

DESIGN MODIFICATIONS FOR RECOVERING 4-METER ICE CORES WITH THE DISC DRILL

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The initial conceptual design of what is now called the Deep Ice Sheet Coring (DISC) Drill envisioned a drill capable of drilling a 3-meter core with ongoing design improvements leading to cores of greater length (Eustes et al., 2003). As the configuration of the drill was finalized during the design process (Shturmakov et al., 2007; Mason et al., 2007), the combined core barrel and screen (chip collection) section was set at approximately 11 meters. Based on the experience others had gained in operating other drills, the ratio of core length to length of chip collecting was calculated and the core length for the final configuration was estimated to be approximately 4 meters with the remaining 7 meters being needed for chip collection.

During the summer of 2006, the DISC Drill was tested in Greenland (Johnson et al., 2007). During the test, it was found that the practical limit of the core length was approximately 2.5 meters although a core of 3.1 meters was collected. The chips were not packed in the screen section as tightly as predicted and the inability to collect more chips limited the core length. During the test, the drill fluid consisted only of Isopar K rather than the Isopar K – HCFC 141b mixture that would be used during production drilling at WAIS Divide. ICDS personnel believed that chip packing and core length would improve with the increased density of the drill fluid. It was also thought that increasing the screen section length would allow for more chip collection and improve the core length in production drilling.

The DISC Drill was first used in a production drilling mode during the 2007-2008 Antarctic field season at WAIS Divide. Core length did improve somewhat at WAIS Divide with lengths of approximately 2.7 meters being consistently achieved; the maximum core length drilled was approximately 3 meters. ICDS engineers determined that the greater density of the drilling fluid had minimal effect on increasing core length and that adding length to the screen section yielded diminishing returns.

Because increased core lengths would save total time required to drill a deep hole by reducing the number of trips in and out of the hole, ICDS started to consider modifications to the drill that would allow core lengths approaching the 4-meter design target. Several, separately or in conjunction with others, appear to be promising and are being pursued as resources allow.

Improvements directly linked to increasing the core length

Direct Flow Control System for Screen Section

Based upon comparison with other drills, the average density of ice chip collection in the DISC drill screen section is not reaching an acceptable level. To calculate the average density of ice chips inside the screen, first calculate the volumetric efficiency by taking the ratio of the volume of solid ice drilled (swept area of the cutter times length of core drilled) to the total collection volume of the screen section. Next, multiply by the

theoretical ice density of 0.920 kg/l to obtain the average density of ice chips in kilograms per liter of screen volume. The volumetric efficiency of the DISC drill for an average 2.7m core is around 0.431 or 43% based on the results of the last season at WAIS Divide. In order to compare to other drills, we multiply this volumetric efficiency of 0.431 by the density of ice 0.920 kg/l to obtain a theoretical average density of 0.397 kg/l. The EPICA drill collects chips for a 2.8m length of core with an average density of 0.42 kg/l (46%). The Japanese JARE drill collects 0.49 kg/l (53%) for a 3.7m core (Augustin et al., 2007).

ICDS has seen little effect on chip density in the screen from under-densified fluid vs densified fluid and increased screen volume from additional screen length. Neither densified fluid nor increased screen length has provided an increase in collection chip density in the DISC drill. In fact, increasing the length of the screen between the Summit test season and WAIS Divide actually had a slightly negative effect on chip density, such that a 25% increase in screen volume yielded only a 12% increase in core length. So while we do recover more core with more screens, there is a diminishing return. Increasing the volumetric efficiency of the DISC drill screen by a few percent, on the other hand, would produce a directly proportional increase in the average length of core retrieved. For example, if we increase the volumetric efficiency from 43% to 53%, the average chip density goes from 0.397 kg/l to 0.490 kg/l. This yields an average core length of 3.3m as compared to 2.7m. Obviously the limit of volumetric efficiency is something much less than 100% where the theoretical chip density is equal to the density of solid ice. Ideally, we wish to improve the volumetric efficiency in the DISC screen as high as possible in order to drill a 4m core. Evidence exists from observations while operating the DISC drill last season to suggest it is possible to make a significant improvement in volumetric efficiencies; however, the maximum value attainable is still a question.

The DISC drill modular screen design and pumping system will allow ICDS to pursue improvements in the volumetric efficiency of ice chip collection without irreversible changes to the drill. Currently, the screen section consists of individual screen cartridges, stacked inside the screen barrel to form a continuous tube. Filtration of the ice chips occurs as fluid passes through the circumferential filter wall of the screen cartridges into the annulus between the screen barrel wall and the outer surface of the screen cartridges. Fluid continues to move upward through the annulus to the pump. The ice chips are trapped within the inner volume of the screen cartridges. Due to the large filter area and free-flowing design, there is no reason for the ice chips to pack tightly in each screen cartridge. It is just easier for the fluid to short circuit to a lesser packed area. It has been observed that only the bottom two screen cartridges will pack to a significantly higher density than the rest of the screen cartridges above because there is no other easier path for the fluid to take.

ICDS has designed a valve shown in Fig.1 to act as a gate that will remain closed and block fluid flow in the annulus. The valve will trip open only at a predetermined and set

pressure. A valve will be installed to control the fluid flow in the annulus after every screen cartridge. In this way fluid will not be allowed to short circuit and flow in the annulus below the screen cartridge currently being packed until a desired chip density is reached and the pump-induced pressure differential across the valve trips it open. This cascade type of operation of the valve system will provide for more uniform top-down filling and dense packing of each screen cartridge.

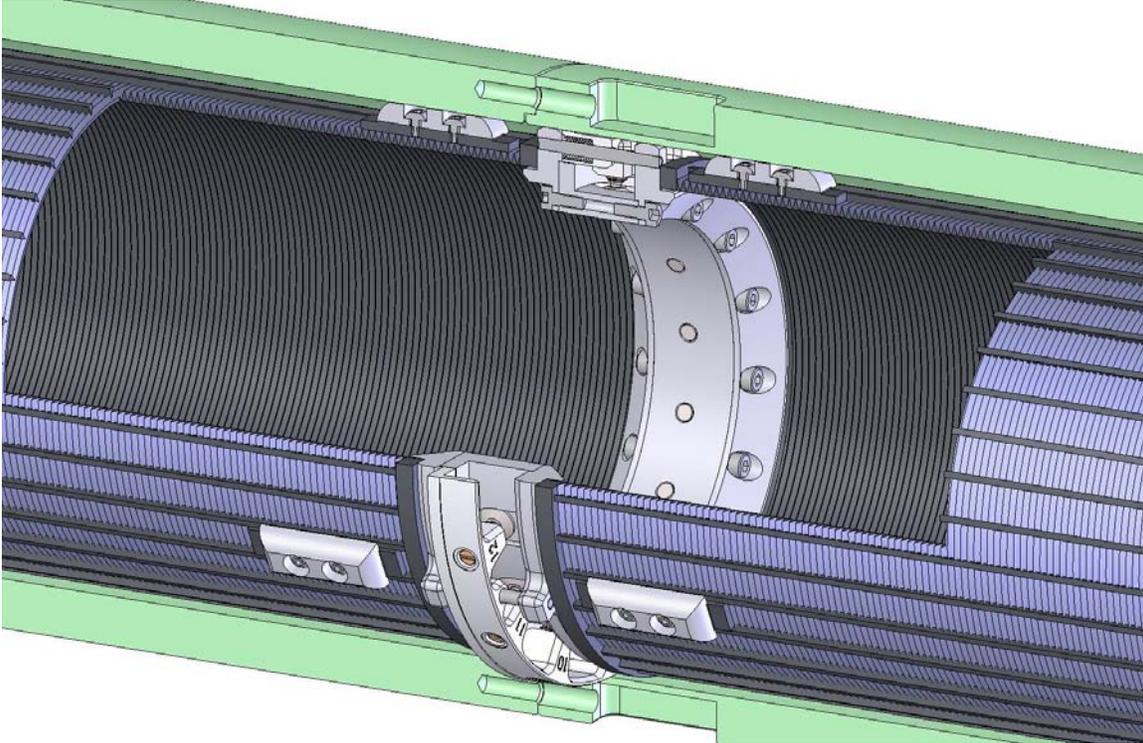


Fig.1 Cut-away of a screen valve

ICDS designed and PSL is in the process of fabricating valve assemblies to be installed in between adjacent screen cartridges. PSL is fabricating one valve assembly to be tested to confirm its operational characteristics. Once the first assembly has been tested, verified, and accepted, PSL will manufacture seven additional assemblies required for one screen barrel. In addition, ICDS is designing a calibration device to preset each valve release pressure to the desired value

Two-stage pump

The operation of the pump in the DISC drill is analogous to drinking a liquid through a straw. As you suck on a straw, liquid moves freely from the container into your mouth. If you squeeze the straw with your finger tips and slowly collapse its cross section, you have to suck harder to get the same amount of liquid into your mouth. In the DISC drill, the pump acts like your mouth to provide the suction. The core barrel, screen barrel, and screen are the straw. As the pump runs, fluid is moving through the drill transporting ice

chips up and away from the cutter and into the screen. As the screen fills, it is like slowly squeezing on the straw where the pump will continue to transport chips away from the cutter, but at a lesser rate until the point is reached where the screen is full and the pump can no longer suck hard enough to move any liquid and drilling is stopped.

With implementation of the screen valves as described above, the density or packing of the chips in each screen cartridge will be directly affected by how much pressure the pump can generate to suck fluid through each screen cartridge without stagnation of flow before a valve trips open. Adding an in-line second stage will nearly double the pressure capacity for any given pumping speed while maintaining the same volumetric flow of the original single stage pump. Multi-stage pumps are commonly configured in this way to obtain the desired pressure-flow characteristics. The DISC drill pump is an irrigation pump manufactured by Goulds which is modular and can be built up of multiple in-line stages.



Fig.2 Cut-away view of two-stage pump assembly

PSL is fabricating the second stage pump bowl upgrade designed to bolt into the existing pump. The complete assembly is shown in Fig.2.

Improvements not directly linked to increasing the core length

Finned-Aluminum Pump Motor Housing

Operation of a two-stage pump will increase the demand on the pump motor significantly. From laboratory tests run by Nicolai Mortensen, the limit for the motor power output is primarily due to thermal management of waste heat. The motor operates about 80% efficient, therefore 20% of the input power is changed to heat which must be conducted away. A finned, aluminum housing shown in Fig.3 will replace the existing un-finned 416 stainless steel housing which will give nearly an order of magnitude better heat transfer. The other limit for pump motor power output is the capability of the motor driver electronics, motor size, and winding configuration. We are not planning to change the motor and believe it will be capable enough due to improved thermal management. This upgrade is necessary in combination with operation of a pump with two stages. If it were done by itself, it would not have an affect on increasing core length.



Fig.3 Finned Pump Motor Housing

Shoe and Cutter Variations

While drilling at WAIS Divide during the 2007-08 season, with a cutter pitch of 3mm, several runs exhibited an instability indicated by large amplitude variations in cutting motor torque. In some cases this instability occurred when too much weight was put on the bit.

Every drill is a different machine and exhibits its own unique behavior while cutting the ice. The DISC drill is heavier, by a factor of two, than any other deep drill in use (Augustin et al., 2007). Because of its weight, the DISC drill behaves notably differently from other drills at the very start of a run. When the cutters touch the ice, they start to cut ice immediately without putting any additional weight on the bit. In contrast, according to Laurent Augustin's experience, with lighter deep drills (ISTUK, EPICA, NGRIP), the cutters do not engage until weight on bit is increased. While this characteristic of the DISC drill is not in itself a disadvantage, it is possible, Laurent believes, that as a result the shape and rear-mounted location of the current shoes could be producing the observed instability. Sigfus Johnsen stressed at the Science Advisory Board meeting that front-mounting of the shoes will result in more stable drilling which will generate a better diversity of ice chip sizes which can lead to an increase in density of the chips packed in the screen. This would have a net result of increasing the length of core.

Based upon these ideas, ICDS is preparing a set of front-mounted cutter shoes, Fig.4, and a set of rear-mounted cutter shoes, Fig.5, to be able to observe and make direct comparisons of the advantages and disadvantages of both mounting configurations. A skate-type shoe configuration, Fig.6, similar to those used on ICDS's Shot Hole Drill, will also be tried.

Cutter Sharpening and Pitch

Small changes in the height of the cutting edge above the shoe affect the actual pitch produced by the cutter. These small changes usually occur due to sharpening of the cutters such that the actual pitch obtained from a set of shoes changes from the nominal pitch the shoe was originally designed to produce as the cutters undergo repeated sharpening. This is true for all shoes; as the running surface of the shoe is positioned closer and closer to the position shown in Fig.4, just behind the cutting edge of the cutter, there is an amplification of the error in pitch. For example, with a front-mounted shoe designed to cut with a 5mm pitch, moving the cutting edge 0.1mm closer to the shoe along the axis of the head will produce an actual pitch of 3mm. That is a ratio of 20:1!

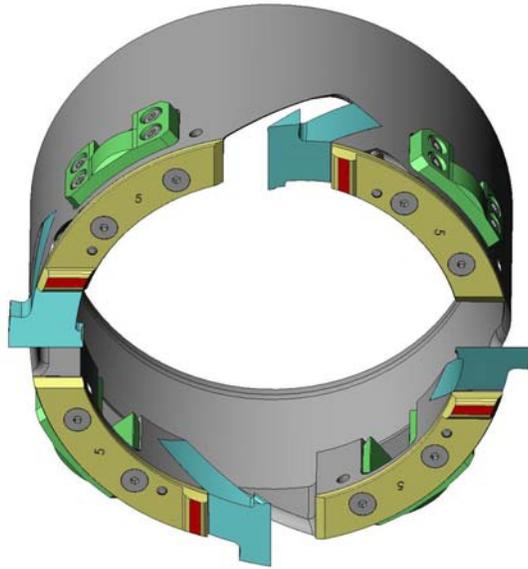


Fig.4 Front-mounted cutter shoe. The shoe contact areas are highlighted in red

As a comparison, to produce the same 2mm change with the rear-mounted shoe shown in Fig.5, from a 5mm pitch to a 3mm pitch, the cutting edge would have to be moved 0.38mm. The rear-mounted shoe is about 4 times less sensitive to a change than the front-mounted shoe. The skate-type shoe shown in Fig.6 is also affected by changes in the position of the cutting edge. The skate-type shoe has a fixed helix angle determined by the pitch it was designed to produce. It would also be very sensitive to the cutting edge moving closer toward the shoe in a similar way to the front-mounted shoe.

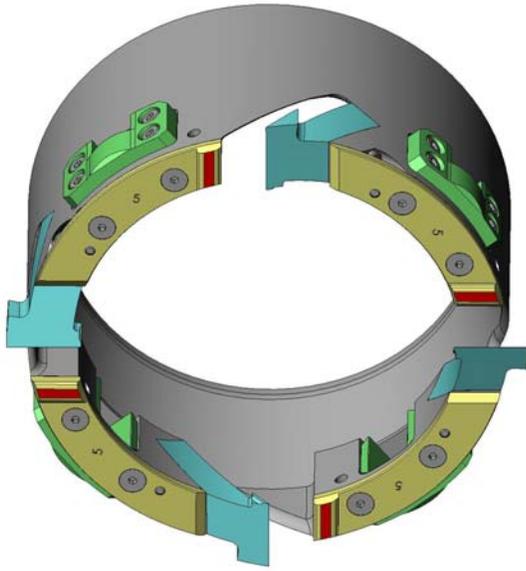


Fig.5 Rear-mounted cutter shoe. The shoe contact areas are highlighted in red

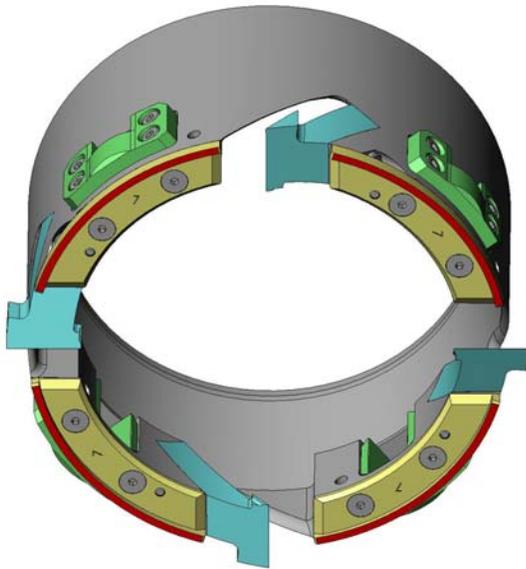


Fig.6 Skate-type cutter shoe. The shoe contact areas are highlighted in red

In the field, drill operations require that, for any shoe designed for a specific pitch, installation and use of that shoe should produce the desired pitch within reasonable expectations. Furthermore, before any testing of shoe configurations, we need to be confident that the cutting edge of each cutter is properly located. ICDS has developed a cutter sharpening concept to be tried and implemented such that cutters are sharpened and verified in the off season in preparation of the upcoming field season. The process developed enables ICDS to dial-in each cutter set such that the shoes will cut to their designed pitch. Some new configurations of cutters are also under consideration. ICDS is planning to take several variations to test in 2008-09.

Further in the Future

Reduced Cutter Kerf

Depending on results of the previous season, ICDS has plans for reducing the kerf of the cutter. This will effectively reduce the volume of ice chips generated and the volume of drilling fluid in the hole. This is not a simple upgrade and will require a large investment in new cutter heads, core barrels, and connectors. In a preliminary design, by taking advantage of a new barrel connection technology to allow reduction of the core barrel wall thickness, the kerf was reduced by approximately 3.0mm, and the borehole diameter was decreased from 170mm to 164mm while maintaining the annular clearance between the borehole wall and outside diameter of the core barrel at 6.25mm and the core diameter at 122mm. This upgrade would constitute a reduction in chip volume of 14% and in fluid volume of 7%.

Enlarged Screen Cartridges

Implementation of this upgrade depends upon results from the screen valve field testing. This upgrade applies the same barrel connection technology developed for the core barrel to thinning the screen barrel wall, in his case to increase the inside diameter of the barrel and enable the use of larger diameter screen cartridges. This upgrade requires a large investment in new screen barrels, screen cartridges, and connectors. It has the potential to increase the internal screen volume by 18%.

Calculations are being made to verify the results of these changes, individually and combined, on drill performance including length of recovered cores and tripping speeds. These calculations are being made for the DISC drill with a goal of producing 4 meter core while minimizing the effect on:

- Core quality; any changes to the drill may have an effect on quality
- Drill length; impacts on physical limits of the tower; tripping speed
- Reduction in drill weight; impacts tripping speed; cutter performance
- WAIS divide setup; impacts slot and floor configuration; screen cleaning; barrel handling
- Tripping speed; impacts drill cycle time
- Cost to implement; impacts the amount and type of improvements possible

Several combinations of reduced cutter kerf and enlarged screen cartridges meet the goal of 4 meter core with attainable ice chip density inside the screen. A revised computational analysis for hydraulic flow circulation along the drill is under development as a tool to help determine the effect on tripping speed. In addition, new chip density results for the screen-valve direct flow control system will be available after field testing. These chip density results are necessary in order to evaluate the best possible option.

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