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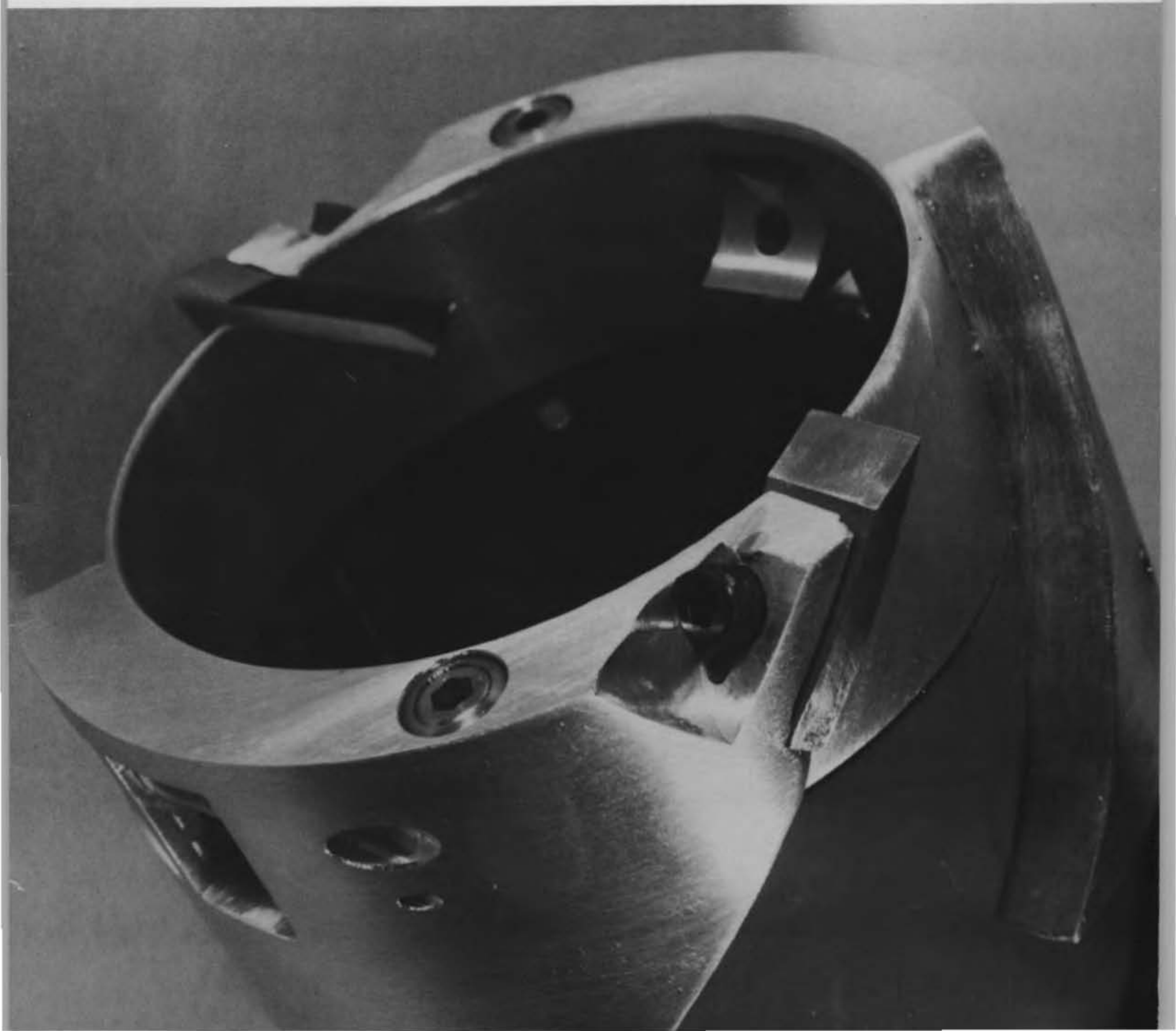
Ice-coring augers for shallow depth sampling



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John Rand and Malcolm Mellor

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The development of lightweight coring augers for ice is reviewed. Emphasis is on equipment designed by the Cold Regions Research and Engineering Laboratory and its predecessor organizations for sampling to depths less than 20 m or so. Design and operation of the ACFEL/SIPRE/CRREL 3-in.-ID corer is discussed, and modifications of the basic design for powered operation and for drilling in frozen soil are outlined. Recent replacements for the traditional coring auger are described, and details are given for the construction and operation of the new 4¼-in-ID coring equipment. A powered 12-in.-ID drill for shallow-depth coring is also described.

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PREFACE

This report was prepared by John Rand, Research General Engineer, Ice Engineering Research Branch, and Dr. Malcolm Mellor, Research Physical Scientist, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The report was produced under DA Project 4A762730AT42, *Design, Construction, and Operations Technology for Cold Regions.*

The authors are grateful to Paul V. Sellmann and Herbert Ueda for their help in preparing and reviewing this report.

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ICE-CORING AUGERS FOR SHALLOW DEPTH SAMPLING

John Rand and Malcolm Mellor

INTRODUCTION

In 1950 an effective ice coring auger (Fig. 1) was developed by the Arctic Construction and Frost Effects Laboratory (ACFEL) for the U.S. Navy Hydrographic Office; see Ueda et al. (1975) for detailed references. It was modified in 1955–56 by the Snow, Ice and Permafrost Research Establishment (SIPRE) to meet the research requirements of the International Geophysical Year (1957), becoming known worldwide as the SIPRE auger. After ACFEL and SIPRE merged in 1961 to form the Cold Regions Research and Engineering Laboratory (CRREL), a few minor changes were made, and the drill gradually came to be known as the CRREL coring auger. A variant was developed for coring in fine-grained frozen soils, but CRREL research on ice drilling technology (directed by B.L. Hansen) was by this time focused on deep coring in Greenland and Antarctica.

The ACFEL/SIPRE/CRREL coring auger was a remarkably successful design. It remained the standard tool for shallow-depth coring in frozen materials for over three decades, and it was adapt-

Figure 1. The original ACFEL ice coring auger, showing the core barrel and the attachment for removing cores.

ed for tasks well outside the original design limits. Although designed primarily as a hand-held tool, with hand rotation, it later became a powered auger, driven by a hand-held electric drill or by a light gasoline unit of some kind. In some cases, it was used on small drill rigs. For one-man operation, a practical depth limit of about 6 m (20 ft) was set, largely by the weight of the auger and the drill rods, but hand-drilling by strong teams went as deep as 55 m (180 ft) in Greenland (Ragle et al. 1964). On the negative side, it was easy for inexperienced or inept operators to overdrive the drill and jam it in the hole, especially in wet conditions (sea ice, "warm ice," or partially thawed soils), and/or with high penetration rates (when production of cuttings outpaces transport or exceeds storage capacity). Intrusion of cuttings between the core and the barrel could twist off the core periodically, and long pieces of unbroken core were recovered only rarely. The core barrel was also quite heavy.

In 1981 CRREL undertook a sea ice study for an industry group headed by Shell Development Corporation, and it was decided that a new coring auger was required for the project (Mellor et al. 1984). The new drill had to produce core of approximately 4¼ in. (108 mm) diameter, instead of the 3-in. (76-mm) core of the existing CRREL augers, and it had to give unbroken sections of core at least 11 in. (280 mm) long so as to provide specimens for mechanical tests. The drill had to be light enough for hand operations at depths up to 10 m.

The new drill was designed and built at CRREL by the first author, with funding from Shell. Design drawings were produced in November/December 1980, and the prototype drill was made early in 1981. After preliminary tests in the CRREL ice well, two identical drills were taken to Prudhoe Bay and put to immediate operational use in sampling multi-year pressure ridges in the Beaufort Sea. Apart from some minor problems with the core-catcher device and with accumulation of cuttings above the core barrel, the drills consistently produced cores of unprecedented quality, frequently in unbroken lengths of 1 m or more. The new drills were easy to handle and use, and were much less prone to jamming than the older CRREL auger.

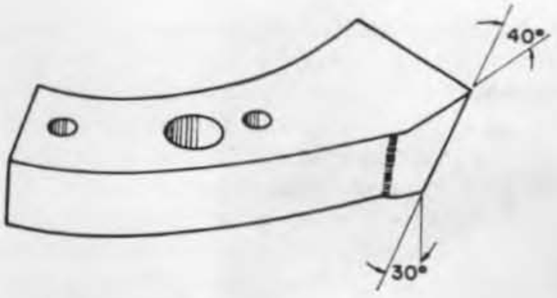
Over the past 4 years a number of small modifications have been made, and the drill is now believed to be a superior replacement for the CRREL 3-inch auger.

The following notes describe the original 3-inch auger, the newer Rand drill, and other tools for shallow-depth ice coring.

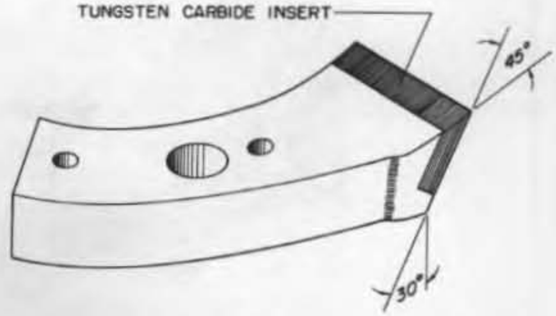
THE 3-INCH ICE CORER

The main component of the 3-inch auger system is the core barrel (Fig. 2). The nominal internal diameter is 3 in. (76 mm), and diameter of the hole is 4.375 in. (111 mm). The overall length of the barrel is approximately 1 m when the cutting shoe and the driving head are fitted. The cutting shoe has two chisel-edge cutters (Fig. 3), each of which has a 30° rake angle, a 40° included angle, and a 20° clearance angle. On a freshly ground cutter, the edge projects about 0.15 in. (3.9 mm) below the base of the cutting shoe. The outside corner of the cutter projects 0.06 in. (1.5 mm) outside the cutting shoe. Mild steel cutters are used when drilling in ice. The *effective* relief angle, which limits the angle of the helical penetration path, is set by elevating screws that can be shimmed with washers (Fig. 4). Ice chips feed from the cutters to two

Figure 2. The 1-m-long core barrel of the SIPRE/CRREL 3-inch ice auger.



a. Steel cutter. The center hole is for a countersunk Allen-head capscrew.



b. Tungsten carbide cutter for use in dirty ice and frozen soil.

Figure 3. Cutters for SIPRE/CRREL 3-inch auger.

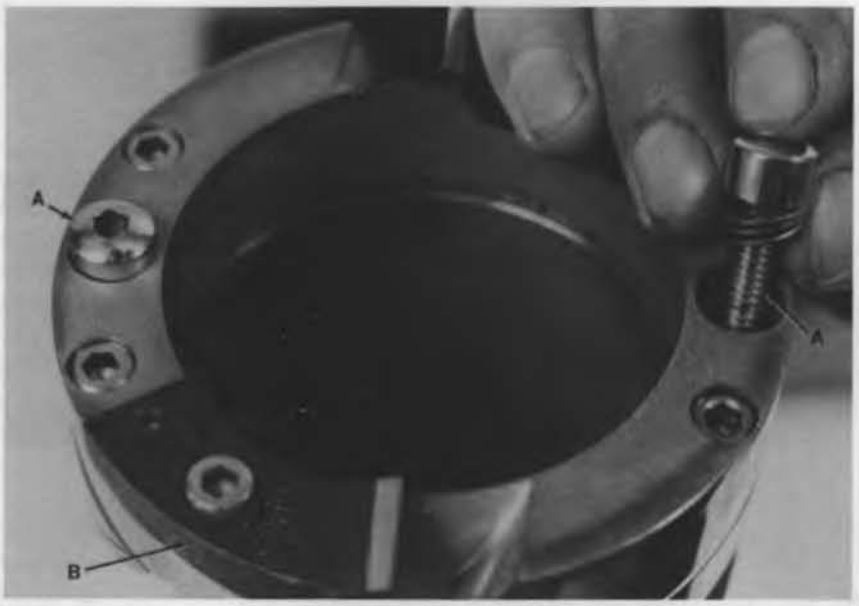


Figure 4. Cutting shoe for SIPRE/CRREL auger, showing elevating screws (a) and replaceable cutters (b).

flights. The pitch of each helix is nominally 8 in., actually about 8¼ in. (210 mm) in recent models. The outside helix angle is 30°. Cuttings were intended to fall through holes in the wall of the barrel, and to accumulate above the end of the core, but appreciable quantities of cuttings are conveyed above the barrel when a power drive turns the barrel at relatively high speeds. Cuttings always accumulate above the barrel if the length of a coring run exceeds about 0.6 m. Cuttings accumulating above the driving head can jam and prevent extraction of the core barrel. The barrel does not have a core-catcher, since the core is usually retained by cuttings jammed between the core and barrel wall.* Jammed cuttings also apply torque to the core, and this is probably why the core breaks into short lengths. The standard material for core barrels was stainless steel. Some had a dull sand-blast finish, some were chrome-plated, others were Teflon-coated. Complete auger kits contained a starting mandrel consisting of a hardwood block with a twist drill for temporary insertion inside the cutting shoe (these were rarely used).

*A. Kovacs (personal communication) improvised a core-catcher for the CRREL auger by sandwiching a projecting ring of rubber sheet between the cutting shoe and its mounting ring.

Figure 5. Core being removed from the upper end of the core barrel of the 3-inch auger (driving head removed).

Figure 6. Driving head on the 3-inch SIPRE/CRREL auger.

For efficient operation, cutters are kept sharp, both on the cutting edge and at the corners. Spare cutters are carried, and dull cutters are re-ground on the rake face. Precise setting is necessary to provide overcut on the inside and outside diameters. Some unauthorized copies of the drill failed to work because subtleties of side-clearance or relief angle were ignored. For drilling in frozen ground, the cutters have tungsten carbide inserts (Fig. 3b). These also have to be kept sharp by grinding on a soft wheel.

In ice, a coring run ends when the barrel is filled with core plus cuttings (about 0.6 m penetration per cycle at depth). The barrel is then removed from the hole, the core is extracted (Fig. 5), and extension rods are added as required. When the drill is used in frozen ground, coring runs sometimes have to be limited to 0.3 m to avoid jamming.

The core barrel is connected to either the drive system or the drill rod by the driving head. The original driving head was a heavy laminated steel block that connected to the reinforced end of the barrel by means of retractable pins engaging in holes (Fig. 6). The pins retract by a lever-actuated cam. The mechanism is prone to freeze-up, which then invites abuse in the form of hammering on the lever, sometimes leading to permanent damage. For heavy duty drilling with powerheads and small drill rigs, robust driving heads with dogs and bolts have been made (Fig. 7). The driving head is removed in order to extract core from the barrel. A ramrod may be needed to push out the core when it is tightly jammed by cuttings.

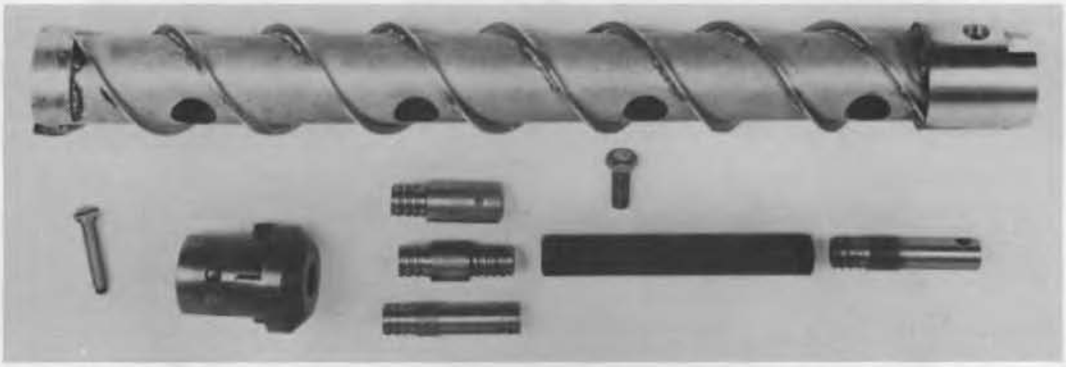


Figure 7. 3-inch CRREL auger with heavy-duty driving head and connectors.

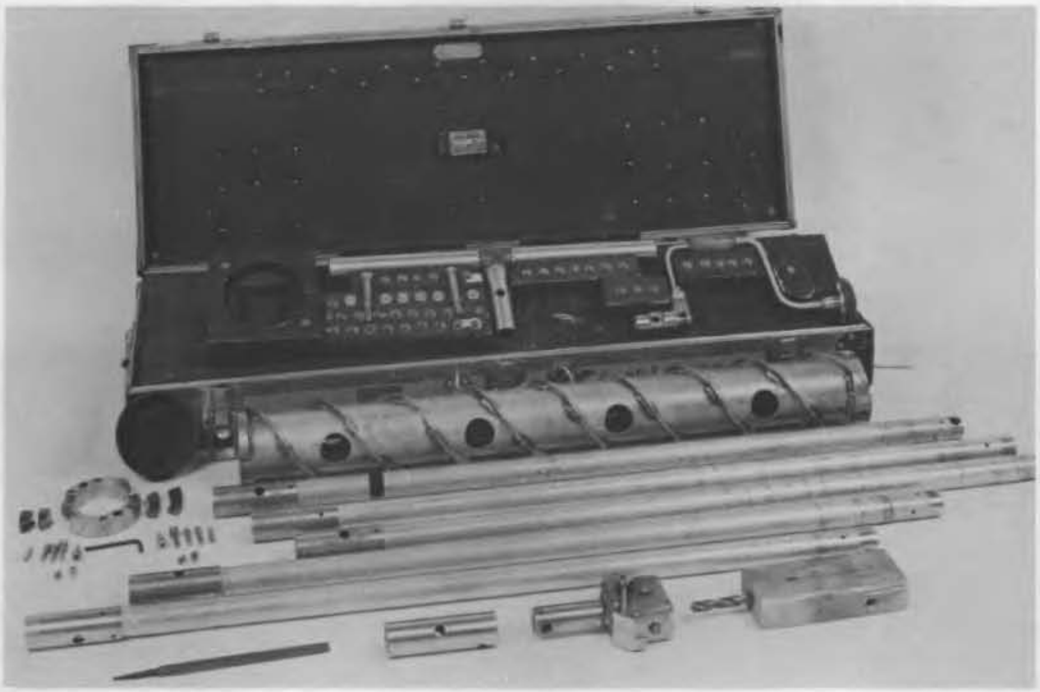


Figure 8. SIPRE/CRREL 3-inch auger kit: core barrel with cutting shoe and cutters, driving head, five extension rods with connector pins, turning brace and tee-handle, starting mandrel, tools (plus an absurdly heavy box).

The drive head normally attaches to the rotary drive unit or to the extension rod by a pinned sleeve connector. The drive head has a solid shaft, and the lower end of the extension rod has a stainless steel sleeve. Precisely aligned holes through the sleeve and shaft admit a connecting pin. Connecting pins have various types of retainers: some are quick-release pushbutton types that have a spring-loaded ball (Lockwell or Hartwell pins), some have a pivoting arm, some are just drilled to take a wire spring clip. Each extension rod is made from 1¼-in. (31.8-mm) aluminum tube, and is 1 m long. One end has a stainless steel sleeve forming a female connector (1½ in. OD, 1¼ in. ID). The other end has a stainless steel plug set into the aluminum tube, forming a male connector 3 in. long and 1$^{3}/_{16}$ in. in diameter. A standard kit has five extension rods, giving a total depth capability of 6 m (20 ft).

The basic auger kit (Fig. 8) provides a turning brace (modified carpenter's brace), and also a tee-handle, for rotating the drill. Hand rotation can give penetration rates up to 0.5 m/min (1.6 ft/min) in ice when the cutters are sharp, but rates in

Figure 9. 3-inch CRREL auger coring in frozen soil with post-hole digger.

Figure 10. Deep coring with the aid of a light tripod for lifting and lowering.

the range 0.15 to 0.35 m/min (0.5 to 1.1 ft/min) are more typical.

The auger can also be rotated by a ¾-in. electric drill turning at about 300 to 500 rev/min. The required adapter has a female end compatible with the extension rods or the core barrel head, and a solid shaft that can be gripped in the chuck of the drill. With electric drive, penetration rates in the range 0.75 to 1.7 m/min (2.5 to 5.5 ft/min) have been achieved (Kovacs 1970, Kovacs et al. 1973, Mellor et al. 1973).

Hand-held gasoline engines can be used to drive the drill. Suitable units are power heads for small post-hole diggers or for ice-fishing augers. These are geared down to give about 200 to 500 rev/min. With gasoline drive, penetration rates around 1 m/min (3.3 ft/min) have been measured.

Another type of gasoline drive has been used, especially for coring in frozen ground. This is a post-hole digger in which the engine is mounted on a wheeled dolly and connected to the rotary drive unit by a flexible cable (Fig. 9). In ice-rich frozen silt, this type of arrangement has given penetration rates up to 3.7 m/min (12 ft/min) with aggressive settings on sharp carbide cutters.

For some projects, the 3-inch auger has been used on small drill rigs (e.g. Mobil Drill B-26) to core in frozen ground.

When penetration depth exceeds 6 m (20 ft), two or three people are needed to raise and lower the drill and to hold the string while adding or removing extension rods. A split collet at the mouth of the hole is useful for supporting the weight of the string, and a tripod or gin pole helps in raising or lowering (Fig. 10).

THE RAND AUGER

Auger specifications for the 1981 CRREL/Shell project called for a core diameter in excess of 4 in. (102 mm) in order to permit precise machining of the ice down to 4 in. diameter (Mellor et al. 1984). Unbroken core was required in lengths to exceed 11 in. (280 mm), and relatively long coring runs were considered necessary (1 m of coring penetration per cycle). When these requirements are met, the weight of core lifted each cycle becomes more than three times the weight of core lifted by the 3-inch auger, so the weight of the drill itself had to be minimized to permit hand operation by two people.

The project requirements were met by fabricating the core barrel from spun fiberglass tubing (CIBA pipe), using aluminum for the cutting head and the drive-head connection (Fig. 11). The cut-

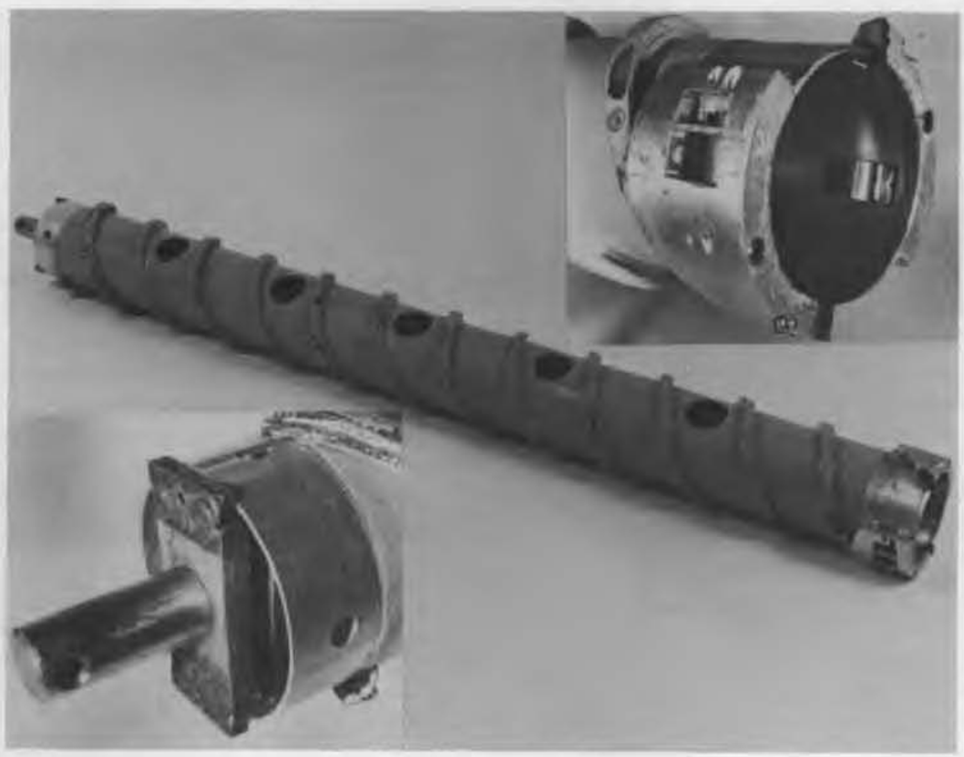


Figure 11. First version of the 4¼-inch Rand auger.

Figure 12. Current version of the Rand auger. Note that holes in the barrel wall have been eliminated.

ting head was fitted with spring-loaded dogs to break and retain core. Extension rods were identical to those used with the 3-in. auger, but aluminum centering discs were provided to stabilize the drill string against flexure and flexural vibration. Slight modifications were made on the basis of field experience; the current version of the drill is shown in Figures 12, 13 and 14.

During the first field season the two prototype drills (Fig. 15) performed well and easily provided the required amount of core. With penetration depths of 2 to 7 m (6.6 to 23 ft), two-man teams extracted a total of 330 m (1083 ft) of core from several different sites in relatively short helicopter forays from Deadhorse (see Cox et al. [1984] for details). The following things caused a few difficulties:

1) cores were hard to break free at the end of a coring run
2) the core-catcher dogs tended to slip and gouge the core during attempts to break the core, or during lifting
3) cuttings accumulated above the core barrel and sometimes blocked the recovery lift.

These initial operating problems were dealt with by: 1) modifying the core dogs (Fig. 14) for more positive action, 2) using an impact device to aid in seating the dogs and breaking the core (Fig. 16 and 17), and 3) adding a short length of wide-scroll auger about the core barrel (Fig. 18) to keep the cuttings agitated (Cox et al. 1985). As experience with the prototypes accumulated, construction details were simplified slightly. The holes in the wall of the core barrel were eliminated in recognition of the fact that most of the cuttings are transported above the core barrel when a power drive is used (see Mellor [1981] for mechanical details of auger transport).

The current version of the auger (Fig. 12) has a fiberglass core barrel, $4\,^{1}/_{2}$ in. (114 mm) outside diameter, $4\,^{5}/_{16}$ in. (110 mm) inside diameter, with a wall thickness of $^{3}/_{32}$ in. (2.38 mm). The cutting head (Fig. 12 and 13) is aluminum, with an inside diameter of $4\,^{1}/_{4}$ in. (108 mm) and an outside diameter of $5\,^{1}/_{2}$ in. (140 mm). It has two helical slots for the cutters, each inclined at 45° to the face of the cutting head. The replaceable cutters are rectangular steel blanks, $1\,^{1}/_{2} \times {}^{11}/_{16} \times {}^{3}/_{16}$ in. (38.1 × 17.5 × 4.76 mm), with one end groundsharp to a 30° included angle, and with holes drilled for locating dowels and a clamping screw (Fig. 13). When clamped into 45° milled sockets in the cutting head (Fig. 13), the cutter has a rake angle of 45°, an included angle of 30° and a clearance angle of 15° (the effective relief angle is smaller, set by the projection of the cutter and the face of

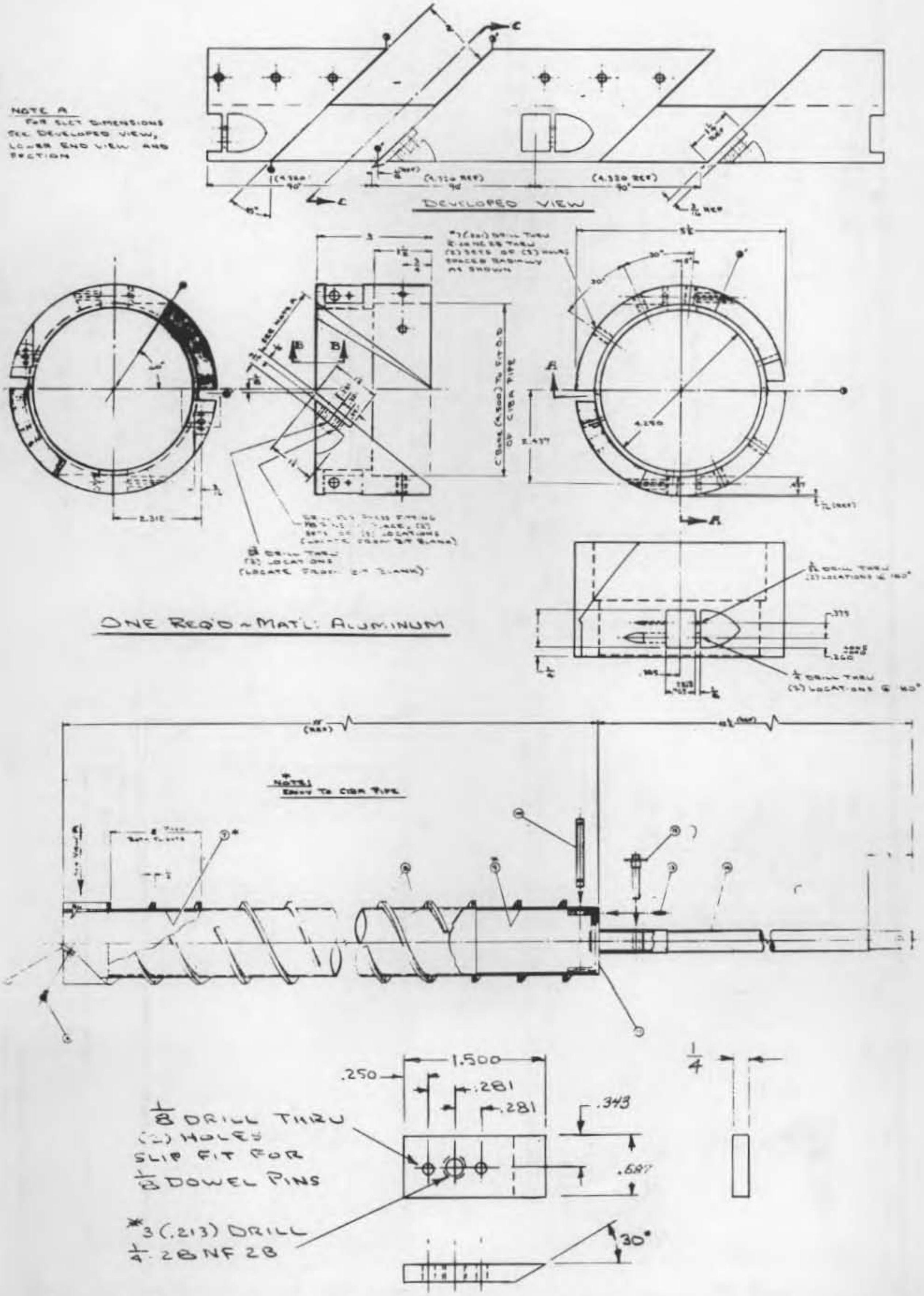


Figure 13. Core barrel assembly and details of cutting head for current version of Rand auger.

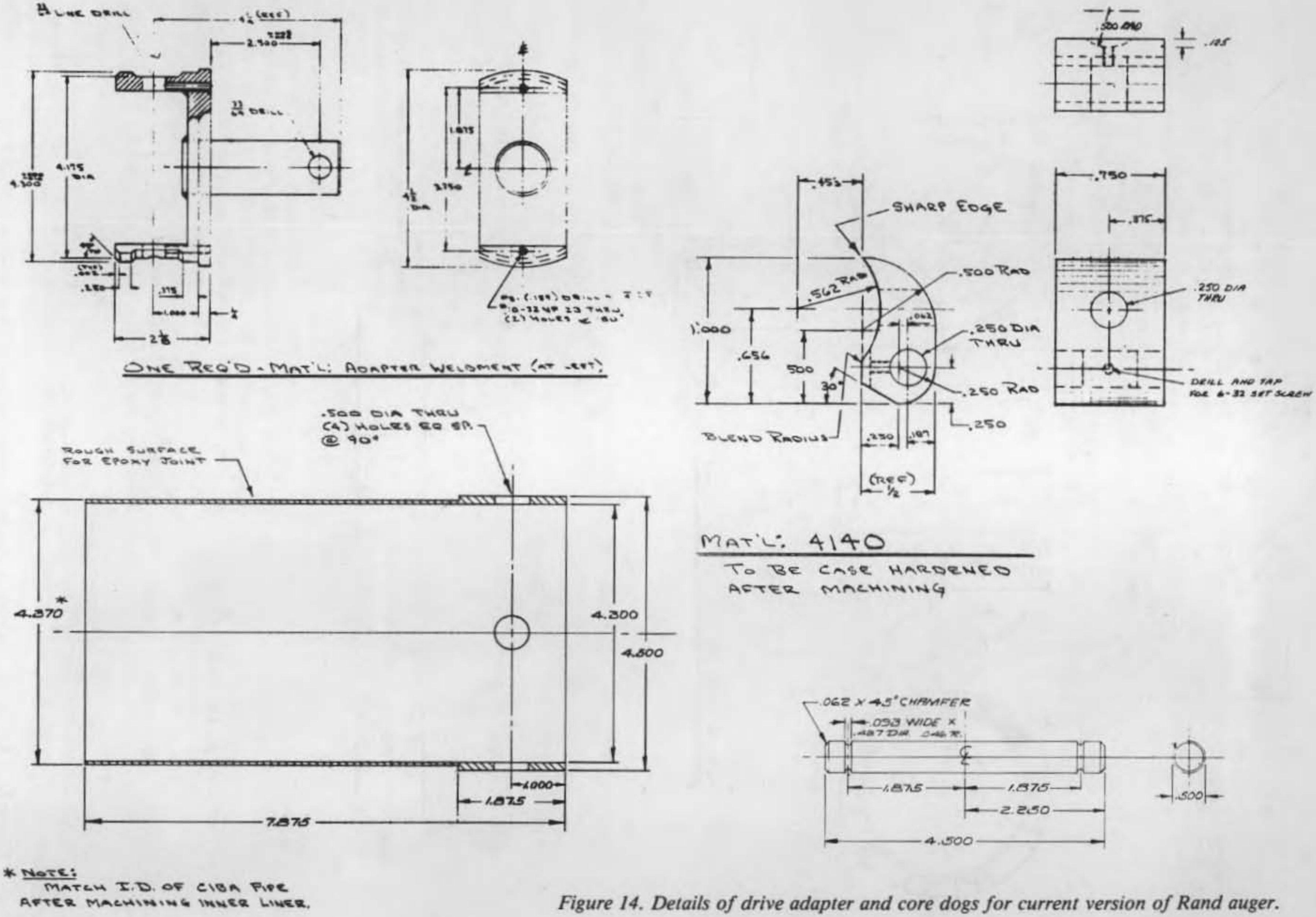


Figure 14. Details of drive adapter and core dogs for current version of Rand auger.

Figure 15. Prototype Rand auger with ¾-inch electric drive.

Figure 16. Using the reverse-impact hammer for seating the core dogs and breaking the core.

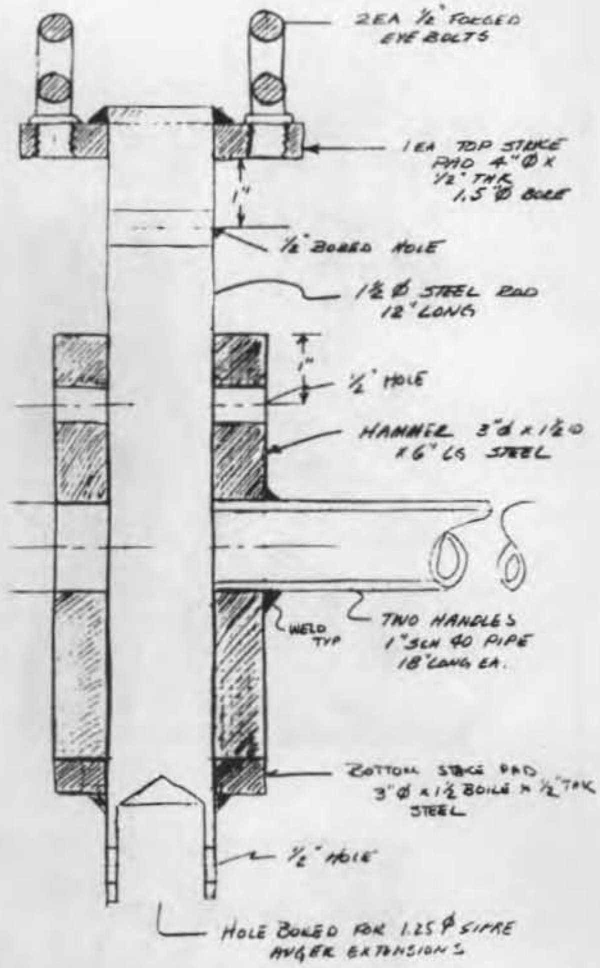


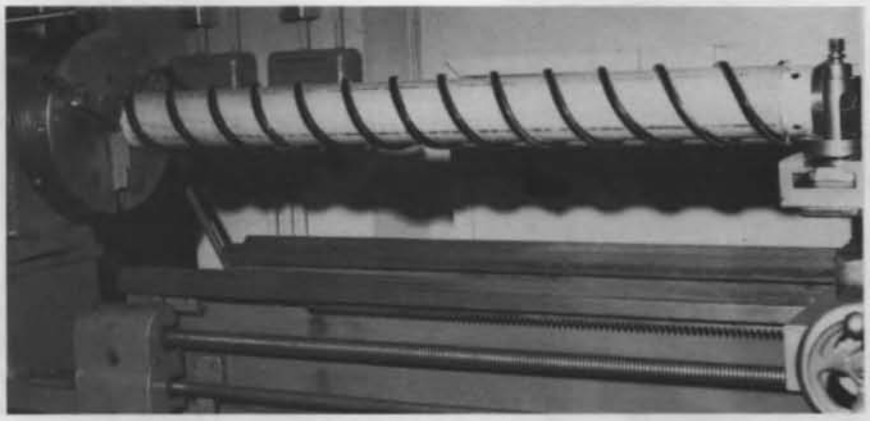
Figure 17. Reverse impact hammer for seating core dogs and breaking core.

the cutter head, or by elevating screws). The cutter is slightly wider than the annular width of the cutter head, cutting to an inside diameter of $4^{3}/_{16}$ in. (106 mm) and an outside diameter of $5^{9}/_{16}$ in. (141 mm). The cutting edge projects $^{1}/_{8}$ (3.2 mm) below the face of the aluminum cutting head.

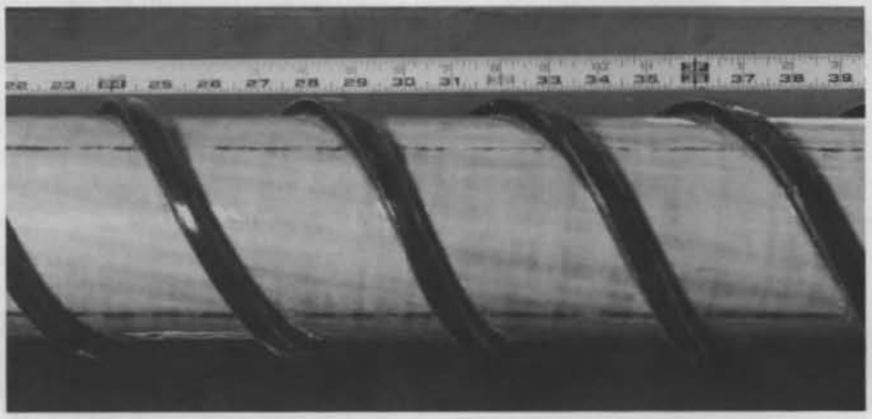
The two flights on the core barrel are made by wrapping on successive layers of $^{1}/_{2}$ in. (12.7 mm) wide nylon webbing that has been dipped in epoxy resin. The finished flights (Fig. 19) are $^{9}/_{16}$ in. (14.3 mm) thick, and their width in the radial direction is $^{1}/_{2}$ in. (12.7 mm). The pitih of each flight is 8 in. (203 mm), giving an outside helix angle of 25°. The fiberglass barrel with the flights attached is finished with a high gloss epoxy paint.

The overall length of the core barrel is 55 in. (1.4 m), but the driving head (Fig. 12 and 14) projects into the top end of the barrel a distance of $1^{7}/_{8}$ in. (47.6 mm), leaving an internal free length of approximately 53 in. (1.35 m). With the present version of the drill, most of this length can be used for core on a single run (unbroken lengths of core up to 1.28 m have been recovered—Fig. 20).

Figure 18. Rand drill with section of flight auger for stirring cuttings above the core barrel.



a. Winding auger flights in lathe.



b. Finished flights.

Figure 19. Core barrel of Rand auger.

Figure 20. Core of multi-year sea ice produced by the prototype Rand auger.

The driving head is a simple bracket that attaches to the reinforced upper end of the core barrel by a ½ in. (12.7 mm) diameter pin. The pin is retained in place by two spring-loaded catches that engage in grooves (Fig. 14). The top of the core barrel is not completely closed off by the driving head, so that some cuttings can fall into the barrel. The driving head could be modified to form a complete cap over the barrel.

To avoid jamming the cuttings during retraction from a deep coring run, a short section of flight auger can be fitted (Fig. 18). This is essentially a ½-m extension rod with a 5½-in.-diameter single-start flight added.

For deep coring, the drill string is stabilized by slipping a centering disc onto the extension rod about every 2 m. The discs are ¼-in. aluminum plate, 5½ in. (140 mm) OD, with a $1\frac{11}{32}$-in. hole that allows the disc to slip over the aluminum tube while being checked by the 1½-in. connector sleeve.

So far, this corer has been driven by ¾-in. and ½-in. electric drills, which turn at approximately 400 to 600 rev/min and are rated at about 1.2 and 0.72 kVA respectively.

Penetration rates of 5.6 to 6.7 ft/min (28 to 34 mm/s) have been measured in cold freshwater ice (Sellmann et al. 1985).

Complete shop drawings for construction of the Rand auger are available from CRREL.

PARALLEL DEVELOPMENT OF COMPARABLE DRILLS

Ice drill development, once concentrated heavily at CRREL, moved to the Polar Ice Coring Office (PICO) at the University of Nebraska, plus some European centers, following the move of Lyle Hansen from CRREL to Nebraska. In recent years, development efforts have been directed mainly to problems of deep coring in ice sheets and glaciers, but a need to replace the CRREL 3-inch auger was not ignored.

In 1982, the University of Nebraska group successfully operated a lightweight hand coring auger intended to replace the SIPRE/CRREL 3-inch auger (Koci 1984). This drill, the PICO auger, has essentially the same core diameter as the SIPRE/CRREL auger, i.e. nominally 3 in.* Like the Rand auger, it uses glass/epoxy pipe for the core barrel, but it also has fiberglass extension rods. This gives a very light system, and the drill can be used without a tripod to a depth of 30 m.

For the PICO auger, the SIPRE/CRREL cutting head was redesigned by adding core-catcher dogs, much like those on the Rand auger, and by increasing the positive rake on the cutters to 45° (again like the Rand auger). The core barrel, which is available in lengths of either 1 m or 2 m, is fiberglass pipe with holes in the wall. The flights, which appear to have a pitch of approximately 8 in. (203 mm), are cut from polyethylene sewer pipe and riveted to the barrel. The extension rods, available in lengths of 1 m and 2 m, are maee from 2-in. fiberglass pipe, and the connections are made with threaded connectors (modified Acme) designed for joining water pipes. To avoid jamming the drill by overdriving, elevating screws on the cutting head are set so as to allow the cutter edges to project only 0.05 in. (1.27 mm) beyond the elevating screw.

* A 4-in. version is now believed to be available.

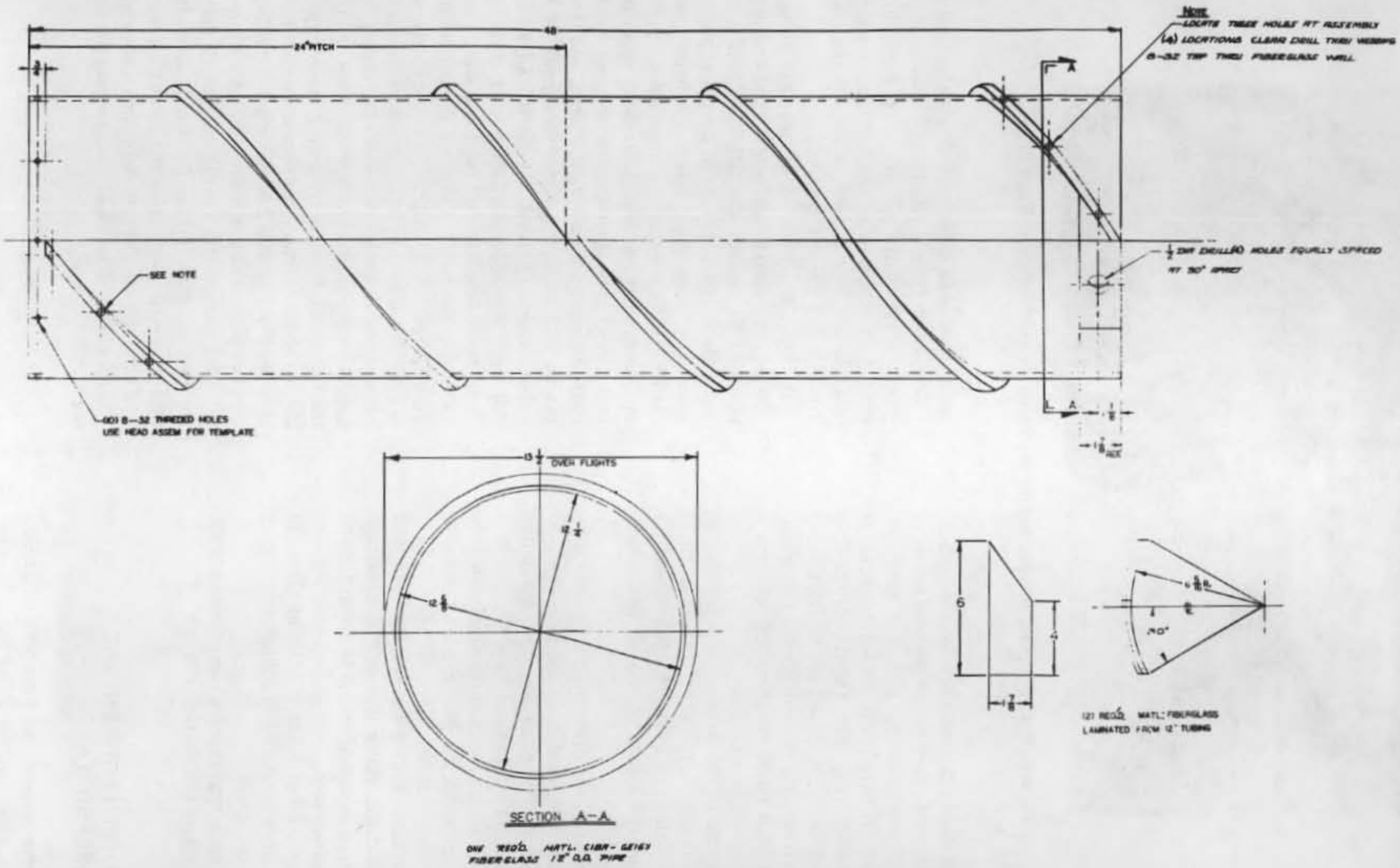


Figure 21. 12-inch-diameter ice coring auger—details of barrel and flights.

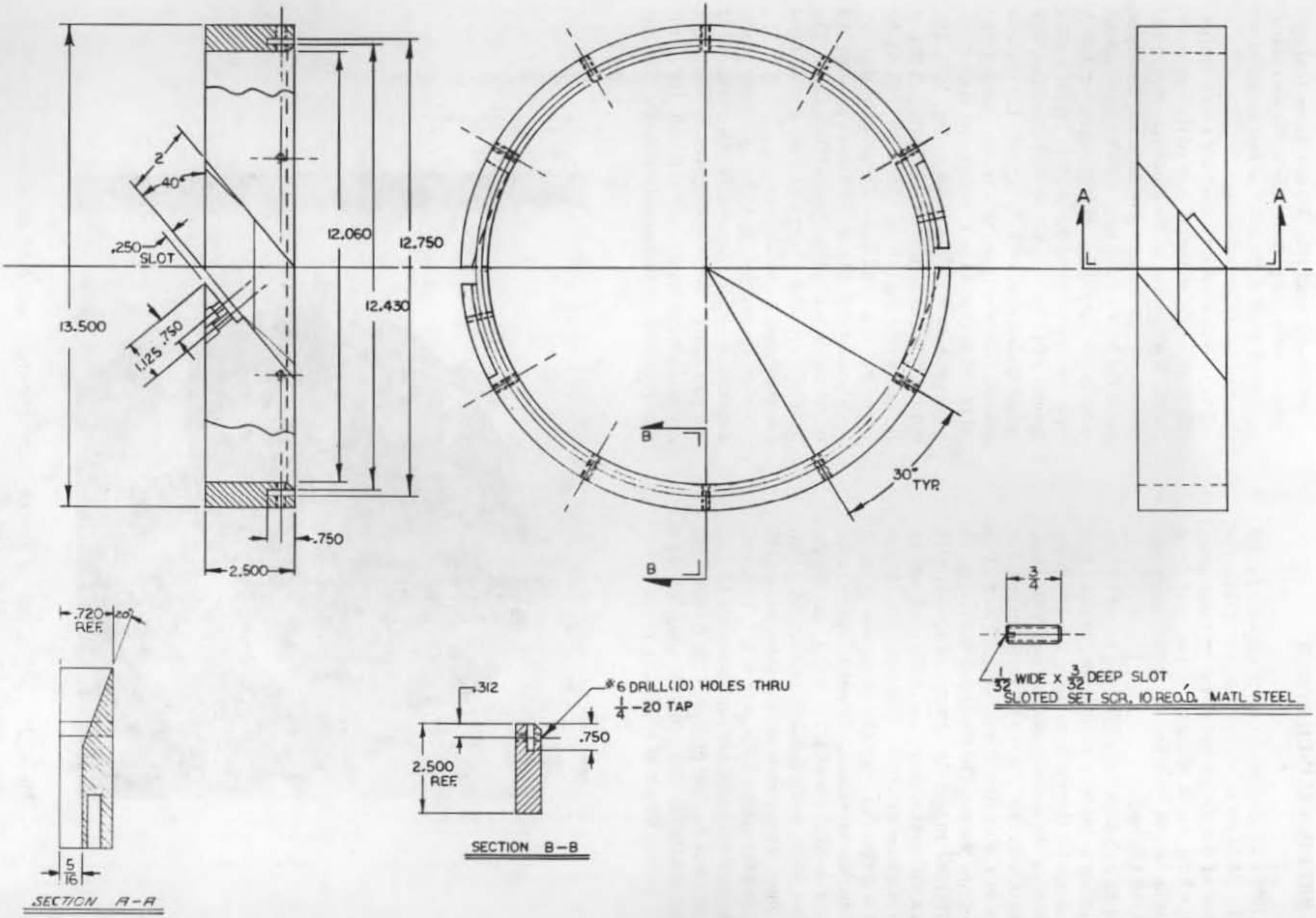


Figure 22. 12-inch-diameter ice coring auger—details of cutting head.

THE BIG JOHN 12-INCH CORER

In 1982 a 12-in.-diameter corer was built for the CRREL/Shell sea ice study (Cox et al. 1985). The purpose of this device was to extract large cores, from which $4^1/_4$-in.-diameter cores were later drilled in various directions so as to provide oriented test specimens.

The 12-inch corer has a fiberglass barrel with an aluminum cutting head at the lower end and a steel driving head at the upper end (Fig. 21). The inside diameter of the cutting head is 12 in. (305 mm), and its outside diameter is $13^1/_2$ in. (343 mm). The height of the aluminum head (Fig. 22 and 23) is $2^7/_{16}$ in. (61.9 mm). The fiberglass barrel (Fig. 21 and 25a) has an outside diameter of $12^1/_2$ in. (318 mm), a wall thickness of $^3/_{16}$ in. (4.76 mm), and an inside diameter of $12^1/_8$ in. (308 mm). The double flight is formed by wrapping on successive layers of $^1/_2$-in. nylon webbing soaked in epoxy resin, giving a radial width of 1/2 in. (12.7 mm) for the finished flight, and a finished thickness of $^9/_{16}$ in. (14.3 mm). The pitch of each flight is 24 in. (610 mm), and the outside helix angle is 30°. The overall length of the barrel and cutting head is $49^3/_4$ in. (1.26 m), but the four prongs of the driving head project into the barrel $4^1/_2$ in. (114 mm), leaving a usable internal length of $45^1/_4$ in. (1.15 m).

The driving head (Fig. 24) is a simple four-arm "spider" attached permanently to the core barrel. Its central shaft steps down in two stages to the standard $1^1/_4$-in. connector size.

The 12-inch corer does not have a core-catcher, although an experimental core-cutter was tested during development of the prototype. At the end of a coring run the barrel is retracted, leaving an unbroken core in the hole. The length/diameter ratio of the core (Fig. 26) is typically ≤ 3.5. A separate core retrieval device (Fig. 25b) is a plain cylinder of 12-in. schedule 40 steel pipe fitted with spring-loaded dogs at the lower end. The retrieval cylinder is shorter than the interior of the core barrel (27 in. against 45 in.), so that core extends beyond the bottom of the retriever (Fig. 25b). The outside diameter is 12¾ in. (324 mm), so that it fits easily into the 13½-in. (343-mm) hole. At the upper end is a small hydraulic actuator that can push against one side of the hole so as to tip the barrel and thus break the base of the ice core. The hydraulic actuator is operated from a small hand pump through a flexible hose.

For coring to depths up to 2 m, a simpler procedure can be used to recover core. After removal of the core barrel, the core is broken by wedging a pry bar between the core and hole wall. The core is then gripped by a mechanical clamp (Fig. 27), and

Figure 23. Cutting head of 12-inch auger (one cutter and both elevating plates have been remoted in this photo).

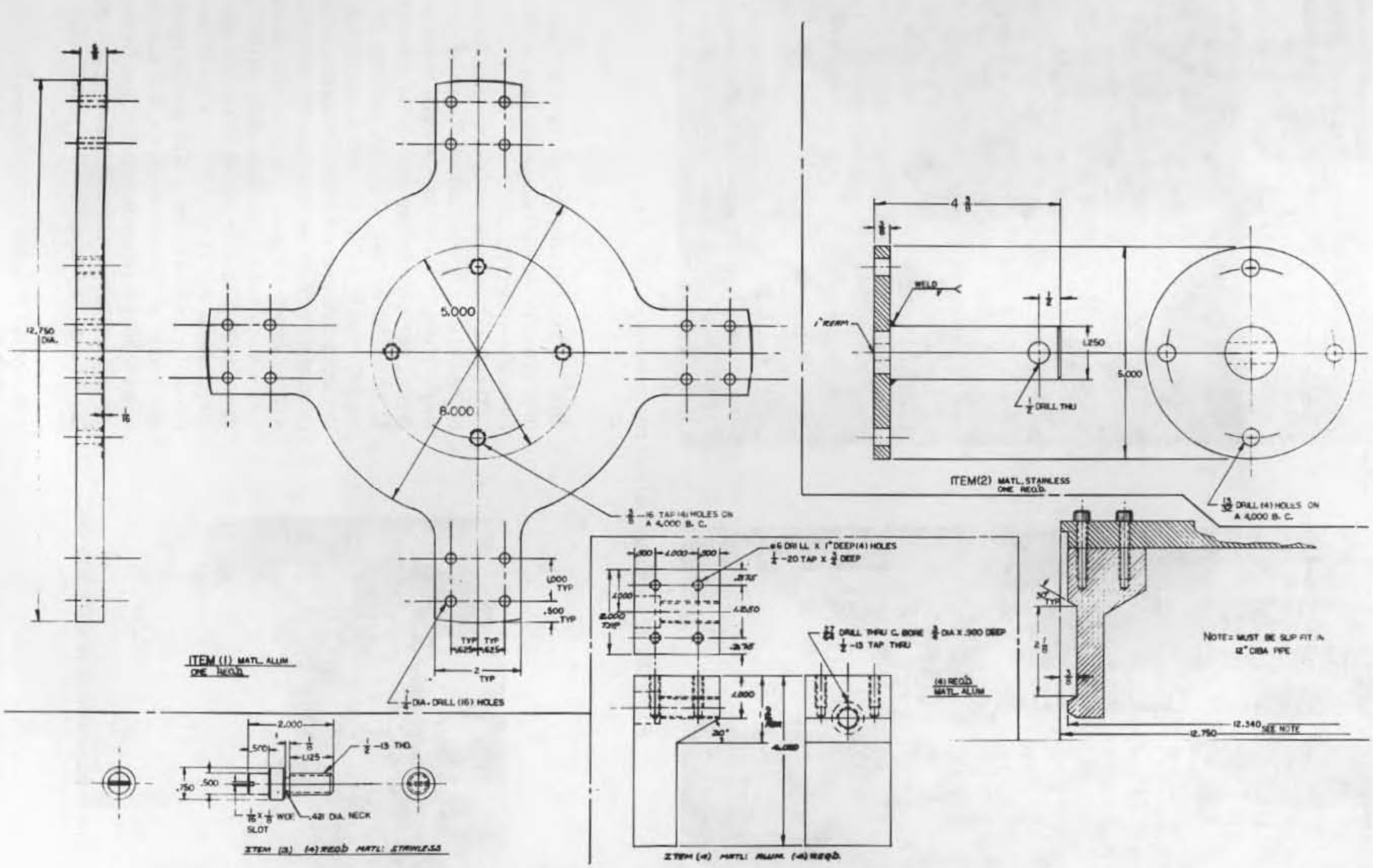


Figure 24. 12-inch-diameter coring auger—details of driving head.

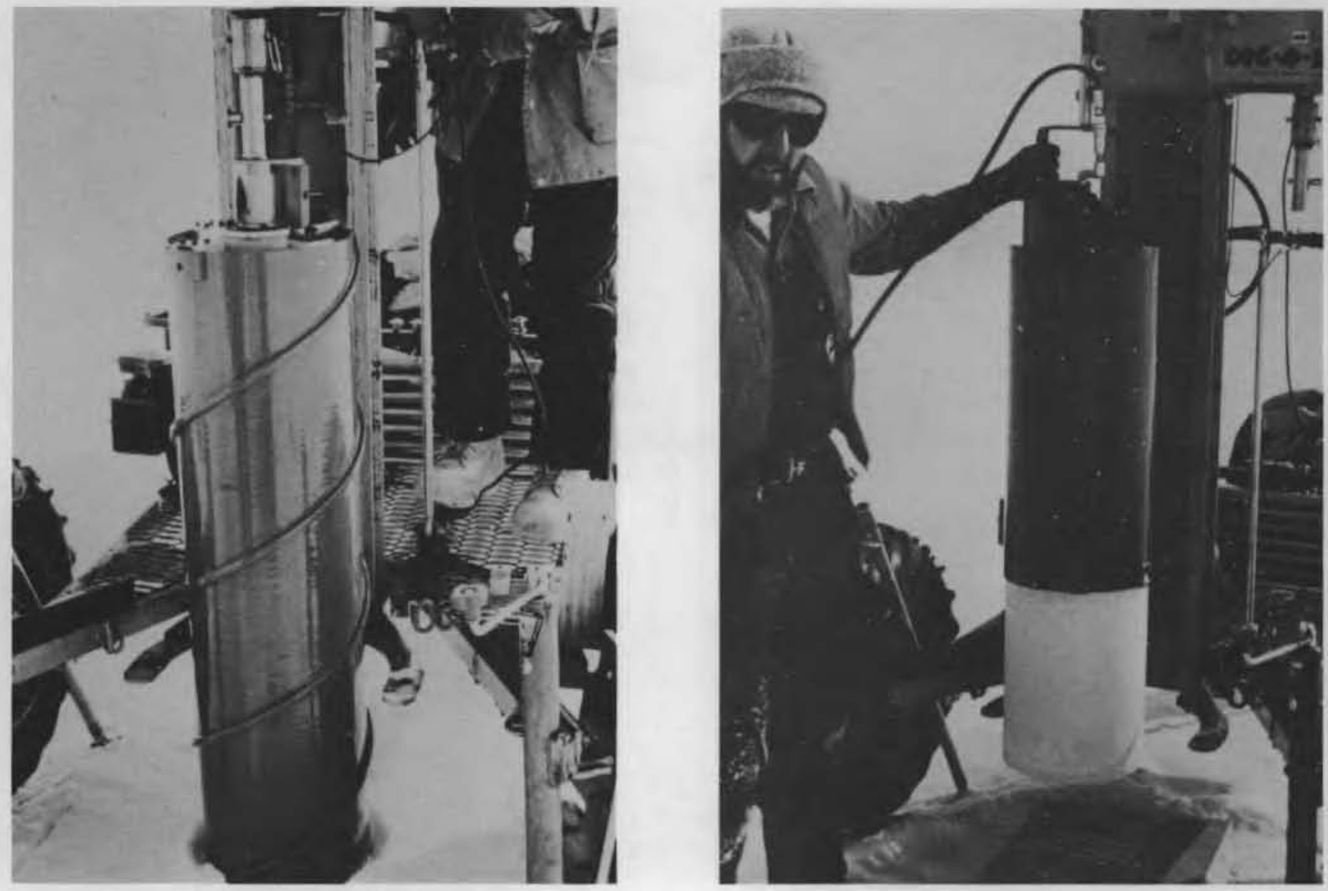


Figure 25. 12-inch corer (a) and core retrieval cylinder (b).

Figure 26. 12-inch-diameter core of multi-year sea ice.

lifted by a cable attached to the drill hoist. A three-prong mechanical clamp has been proposed for future work (Fig. 28).

The 12-inch corer cannot be operated effectively by hand, since a 1-m length of core (Fig. 26) weighs about 150 lb (68 kg). A small commercial drilling rig* was modified and used to operate the 12-inch corer in 1982. The basic drill unit drives the drill head by a 7-hp air-cooled gasoline engine through a spur gear reduction, giving a maximum rotational speed of 144 rev/min. The drill head, with its attached engine, travels up and down a simple mast, using roller drive chain for lift and downthrust. The drive chain travel and downthrust force are controlled by a hand wheel through a double reduction. The base of the drill unit is a trailer. For ice-coring, the drill was fitted with a folding mast extension, with jacks for leveling and stabilizing, and with off-road tires (Fig. 29). The trailer was modified so that it could be

* Dig-R-Mobile, Model 550, General Equipment Co., Owatonna, Minnesota.

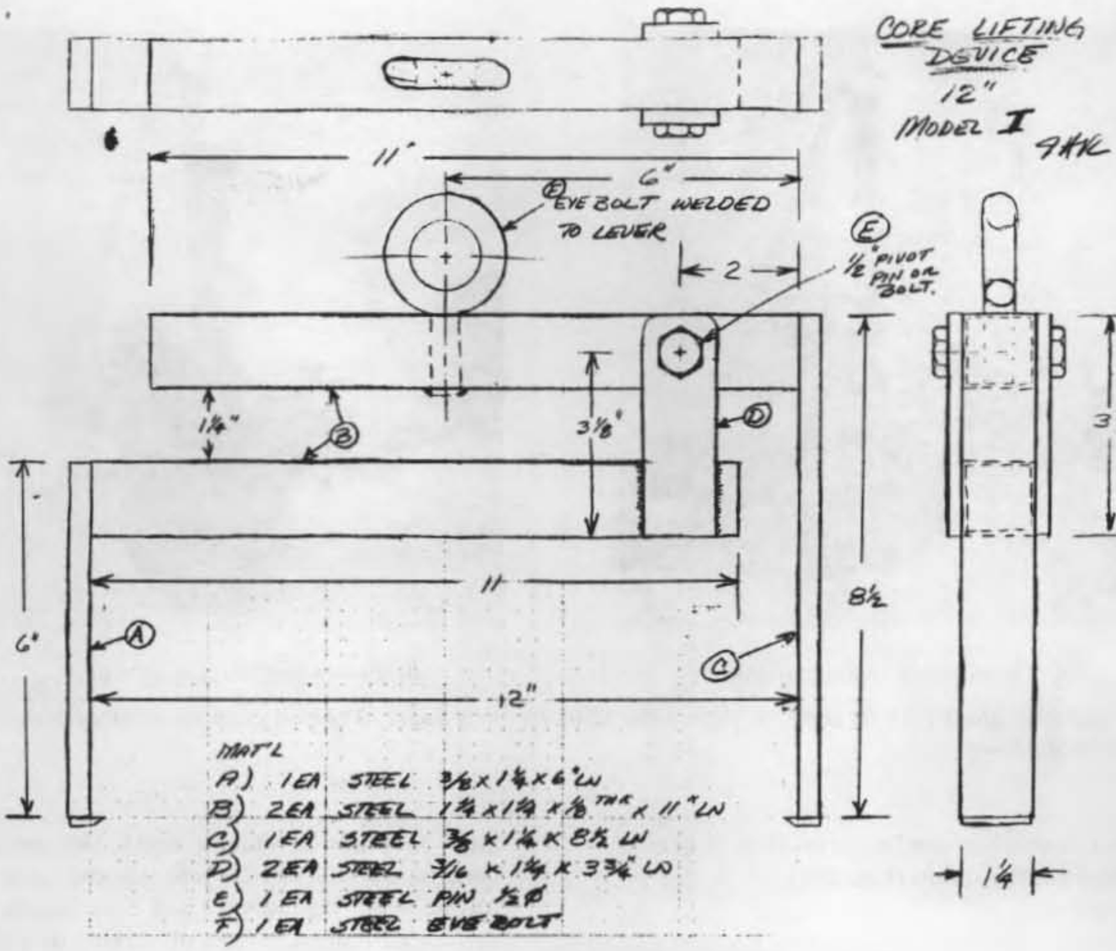


Figure 27. Two-prong gripper for lifting 12-inch ice cores.

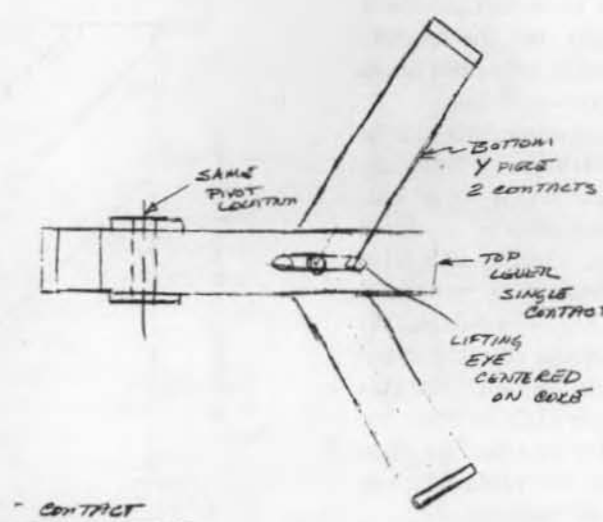


Figure 28. Three-prong variant of gripper for lifting large-diameter ice cores.

a. Three-wheel version of trailer.

b. Two-wheel version of trailer.

Figure 29. Small drill rig used to operate the 12-inch coring auger. The mast extension is folded down in these photos.

used in a three-wheel configuration (Fig. 29a) or a two-wheel configuration (Fig. 29b).

POWER DRIVES

A power drive should match the cutting characteristics of the auger and the physical limits of the operator. It should obviously have enough power and torque to rotate the auger, but the requirements for torque reaction should be within limits that are comfortable for a hand-held unit.

Speed, power and torque requirements can be worked out systematically (Mellor and Sellmann 1975, Mellor 1976, 1981), and transport of cuttings on the auger flights can also be analyzed (Mellor 1976, 1981). However, selection of a drive unit is usually a matter of finding the most suitable commercial item that is readily available. As a rough rule of thumb, a suitable rotation speed for good cutting is one that gives a tangential cutter speed of about 400 ft/min (120 m/min) but faster rotation can improve the transport of chips by the flights. Figure 30 gives workable relations between rotation speed and bit diameter.

With new cutters, elevating screws fully retracted, and heavy downthrust, the SIPRE/CRREL 3-inch auger can penetrate at 0.3 in./rev (7.6 mm/rev), and the Rand auger can penetrate at 0.36 in./rev (9.1 mm/rev). With typical downthrust for hand operation at shallow depth, this amount of penetration will not be realized and, if it were, torque might be excessive and core quality might suffer. To remove effects of varying downthrust, the penetration per revolution can be reduced by using the elevating screws. Maximum penetration rate of about 0.15 in./rev (3.8 mm/rev) is reasonable for the CRREL tools, which gives maximum

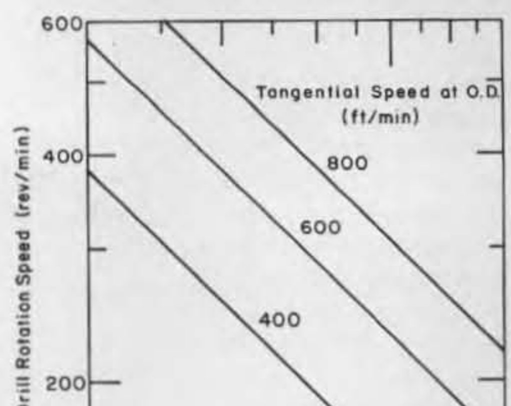


Figure 30. Drill rotation speeds for power-driven ice coring augers.

drilling rates around 3½ ft/min 1.1 m/min) with a drive unit rated at 300 rev/min (typical ¾-in. electric drill).

For a fixed (controlled) penetration rate, the chip clearing rate of the auger can be increased by increasing the rotational speed, but the chip size then decreases, giving greater tendency for adhesion by very small ice fragments. The speeds shown in Figure 30 are adequate and safe with the limits on penetration rate suggested above.

For large diameter augers, the specifications for power drives need to be optimized in accordance with the equipment available. Hand operation of the drilling function is perfectly feasible, but cores cannot be lifted by hand. If a small drilling rig is used for both drilling and core recovery, it becomes practical to apply more torque and power.

A SIMPLE RUSSIAN ICE-CORER

In the Soviet Union a simple ice-fisherman's tool has been adopted for research sampling. Known as the PI-8 (Fig. 31), this improbable-looking device is very effective for coring to depths up to 2 m. Standard versions from fishing shops come in diameters of 120, 180, 210 and 310 mm (4.72, 7.09, 8.27 and 12.1 in.).

The cutting element is a split ring of square or rectangular cross section. The cutting edge is formed directly on the ring and the relief angle can be set and adjusted by straining the ring with a pull in the axial direction of the free ends (making the ring slightly helical). A split ring of this kind should be easy to make from a slice of thick-wall steel pipe.

The extension rod is welded to the cutting ring. Its diameter is less than the wall thickness of the cutter ring so that it can travel freely in the kerf between the core and the hole wall. The device is rotated by hand using an offset turning brace, and cuttings are cleared by lifting the ring to the surface from time to time.

To make precise holes, the device has been modified by increasing the number of rods to three, securing the rods to a fixed ring at the top, and fitting the rods with a sliding guide ring that stays near the top of the kerf (A. Fish, personal communication). This variant can be rotated from a central shaft in the conventional way.

CONCLUSIONS

The design and construction of efficient ice coring augers for penetration to about 30 m is now fairly straightforward. Future developments will probably be refinements for easier operation and lighter weight.

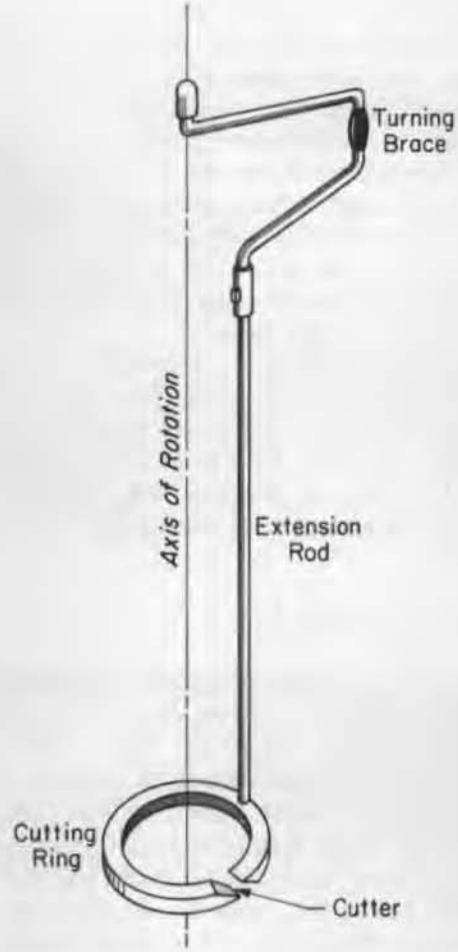


Figure 31. Ice-fisherman's auger (PI-8) used for shallow coring in the U.S.S.R.

Fiberglass core barrels with bonded flights of nylon/epoxy have proved very successful. Devices for breaking and gripping cores are now satisfactory, but some modifications or alternatives might appear in the future. Extension rods of fiber-reinforced composites seem attractive, especially if they have couplings that are convenient and robust. Hand rotation is satisfactory for coring in dense snow (firn), but power drives are likely to be preferred for ice coring. Lifting and lowering the drill string by hand becomes easier as the equipment gets lighter, but simple hoists are useful for deep penetration and for drilling large diameter cores. Added downthrust is not necessary as long as narrow-kerf cutters are employed.

Transport and removal of cuttings have to be dealt with in an orderly way, in both design and operation. With narrow flights, it is possible to overdrive the penetration and clog the flights with ice chips. This could jam the drill, especially in wet or warm conditions. The solution is to set the cutters, or use elevating screws, correctly. Cuttings that are transported above the core barrel could become compacted into a solid plug during withdrawal of the drill, especially when wet or warm, again jamming the drill. This problem can be solved with a wide-scroll auger, or a chip-collector bucket, above the core barrel.

Drilling situations can vary considerably, and there can be troublesome combinations of cold ice and intruding water. Lightweight equipment cannot withstand brute force treatment, or other abuses. It is therefore desirable to have operators with common sense and/or experience.

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