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(54) Title: BOTTOM HOLE ASSEMBLY FOR CASING WINDOW MILLING

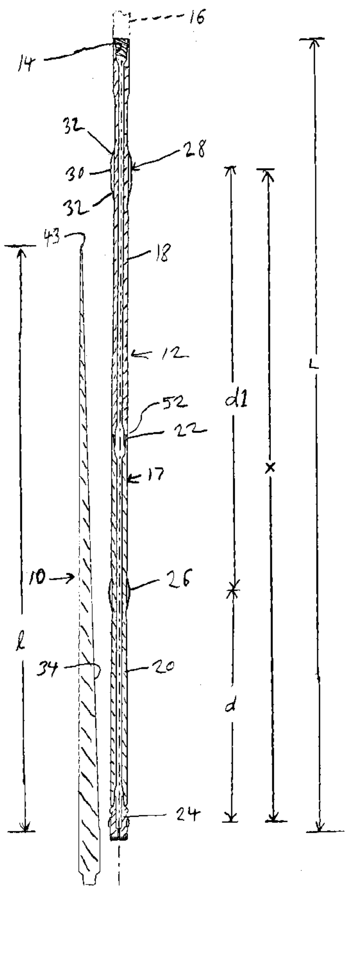

FIG. 1

(57) **Abstract:** A bottom hole assembly for use in cutting a window in a wellbore casing wall. An exemplary bottom hole assembly is described which includes a shaft that carries a window mill. A pair of bearing mills is carried by the shaft above the window mill. Placement of the bearing mills permits the bottom hole assembly to cut a window having a greater length and quality (gage width and reduced burrs/slivers) than windows cut by other bottom hole assembly designs.

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BOTTOM HOLE ASSEMBLY FOR CASING WINDOW MILLING

Cross-Reference to Related Applications

[0001] This application claims the priority of U.S. Provisional Patent Application Serial No. 60/991,432 filed November 30, 2007.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention relates generally to the arrangement of mills on bottom hole assemblies that are used to cut windows in casing strings for the creation of lateral wellbores.

Description of the Related Art

[0003] In modern hydrocarbon production, it is common to create one or more lateral production wellbores which extend outwardly from a central, generally vertical wellbore. In order to form a lateral production wellbore, a window must be cut into the side of casing in the central wellbore. Thereafter, drilling tools are used to form an extended lateral wellbore. Traditionally, whipstocks and milling tools are used to create the window in the central wellbore casing wall.

SUMMARY OF THE INVENTION

[0004] The invention provides an improved milling bottom hole assembly for use in cutting a window in a wellbore casing wall. An exemplary bottom hole assembly (BHA) is described which includes a central shaft. The distal end of the central shaft carries a window mill. A pair of bearing mills is carried by the shaft above the window mill. Placement of the bearing mills permits the bottom hole assembly to cut a window having a greater length and quality (gage width and reduced burrs/slivers) than windows cut by other BHA designs. The above is superior for ingress and egress of long and stiff directional drilling BHAs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The advantages and further aspects of the invention will be readily appreciated by those of ordinary skill in the art as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference characters designate like or similar elements throughout the several figures of the drawing and wherein:

[0006] Figure 1 is a side, cross-sectional cutaway drawing of an exemplary milling tool bottom hole assembly constructed in accordance with the present invention depicted alongside an associated exemplary whipstock.

[0007] Figure 2 is a side, cross-sectional view of an exemplary wellbore containing a whipstock, and milling tool bottom hole assembly shown in Figure 1, during an initial window cutting stage.

[0008] Figure 3 is a side, cross-sectional view of the arrangement depicted in Figure 2, now with the window cutting operation further advanced.

[0009] Figure 4 is a side, cross-sectional view of the arrangement depicted in Figures 2 and 3, now with the window cutting operation further advanced.

[0010] Figure 5 is a graph depicting the correlation of side forces on the window mill with distance of the window mill from the whipstock kick-off point.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] Figure 1 illustrates an exemplary whipstock 10 and a milling tool bottom hole assembly 12, which is constructed in accordance with the present invention. The bottom hole assembly 12 includes a threaded upper end 14 which is used for securing the bottom hole assembly 12 to a drill string 16. The bottom hole assembly 12 includes a central shaft 17 formed of upper and lower string sections 18, 20, which are secured together at threaded joint 22. A window mill 24, of a type known in the art, is secured to the distal end of the bottom hole assembly 12.

[0012] A first bearing mill 26 is located on the lower string section 20 above the window mill 24. The first bearing mill 26 preferably presents a rounded, arcuate cross-section. A second bearing mill 28 is located on the upper string section 18. The second bearing mill 28 preferably presents a cross-section that is curved and oblong, thereby presenting a substantially flat center segment 30 and arcuately curved end sections 32. The second bearing mill 28 may be of the type generally known in the industry as a "watermelon mill." In an alternate embodiment, the second bearing mill 28 presents a cross-section that is arcuately rounded, in the same manner as the first bearing mill 26.

[0013] The overall length "L" of the bottom hole assembly 12 (the bottom hole assembly length) exceeds the longitudinal length "l" of the ramp 34 of the whipstock 10 (the whipstock ramp length). The second bearing mill 28 is preferably located at a distance "x" from the window mill 24 that is from about 1.0 to about 1.25 times the length "l" of the ramp 34. Most preferably, the distance "x" is about 1.15 to about 1.20 times the length "l" of the ramp 34. The first bearing mill 26 is preferably located at a distance "d" from the window mill 24 that is from about one-fifth to about one-half of the length "x". Most preferably, the distance "d" is about one-third of the length "x". It is further noted that the spacing ("d1") between the first and second bearing mills 26, 28 preferably exceeds the distance "d".

[0014] Figures 2, 3 and 4 illustrate the bottom hole assembly 12 in operation to create a window 40 in the casing 42 surrounding a primary wellbore 44. Figures 2-4 also depict the bottom hole assembly 12 exiting the primary wellbore 44 along a departure path 46 through the surrounding earth 48.

[0015] In operation, the drill string 16 and bottom hole assembly 12 are rotated within the casing 42, and the bottom hole assembly 12 is lowered within the wellbore 44 until the bottom hole assembly 12 encounters the whipstock 10 proximate the kick-off point 43. As Figure 2 illustrates, the window mill 24 is urged against the casing 42 and begins to cut the window 40. As the milling operation continues, the window mill 24 cuts downwardly from the upper window end 50 to increase the length of the window 40 (as shown in Figures 3 and 4). At the same time, the incline of ramp 34 urges the window mill 24 laterally outside of the wellbore 44. The lower string section 20 remains substantially rigid between the window mill 24 and the first bearing mill 26. However, due to the substantial distance between the first and second bearing mills 26, 28, the portion of the lower string section 20 above the first bearing mill 26 and the portion of the upper string section 18 below the second bearing mill 28 will bend and flex. The first bearing mill 26 will cut away the upper end 50 of the window 40 during the milling operation, thereby increasing the length of the window 40. It is noted that, as the milling operation progresses, the first bearing mill 26 will reach the upper end of the whipstock 10 before or at the same time as the mid-point (52 in Figure 1 and 3) of the bottom hole assembly 12 due to the spacing of the first bearing mill 26 proximate to the window mill.

[0016] During the milling operation, as illustrated by Figure 4, the flat portion 30 of the second bearing mill 28 will contact the surrounding casing 42 and be urged to remain radially inside of the casing 42. This urging results in additional lateral forces to be imparted to the lower portion of the bottom hole assembly 12, causing the bottom hole assembly 12 to hold against the whipstock 10 for a longer time, thus leading to a longer window 40.

[0017] The design of the bottom hole assembly 12 provides high constraining forces at the window mill 24 while traversing the midsection of the ramp 34 of the whipstock 10.

The use of a bottom hole assembly 12 constructed in accordance with the present invention produces a milled window 40 having an extended length, as measured from the upper end 50 to the lower end 52. The proximity of the first bearing mill 26 to the window mill 24 creates restraining forces on the window mill 24 to urge it properly along the departure path 46 from the primary wellbore 44. Additionally, the proximity of the first bearing mill 26 to the window mill 24 helps in harnessing the efficiency of the cutters of the first bearing mill 26 for additional cutting of the upper end 50 of the window 40. This results in a longer window 40 than with many conventional techniques. Figure 3 depicts the upper end 50 of the window 40 being milled away by the first bearing mill 26. At the same time, the first bearing mill 26 is spaced at an optimum distance from the window mill 24 to avoid an early jump-off of the window mill 24 from the casing 42 near the mid-point of the whipstock ramp 34.

[0018] As noted, the first bearing mill 26 preferably has an arcuate cross-section, thereby providing for point-type contact between the bearing mill 26 and the surrounding casing 42 or the whipstock 10. Point-type contact results from the fact that the surface of the curved bearing mill 26 cross-section will contact the surrounding casing 42 or whipstock 10 at a single point. Figure 3 illustrates the mill 26 contacting the casing 42 at point 54. In addition, the bottom hole assembly 12 can pivot with respect to the surrounding casing 42 about the point 54. Binding of the bottom hole assembly 12 as it turns while moving onto the upper end of the whipstock ramp 34 is dramatically reduced as a result of this point-type contact between the first bearing mill 26 and the casing 42. The combination of these advantages results in a longer service life for the bottom hole assembly 12.

[0019] Figure 5 depicts the side forces imparted to the window mill 24 as it is moved along the whipstock ramp 34 from the kick-off point 43. It can be seen by reference to

Figure 5 that the side forces imparted to the window mill 24 by the bottom hole assembly are kept within a reasonable range throughout the milling operation. Figure 5 is a chart wherein the amount of side force (in kip-force, or klbf) imparted to the window mill (bit) 24 is represented by curve 60. As can be seen, the side forces are within an acceptable limit and are higher at locations along the whipstock ramp 34 where the window mill 24 has maximum chances of early jump-offs. In Figure 5, areas where the curve 60 presents a positive side force (1, 2, 3, 4, etc.) indicate that the window mill 24 is being urged against the ramp 34 of the whipstock 10. Conversely, areas where the curve 60 depicts negative side force (-1, -2, -3, etc.) indicate that the window mill 24 is being diverted away from the ramp 34 of the whipstock 10. Figure 5 indicates that the BHA 12 causes the window mill 24 to be continually urged against the ramp 34 until point 62, which generally coincides with the point at which the window mill 24 has moved entirely outside of the casing 42. As a result of this continuous positive side force, the possibility of the window mill 24 tending to undesirably "jump off" of the ramp 34 during initial phases of window cutting is minimized. More specifically, when the gage O.D. of the window mill 24 clears the casing 42, because of which the casing 42 no longer provides a restraining force urging the window mill 24 against the ramp 34, side forces are maximized. A thorough finite element analysis of the proposed design predicts the trajectory of the lateral bore hole created in the surrounding earth formation 48 after the window mill 24 has moved past the ramp 34 (i.e., beyond point 62 of curve 60). This analysis shows that the window mill 24 and hence the bottom hole assembly 12 will tend to desirably hold or build an angle that is more normal to the casing 42 than with other bottom hole assembly designs, which tend to drop angle. This improved trajectory is desirable for the creation of a lateral wellbore using drilling assembly.

[0020] It can be seen that the bottom hole assembly 12 and the whipstock 10 collectively provide a window cutting arrangement that is operable to form a window in surrounding wellbore casing. It should also be understood that the invention provides an improved method for forming a window within wellbore casing.

[0021] The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention.

CLAIMS

What is claimed is:

1. A bottom hole assembly for use in milling a window in a wellbore casing in association with a whipstock with an angled ramp having a whipstock ramp length, the bottom hole assembly having a bottom hole assembly length and comprising:

a central shaft;

a window mill located proximate a lower end of the shaft;

a first bearing mill upon the shaft;

a second bearing mill upon the shaft;

the window mill and the second bearing mill being spaced from each other by a first distance; and

the first bearing mill being spaced from the window mill at a second distance that is from about one-fifth to one-half of the first distance.

2. The bottom hole assembly of claim 1 wherein the second distance is about one-third of the first distance.

3. The bottom hole assembly of claim 1 wherein the first and second bearing mills are separated from each other by a third distance that is at least as great as the second distance.

4. The bottom hole assembly of claim 1 wherein the first distance is greater than the whipstock ramp length.

5. The bottom hole assembly of claim 1 wherein the first bearing mill presents a rounded, arcuate cross-section.

6. The bottom hole assembly of claim 1 wherein the second bearing mill presents a cross-section having a substantially flat bearing surface.

7. The bottom hole assembly of claim 1 wherein the second bearing mill presents a rounded, arcuate cross-section.

8. The bottom hole assembly of claim 1 wherein the bottom hole assembly length has a midpoint and wherein the first bearing mill reaches an upper end of a whipstock during a milling operation before the midpoint of the bottom hole assembly length reaches the upper end of the whipstock.

9. A window cutting arrangement for forming a window within a wellbore casing, the window cutting arrangement comprising:

a whipstock to be disposed within the wellbore casing, the whipstock presenting an angled ramp and having a whipstock ramp length;

a bottom hole assembly for contacting the angled ramp and cutting a window within the wellbore casing, the bottom hole assembly having a bottom hole assembly length and comprising:

a central shaft;

a window mill proximate a lower end of the shaft and operable for cutting a window in the wellbore casing;

a first bearing mill upon the shaft;

a second bearing mill upon the shaft;

the window mill and the second bearing mill being spaced from each other by a first distance; and

the first bearing mill being spaced from the window mill at a second distance that is from about one-fifth to one-half of the first distance.

10. The window cutting arrangement of claim 9 wherein the second distance is about one-third of the first distance.

11. The window cutting arrangement of claim 9 wherein the first and second bearing mills are separated from each other by a third distance that is at least as great as the second distance.

12. The window cutting arrangement of claim 9 wherein the first distance is equal to or greater than the whipstock ramp length.

13. The window cutting arrangement of claim 9 wherein the first bearing mill presents a rounded, arcuate cross-section.

14. The window cutting arrangement of claim 9 wherein the second bearing mill presents a cross-section having a substantially flat bearing surface.

15. The window cutting arrangement of claim 9 wherein the second bearing mill presents a rounded, arcuate cross-section.

16. The window cutting arrangement of claim 1 wherein the bottom hole assembly length has a midpoint and wherein the first bearing mill reaches an upper end of the whipstock during a milling operation before the midpoint of the bottom hole assembly length reaches the upper end of the whipstock.

17. The window cutting arrangement of claim 12 wherein the first distance is from about 1.0 to about 1.25 times the whipstock ramp length.

18. The window cutting arrangement of claim 17 wherein the first distance is from about 1.15 to about 1.20 times the whipstock ramp length.

19. A method of forming a window in wellbore casing, the method comprising the steps of:

disposing a bottom hole assembly within a wellbore, the bottom hole assembly comprising:

a shaft;

a window mill mounted upon the shaft and located proximate a lower end of the shaft;

a first bearing mill carried by the shaft;

a second bearing mill carried by the shaft;

contacting a whipstock ramp within the wellbore casing with the window mill so that the window mill cuts a window in the wellbore casing;

milling away an upper portion of the window with the first bearing mill; and

contacting the wellbore casing with the second bearing mill so that the first bearing mill and the window mill are retained against the whipstock ramp.

20. The method of claim 19 wherein the bottom hole assembly is disposed within the wellbore casing on a drill string.

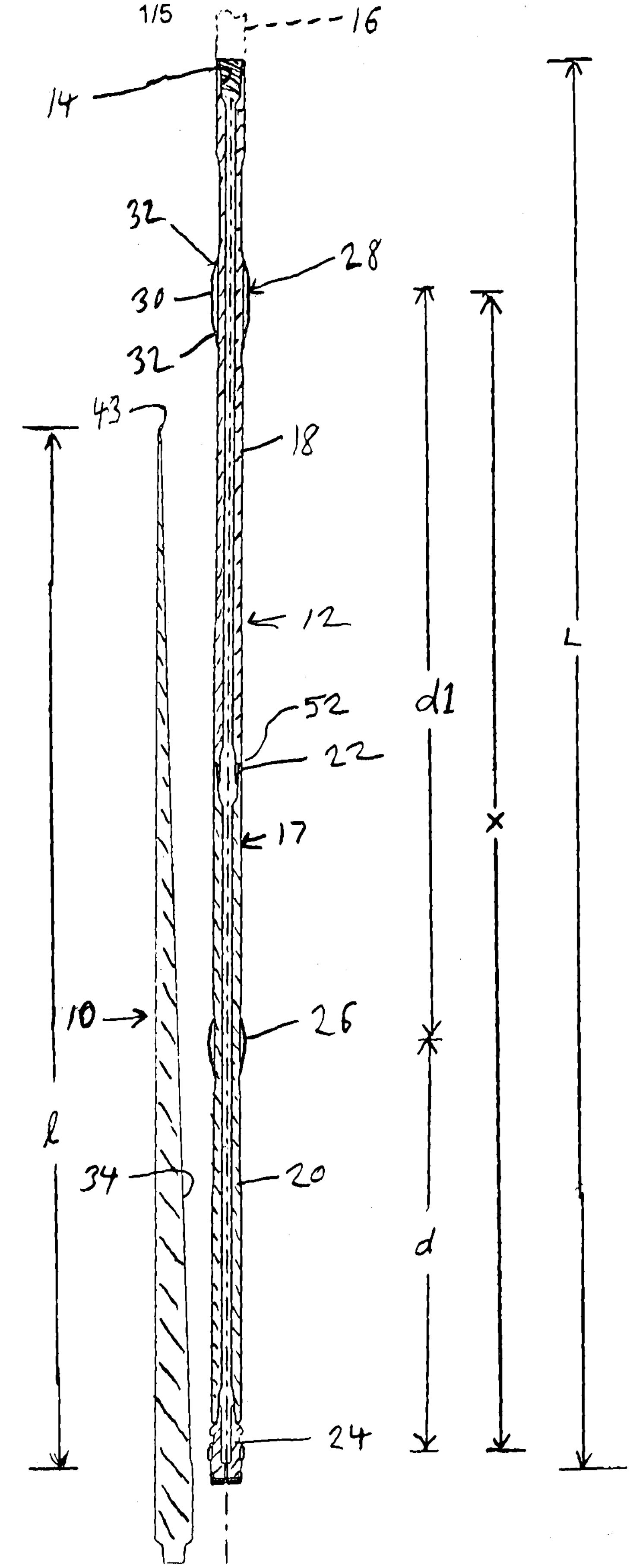

FIG. 1

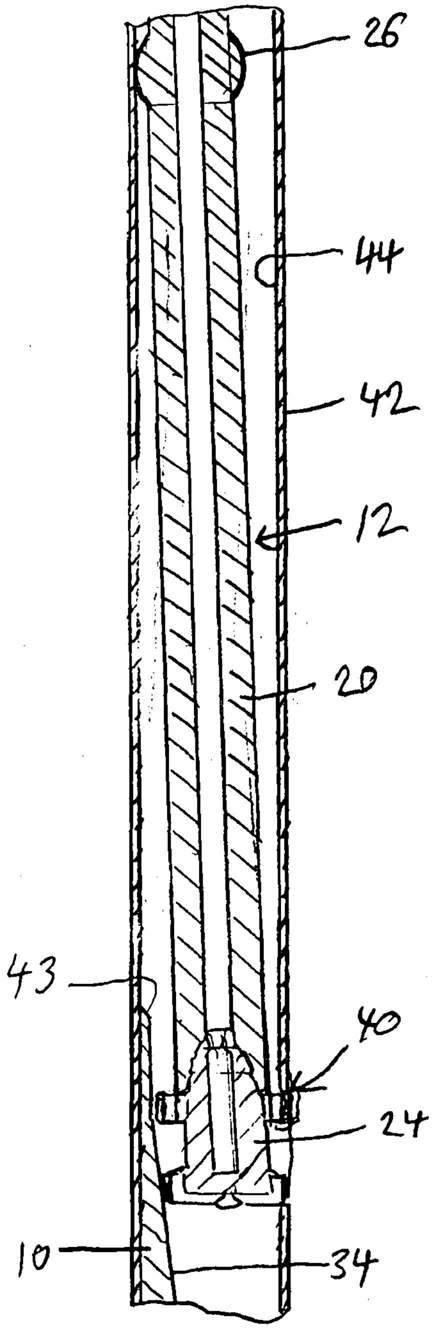

FIG. 2

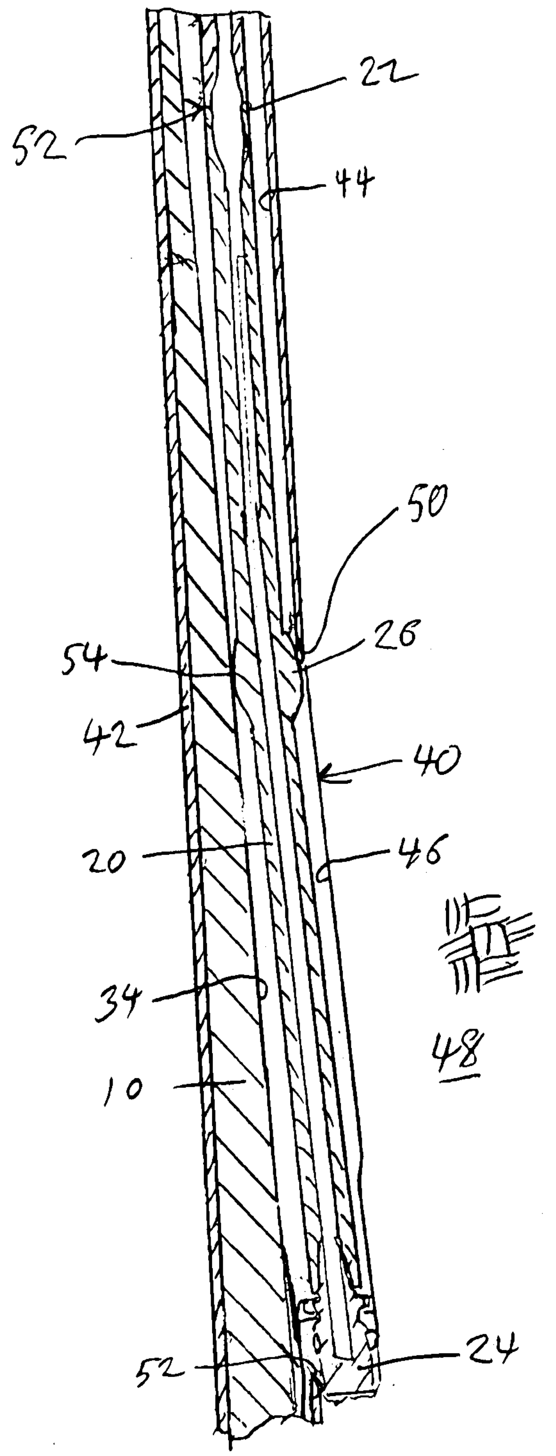

FIG. 3

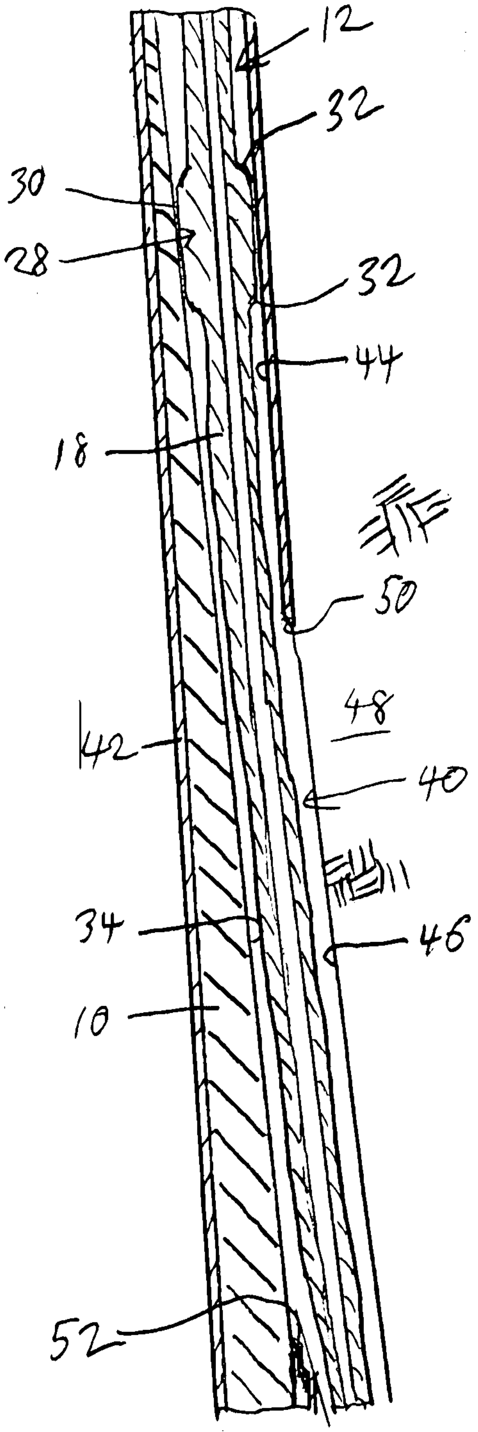

FIG. 4

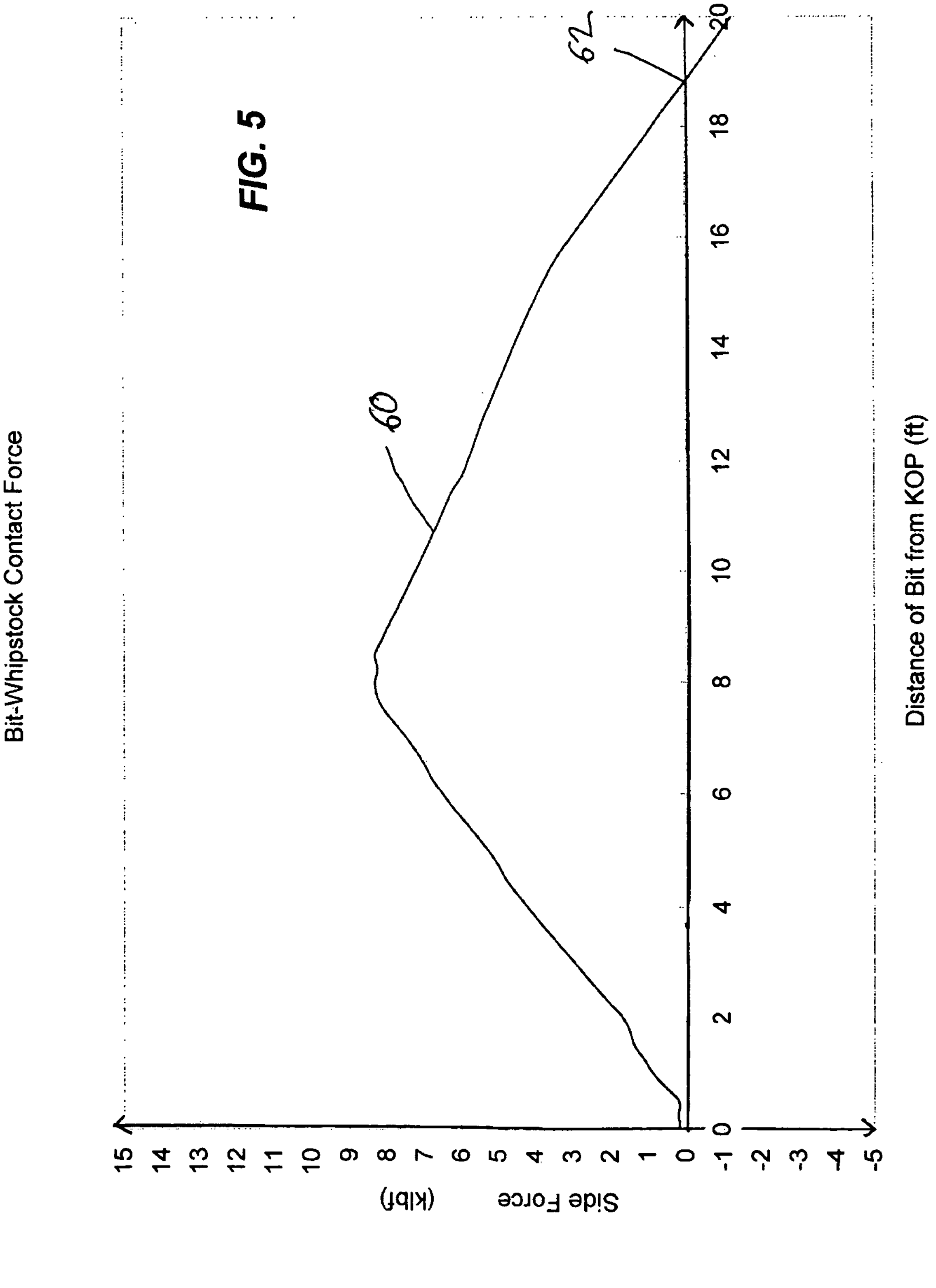
Bit-Whipstock Contact Force
Side Force (klbf)
Distance of Bit from KOP (ft)
60
62
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5
0 2 4 6 8 10 12 14 16 18 20

FIG. 5