United States Patent

[11] **3,579,037**

[72] Inventors **Donald J. Hackman; Ronald L. Legue, Columbus; Jeremy M. Harris; Donald E. Roop, Worthington, Ohio**

[21] Appl. No. **774,622**
[22] Filed **Nov. 12, 1968**
[45] Patented **May 18, 1971**

[73] Assignee **Oceanautic Manufacturing and Research Company Cincinnati, Ohio**

Continuation-in-part of application Ser. No. 754,783, Aug. 23, 1968.

[54] **PORTABLE TOOL**
29 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **317/18,** 310/87, 317/27, 317/45, 318/207
[51] **Int. Cl.** **H02h 3/28,** H02h 7/26
[50] **Field of Search** 310/51, 90, 47, 50, 83, 87; 318/207, 220, 221; 317/18, 27, 45

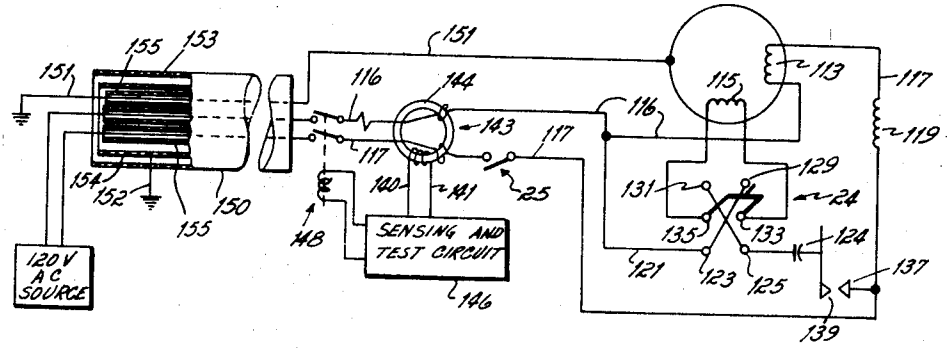
[56] **References Cited**

UNITED STATES PATENTS

2,568,548	9/1951	Howard et al.	310/87X
2,944,297	7/1960	Maynard	310/87X
2,964,660	12/1960	Herrick et al.	310/87
3,048,756	8/1962	Voege	318/207
3,171,062	2/1965	Rowe	317/18
3,267,868	8/1966	Page	310/87X
3,483,407	12/1969	Frohmuller et al.	310/51

Primary Examiner—James D. Trammell
Attorney—Wood, Herron and Evans

ABSTRACT: An electric motor-driven portable tool for use underwater. The tool and motor are insensitive to water depth and corrosion because of the tool design and choice of materials. To minimize the danger of electrical shock to the human operator, the tool is used in combination with a safety trip circuit which is effective to cut off all power to the tool in less than 30 milliseconds in the event of a short circuit or even a minimal current leak in either the tool or cable supplying current to the tool. Additionally, the tool motor is insulated from the housing, the tool housing is grounded by a third ground or neutral wire in the power cable and the cable has a metal sheath which is also grounded at or near the power source.



Patented May 18, 1971 3,579,037

2 Sheets-Sheet 1

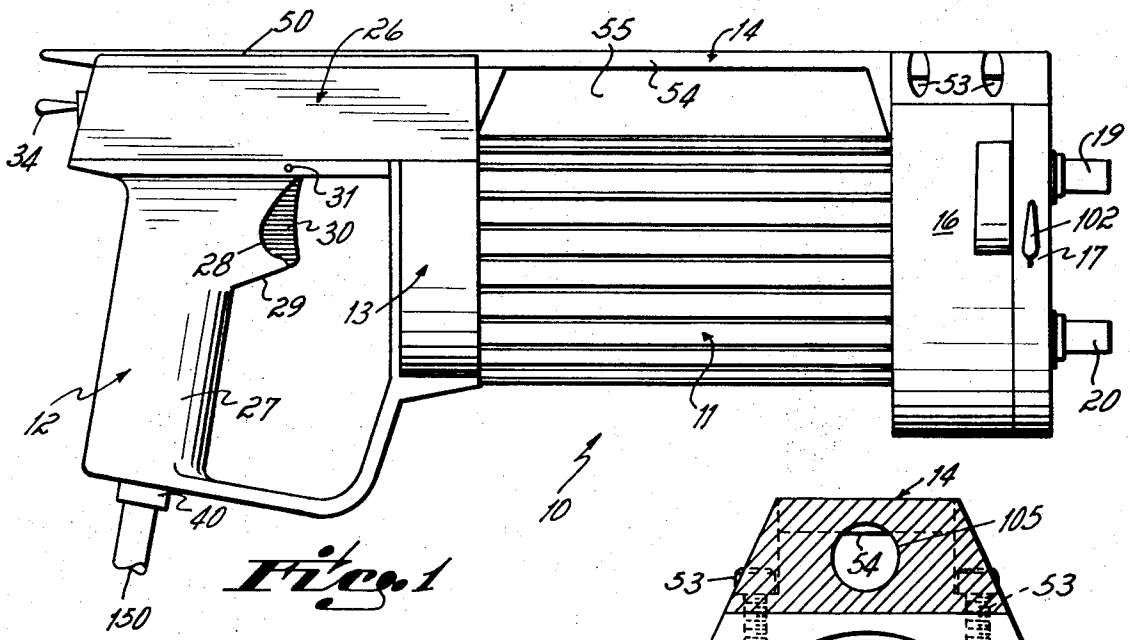


Fig. 1

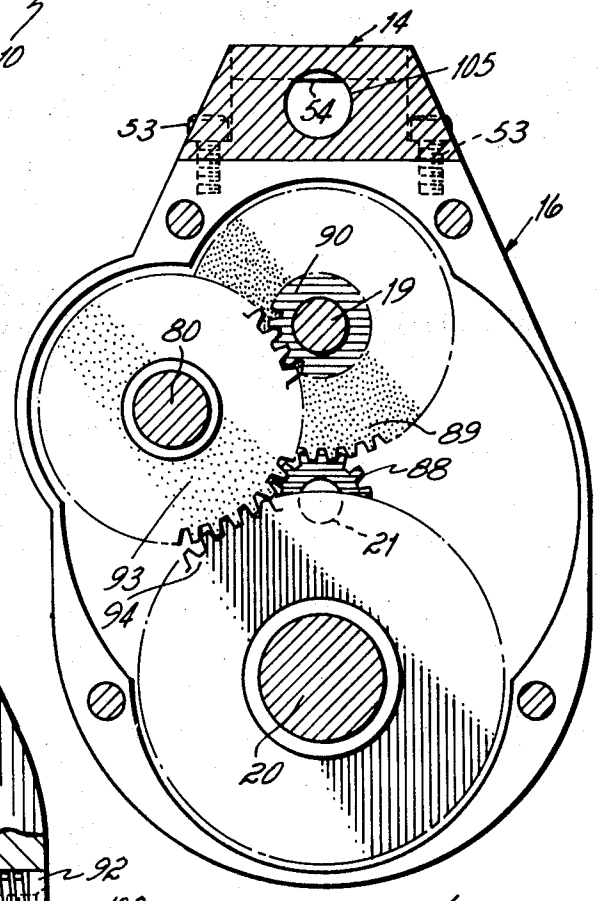


Fig. 3

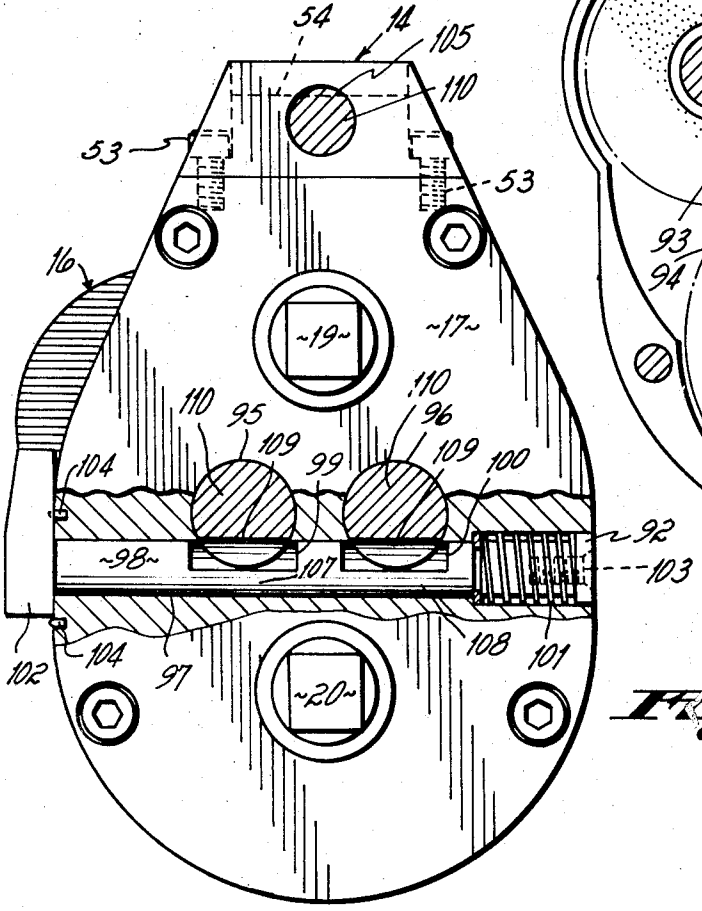


Fig. 4

INVENTORS
Donald J. Hackman
Ronald L. Leque
BY Jeremy M. Harris
Donald E. Koop
Wood, Herron & Evans
ATTORNEYS

2 Sheets-Sheet 2

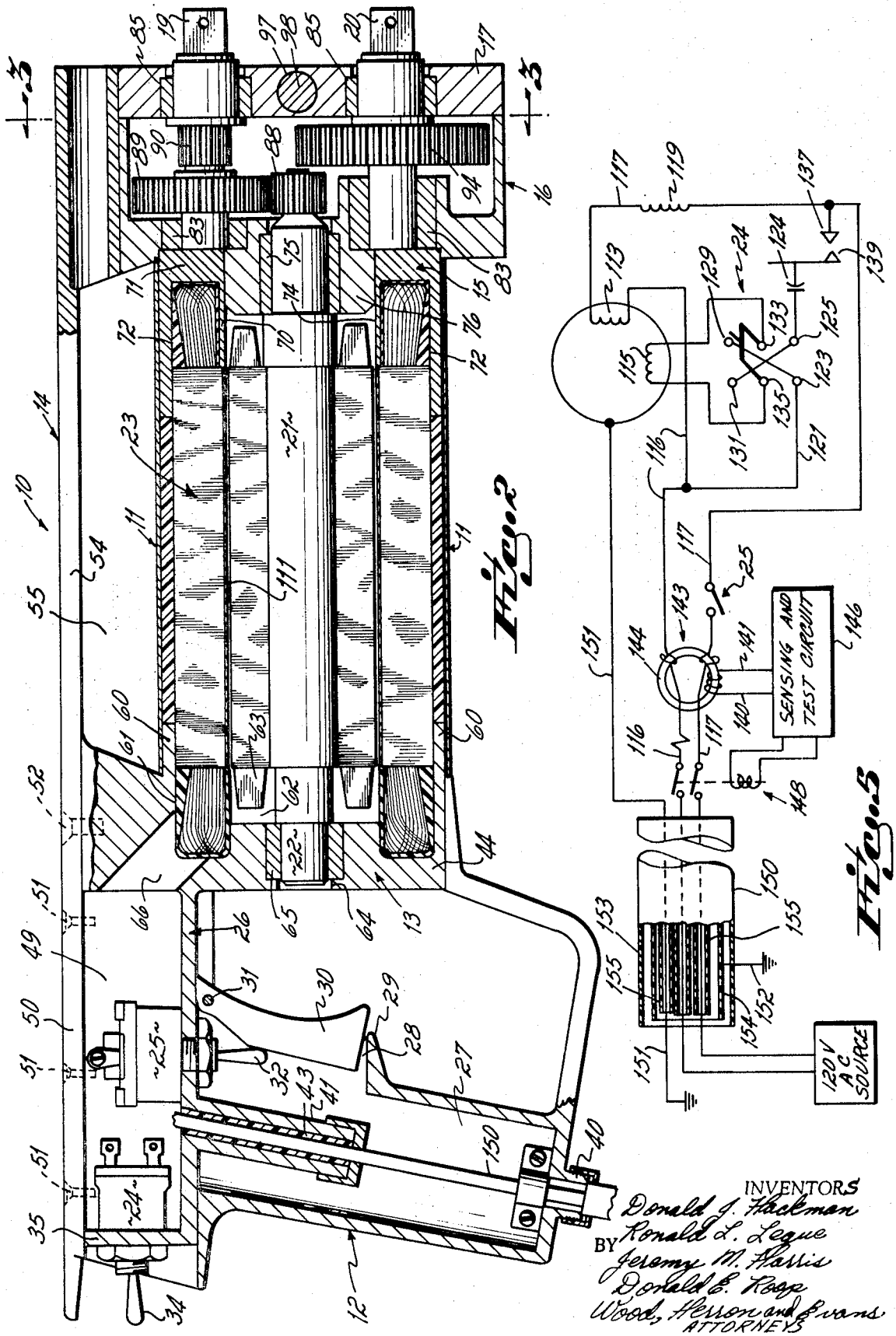


Fig. 2

Fig. 3

INVENTORS
Donald J. Hackman
Ronald L. Leque
Jeremy M. Harris
Donald E. Koop
BY Wood, Herron and Evans
ATTORNEYS

PORTABLE TOOL

This application is a continuation-in-part of application Ser. No. 754,783, filed Aug. 23, 1968.

This invention relates to portable tools and particularly to tools for use underwater by divers.

There has been a long standing need for a portable power-driven tool which could be used underwater by scuba divers up to depths of 1000 feet for such diverse activities as tightening nuts and bolts, cutting, grinding, tapping, sawing and descaling metal. At the present time, though, there is no such tool commercially available. The reasons for the lack of such a tool are numerous and readily obvious. Such a tool must be relatively pressure insensitive and insensitive to exposure to and immersion in salt water. It must also be absolutely fail-safe because of the inherently dangerous environment of its use where even a minimal failure could result in serious injury and possibly death to the operator.

Safety considerations particularly have heretofore militated against the use of electrically driven portable tools and have necessitated that the tool be either pneumatically or hydraulically actuated. While such tools are relatively safe they are generally unsuitable for use by free-swimming scuba divers because of the heavy lines required to tie them to a power source nd because of the pressure problems inherent at depths up to 1000 feet. Therefore, the alternative of a portable power source as, for example, a tank of compressed air or a battery has been considered. However, portable power sources are generally impractical underwater because of the limited power available and the inconvenience of moving large heavy power storage devices.

All of these considerations dictate that the power source be an electrical cord and that the motor be a conventional electric motor. This solution, too, through, has its problems because electrically driven tools underwater are notoriously dangerous and subject to failure because of the corrosive effects of salt water. While corrosion resistance and pressure insensitivity have been major problems, the primary problem has always been safety. As is well known, an electrical current of as little as 25 milliamps can be fatal to a human in a very short time. As the current increases, the duration of the exposure required to effect fatal cardiac fibrillation decreases. For example, a current of 500 milliamps or one-half amp can kill a human in approximately 0.1 amp seconds and a current of 1000 milliamps or 1 amp can be fatal in as little as 0.02 seconds. Since current amplitude is a function of voltage divided by resistance, and since the resistance of a human body is only approximately 200 ohms when immersed in water (as opposed to approximately 100 ohms above water), it is appreciated that exposure of a human body to electrical current underwater is much more dangerous than above water. Consequently, it has heretofore been assumed that an electrically driven portable power tool operating underwater either on 110 or 220 volts was inherently too dangerous to be practical. This was particularly true because of the danger of water under high pressure created by deep water depths leaking into a motor housing and creating a short circuit. Scuba diving is inherently dangerous so that no one has heretofore wanted to add to that danger by having a diver carry an electrically powered tool.

It has therefore been a primary objective of this invention to provide a power-driven portable tool which is satisfactory for use underwater by free-swimming scuba divers and which is safe and convenient to use.

This objective has been accomplished and one aspect of this invention is predicated upon the discovery that an electric motor-driven power tool could be made safe for use underwater if it embodied proper safety precautions to prevent fatal current leakage through a human operator and if it was made properly pressure and depth insensitive so that salt water leakage into the housing could not create a safety hazard.

One specific safety precaution which we have found enables an electric motor-driven portable tool to be used underwater consists of connecting a current leak-responsive trip circuit in the electrical circuit to the motor such that current leakage will be detected and turned off within a time period of less than 30 milliseconds after development of the current leakage. Thus, irrespective of how much current passes through the human operator, the safety circuit will prevent the human operator from being exposed to a fatal dose by limiting the time period of exposure to a safe one. Additionally, to further protect the human operator, we have connected the metallic motor and tool housing to ground near the power source by means of a third neutral wire connected at one end of the housing and at the opposite end to ground. Still further, we have connected the tool housing to ground by a current-conductive metal sheath around the electrical cable. As a still further safety precaution, we have insulated the electrical components of the tool from the housing by embedding the electrical current-carrying portions of the motor in an insulative resin-potting material. Thus, even in the event that a ground current leak should develop in the tool, to reach the human operator the current must leak through the tool housing. Since the housing is connected to ground by a low-resistance electrical lead (of less resistance than the water immersed human body) and by the sheath around the electrical cable, these parallel path ground circuits tap off part of the leakage current so as to prevent the human operator from being exposed to a fatal dosage.

To further render the tool safe for use by a human operator, we have made the tool pressure insensitive so that leakage of salt water into the tool cannot create a short. To this end, the tool housing is open for the flow of salt water therethrough such that the salt water passes between the stator and rotor of the electrical motor and serves to cool the motor. The current-carrying components of the motor, however, are embedded in an insulative resin-potting material so that salt water flowing through the tool does not result in current leakage.

If salt water is to flow around and through an electrical motor, the motor should preferably be of the alternating current type since direct current motors require commutators and commutators are not practical in a salt water environment unless they are sealed. However, AC motors of a specified torque output are inherently larger than DC motors and therefore generally undesirable in portable tool applications. We have found, however, that a capacitor start type of induction motor may be used in a power tool and may be made compact while still maintaining a high-torque output.

Since alternating current-inductive motors have high-speed and low-torque characteristics, to be practical for high-torque applications, the output shaft of the motor must be connected to the tool shaft through a gear reduction unit. If the unit is to be useful underwater, this gear reduction unit must either be sealed so as to resist the inflow of salt water or some provision must be made to resist the corrosive effects of exposure of the unit to salt water environment. We have found that the gear reduction unit may be open and exposed to the flow of salt water if the bearing materials are all nonmetallic, as for example, graphite, and the gears are made from either stainless steel or an acetal plastic such as DuPont's Delrin plastic. If a stainless steel gear is always made to mate with and drive or be driven by an acetal plastic gear, the unit will be sufficiently friction free to be free running even in a salt water environment. Additionally, it is resistant to both salt water and galvanic corrosion.

Another aspect of this invention is predicated upon the construction of a rotor of the motor for driving the portable tool. This rotor comprises a plurality of conventional soft steel plate laminations separated by insulative laminations and surrounded by a chrome plating. The stator of the motor is embedded in epoxy-potting material and has a stainless steel sleeve insert, which sleeve is then closed and sealed by caps at the ends. This construction provides a long-life cycle motor operative for long periods of time even in a salt water environment.

Another aspect of this invention is predicated upon the interconnection of the electrical cord and the tool. In our earlier

filed application, the electrical cord is disclosed as connected to the tool at the top of the tool housing. We have now found that the tool is more easily maneuverable and that the cord may be more easily sealed off from the housing if the cord enters the housing through the bottom of the handle of the tool.

Another aspect of this invention is predicated upon the use of oil-filled switch housings to control and reverse the motor drive. In our earlier filed application Ser. No. 754,783, of which this application is a continuation-in-part, the switches were disclosed as being sealed in an epoxy-potting compound. We have found that that solution is not as reliable as utilizing electrical switches surrounded by oil-filled housings. Oil within the housing resists the ingress of salt water even at pressures up to 700 pounds per square inch.

These and other objects and advantages of this invention will be more readily apparent from the following description of the drawings in which:

FIG. 1 is a side elevational view of the portable tool of this application,

FIG. 2 is a cross-sectional view through the tool taken along the vertical centerline thereof,

FIG. 3 is a cross-sectional view taken along line 3—3 of FIG. 2,

FIG. 4 is a front end elevational view, partially broken away to illustrate the impact tool attachment, of the tool, and

FIG. 5 is an electrical circuit diagram of the motor and control circuitry.

Referring first to FIGS. 1 and 2, it will be seen that the portable tool 10 of this application comprises a motor housing 11, a pistol grip-type handle 12, a rear end cap and switch housing 13, a carrying handle 14, a front end plate 15, a gear reduction unit housing 16, and a front cover plate 17. The gear reduction unit has two output shafts 19 and 20, each of which are connected through a series of spur gears to an output shaft 21 (FIG. 2) of the electrical drive motor 23. Referring to FIG. 2 it will be seen that the flow of current to the drive motor 23 is controlled by a pair of toggle switches. One of these toggle switches 25 is an on-off switch which controls the flow of current to the motor and the other 24 is operable to control reversing of the motor as explained more fully hereinafter.

Since the tool of this invention is designed to be used underwater and particularly in a salt water environment, it must be insensitive to the corrosive effects of this environment as well as insensitive to galvanic corrosion. To this end, all of the external parts of the tool are made from hard coat anodized aluminum. In fact, all of the nonmotor components of the tool are made from hard coat anodized aluminum except for the supporting bearings, the output drive shafts 19 and 20, the gears and gear spacers of the gear reduction unit, and the assembly screws. The supporting bearings are made from graphite and the shafts, gears and gear spacers are made from stainless steel except for two of the gears of the gear reduction unit which are made from an acetal plastic. This combination of materials has been found to be effective against environmental corrosion as well as galvanic corrosion.

It will be noted that none of the stainless steel components are in direct contact with any of the anodized aluminum components except for the small stainless steel screws. It has been found that when the two metals are placed in surface to surface contact, undesirable galvanic corrosion occurs between the two. Since the phenomena of galvanic corrosion is a function of contacting surface area, the detrimental effects which occur between the stainless steel screws and the aluminum components is so minimal as to be acceptable.

Referring now to FIGS. 1 and 2, it will be seen that the pistol grip handle 12 comprises a generally tubular section 27 which has a trigger slot 28 on its front side and a forwardly extending trigger guard 29. A pivotally mounted trigger 30 is connected by a pivot pin 31 near its top to the upper end of the pistol grip. The rear surface of the trigger 30 abuts against the toggle 32 of the switch 25 such that moving the trigger rearwardly causes the toggle to move rearwardly and thereby turn on the current flow to the motor. As explained more fully hereinafter, the direction of this current flow is controlled by the switch 24, the toggle 34 of which extends rearwardly from the rear wall 35 of the switch housing. Both switches are secured to the switch housing by threaded sections of the switch casings which extend through apertures in the switch housing and have nuts threaded thereon. These switches are both enclosed within separate sealed switch housings which are filled with a light oil such a Fluralube. When properly filled, the switches can withstand and are fully operational at water depths of 1000 feet where they are exposed to pressures of approximately 500 pounds per square inch. Electrical leads into the switch cavity 49 pass inwardly through a depending annular lug 40 of the pistol grip into and through a depending tube 41 of the switch housing. This tube, after having had the electrical leads passed therethrough, is closed and sealed by filling with a resinous epoxy material or so-called potting material 43.

The switch housing 26 and end cap 44 of the motor 23 are a unitary die cast unit. This unit is attached to the pistol grip by a series of screws (not shown).

The switch cavity 49 of the switch housing 26 is closed by rear portion 50 of the carrying handle 14. This section of the handle is secured to the switch housing by a series of small screws 51 and a pair of larger screws 52. At its forward end, the handle is secured to the gear housing 16 by four screws 53. Between the middle section 54 of the handle and the motor housing 11 there is a space or open area 55 through which a person's fingers may be inserted so as to grip the tool and facilitate its being carried from area to area.

Between the bottom surface of the carrying handle 14 and the top surface 56 of the switch housing 26, there is an O-ring-type seal (not shown). This seal secures the cavity 49 against the ingress of water even at pressures up to 500 pounds per square inch.

The rear end cap 13 of the housing is made from anodized aluminum and has an annular flange 60 extending forwardly therefrom. It also has an annular channel 61 formed therein which receives the rear of the windings of the stator 23. Additionally, it has a central cup-shaped recess 62 formed therein which receives the end sections 63 of the rotor. The center of this cup-shaped recess has a counterbored aperture 64 therein within which a graphite bearing 65 is press fit. This bearing receives and supports the rear end section 22 of the motor rotor shaft 21.

As may be seen most clearly in FIG. 2, the annular recess 61 of the rear end cap is connected to the open chamber 49 of the switch housing by an interconnecting channel 66 through which epoxy-potting material is inserted to fill the area around the rotor, as explained more fully hereinafter.

The anodized aluminum front end cap 15 consists of a central hub 70 surrounded by a generally annular body 71. Within this body 71, there is an annular channel 72 which receives and supports the front end windings of the stator 23. At the center of this cap is a hole 74 through which the front end of the stainless steel rotor shaft protrudes. A graphite bearing 75 mounted within the central hub section 76 of the gear housing 16 supports the front end of the shaft 21. This hub section 76 of the gear housing is located within the central aperture 74 of the front end cap.

The anodized aluminum gear reduction unit housing 16 is generally hollow and supports three stainless steel shafts for rotation therein. Two of these shafts 19 and 20 extend through the front plate 17 and act as the output drive shafts of the tool 10. The third shaft 80 (FIG. 3) is a stub shaft which supports an intermediate gear thereon. The rear ends of each of these shafts are supported by graphite bearings 83 press fit into the rear wall of the housing 16. Similar graphite bearings 85 mounted in the front cover plate 17 support the forward ends of these shafts 19, 20 and 80.

The input drive gear to the gear reduction unit is a small stainless steel spur gear 88. This gear is operative to drive a larger intermediate gear 89 keyed to the output shaft 19. The

intermediate gear **89** is made from an acetal plastic such as a plastic sold under the trademark Delrin by E. I. DuPont de Nemours and Company.

A small stainless steel output gear **90** is also keyed to the shaft **19** within the housing **16**. This gear **90** is operative to drive an intermediate acetal plastic gear **93** (FIG. 3) mounted upon the idler shaft **80**. The gear **93** is in turn operative to drive a stainless steel output gear **94** which is in turn keyed to the output shaft **20**.

As will now be readily apparent, rotation of the rotor and rotor shaft **21** of the motor results in rotation of the output gear **88** keyed thereto. So long as the gear **88** is rotated, all of the other gears and both of the output shafts **19** and **20** will be correspondingly rotated but through a lesser number of turns as determined by the gear reduction ratio of the gears **88, 89, 90, 93** and **94**.

The outer ends of the shafts **19** and **20** are preferably square in configuration so as to facilitate mounting of sockets, cutting tools, drilling tools, etc., thereon in a driving relationship.

The tool of this invention is adapted to be used with an impacting tool such as a paint chipper or an impacting-type drill. To this end, the front cover plate **17** has a pair of spaced transverse apertures **95, 96** extending therethrough (See FIG. 4). These apertures are intersected by a transverse aperture **97** which extends through the bottom portions of these apertures **95, 96**. A locking shaft **98** is rotatably mounted within the aperture **97** and has a pair of slots **99, 100** milled therefrom. At one end, a coil spring **101** surrounds the shaft so as to secure it against inadvertent movement in an adjusted position. At the other end, a detent **104** positioned knob **102** is nonrotatably mounted upon the shaft so that axial movement and rotation of the knob effects rotation of the shaft **97**. The shaft is limited in its axial movement in the aperture **98** by a washer **92**. A screw **103** extends through the washer and is threaded onto the end of the shaft.

When the portable tool **10** is to be used with an impacting rather than a rotary tool, the impacting unit is mounted on the end of the tool by inserting three prongs of the impacting tool into the apertures **95, 96**, and an upper aperture **105** in the front of the handle **14**. When so mounted, a drive unit of the impacting tool connects to the rotary shaft **19** so that rotary motion of the shaft **19** is converted into axial or a combination of axial and rotary movement of the tool. The locking shaft **97** enables the impacting tool to be locked onto the front end of the unit by rotating the shaft after insertion of two of the prongs **110** of the impacting unit into the apertures **95** and **96**. This rotation of the shaft **97** causes the lower portions **107, 108** of the shaft **97** to be moved upwardly into recesses **109** of the prongs **110**.

To assemble the unit illustrated herein, the rotor is first produced by mounting a multiplicity of thin soft steel plates over the rotor shaft **21**, as is conventional in AC motors. Thereafter, the rotor is chrome plated on its periphery so as to protect the very corrosive soft steel of the rotor against the corrosive effects of the salt water. The body of the housing is then assembled by mounting the end cap **13** over the end of the stator. A thin stainless steel sleeve **111** is then mounted over a mandrel and the mandrel is inserted into the central aperture of the stator. The end cap **15** is then mounted over the stator. The cavities of the stator and end caps are then filled with an epoxy resin-potting material, thereby making the stator, end caps and sleeve **111** a rigid unitary subassembly when the mandrel is subsequently removed. The exterior of this subassembly is then coated with epoxy resin after which the thin anodized aluminum sleeve **11** is placed over the stator and end cap assembly. The stator windings are then completely encased in epoxy. Since the stator is the only current-carrying component of the motor, all of the current-carrying components are then insulated from the tool casing.

With this construction, the epoxy-encased stator forms a structural portion of the portable tool. The thin anodized aluminum motor housing sleeve **11** only protects the motor against corrosion and the admission of water into the stator. It does not serve as a structural or rigidifying element in the assembly. This construction minimizes the weight of the unit by relying upon the motor stator to provide the structural rigidity of the housing assembly.

Thereafter, the graphite bearing **65** is mounted within the end cap **13** and the rotor is assembled onto the stator. The gear housing and handle section of the tool are thereafter attached to the body and the assembly completed.

Referring to FIG. **5**, there is illustrated the electrical circuit diagram which enables this unit to be used safely underwater while water circulates through the unsealed bearings and between the motor stator and rotor. Referring now to this FIG., it will be seen that the running windings of the stator are designated by the numeral **113** and the starting windings are designated by the numeral **115**. The running windings **113** are connected to two leads **116** and **117** of a 120-volt single phase AC power supply. Lead **117** includes a relay **119** and the contacts of the on-off control switch **25**. Lead **116** has a tapoff lead **121** connected to a contact **123** of reversing switch **24**. This reversing switch **24** has a contact **125** connected to a capacitor **124**. Contacts **123** and **125** are connected to contacts **129** and **131**, respectively. Also located within the reversing switch **24** are contacts **133** and **135**. Depending upon the position of switch **24**, the contacts **133** and **135** are either connected to the contacts **129** and **131** or to the contacts **123** and **125**. One position of the switch **24** causes the capacitor **124** to be connected to one side of the starting windings so as to effect rotation of the rotor in one direction and the opposite position of the switch causes the capacitor **124** to be connected to the opposite side of the starting windings **115** for rotation of the rotor in the opposite direction.

When the on-off control switch **25** is thrown, a high rush of current through the current-sensitive relay **119** pulls in the contacts **137, 139** and bridges the capacitor **127** into the starting circuit. Thereafter, as the rotor approaches synchronous speed, the contacts **137, 139** of the relay **119** drop out the starting windings.

The leads **116** and **117** pass through an annular differential transformer core **144** and make one or more wraps around the transformer core. A sensing and test circuit **146** is connected by a pair of leads **140, 141** to a multiple wrap secondary winding **145** around the differential transformer core **144**. The differential current transformer **143** totalizes the magnetomotive force produced by the identical primary windings which excite the magnetic core **144**. So long as the circuit is normal and has no ground leak, the net flux in the core is zero. If, however, current is diverted to ground on the motor side of the transformer **143**, a flux is produced in the core. This flux induces a voltage in the secondary windings **145** and actuates the sensing and test circuit **146**. This sensing circuit then trips a conventional current breaker **148** so as to cut off all current flow to the tool. A differential transformer type of sensing circuit suitable for use in this application is disclosed in Dalziel U.S. Pat. No. 3,213,321, issued Oct. 19, 1965. This safety circuit is operative to sense as little as 5 milliamps of current leakage and to cut off all current flow to the tool in the event of such leakage in a time period less than 30 milliseconds. This is within the safe range even if the current passes directly through a human body immersed in water.

In addition to this safety trip circuit, the cable **150** to the tool contains a third grounding lead **151**. This lead is connected to a slot milled into the surface of the switch housing cavity **49** after the handle and housing are anodized. Since anodized aluminum is a good dielectric, it is important that this ground lead **151** be connected to the housing after the anodizing so that there is no aluminum oxide between the lead **151** and the housing. Since the cavity **49** is sealed and not exposed to the flow of salt water, the ground contact is not subject to corrosion or oxidation accelerated by exposure to salt water.

To still further protect the human operator of the tool against a short circuit, the cable **150** consists of an outer

sheath 153 of polyurethane material. Located within this outer sheath 153 is a sheath of flexible metal steel armor 154. Within the metal armor 154, the three electrical leads 151, 116 and 117 are individually surrounded by polyethylene sheaths 155. Additionally there may be provided an intermediate sheath of polyurethane surrounding the polyethylene-coated leads. The metal sheath 154 is connected to ground as indicated by the lead 152. With this safety arrangement, if a current leakage path does develop in the tool, in order for the leakage current to be transmitted through the human operator to ground, the current must flow through the tool and into the human operator. In all probability, though, the current will not follow this path because the ground wire 151 and the metal armor cable both offer less resistance to connect the tool to ground than the human operator. Therefore, most of the current flow will be through these alternate paths. In the event, though, that any current does flow through the human operator, its flow is detected by the current leakage differential transformer safety circuit which operates to cut off the current flow before it can pass through the operator for a length of time sufficient to be dangerous to him. Specifically, the safety circuit is operative to cut off current flow in less than 30 milliseconds or two cycles of current in a 60-cycle power supply.

In the diagrammatic illustration of FIG. 5, the armor protective cable 150 is illustrated as being located between the transformer 143 and the power source. In actuality, the transformer 143, safety trip circuit 146 as well as the starting relay 119 and capacitor 124 are all located remotely from the tool, preferably above water. The armored cable 150 then extends from above the water to the tool where it enters through the annular lug 40 at the bottom of the handle. This construction necessitates that there be three electrical leads within the armored cable as well as the ground wire 151. It has the advantage, however, of minimizing the size of the tool unit because the starter relay 119 and capacitor 124 are relatively large electrical components which would otherwise require a relatively large watertight housing as an integral part of the tool.

While only a single preferred embodiment of our invention has been disclosed and described herein, those persons skilled in the arts to which this invention pertains will readily appreciate numerous changes and modifications which may be made without departing from the spirit of our invention. Therefore, we do not intend to be limited except by the scope of the appended claims.

We claim:

1. In combination, a portable electric tool for use underwater by a human operator, and an electrical control circuit for actuating said tool, said combination providing minimal danger of harmful electrical shock to said human operator,

said tool comprising a housing, an electrical drive motor having a stator and a rotor, and an output shaft, said stator being fixedly mounted within sad housing, said rotor being operatively connected to said output shaft, said housing having passages therein to permit the flow of water between said stator and rotor,

said electrical control circuit being operatively connected to windings of said stator so as to supply electrical current to said windings, said control circuit including a current leakage responsive trip circuit operative to cut off current to said stator in the event of a leakage current of a magnitude potentially harmful to said human operator when underwater, said trip circuit having a response time less than the cycle time required for current to build to a level harmful to said human operator in the event of said current leakage.

2. The combination of claim 1 wherein said trip circuit is responsive in less than 30 milliseconds to cut off current flow completely in the event of current leakage as small as 5 milliamps.

3. The combination of claim 1 wherein said trip circuit includes a differential transformer to detect said current leakage.

4. The combination of claim 1 wherein said trip circuit comprises a differential transformer connected in series with windings of said stator, said transformer being operative to control a relay, said relay having contacts in the circuit to said stator windings, said contacts being so connected to said control circuit that a current leakage through said portable tool is operative to deenergize said relay, open said relay contacts, and cut off all current to said portable tool.

5. In combination, a portable electric tool for use underwater by a human operator and an electrical control circuit for actuating said tool, said combination providing minimal danger of harmful electrical shock to said human operator,

said tool comprising a tool housing having an electric motor mounted therein, said motor comprising, a stator and a rotor, said stator being fixedly mounted within said housing and electrically insulated therefrom, said rotor being supported by said housing for rotation within said stator, said rotor being operatively connected to an output shaft, said housing having passages therein to permit the flow of water between said stator and rotor,

said electrical control circuit being operatively connected through an on-off control switch to windings of said stator so as to supply electrical current to said windings through at least two electrical leads, said switch being mounted within said tool housing, said control circuit including a current leakage responsive trip circuit operative to cut off current to said tool in less time than 30 milliseconds in the event of a ground current leak of as little as 5 milliamps in said portable tool.

6. The combination of claim 5 wherein said tool housing is made from anodized aluminum and said output shaft is made from stainless steel, said shaft and said housing being separated by nonmetallic bearings.

7. The combination of claim 5 wherein said switch is mounted within a switch housing, said switch housing being filled with liquid so as to preclude high underwater pressures from affecting the operation of said switch.

8. The combination of claim 5 which further includes a third lead connected at one end to said tool housing and at the other end to ground near the source of power supply to said two electrical leads.

9. The combination of claim 5 wherein said two electrical leads are surrounded by a dielectric material, said dielectric material covered leads being surrounded by a metal sheath which is connected at one end to said tool housing and at the opposite end to a ground near the source of power supply to said lead.

10. The combination of claim 9 wherein said metal sheath is surrounded by a dielectric material sheath.

11. The combination of claim 10 wherein the dielectric material surrounding said electrical leads is polyethylene and the dielectric material surrounding said metal sheath is polyurethane.

12. In combination, a portable electric tool for use underwater by a human operator and an electrical control circuit for actuating said tool, said combination providing minimal danger of electrical shock to said human operator,

said tool comprising an anodized aluminum housing having an electric motor mounted therein, said motor comprising a stator and a rotor operative to drive an output shaft, said stator being fixedly mounted within said housing and electrically insulated therefrom by a resinous potting material completely encasing the windings of said stator, said rotor being rotatably mounted within said stator, said rotor including a rotor shaft supported for rotation within said housing, said housing having passages therein to permit the flow of water between said stator and rotor,

said electrical control circuit including a pair of electrical leads connected through an on-off switch to windings of said stator so as to supply electrical current to said windings, said switch being mounted within said housing, said electrical leads being surrounded by a sheath of dielectric material, said dielectric material surrounded leads being encased in a flexible metal sheath, and said

flexible metal sheath being encased in a sleeve of dielectric material.

13. The combination of claim 12 wherein said flexible metal sheath is connected at one end to said housing and is grounded at the opposite end near the source of electrical current to said lead.

14. The combination of claim 12 wherein said rotor shaft is made from stainless steel.

15. The combination of claim 12 wherein said shaft is supported by nonmetallic bearings.

16. The combination of claim 12 wherein said on-off switch is mounted within a sealed switch housing, said switch housing being filled with liquid so as to enable said switch to operate in environmental pressures up to 500 pounds per square inch.

17. The combination of claim 12 wherein all of the components of said tool other than the bearings are made from anodized aluminum or stainless steel, and the metal components made from different materials are only placed in contacting relationship over very small areas so as to minimize galvanic corrosion.

18. The combination of claim 12 which includes a third electrical lead mounted within said flexible metal sheath, said third electrical lead being electrically connected at one end to said tool housing and being electrically connected at the other end to ground near the source of power supplied to said two electrical leads.

19. The combination of claim 18 which further includes a current leakage trip circuit operative to cut off all current flow to said tool in less than 30 milliseconds in the event of a ground current leak of as little as 5 milliamps in said portable tool.

20. The combination of claim 19 wherein said current leakage responsive trip circuit includes a differential current transformer operable to detect current leakage in the control circuit.

21. The combination of claim 12 wherein

said housing comprising a handle grip, a switch enclosure, a pair of end caps and a motor-enclosing sleeve,

said stator is located within said housing sleeve and between said pair of end caps, said stator including current-carrying electrical windings, said windings being encased in a resinous potting material and thereby separated and electrically insulated from said sleeve and end caps, and

said rotor is supported upon a stainless steel rotor shaft, said rotor shaft being supported for rotation upon nonmetallic bearings within said housing.

22. The combination of claim 21 wherein said bearings are made from graphite.

23. The combination of claim 21 wherein said switch is enclosed within a sealed switch housing, said sealed switch housing being filled with liquid so that said switch is insensitive to pressures up to 500 pounds per square inch.

24. The combination of claim 21 which further includes a gear reduction unit mounted upon one end of said housing and secured to one of said end caps, said gear reduction unit comprising an input gear operative to drive at least one output shaft through a series of gears, said output shaft and said rotor shaft being made from stainless steel and supported for rotation within nonmetallic bearings.

25. The combination of claim 24 wherein at least one of the gears located within said gear reduction unit is made from acetal plastic.

26. The combination of claim 21 wherein a stainless steel sleeve is secured to the interior of said stator.

27. The combination of claim 26 wherein water flow passages are provided to enable water to flow between said rotor and stator.

28. The combination of claim 27 wherein said motor is a capacitor start type of induction motor.

29. The combination of claim 21 wherein said stator is surrounded by a thin-walled aluminum sleeve, said sleeve having sufficient rigidity and strength to support said stator, the rigidity of said tool between said end caps being provided by said electrical motor and primarily by said resinous potting material surrounding said stator.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,579,037 Dated May 18, 1971

Inventor(s) D. J. Hackman et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Please correct the assignee of this patent to read:
-- F. L. Cappaert d/b/a Cappaert Enterprises --
as recorded in the Patent Office on October 29, 1970, at Reel 2659, Frames 392 and 393.

Column 1, line 24, after "source", change "nd" to -- and --.

Column 1, line 33, after "too", change "through" to -- though --.

Column 1, line 48, after "100", add -- ,000 -- (to make it read "100,000").

Column 7, line 55, change "sad" to -- said --.

Signed and sealed this 21st day of December 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patents