FOSSIL ENERGY

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# A STUDY TO DETERMINE FEASIBILITY OF DEVELOPING A MECHANICALLY OPERATED, SURFACE-CONTROLLED DEVIATION DEVICE FOR DIRECTIONAL DRILLING

**Final Report**

Work Performed for the Department of Energy
Under Contract No. DE-AC19-80BC10175

Date Published—July 1982

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National Petroleum Technology Office
U.S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

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# A STUDY TO DETERMINE FEASIBILITY OF DEVELOPING A MECHANICALLY OPERATED, SURFACE-CONTROLLED DEVIATION DEVICE FOR DIRECTIONAL DRILLING

**Final Report**

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UNITED STATES DEPARTMENT OF ENERGY

## FOREWORD

The work covered in this report was performed under the Drilling Research Program of the U.S. Department of Energy. The project was monitored by the Bartlesville Energy Technology Center. The purpose of the work was to advance the state-of-the-art for directional drilling by identifying methods to remotely control the wellbore path during directional drilling operations. It is envisioned that if a remote controlled device can be developed for use with the existing mud-pulse telemetry systems, the efficiency and cost of directional drilling will be greatly enhanced. Much time can be saved if the degree of deviation can be specifically changed on demand without pulling the bottom hole assembly out of the hole.

The contractor designed two tools for which patents have been applied. Publication of this report was withheld by DOE's Patent Counsel while the patent application process was being accomplished. The lengthy design drawings and an Appendix (covering literature and patent search printouts) are not being published in this report but will be made available upon specific request to the Branch of Technology Transfer, Bartlesville Energy Technology Center, Bartlesville, Oklahoma.

C. Ray Williams
Technical Project Officer

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# ABSTRACT

This report completes the work under DOE Contract No. DE-AC19-80BC10175. The work was funded by the Division of Fossil Fuel Extraction and was administered by the Bartlesville Energy Technology Center, with Mr. C. Ray Williams as Project Officer.

The state-of-art in the field of surface-controlled, downhole-adjustable well deviation tools is examined for both rotating and non-rotating drillstrings. This investigation is based on a literature survey and both domestic and foreign patent searches. Pertinent patents and devices found in the literature are reviewed for applicability, practicality, capability and possible improvements. A reasonable potential for improvement exists both for bent sub devices for non-rotating drillstrings and for expandable blade stabilizers for rotating strings. A new design is shown for one of each type of tool. Both new tools use the same trigger device and are controlled by varying drillstring circulation pressure, so use of pump-down or wireline or electric controls is avoided. The general design features of both tools appear to have avoided most problem areas reasonably well and seem to offer sufficient improvement over existing or disclosed hardware to justify development. Valid, fairly strong patents can probably be obtained on both tools.

# CHAPTER I

## INTRODUCTION

Deviated drilling is an important facet of oilfield operations for either constraining the wellbore to be relatively straight or to follow an intentionally non-vertical path. One of the most important applications is in using deviated wells to intercept productive zones at substantial distances from an offshore platform or other site. Other important uses are in wild well interception drilling for kill purposes, sidetracking, and crooked-hole control. There is a need for effective deviation control means for both rotating drillstrings and non-rotating strings used with downhole motors.

The hardware available at this time requires expensive round-tripping of the drillstring to change its deviation tendencies appreciably. There appears to be a substantial incentive to provide more effective, readily workable, affordable deviation control means controllable from the surface.

There are currently no surface-controlled, downhole-adjustable deviation control devices being widely marketed. At least one downhole-adjustable bent sub and one rotating drillstring tool were previously offered. Two new downhole-adjustable bent sub tools are being developed at this time, and Directional Stabilizer Systems of Odessa, Texas, has developed and tested a tool system for rotating drillstrings. These tools are being developed to fulfill the evident need in the market.

The intent of this project is to: a) define the requirements for downhole-adjustable deviation devices, b) determine what technology is publicly disclosed at this time, c) evaluate the devices and concepts found, d) select approaches or adaptation candidate devices, e) if sufficient improvement over the best devices found looks feasible, develop new devices. The project tasks include making both a patent and a literature survey and then evaluating the findings. This report details the current state-of-the-art in downhole-adjustable deviation tools. Because reasonably good improvements over what has developed to date appeared attainable, both a new design bent sub and a new expandable blade stabilizer tool were developed. This report explains the new tools and reviews their designs.

## CHAPTER II

## SUMMARY

This project was conceived by C. Ray Williams of the U.S. Department of Energy's Bartlesville Energy Technology Center; funding and project supervision were provided by that agency. The patent search and literature search were subcontracted by Larry Russell & Associates, Inc. to Anna Crull of Chemical Technology Consultants. Of the large number of U.S. and foreign patents reviewed, thirteen were found to be directly pertinent or meriting comment for non-rotating drillstring service. Twenty-four noteworthy patents were found for rotating drillstring devices. These patents are reviewed in detail in Chapter II of this report. Twenty-four articles, papers, manuals, sales brochures, or reports were selected from those found for review in Chapter IV of this report; eighteen other useful references on drillstring behavior are also listed.

It was found that two rotating drillstring tools, other than clamp-on blade stabilizers or conventional stabilizers, are currently available. One of these, the Eastman-Whipstock "Rebel Tool", must be adjusted on the surface to induce a transverse drift out of the vertical plane. (Ref. A-3, A-8). This tool evidently is satisfactory in its field performance, since it has been available for many years. However, its use is typically not required for most deviated holes. The other available tool is a system of three expandable, surface-controlled blade stabilizers, which is undergoing development by Directional Stabilizer Systems of Odessa, Texas. (Ref. A-1). Another tool, the "Bit Boss", was developed and run by Drilco for several years before being discontinued. This latter tool was controllable by wireline-run tools.

No surface-controlled bent sub tools are commercially offered at this time, but two tools are in development and another related bent sub tool is now being introduced to the market. Bowen Industries formerly built a "Dyna-Flex" surface-controllable bent sub tool, which was used for deviated drilling by the Dyna-Drill Division of Smith International, Inc. (Ref. F-1, F-2 and F-3). This tool is not being marketed at this time, but an improved version is currently being developed by Bowen. SMF International and the Institut Francais du Petrole are developing a surface-controlled bent sub in both mechanically and electrically-controlled versions. (Ref. A-4, A-5, F-4). Christensen Diamond Products, U.S.A. has a new "Twist-Kick" bent sub which trips in and out straight, but bends when on bottom. (Ref. F-7).

Review of the tools found in the patent and literature searches indicated a reasonable probability of developing improvements in the mechanisms for achieving surface control. A subsystem responsive to circulation pressure was developed and then incorporated into both an expandable stabilizer design and a bent sub design. The resultant new tools are described and critiqued in this report. Both new tools offer improvements in design features, appear workable, and offer reasonable promise of economic success.

## CHAPTER III

## PATENT REVIEW

### Introduction

U.S. and foreign patents for the period January 1, 1969 to December 31, 1979 were reviewed for finding suitable or adaptable devices for this project. The patent citations retrieved from the data bases were checked for pertinence, and then actual patent copies were ordered for review if there appeared to be any relation to the project. The reviewed patents were classified into four groups:

1. Bent Sub Devices (13 patents, listed in Table 1)
2. Lateral Deflectors for Rotating Drillpipe (24 patents, listed in Table B),
3. Non-Oilfield Mining, Tunneling, and Earthboring Devices (20 patents, listed in Table 3), and
4. Non-Applicable Devices.

The reviews of the first two groups are given in this section.

The most promising art is in the area of bent sub devices for use with non-rotating drillpipe. A formerly commercially available item was found, and, based upon recent publications, more appear to be forthcoming. In part, this maturity of the bent sub area is due to: a) the need for economical deviation tools for offshore platform drilling and, primarily, b) the less difficult technical problems involved in bent sub development.

Several rotating drillpipe devices were found, and one was previously available commercially. Only one new device is known to be in development at this time. This state of affairs appears attributable to: a) difficult technical problems with such devices, b) costs for such devices, c) fairly satisfactory means for avoidance of most crooked hole problems in normal drilling, and d) the availability for a reasonable price of bent sub/downhole motor options for offshore platform deviation work. The rotating drillpipe devices found mostly fall into three classes. One class functions by selectively expanding a stabilizer from undergauge to fullgauge. A second class functions by axially shifting the location of a stabilizer in the string. These first two classes are used to build or decrease deviation, once it is started in a particular direction, by altering the lateral forces on the bit. This technique is discussed in References E1-18. The third class of devices is selectively caused to bear on the side of the borehole in order

## TABLE 1

## BENT SUB DEVICES

The following U.S. and foreign patents were selected as being more or less pertinent to the control of deviations of non-rotating drillstrings with downhole motors.

U.S. Patents

| | | |
|---|---|---|
| 1. | 3,457,999 | Fluid Actuated Directional Drilling Sub, D.L. Massey |
| 2. | 3,561,549 | Slant Drilling Tools for Oil Wells, E.P. Garrison et al. |
| 3. | 3,563,323 | Apparatus for Borehole Drilling, H.T. Edgecombe |
| 4. | 3,637,356 | Directional Drilling Apparatus with Retrievable Limiting Device, E.A. Anderson |
| 5. | 3,667,556 | Directional Drilling Apparatus, J.K. Henderson |
| 6. | 3,713,500 | Drilling Devices, M.K. Russell |
| 7. | 3,811,519 | Remote Control Directional Drilling System, W.B. Driver |
| 8. | 3,841,420 | Directional Drilling Means, M.K. Russell |
| 9. | 3,903,974 | Drilling Assembly, Deviation Sub Therewith, and Method of Using Same, R.H. Cullen |
| 10. | 3,993,127 | Apparatus for Positioning a Working Element in a Borehole, V.G. Chepelev et al. |
| 11. | 4,077,657 | Adjustable Bent Sub, K.H. Trzeciak |

USSR Patents

| | | |
|---|---|---|
| 12. | 275,917 | Turbodrill for Directional Boreholes, B.G. Smirnov et al. |
| 13. | 543,730 | Tool Joint for Helical Rotor Downhole Drills, M.T. Gusman et al. |

## TABLE 2

## LATERAL DEFLECTORS FOR ROTATING DRILLPIPE

The following U.S. and foreign patents were selected as being more or less pertinent to the control of rotating drillsting deviation.

U.S. Patents

| | | |
|---|---|---|
| 1. | 2,891,769* | Directional Drilling Tool, J.S. Page et al. |
| 2. | 3,023,821* | Well Tool, W.H. Etherington |
| 3. | 3,298,449* | Well Bore Apparatus, W.S. Bachman et al. |
| 4. | 3,326,305* | Drill Bit Control Apparatus, W.R. Garrett et al. |
| 5. | 3,370,657* | Stabilizer and Deflecting Tool, W.H. Antle |
| 6. | 3,424,256 | Apparatus for Controlling Directional Deviations of a Well Bore as It Is Being Drilled, J.D. Jeter et al. |
| 7. | 3,460,639* | Latch for Drill Bit Control Apparatus, W.R. Garrett |
| 8. | 3,565,189 | Apparatus for Controlling and Monitoring a Tool in a Borehole, H.J. Hart |
| 9. | 3,572,450 | Well Drilling Apparatus, D.R. Thompson |
| 10. | 3,593,810 | Methods and Apparatus for Directional Drilling, R.Q. Fields |
| 11. | 3,595,326 | Directional Drilling Apparatus, J.R. Claycomb |
| 12. | 3,599,733 | Method for Directional Drilling with a Jetting Bit R.F. Varley |
| 13. | 3,637,032 | Directional Drilling Apparatus, J.D. Jeter |
| 14. | 3,650,338 | Rotary Bit Guide, B.M. McNeely, Jr. |
| 15. | 3,743,034 | Steerable Drill String, W.B. Bradley |
| 16. | 3,746,108 | Focus Nozzle Directional Bit, G.E. Hall |
| 17. | 3,799,279 | Optionally Stabilized Drilling Tool, R.J. Farris |
| 18. | 3,825,081 | Apparatus for Slant Hole Drilling, H.S. McMahon |
| 19. | 3,961,674 | Directional Drilling System, J.T. Craig Jr. et al. |
| 20. | 3,974,886* | Directional Drilling Tool, J.L. Blake, Jr. |
| 21. | 4,015,673 | Directional Drilling System, J.T. Craig, Jr. et al. |
| 22.. | 4,076,084 | Oriented Drilling Tool, R.E. Tighe |
| 23. | 4,108,256 | Sliding Stabilizer Assembly, R.G. Moore, III |

USSR Patent

| | | |
|---|---|---|
| 24. | 616,395 | Drilling Deflector Sleeve, Yv. S. Kostin et al. |

* Included in Maurer Engineering Inc. Report (Ref. B-1).

TABLE 3

PATENTS RELATED TO MINING, TUNNELING AND EARTHBORING DEVICES

U.S. Patents

| | | |
|---|---|---|
| 1. | 3,437,380 | Steering Method and Apparatus, J.C. Lawrence |
| 2. | 3,465,834 | Guided Subterranean Penetrator Systems, H. Southworth, Jr. |
| 3. | 3,525,405 | Guided Burrowing Device, J.C. Coyne et al. |
| 4. | 3,554,302 | Directional Control of Earthboring Apparatus, D.E. Adkins, et al. |
| 5. | 3,526,285 | Angularly Adjustable Auger Head, D.E. Adkins, et al. |
| 6. | 3,589,454 | Mole Guidance System, J.C. Coyne |
| 7. | 3,677,354 | Device for Stabilizing the Course of the Tunnelling Element, A.D. Kostylev et al. |
| 8. | 3,720,272 | Apparatus and Method for Drilling an Arcuate Bore from Ground Surface under an Obstruction to Ground Surface, E.J. Hunter |
| 9. | 3,794,128 | Subterranean Penetrator Steering System Utilizing Fixed and Rotatable Fins, P.F. Gagen et al. |
| 10. | 3,853,186 | Drilling Assembly Deflection Apparatus, H.D. Dahl et al. |
| 11. | 3,888,319 | Control System for a Drilling Apparatus, H.A. Bourne, Jr., et al. |
| 12. | 3,930,545 | Tiltable Coupling, H.V. Sears |
| 13. | 3,945,443 | Steerable Rock Boring Head for Earth Boring Machines, T.W. Barnes |
| 14. | 3,963,080 | Tunneling Machine for Boring a Side Drift, R.W. Walker |
| 15. | 3,986,568 | Apparatus for Making Underground Passages, R. Weiss |
| 16. | 3,997,008 | Drill Director, J.M. Kellner |
| 17. | 4,040,495 | Drilling Apparatus, J.M. Kellner et al. |
| 18. | 4,046,204 | Controlled Directional Drilling Tool, S. Takaoka, et al. |
| 19. | 4,111,486 | Method & System for Performing Attitude Control of Tunnel Excavating Shield, Y. Kumaki, et al. |
| 20. | 4,121,673 | Drilling & Installation System, M.D. Cherrington |

to induce bit deviation tendencies. This latter group of devices supposedly permits kicking-off and then controlling deviation in any desired direction. This is a more versatile type of tool than the first two types, but is typically a more complex tool.

A fairly large group of devices suitable for non-oilfield applications was found. The features of these devices which were judged to be unsuited to the oilfield included excessive size requirements, overly complex control means for downhole use, or general unsuitability due to lack of robustness, constructional features, or the like. A listing of these patents is provided in Table 3 without further discussion.

## Scope of Search and Review

The patent search was made by using the computer data bases accessible to the public. As a consequence of this approach, U.S. patents issued prior to 1969 were not locatable. However, most of the important work in the area of interest has been done since the beginning of the search period. Patents pending and patents issued after 1979 also have not been reviewed because of their unavailability at the time of the search. Table 4 gives a summary of the patent search specifications and numbers of citations found.

The reviews of the patent art are based on what was found in the computer search. Additionally, the pertinent patents reviewed in an earlier DOE study conducted by Maurer Engineering Inc. are included. (Ref. B-1). Most of the patents or devices of interest are included in this report.

The patents that were found were evaluated for practicality as thoroughly as possible, given that only patent drawings, rather than engineering drawings, were available. The evaluations are admittedly subjective, and it is recognized that careful engineering can at least partially overcome many of the anticipated design problem areas. Likewise, certain problems with some concepts have undoubtedly escaped notice. However, it is believed that the most important patents and the main features of each are correctly evaluated here.

## General Technical Considerations

While the economic justification for developing downhole-adjustable tools has existed for some time, fulfilling of the need is not simple. This is due to the severe nature of the oilfield drilling environment, particularly near the bit. A deviation tool must be located near the bit, where it is subject

## TABLE 4

## SCOPE OF PATENT SEARCH

I. U.S. Patents

A. Period Covered: 1969 to 1979, inclusive

B. Data Files Investigated: Office of Technology Assessment and Forecast File and the U.S. Patent and Trademark Office File

C. Patent Classes and Subclasses Investigated:

1. All of Class 175, with Subclasses 1 to 409
2. Appropriate Subclasses of Classes 173, 299 and 340 referenced from Class 175.

D. Number of U.S. Patents Cited in Search: 282

II. Foreign Patents

A. Period Covered: 1960 to 1980

B. Data File Investigated: SDC International Orbit IV File

C. Patent Classes Investigated: E21 b,c,d

D. Number of Foreign Patents Cited in Search: 465

NOTE: Patents issued in the U.S. are not listed under foreign countries in the event of duplicate patent issuances.

to high axial load, torque, and exaggerated bending if poorly stabilized, in a dogleg, or in a deviated hole. Severe vibrations and rotation (if present) can lead to fatigue problems. Hole erosion, caving, hang-up and sticking tendencies, and abrasion from the walls are always a problem. Fluid erosion, sanding up, and the general grit and wear problems (which are amplified by the vibrations and clearances needed for operation in mud) have to be considered. Seal reliabilities are important, since washouts must be avoided and tool oil reservoirs must not be depleted or contaminated. Tool bending can prevent proper piston or sleeve operation, while high hole angles can interfere with wireline operation or cause excess friction with the hole wall. Typically, the more parts a tool has, the worse are its reliability and assembly problems.

A significant number of design limitations arise from the limited diametrical space available to the downhole tool designer. The bore of the drillstring must be kept relatively clear for mud flow and to permit survey tool running. In contrast, the tunneling machine designer has virtually unlimited space for hydraulic or electric sensors and controls, actuators, and structure. If possible battery driven pumps are excluded, the only practical source of hydraulic actuation fluid downhole is the drilling mud itself or an accumulator. In general, to avoid complexity, the drilling fluid stream itself is used. Membranes or pistons can be used to exclude mud from certain locations. For non-rotating pipe, use of control signals and position feedback via electric cable continuously run inside the drillstring produces appreciable delays when breaking for pipe connections, unless a device like the Eastman Whipstock cable side-entry sub is used to avoid cable tripping. (Ref. B-4). This option for control is not practical for rotating pipe without rotating a cable reel or using commutators; even then, it appears undesirable. Use of the string itself as an electrical conductor, as planned for one type of measurement-while-drilling (MWD) system, could avoid these cable problems. Two-way mud-pulse telemetry might also avoid cable problems. Use of two-way signaling and downhole control by either mud-pulse telemetry or non-cable telemetry likely will come about sometime in the future, but considerable technical expertise appears necessary to implement these approaches, given the level of effort going into MWD work.

Occasional bottom-hole assembly adjustments by means of wireline-run or pump-down devices, wireline-retrievable or otherwise, does appear feasible now. Complex electrical controls using signals conveyed by wireline seem possible to some extent with inductive couplings and multiplexed digital techniques. Direct electrical control is considered possible, but direct operation by electric motors or solenoids is believed impractical because of spatial contraints. Hydraulic actuation is feasible with electric control. In such a system, operative fluid sources for hydraulically operated devices can only be practically supplied by:

A. using pressure drops internal to the string, or
B. referencing preset accumulator pressures versus drill-string and/or annulus pressures, or
C. using drillstring versus annulus pressure, or
D. using a downhole (turbine or electric) motor to pump fluid into a storage reservoir or using battery power to run a pump without stored hydraulic fluid.

Option A above can be done by using, say, a dropped, pumped-through ball (which is temporarily landed in a rubber socket) or a wireline-run and retrieved sleeve or blanking sub or other means to cause pressures to be different within parts of the string itself. Options B and D can have an accumulator or reservoir charged to a pressure different than the pressure to be used as a reference at the time of the actuating signal. The accumulator can be charged either at the surface or downhole. Option C has been the most commonly used approach on rotating string tools because of its simplicity, but has potential wash-out problems.

Design Features Considered Particularly Important

Certain design features must be provided to some reasonable degree in tools of this type in order to meet minimum operator standards. Naturally, the level to which these and other design features are present varies with the type and size of tool. In general, a satisfactory bottom-hole component must have the following characteristics:

A. Suitable structural properties, including
--adequate strength
--stiffness comparable to adjacent elements, if rotating
--fatigue resistance.
B. Minimal tendency to hang up or bind in the hole or lose pieces downhole.
C. Minimal likelihood of washing out (implying a minimal number of moving seals between the well bore and the well annulus).
D. Minimal tendency to sand up, lose fluid from reservoirs, fail parts, or jam.
E. Ease in dressing, repairing, and preparations for running downhole.
F. Fail-safe behavior, so that drilling can continue or, at a minimum, circulation can be maintained.
G. Cost effectiveness, as a result of reasonable price, reliability, and performance.

The patents were reviewed with these characteristics in mind.

## Summary of Findings

In the patent art surveyed, it appears that the bent sub design of Anderson in U.S. Patent 3,627,356 is the most workable, advantageous design. This is the patent which is the basis for the "Dyna-Flex" tool. (Ref. F-1, F-2, F-3). This tool was built and run for several years by Dyna-Drill. One of the particular advantages of the tool, other than its downhole-changeable bend angle, is the ability of the tool to apply force to gradually achieve its bend angle limit when "in a bind." This tool is easy to orient and should be good for sidetracks.

Tools of the type shown in M.K. Russell's U.S. Patent 3,713,500 are likely to become available and eventually quite common as an integral part of MWD systems which also offer control ability. At this time, however, it would seem that a purely mechanical system would be better accepted and more easily serviced in the field.

The indexable, skew-axis bent sub in Trzeciak's U.S. Patent 4,077,657 is worthy of mention as the forerunner of recent skew-axis tools such as the SMF-IFP "Telepilot Bent-O-Matic" (Ref. A-4, A-5, F-4), the Christensen "Twist-Kick Sub" (Ref. F-7), and the new bent sub design shown in this report.

For downhole-adjustable rotating drillstring deviation control tools, the Blake U.S. Patent 3,974,886 seems to offer the simplest, most versatile, practical approach for the majority of problems. This patent is the basis of the Directional Stabilizer Systems tools mentioned in Reference A-1. Some design improvements likely are possible on this particular tool, but the basic concept for controlling both wanted and unwanted pre-existing deviations with expandable stabilizers seems practical.

The use of lateral thrust devices downhole would not seem particularly attractive compared to downhole motor and bent sub use for kick-off and bottom hole assembly variation for deviation maintenance. This is due to the presumed complexity of such devices, their likely relative structural weaknesses, and use times. Having such a device in the string could interfere with use of conventionally stabilized bottom-hole assemblies, forcing dependence on the lateral thruster tool. Tools based on the approaches shown in the U.S. Patents 3,424,256 by Jeter et al., 3,593,810 by Fields, and 3,650,338 by McNeely might be workable. The practicality of such tools is difficult to ascertain without field test results.

U.S. Patent 3,457,999 by Dulas L. Massey: Fluid Actuated Directional Drilling Sub

Patent Abstract

A bendable sub for use with a bottom-hole fluid-driven bit in a well string. The sub may be locked or unlocked in either straight or angled positions through variation of pressure of fluid within the well string and sub and by adjusting load of the drill string on the sub and drill bit. An orienting sub member for attachment to the well string is provided with a socket which receives a ball member formed on a mandrel slidable within a body member secured to the orienting sub, the mandrel being in turn attached to the drill bit. The ball of the mandrel, which is slidable within the body member, engages with the socket for directional drilling. Pistons within the mandrel engage apertures within the body member, such pistons being actuated by pressure of fluid within the device.

Review

This tool uses a sliding mandrel mounted in a tubular body. Transversely acting pistons, extended by pump pressure and retracted by springs, latch the mandrel in either an extended or retracted position. Individual upper and lower lugs, clamped to the mandrel, shoulder against the tubular body when the mandrel is extended down or retracted. There, lugs effectively hold the mandrel concentric with body or force it to an eccentric position under appropriate axial loading (either pump-induced mandrel extension forces or "bit weight" compressive forces).

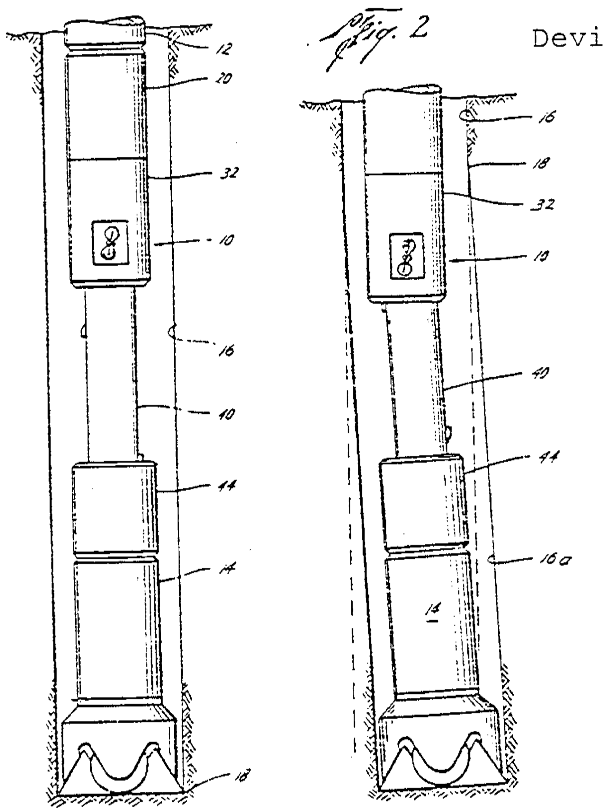
This bent sub tool offers many desirable features, including surface control and two selectable positions (straight or bent). See Figure 1. Setting the tool in either the straight or bent mode only involves picking the bit up off the bottom, turning off the pumps, and either staying off bottom or setting down when the pumps are turned on again to effect the latching. The problems with the tool relate to strength and reliability. There are various slots, holes, excessive clearances, and the like which reduce the strength and stiffness of the tool. Each piston and the ball joint have moving seals, which represent potential washout points, considering the configuration and vibration of the tool. Latching piston retraction is not sufficiently positive, given the possibility of piston bore damage from axial shock loads passing through the latch. These structural problems are probably too serious for this to be a practical tool. The latching pistons unlatch whenever the mud pumps are turned off for a connection.

## FIGURE 1

July 29, 1969 D. L. MASSEY 3,457,999

FLUID ACTUATED DIRECTIONAL DRILLING SUB

Fig. 2 Deviated Drilling




Dulas L. Massey
INVENTOR.

Fig. 1

Drilling
Ahead

U.S. Patent 3,561,549 by Erskine P. Garrison and John E. Tschirky

Patent Abstract

Drill string orienting apparatus for nonrotating drillstrings equipped with down-hole motors, the orienting apparatus preferably being located between the lower portion of the motor and the bit sub and having a laterally projecting portion engageable with the hole formation to bias the bit directionally. Also, orienting apparatus on the string above the downhole motor having a portion projecting laterally opposite to the projection of the first mentioned orienting means. Also, a modification wherein symmetrical stabilizing means is located adjacent the lower end of the motor and laterally disposed directional orienting means is located above the downhole motor in spaced relation to the stabilizing means.

Review

This patent covers a group of devices for inducing bending in the lower portion of a non-rotating drillstring. See Figure 2. The bending is in response to transverse forces from unopposed extendable shoes. In effect, these devices function as bent subs. No basic mechanisms for extending or retracting the shoes are shown. Use of wireline-operated or pressure-operated sleeves or other suitable mechanisms to operate the shoes would be necessary. The advantage of this approach would be the ability to run and pull a straight tool in the hole. The patent really has value only when combined with other mechanisms; the basic practicality can be best determined when looking at specific combinations. The approach is similar to that used in the Drilco tools for rotating pipe, disclosed in U.S. Patents 3,298,449 and 3,326,305.

U.S. Patent 3,563,323 by Howard T. Edgecombe

Patent Abstract

In deviation borehole drilling with a down-hole motor, a plurality of flexible collars is disposed in the drill string between the main stand of weight collars and the deviation assembly. In this way the bending moments of the main stand of weight collars are not transmitted to the down-hole motor and better control of deviation is achieved.

FIGURE 2

Slant Drilling Tools For Oil Wells

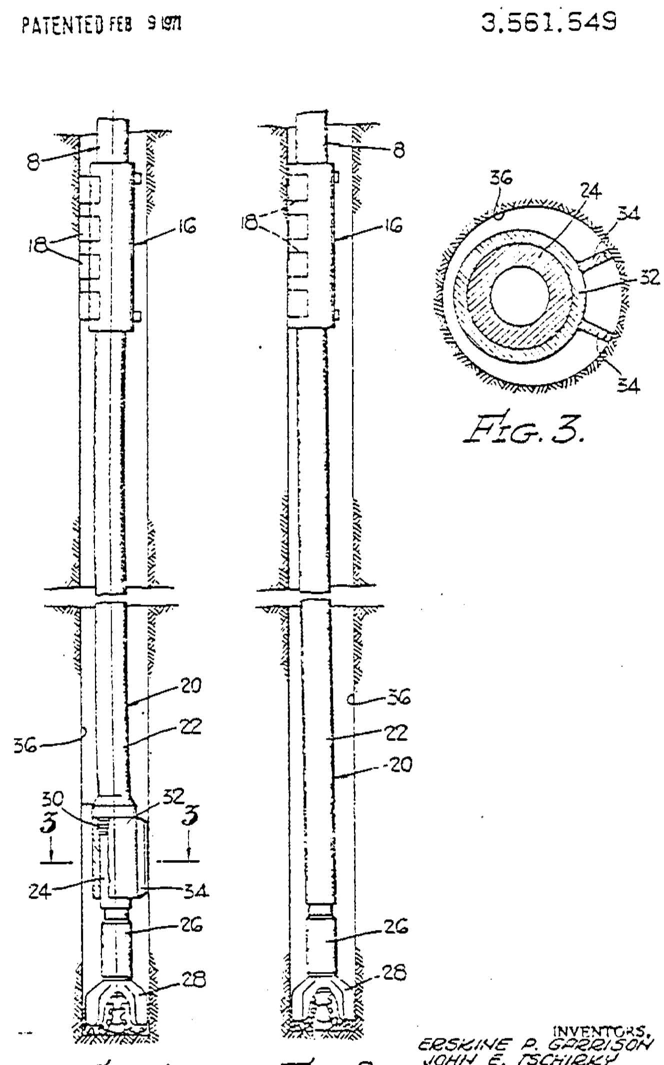



FIG. 1. FIG. 2. FIG. 3.

U.S. Patent 3,563,323 - Cont'd

Review

This invention consists of a group of flexible drill collars and a hinge joint. See Figure 3. The purpose of the hinge joint is to prevent transferral of excessive bending moment into a downhole motor, but still transmit axial load to the bit. This system is really not strongly related to the direct, active control of deviated drilling. The primary uses are avoiding bending over-stress on the downhole motor and assisting in providing a more predictable, constant lateral loading on the bit.

U.S. Patent 3,627,356 by Edwin A. Anderson

Patent Abstract

A deflection tool is provided for use in the directional drilling of a well bore into the earth. The tool includes a lower tubular assembly pivotally mounted within an upper tubular assembly. In use, the upper assembly is coupled to the lower end of a string of drill pipe and the lower assembly is coupled to a downhole fluid motor unit which drives a rotary drill bit. Drilling fluid flowing down the drill string drives a piston and lever mechanism located in the upper tubular assembly for urging the lower tubular assembly to pivot relative thereto. When a zero or other less-than-maximum pivot angle is desired, a retrievable limiting probe is run into the deflection tool for setting a limiting plug which limits the extent of the pivotal movement. Different pivot angles are obtained by using limiting probes of different sizes.

Review

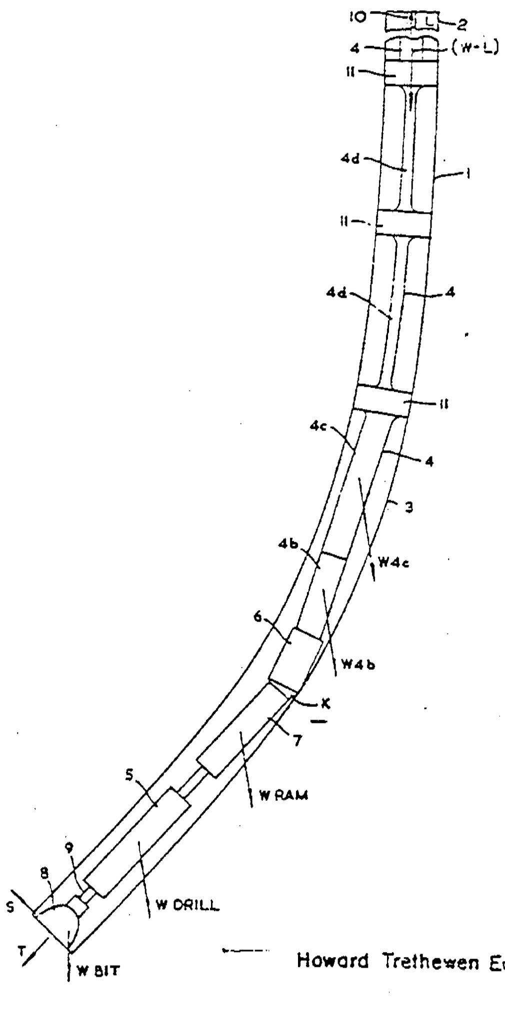
This patent covers the "Dyna-Flex" tool which was offered by Dyna-Drill and built by Bowen. See Figure 4. This bent sub tool operates by using pistons to force a knuckle joint to bend to an angle limited by an adjustable stop. The pistons work off the pressure differential between the string bore and the well annulus. The stop is extended by a wireline-run probe; larger diameter probes cause more extension and, hence, less bend angle.

This tool offers several advantages, particularly in its ability to be run-in straight and then varied without round-tripping the assembly. On the whole, the construction looks fairly robust. The tool has a large number of parts, but most are not overly complex, and tool dressing is likely not extremely difficult. Use of the pistons to urge bending permits the tool to encounter a blockage and still function.

FIGURE 3

Apparatus For Borehole Drilling

PATENTED FEB 16 1971 3,563,323



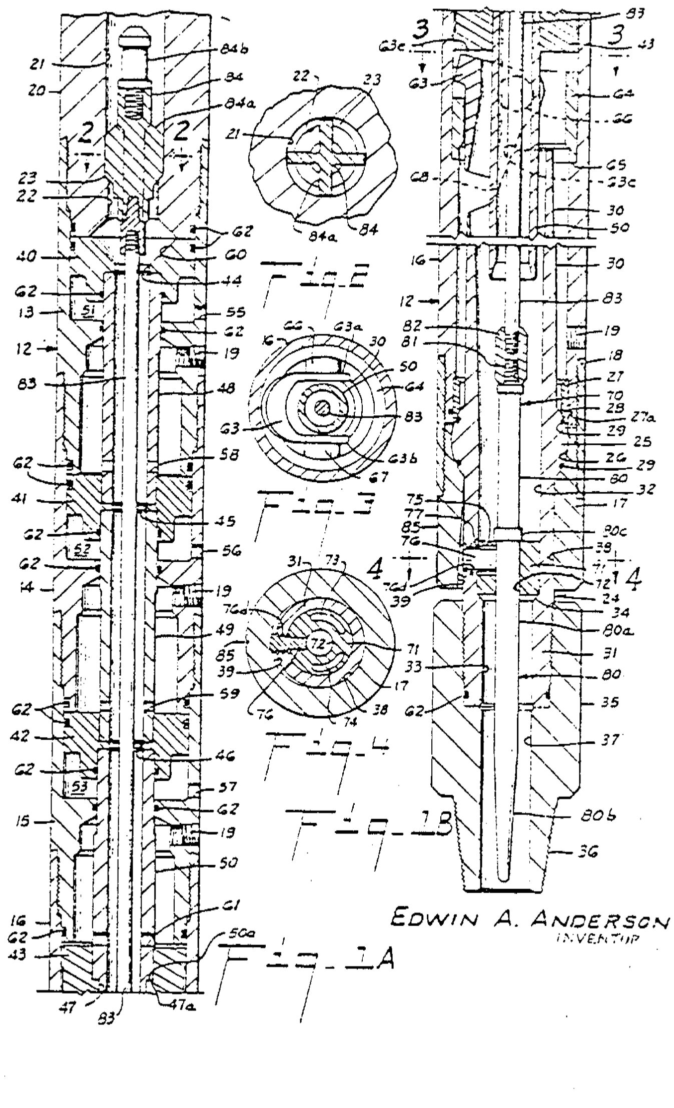

INVENTOR
Howard Trethewen Edgecombe

FIGURE 4

Directional Drilling Apparatus With Retrievable Limiting Device

PATENTED DEC 14 1971

3,627,356



The disadvantages appear to be related to the reduced circulation area available and the moving pistons with attendant wash-out possibilities. Unless the chambers above the pistons sand up, the tool should straighten for retrieval. The survey tool can be arranged to be connected to the top of the wireline-run probe. More commentary on this tool is given in the literature survey in the next section of this report.

## U.S. Patent 3,667,556 by John K. Henderson

### Patent Abstract

This invention relates to a directional drilling apparatus. More particularly, the invention is a drilling tool including provisions for changing the direction of drilling of a borehole, the tool including a tubular body having means at the upper end for attachment of a drill string, a drill bit affixed to the lower end of the body by means of a slip clutch drill bit so that the drill bit is rotated when the tubular body is rotated while permitting the drill bit to be rotated independently of the body, means within the tubular body for rotating the drill bit, and means controllable from the surface of the earth of varying the angle of the drill axis of the drill bit relative to the tubular body.

### Review

This patent covers a tool intended for use with rotating drill-strings. See Figure 5. This tool is included here because, when it is used to deviate a hole, it functions as a bent sub. Routine drilling ahead is done in the normal fashion, but the downhole motor in the string is used with a non-rotating string to induce deviation. The amount of deviation is controlled by a servo used to cause the bit to skew.

This approach would be best suited to large diameter tools because of the space required. Development of adequate power downhole is a problem with an electic motor and the electical connections and size constraints. A bypassable downhole hydraulic motor could conceivably be used as an alternate. Probably the most difficult problem is obtaining sufficient durability in the equipment that will be subjected to the difficult rotary drilling environment

FIGURE 5

Directional Drilling Apparatus

PATENTED JUN 6 1972 3,667,556

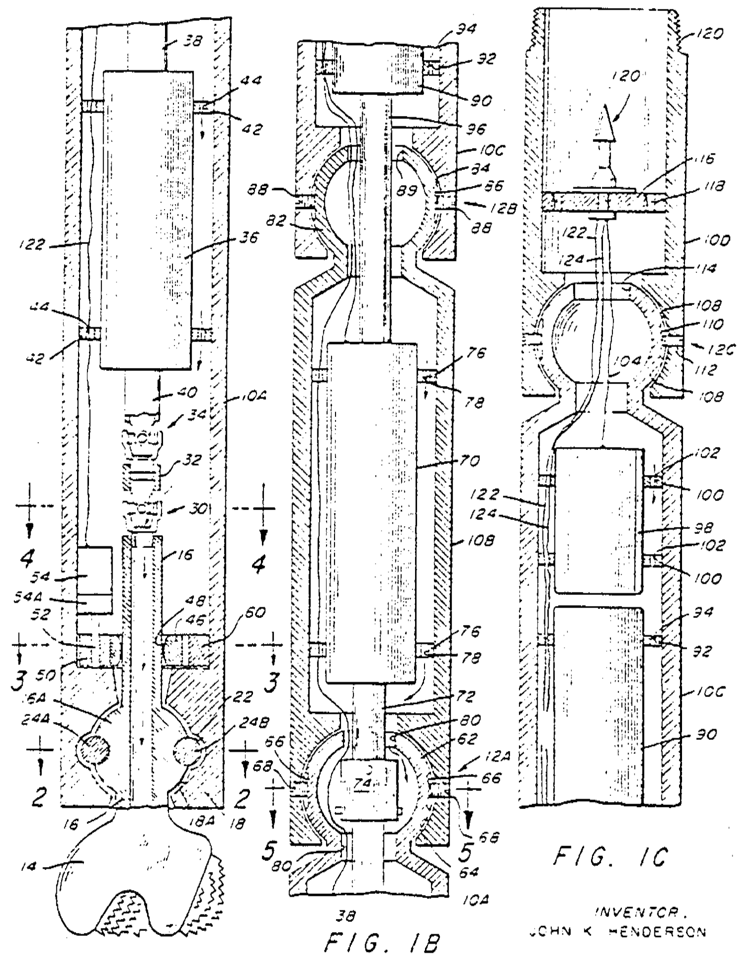



FIG. 1A FIG. 1B FIG. 1C

most of the time. Thin-walled body sections, near-bit clutches and ball joints, and reduced flow areas appear to be likely problems. The downhole electrical connector for high voltages and amperages may not be a real problem. Henderson has another patent covering connectors (U.S. 3,398,392) which could possibly suffice; that patent is not reviewed here. Some commercial subsea connectors could also be satisfactory.

## U.S. Patent 3,713,500 by Michael K. Russell

### Patent Abstract

Control means for fitting at the lower end of a drill pipe adjacent drilling means to control directional drilling comprise servo means for changing the drilling angle and further servo means for turning the control means with respect to the drill pipe axis in order to reorientate the device without changing the drilling angle. The control means also comprise means for programming and/or controlling both servo means by signals set in, or transmitted from, above ground.

### Review

This patent covers a type of sophisticated bent sub device which is likely to become fairly common when "measurement-while-drilling" systems are matured. See Figure 6. A downhole energy source, either hydraulic or electrical, is powered by the circulation through the drillstring. Downhole sensors are used to determine orientation. Sensor outputs are then used to separately control bent sub bend angle and axial rotational position of the tool relative to the drillstring. These two controls are effected by suitable servos. Changes in preprogrammed settings for the downhole controls can be transmitted by wireline or a wireline retrievable pump-down control signal carrier.

The problem with such devices is their complexity and possible sensitivity to the downhole environment. The provision of adequate force from the servos for actuation is also likely a major consideration. Since no detailed apparatus is shown, it is difficult to evaluate the practicality of a device based on this tool.

<u>FIGURE 6</u>

Drilling Devices

PATENTED JAN 30 1973 3,713,500

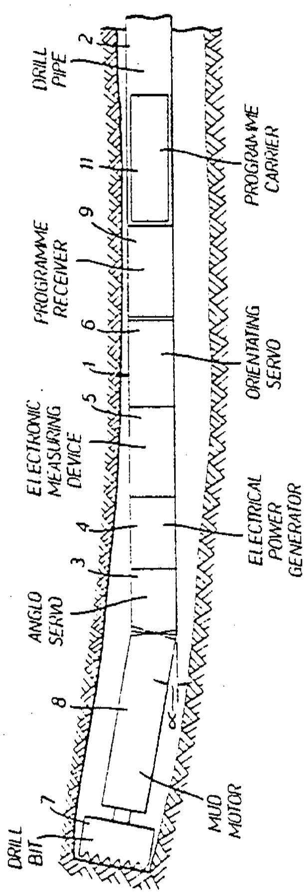



FIG. I.

INVENTOR
MICHAEL KING RUSSELL

## U.S. Patent 3,811,519 by W.B. Driver

### Patent Abstract

According to the invention a downhole remote control directional drilling system uses a downhole motor to operate the drill bit and provide power to generate the electrical and hydraulic power used to operate the system's remote control guidance system and direct the drill bit. Also, the remote control guidance system is controlled by receiving direction commands radiated down the drill pipe string by electromagnetic waves and the remote control guidance system transmits direction and direction control components of the remote control directional drilling system to the top of the well hole.

### Review

This patent is for a bent sub device which is mechanically operated similar to some tunneling machines. See Figure 7. A flex joint is in the body positioned close to the bit and below a downhole motor. The drive shaft from the downhole motor is provided with a U-joint or flexible section adjacent to the body flex joint. Two opposed hydraulic cylinders control body flexure in one plane, and two other cylinders control body flexure in the transverse plane, where both planes intersect the drillstring axis. Power for generating the flow of actuating hydraulic fluid and electric power for operating the valves are taken from an accessory drive or drives off the downhole motor. Specific control means are not described, but use of the drillstring as an electromagnetic wave conductor is mentioned.

This approach could be made to work if the control signals were reliable and the hydraulic cylinders sufficiently strong and stiff. The flex joint could be located above the downhole motor, which would likely somewhat simplify the structure, but perhaps increase the loads on the tool's cylinders. Overall system reliability could be a problem, given the downhole environment.

## U.S. Patent 3,841,420 by Michael K. Russell

### Patent Abstract

A drilling head attachable to a drill pipe for directional drilling in a borehole is arranged to be rotatable with respect to the drill pipe and to be held in required orientation against the drill reaction torque by clutch means or by a torque balancing force.

FIGURE 7

Remote Control Directional Drilling System

PATENTED MAY 21 1974 3,811,519

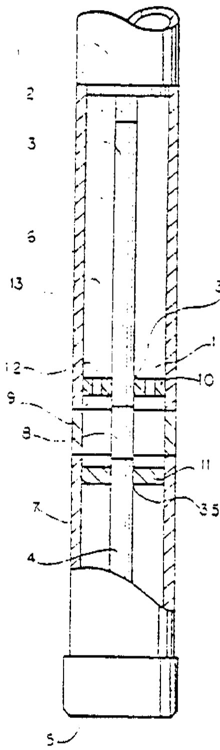



FIG. 1

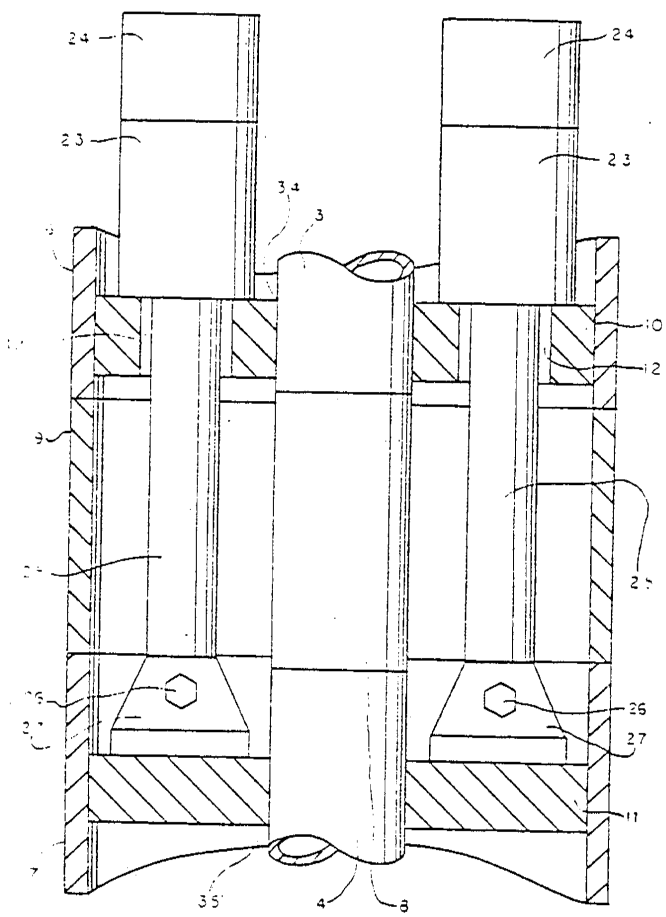



FIG. 3

INVENTOR

W. B. Driver

Patent Abstract-Cont'd

A counter torque may be set up by rotation of the drill pipe and applied as the torque balancing force. A loaded pump driven by the drill pipe is suitable for producing the counter torque, the loading being adjustable by restricting shunt flow or by varying the loading of an electrical generator driven by a hydraulic motor supplied by the pump.

The orientation is measured as an angle in a gravitational and/or geomagnetic frame of reference in a control circuit including a sensor unit located in the drilling head, the control circuit being preset or programmed or subject to command from the surface to hold the head at the required orientation.

Review

The purpose of this invention is to avoid unwanted lateral deflection components transverse to the desired plane of bending of a bent sub. See Figure 8. This is done by using a downhole servo mechanism to rotate the lower portion of the drillstring, including the bent sub or bent housing motor, to offset the torque-induced string windup. This particular patent is related to the same inventor's U.S. Patent 3,713,500, which is also reviewed in this section of the report.

Two forms of the invention are covered: a) a non-rotating pipe corrector, and b) a corrector that requires rotating the pipe continuously. Both tools use either only downhole sensors or also permit control data transmitted into the unit via wireline. This particular patent appears more practical in the non-rotating version, but the need for any device of this type may be limited. Since specific apparatus is not shown, it is difficult to evaluate the practicality of the hardware. In any case, the apparatus is not likely to be simple or cheap.

U.S. Patent 3,903,974 by Roy H. Cullen

Patent Abstract

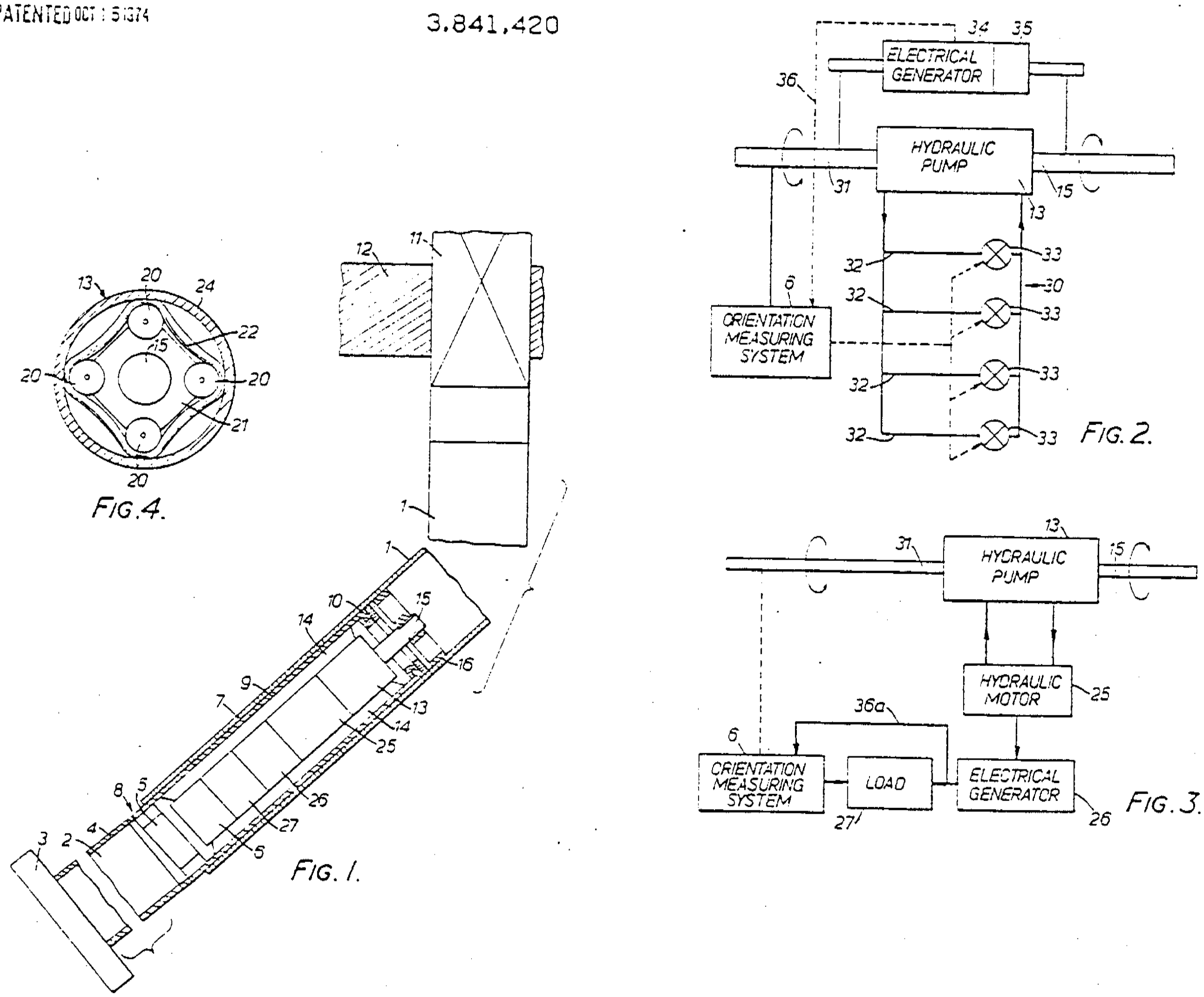
A drilling assembly, deviation sub therewith, and method of using same, wherein the deviation sub is for directional drilling of a well bore, and has an elongate deviation sub body adapted to be positioned in the well bore for extending longitudinally therein, and having a temperature variation means for causing a temperature differential in opposing longitudinal portions of the deviation

FIGURE 8

Directional Drilling Means

PATENTED OCT 15 1974

3,841,420




INVENTOR
Michael King Russell

Patent Abstract-Cont'd

sub body for causing the body to deviate from a first longitudinal position to a second longitudinal position at an angle to the first longitudinal position.

Review

This is an interesting bent sub concept, but it may not be practical because of thermal losses. See Figure 9. The tool curves due to unequal electrical heating of only one side of the body. The curvature attainable is limited due to circumferential heat losses which will tend to even out the expansion of the sub. The problem of transmitting power to the heaters from the surface could be solved by local generation from the mud motor. The unsymmetrical cross-section of the tool will produce bending in the weak direction when any axial load is applied to the tool. Tool behavior with the high level of vibrations and abrasion downhole is likely a problem. This tool is being developed by the Space Division of General Electric as a component of their Eletrodril System. Laboratory tests indicate that the concept may be feasible.

U.S. Patent 3,993,127 by V.G. Chepelev et al.

Patent Abstract

An apparatus is intended for drilling inclined boreholes with high degree of accuracy. The apparatus comprises a working implement having an electric drill and a deep compass with selsyn type sensors whose output signals carry the information on the position of the electric drill in the borehole. Means for controlling the position of the working implement is connected to said sensors and generates a signal in accordance with deviation of the output signals of said sensors from preset values. The output signal from said control means acts upon an actuator of the working implement to position it along a predetermined path.

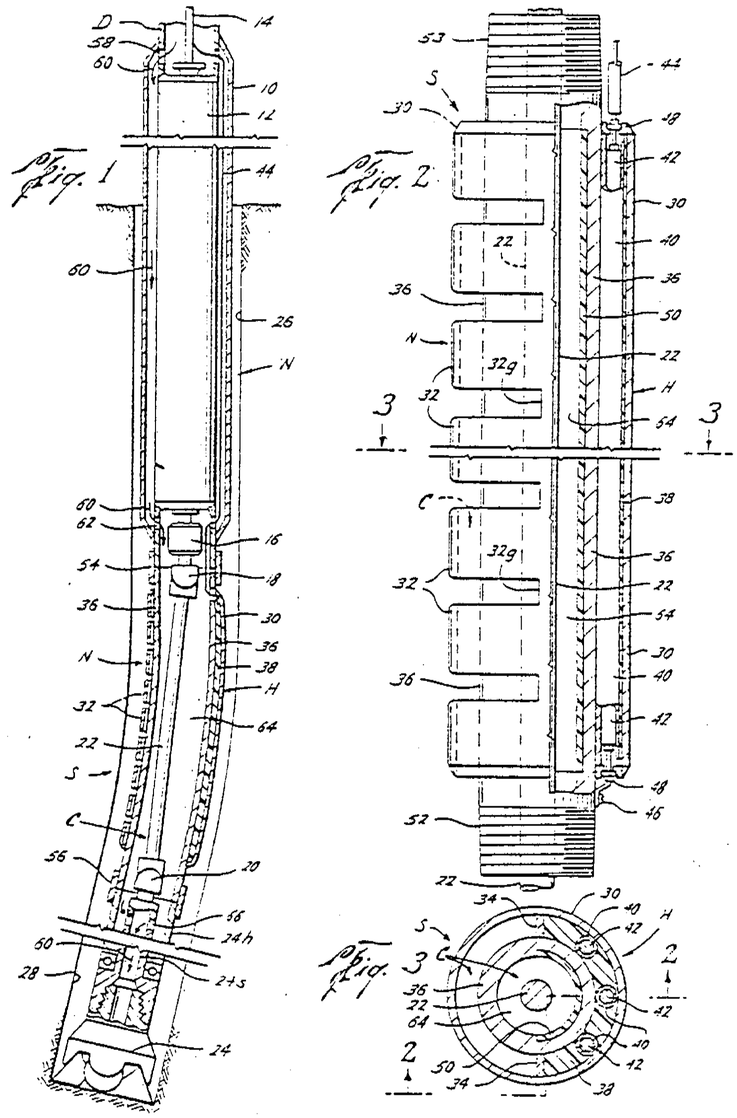
Review

This patent is predominantly related to the downhole electronic controls for a bent sub tool. See Figure 10. A schematic electric drive for rotating the lower portion of the drillstring, including the downhole motor, to a desired position is shown. No device is shown for controlling sub bend angle. Given that the main problem is in developing a satisfactory mechanical portion of the system, this patent is judged to be of only indirect interest on this project.

FIGURE 9

Drilling Assembly, Deviation Sub Therewith, and Method of Using Same

PATENTED SEP 9 1975 3,903,974



INVENTOR

Roy H. Cullen

<u>FIGURE 10</u>

Apparatus For Positioning A Working Implement In A Borehole

U.S. Patent Nov. 23, 1976 3,993,127

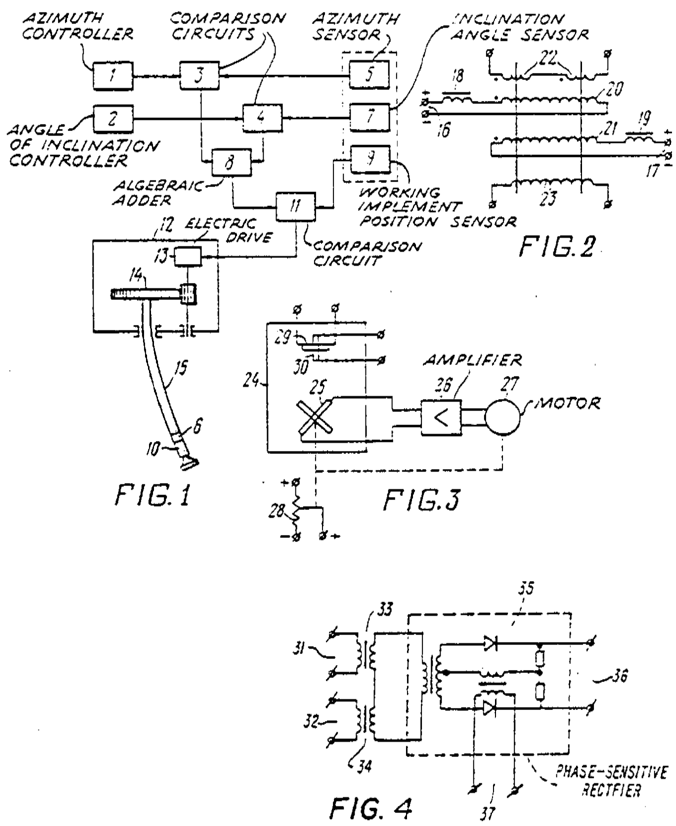



FIG. 1 FIG. 2 FIG. 3 FIG. 4

INVENTOR

Viktor Gavrilovich Chepelev et al.

## U.S. Patent 4,077,657 by Kurt H. Trzeciak: Adjustable Bent Sub

### Patent Abstract

This invention relates to a device for selectively setting the axial alignment of sections of pipe from axial coincidence to an obtuse angle between the pipe sections.

### Review

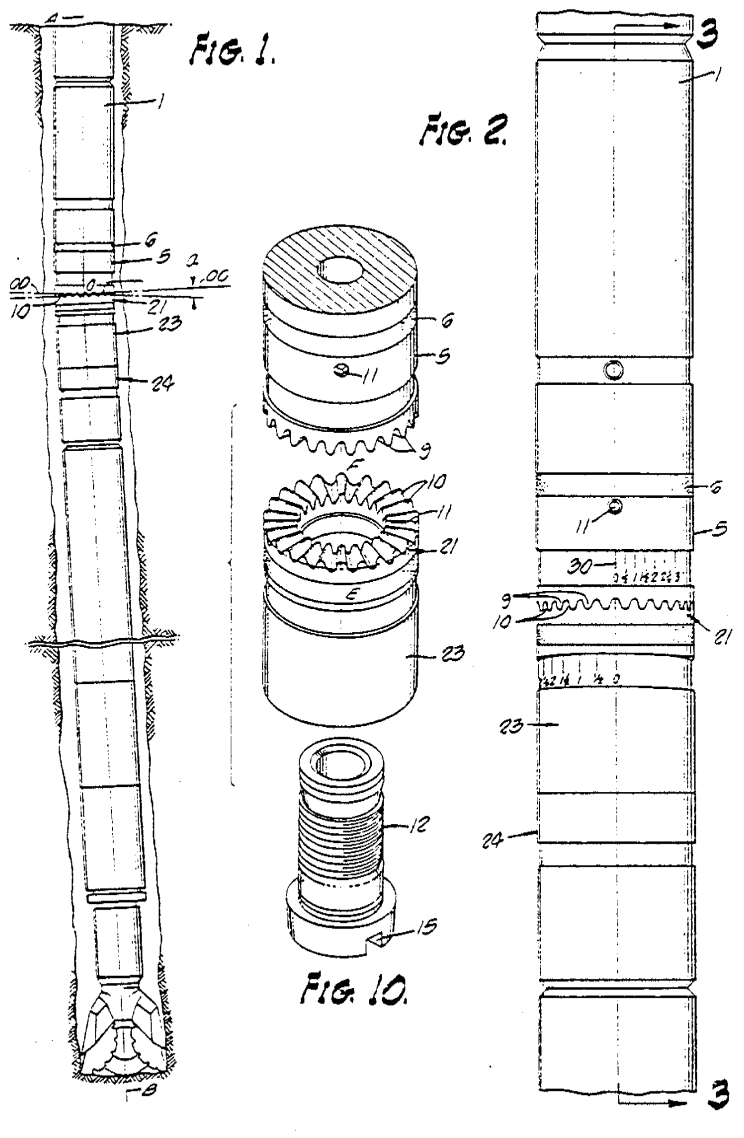
This is a very simple bent sub tool which can only be changed at the surface. See Figure 11. The tool is robust and permits avoidance of maintaining a whole inventory of different angle bent subs. The limitations are otherwise those of standard, non-adjustable bent subs.

The change in angle is effected by using a dog clutch, held by an internal screw, to clamp together upper and lower body pieces. The planes of the dog clutch faces are not normal to the body axes, but are both inclined by the same small amount (say, 2° or 3°) from the body axes. Relative rotation about the respective body axes permits obtaining bend angles from 0° to 2 times the dog clutch plane inclination from perpendicular to the body axis.

FIGURE 11

Adjustable Bent Sub

U.S. Patent March 7, 1978 4,077,657




INVENTOR

Kurt H. Trzeciak

U.S.S.R. Patent 275,917 by B.G. Smirnov et al.: Turbodrill for Directional Boreholes

Summary and Review

This tool is a multi-joint articulated turbodrill. See Figure 12. Guide means are not provided in the tool itself; rather, the weight of the collars buckles the tool to cause it to deviate in the manner of an articulated rotary drillstring. Kickoff probably would require a whipstock. The rate of bending would be such that the holes would be satisfactory only for drainholes. Steel casing could not be run in the resultant hole. The practicality of this tool is difficult to assess, but it would likely be difficult to maintain. This tool is not really related to this study.

U.S.S.R. Patent 543,730 by M.T. Gusman et al. Tool Joint for Helical Rotor Downhole Drills

Summary and Review

This is a simple ball joint type tool with the inner ball having a diameter less than its socket. See Figure 13. The difference in diameters determines the bend angle to some extent and supposedly reduces friction. This tool is not really related to this project; it may conceivably be applicable to articulated drillstring use.

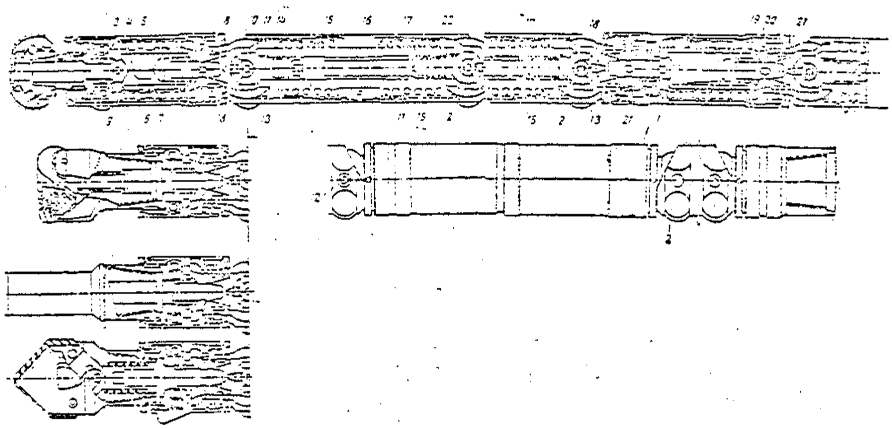
U.S. Patent 2,891,769 by John S. Page, Sr. et al. Directional Drilling Tool

Description

This tool consists of a sleeve body journaling a torque-transmitting mandrel. See Figure 14. On opposite sides of the sleeve at different elevations are extendable pistons which cause stabilizer blades, parallel to the tool axis, to be pressed against the side of the hole. The blades maintain the tool orientation at its presurveyed value and exert a bending moment from a force couple on the string to deviate the bit. The tool can be temporarily latched to the mandrel for positioning.

FIGURE 12

Turbodrill For Directional Boreholes

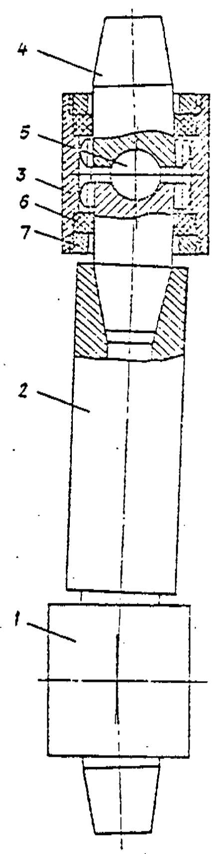


INVENTOR

B. G. Smirnov et al.

FIGURE 13

Tool Joint For
Helical Rotor Downhole Drills




INVENTOR

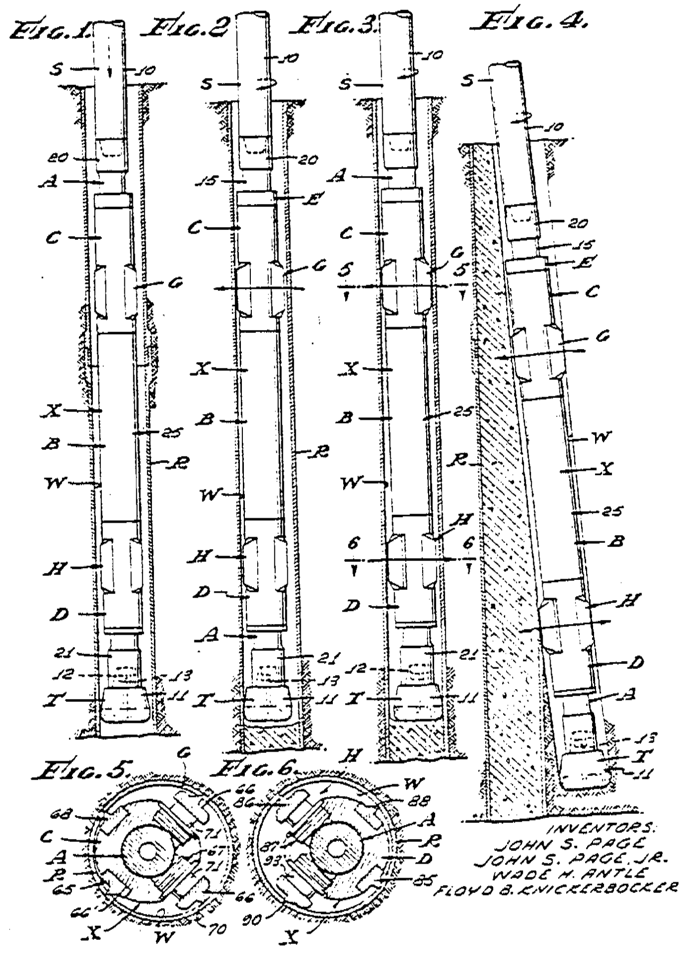
M. T. Gusman et al.

FIGURE 14

Directional Drilling Tool

June 23, 1959 J. S. PAGE, SR., ET AL 2,891,769

DIRECTIONAL DRILLING TOOL



U.S. Patent 2,891,769 - Cont'd

## Review

This rotating string tool is always "on" when the pumps are working, but a wireline-run means of paralyzing the tool could perhaps be devised. The tool is fairly large, with a lot of pieces, so that dressing would be a problem. The tool has several moving seals, with attendant washout possibilities. The tool stiffness, particularly in the mandrel, is likely to cause problems. Withdrawal of the pistons when stopping the mud pumps could also necessitate frequent resurveys. The tool would trip in and out of the hole with the blades retracted. Sanding up could perhaps occur. The generic problems of tools which journal the string in a non-rotating sleeve will apply. On the whole, this tool would probably not be satisfactory in a rotary drilling environment because of reliability and cost problems. Use as a bent sub tool could avoid the worst of the fatigue problems.

## U.S. Patent 3,023,821 by W.H. Etherington
## Well Tool

## Description

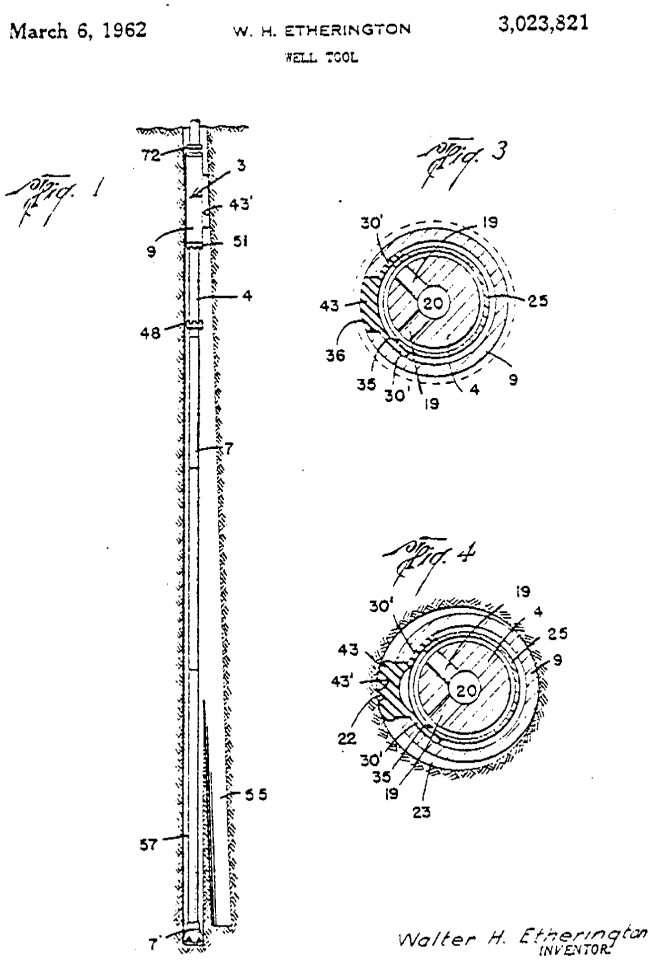
This is a sleeve type tool which shoves laterally on the wellbore and journals the mandrel connecting the drillstring. See Figure 15. The sleeve has a molded-in or bonded-in rubber piston extending parallel to the tool axis on one side. When the mud pumps are on, the piston expands to the side of the hole and displaces the mandrel off-center in the hole. When the pumps are off, the rubber piston retracts. The mandrel has upper and lower stops to limit the axial movement of the sleeve. A dog clutch is provided on the lower stop so the sleeve can be rotated to its desired orientation. The tool must be repositioned at the lower end of the mandrel when its stroke is completed so that it can be restroked.

## Review

This is a simple tool with a minimal number of moving parts. The number of wear points is minimal, but critical. The mandrel is exposed to severe wear unless it is kept fairly short and wiped carefully. Without good mandrel, mandrel wiper, and mandrel seal behavior, a washout will rapidly occur. As a consequence, the tool strokes must be short, so that there is increased potential for disorientation. If the tool is overstroked, the rubber is liable to be damaged or torn. The tool could sand up and the bearings would run in mud. Probably, the tool could be paralyzed

## FIGURE 15

Well Tool



Review-Cont'd

with a wireline-run sleeve. The tool would run in and out retracted. This probably would be an inexpensive tool. With provision of a metal skid plate on the rubbing surface of the rubber piston, stroking could perhaps be avoided. It is difficult to estimate the mandrel strength and stiffness without a design check, but this could be a problem. The tool probably would not be at all satisfactory for rotary drilling as is. Extensive simplification might make it a good near bit deflector for a downhole motor.

## U.S. Patent 3,298,449 by W.S. Bachman et al
## Well Bore Apparatus

### Description

This rotating string tool has a non-rotating sleeve which journals a mandrel connected in the string. See Figure 16. Lateral deflection is obtained by a rubber piston(s) on one side of the sleeve expanded by the differential pressure between inside and outside the string. Alternate rubber piston designs and conventional pistons are shown. A latch is provided to hold the tool in a desired alignment with the drillstring until rotation to the right is begun. Blanking subs can be run on wireline to paralyze the tool. After the tool mandrel is stroked the full length of the mandrel, the tool must be reset.

### Review

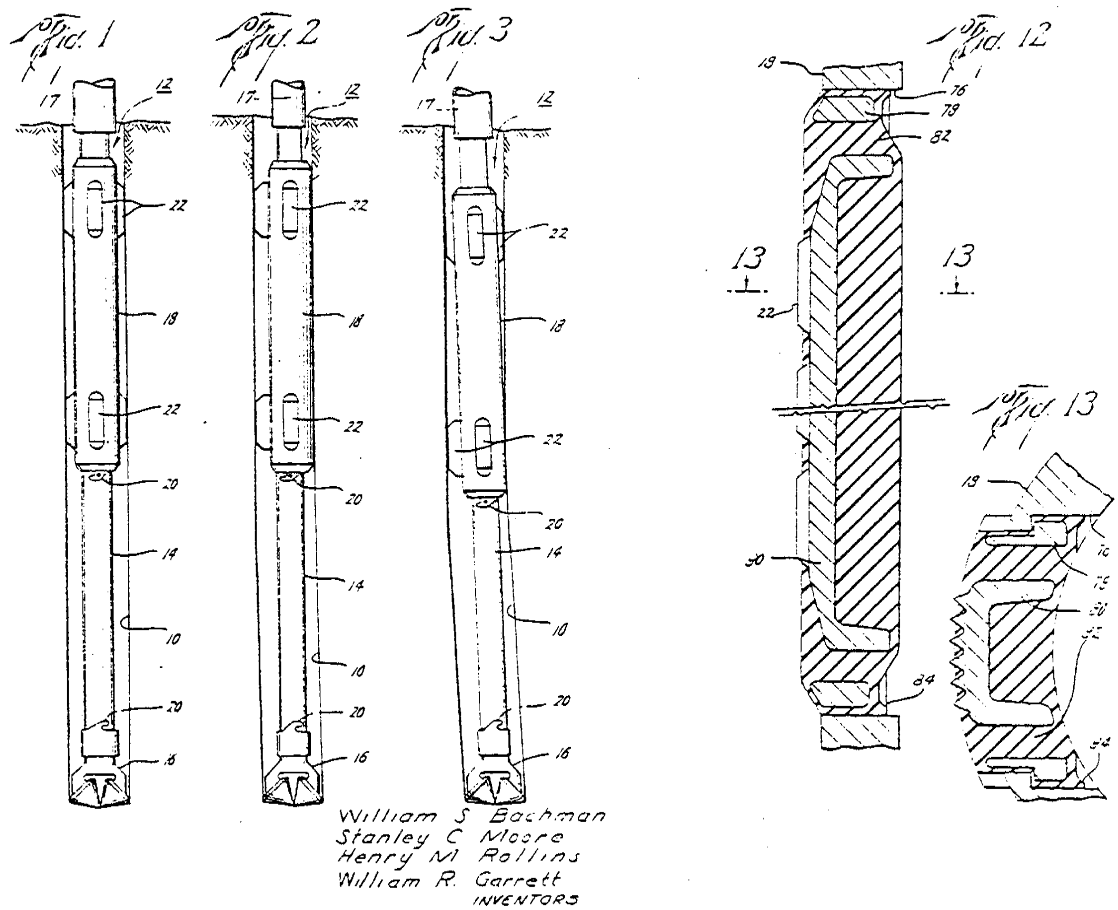
This and related U.S. Patents No. 3,326,305 and 3,460,639 cover the Drilco "Bit Boss" tool features. The tool is relatively simple, with some good design details. In particular, the rubber pistons offer a good way to avoid system contamination. The latch is simple and easy to operate, but unexpected release of torsional strain in the drillstring can necessitate frequent resurveys after resetting the tool for another stroke. The tool structure will be weaker and less stiff than the adjacent drill collars, and therefore could have fatigue problems. The rubber bearings are likely good for use sliding and rotating on the mandrel. Mandrel scratches can lead to a washout. The tool likely is less resistant to washing out than non-sliding tools; if the sleeve end seals leak or the rubber pistons leak or debond, a washout will occur. There is some possibility of sanding-up, as the working fluid is mud, rather than oil.

<u>FIGURE 16</u>

Well Bore Apparatus

Jan. 17, 1967 W. S. BACHMAN ETAL 3,298,449

WELL BORE APPARATUS



U.S. Patent 3,326,305 by William R. Garrett and Jeddy D. Nixon,Jr.
Drill Bit Control Apparatus

Description

This tool for rotating drillstrings is essentially a modified version of U.S. Patent 3,298,449. See Figure 17. A sleeve carrying expandable rubber pistons for laterally thrusting on the wall journals the mandrel in rubber bearings. The tool uses the differential between string internal and external pressure to expand the rubber pistons. An improved latch and alignment section and a paralyzer tool are included. When the tool bears on the bore wall, the mandrel can be rotated and reciprocated through the mandrel.

Review

The wireline-run paralyzer sleeve is an improvement needed for the tool. The improved alignment section and latch are useful and not likely to be sanded up. The tool still appears to have a likelihood of being prone to washing out, particularly if the mandrel is damaged or the rubber in a piston debonds.

U.S. Patent 3,370,657 by W.H. Antle
Stabilizer and Deflecting Tool

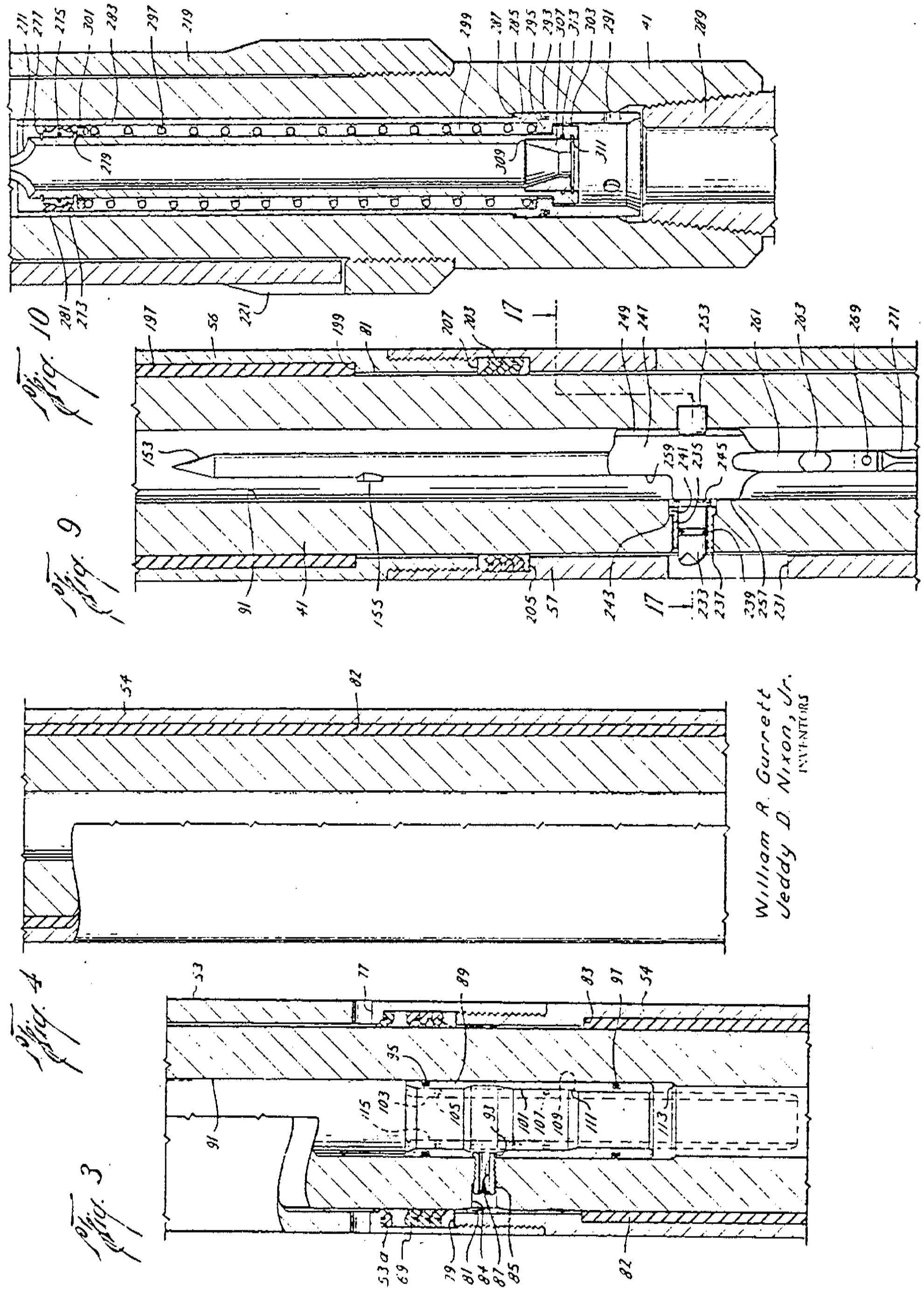
Patent Abstract

A stabilizer and deflecting tool engageable between the lower end of a string of drill pipe and a rotary bit of a well drilling structure including an elongated, vertically disposed, fluid conducting body having a splined socket entering its lower end and secured to a depending from the drill pipe string, an elongated, vertically disposed, fluid conducting mandrel having a splined upper end portion secured to and projecting upwardly from the bit with its splined portion telescopically engaged in the socket in the body to prevent relative rotation and allow for relative axial shifting between the body and mandrel, an elongate, vertically disposed, tubular shell surrounding the mandrel and the body and having a plurality of circumferentially spaced openings therein, means coupling the shell to the body for free relative rotation and for limited relative axial shifting, anti-friction bearing means coupling the lower end of the shell to the mandrel for free relative rotation and against relative axial shifting, an axially shiftable carriage in the shell and surrounding the mandrel, a plurality of circumferentially spaced bore engaging shoes engaged

FIGURE 17

June 20, 1967 W. R. Garrett et al. 3,326,305

Drill Bit Control Apparatus



Patent Abstract-Cont'd

in the openings in the shell for radial shifting only, means operatively connecting the carriage to the shoes to urge the shoes radially outwardly in the openings in the shell upon downward movement of the carriage, a first spring means between the shell and the carriage yieldingly urging the carriage upwardly, and a second spring means in the shell between the lower end of the body and the carriage to urge the carriage downwardly against the resistance of the first spring means upon downward movement of the body relative to the mandrel and the shell.

Review

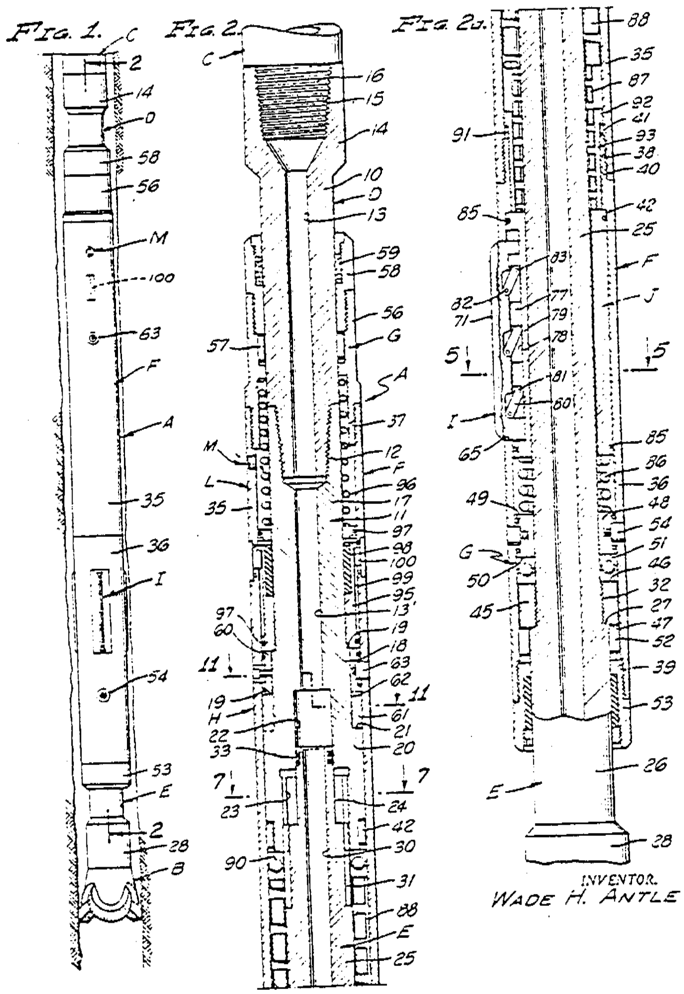
This is a tool for use with rotating drillstrings which could possibly be adapted for use with downhole motors. See Figure 18. A sleeve, carrying an expandable blade or blades, journals a mandrel in the string. A splined, axial slip joint is provided in the mandrel, along with a clutching mechanism to permit orienting the sleeve by temporarily coupling the sleeve to the mandrel. A heavy spring and the weight of the suspended string below the mandrel slip joint normally stroke out the slip joint when the bit is off bottom. When weight is put on the bit, the slip joint strokes in, shifting a piston, which radially forces out the stabilizer blades with a linkage.

The tool appears to have somewhat more than typical structural stiffness. The degree of isolation of the few moving parts from the mud is good. The tool is fairly simple, but may be difficult to dress because of the large springs. The linkage arrangement for the stabilizer blades does not look particularly robust, but does provide positive blade retraction. Positive retention of the blades in the sleeve, even if the linkage fails, is desirable. A reliable tool paralyzation mechanism would improve the tool so that normal drilling could proceed. The tool would be subject to the typical bearing and bearing seal and fatigue problems of rotating type tools. For its planned purpose, this would likely be comparable in performance to similar tools.

## FIGURE 18

Feb. 27, 1968 W. H. ANTLE 3,370,657

STABILIZER AND DEFLECTING TOOL



U.S. Patent 3,424,256 by J.D. Jeter et al
Apparatus for Controlled Directional Deviations of a Well Bore as It is Being Drilled

Patent Abstract

An apparatus for controlled well bore directional deviations with upper and lower laterally movable borehole abutments which exert lateral force on the drill string in which they are incorporated. The force on the upper abutments is transmitted through a hydraulic system to the lower abutments. The hydraulic system has a higher pressure than the pressure of the drilling system and has a substantially constant volume between the abutments.

Review

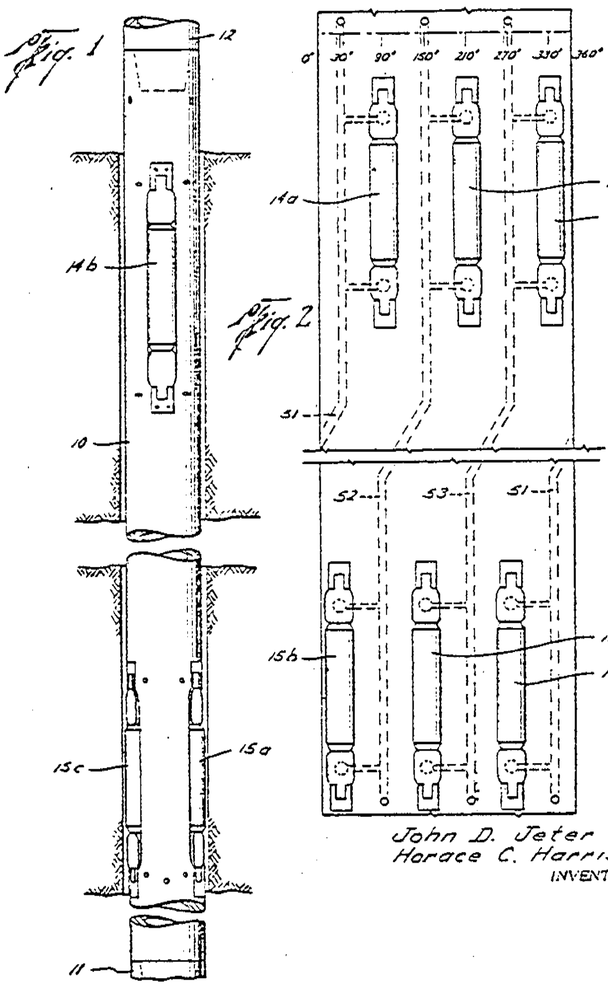
This is a tool for use with rotating drillstrings. See Figure 19. Instead of using extendable stabilizer blades or a non-rotating sleeve, this tool uses an upper and lower set of rollers that are extended by pistons. The upper rollers are used as sensor rollers and the lower rollers as deflector rollers. The two sets of rollers are spaced around the tool body at 120° spacings, but the top set is rotated 60° relative to the bottom set. The hydraulic cylinders behind the pistons of each individual upper roller are interconnected to the corresponding cylinders of the roller below and 60° clockwise (looking down) from the upper roller. When circulation is begun, a piston-balanced reservoir transmits a multiplied pressure differential to extend the rollers of both sets out to the hole wall. The induced displacements (of the upper sensor pistons being "pumped" by the deviations of the string centerline from the hole axis) are used to produce compensating displacements in the lower deflector pistons.

This patent is somewhat similar to that of R.Q. Fields' U.S. No. 3,593,810, reviewed later in this section. The body of this tool is likely stronger and more fatigue resistant than typical tools of this type; structurally, the body is comparable to a roller reamer. There is no paralyzation means shown for the tool, but a wireline-run means could likely be devised. There is some likelihood of washouts with this design. The relative phasing of the transverse loadings used for deflections is not adjustable. Even with minimal hole deviation from gauge, it probably is questionable whether a tool of this type would be able to run true, since the drillstring relative stiffnesses at both roller locations and the restrictions in the flow from piston set to piston set influence response. While the design details of many parts of the tool are good, the overall practicality is questionable.

FIGURE 19

Jan. 23, 1969 J. D. JETER ETAL 3,424,256

APPARATUS FOR CONTROLLING DIRECTIONAL DEVIATIONS OF A WELL BORE AS IT IS BEING DRILLED




John D. Jeter
Horace C. Harris, Jr.
INVENTORS

U.S. Patent 3,460,639 by William R. Garrett
Latch for Drill Bit Control Apparatus

Patent Abstract

The hydraulic guide barrel for a drill bit mandrel is releasably latched to mandrel in lower position of barrel on mandrel by a latch pin radially reciprocable in mandrel into and out of engagement with a slot in the barrel. The pin is positively driven by a cam which reciprocates axially in barrel in response to prodominating of two forces, namely, an upward force provided by a helical compression spring and a downward force provided by fluid in the mandrel acting against piston connected to cam.

Review

This patent for rotating drillstrings is related to U.S. Patents No. 3,298,449 and 3,326,305. See Figure 20. The patent covers a similar device with a different type of latch to clutch the sleeve to the tool mandrel. The device looks satisfactory.

U.S. Patent 3,565,189 by Herbert J. Hart
Apparatus for Monitoring and Controlling a Tool in a Borehole

Patent Abstract

The particular embodiment described herein as illustrative of one embodiment of the invention is directed to control circuitry for a selectively-operable hydraulic system employed for moving a wall-engaging member on a well tool into and out of contact with a well bore wall. To insure that the wall-engaging member is retained in contact with a well bore wall with sufficient force, the control circuitry is uniquely arranged to reactivate the hydraulic system whenever the output pressure thereof decreases below a predetermined level.

Review

This tool is related to oilwell logging work, but is concerned with obtaining a transverse thrust against the hole wall. See Figure 21. The tool is electrically controlled and evidently has no direct adaptation possibilities for deviated drilling use.

# FIGURE 20

**Aug. 12, 1969** W. R. GARRETT 3,460,639

LATCH FOR DRILL BIT CONTROL APPARATUS

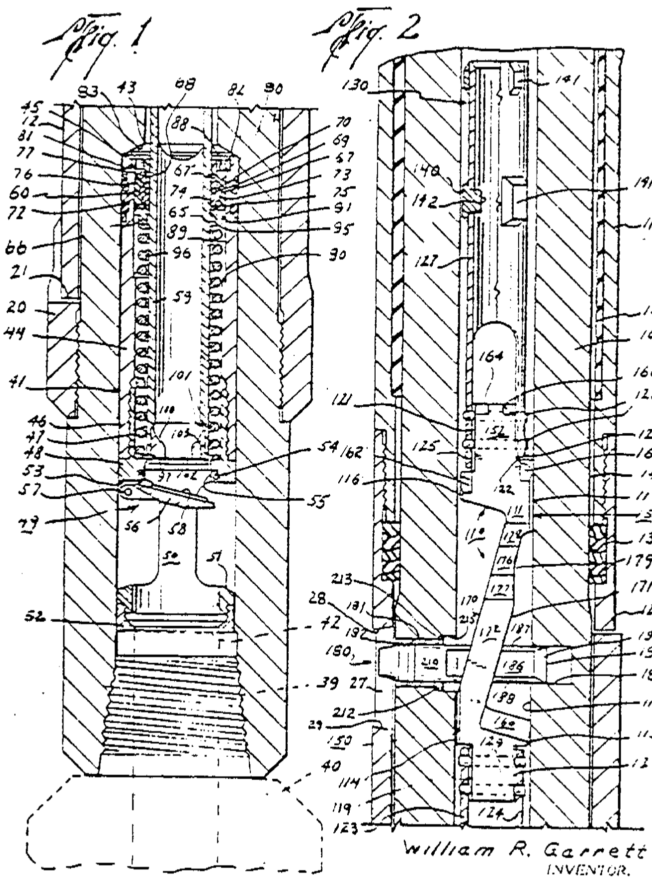


FIGURE 21

Apparatus For Monitoring And
Controlling A Tool In A Borehole

PATENTED FEB 23 1971 3,565,189

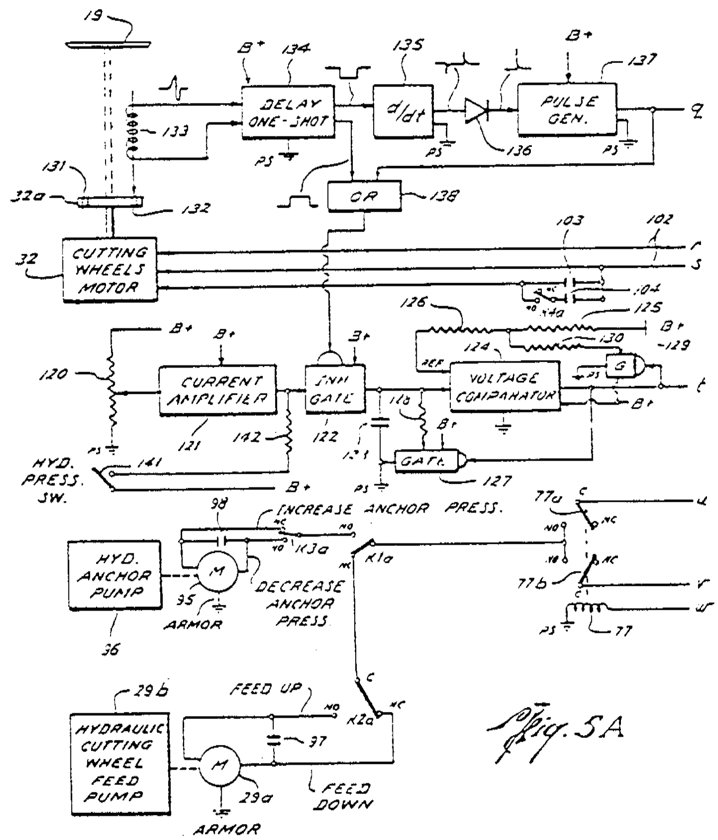


Fig. 5A

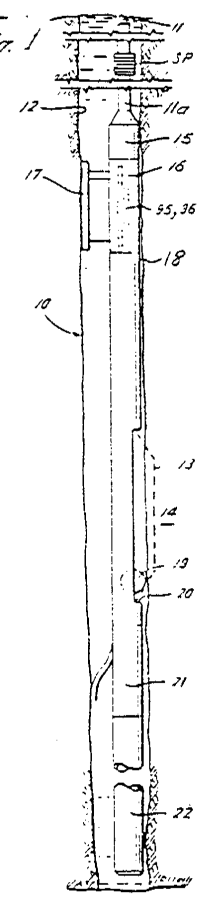


Fig. 1

Herbert J. Hart
INVENTOR.

U.S. Patent 3,572,450 by Derry R. Thompson
Well Drilling Apparatus

Patent Abstract

Apparatus for drilling directional bore holes in the earth and for preventing or correcting lateral drift in bore holes comprising at least one undergauge stabilizer blade and at least one movable stabilizer blade connected to a drill string sub so that flow of drilling mud through an orifice valve in the drill string forces the movable stablizer blade outward and into contact with the wall of the bore hole, thus urging the drillstring toward the opposite wall of the bore hole. The apparatus may be used alone or in pairs to alter the direction of the bore hole.

Review

This simple tool is intended for use with rotating drillstrings, but can also be simplified for use with downhole motors. See Figure 22. A pair of rotationally coupled sleeves journaling the mandrel support upper and lower ends of one extendable and two non-extendable blades. The upper sleeve is rotationally clutched to the mandrel initially. Inside the mandrel is a tubular internal sleeve with a restricted orifice in its bore; mud flow-induced pressure drops bias the internal sleeve downwardly, and a spring biases it up. Pins projecting through the mandrel wall connect the internal sleeve to the upper external sleeve. When the flow pressure drop is sufficient, the internal and upper external sleeves move downwardly to extend out the movable blade stabilizer. Stopping or slowing the pumps retracts the blade.

This tool has positive blade expansion and retraction, but the blade still might be prone to bind in a keyseat. There is a distinct possibility of a washout with the moving seals shown. Use of a dog clutch can avoid accidental misalignments resulting from pump stoppage and the rotational torque applicable with the clutch shown. The orfice can be made wireline retrievable to permit paralyzation of the tool or cause it to be more easily expanded. The bearings and maintenance of outer sleeve alignment are potential problems. The structure of the mandrel is increasingly weakened in smaller diameter tools. The practicality of this tool can be improved from what is shown in the patent drawings, but the potential tool reliability is questionable.

FIGURE 22

Well Drilling Apparatus

Patented March 30, 1971 3,572,450

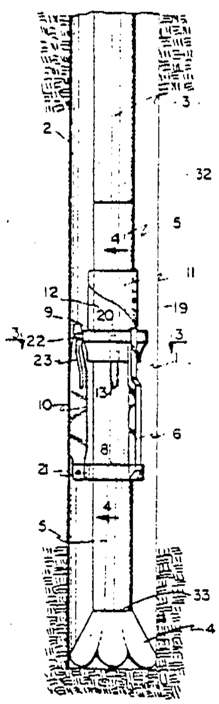



FIG. 1

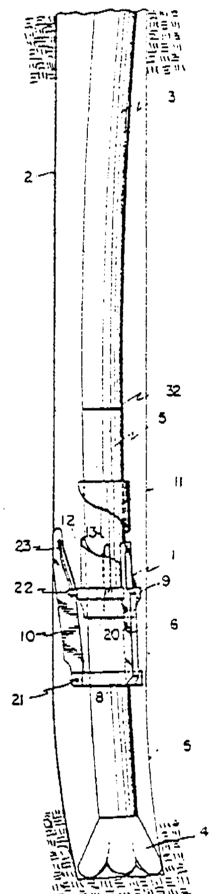



FIG. 2

INVENTOR
DERRY R. THOMPSON

## U.S. Patent 3,593,810 by Roger Q. Fields
## Methods and Apparatus for Directional Drilling

### Patent Abstract

In each of the several embodiments of the apparatus of the invention disclosed herein, a new and improved tool carrying a drill bit is dependently coupled from a drill string and lowered into a borehole which is to be excavated in a desired direction. First and second sets of wall-engaging members are operatively arranged around the tool in such a manner that, as the weight of the rotating tool is successively supported by each of the first members, commensurate outwardly directed forces will be successively imposed on each of the second members for urging the drill bit in a desired lateral direction. Various controls adapted for operation from the surface of the earth are disclosed for selectively interconnecting the first and second wall-engaging members so as to either maintain the course of the drill bit along a vertical axis or else to direct the drill bit in a selected azimuthal direction and inclination. In practicing the methods of the present invention, a tool bit connected thereto is coupled in a drill string and positioned in a borehole. Depending upon the particular tool, the controls on the directional drilling tool are then regulated from the surface to direct the drill bit along a selected course for continuing the excavation of the borehole.

### Review

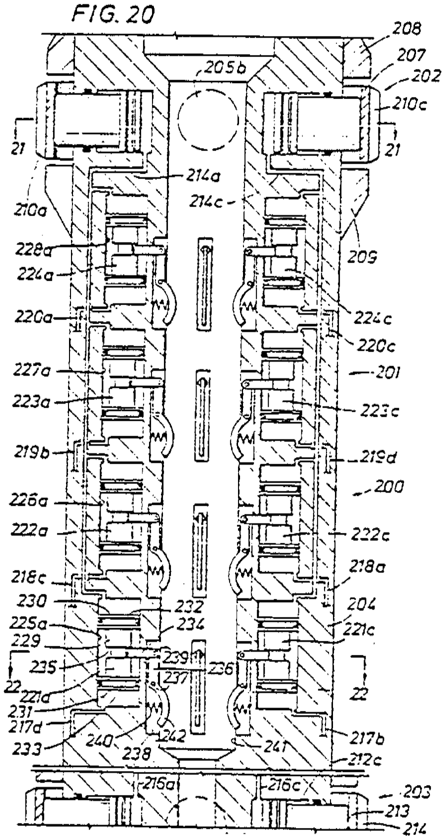
This is a very complex family of similar tools for use with a rotating drillstring. See Figure 23. A pair of spaced-apart, non-rotating stabilizer sleeves journal the tool mandrel connected into the string. The upper stabilizer sleeve serves as a deviation sensor, and the lower, adjacent the bit, serves as the deflector. There are no external wall penetrations by stabilizer blades; rather, pistons for offsetting the mandrel from the bore of the sleeve are mounted in the mandrel itself. These pistons are then dynamically cycled to hold the mandrel in a desired position relative to the sleeve centerline. The sensor sleeve functions in the same manner with its pistons as the deflector sleeve, but serves as a pump. Different control valving arrangements are shown for operating the tool.

The tools shown here are fairly complex hydraulically. Hydraulic system contamination could be critical, but does not look too likely with careful assembly. The separation of the pistons from mud is a very good design detail. The structural stiffness and strength of the tool cannot be determined without investigating an actual design, but may be better than average. Special considerations, such as relative lateral stiffness of the drillstring at the sensor sleeve and the deflector sleeve are important factors for determining if the pump can overcome the feedback pumping resistance of the deflector. Reliable operation of a rotating

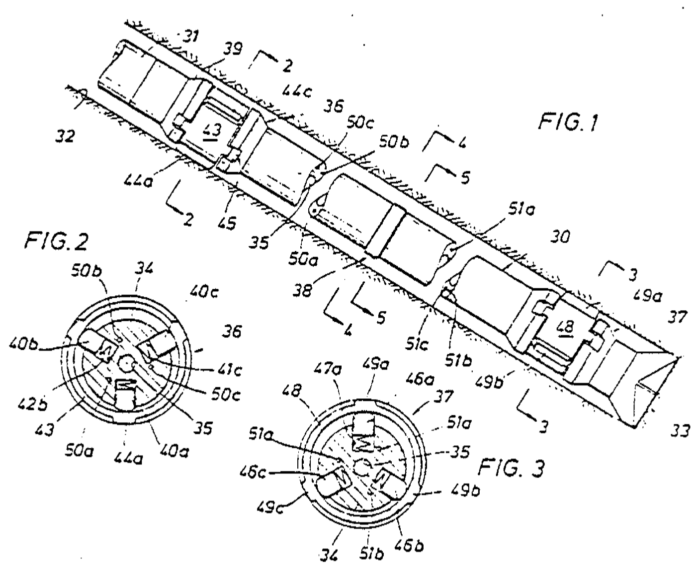
## FIGURE 23

Methods And Apparatus
For Directional Drilling

*FIG. 20*




PATENTED JUL 20 1971 3,593,810




Roger Q Fields
INVENTOR

Review-Cont'd

tool of this type close to the bit is questionable. The tool will be expensive to build, but maintenance costs may not be as severe as for other tools with more exposure of moving parts to mud. The overall practicality and economics of this tool are difficult to evaluate without tests; the complexity of the tool and the control problems make its practicality suspect.

## U.S. Patent 3,595,326 by Jackson R. Claycomb
## Directional Drilling Apparatus

Patent Abstract

As a preferred embodiment of the invention disclosed herein, a new and improved tool carrying a drill bit on its lower end is dependently coupled from a drill string and lowered into a borehole which is to be excavated along a selected axis. One or more pressure-responsive wall-engaging members are operatively arranged on the tool in such a manner that, when correctly oriented and actuated, the drill bit will be diverted in a desired lateral direction. Pressure-actuated control means are arranged on the tool for selectively extending the wall-engaging members in response to deliberate changes in the circulating pressure.

Review

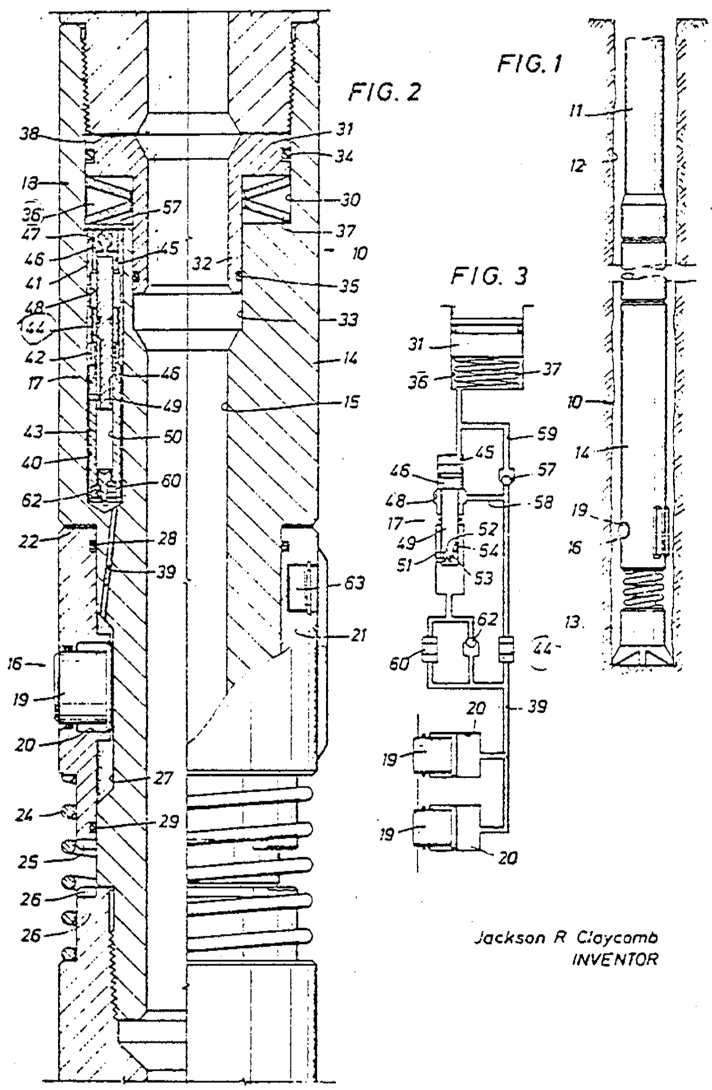
This is a surface-controlled, pressure-operated tool for deviating rotating drillstrings, but it could also be adapted to downhole motor use. See Figure 24. A sleeve having extendable thrusting pistons on one side for bearing on the borehole wall journals the mandrel of the tool. Clutching means are provided for orienting the sleeve to bear on a particular side of the hole. A spring-returned piston, inside the mandrel bore exposed to the differential between internal and external string pressures, separates the hydraulic actuation oil from the mud. The oil passes to the pistons through an alternating control valve that passes fluid on every other pressurization of the actuating oil and blocks fluid in between. The alternating control valve is a modified poppet that uses a barrel cam (or "running J") to obtain its alternating behavior. In operation, the tool is given an extra pressure pulse every time circulation is stopped to ensure that the thrusting pistons are retracted again or re-extended, as desired. The

FIGURE 24

Directional Drilling Apparatus

PATENTED JUL 27 1971

3,595,326



Review-Cont'd

structure of the tool has some potential problem stress areas for rotary drilling. Because of redundant seals, washout is not too likely. The size and wear resistance of the thrusting pistons are likely problems. The tool appears unlikely to sand up, but the exposed spring is undesirable. The rotating sleeve seals and bearings are expected to cause problems. The alternating action requires operating the pumps with care; slip ups are likely. The tool probably could be readily adapted as a downhole motor deflector. Certain of the design aspects are well conceived.

U.S. Patent 3,599,733 by Robert F. Varley
Method for Directional Drilling With a Jetting Bit

Patent Abstract

Method and apparatus are described for changing the direction taken by a bore hole. A drill bit having at least one outlet orifice or nozzle for drilling fluid e.g., mud, is oriented so that the orifice is adjacent the portion of the interior lateral surface of the bore hole into which it is desired for the drill bit to proceed. The drilling fluid is pumped into the interior of a hollow drill string in the bore hole and out through the orifice in the drill bit. A portion of the drill string adjacent the bit is adapted to be closed in a fluid-tight manner by means of a back pressure ball valve, and the portion of the drill string between the valve and the outlet orifice includes a slip joint adapted to be decreased in volume by an inward telescoping motion with vertical reciprocation of the drill string. Decreasing the volume of the drill beneath the above-mentioned valve will serve to compress the fluid therein forcing it out of the outlet orifice at an increased velocity. When the drill string is moved vertically upwardly, the valve opens allowing more drilling fluid to flow therethrough. Repetitive vertical reciprocation of the drill string to open and close the slip joint will result in highly accelerated jetting velocities through the outlet orifices in the drill bit.

U.S. Patent 3,599,733 - Cont'd

## Review

This tool is included in a rotating drillstring for use when lateral deflections are desired. See Figure 25. One jet nozzle in the bit is directed at the side of the borehole as a result of a survey for orientation after rotation is stopped. At that point, the string is elevated to stroke out a near-bit slip joint, which functions as a pump cylinder. The output of the splined pump cylinder is directed to the lateral jet nozzle when the string is lowered. The nozzle outflow is vigorous enough to erode the borehole and permit, following reciprocation, a kick-off to be made.

The problem with such a tool is the wear on the spline and the seals of the sleeve. Further, obtaining a sufficiently high pressure to speedily erode the borehole wall may be a problem. Use of a pressure-controlled or otherwise controlled valve to vector all the pump flow through the special nozzle might be a better approach. Keyseats and doglegs are expected hazards of this sort of approach.

## U.S. Patent 3,637,032 by John D. Jeter
## Directional Drilling Apparatus

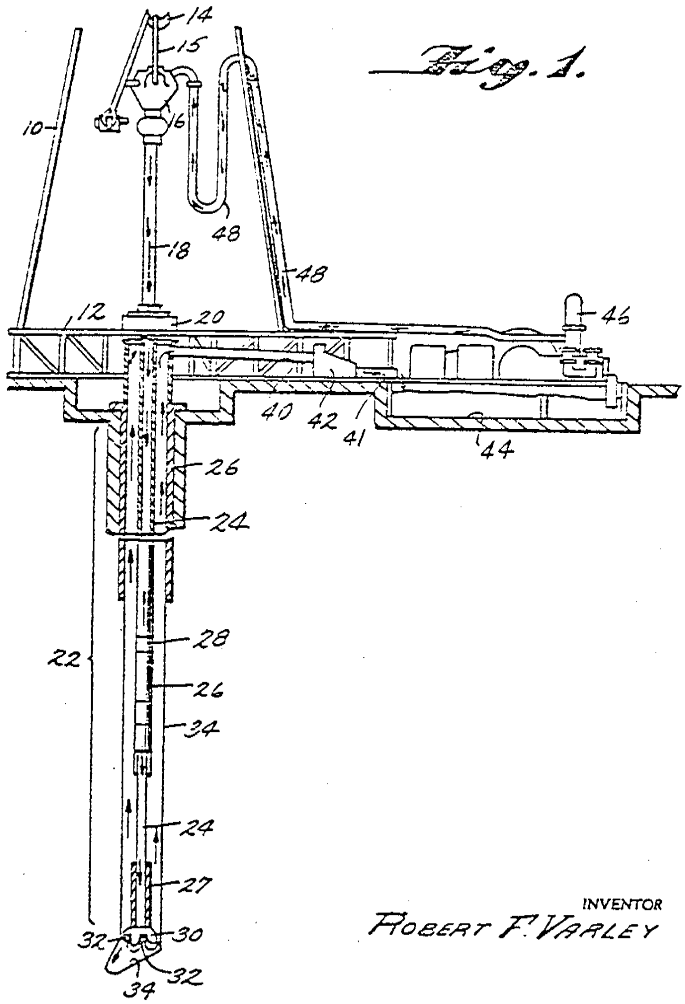
### Patent Abstract

A pendulum is mounted in the drill pipe close to the drill bit to assume a vertical position in the azimuthal plane of the drill pipe. When the position of the pendulum is such that the inclination of the drill pipe is not a preselected amount or the azimuthal direction of the pipe is not the preselected direction, a lateral force is imposed on the drill bit urging it to drill in a direction that will return the drill pipe to said preselected inclination or azimuthal direction. The pendulum and its associated apparatus is rotated in the direction opposite the direction that the drill pipe is rotated and at the same speed, so that the pendulum is substantially nonrotative relative to the earth.

FIGURE 25

Method For Directional Drilling
With A Jetting Bit

PATENTED AUG 17 1971 3,599,733



Review

This is a highly complex apparatus for dynamically adjusting the lower end of a rotating drillstring in order to steer the bit. See Figure 26. The apparatus purportedly can also be used for downhole motor appliations. The tool has a downhole oil pump, driven by mud circulation, located in its upper end. Mud flow is around the interior portion (control section) of the tool. Appropriate mechanical servo valves for sensing deviations from desired positions and producing corrective flows for hydraulic actuator adjustments are included. The control section is counter-rotated relative to the drillpipe in order to keep it substantially stationary relative to the borehole. There are various types of dynamic bit deviators that are hydraulically actuated to control the bit attitude.

The problems of successfully counter-rotating the control section with the required accuracy are non-trivial. Use of gyroscopes close to the bit is likely unworkable, but flux gate sensors may be satisfactory. Electric controls could be substituted for a purely hydraulic system, so that the hydraulics is used mainly for force production or positioning. Several design details and components look promising, but a tool of this type would take substantial time and money to develop.

It is believed that, because of a) the difficulty in surviving the rotating string environment in a tool with reduced body strength and stiffness, and b) the complexity of this tool's reliability problems in that severe environment, this tool is unlikely to be practical for rotating drillstrings. With downsizing and careful layout and design, a tool of this type may be satisfactory for use with a downhole motor system.

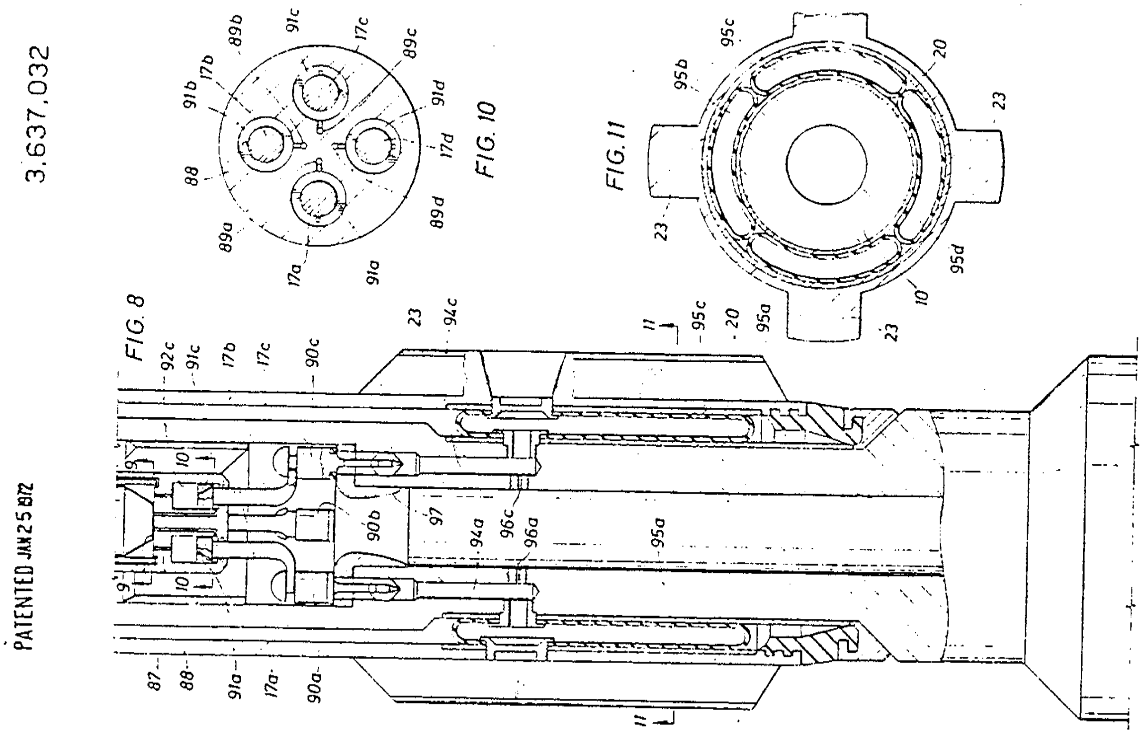
U.S. Patent 3,650,338 by Branch M. McNeely, Jr.
Rotary Bit Guide

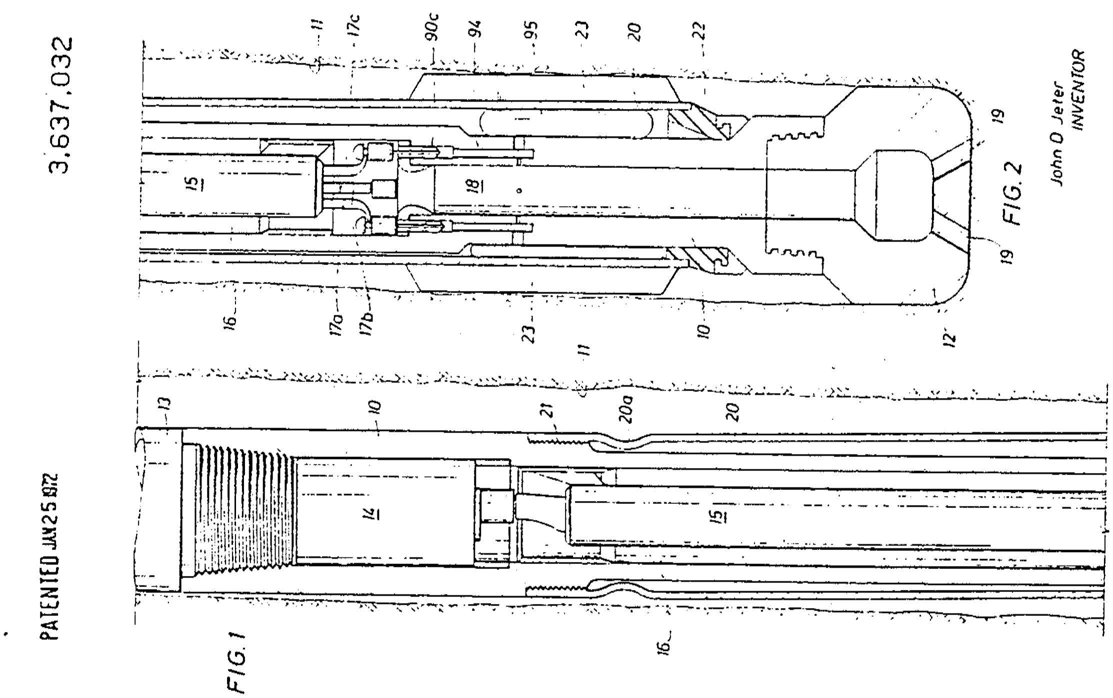
Patent Abstract

A device for controlling the directional deviation of a well bore. An outer member is concentrically spaced around a mandrel which is connectable at opposite end to form part of a drill string, the outer member having longitudinal ribs extending from its outer surface to frictionally engage the walls of the well bore and thereby restrict rotation of the outer member in the well bore. A first set of deformable pressure chambers which preferably

<u>FIGURE 26</u>

Directional Drilling Apparatus



Patent Abstract-Cont'd

comprise part of a rotary pump are located between the outer member and the mandrel. A second set of deformable pressure chambers, located between the outer member and the mandrel, communicate via fluid passageways with the first set of pressure chambers. A fulcrum means is located between and in contact with said outer member and said mandrel whereby, when fluid is transferred from the first set of chambers to the second set of chambers, thereby causing the second set of chambers to apply a force against the mandrel in a lateral direction, the mandrel can pivot relative to the outer member.

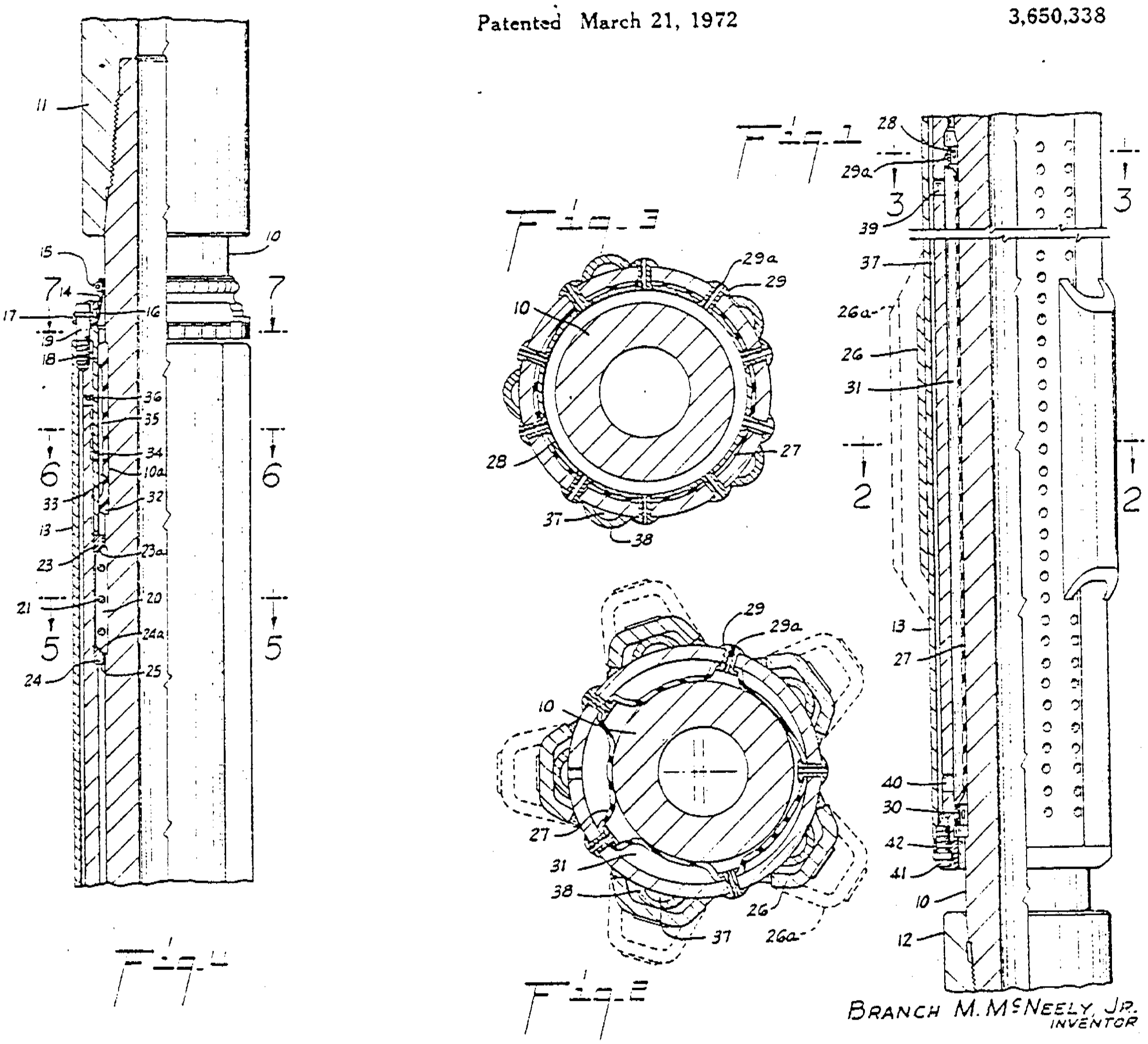
Review

This rotary drillstring tool is a passively controlled device used to keep a drillstring coaxial with its bore. See Figure 27. It uses a nonrotating sleeve bearing against the borehole to support the central mandrel connected in the drillstring. Between the sleeve and mandrel on the upper end of the tool is located a pumping device which has outputs from its individual "cylinders" proportional to the deviation of the mandrel from a central position toward that "cylinder". The mandrel is supported and centralized in a bearing at midheight in the sleeve. Below the bearing, separate pressure chambers bear and rub against the mandrel. Each pressure chamber is connected to a corresponding cylinder in order to receive that cylinder's output. As a result, if there is a deviation from running coaxial with the hole, the mandrel is forced back to a coaxial position by the pump output.

It is expected that wear of the rubber on the mandrel would be a problem, with heat buildup likely being a major factor. The cooling vents are likely to plug. Perhaps a more basic problem is the destabilizing effect of hole erosion, leaky pump cylinders, and potential dynamic instabilities in a flexible pipe string. It would appear that a pair of closely-spaced near-gauge stabilizers would accomplish the same intended result as this tool in a more reliable, less expensive manner.

## FIGURE 27

Rotary Bit Guide



U.S. Patent 3,743,034 by William B. Bradley
Steerable Drill String

Patent Abstract

Method and apparatus for maintaining the orientation of a laterally unsupported driven shaft constant with respect to a non-rotating coordinate system as the driven shaft is rotated by a non-coaxial rotating driving shaft. In a directional drill method, the apparatus is disposed in a well drillstring along with means for adjusting the orientation of the portion of the drillstring below the apparatus to provide a steerable drill string. The apparatus for maintaining the orientation of the shafts comprises an axial-piston machine mounted on one of the shafts and operatively connected to a control flange affixed to the other of the shafts. A universal coupling connects the shaft in driving-driven relationship. The deflection of the shaft at the universal joint is maintained constant with respect to a non-rotating coordinate system by driving the pistons of the axial piston machine in timed relationship with the rotation of the shafts so that each piston completes one reciprocating cycle each time the shafts complete one rotation.

Review

This rotating drillsting tool consists of a downhole hydraulic pump and servo means for maintaining a fixed heading on the universal-jointed lower end of the tool when the string rotates. See Figure 28. Hydraulic cylinders provide the force to deflect the universal joint in response to signals from the control package. This tool is similar in a general way to that of U.S. Patent 3,637,032, but the details differ. See the review of U.S. 3,637,032 in the preceding material.

The bending moment applicable to the lower end of the tool below the ball joint is limited, implying the tool would have to be run close to the bit. The construction is likely to cause the tool to be structurally weak and fatigue-prone for use with a rotating string. The tool is fairly complex and would have to function in a highly adverse environment.

It appears that this tool would be best suited as a bent sub device for non-rotating drillstrings.

FIGURE 28

Steerable Drill String

PATENTED JUL 3 1973 3,743,034

FIG. 2

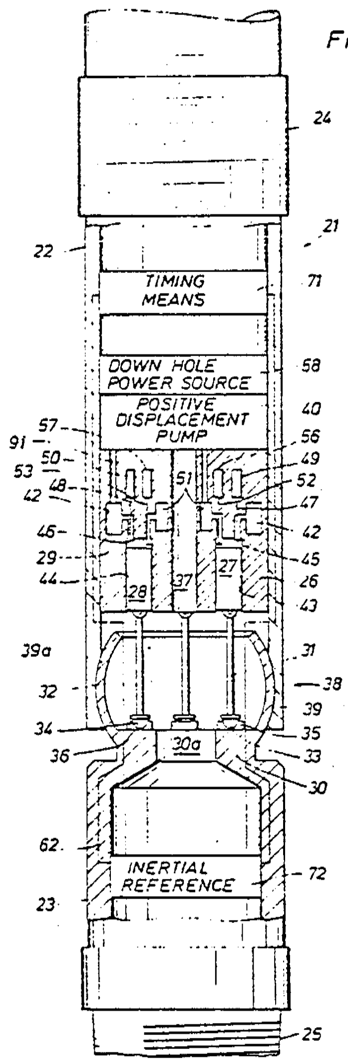
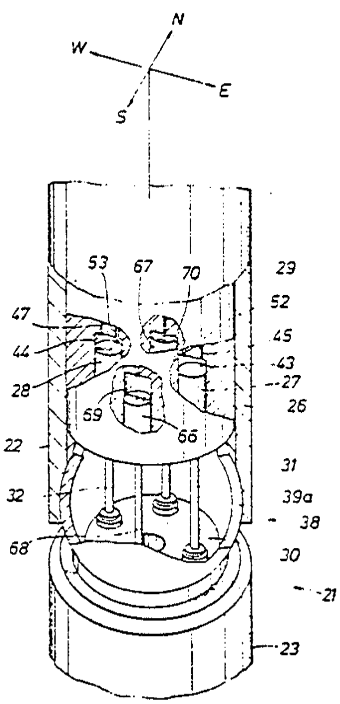



FIG. 4




W. B. BRADLEY
INVENTOR

## U.S. Patent 3,746,108 by Gary E. Hall
## Focus Nozzle Directional Bit

### Patent Abstract

A focus nozzle directional bit according to the present invention includes a body having a central fluid conducting passage adapted to be disposed in communication with the bore of a drillstring used for the drilling of a well. A plurality of branch fluid passages are formed in the body, each being disposed in communication with the central fluid passage. A plurality of jet apertures are defined in the body in communication with the branch passages and are orientated to converge jets of pressurized drilling fluid outwardly and downwardly from the bit adjacent a lateral wall of the well bore for the purpose of directionally eroding the same to allow the drill bit to deviate downwardly and outwardly from the original well bore.

### Review

This is a simple, relatively passive tool for use with a rotating drillstring. See Figure 29. The drillstring rotation is stopped and a nonsymmetrically vectored bit jet or jets are brought into alignment, following a wireline survey, so that the hole adjacent the bit is transversely eroded where the jets impinge the hole wall. The bit is then reciprocated (or a reamer is used above the bit) to smooth the bend that the bit tends to make into the eroded transverse pocket.

The problems with this approach are: a) proper hole and bit cleaning are liable to be sacrificed, b) only soft formations are likely to erode much, and c) the result is likely to be a keyseat or dogleg in the hole. Set against this are the simplicity of the approach and the hardware. This method is not considered likely to be too useful in, say, the indurated formations of the U.S. overthrust belts. In softer sediments, such as found offshore, using one or two jet nozzles larger could possibly work and still give acceptable hole cleaning. However, it appears that there are better, more controllable ways to accomplish deviational control than that shown here.

## FIGURE 29

Focus Nozzle Directional Bit

Patented July 17, 1973 3,746,108

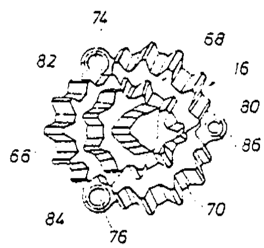



FIG. 3

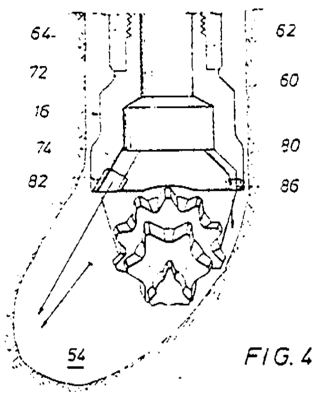



FIG. 4

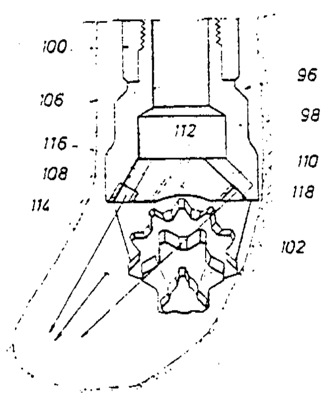



FIG. 5

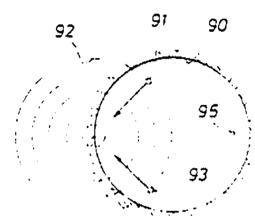



FIG. 6

Gary E Hall
INVENTOR

U.S. Patent 3,799,279 by Ralph J. Farris
Optionally Stabilized Drilling Tool

Patent Abstract

A hollow shaft is tapped and threaded at respective ends for engaging between a drill stem and a conventional cripple bit. A plurality of radially and longitudinally extending stabilizers are spaced longitudinally apart on said shaft. Each stabilizer is fixed to a collar mounted for rotation on the shaft, and retained thereon by fixed collars secured to the shaft overlapping end flanges of rotational collars. The shaft is recessed under each stabilizer to reduce friction of rotation thereon. Transverse holes are defined through the respective stabilizers to equalize pressures on the sides thereof. In rotational drilling, the stabilizers are randomly misaligned around the shaft to stabilize the drilling end portion of the drillstring in its bore. If the bit changes direction to a side for any reason, the stabilizers are all aligned by a near side of the bore and cease to act as stabilizers. Rotational drilling is stopped and percussion drilling is begun with the crippled bit oriented by well-known methods and equipment to correct to original direction. By resuming rotational drilling when correction is made, the stabilizers become misaligned and stabilization is resumed.

Review

This tool is for use with a rotary drillstring. See Figure 30. The drillstring is journaled in a group of eccentric, single-blade stabilizers. These stabilizers randomly align themselves in normal drilling, but, when the string rotation is stopped, the blades are supposed to rotate to the low side of the hole. The unsymmetrical bit is then used to percussively drill a hole away from its known deviation direction following a survey for orientation. This approach is not practical.

U.S. Patent 3,825,081 by Harvey S. McMahon
Apparatus for Slant Hole Directional Drilling

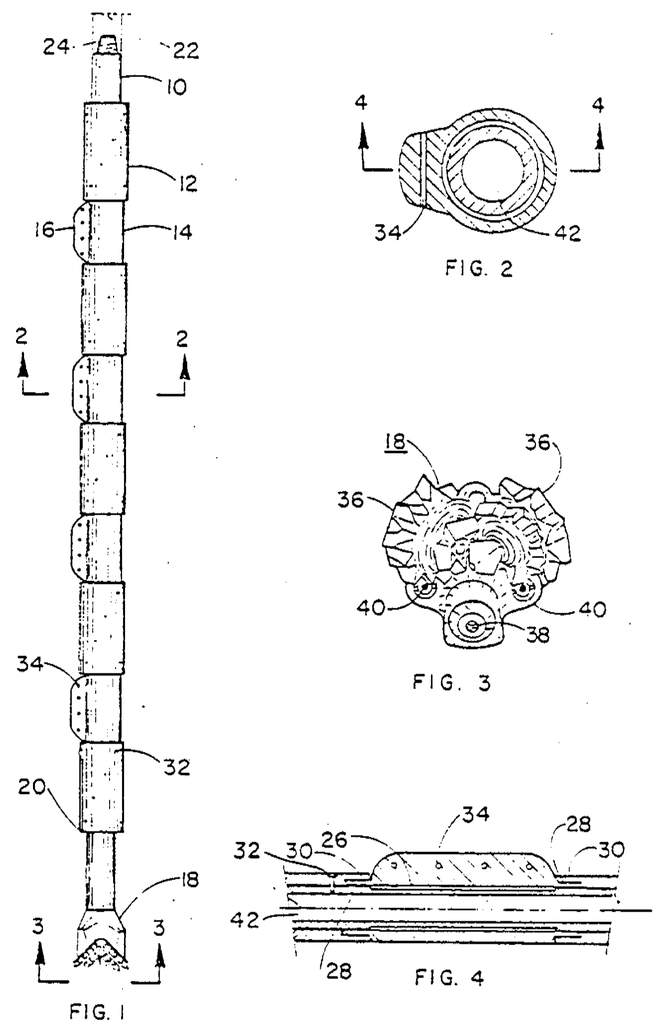
Patent Abstract

Method of slant hole directional drilling using a rotary drill wherein the drill collar carrying a plural cone bit is nudged upwardly on each revolution by a radially projecting lobe being cam bearing on the surface at the low side of the hole, in conjunction with the action of one oversize cone in the bit which, upon each upward nudging of the drill collar, cuts in a predetermined laterally angular direction, whereby the direction of the well bore will be altered.

## FIGURE 30

Optionally Stabilized Drilling Tool

PATENTED MAR 26 1974 3,799,279




INVENTOR
Ralph J. Farris

U.S. Patent 3,825,081 - Cont 'd

Patent Abstract-Cont'd

The apparatus embodies a two cone or tricone bit in which the teeth of one cone are radially enlarged over the teeth of the other cone or cones, the bit being mounted on a drill collar with the larger cone at an angular displacement from a radially projecting lobe or cam mounted on the drill collar.

Review

This is a simple device for use with a rotating drillstring. See Figure 31. An eccentric cam or roller is provided to bear on the low side of the hole whenever it is rotated past that point. When the eccentric encounters the hole wall, it causes a deviational force to be exerted on the diametrically-opposed side of the hole by the bit. If a larger bit cone is positioned other than diametrically opposite, but downwardly spaced by several feet, then deviations out of the vertical plane can be produced. The tool supposedly drills an ovaled hole.

The principal behind this tool is somewhat similar to that of Eastman Whipstock's "Rebel Tool". See References A-3, F-5. Use of a larger cone probably is not attractive if all cones are not set to run simultaneously on the hole bottom. It is hard to evaluate the effectiveness of such a tool without tests. The cam could be selectively extended with additional mechanisms. Conceivably this device has minor to no effect on building deviation in an already deviated hole; bit weight or rotational speed changes may have more significant results.

U.S. Patent 3,961,674 & 4,015,673 by James T. Craig et al.
Directional Drilling System

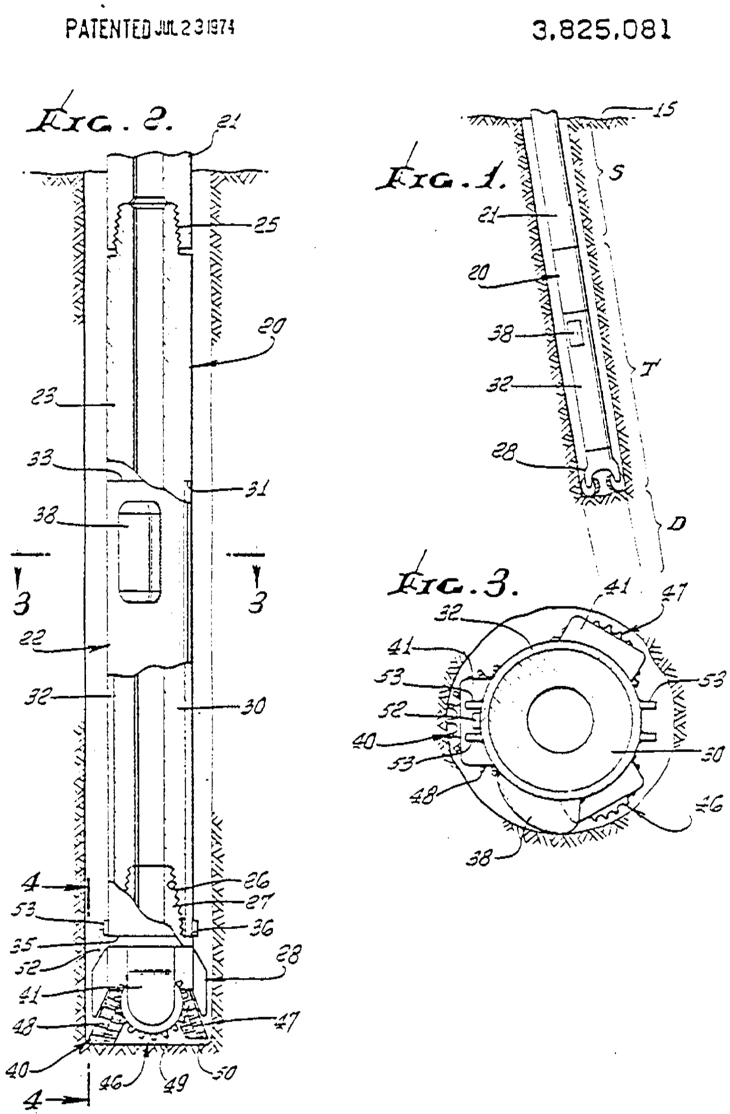
Patent Abstract

Both patents are on the same device; one patent covers the method, and the other the apparatus.

This invention concerns the drilling of boreholes in the earth. It concerns a rotary drilling system having a particular bottom hole assembly (BHA) for use in increasing or decreasing the angle of deviation from the vertical of a borehole. It also teaches a method whereby the angle of deviation can be calculated for each assembly. There is one assembly disclosed for increasing the

FIGURE 31

Apparatus For
Slant Hole Directional Drilling




INVENTOR

Harvey S. McMahon

## Patent Abstract-Cont'd

angle of deviation and another assembly disclosed for decreasing the angle of deviation. Also disclosed is a novel "universal stabilizer" for use in the bottom hole assembly.

## Review

These patents cover both a method for determining rotating string bottom hole assembly stability and a particular blade stabilizer. See Figure 32. The blade stabilizer sleeve is splined to rotate with an inner mandrel. A ball joint intermediate to the sleeve length lets the sleeve swivel its axis away from the mandrel axis. Rubber is used to isolate the ball joint from the mud and restrain and damp the sleeve motion. The stabilizer effectively creates a pin connection for the rotating drillpipe beam. This permits better control of drillstring flexure and, hence, deviational tendencies. The calculations are simple to follow and use.

The tool will work because of its passive, simple action. The tool is not for initially deviating a hole, but can be used to build or reduce pre-existing angle. Wear in the splined ball joint may cause some problem. The tool section may be prone to structural weakness because of the small size of the mandrel.

# U.S. Patent 3,974,886 by Jack L. Blake, Jr.
# Directional Drilling Tool

## Patent Abstract

A tool adapted to be mounted on an elongated fluid-conductive assembly such as a drill string for performance of a predetermined work operation at a remote location, such as the directional control of drilling, the tool having a tool body borne by the fluid-conductive assembly for positioning in the remote location; a work member mounted on the tool body for movement laterally thereof; and a cam member received in the tool body in engagement with the work member for movement longitudinally in the tool body to move the work member laterally of the tool body upon predetermined pressurization of the fluid-conductive assembly.

FIGURE 32

Directional Drilling System

U.S. Patent June 8, 1976 3,961,674

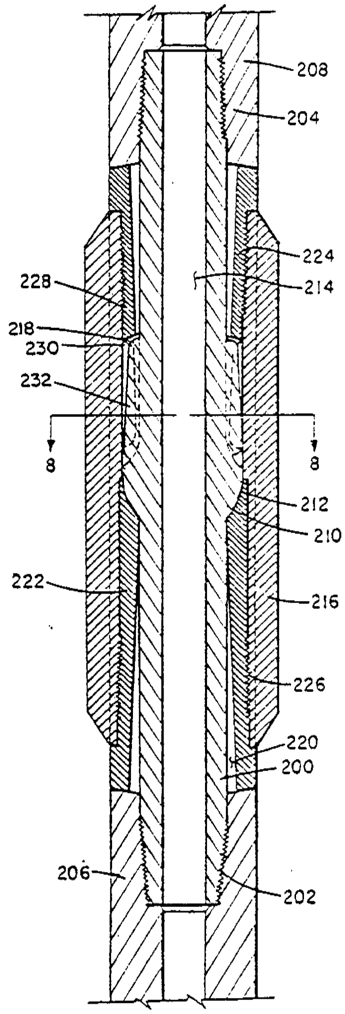



FIG. 7

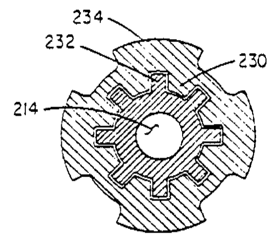



FIG. 8

INVENTOR

James T. Craig et al.

U.S. Patent 3,974,886 - Cont'd

Review

This patent for rotating drillstrings covers a selectively expandible stabilizer which can be run singly or in groups. See Figure 33. The tool is controlled from the surface by dropping balls to partially restrict flows through the tool. This results in an increase in the pressure differential across the tool, so that a piston, normally biased up by the preset pressure in a gas reservoir, is forced downwardly against the gas pressure. As the tubular piston moves down, separate sections of its outside having different, stepped diameters are used as cams to extend out retractible blades housed in the outer body of the tool. The blades are retracted when flow stops and the gas spring raises the tubular piston. Shearable piston travel stops are used to limit the extension of the blades. Use of a wireline blanking plug to temporarily displace the ball and fully block the flow passages through the piston permits developing enough force to shear the piston travel stops out. This, upon blanking plug withdrawal, permits higher pressures in the string to cause the piston to bring a larger diameter cam surface under the blades to cause more extension. When run in multiples, the tools have progressively larger minimum bore diameters higher in the string, so that all tools can be adjusted as desired.

This appears to be a good approach to the problem of controlling rotating drillstrings in pre-deviated holes or intentionally straight holes. The tool is not excessively complex and has considerable operational flexibility. There is some serious structural weakness where the blades penetrate the body, as is the case for all tools of this type. The flow restriction in the tool is objectionable, and there is some likelihood of moving seal leakage and a resultant washout. Sanding up in the blade pocket area may be possible, and blade pocket wear could be a problem. The accumulator gas precharging and possible leakage are possible problems; use of wireline tools and dropped balls is a relatively minor problem compared with round-tripping the string for a change. Overall, this tool looks fairly promising.

U.S. Patent 4,076,084 by Robert E. Tighe
Oriented Drilling Tool

Patent Abstract

This is a drilling tool which can be manipulated from the surface to one position to drill a directionally oriented hole or to a second position to drill a straight hole. A special tool is

## FIGURE 33

Directional Drilling Tool

U.S. Patent   Aug. 17, 1976   3,974,886

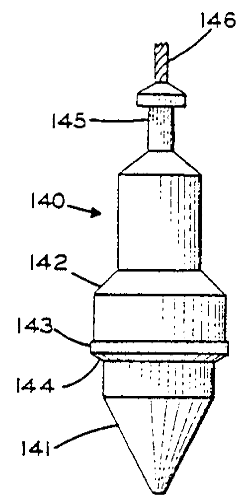


Fig. 9

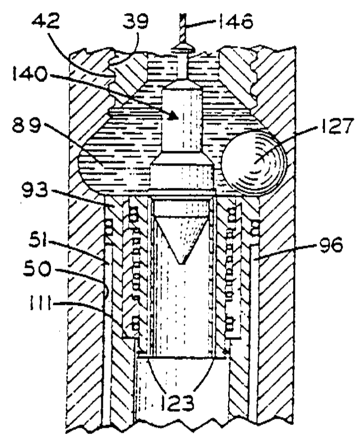


Fig. 10

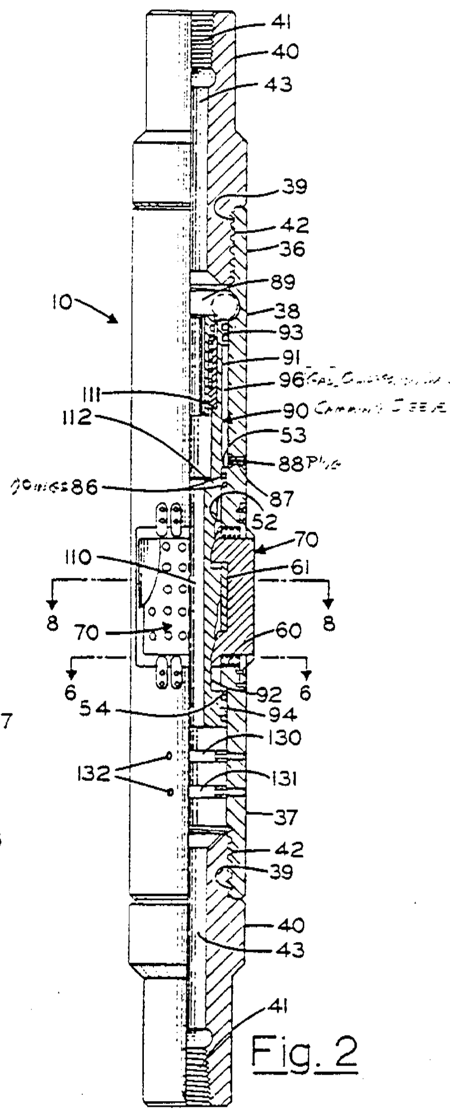


Fig. 2

INVENTOR

Jack L. Blake, Jr.

Patent Abstract-Cont'd

inserted in the drillstring near the bit. It includes a hollow torque member, which is connected into the drillstring. Surrounding the torque member are two eccentrically bored sleeves, one within the other. The two sleeves are rotatable with respect to each other and with respect to the torque member. When the cam sleeves are opposed, the torque member is aligned along the borehole axis. When the cam sleeves are oriented in the same direction, their eccentricity is added and the torque tube is thrown off center to cause the bit to drill in a prescribed direction. Means are provided so that the position of the sleeves can be changed from the surface. Manipulation is by mud circulation and pipe movement.

Review

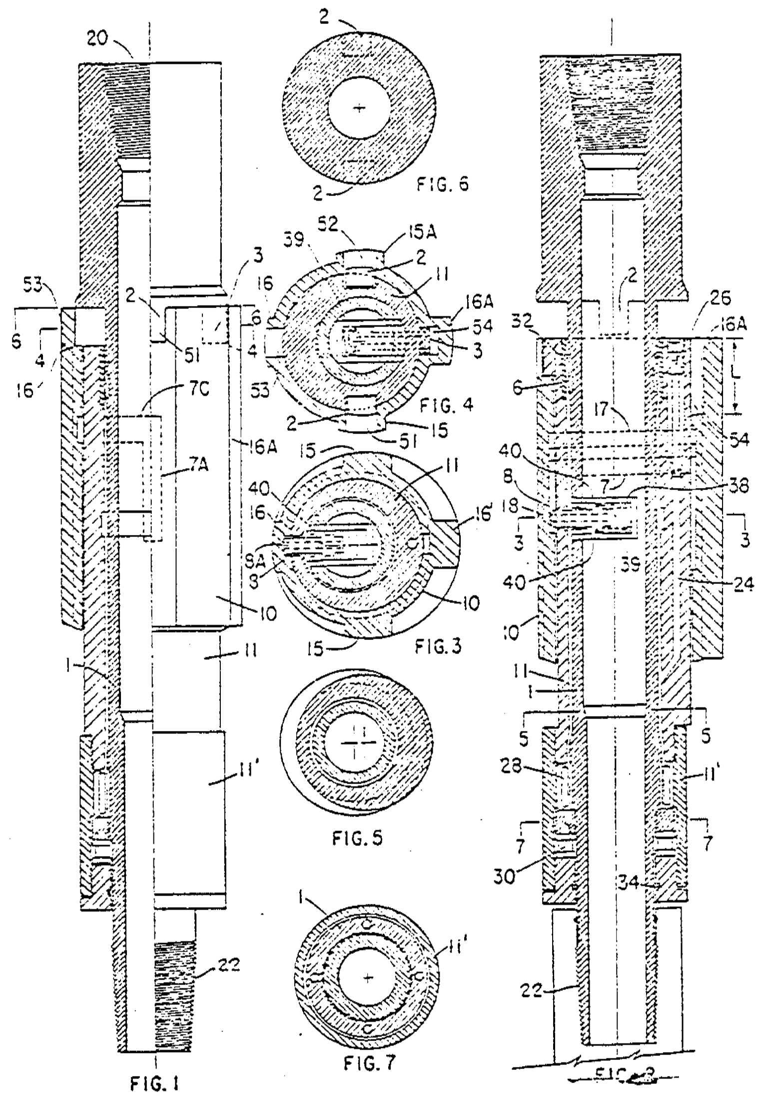
This tool is intended for use with rotating drillstrings, but, as indicated in the comments below, probably is better suited as a bent sub type tool. See Figure 34. A through-mandrel transfers torque inside the tool body. Two sleeves are used: a) an inner one which is mounted inside the outer one and mounted on bearings on the mandrel, and b) the outer one, which has narrow stabilizer blades parallel to the tool axis. The sleeves are both bored eccentric to their outer diameters by a similar amount. When the sleeves are relatively rotated so that their eccentricities cancel, the outer diameter of the outer sleeve is concentric with the mandrel. Rotating the outer sleeve 180° from the former position causes the eccentricities to be additive, so that the outer diameter of the outer sleeve is eccentric to the mandrel. Latching means are provided to latch the two sleeves together when the eccentricities are additive or, alternatively, latch both sleeves to the mandrel when the eccentricities cancel. When the sleeves are latched to the mandrel and non-eccentric, the tool causes no bit deviaiton tendencies. When unlatched from the mandrel and eccentric, the tool shifts the axis of the drillstring so that deviational tendencies are produced. When eccentric, the outer sleeve blade holds the sleeve irrotational with respect to the hole wall, and the bearings in the inner sleeve let the mandrel rotate freely in the sleeves.

The primary problems with this tool are related to the reduced structural section of the mandrel relative to the adjacent drill collars. Use of relatively flexible adjacent members in the string could help this some. The tool manipulation is not simple, but is comparable to that of many successful types of packers. The generic problems of deviation tools that have the string rotating inside them will be common to this tool. The tool could likely be

FIGURE 34

Oriented Drilling Tool

U.S. Patent Feb. 28, 1978 4,076,084




INVENTOR
Robert E. Tighe

Review-Cont'd

used with a downhole motor arrangement if it could be mounted near the bit. Overall, the tool is not extremely complex, but its reliable, proper functioning in a rotary drilling environment would likely be a problem.

## U.S. Patent 4,108,256 by Richard G. Moore, III
## Sliding Stabilizer Assembly

### Patent Abstract

Apparatus and method for drilling generally horizontal holes through subterranean coal beds for release of methane gas from the coal beds are described. A sliding stabilizer on a drill rod is selectively positioned to provide elevational control to a rotating drill bit. The stabilizer is keyed to a slot in the drill rod, and lateral offsets in the slot are used to retain the stabilizer in the desired position on the drill rod.

### Review

This is a relatively simple device for rotating drillstrings. See Figure 35. A sleeve blade stabilizer, keyed to a drillstring mandrel and slidable between upper and lower positions, is latchable in either position by rotating to the right when the key in the sleeve is adjacent recesses in the mandrel slot.

The length of travel for the sleeve is limited to about 25 feet or less; an appreciable change in bit deviational tendencies must be realized with such an offset. Rubbing wear of the mandrel and sanding up the slot could be problems. Provision of a more positive latching mechanism, possibly actuated by pressure differential in the string, could help. If the pressure differential were used to latch, there would of course be a potential washout problem. The basic simplicity of the tool is appealing.

## FIGURE 35

Sliding Stabilizer Assembly

U.S. Patent Aug. 22, 1978 4,108,256

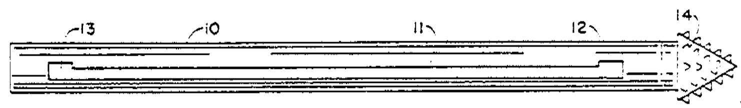



FIGURE 1

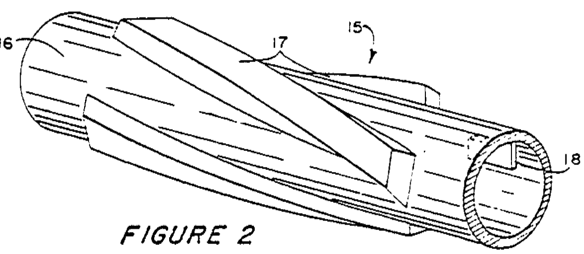



FIGURE 2

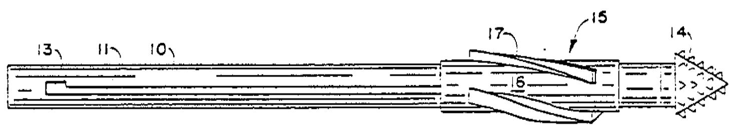



FIGURE 3

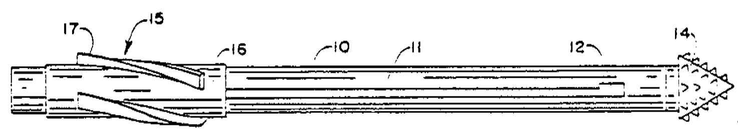



FIGURE 4

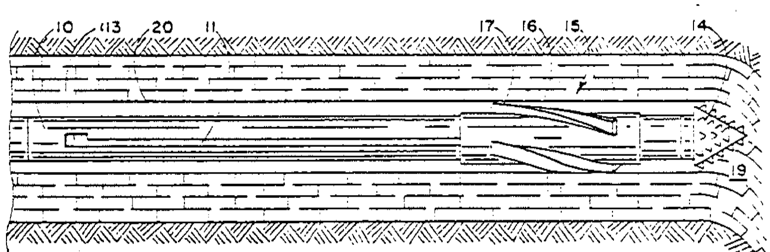



FIGURE 5

INVENTOR

Richard G. Moore, III

U.S.S.R. Patent 616,395 by Yv. S. Kostin et al.
Drilling Deflector Sleeve

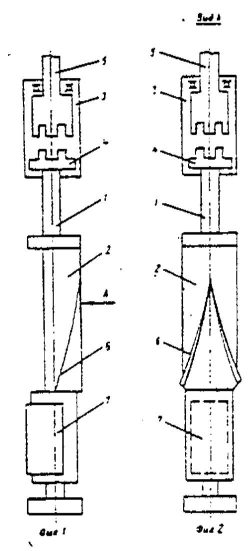
Summary and Review

This tool shown only in schematic, consists of a rotatable eccentric sleeve brought to the low side of the hole by its weight. See Figure 36. A converging rib pattern on the outer diameter of the sleeve is supposed to maintain the sleeve on the low side of the hole. This tool appears impractical because of structural problems and its general principles of operation. The bearing and seal friction would be impossible to overcome except (perhaps) in extremely deviated holes. Positioning with a wireline tool to locate a magnet in the sleeve to the low side of the hole is possible, but the converging ribs do not appear likely to work as described. The general difficulties of tools journaling the string in a non-rotating sleeve of course apply to this tool.

FIGURE 36

Drilling Deflector Sleeve

USSR 616,395



INVENTOR

Yu. S. Kostin et al.

# CHAPTER IV

## LITERATURE SURVEY

### Introduction

The particular objective of the overall study, defined by the U.S. Department of Energy, was to determine the need, possibility, and feasibility of developing a surface-controlled tool able to alter the wellbore path on command as needed. Given the narrowness of the objective, the amount of pertinent literature is rather limited. The literature examined included both U.S. technical journal articles and U.S. and foreign manufacturers' sales information and operational manuals.

The evaluations given are based on the available descriptions, interviews with the manufacturers, and technical judgement.

The Composite Catalog of Oil Field Equipment and Services, 1980-1981 (Ref. F-6) was carefully searched to identify any suitable tools currently offered. Selected manufacturers' literature and prior Composite Catalogs were also reviewed. The search of prior Composite Catalogs was necessary because only one tool which could be made in a surface-controllable version is shown in the current volumes; a surface-controllable bent sub was shown in earlier editions. The new tools undergoing development are not yet described in the Composite Catalog.

In order to search the technical journals, literature citations of interest to this project were retrieved using key word analysis from the Petroleum Abstracts system. Controlled assigned vocabulary retrieval was utilized to cite the references and abstracts. Articles of interest were obtained, following preliminary evaluations based on the abstracts, and reviewed to establish the present need, methods, and available hardware for deviated drilling. A total listing of the 190 referenced abstracts were submitted to the DOE in an appendix format that is not being published with this report. Copies of this Appendix are available by request from the Technology Trasfer Section at the Bartlesville Energy Technology Center. Sufficient information is included in the computer printout in the appendix so that hard copy citations can be obtained. The summary and evaluation of key reference articles of specific interest to this project are given in this section.

The listed articles include groups related to: a) announcements of new tools or field test results, b) related technology, c) the status of foreign technology, d) the need for new technology or general interest, e) general information on stabilization and deviation control for rotating drillstrings, and f) manufacturers' literature on tools. The described technology and tools are reviewed using the same guidelines as used for the patent review in the previous section. Detailed reviews are primarily given for the new tools, the "Rebel Tool" and the "Dyna-Flex" tool, covered in References F-1 through F-7.

The section on related technology is included here because improvements related to:

1) avoidance of wireline tripping for drillpipe connections, or
2) avoidance of wireline presence inside the drillstring, thereby leaving the conduit open for other hardware, such as pumpdown devices, or
3) avoidance of any wirelines or control hardware means run through the string.

All these factors have an appreciable impact on the feasibility and economic justificiation of downhole control. Successful use of electrical control signals to adjust downhole apparatus is very desirable if wireline tripping for drillpipe connections does not impair the economics of such a drilling procedure. Downhole control by means of acoustic pulse signals sent in both directions can possibly avoid this limitation.

## Summary of Findings

There are two types of equipment mentioned in the literature for surface control of downhole deviation devices. The first type is the class of downhole-adjustable bent subs for use with non-rotating pipe and drilling motors. Only three bent sub tools, one in the development stage, one just becoming commercial, and another undergoing redesign, appear in the current literature. The one tool of this type which has worked successfully over a long period is the "Dyna-Flex." (Ref. F-1, F-2 and F-3). This tool was built by Bowen Tools, Inc. and rented by the Dyna-Drill Division of Smith International, Inc. An improved version of this tool is being developed by Bowen. SMF International and the Institut Francais du Petrole (IFP) also are jointly developing both electrical and mechanical versions of a downhole-adjustable "Telepilot Bent-O-Matic" bent sub. (Ref. F-4, A-4). Neither of these tools are advertised as being currently offered in the manufacturers' catalogs. Some of the Dyna-Flex tools may still be available, but evidently Dyna-Drill is not attempting to market them. Both the new Dyna-Flex and the new Telepilot Bent-O-Matic are described as being about a year to six months from commercial availability as of May, 1981. The Christensen Diamond Products, U.S.A. "Twist-Kick Sub" has just become available in mid-1981. (Ref. F-7). This simple tool, while overcoming many of the disadvantages of conventional bent subs, is not a surface-controlled tool. An adaptation to provide surface control seems feasible.

Another, quite different class of downhole-adjustable deviation device is required for rotating drillpipe situations. It is possible to accomplish bit deviation by pushing laterally on the well bore with an eccentric, non-rotating sleeve. However, no mention of oil field tools using such an approach was found in recent technical journals or current product literature, although several patents for such tools have been issued. While Drilco at one time offered a tool, the "Bit Boss" (based on U.S. Patent No. 3,298,449 and related patents), this tool evidently is no longer commercially available. (Ref. A-2, A-6, A-9). Such tools are evidently not offered currently because their complexity and size would make them expensive to rent or purchase. The complexity of the apparatus required for such tools and the severe operating environment and other constraints would tend to make tool maintenance and reliability a major problem in oilfield use. Such devices do, however, exist for large-bore tunneling, river crossing drilling, and mining tools where bit "round trips" are simpler or where more space permits stronger and more complex mechanisms.

For the case of rotating drillpipe, mention of two currently available tools has been found in the literature. These tools rotate with the drillstrings. The first, Eastman Whipstock's "Rebel" tool, actually is not downhole-adjustable. (Ref. A-3, A-8, F-5). However, from its description, it appears that it could be made to be selectively disabled from the surface by insertion of a wireline-run tool for either clamping or releasing the actuating mechanism. The tool is used for controlling transverse "bit walk" in already deviated holes. The Rebel tool must be pulled to change its deflection tendencies from leftward to rightward. Leftward and rightward refer to deviating tendencies normal to the vertical plane containing the wellbore adjacent the bit. This tool is included here because of its applicability in certain special rotating drillpipe situations. Its use can be simultaneous with vertical deflection building or decreasing done by varying bit and string stabilization, bit weights, and rotational speeds. The requirement for such a tool appears rather limited, but it is simple and it works.

The second, currently available rotating drillpipe tool, operated by Directional Stabilizer Systems of Odessa, Texas, operates by selectively expanding or contracting stabilizer blades to alter the deviation tendencies of the drillstring. The basic approach is detailed in U.S. Patent 3,974,886. (Ref. A-1). This set of stabilizers comprising the tool can have their diameters altered by a wireline-run tool. Use of this approach appears promising if sealing and other technical problems can be reliably overcome. The influence of varying the surface-adjustable drilling parameters, along with effectively adding or subtracting stabilizers, can be evaluated from the guidelines in the selected articles on that subject. This particular stabilizer system appears to be very versatile and able to yield a high degree of control suitable for most situations. Of all the rotating drillstring tools, this system appears to offer the best approach. A field test has already been run offshore Louisiana for this system.

## Reviews of Pertinent Literature

### A. Announcements of New Tools or Field Results

A-1 Leonard, Jeff, "Expandable Stabilizers Provide Assembly Variation Without Tripping," World Oil, July, 1980, pp. 63-65.

This article describes the expandable blade stabilizer tools offered by Directional Stabilizer Systems of Odessa, Texas. This tool system is in part based on U.S. Patent 3,974,886 by Jack L. Blake, Jr., but evidently some improvements have been made from the patent. The stabilizer blades of as many as three different stabilizers can be selectively expanded in stages by running a wireline blanking sub. The appropriate choice of stabilizers to be expanded can cause a bottom-hole assembly to maintain, build, or decrease deviation angle. To cause all the stabilizer blades to retract, a ball is pumped down the string.

Due to the brevity of the article, a phone call was made to Directional Stabilizer Systems for more information. A set of 8-5/8-inch body tools expandable to 9-3/8-inch, 9-5/8-inch, 9-3/4-inch, or 9-7/8-inch diameter has been built and run offshore Louisiana. The tools evidently worked well in building angle in a 12-1/4-inch hole. The improvements in the wireline operation required appear to be advantageous, but drawings are not available for full evaluation.

A-2 Garrett, W.R., and Rollins, H.M., "New Deviation Control Looks Good in Field Tests," World Oil, October, 1964. pp. 122-127.

This article describes the Drilco "Bit Boss" rotating drillstring deviation control tool and its operation. This tool is covered by U.S. Patents 3,298,449; 3,326,305 and 3,460,639. The tool is a reciprocatable sleeve which, while journaling a mandrel connected in the string, thrusts laterally on the well bore in a selected direction when activated. The tool must be reset when full axial travel on the mandrel is completed. Only a short stroke on the mandrel was available at the time of writing, but a 10-ft. stroke is considered feasible. The tool was run as deep as 10,000 feet. Some repair work typically was required, along with attendant extra surveys and handling time. A full-time operator was acquired.

A phone call was made to Drilco to investigate the tool. It is not available for use commercially at this time. The level of demand currently is evidently not sufficient to justify offering this relatively expensive rental tool. Evidently the tool did work reasonably well.

A-3 Keene, Don, and McKenzie, Don, "Deviation Tool Controls Bit Walk," Oil & Gas Journal, September 3, 1979.

This article describes a tool that introduces a leftward or rightward drift tendency normal to the vertical plane containing the lower portions of the well bore. The "Rebel Tool" was first offered by Eastman Whipstock in the 1950's, but has been improved. Before the tool is run, appropriate changes are made to cause it to drift left or right. The deviation is induced by using weight-induced transverse deflection of a paddle mounted on the upper end of the tool to cause a second paddle, adjacent the bit, to shove laterally on the borehole. The two paddles are interconnected by a shaft. Field test results and cost comparisons with downhole motor and bent sub use are given.

A-4 "Multi-Angle Bent Sub Operated from the Surface," Ocean Industry, June, 1980. pp. 39-40.

This article describes a new surface-controlled bent sub tool. In order to avoid making round trips to change bent sub angles for drilling with downhole motors, SMF International and Institut Francais du Petrole (IFP) have developed two promising devices. Both devices are based on a similar arrangement where a lower body end shaft is journaled in an upper body end, with the journal and shaft axes passing through the axis of both upper and lower bodies, but inclined at the same small angle, $\theta$, to those axes. Thus, when the lower body is rotated relative to the upper, the angle of bend between the upper and lower bodies varies between 0 and $2 \cdot \theta$. The means of rotation for both tools is a barrel cam axially-cycled by a piston and spring.

The electrically operated tool opens a solenoid valve to permit the actuation piston for the barrel cam to be forced downward by mud pressure. The spring returns the piston after the barrel cam rotates the lower body one cam slot increment. The mechanical tool temporarily closes a central passage in the annular operating piston by a dropped ball, effectively plugging the piston and causing it to move downwards until shouldering so the ball is blown through its receptacle by pump pressure. The design detail on this tool appears good.

A-5 Leonard, Jeff, "Remote-Controlled Bent Sub Changes Angle Downhole," World Oil, July, 1980, p.63.

This article covers substantially the same material as Reference A-4 above.

A-6 Rollins, H.M., "Deviation Control Using Fluid-Operated Bit Guiding Tools," presented at the Spring Meeting of the Rocky Mountain District, API Division of Production, April, 1966.

This reference was not obtainable locally, but persumably covers further experience with the Drilco "Bit Boss" tool, discussed in Reference A-2.

A-7 Sullivan, Wayne, "Drilling Centralizer Controls Directional Wells," Oil & Gas Journal, November 5, 1979. pp. 101-102.

The tool described in this article is EMTEC's clamp-on blade stabilizer, covered by U.S. Patent 4,101,179 of Alvie Barron. The stabilizer sleeve is fitted to a drill collar in a desired position and then clamped with a nut compressing a split, tapered ring in the manner typical of many collet connectors. The tool when downhole is not controllable from the surface, but is simple and quite effective. The primary value of this article for this project is the indication, in test results, of the effectiveness of proper stabilizer positioning.

A-8 Harris, H.C., Jr., "Principle of, and Results With, the Rebel Tool," Part III of Panel Discussion on New Developments in Directional Drilling, API Division of Production, Abstracts Paper 801-A1-D, Vol. 45 (IV), 1963. Also covered in Drill Bit, Vol. XIII (4) 30, July, 1965.

This presentation covered the field results and theoretical behavior of the Whipstock, Inc. "Rebel Tool". See Reference A-3. The Rebel tool was introduced in 1963 as an aid to solving problems of lateral drift in directional drilling. The past year provided ample job experience to support a study to evaluate the tool's ability to correct a bit's tendency to walk left or right. Three primary conclusions may be drawn from this study: a) although the tool has proved effective in correcting lateral drift in a majority of cases, its primary usefulness

is in preventive measures--to avoid subsequent jetting or whipstocking operations; b) the tool operates more efficiently where the formation is firm; c) approximately the same degree of success may be expected in correcting either left- or right-hand walk.

A-9 Moore, S.C., "New Technique for Full-Gauge Directional Drilling," Part II of Panel Discussion on New Developments in Directional Drilling, API Division of Production Paper 801-41-C, Vol. 45 (IV), 1965.

This presentation covered Drilco's experience up to 1965 with their "Bit Boss" tool. See Reference A-2. The tools and techniques for a new method of directional control of the full-gauge well bore are the result of a 13-year research and development program by Drilco Oil Tools, Inc. The technique itself is simple enough, employing a bottom-hole anchor which develops a resilient off-center lateral load on the bit. The anchor is set in the open hole, immediately above the bit, and the drill collar makes a short stroke of about 5 ft. through it. The anchor is then repositioned immediately above the bit and the cycle repeated. Most of the testing, in some 20 wells to date, has been necessary for the development and refinements of the tool's use. The principles were proved to some degree from the very first test. This paper describes the principles involved, the development work, and field results.

B. <u>Related Technology</u>

B-1 Dareing, D.W., "State-of-the-Art of Drilling Thrusters," Houston, Texas, Maurer Engineering, Inc. Report TR 79-21 to Sandia Laboratories, August, 1979.

This report reviews the patents and commercially-available tools that are related to either longitudinal or transverse thrusting on the borehole wall. Tools of the latter type can be used for steering downhole. Several of the patents reviewed in this report are also covered in Dareing's report. Most of the patents are briefly described. Several mining and tunneling devices are covered. Some useful information from interviews describing tool use is given. The technology described

is mostly not suitable for oilfield deviation control, but review of other approaches is useful, since adaptation of other types of device is often feasible. This report is the most complete reference available in terms of number of devices (both directly and indirectly related) described.

B-2 Enenback, H., "Directional Drilling Technology Strives for Speed & Accuracy," Petroleum Engineer International, Sept. 1980. pp. 124-132.

This article covers some of the directional survey equipment available and in development. A brief description is given of some of the new measurement-while-drilling (MWD) hardware. Use of any deviation control tool will require some survey equipment, probably one of the types discussed in this article.

B-3 Katz, L.J., "Drill Bit Location, Guidance by Seismic Seen Feasible," Oil & Gas Journal, July 28, 1980. pp. 197-200.

This article describes research work by Utah Geophysical, Inc. for using a surface seismic sensor array to locate a drillbit downhole. The advantage of such an approach, if commercial, would be the ability to survey without the inconvenience of wireline-run sensors. This, in turn, would provide more flexibility for deviation tool design. Use of such a technique offshore would probably involve cable problems, and the accuracy near a platform could be problematic because of piling and the closeness of other conductors.

B-4 Leonard, Jeff, "Kelly Bushing Has Wireline Side Entry on Steering Tools," World Oil, July, 1980. p.65.

This article describes a special kelly bushing offered by Tullos and Woods Tools, Inc., Lafayette, Louisiana. In combination with Sperry-Sun's wireline side entry sub, the Kelly bushing permits keeping the wireline survey tool in the hole while making connections. This results in very large time savings when directional drilling with a downhole motor. If special inductive, two-way data links were used, electrical control of near-bit hydraulic servos could become practical. The wireline side entry sub is covered by U.S. Patent 4,062,551.

B-5 Weeden, Scott L., "Recent Advances in Drilling Tools and Technology," Ocean Industry, June, 1979. pp. 40-46.

Nothing directly related to the project is included in the article, but a low-speed, high-torque turbodrill is described. A reduction gear is used to develop the higher torques, so that the turbodrill can be used with higher, more effective bit loadings. The work was done by the Association de Recherche sur les Techniques d'Exploitation de Petrole (ARTEP).

B-6 Thorogood, J.L., "How BNOC Controls Directional Drilling," Petroleum Engineer International," May, 1980. pp. 26-44.

This article relates to measurement and computation of downhole survey data only.

C. Status of Foreign Technology

C-1 "China Claims Advanced Drilling Ability," Oil & Gas Journal, October 22, 1979. pp. 24-25.

No mention is made of deviation control tools other than bent subs.

C-2 Murray, A.S. & Tilbe, J.R., "Canadians Report Results of Drilling Exchange with Soviets," Oil & Gas Journal, April 23, 1979. pp. 51-60.

No mention is made of new deviation control equipment.

D. Need for Technology or General Interest

D-1 Dellinger, T.B.; Gravley, W.; and Tolle, G.C., "Directional Technology Will Extend Drilling Reach," Oil & Gas Journal, Sept. 15, 1980. pp. 153-169.

This article deals with problems when rotary drilling in highly-deviated holes. No mention is made of deviation control means, but the low bit weights obtainable in deep, highly-deviated holes could make control a problem. The possible need for a downward thruster to enhance bit weight is mentioned. Such a tool could also be adapted to steer.

D-2 King, C.M. and McKenzie, D., "Drilling Wells on Target," Offshore, May, 1980. pp. 125-133.

This article deals with relief well drilling primarily, with emphasis on the surveying. Use of bent subs is suggested for kicking off. Variation of bottom-hole assembly (BHA) arrangements to build, drop or maintain angle when rotating the string to drill is suggested. There is mention of the difficulty in predicting BHA behavior in unknown formations.

D-3 Millheim, K., "Operators Have Much to Learn About Directional Drilling," Oil & Gas Journal, Nov. 6, 1978. pp. 60-64.

This is the first article in an eight-part series on directional drilling. An extensive set of references on bottom-hole assembly behavior and deviated drilling are given. Several situations requiring application of directional techniques are discussed.

D-4 O'Donnell, H.W., "Directional Drilling Eases Ship Channel Pipeline Crossings," Oil & Gas Journal, Mar. 25, 1980. pp. 161-164.

This article discusses a specialized deviated hole application. A slant-hole rig is used, and the holes are deviated to dip under a body of water.

E. General Information on Stabilization and Deviation Control for Rotating Drillstrings

These articles are not reviewed individually here. In aggregate, the articles present several practical considerations for rotating drillstring control. Several of the articles have analytical treatments for predicting bottom-hole assembly behavior. The Millhelm (References D-3 and E-5 to E-10) and Callas articles (Reference E-15 to E-18) are some of the more recent articles.

F. Manufacturers' Literature

F-1 "Bowen Dyna-Flex Joints," Bowen Tools, Inc. 1978-1979 General Catalog, Houston, Texas, 1978.

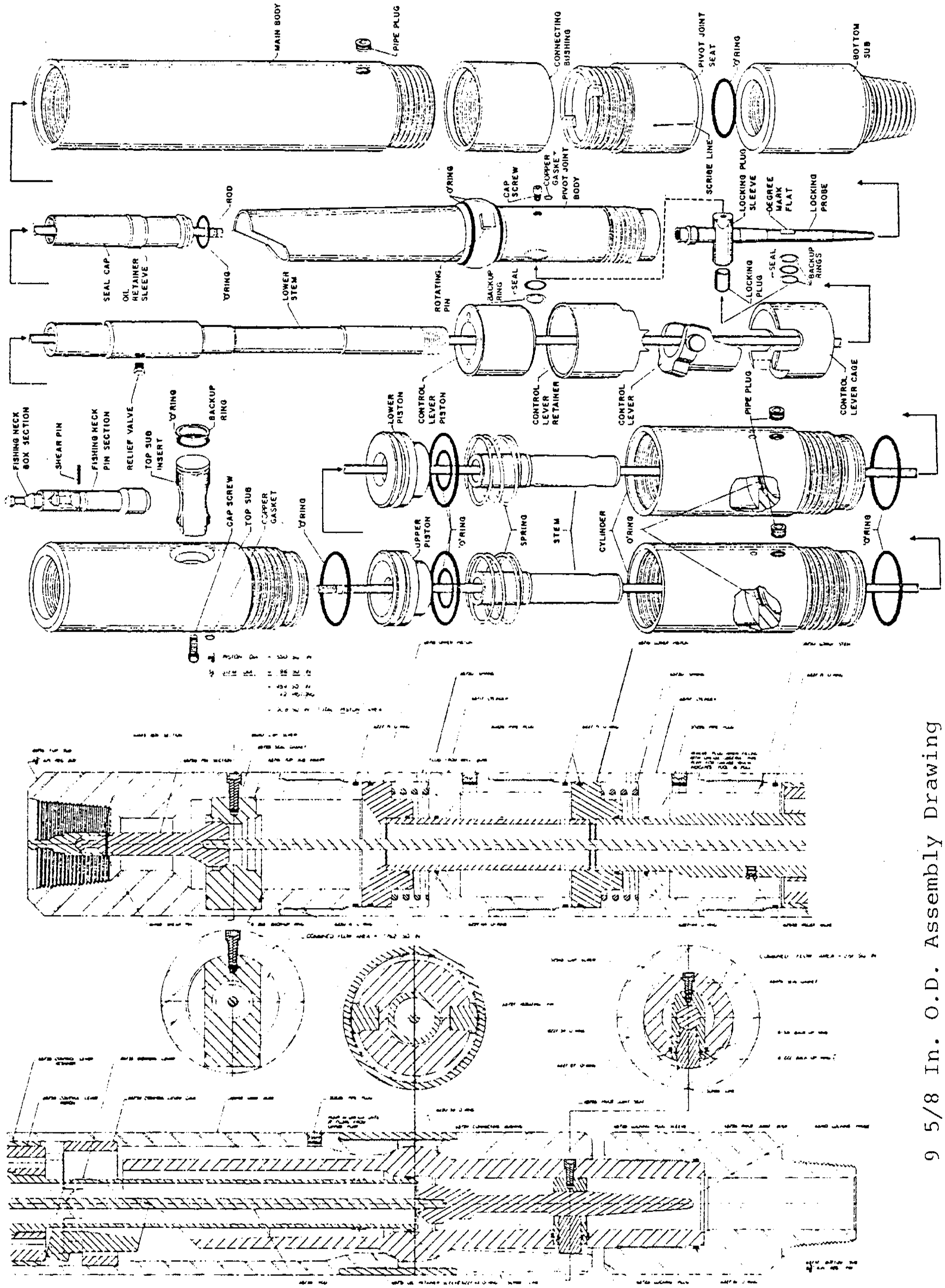
This reference, as well as References F-2 and F-3, describes the Dyna-Flex tool. A quarter-section tool drawing is given, tool specifications are provided, and the general operation is described on one page. Use of the bend angle limiting probe is described; the probe is go-deviled or landed with a releasing wireline overshot tool and retrieved with an overshot. The tool remains free to flex between 0° and the limits set by the probe at the knuckle joint provided until pump pressure is applied. Coacting pistons working off the difference between pressures inside and outside the tool urge the knuckle joint to bend to the limit set by the probe. See Figure 37. One important limitation of the tool is the very restricted flow areas available, even in large diameter tools.

F-2 "Instruction Manual-Bowen Dyna-Flex Joint," Manual No.5/4820, Bowen Tools, Inc. Houston, Texas, 1974.

This is a detailed operating and servicing manual of the Dyna-Flex tool. Exploded drawings, tool sections, and full assembly specifications are given. Mr. Ed Anderson, the tool inventor, was interviewed about the tool. He mentioned that the tool permits getting off a plug for sidetracking easily. Anderson believed that the main advantage for the tool was its easy orientation and ability to run in and out of the hole straight before bending.

FIGURE 37

The Dyna-Flex Bent Sub




Exploded View

9 5/8 In. O.D. Assembly Drawing

The tool was normally run for only a few hundred feet. He said that downhole bend corrections were "not too practical," but he had done it several times. He mentioned that the tool was expensive to maintain and hence had some operator acceptance problems. Review of the operation and design information in this manual does indicate a well-designed tool with several good features. See Figure 37.

F-3 "Dyna-Flex Selection," Dyna-Drill Handbook, 2nd Edition, Dyna-Drill Division of Smith International, Inc., Long Beach, Cal. circa 1976. pp. 30-32.

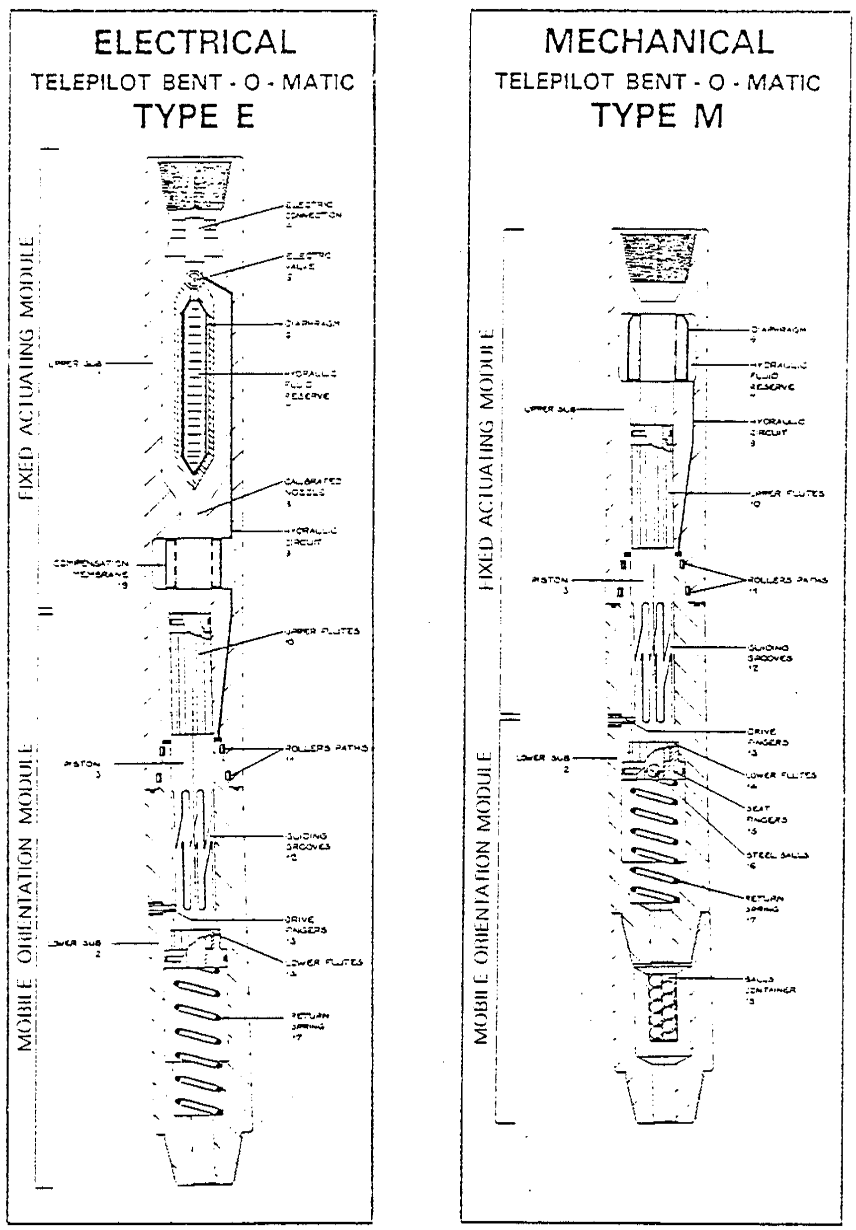
This short section in Dyna-Drill's instruction book describes briefly the tool operation, advantages, and sizes available. One cross-sectional drawing is given. A local Dyna-Drill salesman was questioned about the lack of mention of the tool in current Dyna-Drill literature, since they previously ran the tool. (See Ref. F-6). He said they had discontinued the tool, but could perhaps provide one for a client. Troubles with probe seating and retrieval were mentioned operational problems.

F-4 "Remote-Controlled Bent Sub Telepilot Bent-O-Matic," SMF International & IFP Joint Project Product Brochure, Paris, France, 1980.

This brochure provides the description of both the mechanical and electrical versions of this tool. The working description is given in the review of Reference A-4. This tool in the mechanical version is simple, easy to alter, and exhibits good mechanical design. The drawings, shown in Figure 38, are conceptual and omit some tool joints, for instance. The number of changes which can be made by the mechanical tool are limited by ball storage capacity. The barrel cam arrangement will not be prone to overstress when camming because of the ball release in excess pressure conditions. There is some flow restriction in the ball socket. The critical tool parts are bathed in oil. Probably the main question about tool performance is the ability to index when bending is restrained by the borehole. Surveying after ball dropping would typically be required to verify indexing. One major problem with the tool is the need to rotate the string to compensate for unwanted transverse bend components. This also requires surveying after incrementing. This tool does appear to offer promise of success in its mechanical version: availabilty is expected probably in 1982. The electrically controlled version will be introduced after the mechanical tool.

FIGURE 38

The Telepilot Bent-O-Matic Bent Sub



F-5 "The Rebel Tool," Eastman-Whipstock General Catalog 1980-1981 Houston, Texas, 1981. p. 21.

This reference provides a brief description of the Rebel tool and gives specifications. The tool is shown in Figure 39. The tool is a drill-collar-type body run near the bit. An upper "paddle" is connected to a lower "paddle" by a torsion-transmitting shaft. The paddles extend out somewhat from the body. When the weight on the bit causes string flexure so the upper paddle is forced inward relative to the body during the rotation of the upper paddle under the string and against the borehole wall, a twist is given to the shaft. The torque in the shaft causes a lateral thrust to be given to the hole wall adjacent the bit by the lower paddle. Changing paddles before running the tool can cause the lateral thrust to produce either leftward or rightward deviation tendencies normal to the vertical plane through the borehole adjacent the bit. This passive, surface-adjusted tool can thus compensate for certain unwanted deviations. Its use may exclude using other tools to control deviations in the vertical plane. It is expected that the need for the tool is somewhat limited, but it is a well-proven device. The main wear problem will be the paddles, which are easily replaced. The tool is quite simple and easy to service and will accomplish certain limited goals.

F-6 Composite Catalog of Oilfield Equipment and Services, 1980-81 Gulf Publishing Co., Houston,Texas, 1980.

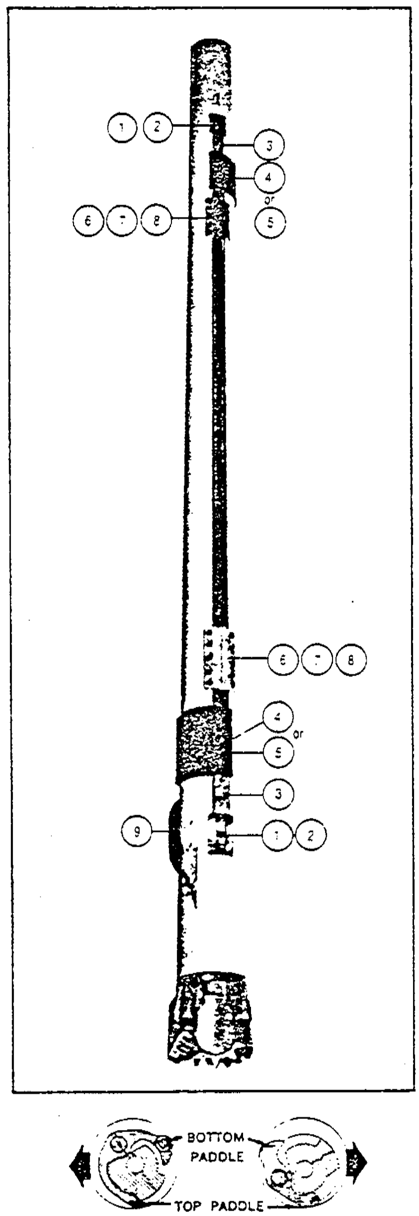
This reference lists almost all the catalogs of oilfield equipment builders, service companies, and suppliers. It serves as a good starting place for locating a particular tool. The only tool closely related to the project found in this most current version of the catalog is the Rebel Tool, described above in Reference F-5.

F-7 "Twist-Kick Sub" Christensen Diamond Products, USA Downhole Tools Division Product Brochure DT-810, Salt Lake City, Utah, 1981.

This brochure describes a new, extremely simple bent sub that probably will become very popular. The lower section of the tool is mounted on a skewed axis, as is the device shown in Trzeciak's U.S. Patent 4,077,657 and the SMF-IFP Bent-O-Matic. Mutual rotation of the upper and lower

FIGURE 39

The Rebel Tool

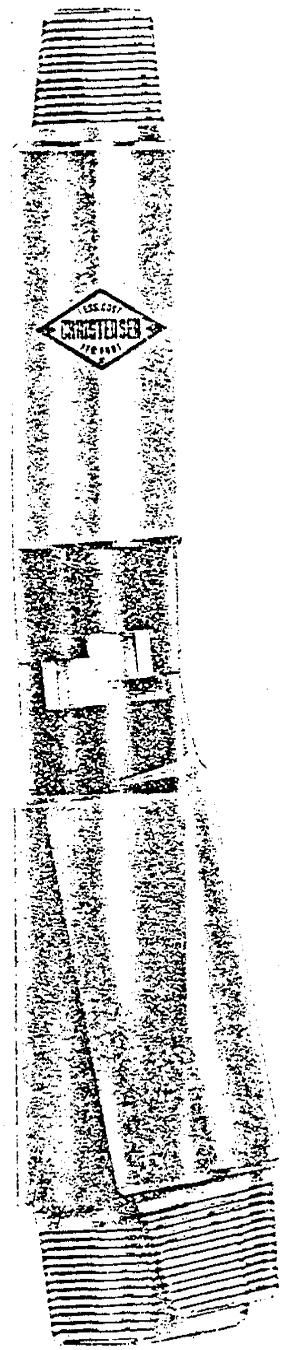



**To walk bit left:** with left paddles (seen here in cross section from above) the bottom paddle kicks bit to the left when extended by weight on its opposing member

**To walk bit right:** with short paddles (seen here in cross section from above) the bottom paddle kicks bit to the right when extended by weight on its opposing member pieces is possible about the skew axis. Lugs, mounted on both the upper and lower pieces, engage to limit the rotation about the axis and, hence hold the tool to a given bend angle when reaction to the downhole motor torque causes rotation. The tool trips in and out of the hole straight as a result of torque relaxation. There may be some orientation problem because of spurious out-of-plane bending components. However, this tool is about as simple and cheap as can be achieved. Wear, servicing, reliability, and operator problems should be minor. See Figure 40.

FIGURE 40

The Twist-Kick Sub



# CHAPTER V

## AREAS FOR DESIGN IMPROVEMENT

### Control Means Improvement

Several of the tools shown rely upon wireline or pumpdown control means for actually effecting tool operation or modifying tool settings. In some cases, such devices cause flow restrictions, but in all cases, use of such devices costs time. Where only occasional changes in a device are needed, such control means are fairly acceptable, providing they can be seated, do not jam, and avoid any other problems. However, it would seem that a better way could be found, specifically, a control means responsive only to circulation pressures in excess of normal values by a predetermined amount.

Such a pressure-responsive control means has been devised for use with downhole tools. This means, which has broad applicability to a variety of tools, is shown in the tool layout drawings (availability is described in the foreword). The new control means consists of a ball valve mechanism which closes when predetermined circulation pressure levels are exceeded, causing the tubular ball valve housing sleeve inside the tool body to reciprocate and thereby alter the tool behavior. When the ball housing sleeve activates a latch or barrel cam, sometimes termed a "running J," then release of circulation pressure permits the ball to open so that normal circulation can be reinitiated without change of the tool adjustment. By referencing a preset accumulator pressure on the ball-closing tubular piston, rather than the differential across the tool wall, washout problems can be avoided. The penalty for this is the problem of accumulator charging and charge maintenance. Use of an orifice to move an actuator piston is considered impractical because of bore restriction and the limited stroking force available.

The advantages of such an approach are the avoidance of wireline or pumpdown control means, minor or no bore restriction, minimization of washout possibilities, and action sensible on the pump pressure recorder. Use of ball valves with such mechanisms is proven; a long valve life can be expected. The full force of the pressure differential across the closed ball is available for activating a tool setting change. Remedial measures can be taken to overcome accumulator pressure losses, and downhole accumulator pressure adjustments are feasible in some cases. Use of oil-bathed mechanisms is feasible for much of such a control apparatus.

The costs of such a tool initially will be somewhat higher in most cases, but not restrictively so. Use of numerically controlled machining can considerably reduce the production costs for balls, seats, and barrel cams. Using elastomeric ball seats gives good reliability and permits opening up part tolerances. Investment casting can also be used to appreciably reduce manufacturing costs. The savings from reduced rig time requirements and, in some cases, better tool reliability are expected to offset any increased manufacture and field dressing costs.

## Drilling Cost Reductions for New Control Means

Quantifying potential savings for an untested design is not simple, but probable trends can often be established. The main savings will come in rig time for either a bent sub or a rotating drillstring tool of good design. Each time a wireline trip is avoided, approximately forty minutes to one hour or more can be saved, depending on depth and hole deviation. Likewise, avoidance of a typical roundtrip can save anywhere from, say, six to twelve hours on an average intentionally deviated well or accidentally deviated well.

If a bent sub can be varied without either wirelines or tripping, then tripping times are reduced by tripping with the sub straight, and the mud cake on the bore wall will not be damaged. This downhole variability can permit firmly establishing the kicked off well trajectory without any need for changing bottom-hole assemblies. This should save an occasional trip. Time savings for a bent sub should be about one to two hours per run just for trip time or wireline time; additional time savings could come from avoidance of extra bent sub runs for hole correction by utilizing the finer control available with the new bent sub.

For a variable rotating drillstring bottom-hole assembly (BHA), appreciable time savings are realized from longer runs to avoid BHA changes. This should save at least one trip per deviated well, but could reasonably be expected to save as many as three or more for an average case. Use of a pressure-responsive control instead of a wirelined or pumped-down control would save an additional few hours. One particularly nice advantage of a pressure-responsive control is the ability to rotate, reciprocate, and circulate essentially continuously, even while changing tool configurations. This will lead to a significant reduction in stuck pipe problems.

## Bent Subs

The Dyna-Flex tool offered good adjustability and, also, urged the knuckle joint to bend so that, even if it initially could not bend, it would gradually increment its bend to the desired value lower in the hole. The use of the wireline probe for control interfered with surveying. There were evidently some problems with probe changing and seating. There was also some problem with the plating on the cylinder walls. Maintenance was expensive and since most kickoffs are done at shallow depths, it was difficult to compete with quickly round-tripped conventional bent subs. Orientation of the Dyna-Flex was comparatively much simpler than for a conventional bent sub, and tripping in and out of the hole straight was quite desirable.

The SMF-IFP Telepilot Bent-O-Matic tool offers the advantage of having its critical parts bathed in oil and having minimal washout possibilities. Changing bend angle in the mechanical version of the tool is simple, but requires survey tool removal prior to dropping the balls. Whenever the angle of the bend is changed, the drillstring must be rotated for compensating unwanted transverse bend components. This is problematical, due to stick-slip behavior and the length of the drillstring. The camming pin or its groove are unlikely to be overstressed, since the ball will dislodge in an overload situation. The practicality of this tool has yet to be demonstrated with extensive testing.

The proven Dyna-Flex knuckle-joint bend limitation approach could be modified to incorporate the intended pressure-activated control means. However, the development of a tool design for this approach seems relatively more difficult than adapting the Telepilot Bent-O-Matic bend production approach to include the new control means. Further, elimination of the Telepilot Bent-O-Matic drillstring rotation requirement when indexing seems tractable. Accordingly, the skewed journaling of the lower body of this latter tool was used as a starting point for the new bent sub design.

## Rotating Drillstring Tools

There are several possible approaches shown in the patent art to which pressure-responsive control means could be adapted. Typically the adaptation would involve selectively opening and closing a port to the primary actuator means in order to avoid using wireline-run blanking sleeves or plugs. The means for opening and closing the port would be the same basic pressure-responsive mechanism that is incorporated in both of the new tool designs produced for this report.

It was decided that the simplest, most reliable tool type for rotating drillstring deviation control would be an expandable stabilizer that would achieve that same result as that in Jack Blake's U. S. Patent 3,974,886. This tool system has a minimal need for manipulation to make it function, and, once set, no parts are in relative motion. The structural problems in that type tool are expected to be reducible to a tolerable level, and the tool dressing and wear problems seem likely to be minimal.

The expandable stabilizer type tool has no controllable kickoff abilities, but should provide satisfactory control for a significant share of deviation control problems. The simplicity of operation is an important plus for this class of devices.

The tool does not appear particularly amenable to simplification. However, use of the pressure-responsive control means could eliminate the need to use pumpdown or wireline devices to alter the system settings. This would have attendant time savings. Accordingly, this is the approach selected for a new rotating drillstring deviation control tool.

# CHAPTER VI

## NEW DESIGN BENT SUB TOOL

Several promising starting points for developing a novel, surface-controlled bent sub device exist in the prior art. Such a device, to be practical, should ideally have the following attributes. The ideal tool:

a) Trips in and out of the hole straight.

b) Is compatible with use of wireline survey equipment in the drillstring.

c) Has minimal flow restriction and is compatible with a downhole motor.

e) Will not sand up or wash out if a moving seal leaks.

f) Is immune to the mud pumps being turned on and off.

g) Is compatible with use of a fill-up or dump valve in the string.

h) Is easy to dress, repair, check-out, and prepare for use with minimally trained personnel.

i) Is readily manipulated from the surface without running wireline or pump-down tools.

j) Gives positive indication of operation.

k) Fails "safe" without interfering with routine drilling or circulating.

l) Can flex to as many as 3 to 5 different bend angles for fine control.

m) Is inexpensive and cost effective.

Any given design will meet these objectives with more or less success; certainly it is difficult to be optimal in all respects. The tool developed as a part of this study is believed to be good in most of the areas of performance listed above. Avoidance of the use of electronics, complicated actuation mechanisms and the more obvious trouble-prone design features has been achieved. The tool geometry is not particularly simple, but the basic mechanisms used are straightforward.

The bent sub developed is controlled by mud pump pressure, without use of wireline tools, drillstring reciprocation or rotation or pumpdown tools. This device is shown, drawn to scale, in Drawing No. "Layout A."

The tool, 149-1/4-inch long x 7-3/4-inch outer diameter and 2-inch bore, is a bent sub controlled from the surface by varying the circulating pressure inside the drillstring. The bend angle of the tool can be increased from 0° to 5/8°, 1-3/8°, 2°, and, finally, to 2-1/2°, and then reduced back to 0° by reverse sequence. This is done by raising the drillstring pressure to a level such that the operating mechanism produces a change in the tool angle by one increment following release of the string pressure. This procedure can be repeated as often as desired and in a rapid, efficient manner without running any tools down the drillstring.

The tool body is divided into upper, middle, and lower sections which can be rotated relative to each other. The middle section (Parts 11, 12) is coaxially journaled in the upper body (1) and retained by ball bearings (27). The bottom section (14) is journaled in the middle section (12, 13) with a skew axis that intersects the axis of the upper and middle sections (the tool axis), as well as the central axis of the lower body (14). The skew axis is inclined at a 1.25° angle to the tool axis and the axis of the lower body (14). Rotation of the lower body (14) about the skew axis causes it to have an effective apparent bend angle of 0° minimum and (2) × (1.25°) = 2.50° maximum. This is due to the movement of the axis of the lower body (14) in a circular path which intersects the tool axis. The function of the other components of the tool is to cause such rotation to occur in a controllable manner and to remove any motion components which are not in the desired plane of bending of the bent sub tool. The desired plane of bending contains both the tool axis and the skew axis.

Inside the body (1, 11, 12, 13) is a camming assembly (9) composed of an upper (9a), lower (9c), and linking tube (9b), all joined with two U-joints. The body sections are bored to receive the camming assembly (9). The middle body (12) is not permitted to rotate relative to the camming assembly (9) because of a camming pin (26) mounted in the middle body (12) and constrained to work in a straight slot parallel to the lower tube (9c) axis. Reciprocation (down & back up) of the camming assembly (9) forces the lower body section to rotate one increment around the lower barrel cam on the lower tube (9c). Reciprocation of the camming assembly (9) forces the camming assembly (9) to be rotated relative to the upper body (1). The amount of reciprocation permitted is approximately 9 inches, which is sufficient to operate the lower barrel cam. Review of the barrel cam pattern for the upper barrel cam on part 9a indicates that an axial-motion-permitting "slip clutch" arrangement is required in order to avoid bottoming-out the upper camming pin (22) in the short grooves of the upper barrel cam. Accordingly, while the clutching sleeve (10) that mounts the upper camming pin (22) cannot rotate relative to the upper body (1), it can translate with the camming assembly and, hence, avoid bottoming-out by being "declutched" from the upper body (9a). This declutching is accomplished by causing a properly-positioned "sink" (machined in the outer surface of the upper tube (9a)) to arrive adjacent the declutching ball (28) when declutching is desired. The declutching ball (28) will then disengage from the recess in the declutching ball retainer (23), which is screwed into the upper body (1). The declutching ball (28) is then engaged by the sink in the upper tube (9a) until the reciprocation is reversed, so that the declutching ball again engages the declutching ball retainer.

Reciprocation is caused by closing the ball valve so that the hole through the tool bore is blocked; drillstring pressure/flow then strokes the camming assembly (9) downwardly until it "bottoms" on shoulders provided on parts 11 and 14. Full release of the pump pressure on the drillstring then lets the ball opening spring (17) reopen the ball (5) so that the springs (15, 16) can raise the camming assembly (9) to its normal position (up, as shown in the drawing). Movement of fluid around the enlarged diameter of ball housing (2) damps the motion of the upper tube (9a). The bottom extension of the lower tube (9c) encounters a reduced bore section when it moves adjacent lower spring stop (14) prior to completing a full 9-inch stroke. A flow restriction thus results for the fluid attempting to escape between the lower extension of part 9c and the lower spring stop (14), thus damping the motion of the lower tube (9c).

Prior to running the tool downhole, the accumulator chamber formed between the ball housing (2), the piston (3), and the upper ball stop (4) is precharged to a presure $P_A$ in excess of the total pressure (hydrostatic and pump-induced drillstring internal circulation pressure) at the anticipated deepest part of the "run." This pressure $P_A$ should be chosen to be attainable with the rig pumps, downhole motor, and bit nozzles used; $P_A$ should be as low as possible

Downhole, when the pressure internal to the drillstring is raised in excess of $P_A$, the piston (3) attempts to overcome the biasing pressure $P_A$ and the ball-opening spring (17) to close the ball (5). The desired ball-closing procedure is to raise the drillstring pressure, in some manner, to the maximum mudmotor rating for standard drilling, but then to rapidly raise the mud pump pressure sufficiently in excess of $P_A$ to ensure ball closure. Ball (5) closure serves to protect the downhole mudmotor, located downstream of this tool, from excessive overpressures of any significant duration. Ball closure converts the camming assembly (9) effectively into a piston responsive to the flow pressure trapped in the drillstring by the ball (5). This pressure forces the camming assembly (9) to make the downward part of its reciprocatory motion, so that the barrel cams on parts 9a and 9c can function for the downstroke portion of an incremental rotation. Full release of pump pressure lets the ball reopen and then lets the camming assembly rise, completing one camming assembly reciprocation and one lower body-bending increment. Tool actuation is best done with the bit off the bottom so that resistance to movement is reduced.

The U-joint arrangement shown is similar to that used in articulated drill collars, certain fishing tools, and Smith International's Dynadrill. The rubber sleeve (35) over the U-Joints prevents mud from intermingling with the oil used to lubricate the bearings in the body and the camming assembly (9). The oil is injected through the ports filled by plugs 20, 21. The rubber sleeve (35) also equalizes the pressure between the lubricating oil and the tool bore and, by expanding to compensate for oil loss, ensures a long-lived supply for lubrication.

The ball cage (6) has a pair of identical halves. Each half has an elongated slot to accomodate the diametrically opposite central guide pins on the ball (5). Rotation of the ball (5), in response to its travel along the tool axis, is caused by eccentric camming pins on the ball cage (6) halves engaging off-center slots on the ball (5). Axial thrusts applied to the ball (5) by the piston (3) or the ball pusher (8) are resisted by off-center resistances applied to the ball (5) slots by the camming pins, so a rotational torque is induced on the ball (5). This mechanism is substantially the same as shown in U.S. Patent 4,220,176.

The particular advantages of this tool include the following.

1) Tool bending is confined to one plane.

2) The tool can be run and retrieved straight, but can be quickly adjusted to an appropriate angle (up to a relatively large 2.5°).

3) Bend angle adjustment is rapid and, other than picking up off bottom, requires only increasing mud pump pressure and keeping count of increments to operate. A semi-reliable indicator of tool function is the buildup of string pressure as the mud pumps "deadhead" against the closed cam tube at the bottom of its stroke.

4) Almost all critical parts are oil-bathed, and the tool is unlikely to sand up or wash out.

It is expected that field personnel can be taught to reliably dress and run the tool, since dressing will not be overly difficult. The cost of the tool will not be cheap, but use of NC machining of the barrel cams, investment casting for the ball cage, and care in boring the skew hole in parts 12 and 13 will keep fabrication costs within reason. Most of the tolerances are not overly critical, and the oil bath for many of the parts should enhance their lives.

The primary deficiencies of the new tool are likely to be related to items h), j), k), and m), listed earlier in this section. The deficiency with regards to item k) is mostly related to the inability to change the bend angle, should a failure occur, so that a trip out of the hole with a bent tool is required. This is comparable to tripping out with a conventional bent sub. In most other respects, the tool will fail "safe", except for the unlikely prospect of pulling it apart. If the accumulator gas is lost downhole, the loss will occur only to the point where the ball will close prematurely; a wireline-run sleeve insert will permit circulating in such a case. Loss of gas uphole can result in locking the ball closed, but checking for gas bleed-off before sending the tool downhole can markedly reduce the likelihood of such problems. Use of a bellows or bladder arrangement for gas containment will further reduce leak probabilities.

Overall, it is believed that the tool offers enough operational features and improvements, while having minimal negative design features, to become a successful commercial item. Final design and prototype testing are not expected to be difficult. There is a fair likelihood of a reasonably defensible patent, so that any licensee would feel justified investing in tool development. There would seem to be enough differences between this tool and that shown in Reference F-4 to permit obtaining a useful patent.

## CHAPTER VII

## NEW DESIGN ON-OFF BLADE STABILIZER

Development of a successful deviation control tool for rotating drillstrings is in many ways more problematic than developing a bent sub. One major difference in the two types of tools is the significantly higher loadings and rotationally induced fatigue problems for a rotating string tool. There are several arguments to support the development of a transverse thruster tool that journals the rotating string while bearing or simultaneously bearing and sliding on a preselected side of the hole. However, it is believed that most needs can be met by using retractable blade stabilizers, which are a simpler type of tool.

Retractable blade stabilizers, if properly located in the drillstring and then activated as needed, can control either angle building or reduction when bit weights and rotational speeds are appropriately maintained. The series of articles by K. Millheim (E-5 to E-10), as well as similar articles by others, indicates an analytical approach for estimating the deviational tendencies of a drillstring. For, say, offshore platforms, use of curved well conductors can provide the initial well deviation, which can then be increased with depth as desired by adjusting retractable blade stabilizers. For controlling unwanted well deviations, there typically is not a kick-off problem unless the formations are steeply dipping, so an on/off retractable blade stabilizer would usually suffice.

In contrast to a transverse thruster tool, use of a retractable stabilizer avoids rotating seal and bearing problems, while permitting a somewhat stronger, stiffer tool cross-section. Wireline survey location of the transverse thruster orientation would be required, but this is not needed with a retractable blade tool. What is required is advance knowledge of what the drillstring behavior will be for any stabilizer condition and location. This can be precalculated or predetermined by experience.

The basic requirements for an ideal retractable blade stabilizer include the following.

a) Maximum body cross section (without major stress risers) and with stiffness and strength roughly comparable to adjacent drill collars.

b) Resistance to sanding up and washing out if a moving seal leaks.

c) Minimal flow restriction and compatibility with wireline survey tool use.

d) Immunity to turning the mud pumps on and off.

e) Ease of dressing, repair, checkout and preparation for use with minimally trained personnel.

f) Readily manipulated from the surface without running wire-line or pump-down tools.

g) Positive indication of operation.

h) "Fail-safe" behavior that will not interfere with routine drilling and circulating.

i) Inexpensive and cost effective.

As in the case for bent sub designs, the degree to which these criteria are met varies for any given design. It should be noted that the particular design chosen here is weak with regard to item a) above. However all such tools will be less than optimal relative to item a); this particular tool would be generally comparable to competitive equipment in this regard.

The design chosen, shown in Figure B-0, is similar in many respects to that used for the bent sub, described in the preceding section. Actuation does not involve electronics or pump-down or wireline tools. Most of the potentially problematical design features have been eliminated, and the resulting tool is believed to be a practical device.

The tool consists of 1) an 8-inch diameter body section (parts 1 and 10), 2) three stabilizer blades which can be expanded to a 9-7/8-inch outer diameter from their normally retracted 8-inch diameter (parts 12), and 3) a pressure-responsive blade expander/retractor mechanism, or actuator. The through bore of the tool is 2 inches. The ball and accumulator mechanism is substantially identical to that of the bent sub tool, described in the preceding section.

The ball (5) of the actuator is normally biased open by ball opening spring (16) and ball pusher (8). A nitrogen-filled chamber is charged to pressure $P_A$ through check valve (18), where $P_A$ is somewhat in excess of the expected maximum normal drilling string pressure while drilling. This accumulator chamber is located between the ball housing (2), piston (3), and upper ball stop (4). The piston (3) is normally held open against its stop, the Spirolox ring (17), so that the ball (5) remains open. When circulation is increased to a rate such that the string interior pressure sufficiently exceeds the pressure $P_A$, the piston (3) forces the ball (5) to close. At that point, circulation through the actuator assembly is blocked, and the actuator is moved downwardly, overcoming cam return spring (15). This causes the cam (9) to rotate and, overtraveling, expand the blades (12). When the pump pressure is released from the string, the ball (5) reopens and the cam (9) is rotated and moved to its next position, to hold the blades (12) expanded, by the cam return spring (15). The blades (12) are retracted by again raising the string interior pressure to a level sufficiently above $P_A$ in order to close the ball (5) and thus cause the actuator to move downwardly and rotate. Then, when the pressure is released, the actuator moves up sufficiently to permit the blade retraction springs (14) to retract the blades (12).

The particular advantages of this tool include the following.

1) Blade position control is simple and rapid, requiring only surface mud pump manipulation. String rotation and reciprocation can be continued during blade position changes.

2) Almost all critical parts are oil-bathed, and the tool is unlikely to sand up or wash out.

3) The tool is fairly easy to dress, and the blades are easily replaced.

4) A fairly reliable indication of tool function is the pressure rise that occurs following ball closure and actuator "bottoming out."

The weaknesses in the design are primarily related to items e), g), and h) in the preceding list of design requirements. The main problem in preparing the tool for use is the accumulator charging, as is the case for the bent sub. Personnel can be trained in the accumulator charging procedures fairly quickly. Otherwise, the tool dressing is fairly straightforward. The blade openings in the body should always be checked for damage and cracks adjacent the openings following each run, but this can likely be handled with blade "play" measurements, visual inspection, and dye penetrant tests. There is no positive indication of blade extension or retraction in the current design, although this could be made sensible by a wireline-run instrument. Typically, though, this problem is not expected to be a significant constraint. The earlier comments about fail-safe operation for the bent sub similarly pertain here. Essentially, careful operational procedures and suitable accessories can eliminate most of the problems related to obtaining fail-safe behavior. Use of gas bladders or bellows to minimize leakage possibilities can also aid in enhancing tool reliability, if required.

This tool should permit reliable dynamic control of rotating string deviation tendencies in a manner adequate for most purposes where dynamic, rather than passive control, is needed. The cost of the tool is not expected to be excessive, and its wear and breakage rate is likely to be acceptable, even given its location in the drill collar string. There is a reasonable likelihood of a patent issuing on this tool, with an attendant enhancement of its commercial value.

## CHAPTER VIII

## CONCLUSIONS

Interest is reviving in downhole-adjustable deviation control tools, as evidenced by new tool development projects and tool introductions. Two new downhole-adjustable bent subs are being developed, one by Bowen Tools, Inc. and one by a SMF-Institut Francais du Petrole cooperative effort. Another related tool for overcoming objectionable bent sub behavior, the Christensen Twist-Kick bent sub, is now being marketed. A promising concept for rotating drillstring control, based on selectively operating a system of three independent, expandable blade stabilizers, has been tested by Directional Stabilizer Systems of Odessa, Texas. There appears to be a good chance of these tools becoming commercial successes if they are debugged well and provided with good marketing and field service. The potential time and cost savings from these tools should cause them to be accepted if given proper marketing and technical support.

The reviewed patent and technical literature found a limited number of downhole-adjustable concepts which have been used in the past, but are not now being marketed. The Drilco Bit Boss lateral thruster for rotating drillstring control was marketed and used for several years, as was the Bowen Dyna-Flex Bent Sub. Other concepts were found which had merit, but seemed to present possible design problems. Probably the most potential in the reviewed concepts is in the area of bent subs; several of the rotating drillstring tools could be converted to bent sub duty, where the working stresses would be more tolerable.

There still seems to be room for appreciable improvement in the devices found. In particular, elimination of wireline trips or pumping control devices down to the tool can provide good time savings. This can be achieved by providing the tools with a mechanical control device which responds to drillstring pressures in excess of normal circulation levels. Such a control means has been developed as a part of this project. This control means has wide applicability for drilling tools. It is included in both of the new tools which were designed for this project, but could also be adapted to serve as the operator in others.

The new bent sub design is simpler to orient than the SMF-IFP design and requires only pressure manipulation to adjust the tool. The avoidance of wireline trips necessitated for operation of similar mechanical tools also gives a good improvement in efficiency. Because the parts work primarily in oil, the seals are redundant with one exception, and since the operating principles of the control means are well proven, it can be expected that the tool will be reliable. The primary questions about the new design relate to: 1) the ability of the angle adjustment mechanism to increment in spite of flexural restraints from the borehole, and 2) the strength of any patent coverage obtainable. Remedial measures are likely possible for the first potential problem.

The new expandable blade stabilizer design is easier to change downhole than the Directional Stabilizer Systems' tool, since no wireline tools or pumpdown balls are used. This results in a reasonable time saving over the other tool design. The primary questions relating to a design of this type are: 1) tool durability in the hole, in particular relating to the blades and their mounting slots, and 2) the strength of the patent coverage obtainable in light of possible improvements as yet not in the public domain, to the Jack Blake U. S. Patent No. 3,974,886.

Should patentability or design problems exist with the deviation-inducing mechanisms of the two new designs produced for this report, the control means itself probably is still unique and patentable. This control means is definitely adaptable to other tools of the sort needed for downhole-adjustable deviation control tools. Because of the straightforward mechanism of the control means and its simple operation, it offers a good advance in technology.

CHAPTER IX

REFERENCES:

BIBLIOGRAPHIC INDEX TO LITERATURE SURVEY


A. Announcements of New Tools or Field Results

1. Leonard, Jeff, "Expandable Stabilizers Provide Assembly Variation Without Tripping," World Oil, July, 1980. pp.63-65.

2. Garrett, W. R., and Rollins, H. M., "New Deviation Control Looks Good in Field Tests," World Oil, Oct., 1964.

3. Keene, Don, and McKenzie, Don, "Deviation Tool Controls Bit Walk," Oil & Gas Journal, Sept. 3, 1979.

4. "Multi-Angle Bent Sub Operated from the Surface," Ocean Industry, June, 1980. pp. 39-40.

5. Leonard, Jeff, "Remote-Controlled Bent Sub Changes Angle Downhole," World Oil, July, 1980. p. 63.

6. Rollins, H. M. "Deviation Control Using Fluid-Operated Bit-Guiding Tools," presented at the Spring Meeting of the Rocky Mountain District, API Division of Production, April, 1966.

7. Sullivan, Wayne, "Drilling Centralizer Controls Directional Wells," Oil & Gas Journal, Nov. 5, 1979. pp. 101-102.

8. Harris, H. C., Jr. "Principle of, and Results With, the Rebel Tool," Part III of Panel Discussion on New Developments in Directional Drilling, API Division of Production, Abstracts Paper 801-A1-D, Vol. 45 (IV), 1965.

9. Moore, S. C. "New Technique for Full-Gauge Directional Drilling," Part II of Panel Discussion on New Developments in Directional Drilling, API Division of Production Paper 801-41-C, Vol. 45 (IV), 1965.

B. Related Technology

1. Dareing, D. W., "State-of-the-Art of Drilling Thrusters," Houston, Texas, Maurer Engineering, Inc. Report TR 79-21 to Sandia Laboratories, Aug. 1979.

2. Enenback, Joseph H. "Directional Drilling Technology Strives for Speed & Accuracy," Petroleum Engineer International, Sept. 1980. pp. 124-132.

3. Katz, L. J. "Drill Bit Location, Guidance by Seismic Seen Feasible," Oil & Gas Journal, July 28, 1980. pp. 197200.

4. Leonard, Jeff, "Kelly Bushing Has Wireline Side Entry on Steering Tools," World Oil, July, 1980. p. 65.

5. Weeden, Scott L., "Recent Advances in Drilling Tools and Technology," Ocean Industry, June, 1979. pp. 40-46.

6. Thorogood, J. L., "How BNOC Controls Directional Drilling," Petroleum Engineering International, May, 1980. pp. 26-44.

C. Status of Foreign Technology

1. "China Claims Advanced Drilling Ability," Oil & Gas Journal, Oct. 22, 1979. pp. 24-25.

2. Murray, A. S. and Tilbe, J. R., "Canadians Report Results of Drilling Exchange With Soviets," Oil & Gas Journal, Apr. 23, 1979. pp. 51-60.

D. Need for Technology or General Interest

1. Dellinger, T. B., Gravley, W., and Tolle, G. C., "Directional Technology Will Extend Drilling Reach," Oil & Gas Journal, Sept. 15, 1980. pp. 153-169.

2. King, C. M. and McKenzie, Don, "Drilling Wells on Target," Offshore, May, 1980. pp. 125-133

3. Millheim, K. "Operators Have Much to Learn about Directional Drilling," Oil & Gas Journal, Nov. 6, 1978. pp. 60-64.

4. O'Donnell, H. W. "Directional Drilling Eases Ship Channel Pipeline Crossings," Oil & Gas Journal, Mar. 25, 1980. pp. 161-164.

E. General Information on Stabilization and Deviation Control for Rotating Drillstrings

1. Bradley, W. B., "Factors Affecting the Control of Borehole Angle in Straight and Directional Wells," SPE Preprint No. 5070, Presented Oct. 6-9, 1974, in Houston, Texas.

2. Drilco Drilling Assembly Handbook, Drilco Division of Smith International, Inc., Houston, Texas, 1977. pp. 5-28, 31-34.

3. Fischer, J. F., "Analysis of Drill Strings in Curved Boreholes," SPE Preprint No. 5071. Presented Oct. 6-9, 1974, in Houston, Texas.

4. Lubinski, Arthur, "Maximum Permissible Dog-Legs in Rotary Boreholes," Journal of Petroleum Technology, Feb., 1961. pp. 175-194.

5. Millheim, K., "Proper Application of Directional Tools Key to Success," Oil & Gas Journal, Nov. 29, 1979. pp. 156- 165.

6. Millheim, K., "Here are Basics of Bottom-Hole Assembly Mechanics," Oil & Gas Journal, Dec. 4, 1978. pp. 98-106.

7. Millheim, K., "Single-Stabilizer Behavior Described," Oil & Gas Journal, Dec. 18, 1978. pp. 52-61.

8. Millheim, K., "The Behavior of Multiple-Stabilizer Bottom-Hole Assemblies," Oil & Gas Journal, Jan. 1, 1979. pp. 59-64.

9. Millheim, K., "Control Techniques for Medium-Soft and Medium Formations," Oil & Gas Journal, Jan. 29, 1979. pp. 178-186.

10. Millheim, K., "Hard-Formation Directional Drilling Calls for Special Care," Oil & Gas Journal, Feb. 12, 1979. pp. 136-138.

11. Murphey, C. E., and Cheathan, J. B., "Hole Deviation and Drill String Behavior," SPE Preprint No. 1259. Presented Oct. 3-9, 1965, in Denver, Colorado.

E. General Information on Stabilization and Deviation Control for Rotating Drillstrings

12. Walker, H. B., "Some Technical and Economic Aspects of Stabilizer Placement," Journal of Petroleum Technology, June, 1973. pp.663-672.

13. Woods, H. B., "Effect of Collar Size in Crooked Holes," Paper presented at API Mid-Continent Spring Meeting, Tulsa, Oklahoma, March, 1955.

14. Woods, H. B., and Lubinski, Arthur, "How to Determine Best Hole and Drill Collar Size," Oil & Gas Journal, June 7, 1957.

15. Callas, N. P., and Callas, R. L., "Drill String Analysis Shows Forces Overcome by Stabilization," Oil & Gas Journal, Nov. 24, 1980. pp. 142-152.

16. Callas, N. P., and Callas, R. L., "Finite Element Analysis Predicts Multiple Stabilizer Behavior," Oil & Gas Journal, Dec. 1, 1980. pp. 140-155.

17. Callas, N. P., and Callas, R. L., "Boundary Valve Problem Is Solved," Oil & Gas Journal, Dec. 15, 1980. pp. 62-66.

18. Callas, N. P., and Callas, R. L., "Solution of Exact Equation by Analog Computer," Oil & Gas Journal, Dec. 29, 1980. pp. 186-190.

F. Manufacturers' Literature

1. "Bowen Dyna-Flex Joints," Bowen Tools, Inc. 1978-1979 General Catalog, Houston, Texas, 1978.

2. "Instruction Manual-Bowen Dyna-Flex Joint," Manual No. 5/4820, Bowen Tools, Inc. Houston, Texas, 1974.

3. "Dyna-Flex Selection," Dyna-Drill Handbook, 2nd Edition, Dyna-Drill Division of Smith International, Inc., Long Beach, California, circa 1976. pp. 30-32.

4. "Remote-Controlled Bent Sub Telepilot Bent-O-Matic," SMF Int'l & IFP Joint Project Product Brochure, Paris, France, 1980.

F. Manufacturers' Literature-Cont'd

5. "The Rebel Tool," Eastman Whipstock General Catalog 1980-1981, Houston, Texas, 1980, p. 21.

6. Composite Catalog of Oil Field Equipment and Services, 1980-1981, Gulf Publishing Company, Houston, Texas, 1980.

7. "Twist-Kick Sub," Christensen Diamond Products, USA, Downhole Tools Div., Product Brochure DT-810, Salt Lake City, Utah, 1981.

☆ U.S. GPO: 1982 - 569-028/23