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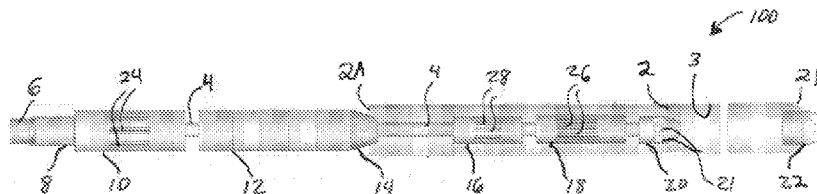


FIG. 1

(57) Abstract: Systems, apparatus and well intervention methods are described. Tubular member radial expansion apparatus includes a support member having forward and rearward ends; a drive unit and an expansion member disposed on the support member providing force for propelling the expansion member through an expandable tubular and expanding it, the drive unit disposed rearward of the expansion member; front and rear anchors disposed on the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular; a casing lock disposed on the support member and positioned between the expansion member and the front anchor, securing the expandable tubular to the support member during running-in-hole (RIH); and a valve attached to the forward end of the expandable tubular.

EXPANDABLE TUBULAR INSTALLATION SYSTEMS, METHODS AND APPARATUS

Cross-reference to related applications

[0001] This application claims domestic priority benefit under 35 U.S.C. § 120 from applicants' provisional patent application serial number 61/119,227, filed December 2, 2008, and non-provisional patent application serial number 12/628,925, filed December 1, 2009, which is incorporated herein by reference.

[0002] BACKGROUND INFORMATION

[0003] Technical Field

[0004] The present disclosure relates in general to well construction, completion, remediation, and intervention methods and systems. More particularly, the present disclosure relates to well intervention methods, systems and apparatus such as open-hole clads, sidetracking, cased-hole patches, and the like, especially those applications in which the pre-expanded launchers of standard, bottom-up hydraulic systems cannot pass through wellbore restrictions.

[0005] Background Art

[0006] Current practice for well construction, completion, remediation and other well interventions in openhole and cased-hole use "bottom-up", radially expandable tubulars, as exemplified by Weatherford's openhole and cased-hole solid-expandable systems known under the trade designation MetalSkin[®], and featured in their brochure entitled "MetalSkin[®] Solid Open and Cased Hole Expandable Systems for Open and Cased Hole" (2007). These systems are advertised as being designed with running clearance in mind to avoid equivalent-circulation-density problems and differential sticking. The Weatherford systems include retrievable collapsible/expandable cones for contingent recovery, metal-

to-metal expandable connectors, and elastomeric sealing elements. Also, each system includes a hydraulically assisted backup expansion system, which provides an operational contingency. The systems use a positive seal with a circulation valve for more-reliable pressure containment than conventional dart seals. These systems are advertised to provide single-trip efficiency, and four distinct solutions have been developed: openhole-clad, openhole-liner, cased-hole-liner system, and monobore system. The monobore system is advertised as an openhole liner system that can extend casing and maintain drift of the expanded casing, where “drift” is assumed to mean the drift diameter, which is the inside diameter that the pipe manufacturer guarantees per specifications. U.S. Pat. Nos. 7,363,984 and 7,172,025 disclose similar bottom-up expandable tubulars, systems, and methods. Published U.S. patent applications 2007/0151360 and 2008/0257542 disclose metallurgical and other properties of expandable metal tubulars.

[0007] Many pre-expanded launchers of standard, bottom-up hydraulic systems cannot pass through wellbore restrictions, do not provide adequate expansion ratio, and/or do not provide adequate bend radius for interventions in curved and lateral wellbores. It would be advantageous if well intervention systems, methods and apparatus were available that allow expansion of tubulars with acceptable expansion ratio and bend radius, as well as allow the launcher and other system components to be retrieved easily from the wellbore should a problem develop downhole. The systems, methods and apparatus of the present disclosure are directed to these needs.

[0008] SUMMARY

[0009] In accordance with the present disclosure, wellbore intervention systems, methods, and apparatus have been developed which reduce or overcome many of the faults of previously known systems, methods and apparatus.

[0010] A first aspect of the disclosure is an apparatus for radially expanding a tubular member, the apparatus comprising:

- a) a support member having a forward end and a rearward end;
- b) a drive unit and an expansion member disposed on the support member providing force for propelling an expansion member through and radially expanding an expandable tubular, the drive unit disposed rearward of the expansion member;
- c) front and rear anchors disposed on the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular;
- d) a casing lock disposed on the support member and positioned between the expansion member and the front anchor, releasably securing the expandable tubular to the support member during running-in-hole (RIH); and
- e) a valve attached to the forward end of the expandable tubular.

[0011] In certain embodiments, apparatus of this disclosure comprise a flow valve fluidly connected to the forward end of the support member, providing the ability for circulation during RIH. After deploying to a desired location in the wellbore, the flow rate may be increased to a level higher than circulation flow rate and then reduced to zero for permanent valve closure thus sealing the tool. If circulation is not possible or undesirable, the valve may be replaced with an end cap. In certain embodiments, the apparatus further comprises a fluid filter fluidly

connected to the support member and positioned at the forward end of the support member, preventing large mud particles from reaching the tool seals and inner mechanisms. In certain embodiments the valve attached to the forward end of the expandable tubular assists tool run-in and prevents packing of the expandable tubular with debris. It may also be used to divert flow of drilling fluid around the borehole, thus cleaning and carrying debris through the annulus to surface.

[0012] Another aspect of this disclosure are systems for radially expanding tubular members, the systems comprising an apparatus of this disclosure secured to a deployment component such as a coiled tubing (CT) or jointed drill pipe (DP). In an embodiment of this aspect, the invention is directed to a tubular member radial expansion system comprising:

- a) a deployment component; and
- b) a tubular member radial expansion apparatus comprising:
 - i) a support member having a forward end and a rearward end;
 - ii) a drive unit and an expansion member disposed on the support member providing force for propelling the expansion member through and radially expanding an expandable tubular, the drive unit disposed rearward of the expansion member;
 - iii) front and rear anchors disposed on the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular;
 - iv) a casing lock disposed on the support member and positioned between the expansion member and the front anchor, releasably securing the expandable tubular to the support member during running-in-hole; and
 - v) a valve attached to a forward end of the expandable tubular.

[0013] Another aspect of the disclosure are methods of radially expanding tubular members, the method comprising:

a) deploying an expandable tubular and expansion tool into a wellbore, the expandable tubular secured to a support member of the expansion tool, the support member having a forward end and a rearward end, the rearward end attached to a deployment component communicating with the surface; and

b) performing an intervention operation on the wellbore comprising using the expansion tool to expand the expandable tubular and so complete the wellbore,

wherein the expansion tool further comprises a drive unit and an expansion member disposed on the support member providing force for propelling the expansion member through the expandable tubular axially from rear to forward and radially expanding the expandable tubular, the drive unit disposed rearward of the expansion member; front and rear anchors disposed on the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular.

[0014] Well intervention operations may proceed via coiled tubing or drill pipe, provided the surface arrangement includes a hydraulic workover unit. The method may be used for interventions such as, but not limited to, open-hole clads, sidetracking, and cased-hole patches.

[0015] The systems, methods and apparatus described herein may provide other benefits, and the methods for well intervention are not limited to the methods noted; other methods may be employed.

[0016] As used herein the term “expandable tubular” refers to metallic tubulars having the metallurgical compositions and physical properties described more fully herein.

[0017] These and other features of the systems, methods, and apparatus of the disclosure will become more apparent upon review of the brief description of the drawings, the detailed description, and the claims that follow.

[0018] BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The manner in which the objectives of this disclosure and other desirable characteristics can be obtained is explained in the following description and attached drawings in which:

[0020] FIG. 1 is a schematic side elevation view of one system embodiment within the present disclosure;

[0021] FIG. 2 is a cross-sectional view of a cased vertical wellbore, and a non-cased lateral wellbore branching off the cased wellbore, illustrating certain features of apparatus, systems, and methods of this disclosure;

[0022] FIG. 3 is a side elevation schematic similar to FIG. 1 illustrating a specific system within the present disclosure;

[0023] FIG. 4 is a cross-sectional view of one embodiment of a fishing tool that may be used in conjunction with an embodiment of the present disclosure;

[0024] FIGS. 5 and 6 illustrate logic diagrams of certain aspects of a method within this disclosure;

[0025] FIGS. 7A, 7B, and 7C illustrate schematic longitudinal cross sectional views of a valve with a piston in the outer body of the valve in a first position, a second position, and a third position, respectively; and

[0026] FIG. 8 is a photographic representation of an improved upper anchor sub-system used in a trial test.

[0027] It is to be noted, however, that the appended drawings are not to scale and illustrate only typical embodiments of this disclosure, and are therefore not to be

considered limiting of its scope, for the disclosure may admit to other equally effective embodiments. Identical reference numerals are used throughout the several views for like or similar elements.

[0028] DETAILED DESCRIPTION

[0029] In the following description, numerous details are set forth to provide an understanding of the disclosed methods and apparatus. However, it will be understood by those skilled in the art that the methods and apparatus may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0030] All phrases, derivations, collocations and multiword expressions used herein, in particular in the claims that follow, are expressly not limited to nouns and verbs. It is apparent that meanings are not just expressed by nouns and verbs or single words. Languages use a variety of ways to express content. The existence of inventive concepts and the ways in which these are expressed varies in language-cultures. For example, many lexicalized compounds in Germanic languages are often expressed as adjective-noun combinations, noun-preposition-noun combinations or derivations in Romantic languages. The possibility to include phrases, derivations and collocations in the claims is essential for high-quality patents, making it possible to reduce expressions to their conceptual content, and all possible conceptual combinations of words that are compatible with such content (either within a language or across languages) are intended to be included in the used phrases.

[0031] As noted above, wellbore intervention systems, methods and apparatus involving radially expandable tubulars have been developed which reduce or overcome many of the faults of previously known systems and methods.

[0032] The primary features of the systems, methods and apparatus of the present disclosure will now be described with reference to FIGS. 1-8, in conjunction with some of the operational details. The same reference numerals are used throughout to denote the same items in the figures. In accordance with the present disclosure, as illustrated in FIG. 1, a first embodiment 100 of a system

for radially expanding a tubular member is illustrated in side elevation view, and includes an expandable tubular 2 (illustrated in pre-expanded state) having a rearward end 2A, a forward end 2B, and defining an internal diameter (ID) 3; a support member 4, which may be a tubular member, and defines one or more internal fluid passages (not shown in this view); a conveyance member 6, which may be coiled tubing or drill pipe; a filter 8, a rear anchor 10 having one or more engagement means 24 for engaging the ID of expandable tubular 2; a drive unit 12; an expansion member 14, which may be conical as illustrated or another functional shape, such as spherical; a casing lock 16 having a plurality of engagement means 28 thereon for engaging the ID of expandable tubular 2; a front anchor 18 having a plurality of engagement means 26 for engaging the ID of expandable tubular 2; an optional flow valve 20 having a plurality of flow ports 21, which in certain embodiments may be replaced by an end cap (not illustrated); and a flow valve 22. FIG. 3 provides typical dimensions for one apparatus and system embodiment within this disclosure.

[0033] As used herein, the term “expandable tubular” means metallic tubulars having the metallurgy such as detailed in Table 1, from United States published patent application number 2008/0257542, published October 23, 2008, and incorporated herein by reference in its entirety. Note that the term “liner” is sometimes used herein, and those of skill in this art will understand this term is shorthand for “expandable tubular.” As reported in the ‘542 application, in one embodiment, a sample of an expandable tubular member composed of steel Alloy A exhibited a yield point before radial expansion and plastic deformation YP_{BE} , of about 16%, and a yield point after radial expansion and plastic deformation, YP_{AE} , of about 24%. Further, the ductility of the sample of the expandable tubular member composed of Alloy A also exhibited a higher ductility prior to radial expansion and plastic deformation than after radial expansion and plastic deformation. Many other physical properties of steel Alloys A, B, C, and D, such as tensile strength before and after expansion, anisotropy, strain hardening

exponent, carbon equivalent value, and the like, are disclosed in great detail in the '542 published application.

Steel	Element and Percentage By Weight							
Alloy	C	Mn	P	S	Si	Cu	Ni	Cr
A	0.065	1.44	0.01	0.002	0.24	0.01	0.01	0.02
B	0.18	1.28	0.017	0.004	0.29	0.01	0.01	0.03
C	0.08	0.82	0.006	0.003	0.30	0.16	0.05	0.05
D	0.02	1.31	0.02	0.001	0.45	—	9.1	18.7

Table 1: Metallurgy and Physical Properties of Suitable Expandable Tubulars

[0034] The collection of components other than expandable tubular 2 and conveyance member 6 are sometimes simply referred to herein as an expansion tool, or simply a tool. It is also noted that apparatus and systems within the disclosure may be described as modular in nature.

[0035] In operation of embodiment 100 of FIG. 1, drive unit 12 provides the necessary force for propelling expansion member 14 through expandable tubular 2 and expanding it. Front anchor 18 engages expandable tubular 2 ID to provide the necessary reaction force to propagate expansion member 14 through expandable tubular 2. Rear anchor 10 provides a reaction force during the last few strokes after front anchor 18 has exited expandable tubular 2 and can no longer provide reaction force. Casing lock 16 secures expandable tubular 2 to support member 4 during Running-In-Hole (RIH). Flow valve 20 at the forward end of support member 4 provides the ability for circulation during RIH. After deploying to a desired location, the flow rate may be increased to a level higher than circulation flow rate and then reduced to zero for permanent valve closure thus sealing the support member. If circulation is not possible or undesirable, flow valve 20 may be replaced with an end cap. Flow valve 22 at the forward end of expandable tubular 2 helps tool run-in and prevents packing of expandable tubular 2 with

debris. It also diverts the flow of drilling fluid around the borehole thus cleaning and carrying debris through the annulus to surface. Fluid filter 8 at the rearward end (top) of the tool prevents large mud particles from reaching the tool seals and inner mechanisms.

[0036] Figure 7A illustrates a schematic longitudinal cross-sectional view of one embodiment of flow valve 22 in an open position (first position). In an embodiment as shown, valve 22 includes an outer body 41 having an upper portion 45 and a lower portion 44. Upper and lower portions 45, 44 are joined together by a threaded joint (not shown), and a piston 51 slidably disposed in an inner cavity 43 formed inside the outer body 41. Upper portion 45 includes one end 58 with threads 46 to mate with the corresponding forward end 2B of expandable tubular 2. Lower portion 44 includes a support flange 62 with flange fluid passage 50, which allows fluid flow in and out from inner cavity 43. Outer body 41 also includes one or more fluid passage exits 49 to allow fluid flow out from inner cavity 43. In an embodiment, piston 51 is a cylindrical member having a piston inner cavity 52 and one or more piston fluid passages 54 to allow fluid flow from piston inner cavity 52 to fluid passage exits 49. It is to be understood that piston 51 is not limited to the embodiment illustrated in FIG. 7A but instead may include other embodiments having configurations suitable for slidable disposition in inner cavity 43.

[0037] As illustrated in FIG. 7A, a flow restriction member 55 is disposed inside piston inner cavity 52. Flow restriction member 55 may be a nozzle, an orifice, or any other flow restriction member that may be sized to provide a certain force at a given flow rate.

[0038] As further illustrated in FIG. 7A, a shear member 61 is disposed in lower portion 44 and engaged in groove 56. Shear member 61 may be a set screw, a shear pin, a shear ring, or other shear member capable of controlling the position of piston 51 relative to the outer body 41 in the longitudinal direction. In an embodiment, shear member 61 is designed to allow for release of piston 51 at a certain selected

force applied to piston 51 in the longitudinal direction and then to allow unconstrained movement of piston 51 inside outer body 41. The combination of the size of flow restriction member 55 and the size of shear member 61 may be selected to allow release of piston 51 relative to outer body 41 at a selected flow rate of operational fluid.

[0039] In addition, as shown in FIG. 7A, a bias member 48 is disposed in inner cavity 43 of outer body 41. In an embodiment, bias member 48 is disposed in inner cavity 43 of lower portion 44. Bias member 48 may be a spring (*i.e.*, such as a coil spring), an elastomeric member, a solenoid operated piston, or other member capable of applying a longitudinal force to piston 51. Bias member 48 engages piston 51 on one end 63 and the outer body 41 on the other end 64. In some embodiments, bias member 48 engages the lower portion 44 on the other end 64. In an embodiment, bias member 48 is adapted to bias piston 51 in an upward position.

[0040] As shown in FIG. 7A, a position control member 53 is disposed in groove 60. Position control member 53 may be a C-ring, a collet, or other position control member capable of locking piston 51 in outer body 41 thereby preventing longitudinal movement of piston 51 relative to outer body 41. When piston 51 is urged into the closed position (*i.e.*, the third position illustrated in FIG. 7C), position control member 53 engages valve body groove 42 and permanently locks piston 51 against outer body 41. In an embodiment, position control member 53 is adapted to lock piston 51 in a position preventing longitudinal movement of piston 51 in outer body 41.

[0041] FIG. 7A also illustrates a sealing member 57 disposed in a sealing groove 59 located adjacent to piston fluid passages 54. Sealing member 57 may be an elastomeric O-ring or any other hydraulic piston seal capable of providing a hydraulic seal between piston 51 and outer body 41.

[0042] During tool deployment, valve 22 is in the first open position as illustrated in the embodiment of FIG. 7A and operational fluid is pumped through valve 22 at a selected circulation flow rate. For illustrative purposes, the selected circulation flow rate is referred to as the first flow rate. The operational fluid passes through flow restriction member 55, piston fluid passage 54, and fluid passage exit 49 out into the wellbore to wash debris away from valve 22 and into the wellbore annulus. The fluid flow creates a pressure drop through the flow restriction member 55, which results in a force urging the piston 51 toward lower portion 44. The shear member 61 exerts a counterforce that maintains the piston 51 in the first position maintaining alignment of piston fluid passages 54 and fluid passage exits 49, thereby allowing flow of the fluid out of the valve 22. In an embodiment, size of flow restriction member 55 and size of shear member 61 are selected to maintain piston 51 in a first position with one or more piston fluid passages 54 and one or more fluid passage exits 49 aligned at flow rates below or about equal to the first flow rate.

[0043] In an embodiment as illustrated in FIG. 7A, after the tool has been deployed to the desired location, the fluid flow rate is increased to a second flow rate. The second flow rate develops increased pressure drop in the flow restriction member 55, which results in a force sufficient to shear the shear member 61 thereby releasing the piston 51 and allowing its longitudinal movement inside the outer body 41. As illustrated in FIG. 7B, piston 51 moves toward the support flange 62 into the second position, thereby compressing the bias member 48. In the second position of the piston 51, piston fluid passage 54 and fluid passage exit 49 remain aligned, allowing fluid flow through the valve 22, and, therefore, the valve 22 remains open at a second flow rate. To close valve 22, the fluid flow rate is gradually decreased to about zero or near zero allowing the bias member 48 to move piston 51 backwards to the third position, as illustrated in FIG. 7C. In an embodiment, flow restriction member 55, shear member 61, and bias member 48 are selected such that at a flow rate equal to about the second flow rate, shear member 61 releases piston 51 and piston 51 moves longitudinally inside outer body

41 to a second position with one or more piston fluid passages 54 and one or more fluid passage exits 49 aligned in the second position.

[0044] In the embodiment as illustrated in FIG. 7C, when piston 51 reaches the third position, the position control member 53 engages the valve body groove 42 thereby locking piston 51 relative to outer body 41 and preventing longitudinal movement of piston 51 in outer body 41. Position control member 53 is designed to sustain force greater than the force generated by pressure sufficient for operation of the tool. In the third position, sealing member 57 is located between fluid passage exit 49 in outer body 41 and piston fluid passage 54 in piston 51 thereby preventing fluid flow through valve 22. Valve 22 is permanently closed and hydraulically sealed.

[0045] In an embodiment, bias member 48 is selected to generate a minimal force sufficient for the longitudinal displacement of piston 51 in outer body 41. Thus, the displacement of piston 51 to the third position occurs only during very low pressure drop in flow restriction member 55, and, therefore, valve 22 closure takes place at near zero fluid flow rates, practically eliminating the pressure surge.

[0046] Certain embodiments of systems, methods and apparatus of this disclosure allow installation and expansion of 3-1/2 inch (8.9cm)-OD expandable tubular 2 into an open hole through a 4-1/2 inch (11.4cm)-OD base casing. The following paragraphs discuss procedures for tubular/tool system make-up, deployment, tubular expansion, and system retrieval, and additionally discuss system performance and specifications along with contingency mitigation procedures.

[0047] Systems of this disclosure may be used in many applications, especially those in which the pre-expanded launchers of standard, bottom-up hydraulic systems cannot pass through wellbore restrictions. Possible applications include open-hole clads, sidetracking, cased-hole patches, and the like.

[0048] Systems of this disclosure, including the expansion tool and expandable tubular, can be deployed downhole either on drill pipe (DP) or on coiled tubing (CT), through which the operational fluid (mud) is transmitted to the tool. The tool is positioned above the expandable tubular, and expansion takes place in top-down mode. Thus, if necessary, during the expansion process, the tool can be disconnected from the tubular, retrieved, repaired or replaced with a spare tool, and redeployed in the well.

[0049] One complete expansion process cycle comprises, as its primary steps, an expansion step or stroke, where the expansion member moves axially to radially expand the expandable tubular, and a resetting stroke, where one or both anchors is moved axially within the pre-expanded expandable tubular, except in the last few strokes, where the rear anchor moves axially within an expanded section of expandable tubular. Each expansion stroke involves the application of pressure to the tool and release of pressure at the end of the stroke. Each resetting stroke involves lowering the tool through the DP or CT. System operating specifications may be as shown in Table 2, while Table 3 provides some emergency pressure levels and related events.

TABLE 2: System operating specifications.

	Range	Embodiment 1
Deployment	-	DP or CT
Tubular Weight	8-10lb/ft (11.9-14.9kg.m)	9.2 lb/ft (13.7 kg/m)
Tool Weight	1000-1400 lb (380- 530kg)	1200 lb (545kg)
Tool Length	35-55 ft(11-17m)	45 ft (13.7m)
Expansion Stroke	3-5 ft (92-153cm)	4 ft (122cm)
Max. Tool Run-in OD	-	3.80 in (9.65cm)
Min. Pass-Thru Restriction	-	3.81 in (9.68cm)
Expansion Ratio of expandable tubular	20-40%	27 %
Max. Dog-Leg Severity*	20-50°/100 ft (20-50°/30.5m)	50°/100 ft (50°/30.5m)
Nominal Expansion Force	50-90 klb _f (225-400 newtons)	60 klb _f (270 newtons)
Maximum Expansion Force	-	90 klb _f (400 newtons)

Maximum Pressure **	-	7,500 psi (52 MPa)
Maximum Temperature	-	250°F(121°C)
Push Limit	-	100 klb _f (445 knewtons)
Pull Limit	-	90 klb _f (400 knewtons)

* Also referred to as “bend radius” or “build up radius” (BUR)

**Without axial load.

TABLE 3: Standard and emergency pressure levels and related events.

Differential Pressure, psi (MPa)	Event
900 (6)	Drive Unit Burst Disk Breaks
1,800 (12)	Rear Anchor Shear Pin Breaks
2,300 (16)	Operating Expansion Pressure*
3,800 (26)	Casing Lock Shear Pin Breaks for Emergency Release
4,500 (31)	Rear Anchor Burst Disk for Emergency Release

*May vary by as much as 20 % due to: anchoring in open hole, well bore fluid, temperature, friction, tool drag, dog-leg severity and connector expansion.

[0050] Referring to FIG. 2, in certain embodiments of this disclosure, a vertical base casing 29 (for example, a 4-1/2 inch (11.4cm) base casing) has already been installed and cemented in a vertical wellbore, and a liner 30 and deflector or whipstock 31 installed. A forklift and crane may optionally be used to move the tool into position and attach it to CT or DP as the case may be. For embodiments where 4-1/2 inch (11.4cm) base casing 29 is in place, slips or dog collars for 3-1/2 inch (11.4cm) OD pipe and 3.70 inch (9.4cm) OD tool may be used. For other sizes of base casing, the slips and dog collars would be sized accordingly. Typically, a mouse hole (not shown in FIG. 2) would be drilled near the main wellbore for insertion of a positioning tool and shroud to assure the tool remains vertical. The mouse hole may have an ID of 6 inches (15.2cm) minimum, and a depth of 40 ft (12.2m) minimum.

[0051] Still referring to FIG. 2, and emphasizing that these dimensions are merely for purpose of example, to install expandable tubular 2 into a dog-leg 32, first a window 34 is milled, having a minimum window length, w, of 3.81 inches

(9.68cm). The build section, 36, may have a minimum ID of 4.75 inch (12.07cm). The Dog-Leg Severity (DLS) in this embodiment is $45^{\circ}/100\text{ft}$ ($45^{\circ}/30.5\text{m}$), which is near the maximum for systems and apparatus of this disclosure. The length of the dog leg rat hole, r , is calculated based primarily on the length of dimension “e” in FIG. 2, defined as the distance between the bottom of window 34 to bottom of the unstable shale section. In preparing dog-leg 32, window 34, and build section 36, as well as actually installing the tool and expandable tubular, equipment such as a weight indicator, a pressure monitoring system, a depth measuring device, a pop-off valve, and the mud pumps may be used. These components are readily known by those skilled in the art and are therefore not shown, and do not form a part of the present disclosure.

[0052] The cladding of expandable tubular 2 occurs within the first expansion stroke right below the window’s lower edge. FIG. 2 illustrates one system set up in accordance with this disclosure right on the onset of expansion, with the expansion member 14 below the lower edge of milled window 34. The operator must be aware of the distance “e” between the bottom of the window (BOW) to the bottom of the shale, or equivalently, the minimum ‘true measured depth’ of where the expandable tubular must sit after expansion minus the depth of the bottom of the milled window. The parameters in FIG. 2 are as follows:

[0053] e = distance between bottom of window to end of shale

[0054] a = distance between bottom of window to expansion member 14

[0055] R = downhole rathole

[0056] L = pre-expanded tubular length

[0057] s = extra tubular length below bottom of shale

[0058] r = installed rathole

[0059] t = distance between expansion member 14 and drill pipe connection

[0060] α = Exit angle at bottom of shale

[0061] w = Window length.

[0062] After the distance “e” is determined, Table 4 is used to determine the downhole rathole length “R” needed after the shale is exited. “L” corresponds to the total length of expandable tubular (liner) before expansion. During drilling of the bend, once shale is exited, drilling must continue until a rathole “R” is completed.

TABLE 4: Determination of Downhole Rathole

e, ft(m) deg/100ft	L, ft(m)	R, ft (m)	DLS, (deg/30.5m)
180(55.0)	207(63.1)	50(15)	50
185(56.4)	213(64.3)	51(16)	49
190(57.9)	218(66.4)	51(16)	47
195(59.4)	224(68.3)	52(16)	46
200(60.9)	230(70.1)	53(16)	45
205(62.5)	236(71.9)	54(16)	44
210(64.0)	241(73.5)	54(16)	43
215(65.5)	247(75.3)	55(17)	42
220(67.0)	253(77.1)	56(17)	41
225(68.5)	259(78.9)	57(17)	40
230(70.1)	264(80.5)	57(17)	39
235(71.6)	270(82.3)	58(18)	38
240(73.1)	276(84.1)	59(18)	38
245(74.6)	282(86.0)	60(18)	37
250(76.2)	287(87.5)	60(18)	36
255(77.7)	293(89.3)	61(19)	35
260(79.2)	299(91.1)	62(19)	35
265(80.7)	305(92.9)	63(20)	34
270(82.3)	310(94.4)	63(20)	33
275(83.8)	316(96.3)	64(20)	33
280(85.3)	322(98.1)	65(20)	32
285(86.8)	328(99.9)	66(21)	32
290(88.4)	333(101)	66(21)	32
295(89.9)	339(103)	67(21)	31
300(91.4)	345(105)	68(21)	30
305(92.9)	351(107)	69(21)	30
310(94.5)	356(108)	69(21)	29
315(96.0)	362(110)	70(22)	29
320(97.5)	368(112)	71(22)	28
325(99.0)	374(114)	72(22)	28
330(101)	379(115)	72(22)	27
335(102)	385(117)	73(23)	27

340(104)	391(119)	74(23)	26
345(105)	397(121)	75(23)	26
350(107)	402(123)	75(24)	26
355(108)	408((124)	76(24)	25
360(110)	414(126)	77(24)	25
365(111)	420(128)	78(25)	25
370(113)	425(130)	78(25)	24
375(114)	431(131)	79(25)	24
380(116)	437(133)	80(25)	24
385(117)	443(135)	81(26)	23
390(119)	448(137)	81(26)	23
395(120)	454(138)	82(26)	23
400(122)	460(140)	83(27)	23
405(123)	466(142)	84(27)	22
410(125)	471(144)	84(27)	22
415(127)	477(145)	85(27)	22
420(128)	483(147)	86(27)	21
425(130)	489(149)	87(28)	21
430(131)	494(151)	87(28)	21
435(133)	500(152)	88(28)	21
440(134)	506(154)	89(28)	20

[0063] An operational procedure for making up the embodiment illustrated in FIGS. 1, 2 and 3 may be as follows, and is also illustrated as a process logic diagram in FIG. 5. In this embodiment 500, at the surface, tubular bundles are unloaded from trucks using slings to prevent scratching and banging of tubulars (box 502). A check should be made that the surface rat hole is 40 ft (12.2m) deep minimum (box 504). A rated sling may then be wrapped around the collar of the tool shroud (box 506). The combined weight of tool plus shroud is less than 2,100 lb_f (9.3 kN). Lift the shroud with tool vertical and insert in surface rat hole. Leave there until tool is ready to be deployed (box 508). Unclamp the tubular bundles and check for any damage to the DP (or CT if used), and check every connection for damage before make up (box 510). Clean the hole where tubular will be expanded at flow rate as specified by an Expansion Job Sheet (box 512). Attach a lifting sub to a box connection of the pup-joint with the nozzle and lift. Weight may rest on the nozzle. Insert pup-joint into well and clamp so that connector is 3-4 ft (91-122cm) above well head (box 514). Unscrew lifting sub, and

install stabbing guide onto exposed box connection (box 516). Select the next joint according to Expansion Job Sheet (box 518). Leave the Range-3 joints (35-37 ft) (10-10.7m) to the end. Replace box protector with lifting sub, and lift joint and position it above the joint inserted in well (box 520). Remove thread protector from the pin. Stab-in and make-up connector by hand using a strap wrench (box 522). In certain embodiments, pipe dope or grease is not used (in these embodiments connectors come ready for make-up). Remove stabbing guide; torque the connector to 600 ft-lb (83 kg-m) by hand (box 524). Unclamp and lower tubulars in well until lifting sub is 3-4 ft (91-122cm) above well head (box 526). Clamp/secure tubular in well head (box 528). Continue until the desired length of tubular is made-up according to the Expansion Job Sheet (box 530).

[0064] The make-up may proceed as follows. Lift the 46-foot (14m)-long tool out of protective shroud, remove the pin thread protector on tubular. Position the lower end of the tool above the box of the tubular inserted in well. Lower expansion tool and complete the following checks: (1) check for damage or wear on the welded strips on pipe next to the expansion member; (2) check the distance of exposed shaft between the rear anchor and drive unit (this should be no more than 1/2 in (1.3cm)); (3) check if rear shear screw is fully screwed into rear anchor; (4) check if all rear anchor bows are in place and with two socket screws fully screwed per bow; (5) check if rear anchor pads are retracted.

[0065] Once the above checks are completed, clamp the expansion tool fluid filter above the rear anchor and rest the tool with liner (expandable tubular) on the well. The maximum weight of the hanging equipment at this point should be no more than 7,000 lbf (31 kilonewtons). Remove lift hook and unscrew lifting sub and eye bolt from the tool. Connect pin connector of next string to the tool's 2-3/8 inch (6 cm) P.A.C. box (a type of thread used on thru-tubing tools). Different crossovers may have to be procured depending on what DP is used. Apply the recommended torque.

[0066] Deployment for embodiments having an end cap (and no flow valve) is similar. The DP or CT is lowered. The tool string is set so that the expansion member (cone) is a distance of about 5 ft (1.5m) below the bottom of the window (see FIG. 2). The distance between the expansion member (cone) and the end of the fluid filter (end of tool) is about 33 ft (10m).

[0067] Expansion of the expandable tubular or liner may proceed according to the following non-limiting procedure, as illustrated in FIG. 6. Set the surface pop-off valve at 3500 psi (24 MPa) (box 602). Start increasing the system pressure with the smallest GPM the pump can provide. Pressure will start increasing while the following sequence of events takes place (box 604). Drive unit shear disk breaks at 900 psi (6 MPa) (box 606). Rear anchor shear screw breaks at 1800 psi (12 MPa) (box 608). The expansion pressure during the first stroke should be within the 2,200-2,800 psi (15-19 MPa) range (box 610). This is larger than the uniform expansion pressure due to the anchoring mechanism during the first stroke. During every pressure stroke, the shortening of the liner (expandable tubular) due to expansion will be seen at surface as a decrease in the weight indicator's reading by about 8,000 lbf (36 newtons) in DP, and 3,000 lbf (13 newtons) in CT. This decrease occurs gradually throughout each expansion stroke. After the pop-off valve releases pressure, lower the DP or CT at a speed no faster than 4 ft/min (122cm/min) for about 4 ft.(122cm) until the weight indicator shows approximately 5,000 lbf (22 newtons) of weight decrease (box 612). Then start increasing the system pressure with the smallest GPM the pump can provide (box 614). Pressure should come up to steady expansion pressure of approximately 2,200 psi (15 MPa) for the length of the stroke. At the end of the stroke pressure will rise which will again trigger the pop-off valve (box 616). Continue repeating these steps until all the expandable tubular length has expanded. Monitor the length of expanded tubular by the length of the lowered DP or CT, accounting for the tubular shrinkage due to expansion. Also, monitor the number of expanded connectors by their pressure variation signature (box 618). Use Expansion Job Sheet. In the second to last resetting stroke, the expansion tool should remove valve 22 from the

expandable tubular. This requires approximately 500 lb_f (22 newtons), which should be seen on the weight indicator. After the expansion member exits the forward end of the expandable tubular, the pressure drops and then sharply rises triggering the pop-off valve after last stroke gets consumed. To ensure that expansion has been completed, lower the DP or CT for more than 4 ft (122cm).

[0068] Retrieval of the expansion tool may proceed according to the following non-limiting procedure. After completing expansion, pull the DP or CT all the way out through the expanded pipe, open hole and production casing. The load to pop the expansion member off the mouth of the expanded liner should be no greater than 13,000-15,000 lb_f (56-65 newtons). This should be seen as an equivalent increase in the weight indicator. In case the pull out load at any point increases by as much as 30,000 lb_f (133 newtons), stop pulling, increase pressure to 4,500 psi (31 MPa) to shear the rear anchor for permanent closure. Continue pulling the string out. Clamp the tool on well head through the fluid filter. Disconnect DP or CT pin connection from the expansion tool. Install lifting sub with eye bolt on tool and retrieve from hole. Insert tool on its respective shroud still in the rat hole. Tie the eye bolt on the tool to collars on the shroud. Lift tool shroud and load back into truck for take back.

[0069] The risk assessment table, Table 5, contains a non-limiting list of 14 possible scenarios that could decrease the degree of success of a specific expansion job in different degrees. The legend used to quantify each risk was as follows:

[0070] Likelihood, L: Probability of risk to occur

[0071] 1 = Improbable

[0072] 2 = Unlikely

[0073] 3 = Possible

[0074] 4 = Likely

[0075] 5 = Probable

[0076] Severity, S: Impact of risk on Job economics and HSE

[0077] 1 = Low: Loss of a few thousand dollars or a few hours, no HSE risk

[0078] 2 = Med-Low: Loss of a few tens of thousands of dollars or tens of hours, minimal HSE risk

[0079] 3 = Medium: Loss of 10% of well cost or several days, medium HSE risk

[0080] 4 = Med-high: Loss of 50% of well cost or several weeks, major HSE risk

[0081] 5 = High: Total scrap of well, HSE fatality.

[0082] Exposure, E: $L \times S$, ranges from 1 to 25, with 1 being a “good” result and 25 a “bad” result.

TABLE 5: Risk mitigation table.

No.	Risk Description	Stage	L	S	E	Mitigation Plan
1	Damaged connectors / Joints do not make up	Make up	3	1	3	Carry spare joints
2	Cone stuck in base casing ID	Deploy.	3	1	3	Clean base casing ID
3	Nozzle does not past thru window	Deploy.	3	1	3	Different RIH speeds / re-mill window
4	Loosing the liner	Deploy.	2	2	4	Push it to position / pick up with Front Anchor
5	Loosing system and liner	Deploy.	1	3	3	Fishing operation
6	Cone stuck on 1st stroke and pipe cladded	Deploy.	3	2	6	Pressure up to 3800 psi (26 MPa) to unlock tool-liner thru Casing Lock / use back up tool / fish pipe out
7	Cannot expand mid-liner	Exp.	3	2	6	Use back up tool / fish pipe out
8	Expansion pressure drops dramatically	Exp.	2	3	6	Use back up tool / fish pipe out
9	Cannot expand three last Strokes	Exp.	3	2	6	Use back up tool / stronger Rear Anchor burst disk / cut casing
10	Need well control	Exp.	2	2	4	Pressurize to 4,500 psi (31 MPa)

						to open tool thru Rear Anchor.
11	Cannot pull tool thru end of liner	Retrieval	3	1	3	Pull 20-40 klbf (90-180 newtons) to shear AI nozzle
12	Cannot pull tool thru expanded liner / base casing	Retrieval	3	2	6	Pressurize to 4,500 psi (31 MPa) to burst rear anchor disk for retraction.
13	Cannot pull tool thru open hole section below window.	Retrieval	2	1	2	Pressurize to 4,500 psi (31 MPa) and circulate to clean debris.
14	Tool did not catch nozzle	Retrieval	3	1	3	Drill out on next trip

[0083] In embodiments where expansion cannot be completed, the semi-expanded liner would have to be fished out of the well. A fishing mechanism could engage either on the pre- or post- expanded ID of the expandable tubular. In one embodiment their dimensions are as follows:

[0084] Pre-expanded tubular dimensions: ID: 2.992 inch (7.599cm),

[0085] OD: 3.510 inch (8.915cm)

[0086] Post-expanded tubular dimensions: ID: 3.81 inch (9.68cm),

[0087] OD: 4.27 inch (10.8cm).

[0088] Due to the tandem open hole anchors (not illustrated) that fix the casing to the formation during the first stroke, in this example the semi-expanded casing would need a maximum of 70,000 lbf (311 newtons) of pull to start sliding the liner out of hole.

[0089] A fishing tool that might be used in the above example if the expansion tool is lost in the well is illustrated in cross-section in FIG. 4, which contains all the dimensions of the connection on which breakage may occur.

[0090] The skilled operator or designer will determine which system, method, and apparatus within this disclosure is best suited for a particular well and formation

to achieve the highest efficiency, safety, and environmentally sound well intervention without undue experimentation.

[0091] EXAMPLES

[0092] Expandable Liner Example Trial 1

[0093] RIH with 408 feet of un-expanded 3.5 inch liner, through maximum Dog Leg Severity (DLS) of 37°/100 feet. Tool expanded 46 inches of liner, but not all of the liner; however, it was learned that the tool did not fail, pressure readings at the surface could readily be understood, and the upper anchor sub-system needed to be improved as described hereinafter. The un-expanded liner was successfully fished, and the well-bore was saved.

[0094] Expandable Liner Example Trial 2

[0095] Applied lessons learned from Example Trial 1. Reconfigured the piston system within the expansion tool to stroke to 48 inches. Added a third cladding to increase support for upper (rear) anchor (see FIG. 8, claddings are noted at 70, 72, and 74, with 74 being the additional cladding). RIH with 447 feet of un-expanded 3.5 inch liner, through maximum DLS of 31°/100 feet. Pumped through large diameter iron, reading pressures at the stand pipe. Experienced some tight spots while expanding, but managed to get the cone of the tool down. Lost 5 slip bodies at the end of expansion process. RIH with a 3.75 inch “crayola” mill to bottom. Found that liner had slid downward, expansion was not complete (lacked about 14 feet).

[0096] Lessons learned: fluid used for the expansion process (mud), while not necessary to be ultra-pure, cannot comprise any large-scale debris, cedar fibers or other similar solids that may be retained by the filter or other system components and cause pressure to increase severely.

[0097] From the foregoing detailed description of specific embodiments, it should be apparent that patentable methods, systems and apparatus have been described. Although specific embodiments of the disclosure have been described herein in some detail, this has been done solely for the purposes of describing various features and aspects of the methods, systems and apparatus, and is not intended to be limiting with respect to the scope of the methods, systems and apparatus. It is contemplated that various substitutions, alterations, and/or modifications, including but not limited to those implementation variations which may have been suggested herein, may be made to the described embodiments without departing from the scope of the appended claims.

What is claimed is:

1. A tubular member radial expansion apparatus comprising:

- a) a support member having a forward end and a rearward end;
- b) a drive unit and an expansion member disposed on the support member providing force for propelling the expansion member through and radially expanding an expandable tubular, the drive unit disposed rearward of the expansion member;
- c) front and rear anchors disposed on the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular;
- d) a casing lock disposed on the support member and positioned between the expansion member and the front anchor, releasably securing the expandable tubular to the support member during running-in-hole; and
- e) a valve attached to a forward end of the expandable tubular.

2. The apparatus of claim 1 wherein the support member defines one or more internal fluid passages.

3. The apparatus of claim 2 comprising a flow valve fluidly connected to the forward end of the support member and at least one of the internal fluid passages.

4. The apparatus of claim 1 comprising a fluid filter fluidly connected to the support member and at least one of the internal fluid passages and positioned at the rearward end of the support member preventing large mud particles from reaching the tool seals and inner mechanisms.

5. The apparatus of claim 1 wherein the support member is tubular.

6. The apparatus of claim 1 wherein the expansion member is conical, having an outer surface engaging an inner surface of the expandable tubular, the outer surface having a diameter which decreases from a forward end to a rearward end of the expansion member.
7. The apparatus of claim 1 comprising an end cap attached to the forward end of the support member.
8. The apparatus of claim 1 wherein the expandable tubular is metallic and has an expansion ratio ranging from about 20 to about 40 percent.
9. The apparatus of claim 8 able to achieve a bend radius ranging from 20-50°/100 ft (20-50°/30.5m).
10. A tubular member radial expansion system comprising:
 - a) a deployment component; and
 - b) a tubular member radial expansion apparatus comprising:
 - i) a support member having a forward end and a rearward end;
 - ii) a drive unit and an expansion member disposed on the support member providing force for propelling the expansion member through and radially expanding an expandable tubular, the drive unit disposed rearward of the expansion member;
 - iii) front and rear anchors disposed on the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular;
 - iv) a casing lock disposed on the support member and positioned between the expansion member and the front anchor, releasably securing the expandable tubular to the support member during running-in-hole; and

v) a valve attached to a forward end of the expandable tubular.

11. The system of claim 10 wherein the deployment component is selected from coiled tubing and drill pipe.

12. The system of claim 10 wherein the support member defines one or more internal fluid passages.

13. The system of claim 10 wherein the expansion member is conical, having an outer surface engaging an inner surface of the expandable tubular, the outer surface having a diameter which decreases from a forward end to a rearward end of the expansion member.

14. The system of claim 10 wherein the expandable tubular is metallic and has an expansion ratio ranging from about 20 to about 40 percent.

15. The system of claim 14 able to achieve a bend radius ranging from about 20 to about 50°/100 ft (20-50°/30.5m).

16. A method of expanding a tubular member, comprising:

a) deploying an expandable tubular and an expansion tool into a wellbore, the expandable tubular secured to a support member of the expansion tool, the support member having a forward end and a rearward end, the rearward end attached to a deployment component communicating with the surface; and

b) performing an intervention operation on the wellbore comprising using the expansion tool to expand the expandable tubular and so complete the wellbore,

wherein the expansion tool further comprises a drive unit and an expansion member disposed on the support member providing force for propelling the expansion member through the expandable tubular axially from rear to forward and radially expanding the expandable tubular, the drive unit disposed rearward of the expansion member; front and rear anchors disposed on

the support member for engaging the expandable tubular's ID to provide reaction forces to propagate the expansion member through the expandable tubular, the rear anchor positioned behind the drive unit and providing its reaction force after the front anchor has exited the expandable tubular.

17. The method of claim 16 wherein the deploying proceeds by using deployment components selected from coiled tubing and drill pipe.

18. The method of claim 16 wherein the well intervention operation is selected from open-hole clads, sidetracking, and cased-hole patches.

19. The method of claim 16 comprising radially expanding the expandable tubular to an expansion ratio ranging from about 20 to about 40 percent.

20. The method of claim 19 comprising deploying the expansion tool and expandable tubular into a non-horizontal wellbore having a bend radius ranging from about 20 to about 50°/100 ft (20-50°/30.5m).

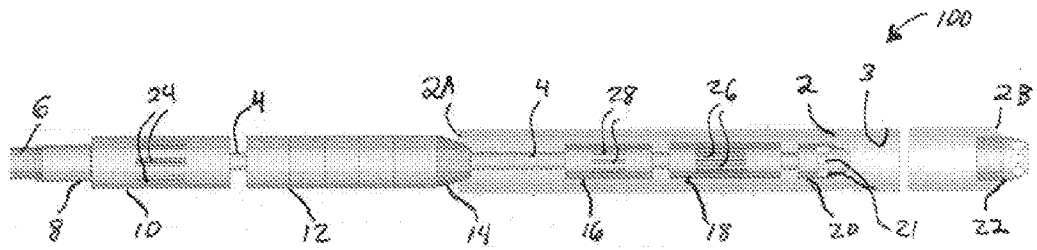


FIG. 1

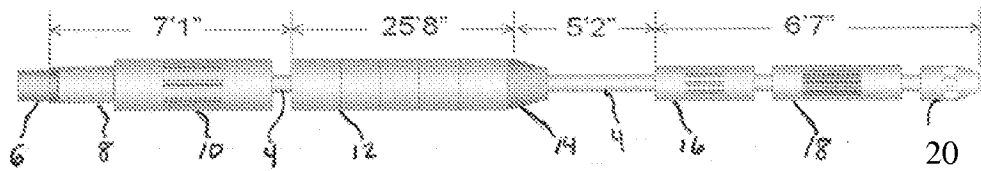


FIG. 3

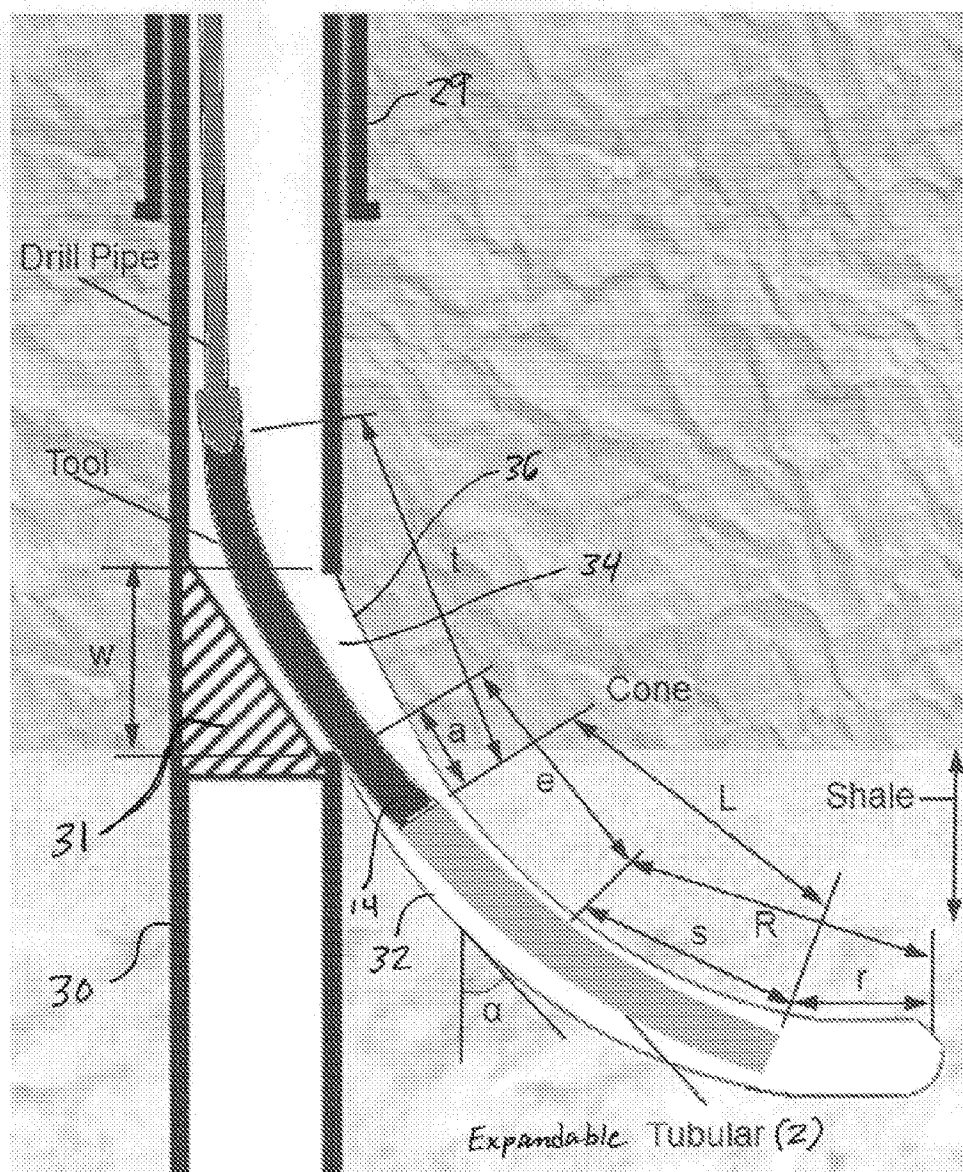


FIG. 2

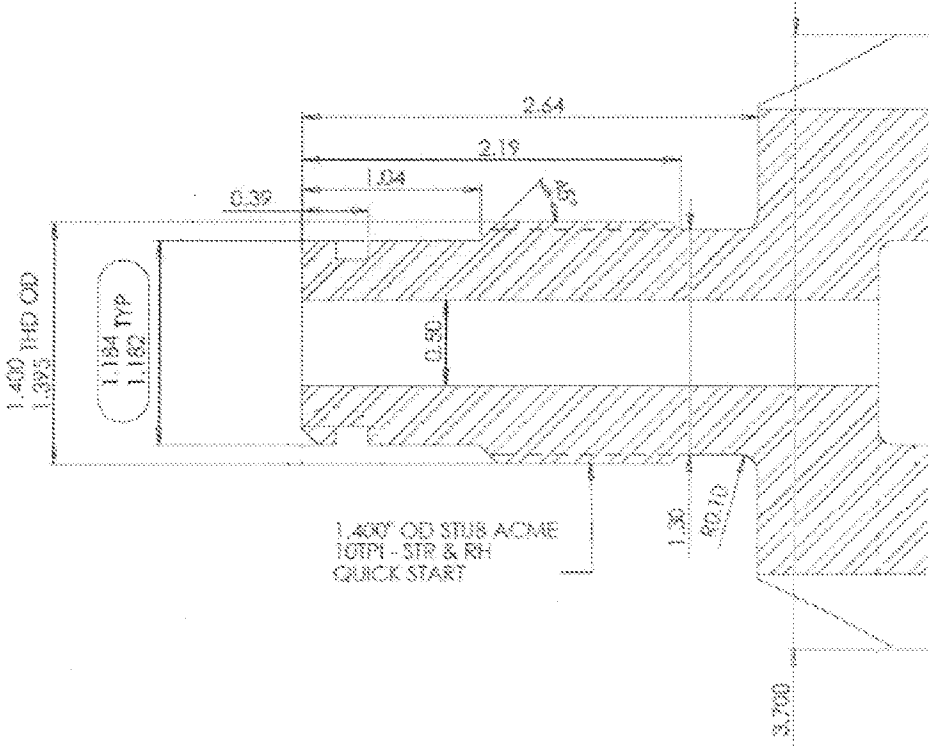
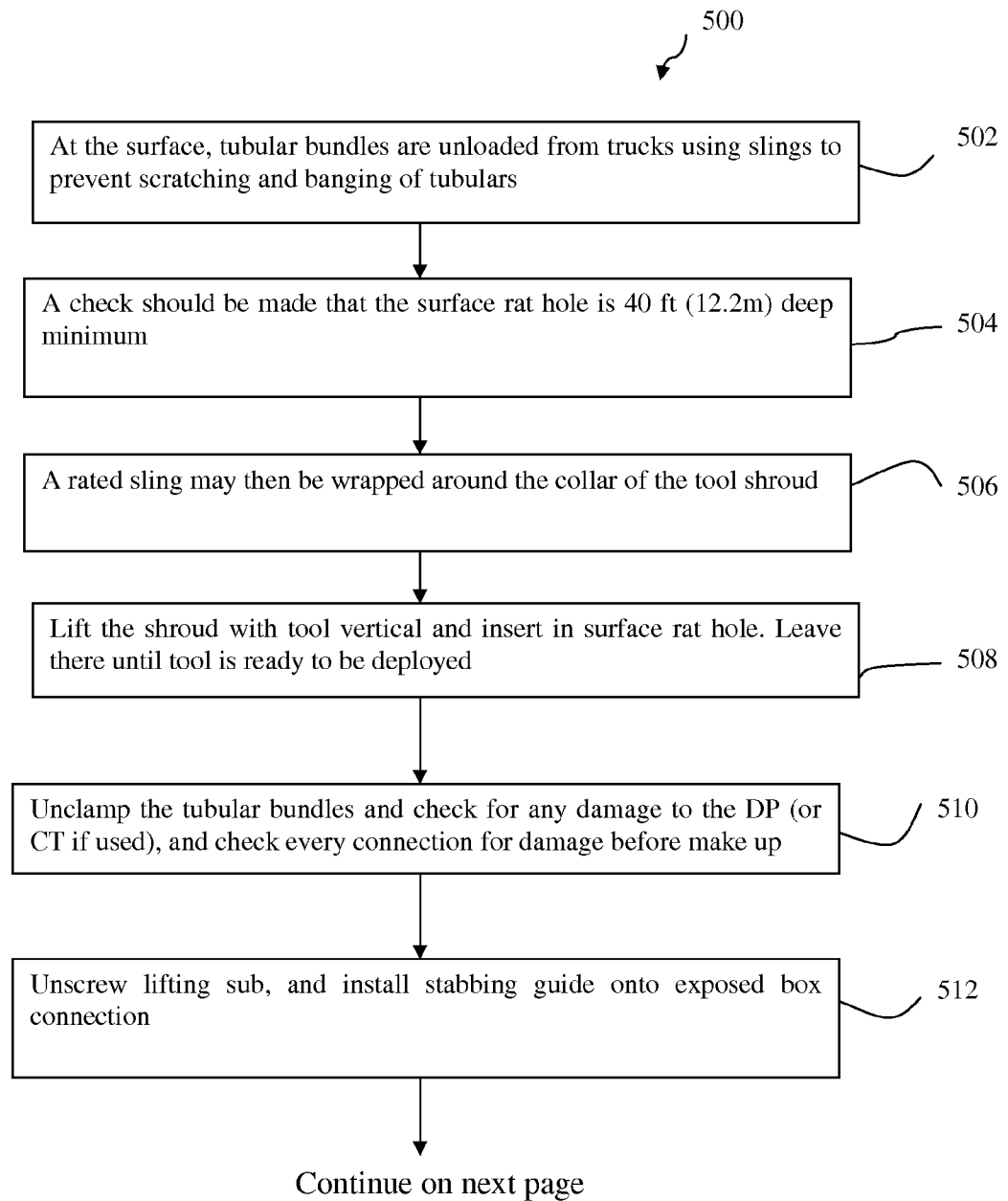


FIG. 4

**FIG. 5**

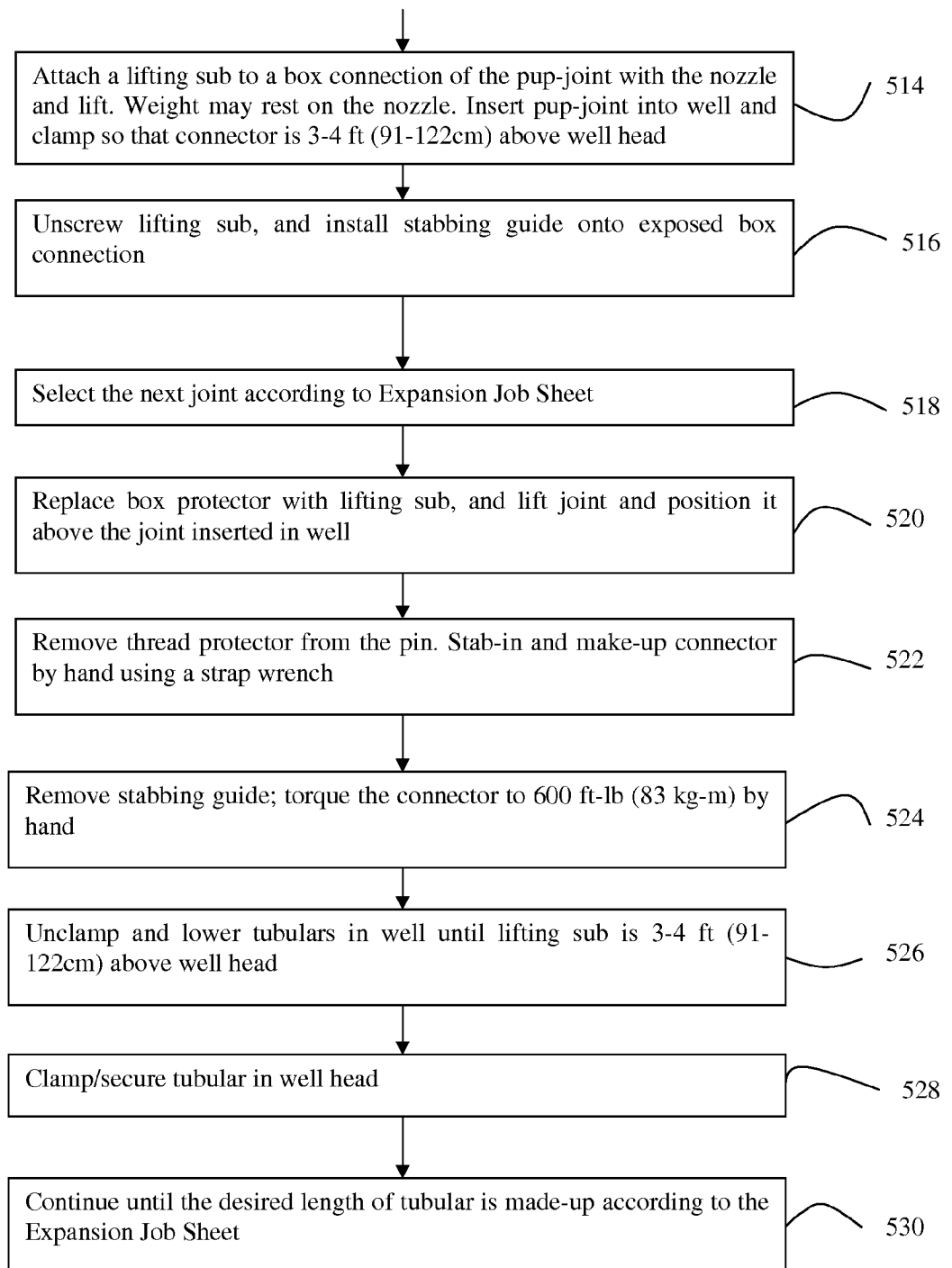
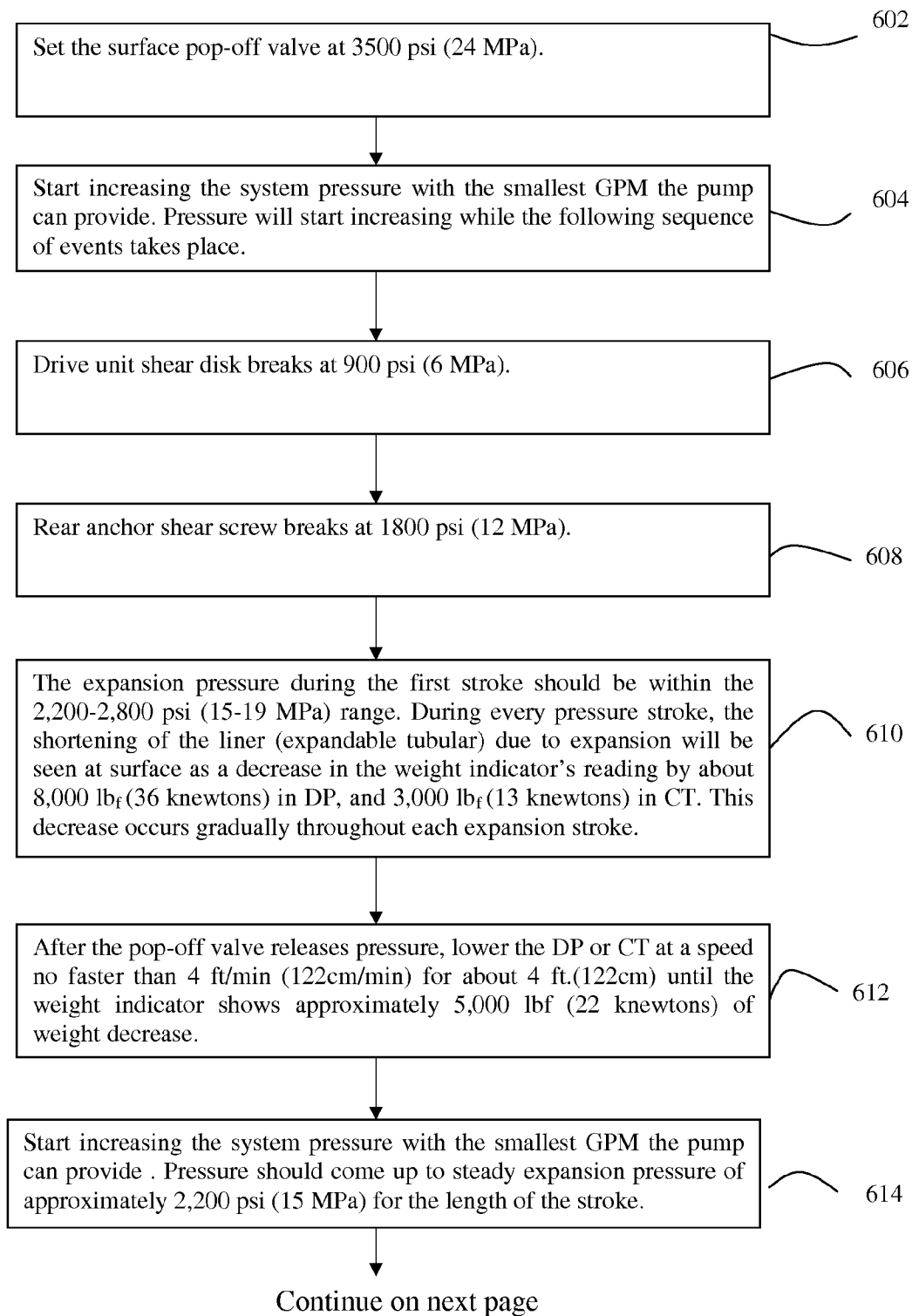
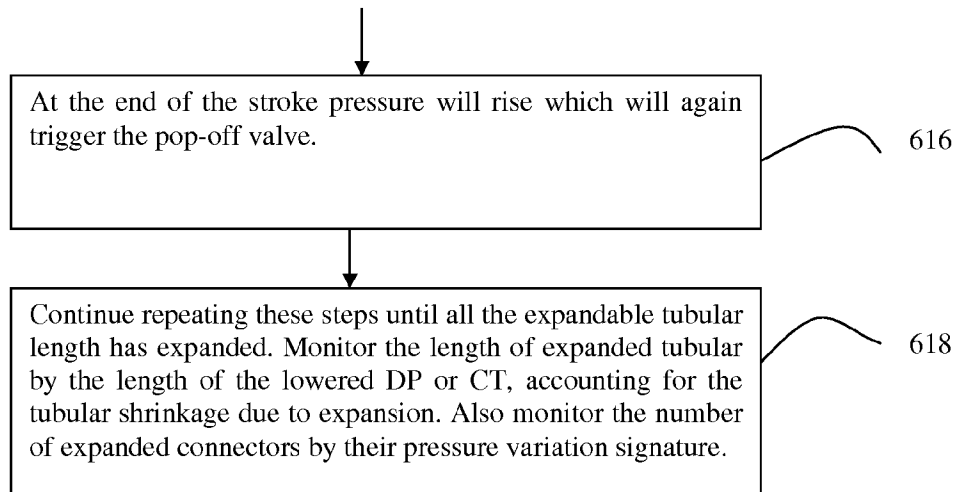


FIG. 6





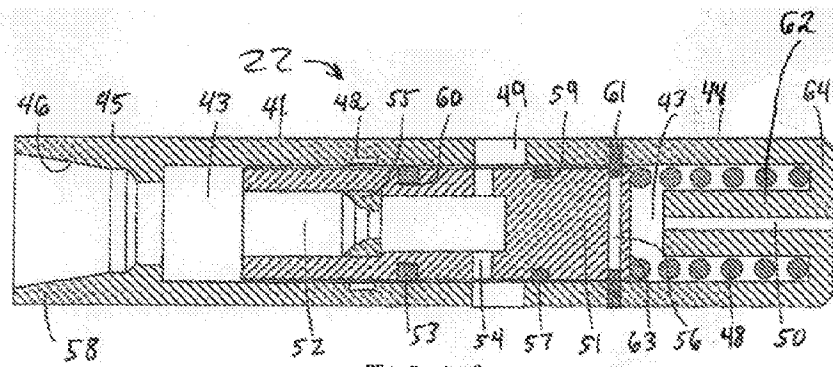


FIG. 7A

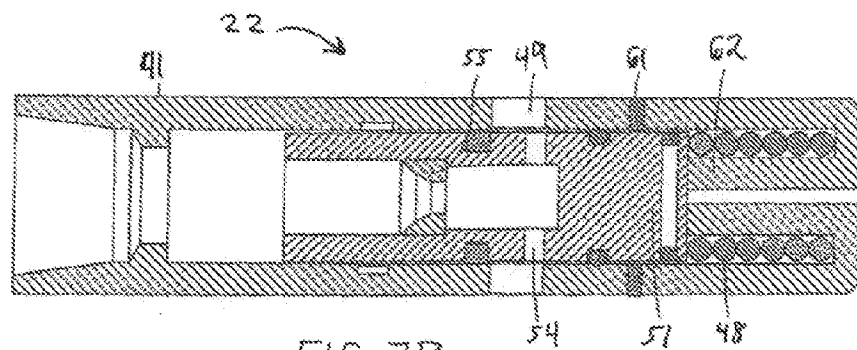


FIG. 7B

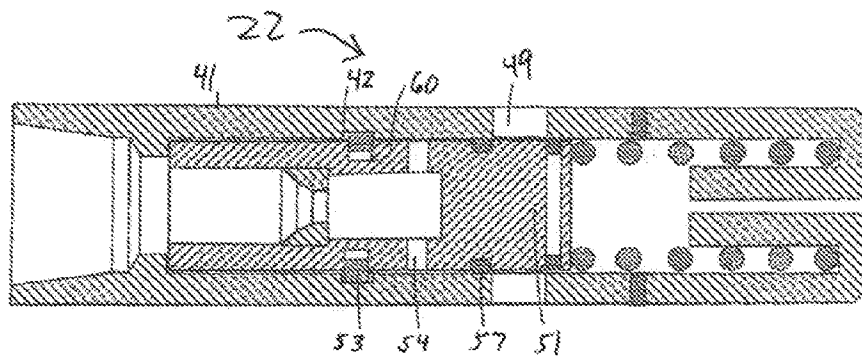
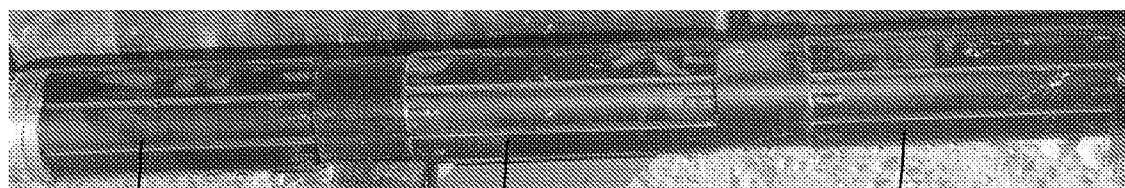


FIG. 7C

FIG. 8



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