Sept. 15, 1970 C. C. BROWN 3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

Filed Aug. 21, 1968 6 Sheets-Sheet 1

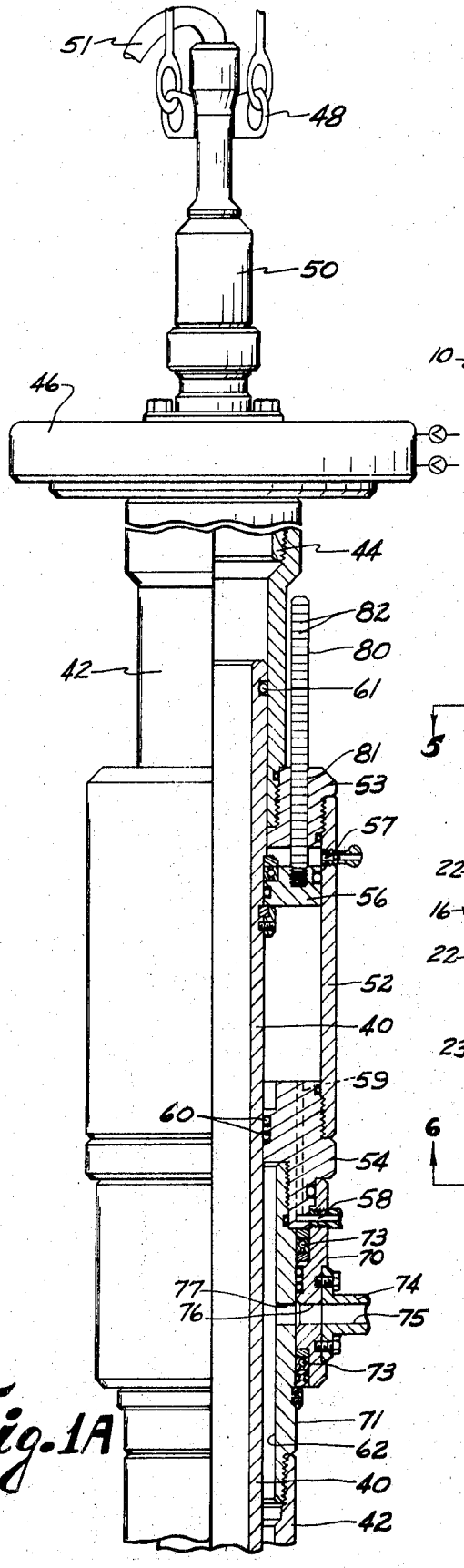

Fig. 1A

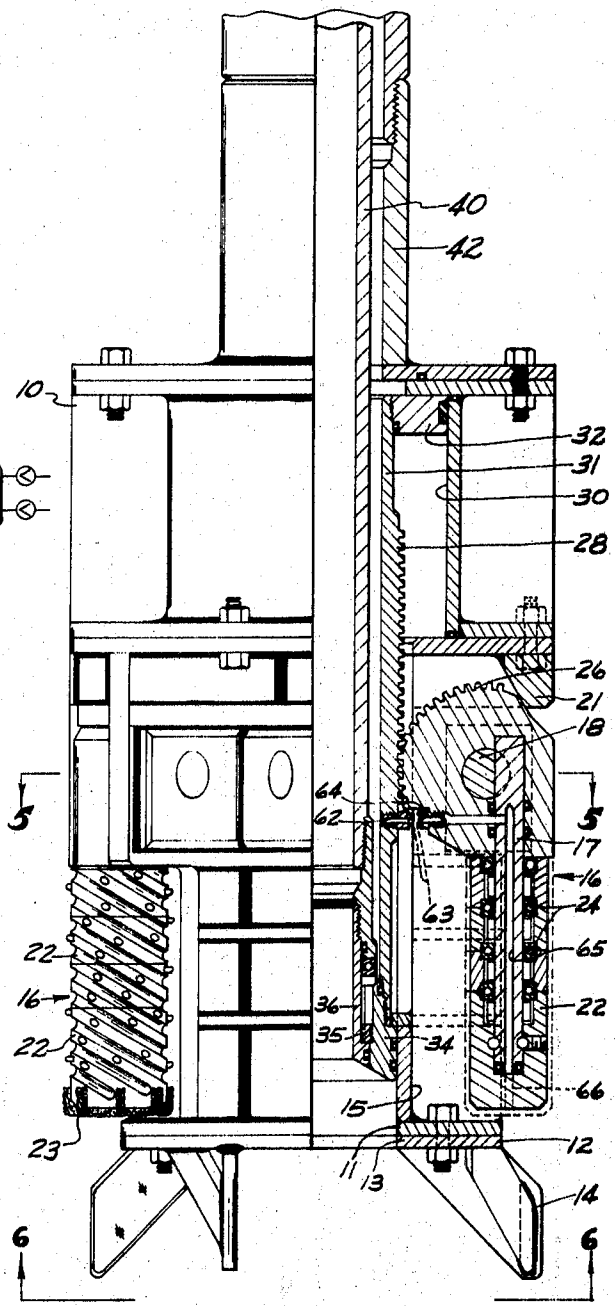

Fig. 1B

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Sept. 15, 1970 C. C. BROWN 3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

Filed Aug. 21, 1968 6 Sheets-Sheet 2

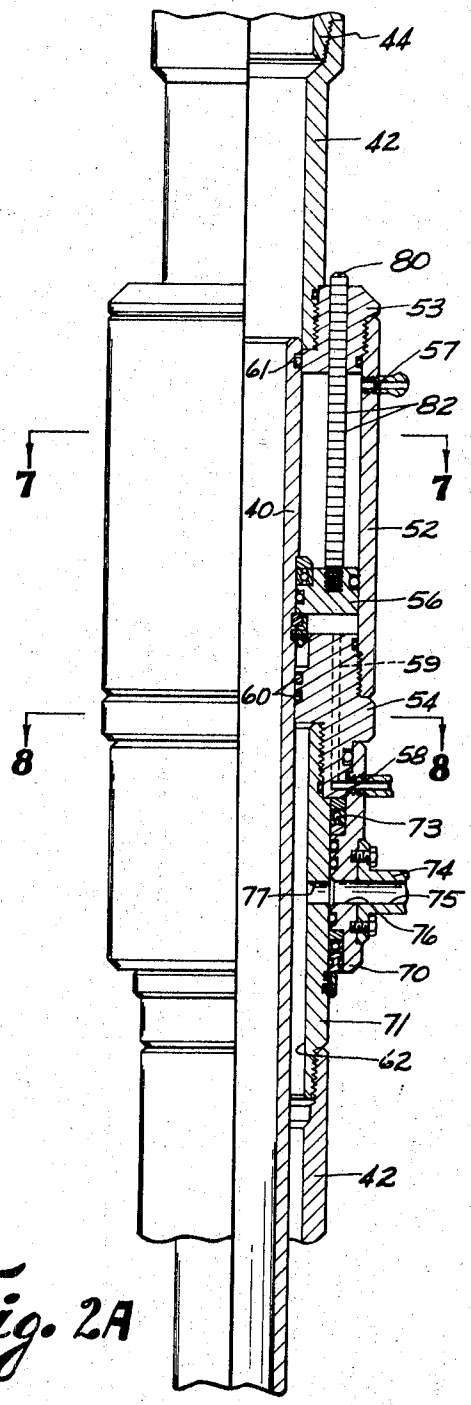

Fig. 2A

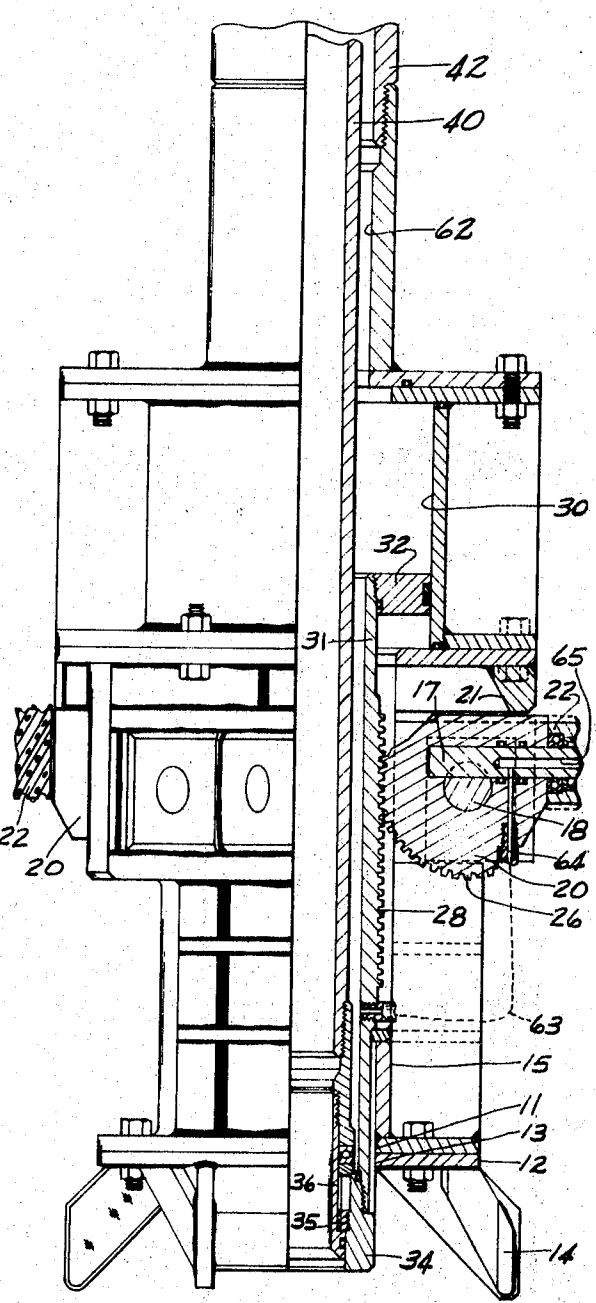

Fig. 2B

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Sept. 15, 1970 C. C. BROWN 3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

Filed Aug. 21, 1968 6 Sheets-Sheet 3

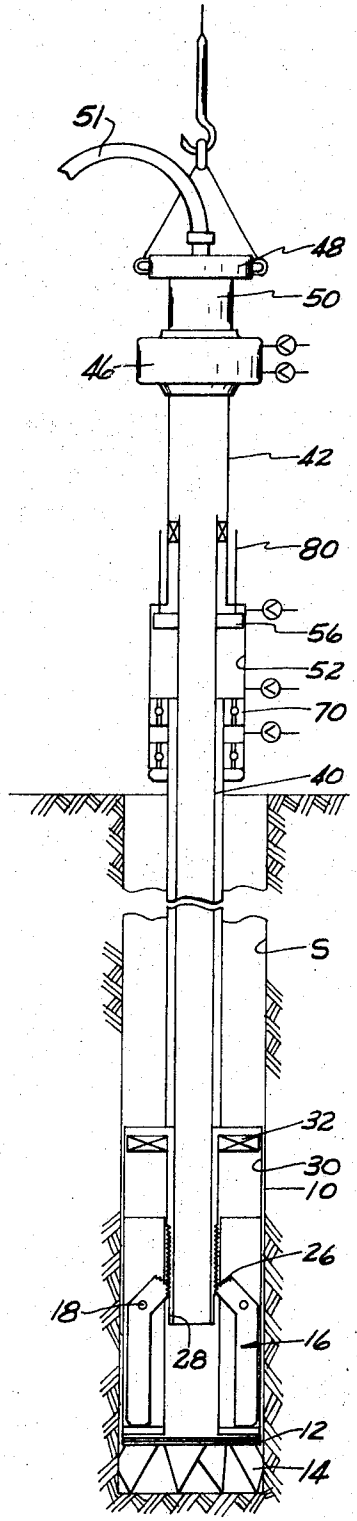
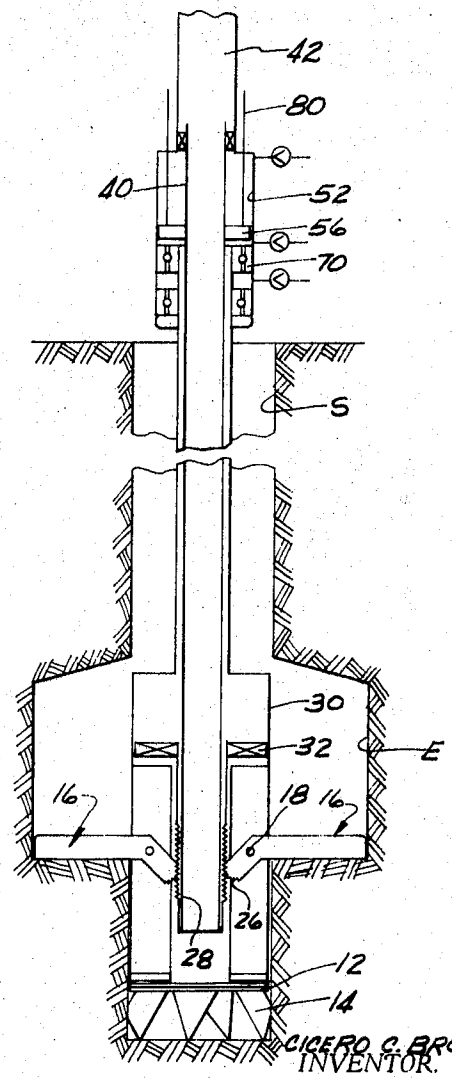


Fig. 3

Fig. 4



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Sept. 15, 1970 C. C. BROWN 3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

Filed Aug. 21, 1968 6 Sheets-Sheet 4

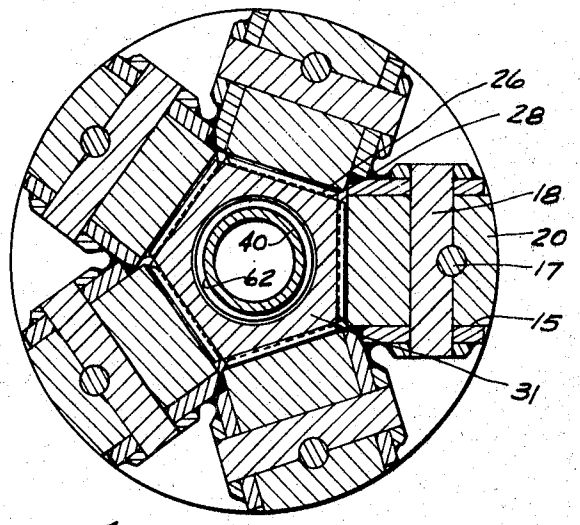

Fig. 5

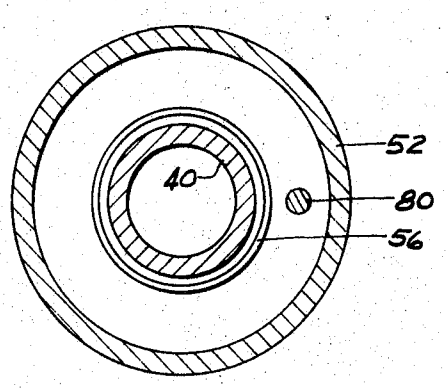

Fig. 7

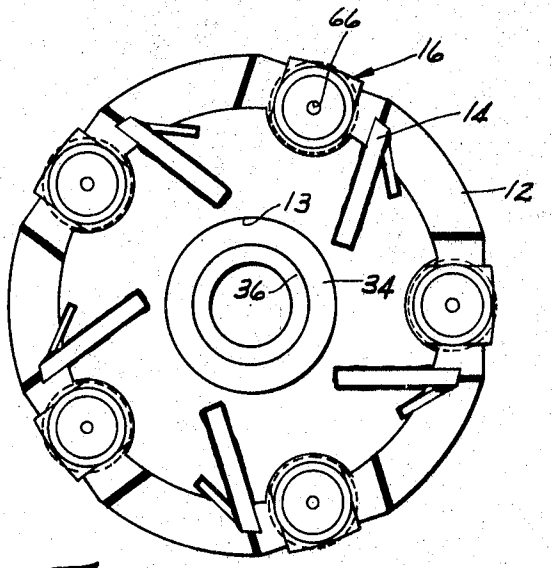

Fig. 6

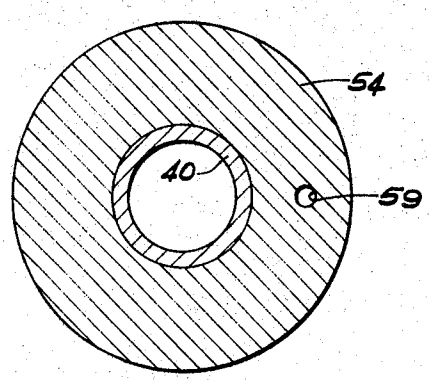

Fig. 8

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Sept. 15, 1970 C. C. BROWN 3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

Filed Aug. 21, 1968 6 Sheets-Sheet 5

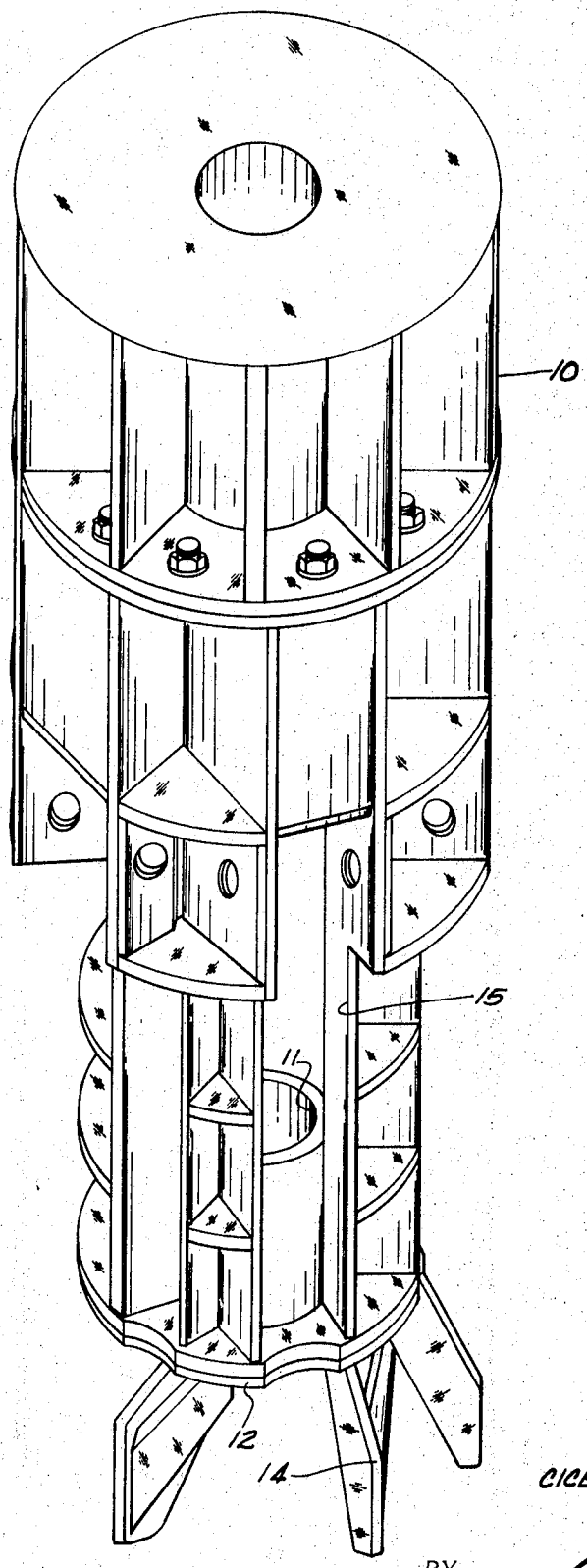

Fig. 9

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Sept. 15, 1970 C. C. BROWN 3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

Filed Aug. 21, 1968 6 Sheets-Sheet 6

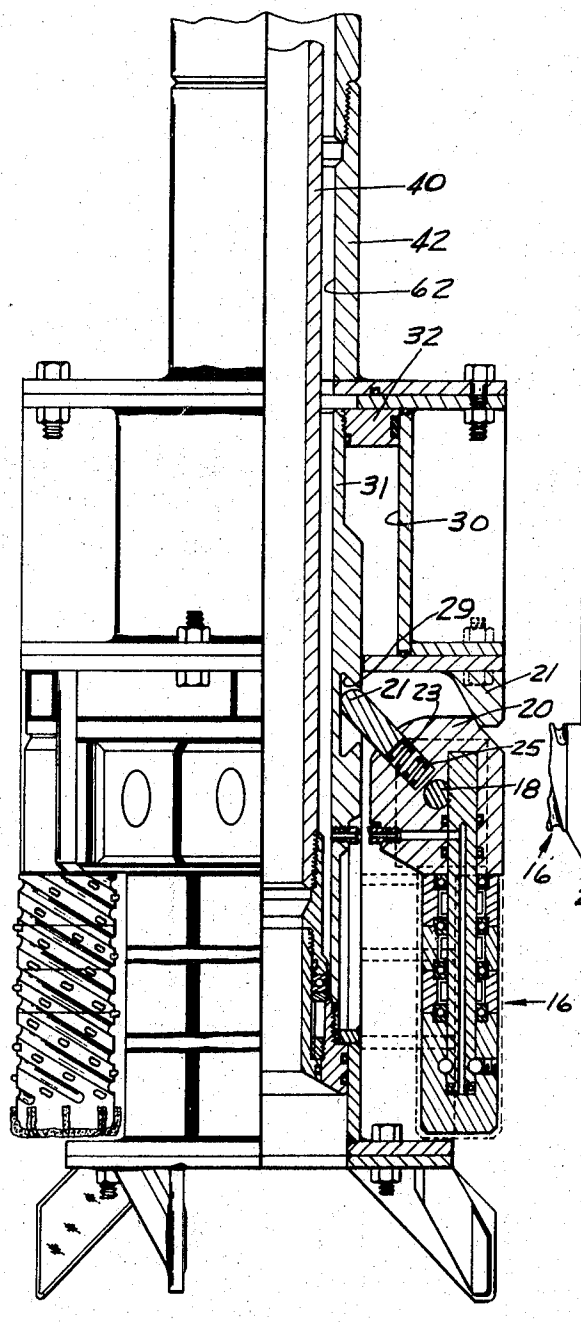

Fig. 10

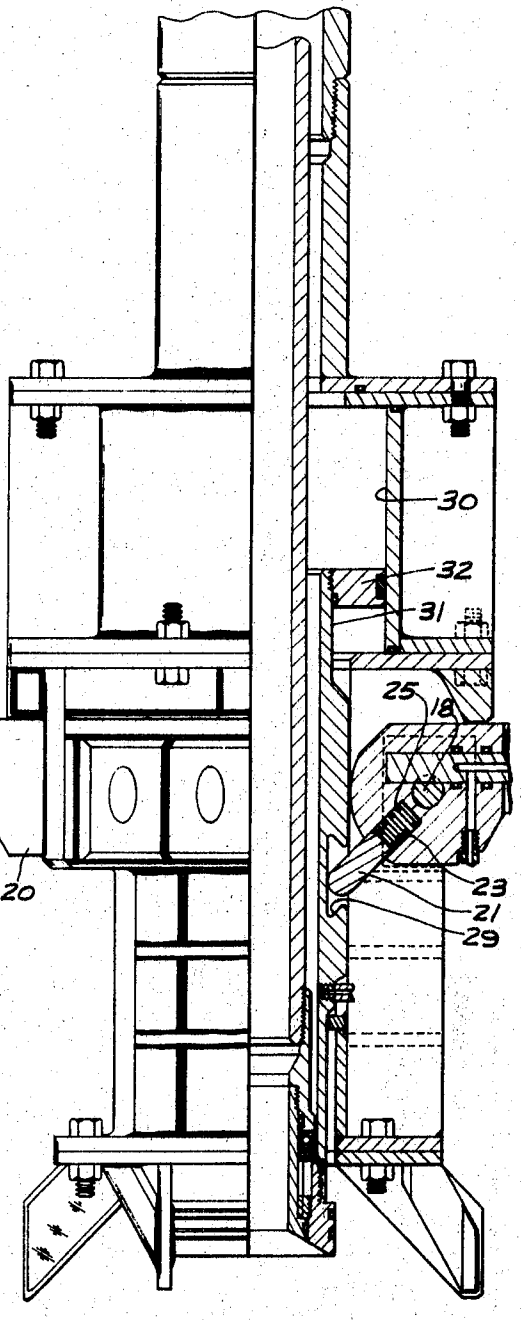

Fig. 11

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United States Patent Office 3,528,516 Patented Sept. 15, 1970

3,528,516

EXPANSIBLE UNDERREAMER FOR DRILLING LARGE DIAMETER EARTH BORES

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Int. Cl. E21b 9/26
U.S. Cl. 175—267 9 Claims

ABSTRACT OF THE DISCLOSURE

A rotary drilling tool comprising expansible underreamer elements designed especially for enlarging a large diameter shaft at a selected and great depth in the earth to provide a subterranean room or section of greatly enlarged diameter. The tool includes means at the surface for actuating the underreamer elements and for providing an indication of the extent of radial expansion of the latter as a measure of the diameter of the enlarged section.

In recent years, it has become necessary to open large diameter bore or shafts in the earth for various purposes, as for missile silos, mine shafts, and in the case of the Atomic Energy Commission, for access to deep subterranean cavities in which test explosions of atomic devices may be effected. In the latter case particularly, as the test firings must be conducted at depths great enough to assure effective and safe confinement of the forces of the explosions, it has become a matter of great difficulty and expense to provide the required enlarged cavities at the requisite depths. Transporting men, machines and materials through the main shaft to the work area, protecting them while carrying on the work, and removing the cuttings, necessarily involve such difficult, expense and hazard that some more practical way was required.

While large diameter drill bits have now been developed by means of which vertical bores of adequate diameter may be drilled to the desired depths, no practical means has heretofore been devised to provide the requisite enlarged cavities at the desired depth without employing men at the bottom of the hole to provide the desired enlargement.

As an example of the situation which is involved in providing a deep subterranean cavity or "room" for purposes required by the Atomic Energy Commission, the problem involves providing a "room" of from 15 to 30 feet in diameter at depths of the order of from 5000 to 8000 feet or more. While it is possible with presently available drilling equipment to drill a vertical bore or shaft of about five or six feet in diameter to the projected depth through rock formations, no reasonably practical machines or methods have heretofore been available to provide the desired enlargement at the bottom or at such depths as those mentioned.

Accordingly, the present invention has for its primary objects the provision of a tool which may be operated from the surface of the ground through a previously drilled shaft to enlarge a section of the shaft at any selected depth to greatly expand dimensions, which obviates the need for employing men inside the shaft; and which greatly reduces the time, cost, and labor for providing desired subterranean cavities at great depths which in some instances, may be as much as several thousand feet.

The tool in accordance with the present invention comprises a tubular body dimensioned to pass freely through a previously drilled shaft and adapted to be mounted on the lower end of a string of pipe which may be rotated from the surface to serve as a rotary drill string. The tool body carries a plurality of angularly spaced underreamers, comprising arms pivotally mounted for radial retraction and extension to the radial dimensions desired. The arms

carry roller-type cutters for grindingly engaging and undercutting the wall of the shaft. The underreamers are actuated from the surface by means of an actuating stem comprising a string of pipe of smaller diameter than the rotary drill string and mounted therein for limited longitudinal movement. Means are provided to form a lever-acting drive connection which is arranged between the lower end of the actuating stem and the pivoted underreamer arms to radially extend and retract the underreamers in response to longitudinal movement of the actuating stem.

The latter is connected to a fluid pressure-operated means by which the desired longitudinal movement of the actuating stem is effected. Generally the fluid pressure-operated means will be employed to raise the actuating stem in order to retract the underreamers, while the weight of the actuating stem will function as the principal force for extending the underreamers. The fluid pressure-operated means may be employed to supplement the expansive force supplied by the weight of the actuating stem.

The tool also includes an indicating device connected to a moving element of the fluid-operated means arranged to provide an indication of the extent of radial expansion of the underreamers to thereby provide at the surface a measure of the diameter of the enlarged section being cut by the underreamers.

Other and more specific objects and advantages of this invention will become more readily apparent from the following detailed description when read in conjunction with the accompanying drawing which illustrates useful embodiments in accordance with this invention.

In the drawing:

FIGS. 1A and 1B, together, comprise a longitudinal, partly sectional view of one embodiment of the underreaming tool and operating elements in accordance with this invention, showing the underreamer parts in the retracted or unactuated positions;

FIGS. 2A and 2B, together comprise a view similar to FIGS. 1A and 1B, showing the parts with the underreamers fuly extended;

FIG. 3 is a generally diagrammatic view showing the string of tools constituting the underreamer system being lowered into a bored shaft;

FIG. 4 is a view generally similar to FIG. 3 showing the enlargement of the shaft produced with the tool;

FIG. 5 is a cross-sectional view taken along line **5—5** of FIG. 1B;

FIG. 6 is an end view, looking upwardly, along line **6—6** of FIG. 1B;

FIGS. 7 and 8 are cross-sectional views taken along lines **7—7** and **8—8**, respectively, of FIG. 2A;

FIG. 9 is a perspective elevational view of the underreamer body; and

FIGS. 10 and 11 are fragmentary, partly sectional views generaly similar to the corresponding portions illustrated in FIGS. 1B and 2B, respectively, showing a modification of the underreamer actuating connection.

Referring to the drawing, the tool includes a generally tubular body **10** having a central bore **11**. Body **10** is of necessarily massive construction, being fabricated from suitably thick plates and tubes properly buttressed and reinforced, as illustrated particularly in FIG. 9, to provide a structure which will withstand the relatively large forces developed in its operation. An annular bit head **12** may be secured to the lower end of body **10** and has a central opening flush with the bore of the body. Bit head **12** is provided with a plurality of spaced blade-type cutters **14** and may be employed as a pilot bit or scraper to clear obstructions and scrape the wall of the shaft through which the tool is to be passed.

Body **10** is fabricated to provide a plurality of angularly spaced longitudinal pockets **15** to confine the re-

tracted underreamers, designated generally by the numeral **16**. Each of the underreamers **16** comprise a tubular shaft **17** pivoted for swinging movement about a pivot pin **18** journalled transversely of pockets **15** in the walls defining the respective pockets. The inner end of each of the underreamer shafts **17** is provided with an angular extension **20** which forms a lever or crank by which shaft **17** may be swung radially outwardly and inwardly about pivot pin **18**. Cutters **22**, of generally cylindrical shape, are mounted on each of the underreamer shafts **17** for rotation about the shaft on suitable bearings **24**. The outer ends of the shafts are also enclosed by end cutters **23**. The free end of crank **20** is cut to form a sector gear **26** which is adapted to mesh with a toothed rack **28** mounted on a sleeve **31** for longitudinal movement in bore **11** of the tool body. The upper end of bore **11** is enlarged to form a cylinder **30** in which is slidably mounted an annular piston **32** secured to the upper end of rack sleeve **31**. The lower end of sleeve **31** is secured to a sealing collar **34** having slidable sealing engagement with the wall of bore **11**. Collar **34** is threadedly connected internally to a nut **35** having a longitudinally splined connection to a tubular sleeve **36** which forms an extension of the lower end of a tubular actuating stem **40** which extends into bore **11** of the tool body. Upward swinging movement of the underreamers will be limited to the horizontal by stop lugs **21** mounted in the upper ends of pockets **15**.

The upper end of body **10** is connected to a tubular operating string **42**, the upper end of which is connected to a drive spindle **44** driven by a suitable rotary drive means such as a fluid pressure operated drive head **46** suspended from a conventional derrick or other hoist structure (not shown) by means of a swivel **50**. Drive head **46** may be of any known form, but is preferably a power sub of the kind illustrated and described in my copending application Ser. No. 736,179, filed June 11, 1968, now Pat. 3,467,202.

Actuating stem **40** comprises a string of pipe somewhat smaller in diameter than the internal diameter of operating string **42** and extends to a point therein which will be above the surface of the ground when the device is in operation. Stem **40** is movable longitudinally inside the bore of operating string **42** to actuate underreamers **16**. By reason of the connection of the lower end of stem **40** to the lower end of rack sleeve **31**, it will be seen that downward movement of the stem and the rack will cooperate with sector gears **26** to swing the several underreamers radially outwardly of the bore to the positions illustrated in FIG. 2B, while upward movement of the actuating stem will retract the underreamers to the positions shown in FIG. 1B.

A cylinder **52** is installed in operating string **42** at a point a short distance below the upper end of actuating stem **40**. Upper and lower cylinder heads **53** and **54**, respectively, slidably close the opposite ends of the cylinder about the adjacent portion of actuating stem **40**. A piston **56** is slidable inside cylinder **52** and is secured to actuating stem **40** for reciprocation therewith. A port **57** opens through the wall of cylinder **52** at a point above piston **56**, and a second port **58** is connected to lower cylinder head **54** and communicates with a passage **59** opening into the interior of cylinder **52** below piston **56**. Thus, it will be seen that by introducing pressure fluid into the lower end of cylinder **52** through port **58** and passageway **59** and venting through port **57**, piston **56** will be moved upwardly raising actuating stem **40**, while introduction of fluid pressure through port **57** and venting through port **58** will move the piston and actuating stem in the downward direction. Seal packing **60** is provided between lower cylinder head **54** and the exterior of actuating stem **40** and seal packing **61** is provided between actuating stem **40** and the inner wall of operating string **42** at a point above cylinder **52**.

The annular space **62** between operating string **42** and actuating stem **40** below cylinder head **54** forms a passage

for circulating drilling or wash fluid downwardly between the operating string and the actuating stem to a point opposite the underreamers at which water courses **62** (one shown), extending through rack sleeve **31**, are connected by flexible hoses **63** to water courses **64** extending through crank arms **20** and communicating with axial water courses **65** extending lengthwise of underreamer shafts **17** and opening through the ends of cutters **23** through passages **66**. The wash fluid will then return to the surface through the bore of actuating stem **40** and thence through swivels **44** and **50** through a discharge pipe **51**.

To introduce wash fluid into the circulation passages, a collar **70** is mounted about a tubular swivel stem **71** which connects lower cylinder head **54** to the section of operating pipe **42** immediately therebelow. Anti-friction bearings **73**, **73** are disposed between collar **70** and swivel stem **71** so that with collar **70** stationary the swivel stem may rotate relative thereto while operating string **42** is being rotated by power sub **46**. A pipe connection **74** having a central passage **75** is connected to the exterior of collar **70** and registers with ports **76** and **77**, respectively provided in collar **70** and swivel stem **77**. Wash fluid or drilling fluid, which may be liquid or gaseous fluid, may, therefore, be introduced through pipe connection **74** into annular space **62** for circulation during drilling in a generally conventional manner.

An indicating device comprising a cylindrical gauge rod **80** extends slidably through an opening **81** in upper cylinder head **53** and is secured to piston **56**. Gauge rod **80** has a length to project above cylinder head **53** throughout the full length of travel of piston **56** and therefore of actuating stem **40**. Gauge rod **80** will be marked with indicia **82** of any suitable form, which will be calibrated in relation to the angular movement of underreamers **16** so that the indicia on gauge rod **80**, which are visible to the operator, will provide a measure of the extent to which underreamers **16** extend radially at any stage of operations, to thereby provide at the surface a measure of the diameter of the enlarged section being produced by action of the underreamers.

With reference now to FIGS. 3 and 4, in operation, the string of tools will be lowered into a shaft S which has been previously drilled to some predetermined depth. The string of tools, with underreamers **16** in their retracted position (FIGS. 1B and 3), will be lowered through shaft S to the depth at which an enlargement is to be made. Pressure fluid will have been supplied to the lower end of cylinder **52** to elevate piston **56** and thereby hold actuating stem **40** in the elevated position in which the underreamers **16** are maintained in their retracted positions. Rotation of the operating string will now be begun as fluid is vented from beneath piston **56**, thereby allowing the weight of actuating stem **40** to apply a downward force through rack **28** to sector gears **26**, and thence to the underreamers so as to swing the latter outwardly. As the underreamers move outwardly, the cutters thereon will begin to grind away the wall of shaft S and this action will continue until the cutting action of the underreamers and the force applied through the weight of actuating stem **40** will finally swing the underreamers out to the radial distance required to produce an enlarged shaft section of the desired diameter.

FIG. 4 illustrates the positions of the parts when the underreamers have been fully extended and are cutting away an enlargement of the maximum dimensions. It will be understood also that wash fluid will be circulating through collar **70**, washing the cuttings through the bore of the actuating stem to the surface. Obviously, by the position of gauge rod **80**, the operator will be advised at all times of the diameter of the enlargement being made by the underreamers. If it is desired, in cutting an enlargement smaller than the maximum diameter of which the underreamers are capable, the proper angular position of the underreamers may be maintained by controlling the pressure fluid entering and leaving cylinder **52**. It will

also be evident that if the weight of actuating stem **40** should be insufficient to cause maximum extension of the underreamers, additional downward force may be applied to the actuating stem by the introduction of pressurizing fluid above piston **56**.

When drilling of the enlargement is completed to the required depth, the tool string may be raised to disengage the underreamers from the bottom of the enlargement. Then by introduction of pressure fluid into cylinder **52** below piston **56**, the actuating stem may be raised so as to retract the underreamers into pockets **15** and allow the tool string to be withdrawn from the well.

As noted previously, cutters **14** carried by bit head **12** may be employed when running a string of tools into the shaft to scrape the wall thereof and clear out obstructions and also to form a pilot hole in advance of the underreamers, if necessary.

FIGS. 10 and 11 illustrate a modified arrangement which may be substituted for the toothed rack and sector gear structure for swinging the underreamers between retracted and extended positions.

In this modification, toothed rack **28** is replaced on sleeve **31** by an annular dovetail notch **29** and sector gear **26** on each of the underreamers is replaced by a crank pin or slide **21** slidably mounted in a socket **23** disposed in crank arm **20** at a desired angle predetermined to effect the desired range of angular movement of the underreamers **16**. A coil spring **25** biases crank pin **21** outwardly of socket **23**.

With this modification, it will be seen that longitudinal movement of sleeve **31** will cause the end of crank pin **21** to be engaged by one or the other of the edges of notch **29**, which, acting through pins **21**, will then function as levers for swinging the several underreamers about their pivots as in the previously described embodiment. For purposes of this description, the rack and sector gear structure and the notch and crank pin structure are both encompassed by the terms "lever-acting connection," or "lever means."

It will be understood that in running the tool string into and out of the well, sections of operating string **42** and actuating stem **40** will have to be added or removed as required. These operations will be conducted by methods and means well known in the well drilling industry for locating the underreamer at a predetermined depth and for removing it at the conclusion of the shaft enlarging operation.

To exemplify the unusual dimensional and functional characteristics of an underreamer constructed in accordance with the present invention, one model presently under construction will employ a body having a nominal diameter of about 5 feet, 6 inches and underreamers which will be projectable to produce an enlarged shaft section of up to about 21 feet in diameter and of any desired vertical length. This underreamer will be run on an operating pipe string constructed of 13⅜ inch steel drill pipe.

It will be evident that various modifications may be made in the illustrative embodiments within the scope of the appended claims.

What I claim and desire to secure by Letters Patent is:

1. A rotary underreamer for large diameter earth bore, comprising:

(a) a tubular drill string connectible to rotary drive means;

(b) a tubular body secured to the drill string and having a central bore therethrough coaxial with the drill string;

(c) a plurality of angularly spaced underreamers pivotally mounted on the body for movement between retracted and radially extended positions;

(d) a tubular actuating stem extending through the bore of the drill string and movable longitudinally therein;

(e) lever means connecting said stem to said underreamers constructed and arranged to radially extend and retract said underreamers in response to said longitudinal movement, said lever means comprising an annular dovetail groove in the exterior of said actuating stem and crank pins slidably mounted in angular extensions of said underreamers and projecting into said groove; and

(f) fluid pressure actuated means operably connected to said stem to effect said longitudinal movement.

2. A tool according to claim **1** including indicator means operable in response to the longitudinal movement of said actuating stem to provide an indication of the radial extension of said underreamers.

3. A tool according to claim **1** wherein each of said underreamers comprises a cylindrical shaft having an angular extension forming a part of said lever means, and generally cylindrical cutters rotatably mounted on said shaft.

4. A tool according to claim **1** wherein said fluid pressure-actuator means includes:

(a) a cylinder mounted on said drill string to enclose a portion of said actuating stem;

(b) a piston secured to said actuating stem and slidably disposed in said cylinder; and

(c) means for introducing and venting pressure into and from said cylinder at points above and below said piston.

5. A tool according to claim **4** including indicator means connected to said piston and operable in response to the longitudinal movement thereof with said actuating stem to provide an indication of the radial extension of said underreamers.

6. A tool according to claim **1** including a pilot bit secured to the lower end of said body.

7. A rotary underreamer for large diameter earth bores, comprising:

(a) a tubular drill string connectible to rotary drive means;

(b) a tubular body secured to the drill string and having a central bore therethrough coaxial with the drill string;

(c) a plurality of angularly spaced underreamers pivotally mounted on the body for movement between retracted and radially extended positions;

(d) a tubular actuating stem extending through the bore of the drill string and movable longitudinally therein;

(e) lever means connecting said stem to said underreamers constructed and arranged to radially extend and retract said underreamers in response to said longitudinal movement;

(f) fluid pressure actuated means operably connected to said stem to effect said longitudinal movement; and

(g) means for circulating drilling fluid through the tool, including:

an annular space between the operating string and the actuating stem sealed off at longitudinally spaced points;

fluid discharge passages extending longitudinally through said underreamers to the outer ends thereof;

conduit means communicating said annular space with said discharge passages; and

means for introducing drilling fluid into said annular space, the bores of said actuating stem and said operating string defining a conduit for returning said fluid to the surface.

8. A tool according to claim **7** wherein said lever means comprises a toothed rack mounted on the actuating stem and cooperating sector gears mounted on angular extensions of said underreamers.

9. A rotary drilling system for greatly enlarging a section of previously drilled earth bore, comprising:

(a) a tubular drill string;
(b) rotary drive means operably connected to the upper end of said drill string;
(c) a tubular body secured to the lower end of the drill string and having a central bore therethrough coaxial with said drill string;
(d) a plurality of angularly spaced generally cylindrical underreamers mounted for rotation about their respective axes and pivotally mounted on the body for movement between retracted and radially extended positions;
(e) a tubular actuating stem extending concentrically through the bore of said drill string and movable longitudinally therein;
(f) lever means connecting the lower end portion of said stem to said underreamers constructed and arranged to radially extend and retract said underreamers in response to said longitudinal movement;
(g) fluid pressure-actuated means operably connected to said actuating stem to effect said longitudinal movement;
(h) means operable in response to said longitudinal

movement of the actuating stem to provide an indication of the radial extension of said underreamers; and
(i) means for circulating drilling fluid downwardly through the annular space between said actuating stem and said underreamers and back through the bore of said actuating stem to the surface.

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