ABSTRACT: A rotary well drilling system employing well casing as the drill string; a bit assembly having radially expandable cutters bodily insertable and removable through the bore of the casing and releasably connected thereto; and a drive connection means releasably insertable into the upper end of the casing bore including casing-gripping means nonthreadedly engageable with the casing bore wall for transmitting rotational torque to the casing.
SYSTEM FOR ROTARY DRILLING OF WELLS USING CASING AS THE DRILL STRING

BACKGROUND OF THE INVENTION

In conventional rotary drilling, the drilling string generally comprises a relatively small diameter string of drill pipe having the drill bit threadedly connected to the lower end thereof, the bit size being such as to drill a borehole of substantially larger diameter than that of the drill string. After drilling the borehole to a predetermined depth, the drill string is withdrawn and the borehole lined with casing to support the earth formations defining the borewall. During drilling, a suitable drilling fluid is generally circulated down through the drill string, out the bit and up through the annulus to the surface.

In such conventional drilling procedures, the borewall, particularly where constituted by relatively soft formations, will tend to slough off or cave, this action being frequently accentuated by the washing action of the drilling fluid. This will often seriously interfere with the drilling operation and may cause sticking of the drilling string with its many attendant problems. Also, the operations in the open hole, as when withdrawing the drill string to change bits and returning it into the borehole, and the procedure for running casing to line the borehole, are all subject to many hazards resulting from the fact that the borewall is exposed during all such operations.

Various efforts have heretofore been made to overcome difficulties such as those mentioned by procedures in which the well casing is run closely following the advance of the drill but none of these earlier procedures have proven to be successful, particularly when attempts were made to employ them in drilling deep wells where borehole diameters are relatively large as compared with the size of the drill string.

SUMMARY OF THE INVENTION

In accordance with the present invention a system is provided which employs the well casing itself as the drill pipe. A bit assembly which is bodily insertable and withdrawable through the bore of the well casing, is releasably secured to the lower end thereof, and includes radially expansible cutter elements to enable drilling of a borehole having a diameter such as to freely accommodate the casing/drill pipe. A drive connection is provided for transmitting rotational power to the upper end of the casing string and includes a drive connector means which is slidable insertable into the upper end of the casing and includes casing gripping means which are nonthreadedly engageable with the casing wall for transmitting rotational torque to the casing.

By means of a system such as described, the borewall will at all times be fully supported by the casing which will remain in the wellbore while the bit assembly may be withdrawn for repair or replacement. Moreover, by the employment of the readily insertable drive connection, effective rotary torque can be applied to the casing with minimum manipulative operations for making and releasing the drive connection.

The system in accordance with this invention will obviate the difficulties encountered in more conventional rotary drilling systems; will assure protection for the wall of the wellbore throughout the drilling; permits ready installation and removal of the bit assembly through the bore of the casing; and provides simple means for attaching and releasing the drive connection to the casing when adding sections thereto.

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

In the drawings, FIGS. 1A and 1B, together, comprise a longitudinal, partly sectional view of a drilling system in accordance with the present invention in place in a wellbore, the parts being shown in the positions occupied while drilling proceeds;
placing dogs 14 opposite recess 15. An annular packing, such as 19, is mounted about the upper end of cage 12 to seal with the wall of bore 11 when the bit assembly is fully inserted in the housing. A tubular dog actuating sleeve 20 having a bore 20a is slidably mounted in the bore of cage 12 and is provided at an intermediate point thereon with external enlargements 21 adapted to engage the inner faces of dogs 14 when in registration therewith to urge the latter outwardly into recess 15 to lock the cage to housing 10, and to release the dogs when moved out of registration with the dogs. The portion of latching sleeve 20 above enlargements 21 is reduced in external diameter to define the upwardly facing shoulder 29 and is threaded with cage 12 the annular space 22. A spacer collar 23 is inserted concentrically between the upper portion of sleeve 20 and cage 12 and is threadedly secured at 24 to the upper end of the cage. The inner end of spacer collar 23 terminates above the shoulder 29 and a coil spring 25 is mounted in compression in annular space 22 between the inner end of spacer collar 23 and shoulder 29. An annular seal 26 is disposed about the upper end portion of sleeve 20 in slidable sealing engagement with the bore wall of spacer collar 23. An annular latchgroove 27 is provided in the bore wall of sleeve 20 for purposes to be described later. Spring 25 functions to normally bias sleeve 20 downwardly toward the position placing enlargement 21 in registration with dogs 14.

Sleeve 20 is initially held in retracted position compressing spring 25. (FIG. 2) by shear pins 60 connecting it to a running tool R, as shown in FIG. 2, but which, since the general arrangement is generally conventional, does not itself form a part of the present invention. Running tool R includes an over-shot portion 0 also initially connected by shear pins 61 to the upper end of collar 23. The running tool also includes a jarring sleeve J which, when it is desired to release locking sleeve 20, may be actuated through manipulation of the running string in the well known manner to apply a downwardly directed blow against the upper end of sleeve 20 sufficient to break shear pins 60, whereupon spring 25 will expand thrusting sleeve 20 downwardly to cause enlargements 21 to engage the inner faces of dogs 14 and push them outwardly into locking engagement in recess 15 (FIGS. 1 and 3) effectively locking the bit assembly to housing 10. Thereupon, upward pull applied to over-shot 0 will act to break shear pins 61, releasing the running tool for withdrawal from the casing.

The lower end portion of latching sleeve 20 is also reduced in external diameter to extend slidably into the lower end of cage 12 and an annular seal 28 is provided between the lower end portion of the latching sleeve and the cage. The lower end portion of sleeve 20 is provided with an externally threaded pin 30 receivable in the internally threaded socket 31 of a cylinder 32 which carries an annular seal element 33 in sealing engagement with the lower end of bore 11. A piston 35 is slidably mounted in cylinder 32 and is connected to a piston rod 36 which projects downwardly through an opening in the lower end of cylinder 32 into an underreamer body 37 which is formed as an extension of cylinder 32. The lower end of underreamer body 37 is formed to provide a reduced diameter tubular extension 38 having an internally threaded box 39 at its lower end into which is screwed a conventional rotary bit 40. Extension 38 and bit 40, together, comprise the pilot bit section of the bit assembly. Extension 38 carries a plurality of fixed radially extending underreaming cutters 41 adapted to cut a hole diameter to the gage of underreamer body 37. A piston rod 36 extends slidably through a central bore 42 in extension 38 and bears against a coil spring 43 disposed in compression between the lower end of piston rod 46 and the upper end of bit 40. An annular seal element 44 is arranged to seal between bore 42 and the lower end of the piston rod.

A plurality of underreamer cutters 45 are pivotally mounted in longitudinal slots 46 in the wall of body 37 for radial movement between positions projecting outwardly at right angles to the axis of the bit assembly and retracted positions generally parallel to the axis of the assembly. When retracted, the cutters will be substantially fully enclosed within slots 46 so that the bit assembly will be freely movable through casing C and into and out of housing 10. Cutters 45 are rollably mounted on hollow shafts 45a (FIG. 2) which terminate in flattened heads 47 which extend into slots 46 and are mounted for pivotal movement about hollow pivot pins 48 extending transversely of slots 46 (FIGS. 7 and 9). The inner ends of heads 47 are formed as sector gears 49 each of which is arranged to mesh with a rack 50 formed on the opposite exterior face of piston rod 36, which is made generally square in cross section to accommodate the several racks.

With the cutter arrangement and piston elements described, it will be seen that when piston 35 is in its elevated position in cylinder 32 (FIG. 2) racks 50 in cooperation with sector gears 49 will move cutters 45 to their retracted positions (FIGS. 2, 4, 5 and 7). When piston 35 is moved downwardly to its lowermost position, shown in FIGS. 1B, the rack and gear cooperation will swing cutters 45 to their radially outwardly projecting positions (FIGS. 1B, 3 and 9). Piston 35 and piston rod 36 are formed with an axial passage 51 providing fluid communication with the interior of cylinder 32 at one end and with the interior of extension 38 at the other. The latter communicates through passages 52 (FIGS. 2, 3 and 8) which exit through the outer ends of cutters 41. Other passages 53 (FIGS. 3, 7 and 9) communicate the interior of extension 38 with passages 54 through hollow pivot pins 48 and thence through passages 55 in shafts 45a exiting through the outer ends of cutters 45. Bit 40 is provided with fluid jet passages 56 which communicate with the interior of extension 38. The reciprocating movements of piston 35 in cylinder 32 are limited to one direction by the inner end of pin 30, the fully retracted positions of cutters 45, and at the opposite end by an internal shoulder 32c in cylinder 32, the fully extended position of cutters 45.

Drive connector assembly B, illustrated in FIGS. 1 and 10 to 13, inclusive, includes a tubular mandrel or support member 60 having an axial bore 60a and provided with a threaded box 61 at its upper end for connection to a power source. A tubular bushing 62 is rotatably mounted about the upper portion of the mandrel on antifriction bearings 63 and has a radially extending flange 64 dimensioned to rest on the upper end of the uppermost section of casing C which will normally project upwardly above the upper end of the well bore. Flange 64 forms stop means engageable with the upper end of the casing section to limit inward movement of the connection assembly into the bore of the casing. The inner end of bushing 62 includes an inwardly turned lip 65 on which a plurality of pipe-gripping wedges or slips 66 are hingedly supported by means of outwardly projecting hanger lips 67 formed on the upper ends of the slips. An upwardly and inwardly tapering conical expander 68 is disposed about mandrel 60 between the latter and slips 66 and is provided with radially outwardly directed relatively coarse left-hand threads 69 engageable by a complementary section of threads 70 formed on mandrel 60 and intermediate the ends thereof. With this left-hand threaded connection between the expander and the mandrel it will be seen that right-hand rotation of the mandrel will cause expander 68 to move upwardly relative to slips 66, the complementary tapered surfaces thereof cooperating to move the slips outwardly into gripping engagement with the wall of casing C. Reverse rotation of the mandrel will move the expander downwardly to release the slips from gripping engagement with the casing.

The lower portion of expander 66 is provided with an annular outwardly opening recess 71 defined by a cylindrical bottom wall 72 and at its outer end by oppositely extending annular lips 73-73.

Pipe-engaging elements, designated generally by the numeral 74, are mounted in recess 71 and are operable in response to angular movement of the mandrel to apply torsional force to the casing. This form of the gripping elements 74 is described in detail in my U.S. Pat. No. 3,322,006, issued May 30, 1967, and constitute casing-gripping means which are nonthreadedly engageable with the casing for transmitting rotational torque thereto. While the specific details of these casing-gripping elements do not form a part of the present in
vention in view of the earlier patent thereon, a brief description will be helpful in connection with the present disclosure.

Mounted within recess 71 concentrically with bottom wall 72 is a pair of generally semicircular pipe-gripping shoes 75 which are normally under compression against the casing by means of relatively light coil springs 76 seated in suitable sockets 77 in the opposed ends of the shoes, as best seen in FIGS. 12 and 13, the spacing between the inner ends of the shoes permitting a limited amount of independent movement of the shoes. The upper and lower end edges of the shoes are provided with oppositely extending upper and lower flanges 78-79 which are adapted to engage lips 75a and 75b on the casing, and the latter will prevent the shoes from being radially expelled from recess 71. Each of the shoes is provided centrally on its external surface with a longitudinally extending convex, generally smooth arcuate surface portion 79, which has a circular radius adapted to provide smooth or nongripping engagement with the inner wall of a surrounding pipe, such as well casing C. Surface portion 79 extends for a relatively short angular distance about the outer periphery of the shoes. On each side of surface portion 79 the exterior of the shoes is offset slightly radially inwardly at 80 and these radially offset portions are provided with a few parallel, longitudinally extending, radially projecting teeth 81 which are normally out of contact with casing C when portion 79 is engaged with the casing wall. The teeth 81 are adapted, upon relative rotation or oscillation between the shoes and casing C, to engage the casing and prevent further relative rotation between the shoes and the casing, and to then apply a strong torsional force to the casing in response to rotational force transmitted from the expander body to the shoes. By reason of the longitudinally extending form of the teeth, some longitudinal slippage between the teeth and the casing can occur, even though the torsional force will prevent relative rotation between the teeth and the casing, as will appear subsequently. To effect relative rotation or rocking movement of the shoes, bottom wall 72 is machined to provide oppositely radially extending lugs 82, the lugs on opposite sides of recess 71 having openings 83 through which a cylindrical shaft 84 extends. A series of rollers 85 are mounted on each shaft 84 on opposite sides of the lugs 82 and constitute cam followers, the sets of the cam followers thus being mounted on diametrically opposite sides of recess 71. The inner periphery of shoes 75 on each side of the central portion thereof is provided with a noncircular cam surface 86 which are engageable by cam followers 85 in response to angular movement between expander 68 and the shoes. As best seen in FIG. 13, cam surfaces 86 are also engaged with cooperating cams 85 to rock shoe 75 angularly relative to casing C, so as to project teeth 81 into torsional gripping engagement with the wall of casing C.

The lower end portion of expander 60 is provided about the exterior thereof below recess 71 with an annular seal element 90 arranged for slidable sealing engagement with casing C and an internal annular seal element 91 arranged for slidable sealing engagement with the exterior of mandrel 60. Upper and lower stop collars 92 and 93, respectively, are mounted about mandrel 60 above and below the ends of the connector assembly to limit the extent of relative longitudinal movement between the mandrel and the other parts of the assembly. Mandrel 60 is adapted to be connected by means of box 61 through a drive nipple 95 to the tubular drive spindle 96 of a fluid-pressure-operated rotary power unit 97 of any well-known construction. Such a unit is described in my copending application, Ser. No. 736,179, filed June 11, 1968, now U.S. Pat. 3,467,202. Power unit 97 is carried on a swivel 98 suspended in a well derrick (not shown) on elevators 99 connected in conventional drawworks (not shown) of a drilling rig, by means of which the power unit and the elements connected thereto may be raised and lowered relative to the well as required in the course of operations. Swivel 98 is provided with a goose neck 100 through which drilling fluid may be circulated through passages communicating with the bores of spindle 96, nipple 95 and bore 60a of mandrel 60 whence the fluid will be directed through casing C to bit assembly A to the various jet discharge passages provided therein. The fluid discharging from the passages in the bit assembly will flow upwardly through the annulus between the drilling string and the well bore to the surface.

**OPERATION OF THE SYSTEM**

The apparatus may be assembled by any suitable and known procedures. Usually a string of casing C carrying housing 10 on its lower end will be run in conductor casing K and suspended therein from wellhead fitting F on slips G. Bit assembly A will then be lowered through the casing on running string 18 wherein a downward jar on latching sleeve 20 will actuate the anchor dogs to lock them into recess 15 (FIG. 3), after which the running tool may be released by upward pull as previously described.

Connector assembly B suspended from power unit 97 will now be lowered into the upper end of casing C until flange 64 rests on the upper end of the casing (FIG. 10). Right-hand rotational movement will now be imparted by the power unit to mandrel 60 causing expander 68 to move upwardly relative to the mandrel and setting slips 66 into the wall of casing C (FIGS. 1 and 11). Because of the longitudinal arrangement of teeth 81 on shoes 75, pipe-gripping units 74 will slide upwardly on the casing wall for the distance required to accommodate the slip-setting movement of the casing. As slips 66 are tightly set, however, further rotational force applied to mandrel 60 will produce the relative angular movement operative to rock shoes 75 to positions at which such rotational force will be transmitted as driving torque to the casing. As soon as slips 66 are set, the hanger slips G may be removed freeing the casing string for rotation by power transmitted from power unit 97 to connector assembly B.

Fluid circulation is now begun as drill string is rotated with the pilot bit section making the hole. The flow restrictions formed by the several jet passages through the cutter elements will cause the fluid pressure to build up in cylinder 32 above piston 35 forcing the latter downwardly and swinging underreamer cutters 45 outwardly to the positions shown in FIGS. 1 and 3. Continued rotation of the drill string will now be operative to drill a well bore having a diameter of freedom and continuously accommodate the casing as the drill progresses downwardly.

To add a casing section to the upper end of the casing string, the string may again be suspended and anchored in slips G, whereupon reverse or left-hand rotation of spindle 96 for a few turns will be sufficient to back expander 68 away from slips 66, releasing the latter from gripping engagement with the casing. The connector assembly can now be pulled out of the top of the casing. A new section of casing may now be attached to the upper end of the casing hanging in the wellhead fitting, and connector assembly B inserted in the upper end of the added casing section, and reactivated by right-hand rotation of the mandrel. Hanger slips G may now be removed and drilling continued.

In order to remove the bit assembly, as for repair or replacement of the cutter elements, without removing the casing string from the well bore, the casing string will again be hung in hanger slips G and connector assembly released and removed. A fishing tool D (FIGS. 4 and 5) of any well-known design is run through the bore of the casing so that gripping elements E will be caused to latch into recess 27 of the latching sleeve. Thereupon, upward pull applied through the fishing tool will retract latching sleeve 20 to the position shown in FIG. 5, at which dogs 14 will be released for retraction from anchor recess 15. Upward pull applied to sleeve 20 will be transmitted to cage 12 and the entire bit assembly A may now be pulled out of housing 10 and upwardly through casing C to the surface. Casing C being left in the well bore will support and protect the wall thereof throughout its full length.
With fluid circulation cut off, the pressure on piston 35 will be relieved sufficiently so that as the bit assembly is pulled upwardly, the extended underreamers will engage the lower end of housing 10 and will be forced thereby to swing downwardly, and sector gear 49 acting through rack 50 will move piston rod 36 and piston 35 back upwardly to their retracted positions at which the underreamers will return to their fully retracted positions in slots 46 (FIG. 5).

FIGS. 14 to 16 illustrate a modification of the bit assembly portion of the drilling system hereby described, the other parts of the system being unchanged.

In this modification the toothed rack-and-sector gear connection between the underreamer cutters and the actuating piston are replaced by a cam-and-lever connection. Modification of some of the other details of the bit assembly are also employed as will appear hereinafter.

In this modification a tubular housing 110 is secured to the lower end of casting C and is provided with an anchor recess 115 in the bore wall thereof. Stop pins 118 are mounted in the housing below recess 115. The bit assembly includes the tubular cage 112 having radial windows 113 for the reception of anchor dogs 114. Guide slots 116 for cooperation with stop pins 118 are provided in the exterior of cage 112 below windows 113. Cage 112 is made unitary with underreamer body 137 and is provided with a central bore a portion of which forms the cylinder 132 in which is slidably mounted the piston 135 connected to a hollow piston rod 136 which extends slidably through an opening 130 into a hollow box 138 into which is screwed the shank of a rotary pilot bit 140.

A latching sleeve 120 carrying external enlargements 121 is slidably disposed in the bore of cage 112 for axial movement between an upper position (FIG. 14) releasing dogs 114 and a lower position (FIG. 15) at which dogs 114 are held in projected anchoring position in recess 115. Latching sleeve 120 is provided with an internal latching groove 127 having the same function as groove 27 of the previously described embodiment. Elongate hanger bolts 150 having heads 151 extending slidably through perforate ears 152 carried by the lower end of sleeve 20 and are secured to piston 135.

Underreamer body 137 is provided with angularly spaced longitudinal slots 146 for receiving underreamer cutters 145 which are mounted on shafts 145a terminating in heads 147 mounted for pivotal movement on pivot pins 148 which extend transversely of slots 146 (FIG. 17). Heads 147 are formed with angularly extending lever arms 149 which extend past the exterior of piston rod 136 and carry crank pins 160 receivable in cam slots 161 formed in the adjacent face of piston rod 136.

With this arrangement it will be seen that downward movement of piston rod 136 to the position shown in FIG. 15 will swing underreamer cutters 145 outwardly to their projected position. Retraction of piston rod 136 to the position shown in FIG. 14 will return the underreamer cutters to their retracted positions.

In this modification gage cutters 41 have been dispensed with, as a pilot bit 140 is employed dimensioned to cut a bore to the gage of body 137. It will be understood, however, that radial gage cutters may be incorporated in the bit assembly as in the previously described embodiment.

It will be understood that numerous other alterations and modifications may be made in the details of the illustrative embodiments within the scope of the appended claims but without departing from the spirit of this invention.

I claim:

1. A system for rotary drilling of wells using casing as the drill string comprising:
   a. a string of well casing;
   b. a bit assembly constructed and arranged to be bodily inserted and removed through the bore of the casing;
   c. latch means releasably securing said bit assembly to the lower end of the casing for rotation thereby;
   d. radially expansible and retractable cutter elements carried by the bit assembly for drilling a well bore to a diameter to receive said casing; and
   e. drive connection means operatively associated with said string of casing and adapted to be connected to a rotary drive power source and releasably insertable into the upper end of the bore of the casing having casing-gripping means nonthreadedly engageable with the casing bore wall for transmitting rotational torque from said source to the casing.

2. A system according to claim 1, wherein said bit assembly includes: means actuated by fluid pressure applied through the casing for expanding said cutter elements.

3. A system according to claim 1, wherein said bit assembly includes:
   a. a generally tubular body;
   b. a pilot bit centrally secured to the lower end of said body; and
   c. fixed radial cutters mounted on the body between said cutter elements and said pilot bit adapted to drill said well bore to at least the diameter of said body.

4. A system according to claim 1, wherein said bit assembly includes:
   a. a generally tubular body;
   b. pivot means pivotally connecting said cutter elements to said body;
   c. a cylinder in said body;
   d. piston means slidable in said cylinder in response to fluid pressure in said casing; and
   e. lever means operatively connecting said piston means to said cutter elements for extending and retracting the same.

5. A system according to claim 4 wherein said lever means comprises toothed rack-and-gear means.

6. A system according to claim 4, wherein said lever means comprises crank-and-pin connection means.

7. A system according to claim 1, wherein said bit assembly includes:
   a. a tubular housing coaxially connectable to the lower end of said casing and having an annular latching recess intermediately thereof;
   b. a generally tubular body coaxially insertable in said housing;
   c. latch elements mounted in the wall of said body for radial movement into and out of latching engagement with said recess;
   d. an expander sleeve slidably mounted in the bore of said body for axial movement therein between positions projecting said latch elements into said recess and releasing said latch elements for retraction from said recess; and
   e. means normally biasing said expander sleeve toward the latch-projecting position.

8. A system according to claim 1, wherein said drive connection means includes:
   a. a tubular mandrel adapted to be connected to a rotary drive power source;
   b. a pipe-gripping assembly mounted about the mandrel including pipe-gripping elements radially movable into and out of gripping engagement with the casing in response to rotation of said mandrel; and
   c. arcuate shoe elements rockably disposed about said mandrel and carrying vertically extending teeth movable into and out of torsion-applying engagement with said casing in response to relative angular movement between the mandrel and the shoes.

9. A system according to claim 1, wherein said drive connection means includes:
   a. a tubular mandrel adapted to be connected to a rotary drive power source;
   b. stop means on the mandrel engageable with the upper end of the casing to limit inward movement of the mandrel;
   c. pipe-gripping slips mounted on the mandrel for radial movement into and out of gripping-engagement with the casing;
   d. expander means mounted on the mandrel for axial movement into and out of wedging engagement with said slips in response to rotation of said mandrel; and
9. Pipe-engaging shoes rockably mounted about the mandrel for movement thereby into said nonthreaded engagement with the casing.

10. A system according to claim 9 including complementary left-hand thread means connecting said mandrel to said expander means.