable/insulation damage		
SLOT			
Floor-wall liner	Inspect for functionality and damage. Clear slush/verify casing drainage holes are open		
Hose-casing connection	Verify proper connection of fluid hose to casing		
TOWER/WINCH/LEVEL WIND			
Crown sheave	Inspect for damage and ice buildup		
Components	Inspect for damage/fluid and ice buildup		
Cabling	Inspect for wear/damage at connections		

OVER →

ITEM	ACTION	DATE	INITIALS
VACUUM FOR FED AND CABLE CLEANER			
Check tanks	Empty as needed		
CONTROL ROOM			
Structure	Inspect for damage		
Heater	Verify function		
DRILL TENT			
Structure and fabric	Inspect for damage		
Directional wind caps	Verify they are free of snow and operating properly		

Foro 3000 Drill Preventive Maintenance Checklist			
SEASONAL CHECKS (to be performed once per drill season)			
ITEM	**ACTION**	**DATE**	**INITIALS**
CABLE			
Cable/cable termination	Inspect for damage		
CHIP MELTER			
Chip melter tank and fittings	Inspect for damage/leaks		
Heater power cable	Inspect for damage		
Heater element	Inspect for damage		
Heater thermostat	Verify functionality and set to correct temperature		
CONTROL SYSTEM			
Hard stop switch on tower	Verify function		
Sonde home switch	Verify function		
Cable payout/tension sensor	Check calibration		
E-Stops (5)	Verify function		
Control box wiring	Check for loose connections		
Control box heater	Verify function		
Control box cooling fan	Verify function of fan and thermostat		
CONTROL ROOM			
Structure	Inspect for damage		
Heater	Verify function		
DRILL TENT			
Structure and fabric	Inspect for damage		
Directional wind caps	Verify they are free of snow and operating properly		
CORE PULL OUT TABLE			
Table	Verify alignment with drill on the tower		
Table fasteners	Check for loose connections		

OVER ➡

ITEM	ACTION	DATE	INITIALS
CORE PROCESSING			
Core processing system	Verify alignment of core barrel, FED and core trays		
Fluid Evacuation Device (FED)	Verify operation and air passages are free of chips		
Core saw	Verify operation and inspect for damage		
FLUID HANDLING SYSTEM			
Fluid hoses/plumbing	Check for damage and leaks		
Drum pump	Inspect for functionality and damage		
SAFETY EQUIPMENT			
Batteries	Check for dead/leaking batteries		
Lifting straps	Inspect for damage/wear		
SONDE			
Connections	Verify secure connections		
Grounding	Verify ground continuity		
TOWER			
Grounding	Verify ground continuity		
Tower assembly	Inspect for damage		
Tower fasteners	Check for loose bolts/torque as needed		
Tower/Sonde alignment	Adjust sonde rests as needed		
Actuator	Inspect for functionality/brake operation		
Crown sheave	Verify smooth rotation; check before cable is connected		
WINCH/LEVEL WIND			
Winch system	Inspect for damage		
Winch gear box	Check torque on shrink disk (output shaft connection)		
Winch gear box	Check torque on input shaft coupler (connection to winch motor)		
Winch drum	Check torque on drum axel flange bolts		
Winch motor	Inspect for functionality/brake operation		
Level wind	Inspect for functionality/brake operation		
Level wind drive belt	Inspect for damage and proper tensioning		
Level wind slide	Grease w/ Shell Aero 7 as per manual		

18.0 Appendix C: Drill Run Log Template

Note: Logs can be maintained as hardcopy or electronic

Run Number:	**Date:**	**Run Start Time:**	**Drillers:**	
Previous End Depth (m):	**Start Depth (m):**	**End Depth (m):**	**Delta Depth (m):**	
Drill Voltage:	**Fluid Level (m):**	**Max Break Tension (N):**	**Actual Core Length (m):**	
Drilling Speed:	**DRILL CONFIGURATION**			
	Anti-Torque: **A B**	**Motor Section:** **1 2**	**Chips Chamber:**	**Core Barrel:**
	Cutter Head:	**Cutter Set:**	**Shoe Pitch:**	**Anti-Torque setting:**

Notes:

Run Number:	**Date:**	**Run Start Time:**	**Drillers:**	
Previous End Depth (m):	**Start Depth (m):**	**End Depth (m):**	**Delta Depth (m):**	
Drill Voltage:	**Fluid Level (m):**	**Max Break Tension (N):**	**Actual Core Length (m):**	
Drilling Speed:	**DRILL CONFIGURATION**			
	Anti-Torque: **A B**	**Motor Section:** **1 2**	**Chips Chamber:**	**Core Barrel:**
	Cutter Head:	**Cutter Set:**	**Shoe Pitch:**	**Anti-Torque setting:**

Notes:
