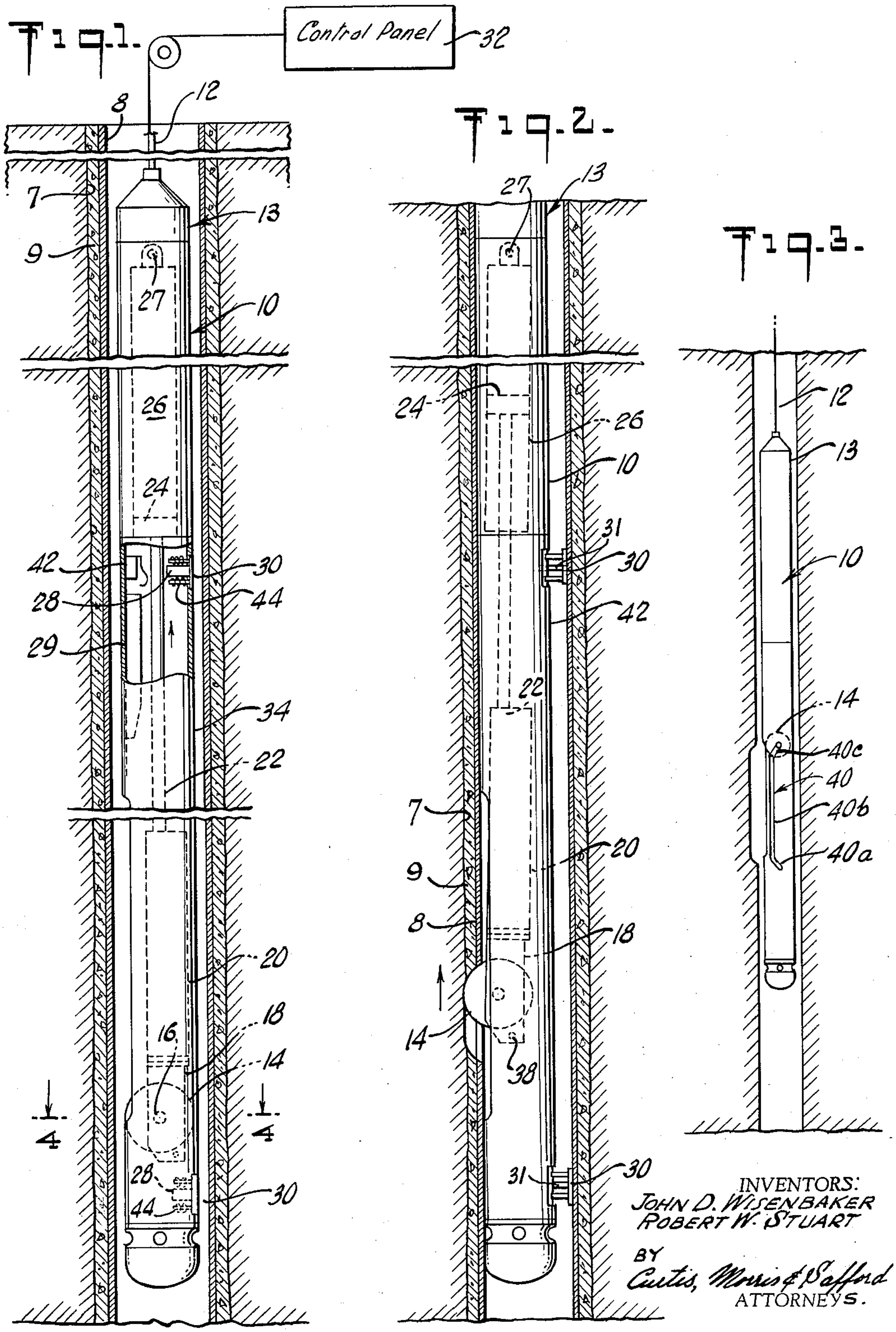
Dec. 28, 1965 J. D. WISENBAKER ETAL 3,225,828

DOWNHOLE VERTICAL SLOTTING TOOL

Filed June 5, 1963 3 Sheets-Sheet 1



INVENTORS:
JOHN D. WISENBAKER
ROBERT W. STUART
BY
Curtis, Morris & Safford
ATTORNEYS.

DOWNHOLE VERTICAL SLOTTING TOOL

Filed June 5, 1963

FIG. 4.

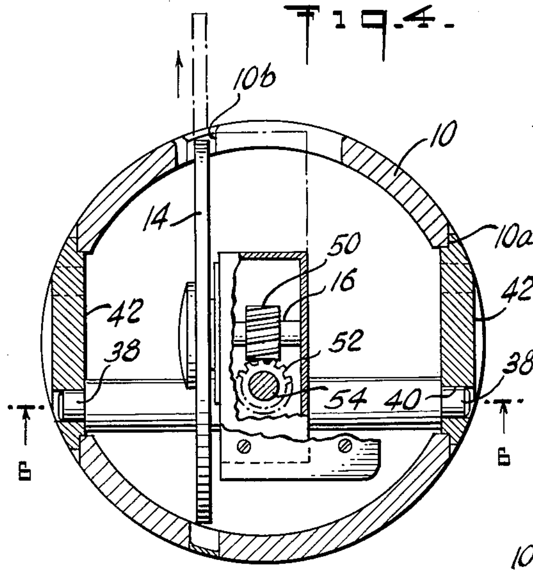


FIG. 5.

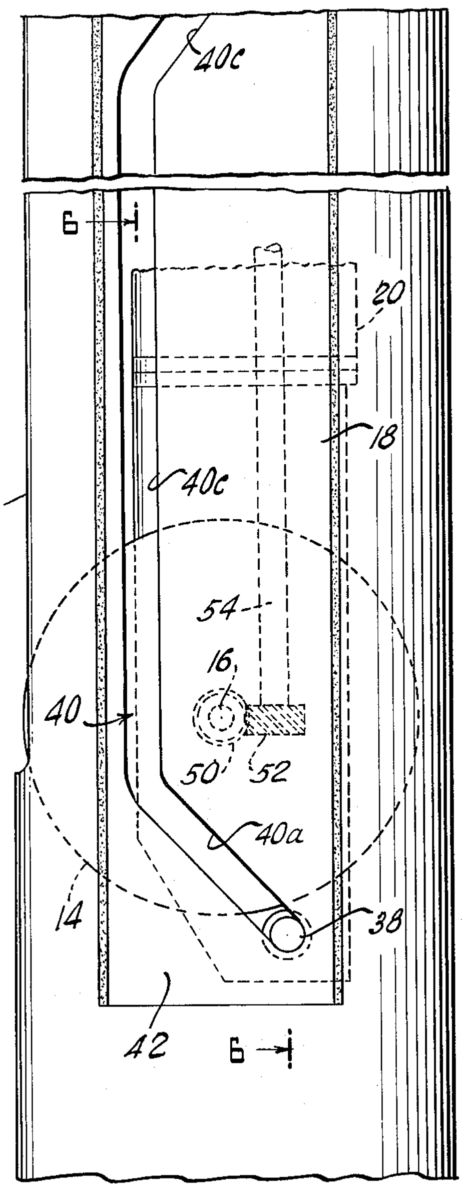
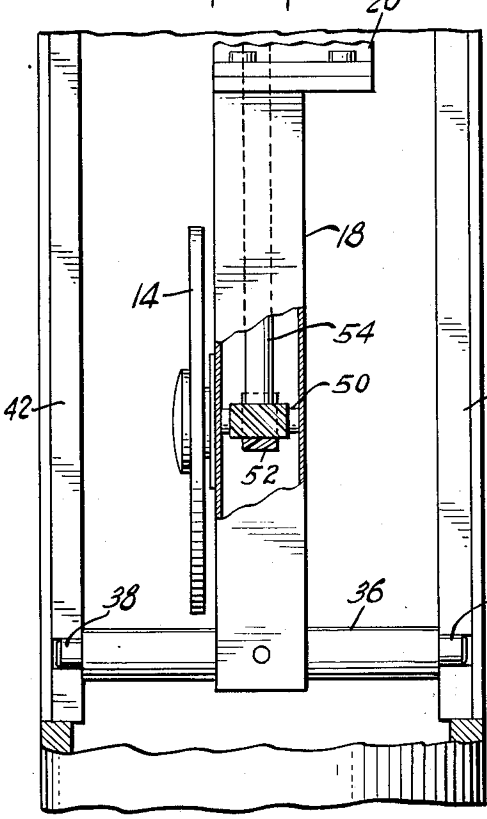


FIG. 6.

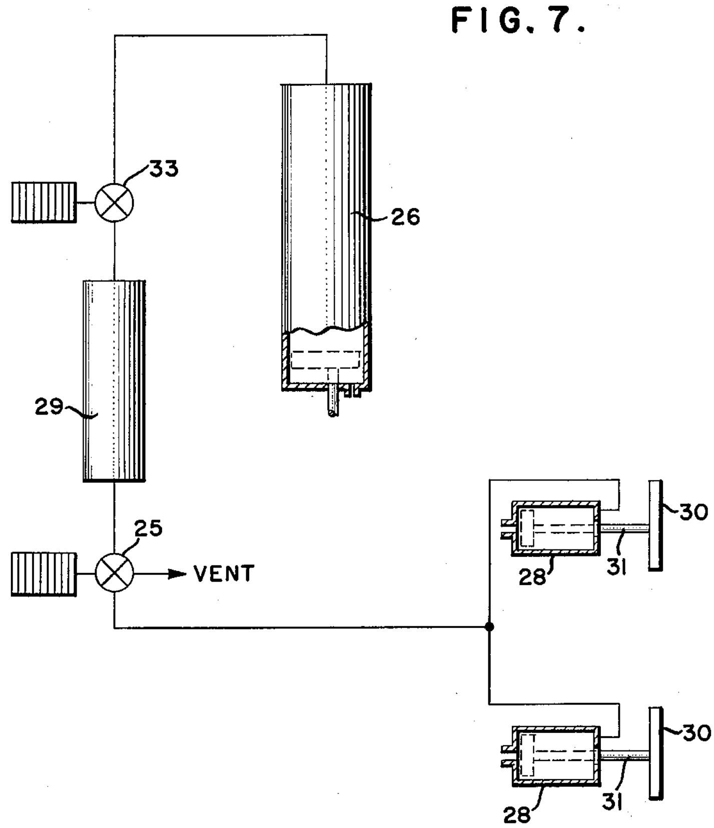


INVENTORS:
JOHN D. WISENBAKER
ROBERT W. STUART
BY
Curtis, Morris & Safford
ATTORNEYS.

DOWNHOLE VERTICAL SLOTTING TOOL

Filed June 5, 1963 3 Sheets-Sheet 3

FIG. 7.



INVENTORS
JOHN D. WISENBAKER
ROBERT W. STUART

BY Curtis, Morris & Safford
ATTORNEYS

United States Patent Office
3,225,828
Patented Dec. 28, 1965

3,225,828

DOWNHOLE VERTICAL SLOTTING TOOL

John D. Wisenbaker and Robert W. Stuart, Dallas, Tex., assignors to American Coldset Corporation, Teterboro, N.J., a corporation of Texas

Filed June 5, 1963, Ser. No. 285,816
7 Claims. (Cl. 166—55)

This invention relates to a tool for making vertical slots in the sidewalls of either cased or uncased well boreholes.

In the drilling and production of oil and gas wells, a vertical slotting tool has many useful applications, most of which relate to the completion of the well for production.

Wells are sometimes completed by setting and cementing casing into the top portion of the producing horizon and leaving the pay zone as "open hole." In most cases the casing extends through all, or a major portion of the productive interval, and cement fills the space between the casing and the wall of the borehole. The casing and the cement sheath are then perforated opposite the selected interval to permit flow of fluid from the formation into the wellbore.

Common perforating techniques in commercial use today involve the use of perforating "guns" which employ high explosives to "fire" steel projectiles through the casing and cement sheath and into the surrounding formation or which develop high temperature, high velocity jet streams from "shaped" charges which penetrate the casing and cement sheath and a portion of the surrounding formation. These methods have certain disadvantages, one of the more notable ones being that the guns frequently misfire, and sometimes the projectiles fail to penetrate the casing. Either occurrence not only fails to provide the proper perforation, but also leaves in the well metallic debris which may seriously interfere with subsequent operations. Moreover, the use of conventional perforating guns or jets results in the formation of a limited number of relatively small perforations at spaced points which, particularly in dense formations of low permeability, may substantially restrict the rate of production of the well. And, further, the spent bullets and jet cases remain in the formation directly opposite the perforations and interfere, in varying degrees, with flow into the perforations. No positive measure of the adequacy or inadequacy of the penetration made by the perforating guns can be made. Thus, it is extremely difficult to determine whether the ultimate production rate is limited by the surrounding formation or by the inadequacy of the perforation.

Large perforations and slots are also sometimes made by means of abrasive jet tools whereby a high velocity stream of abrasive particles in a liquid medium is directed against the surface to be penetrated. Major disadvantages of this procedure are that it requires the running of pipe to conduct the abrasive fluid, requires special pumping equipment to develop required jet velocity, provides no indication of degree of penetration and leaves abrasive material in the hole for removal by expensive means.

Still another way of providing perforated casing for the purpose of well completion is to pre-perforate sections of casing at the surface and incorporate them in the casing string at the desired point. Although this method has the advantage of making it possible to provide larger openings and even slots of any desired length, it is obviously relatively expensive and troublesome. Moreover, it is extremely difficult to place the perforated section of casing at exactly the desired horizon in the well, and an error in its placement will result in opening up the

well at the wrong point, either missing the desired formation altogether or excluding part of the desired formation while opening up adjacent formations which may admit water into the well, seriously limiting or even effectively destroying its useful oil production capacity.

Another important use of casing perforations is in connection with squeeze cementing operations, such as are performed in an attempt to shut off the flow of water from lower zones, close the perforations used in drill stem testing and improve the bond or seal between the casing and the formation. These cementing operations normally involve forcing a cement slurry through the casing perforations. Where the perforations are formed by a perforating gun or jet as described above, the limited flow capacity of the relatively small, spaced perforations may restrict the efficacy of the operation.

Casing perforations are also used for such operations as hydraulic fracturing. While the fracturing fluid can be injected through the multiple spaced perforations created by a perforating gun or jet, current technology favors injection of the fracturing fluid through a single linear opening to concentrate the fluid and achieve greater penetration of the fracture into the surrounding formation. Although such single entry fracturing is usually performed through a horizontal opening, under certain circumstances beneficial results may be achieved by injection through vertical slots in the casing.

Vertical slots are also useful to a lesser degree in connection with other types of well operations, such as water injection, with or without tracers, ripping of pipe for fishing or other remedial operations, and so on.

The present invention provides a simple, inexpensive, and practical downhole tool for forming vertical slots in casing or in the sidewall of uncased holes. The tool is capable of forming one or more continuous vertical slots of any desired length. This not only gives excellent communication between the borehole and the surrounding formation, either for purposes of well production or for purposes of injection of cement slurries, fracturing or treating liquids and the like, but also insures positive penetration not only of the casing but of the cement behind the casing and even the adjacent portion of the surrounding formation, if desired, and obviates the leaving in the borehole any metallic debris or other "junk" which might interfere with subsequent operations.

Since the slotting tool of the present invention may be lowered into the borehole on a wire line, and does not involve one or more round trips into the hole with pipe, as in the case of most prior slotting tools, its operation is rapid and inexpensive. Moreover, it is possible to position the slots with extreme accuracy. For example, the slotting tool may be lowered into the borehole on the same wire line apparatus which was employed in making the usual downhole electrical or radioactivity logs, so that, even though there is an indeterminate error in the absolute depth indication of the wire line depth gauge, so long as its indications are reproducible, the slotting tool can be positioned at a depth corresponding to any selected point on the downhole log. Alternatively, the electrical or radioactivity detector sonde may be lowered into the borehole simultaneously with the slotting tool, with the two in predetermined spatial relation on the same wire line, so that the electrical or radioactivity plot may be traced or retraced until the desired point is reached.

In addition, the downhole radioactivity log may be correlated with a surface log of radioactivity made on core samples as the surface of the ground according to the method disclosed in U.S. Patent No. 3,025,398, to insure that the slotting tool is positioned to perforate the casing opposite the formation from which any selected core sample or group of samples was taken. Similarly, the downhole radioactivity log from the well in question may be correlated with downhole radioactivity logs made in adjacent wells to position the slotting tool adjacent a selected formation which is thus clearly identified from well to well.

The invention also provides, in conjunction with the slotting tool, an orienting device of conventional type so that the casing may be selectively perforated at any desired side, or the slots may be equally spaced around the casing, if desired.

In the drawings:

FIGURE 1 is a foreshortened vertical sectional view through a cased borehole containing a vertical slotting tool embodying features of the present invention, with the tool being shown partly broken away and partly in phantom to reveal its inner construction.

FIGURE 2 is a view similar to FIGURE 1, but showing the slotting tool fixed in position at the desired depth in the borehole and in the process of forming a vertical slot in the casing.

FIGURE 3 is a vertical sectional view through the borehole, at reduced scale, showing the tool after the cutting of the vertical slot has been completed and the tool has been released for removal from the borehole.

FIGURE 4 is a transverse sectional view through the tool, taken generally along the line 4—4 of FIGURE 1.

FIGURE 5 is an enlarged side elevational view of one vertical segment of the tool, with certain of the internal parts being shown in phantom.

FIGURE 6 is a fragmentary longitudinal sectional view taken generally along the line 6—6 of FIGURES 4 and 5.

FIGURE 7 is a schematic diagram of the hydraulic circuit for controlling the operation of the tool.

In FIGURE 1, the reference numeral **7** identifies the sidewall of the borehole, which is lined with a steel casing **8**, with cement **9** filling the annular space between the casing **8** and the sidewall **7**.

Shown in the borehole is an illustrative vertical slotting tool, which is enclosed in a tubular housing **10** and is adapted to be lowered into the borehole on a wire line **12**. Running along the line **12** is an electrical cable (not separately identified) for supplying electrical power to the unit for controlling its operation, and for carrying back to the surface electrical signals from a conventional direction sensing device, generally designated **13**, which is used, if desired, for orienting the tool in the borehole. Such instruments may incorporate either a compass or a gyroscope and photographic means for recording the position thereof or electrical means, such as a selsyn, for transmitting such positional information to the surface of the ground. Representative instruments are available from the Eastman Oil Well Surveying Company and the Sperry-Sun Well Surveying Company and are described more completely in the Eastman Directional Drilling Instrumentation Manual and the Sperry-Sun Well Surveying Instruments and Services Manual, respectively.

Shown in phantom within the housing **10** are the major mechanical components of the tool, including a circular cutting wheel **14** which is fixed on a shaft **16** rotatably journalled in a gear box **18** which is secured at the lower end of an electric motor **20**. Attached to the upper end of the motor **20** and projecting upwardly therefrom is a piston rod **22**, the upper end of which is connected to the piston **24** of an hydraulic cylinder **26** whose upper end is pivotally attached near the upper end of the housing **12** on a clevis pin **27**.

As may be seen in FIGURES 4–6, the drive shaft **16**, on which the cutting wheel **14** is fixed, has keyed thereon a worm gear **50** which meshes with a worm **52** fixed at the lower end of the motor shaft **54**. Thus, the cutting wheel **14** is driven by the motor **20** whenever electrical power is supplied thereto. The cutting wheel **14** may, for example, be of the diamond type, for readily cutting through the steel casing **8** and the cement **9** behind it.

FIGURE 1 shows the various parts of the tool in the positions which they occupy as the tool is lowered into the borehole prior to the start of a slotting operation. The piston **24** is at the extreme lower end of the cylinder **26** and the piston rod **22**, motor **20** and cutting wheel **14** are in their extreme lower positions, with the cutting wheel **14** fully retracted within the housing **10**.

When the tool reaches the desired depth, the movement of the hoisting cable **12** is stopped and, by actuating a switch on the control panel **32** at the surface of the ground, electrical current is supplied through the cable to drive the electric motor **20** to rotate the cutting wheel **14**. In addition, and simultaneously therewith, the current energizes a solenoid valve **25** (FIGURE 7) to open a line from a pair of hydraulic cylinders **28** (FIGURE 1) to a dump chamber **29** which contains only air at normal surface atmospheric pressure. Since the rear face of the piston of each of the cylinders **28** is always exposed to the formation fluid at elevated downhole pressures, this permits the pistons of the cylinders to be pressed outwardly, moving the hydraulic fluid ahead of the pistons into the dump chamber **29**, and compressing the air therein. This movement of the pistons causes a pair of presser feet **30**, to which they are respectively connected by piston rods **31**, to move from their normal retracted positions flush with the side wall of the housing, in which positions they are shown in FIGURE 1, outwardly against the casing at one side of the borehole, as shown in FIGURE 2. This forces the housing **10** of the tool against the inner wall of the casing **8** at the opposite side of the borehole.

Also simultaneously, a second solenoid valve **33** (FIGURE 7) is energized, opening a line between the upper end of the cylinder **26** and the dump chamber **29** permitting the high-pressure formation fluid to which the lower end of the piston **24** is exposed, to drive the piston **24** upwardly, forcing the hydraulic fluid in the cylinder **26** above the piston into the chamber **29**. As the piston **24** moves upwardly, the piston rod **22**, motor **20**, gear box **18** and cutting wheel **14** are moved upwardly with it.

As shown in FIGURES 4–6, the lower end of the gear box **18** has projecting from each side a crossbar **36** which extends across the full width of the housing and is provided at its opposite ends with cam follower pin portions **38** of reduced diameter. These cam follower pins **38** are slidably received in elongated cam slots **40** extending through cam plates **42** welded in conforming rectangular openings **10*a*** in the housing **10**.

As best shown in FIGURE 5, the lower portion of the cam slot **40** is provided with an outwardly and upwardly inclined portions **40*a*** so that at the commencement of the upward movement of the gear box **18** and cutting wheel **14**, the cam follower pins **38**, riding along the slots **40**, cause the cutting wheel to move obliquely outwardly, and to project through an elongated longitudinal slot **10*b*** in the housing **10** into cutting engagement with the casing **8**. After the cutting wheel has cut its way through the casing **8**, and continues its upward and outward movement, it cuts through part or all of the cement **9** between the casing and the side wall **7** of the borehole and perhaps for a short distance into the surrounding formation, as shown in FIGURE 2.

As shown in FIGURE 5, the elongated central portion **40*b*** of the cam slot **40** is straight and vertical, so that as the gear box **18** and cutting wheel **14** continue their upward movement, the cutting wheel **14** cuts straight upwardly through the casing **8** and cement **9**, forming an elongated vertical slot therein. The upper end **40*c*** of the slot **40** is inwardly and upwardly inclined, as partially shown in FIGURE 5 and fully shown in FIGURE 3, so that as the gear box **18** and cutting wheel **14** near the upper end of their vertical movement, they are moved inwardly to retract the cutting wheel **14** within the housing, as shown in FIGURE 3.

As the cutting wheel reaches the upper end of its movement, the upper end of the motor **20** actuates a switch **42**, opening the electrical circuit to the motor **20** and stopping the driving of the cutting wheel **14**. The actuation of the switch **42** also deenergizes the solenoid valve **25** which is connected in the line ahead of the pistons of the hydraulic cylinders **28**, and actuates the valves so that instead of connecting the cylinders **28** to the dump chamber **29**, they vent the cylinders to the formation fluid within the tool. Thus both sides of the pistons are now exposed to the formation fluid at the same pressure, permitting the springs **44** to retract the presser feet **30** out of engagement with the casing **8** and flush against the sides of the housing **10**. This allows the tool to hang freely within the borehole, as shown in FIGURE 3, so that the tool may be withdrawn from the borehole.

It will be readily understood that although the illustrative tool shown and described has only one cutting wheel, the same principles could be applied to provide a tool having two or more cutting wheels for simultaneously cutting a number of vertical slots.

It will also be understood that even a tool having only one cutting wheel can be adapted to cut more than one slot on each trip into the well by providing means for returning the cutting wheel downwardly to its starting position at the end of its upward stroke. For example, the hydraulic cylinder **26** could be replaced by an electric motor driving a lead screw, with either the lead screw or the motor being reversible to drive the motor **20**, gear box **18** and cutting wheel **14** back downwardly. Such a tool could be arranged to cut on both the upward and downward strokes, or only on the upward strokes, with the tool hanging free of the sidewalls and being rotated to a new orientation during the downward strokes of the cutting wheel.

From the forgoing description, it will be apparent that the present invention provides a practical tool which is capable of forming elongated vertical slots at desired longitudinal positions in cased boreholes. However, it should be emphasizes that the particular embodiments of the invention which are described herein and shown in the accompanying drawings, are intended as merely illustrative of the principles of the invention rather than as restrictive thereof, and that various modifications may be made therein without departing from the principles of the invention, and that the scope of the invention is therefore intended to be limited only by the appended claims. In the claims, the term "sidewall" is intended to include either the sidewall of uncased boreholes or the casing in cased boreholes.

We claim:

1. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a well borehole on a wire line, and having an elongated longitudinally extending opening in the wall thereof, a motor within said housing, means for supplying power to said motor, a cutter mounted for movement in a vertical plane and mechanically coupled to said motor to be driven thereby, means for moving said cutter longitudinally of said housing, and means for moving said cutter transversely of said housing to cause it to project through said opening and into cutting relation with the sidewall of said borehole at the first portion of such longitudinal movement, then to cause it to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to cause it to retract into said housing at the latter portion of such longitudinal movement.

2. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a well borehole on a wire line, and having an elongated longitudinally extending opening in the wall thereof, a motor within said housing, means for supplying power to said motor, a cutter mounted for movement in a vertical plane and mechanically coupled to said motor to be driven thereby,

means for moving said cutter longitudinally of said housing, and cam means on said housing engaging follower means associated with said cutter for moving said cutter transversely of said housing to cause said cutter to project through said opening into cutting relation with the sidewall of said borehole during the first portion of such longitudinal movement then to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to retract said cutter into said housing during the latter portion of such longitudinal movement.

3. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a well borehole on a wire line, and having an elongated longitudinally extending opening in the wall thereof, a motor within said housing, means for supplying power to said motor, a circular disc-type cutter mounted for rotation about a horizontal axis which is in fixed spatial relationship to said motor, and driving means connecting said cutter to said motor to be driven thereby, means for moving the motor and cutter assembly longitudinally of said housing, and cam means on said housing engaging follower means associated with said cutter for moving said cutter transversely of said housing to cause said cutter to project through said opening into cutting relation with the sidewall of said borehole during the first portion of such longitudinal movement then to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to retract said cutter into said housing during the latter portion of such longitudinal movement.

4. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a borehole on a wire line and having an elongated longitudinally extending opening through the wall at one side thereof, a shoe mounted at the opposite side of said housing for movement inwardly and outwardly, means for moving said shoe forcibly outwardly against the sidewall at one side of said borehole to press said housing against the sidewall at the opposite side of said borehole, a motor within said housing, means for supplying power to said motor, a cutter mounted for movement in a vertical plane and mechanically coupled to said motor to be driven thereby, means for moving said cutter longitudinally of said housing, and means for moving said cutter transversely of said housing to cause it to project through said opening and into cutting relation with said sidewall at the first portion of such longitudinal movement, then to cause it to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to cause it to retract into said housing at the latter portion of such longitudinal movement.

5. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a borehole on a wire line and having an elongated longitudinally extending opening through the wall at one side thereof, a shoe mounted at the opposite side of said housing for movement inwardly and outwardly, means for moving said shoe forcibly outwardly against the sidewall at one side of said borehole to press said housing against the sidewall at the opposite side of said borehole, a cutter mounted for movement in a vertical plane and mechanically coupled to said motor to be driven thereby, means for moving said cutter longitudinally of said housing, and cam means on said housing engaging follower means associated with said cutter for moving said cutter transversely of said housing to cause said cutter to project through said opening into cutting relation with said sidewall during the first portion of such longitudinal movement then to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to retract said cutter into said housing during the latter portion of such longitudinal movement.

6. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a borehole on a wire line and having an elongated longitudinally extending opening through the wall at one side thereof, a shoe mounted at the opposite side of said housing for movement inwardly and outwardly, means for moving said shoe forcibly outwardly against the sidewall at one side of said borehole to press said housing against the sidewall at the opposite side of said borehole, a circular disc-type cutter mounted for rotation about a horizontal axis which is in fixed spatial relationship to said motor, and driving means connecting said cutter to said motor to be driven thereby, means for moving the motor and cutter assembly longitudinally of said housing, and cam means on said housing engaging follower means associated with said cutter for moving said cutter transversely of said housing to cause said cutter to project through said opening into cutting relation with said sidewall during the first portion of such longitudinal movement then to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to retract said cutter into said housing during the latter portion of such longitudinal movement.

7. A down-hole vertical slotting tool comprising a housing adapted to be lowered into a well borehole on a wire line, and having an elongated longitudinally extending opening in the wall thereof, a motor within said housing, means for supplying power to said motor, a cutter mounted for movement in a vertical plane and mechanically coupled to said motor to be driven thereby, means for moving said cutter longitudinally of said housing, means for moving said cutter transversely of said housing to cause it to project through said opening and into cutting relation with the sidewall of said borehole at the first portion of such longitudinal movement, then to cause it to move longitudinally of said housing while projecting through said opening and cutting a vertical slot in said sidewall, and finally to cause it to retract into said housing at the latter portion of such longitudinal movement, means associated with said housing for sensing the orientation of said housing in said borehole and for transmitting information as to said orientation to the surface.

References Cited by the Examiner

UNITED STATES PATENTS

602,301	4/1898	Bramlette	166—55.3
1,048,875	12/1912	Rader	83—488
1,105,140	7/1914	Hendee	83—488 X
1,298,131	3/1919	Wilkirson	166—55.1
1,789,993	1/1931	Switzer	166—55.3
2,053,698	9/1936	Church	175—77 X
2,327,023	8/1943	Danner	175—99 X
2,500,785	3/1950	Arutunoff	175—104 X
3,010,517	11/1961	Lanmon	166—55.1 X

CHARLES E. O'CONNELL, *Primary Examiner.*

BENJAMIN BENDETT, *Examiner.*

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,225,828 December 28, 1965

John D. Wisenbaker et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

In the grant, lines 2 and 3, for "assignors to American Coldset Corporation, of Teterboro, New Jersey, a corporation of Texas," read -- assignors of one-half to American Coldset Corporation, of Teterboro, New Jersey, a corporation of Texas, and one-half to Core Laboratories, Inc., of Dallas, Texas, --; line 12, for "American Coldset Corporation, its successors" read -- American Coldset Corporation and Core Laboratories, Inc., their successors --; in the heading to the printed specification, lines 4 and 5, for "assignors to American Coldset Corporation, Teterboro, N. J., a corporation of Texas" read -- assignors of one-half to American Coldset Corporation, Teterboro, N. J., a corporation of Texas, and one-half to Core Laboratories, Inc., Dallas, Tex. --.

Signed and sealed this 16th day of August 1966.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents