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- 1 -

SHOE FOR A TUBULAR ELEMENT IN A WELLBORE

The present invention relates to a shoe for a tubular element in a borehole extending into an earth formation.

5 Wellbores for the production of hydrocarbon fluid generally are provided with steel casings and/or liners to provide stability to the wellbore wall and to prevent undesired flow of fluid between the wellbore and the surrounding earth formation. A casing generally extends
10 from surface into the wellbore, whereas a liner may extend only a lower portion of the wellbore. However in the present description the terms "casing" and "liner" are used interchangeably and without such intended difference.

In a conventional wellbore, the wellbore is drilled in
15 sections whereby each section is drilled using a drill string that has to be lowered into the wellbore through a previously installed casing. In view thereof the wellbore and the subsequent casing sections decrease in diameter with depth. The production zone of the wellbore therefore
20 has a relatively small diameter in comparison to the upper portion of the wellbore. In view thereof it has been proposed to drill a "mono diameter" wellbore whereby the casing or liner to be installed is radially expanded in the wellbore after lowering to the required depth. Subsequent
25 wellbore sections may therefore be drilled at a diameter larger than in the conventional wellbore. If each casing section is expanded to the same diameter as the previous section, the wellbore diameter may remain substantially constant with depth.

30 During installation of the casing into the wellbore, either conventional or mono diameter, the shoe at the lower end of the casing may encounter obstructions such as ledges, rock particles and debris. To overcome such obstructions it has already been proposed to provide the

casing shoe with reaming members and ports for pumping fluid into the wellbore.

US 6,401,820 B1 discloses a liner shoe provided with jetting ports provided at an eccentric nose portion of the shoe.

Such jetting ports may become clogged, for example during pumping of cement into the wellbore, thereby potentially leading to damage to the shoe and/or to unsuccessful cementation of the casing in the wellbore.

US patent application US2010/0252331 discloses a reamer shoe that is able to drill through modest obstructions within a previously drilled borehole and which is provided with nozzles(25) formed by apertures and frangible regions that can be breached to form additional apertures(28) that may be used to provide fluid communication between the interior and exterior of the reamer shoe when the nozzles (25) are plugged. A disadvantage of this known reamer shoe is that the frangible regions do not have larger flow areas than the nozzles, so that when the nozzles(25) are clogged by large size debris, also the additional apertures(28) will be clogged by such large size debris.

There is a need for an improved shoe for a tubular element in a borehole extending into an earth formation, which overcomes the drawbacks of the prior art.

In accordance with the invention there is provided a shoe for a tubular element in a borehole extending into an earth formation, the shoe comprising a body adapted to be connected to the lower end of the tubular element, the body being provided with:

- a fluid channel;
- at least one nozzle for jetting fluid into the borehole, each nozzle being in fluid communication with the fluid channel; and
- an additional fluid outlet for pumping fluid from the

fluid channel into the borehole, the fluid outlet being closed by a closure device arranged to open at a selected fluid overpressure in the fluid channel relative to a fluid pressure in the borehole;

5 - characterized in that the additional fluid outlet has a flow area larger than each nozzle.

In this manner it is achieved that, in case one or more of the nozzles become clogged, the fluid pressure in the fluid channel increases as pumping proceeds until the pressure reaches the selected overpressure at which the closure device opens and debris that plugged the nozzles is cleared via the additional fluid outlet. Thereby the fluid outlet becomes available for discharging fluid from the fluid channel into the borehole. Thus the closure device forms a safety system that prevents damage to the shoe due to the pressure rating of the shoe being exceeded.

10 Moreover, if such clogging occurs during pumping cement into the wellbore, the cementation procedure may proceed by pumping cement via the fluid outlet into the borehole once the closure device has opened.

Suitably the closure device includes a section of reduced wall thickness of the body, which section is arranged to shear off from the body upon the fluid pressure in the fluid channel reaching the selected overpressure. For example, the section of reduced wall thickness may comprise a burst plate.

25 The fluid outlet may have a flow area of, for example, between about 2 to 3 square inch (12 to 20 cm²). The total flow area of said at least one nozzle may be less than 1 square inch (6.5 cm²).

30 Advantageously the fluid channel may be provided with a seat for receiving a plug for closing the fluid channel. Further, the fluid channel may be provided with locking means for locking the plug in the fluid channel. For

example, the locking means may comprise a recess formed in a selected one of the fluid channel and the plug, and the other of the fluid channel and the plug may be provided with a locking member arranged to snap into the recess upon the plug landing on the seat. In one embodiment the recess comprises an annular groove formed in the fluid channel, and the locking member comprises a lock ring provided to the plug.

To promote proper seating of the plug into the fluid channel, the body may be provided with a chamber arranged to receive debris from the fluid channel, wherein the plug is adapted to move the debris from the fluid channel into the chamber.

Suitably the body includes a flange provided with at least one radially extending rib, each rib being arranged to prevent rotation of the flange during drilling-out of the shoe in the borehole.

Also, the body may include a reamer for reaming the borehole during lowering of the tubular element into the borehole. Each nozzle may be positioned at the reamer.

To prevent rotation of the reamer with the drill bit or milling tool during drilling-out the shoe, suitably the reamer has a nose section arranged eccentrically relative to a central longitudinal axis of the tubular element when the shoe is connected to the tubular element. Furthermore, the reamer may be provided with at least one cutter blade for cutting rock particles during reaming of the borehole, each cutter blade being arranged to prevent rotation of the reamer during drilling-out the shoe in the borehole.

The tubular element may be, for example, a casing or a liner adapted to be arranged in the borehole. Alternatively the shoe may be included in a bottom plug arranged in an expandable casing or liner below an expander for expanding the casing or liner in the borehole.

The invention will be described hereinafter in more detail and by way of example, with reference to the accompanying schematic drawings in which:

Fig. 1 schematically shows an assembly including a first embodiment of the shoe of the invention;

Fig. 2 schematically shows the assembly after pumping cement into the wellbore;

Fig. 3 schematically shows the assembly during expansion of the clad element;

Fig. 4 schematically shows the assembly after the bottom plug has been set;

Fig. 5 schematically shows the assembly during drilling-out of the bottom plug;

Fig. 6 schematically shows a modified bottom plug for use in the assembly; and

Figs. 7a-d schematically show an assembly including a second embodiment of the shoe of the invention.

In the description and the figures, like reference numerals relate to like components.

Fig. 1 shows an assembly 1 for expanding a tubular element 2 in a wellbore 3 extending into an earth formation 4. The assembly 1 comprises a primary expander 6 connected to an expansion mandrel 8 suspended in the wellbore 3 on a drill string (not shown) that normally may be used for drilling of the wellbore. The primary expander 6 has a cylindrical upper portion 6a of diameter substantially equal to the inner diameter of the unexpanded tubular element 2 and a conical lower portion 6b of diametrical size adapted to expand the tubular element 2 to the desired diameter to form a liner in the wellbore 3. The tubular element 2 is suspended on the primary expander 6 whereby the cylindrical portion 6a thereof extends into the lower end of the tubular element 2.

The assembly 1 furthermore comprises a bottom plug 10 arranged below the primary expander 6 and connected to a plug mandrel 12 in releasable manner, the plug mandrel being fixedly connected to the lower end of the expansion
5 mandrel 8. The plug mandrel 12, the expansion mandrel 8 and the drill string have a common fluid channel 13 for fluid pumped from surface to the bottom plug 10. The bottom plug 10 comprises a flange 14 having a recess 16 into which a lower end part 18 of the plug mandrel 12 fits. The recess
10 16 and lower end part 18 have complementary hexagonal shapes so as to allow torque to be transmitted between the plug mandrel 12 and the bottom plug 10, however any other suitable shape may be selected to allow torque to be transmitted. A radially expandable tubular clad element 20
15 is fixedly connected to the flange 14 and extends coaxially around the plug mandrel 12. A secondary expander 22 is arranged inside the clad element 20, the secondary expander having a cylindrical upper portion 22a of diameter substantially equal to the inner diameter of the unexpanded
20 clad element 20 and a conical lower portion 22b of maximum diameter adapted to expand the clad element 20 against the inner surface of tubular element 2 after radial expansion thereof. The clad element 20 has a launcher section in the form of thin walled lower section 24 with an oversized
25 inner diameter to accommodate the conical lower portion 22b of the secondary expander. The clad element further includes a lower anchoring section 26, an upper anchoring section 28 axially spaced from the lower anchoring section, and a sealing section 30 located between the lower and
30 upper anchoring sections 26, 28. Each anchoring section 26, 28 is at the outer surface provided with a coating of friction material, for example a coating including carbide particles embedded in a substrate that is metallurgically bonded to the outer surface by means of laser welding. The

sealing section 30 is at the outer surface provided with annular seals 34.

The plug mandrel 12 extends through a central bore 36 of the secondary expander 22 in a manner allowing the secondary expander 22 to slide in axial direction along the plug mandrel 12. The plug mandrel 12 is provided with flow ports 38 fluidly connecting the fluid channel 13 with a fluid chamber 40 formed between the large diameter end of the secondary expander 22 and the flange 14. Initially the axial size of the fluid chamber 40 is very small but increases during expansion of the clad element 20 as will be explained hereinafter. The upper end of the clad element 20 is covered by a removable debris cap 42 having a central bore 44 through which the plug mandrel 12 extends in a manner allowing the debris cap 42 to slide in axial direction along the plug mandrel 12. The debris cap 42 serves to prevent debris entering the clad element 20 prior to radial expansion thereof. Further, the bottom plug 10 is provided with a reamer 45 having outlet openings in the form of nozzles 46 in fluid communication with the fluid channel 13 via an internal chamber 47 of the reamer and a bore 48 in the flange 14. The chamber 47 has a wall section of reduced thickness in the form of burst plate 49 that is adapted to shear off at a selected fluid overpressure in the chamber 47 relative to a fluid pressure in the borehole i.e. exterior of the bottom plug 10. When sheared off, the burst plate 47 leaves a fluid outlet from the chamber with a flow area larger than the flow area of each nozzle 46. The bore 48 has a seat 50 for receiving a trailing plug 52 (Fig. 2) to close the bore.

Fig. 2 shows the assembly 1 whereby a fluidic cement column 53 surrounds the tubular element 2 and the assembly 1. The trailing plug 52 is received on the seat of the bore 48 and thereby closes the bore.

Fig. 3 shows the assembly 1 after a lower portion 54 of the tubular element 2 has been expanded by the primary expander 6, whereby the bottom plug 10 is positioned in the expanded lower portion 54 and the clad element 20 is partly expanded against the inner surface of the expanded lower portion 54. A volume of hydraulic fluid 56, such as spacer fluid or drilling fluid, has been pumped into the fluid chamber 40 via the fluid channel 13 and flow ports 38.

Fig. 4 shows the assembly 1 after the clad element 20 has been fully expanded against the inner surface of the expanded lower portion 54 of the tubular element 2, whereby the plug mandrel 12 is released from the flange 14. The secondary expander 22 and the debris cap 42 maintain positioned at the plug mandrel.

Fig. 5 shows the assembly 1 after tubular element 2 has been fully expanded, and the expansion mandrel 8 and the plug mandrel 12 together with the secondary expander 22 and the debris cap 42 have been removed from the wellbore 3. A drill string 58 with a polycrystalline diamond compact (PDC) bit 60 is lowered into the expanded tubular element 2 to drill out the remainder of the bottom plug 10. Instead of the PDC bit 60, a dedicated milling tool may be applied to drill out the remainder of the bottom plug.

Fig. 6 shows a modified bottom plug 64 which is substantially similar to the bottom plug 10 except regarding the following. The reamer 45 has a nose section 66 arranged eccentrically relative to a central longitudinal axis of the plug mandrel 12. Furthermore, the modified bottom plug 64 is provided with an activation sleeve 68 positioned in the bore 48 to temporarily close the flow ports 38. The activation sleeve 68 is locked in place by suitable shear pins (not shown) and is adapted to slide axially downward through the bore 48 when the shear pins are broken whereby the flow ports 38 are freed. The

seat 50 for the trailing plug 52 is provided in the activation sleeve 68 rather than in the bore 48.

Furthermore, the modified bottom plug 64 is provided with a protective sleeve 70 extending around the sealing section 30 and the anchoring sections 26, 28 of the clad element 20.

The sleeve 70 is fixedly connected to the debris cap 42, the latter having a cylindrical part 42a that extends into the clad element 20 and abuts against the secondary expander 22. Reamer 45, flange 14 and clad element 20 are interconnected by a crossover sub 71.

Figs. 7a to 7d show an assembly 80 using a second embodiment of the shoe of the invention, whereby Fig. 7a shows a side view and Figs. 7b-d show a longitudinal section of the assembly. The assembly 80 includes a shoe 82 connected to the lower end of a wellbore casing (or liner) 84. The shoe 82 is provided with a reamer 86 having an eccentric nose section 87 relative to a central longitudinal axis of the casing 84. The reamer 86 is provided with nozzles in the form of flow ports 88 to enable drilling fluid to be circulated during running into a wellbore. The size of the flow ports 88 is such that the total flow area of the flow ports 88 is similar to, for example, the flow area of a conventional PDC drill bit i.e. typically less than 1 square inch so as to provide the necessary jetting action for hole cleaning purposes. The flow ports 88 are arranged such that an optimum flow distribution and scavenging of the wellbore by jet action is obtained. The inner surfaces of the flow ports may be provided with a hard facing to mitigate erosion during circulation.

The reamer 86 is at its outer surface provided with a plurality of cutter blades 90 having abrasion resistant cutting elements 92 e.g. carbides that may be brazed on the outer surface of the reamer. The reamer 86 is connected to the casing 84 by means of a crossover sub 94 which forms the

transition between the casing 84 and a flange 96 of the shoe 82. The flange 96 is provided with a profiled bore 98 having a seat 99 for receiving a trailing plug 102 (Fig. 7d) used during pumping cement into the wellbore. The bore 98 is in fluid communication with the flow ports 88 via a chamber 103 formed in the shoe. A groove 104 is provided in the bore 98 to enable the trailing plug 102 to be locked in place once seated (Fig. 7d). The flange 96 may optionally be provided with radial ribs (not shown) that are surrounded by cement after cementation to prevent rotation of the flange 96 during drilling out the shoe from the wellbore. Further, the flange 96 may optionally be provided with arms (not shown) connected to the reamer 86 to provide mechanical support to the reamer. The reamer 86 has a section of reduced wall thickness in the form of burst plate 108 that is adapted to shear off from the reamer at a selected fluid overpressure in the chamber 103 relative to a fluid pressure in the borehole i.e. exterior of the shoe 82. When sheared off, the burst plate 108 leaves an outlet opening 109 of chamber 103 with a flow area larger than the flow area of each flow port 88 (Fig. 7c).

Normal operation of the assembly 1 is as follows. The assembly 1 is lowered into the wellbore 3 on drill string and may be rotated to ream sections of the wellbore 3 by reamer 45. Simultaneously drilling fluid may be pumped into the wellbore via fluid channel 13, chamber 47 and nozzles 46. The pumped fluid assists in reaming the wellbore and transports rock particles to surface. Once the assembly 1 has reached target depth of the wellbore, the tubular element 2 is at its upper end anchored in the wellbore 3. Subsequently a volume of leading spacer fluid (not shown) is pumped into the wellbore via the fluid channel 13 to clean the fluid channel from drilling fluid, followed by the fluidic cement column 53 and the trailing spacer fluid 56

(Fig. 3). Instead of trailing spacer fluid, drilling fluid may be used. The leading spacer fluid and the fluidic cement 53 may be separated by a foam ball that crushes upon arriving in the bore 48 of the bottom plug 10 and is released through the outlet openings 46. The fluidic cement 53 and the trailing spacer fluid 56 are separated by the trailing plug 52 that seats on the seat 50 upon arriving in the bore 48. Thus, at this stage the trailing spacer fluid 56 is present in the fluid channel 13, and the cement column surrounds the bottom plug 10 and the tubular element 2. The trailing plug 52 closes the bore 48 and thereby seals the fluid channel 13 from the annular space around the assembly 1 in the wellbore 3. The primary expander 6 abuts against the lower end of the tubular element 2 therefore fluidic cement cannot enter the tubular element 2 (Fig. 2).

In the event that one or more of the nozzles 46 become clogged before the fluidic cement column 53 has been fully pumped into the wellbore, the fluid pressure in chamber 47 increases as pumping continues until the burst plate 49 shears off upon the fluid pressure reaching the selected overpressure. Thereby, the relatively large flow area in the wall section of the former burst plate becomes available for pumping cement into the wellbore. In this manner the burst plate 49 forms a contingency device that prevents a catastrophic situation whereby the cementing procedure cannot be completed successfully.

The burst plate 49 also protects the reamer 45 against pressure shockwaves that may occur in the fluid channel 13, for example during setting of a liner hanger or the activation of the expansion system. Such shockwaves may have amplitudes up to 3500 psi and will almost entirely reflect against the reamer 45 thereby doubling in amplitude. The

burst plate 49 shears off at such high pressure peaks and thereby protects the reamer 45 against damage or failure.

Furthermore, debris that may be present in the bore 48 is pushed into the chamber 47 by the trailing plug 52 as it moves into the bore 48. In this manner proper seating of the trailing plug 52 in the bore is not hampered by such debris.

After seating of the trailing plug 52 in the bore 48, the primary expander 6 is pulled into the tubular element 2 by pulling the drill string whereby the lower portion 54 of the tubular element 2 is expanded (Fig. 3). Expansion is proceeded until the bottom 10 plug is fully inside the expanded lower portion 54. While maintaining the drill string under tension, fluid pressure is applied in the fluid channel 13 so that the trailing spacer fluid 56 flows via the flow ports 38 of the plug mandrel 12 into the fluid chamber 40. The secondary expander 22 thereby slides along the plug mandrel 12 away from the flange 14 and gradually expands the clad element 20 against the expanded lower portion 54 of the tubular element 2. The lower anchoring section 26 first engages the expanded lower portion 54, followed by the sealing section 30 and subsequently the upper anchoring section 28. Upon the sealing section 30 engaging the expanded lower portion 54, the tubular element 2 is simultaneously further expanded with the primary expander 6 to maintain volume balance in the expanded section of the tubular element 2 between the bottom plug 10 and the primary expander 6.

Once the clad element 20 is fully expanded against the expanded tubular element 2, the secondary expander 22 moves out of the clad element and thereby pushes the debris cap 42 off the clad element 20. The interior of the expanded clad element 20 is then filled with trailing spacer fluid that may be contaminated with cement. In a subsequent step the

remainder of the tubular element 2 is expanded with the primary expander 6 whereby the secondary expander 22 and the debris cap 42 are carried out of the wellbore 3 on the plug mandrel 12 (Fig. 4). After the bottom plug 10 has been set
5 in the expanded lower portion 54 of the tubular element, fluid pressure can be applied below the primary expander 6 via the fluid channel 13 to provide additional upward force to the primary expander 6 (hydraulic assist). Alternatively, the entire expansion force required to expand the tubular
10 element 2 may be provided by such fluid pressure i.e. without applying tensile force to the drill string.

The design functionalities of the upper and lower anchoring sections 26, 28 and the sealing section 30 are as follows. When the fluid pressure in the interior space of
15 the fully expanded clad element 20 is higher than the fluid pressure below the bottom plug 10, the clad element is subjected to balloon deformation whereby the lower anchoring section 26 becomes firmly pressed against the expanded tubular element 2. Conversely, when the fluid pressure below
20 the bottom plug 10 is higher than the fluid pressure in the interior space of the fully expanded clad element 20, for example due to swab pressure below the primary expander 6 during expansion of the tubular element 2, the clad element is subjected to balloon deformation whereby the upper
25 anchoring section 28 becomes firmly pressed against the expanded tubular element 2.

After the cement has fully cured, the bottom plug 10 is drilled out with the PDC bit 60 or milling tool on drill
string 58 whereby the bottom plug is supported by the cement
30 53 surrounding it (Fig. 5).

In a variation of normal use, the cement 53 is pumped into the wellbore after the lower portion 54 of the tubular element has been expanded and the bottom plug 10 has been pulled into the expanded lower portion 54. This approach

may be followed if there is a risk that the secondary expander 22 is activated before the bottom plug 1 is inside the lower portion 54 of the tubular element, e.g. due to pressure waves in the fluid channel 13 propagating into the fluid chamber 40 during pumping of cement into the wellbore. However since in the alternative method there is reduced annular space between the expanded lower portion 54 of the tubular element and the wellbore wall, the pressure drop required to pump the cement at a certain rate through the annular space increases, which may lead to an increased risk of formation fracturing in critical pressure regimes.

Stabilization of the PDC bit or milling tool 60 during drilling-out of the bottom plug 10 may be optimized as follows. In the methods described above the clad element 20 is hydraulically expanded with the trailing spacer fluid 56 as a pressure medium. Consequently after completion of the expansion process the interior of the clad element 20 is filled with trailing spacer fluid that may be contaminated with some cement. In order to optimize stabilization of the PDC bit or milling tool 60 during drilling-out of the bottom plug 10 an additional volume of cement may be pumped behind the trailing plug 52 to expand the clad element 20. A trailing foam ball (not shown) may be pumped behind the cement, optionally followed by trailing spacer fluid. After the trailing plug 52 has seated in the bore 48, the installation process is continued as described above whereby the pressure medium used for the expansion of the clad element 20 is cement rather than trailing spacer fluid or drilling fluid. During expansion of the tubular element 2 the trailing foam ball is pumped out of the plug mandrel 12 into the wellbore. Thus, after curing of the cement the bottom plug 10 is surrounded by cured cement, optionally with excess cured cement above the clad element 20 to mitigate the risk of damage to the PDC bit or milling tool

60 upon tagging the bottom plug 10 and to provide optimum conditions for drilling-out of the bottom plug 10.

In addition to the above, the risk of damage to the cutters of the PDC bit or milling tool 60 when tagging the top of the clad element 20 can be further mitigated by connecting a short pipe section (not shown) of a soft metal, for example copper, to the top of the clad element 20. The pipe section is subjected to plastic deformation due to loading by the PDC cutters thereby limiting the peak contact load and thus the risk of impact damage to the PDC cutters.

Normal operation of the assembly 1 when provided with the modified bottom plug (Fig. 6) is substantially similar to normal operation described above. In addition the eccentric nose section 66 of the reamer 45 helps in preventing rotation of the reamer during drilling out the bottom plug 10 with the PDC bit 60 or the milling tool. The activation sleeve 68 prevents unintentional expansion of the clad element 20 by the secondary expander 22 due to fluid pressure peaks in the fluid channel 13 before the trailing plug 52 has landed in the activation sleeve. As the trailing plug 52 lands into the activation sleeve 68, the trailing plug pushes the activation sleeve downward whereby the shear pins 69 are broken and the flow ports 38 are freed. Furthermore, the protective sleeve 70 protects the sealing section 30 and the anchoring sections 26, 28 before expansion of the clad element 20. During expansion of the clad element 20, the protective sleeve 70 moves in axial direction away from the clad element 20 together with the debris cap 42. In this manner optimum protection is provided to the sealing section 30 and the anchoring sections 26, 28 which become exposed only just before the secondary expander expands these sections.

Normal operation of the assembly 80 (Figs. 7a-d) is as follows. The shoe 82 is connected to the lower end of the

casing 84 and the assembly 80 is run into a wellbore (not shown). When an obstruction is encountered in the wellbore, e.g. ledges in a deviated hole, the assembly 80 may be rotated while moving down to enable the reamer 86 to overcome the obstruction. If debris has accumulated in the wellbore due to, for example, downward movement of the assembly in a deviated wellbore, drilling fluid may be circulated simultaneously via the flow ports 88 to remove such debris by jetting action. In case of mechanical hole stability problems, rock cavings that cannot be removed by jetting only may obstruct lowering of the assembly 80. In such case the cutter blades 90 cut the cavings into jetttable chunks which are transported to surface by the circulating drilling fluid. Once the target depth of the open hole has been reached, a volume of cement is pumped into the wellbore via the bore 98, the chamber 103 and the flow ports 88. The cement fills up the annulus between the casing and the wellbore wall. Following the cement, the trailing plug 102 is pumped onto the seat 99 of the flange 96 (Fig. 7d). An elastomer seal (not shown) at the outer surface of the trailing plug seals the trailing plug relative to the bore 98. A lock ring 110 of the trailing plug snaps into the groove 104 so as to prevent the trailing plug from being pushed back by U-tubing pressure of the cement. Any debris that may be present in the bore 98 is pushed into the chamber 103 by the trailing plug 102 as the latter lands into the bore 98.

The relatively small size of the flow ports 88 (required to provide the necessary jetting capability during reaming) involves the risk of clogging of the flow ports 88 during cementation. In case of such clogging (Fig. 7c) the fluid pressure in the reamer 86 will increase until the pressure rating of the burst plate 108 is exceeded so that the burst plate shears off. Thereby a new flow port 112 with a flow

area of some 2 -3 square inches is provided which is typical for conventional cementing shoes. This enables the cementing operation to be completed successfully by pumping the remainder of the cement via the new flow port 112 into the annulus.

Once the cement is cured the shoe 82 is drilled out preferable using a PDC drill bit. The components of the shoe 82 are bonded to the cured cement and therefore are locked in place during drilling out. For example, the ribs (if present) and the cutter blades 90 assist in such locking of the components. Further, the eccentric nose section 87 of the reamer 86 prevents rotation of the reamer with the drill bit. All components to be drilled out are suitably made from easily drillable material e.g. cast iron or aluminium, and the cutting elements on the cutting blades are of small size and are embedded in a relatively soft substrate such as brazing material. In this manner the hard cutting elements can easily be broken out of the substrate and discharged from the wellbore by the drilling fluid.

The present invention is not limited to the above-described embodiments thereof, wherein various modifications are conceivable within the scope of the appended claims. For instance, features of respective embodiments may be combined.

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C L A I M S

1. A shoe for a tubular element in a borehole extending into an earth formation, the shoe comprising:

5 a body adapted to be connected to a downhole end of the tubular element, the body being provided with:

- a fluid channel;

- at least one nozzle for jetting fluid into the borehole, each nozzle being in fluid communication with the fluid
10 channel, and

- an additional fluid outlet for pumping fluid from the fluid channel into the borehole, the fluid outlet being closed by a closure device arranged to open at a selected fluid overpressure in the fluid channel relative to a fluid
15 pressure in the borehole;

- characterized in that the additional fluid outlet has a flow area larger than each nozzle.

2. The shoe of claim 1, wherein the closure device includes a section of reduced wall thickness of the body, which section is arranged to shear off from the body upon
20 the fluid pressure in the fluid channel reaching the selected overpressure.

3. The shoe of claim 2, wherein the section of reduced wall thickness comprises a burst plate.

4. The shoe of any one of claims 1-3, wherein the fluid outlet has a flow area between about 2 to 3 square inch (12 to 20 cm²).

5. The shoe of any one of claims 1-4, wherein the total flow area of said at least one nozzle is less than 1 square
30 inch (6.5 cm²).

6. The shoe of any of claims 1-5, wherein the fluid channel is provided with a seat for receiving a plug for closing the fluid channel.

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7. The shoe of claim 6, wherein the fluid channel is provided with locking means for locking the plug in the fluid channel.

8. The shoe of claim 7, wherein the locking means comprises a recess formed in a selected one of the fluid channel and the plug, and wherein the other of the fluid channel and the plug is provided with a locking member arranged to snap into the recess upon the plug landing on the seat.

9. The shoe of claim 8, wherein the recess comprises an annular groove formed in the fluid channel, and wherein the locking member comprises a lock ring provided to the plug.

10. The shoe of any one of claims 6-9, wherein the body is provided with a chamber arranged to receive debris from the fluid channel, and wherein the plug is adapted to move the debris from the fluid channel into the chamber.

11. The shoe of any one of claims 1-10, wherein the body includes a flange provided with at least one radially extending rib, each rib being arranged to prevent rotation of the flange during drilling-out of the shoe in the borehole.

12. The shoe of any one of claims 1-11, wherein the body includes a reamer for reaming the borehole during lowering of the tubular element into the borehole.

13. The shoe of claim 12, wherein each nozzle is positioned at the reamer.

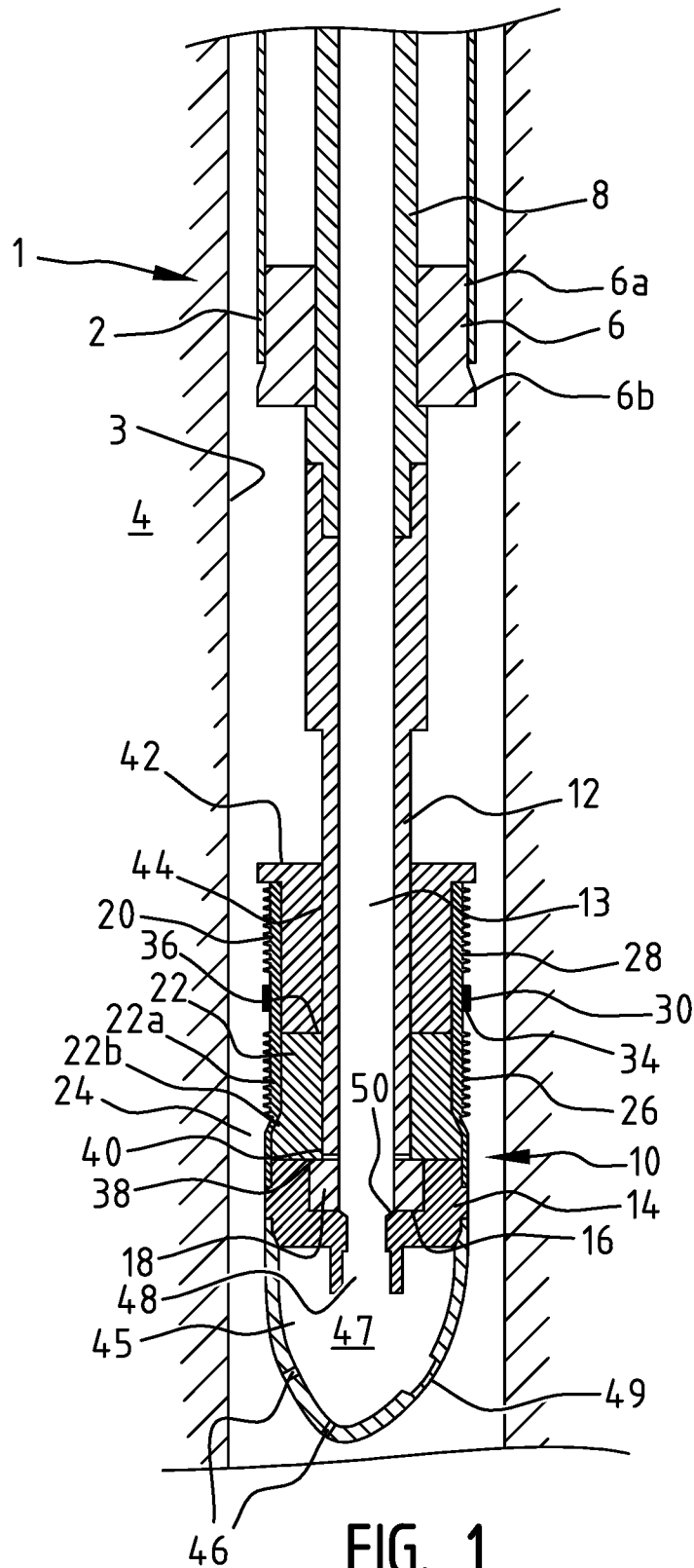
14. The shoe of claim 12 or 13, wherein the reamer has a nose section arranged eccentrically relative to a central longitudinal axis of the tubular element when the shoe is connected to the tubular element.

15. The shoe of any one of claims 12-14, wherein the reamer is provided with at least one cutter blade for cutting rock particles during reaming of the borehole, each

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cutter blade being arranged to prevent rotation of the reamer during drilling-out of the shoe in the borehole.

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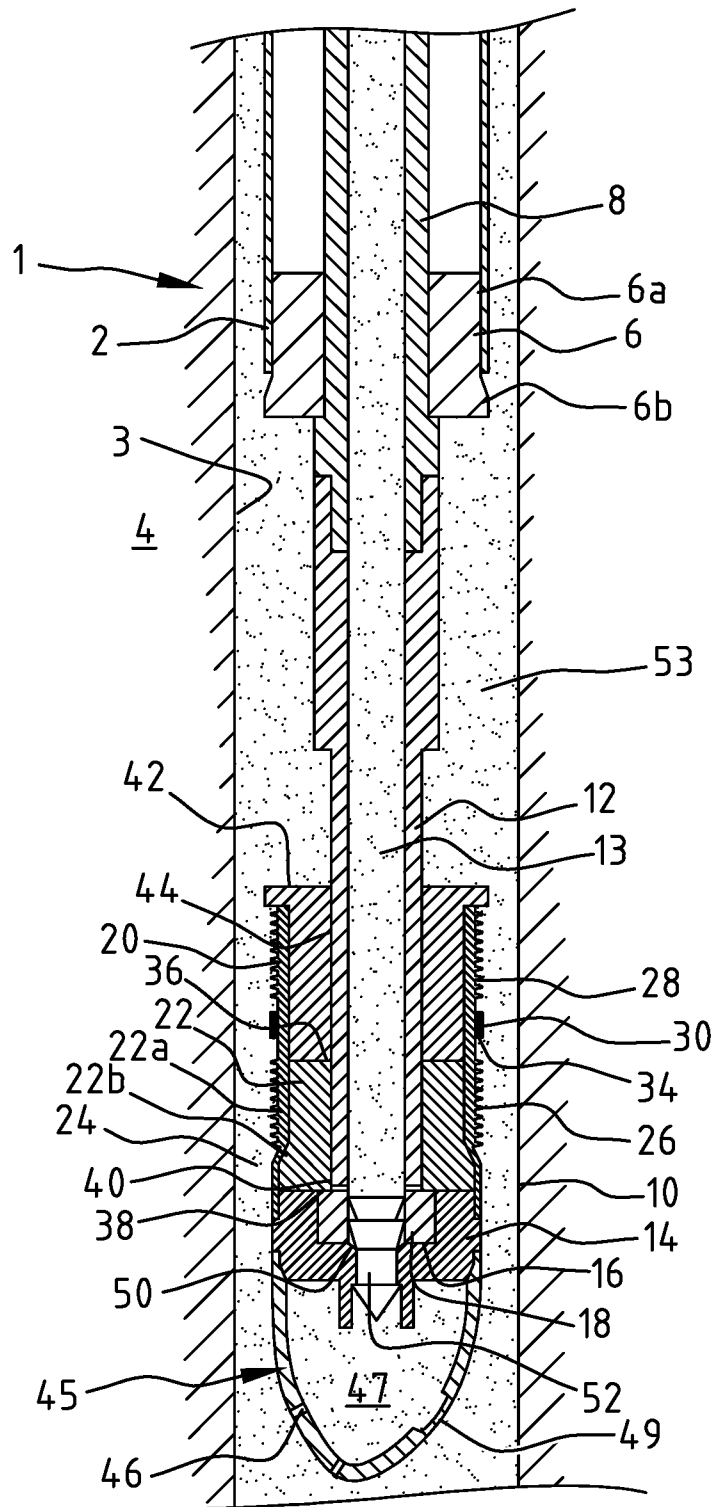


FIG. 2

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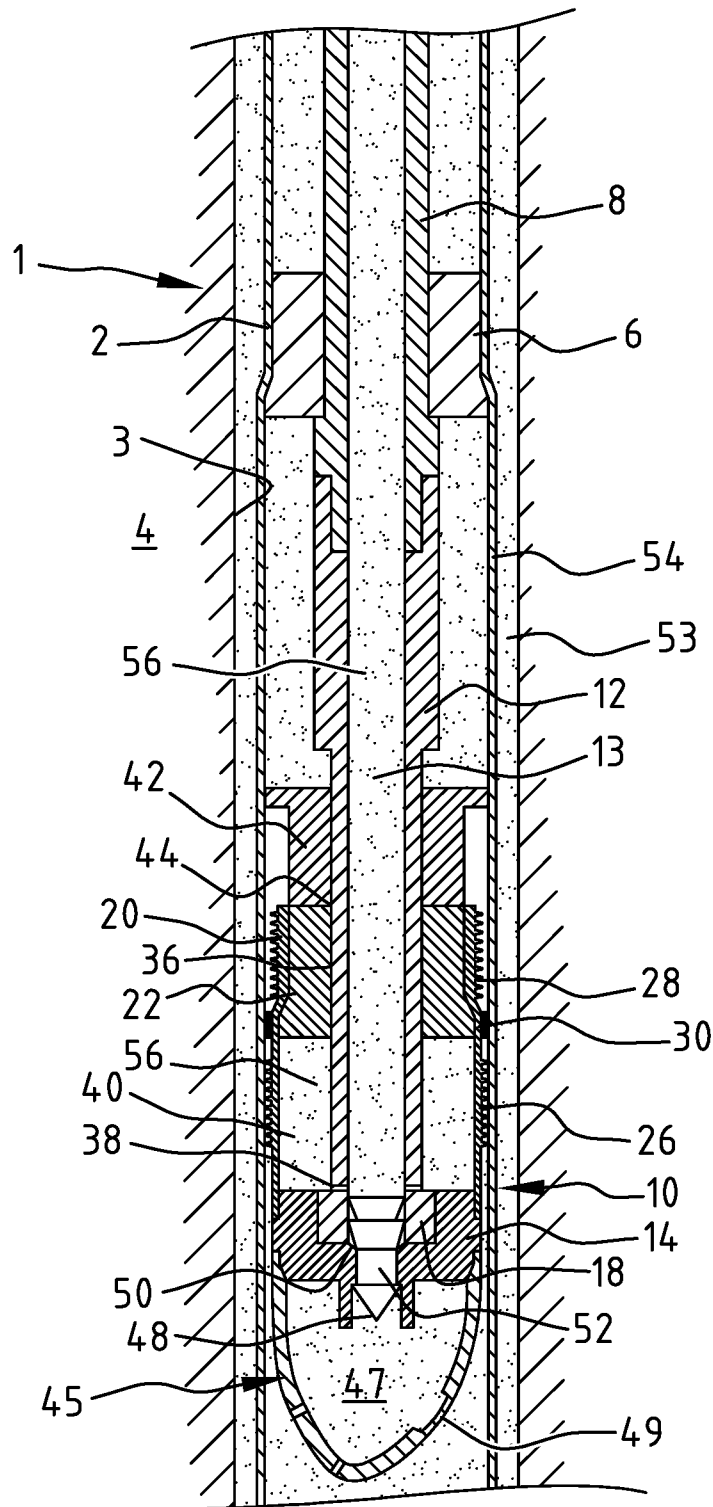


FIG. 3

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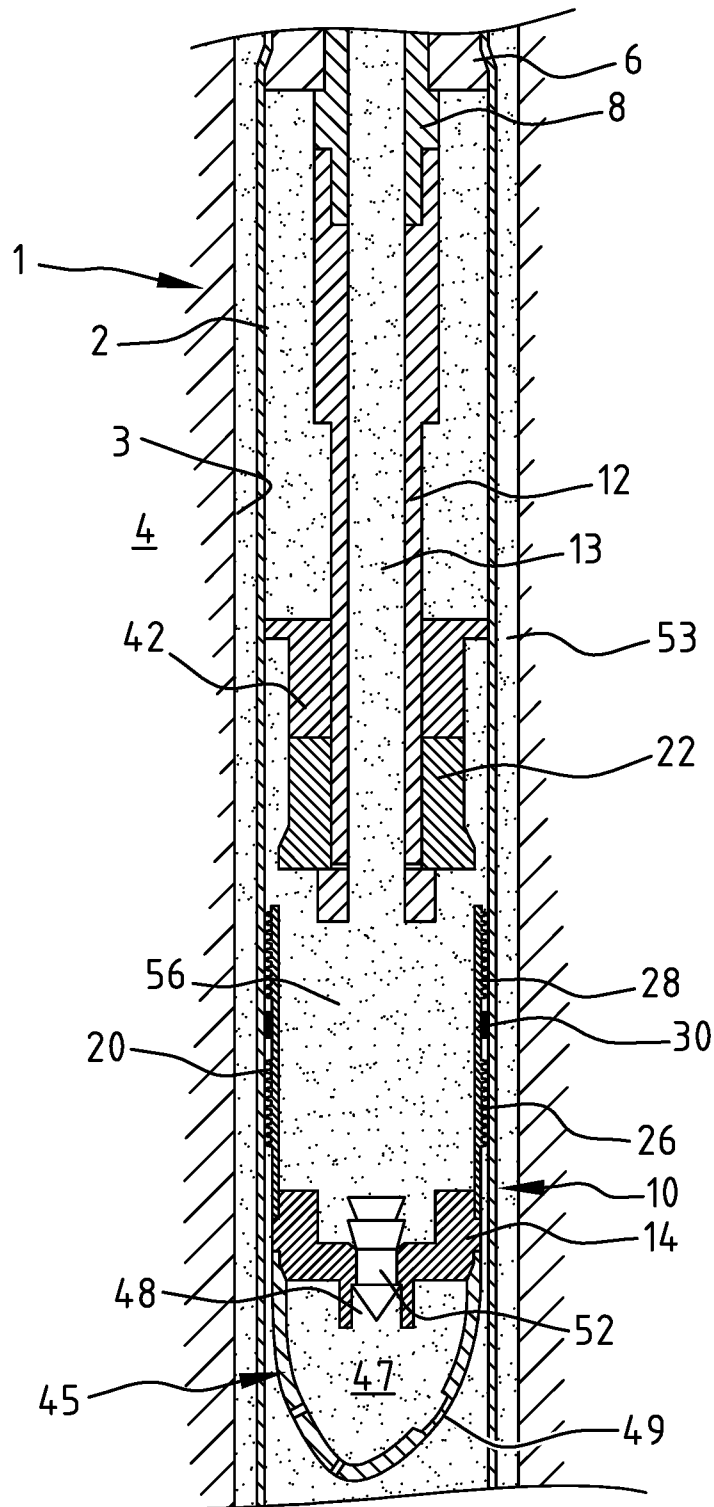


FIG. 4

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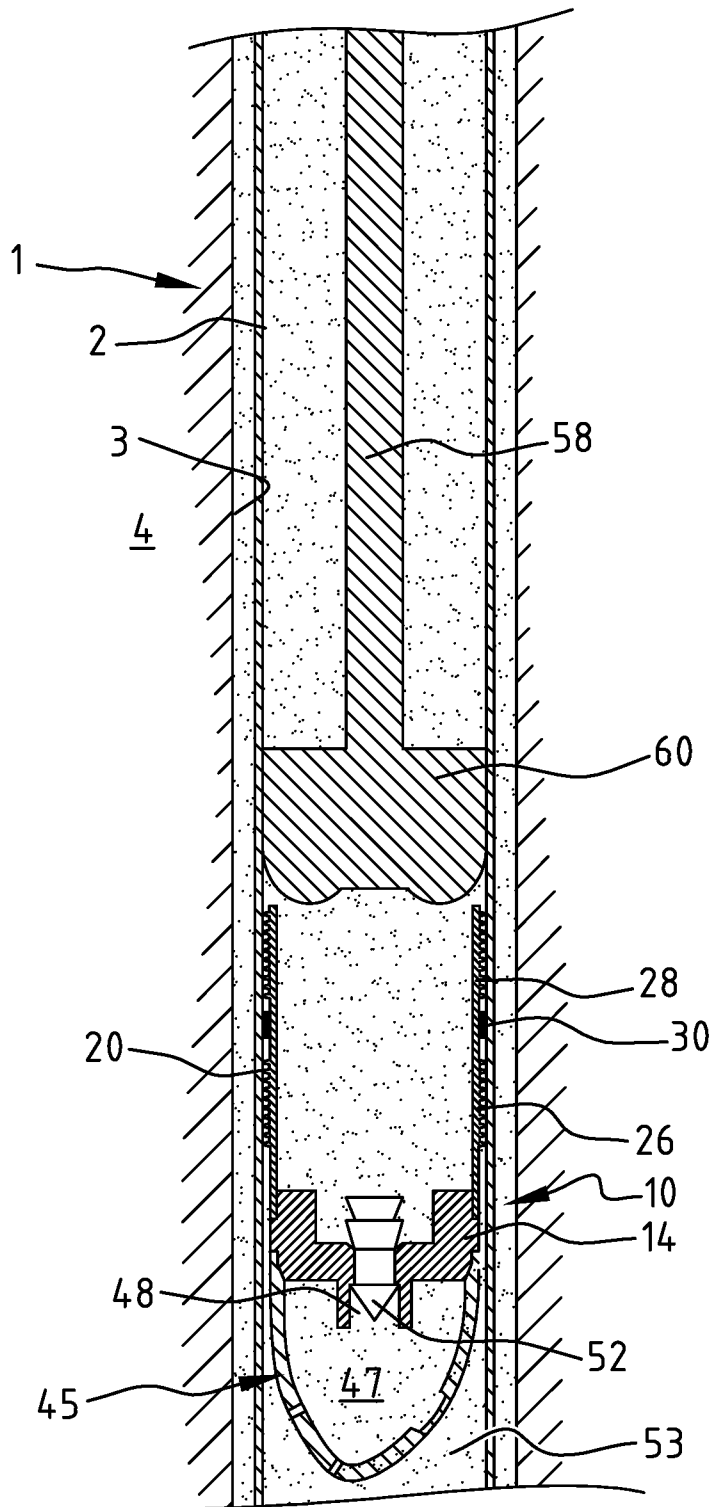
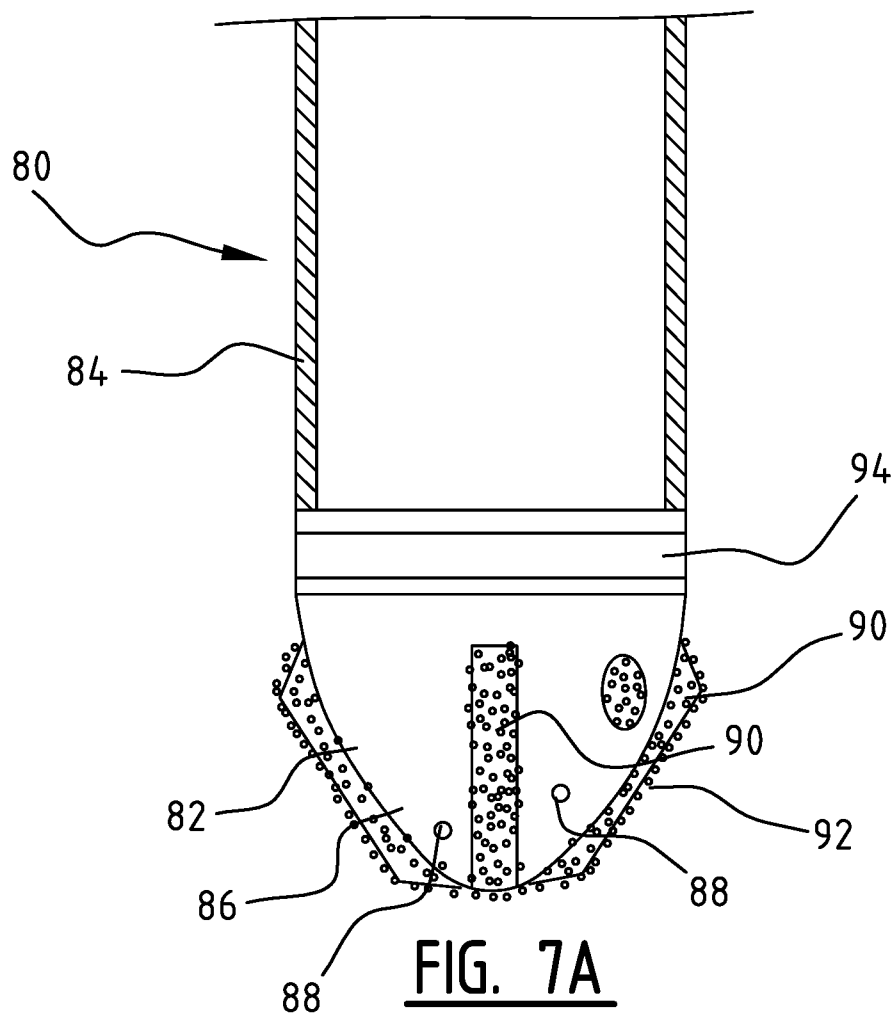
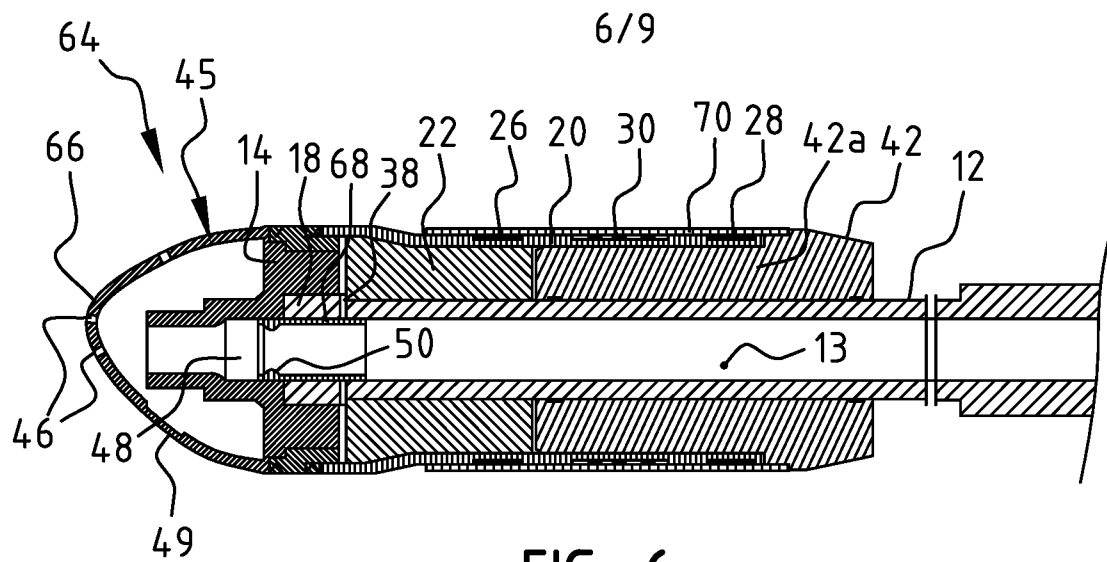


FIG. 5



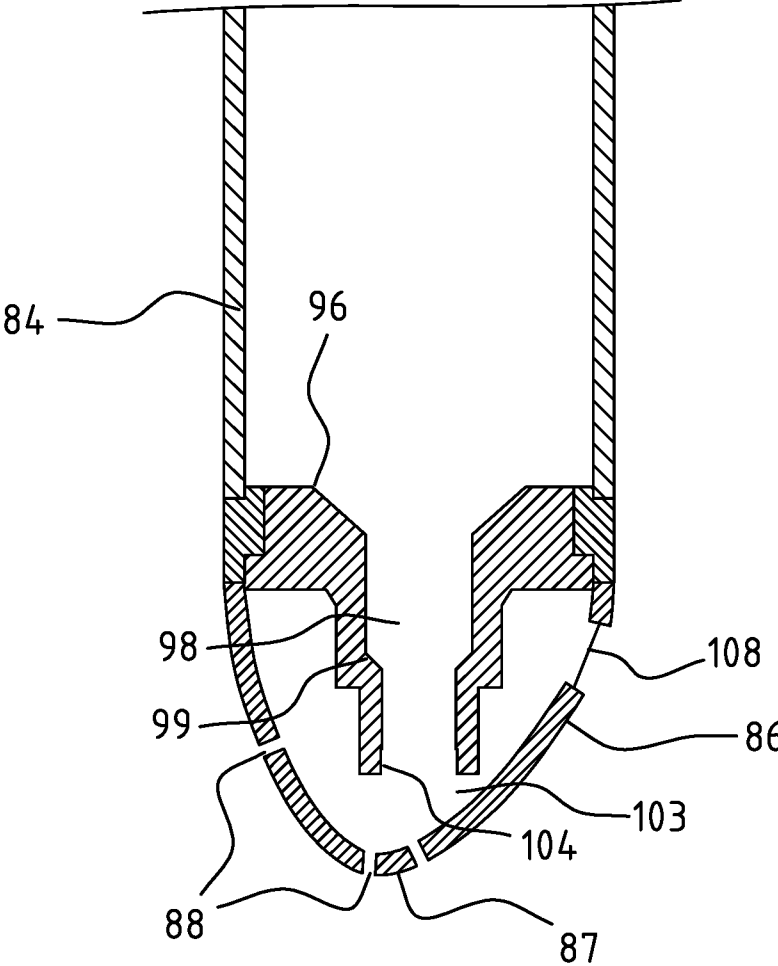
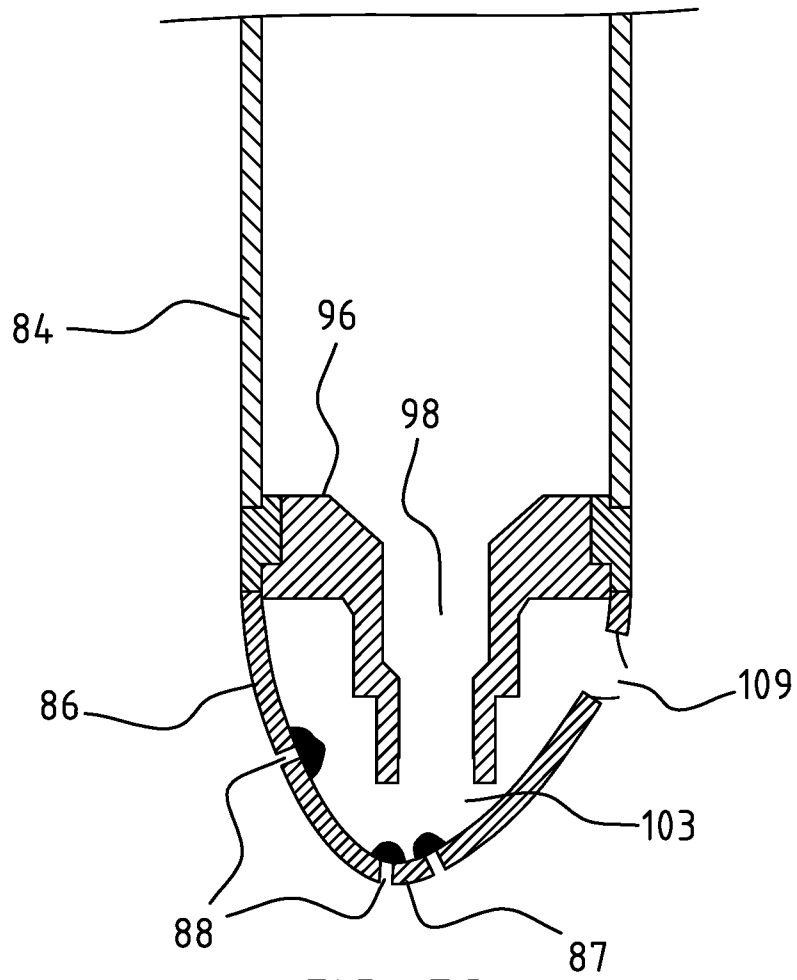


FIG. 7B

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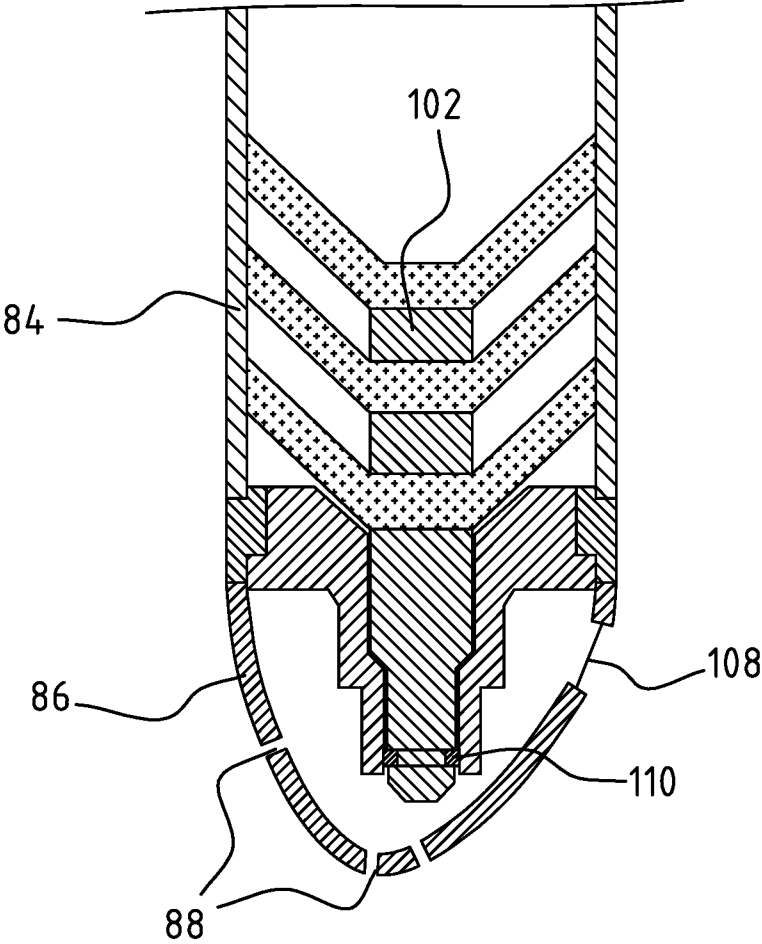


FIG. 7D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2015/064273

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
1-3, 6-10, 12, 13, 15
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/064273

A. CLASSIFICATION OF SUBJECT MATTER INV. E21B34/06 E21B10/26 E21B10/60 E21B17/14 E21B29/00 E21B33/12 ADD. According to International Patent Classification (IPC) or to both national classification and IPC														
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) E21B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data														
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category*</th> <th style="width: 70%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width: 20%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top;">X</td> <td>US 2010/252331 A1 (HIGH ANGELA D [US] ET AL) 7 October 2010 (2010-10-07) paragraphs [0024], [0029]; figure 1 -----</td> <td style="text-align: center; vertical-align: top;">1-3,12, 13,15</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>WO 01/83932 A1 (BBL DOWNHOLE TOOLS LTD [GB]; BAIN JAMES [GB]; HAITES BINNERT RUERD [GB]) 8 November 2001 (2001-11-08) page 6, lines 10-12, 21-26; figure 2 -----</td> <td style="text-align: center; vertical-align: top;">1-3,12, 13,15</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>US 2006/021801 A1 (HUGHES JOHN [CA] ET AL) 2 February 2006 (2006-02-02) figure 1A ----- -/-</td> <td style="text-align: center; vertical-align: top;">1-3,12, 13,15</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	US 2010/252331 A1 (HIGH ANGELA D [US] ET AL) 7 October 2010 (2010-10-07) paragraphs [0024], [0029]; figure 1 -----	1-3,12, 13,15	A	WO 01/83932 A1 (BBL DOWNHOLE TOOLS LTD [GB]; BAIN JAMES [GB]; HAITES BINNERT RUERD [GB]) 8 November 2001 (2001-11-08) page 6, lines 10-12, 21-26; figure 2 -----	1-3,12, 13,15	A	US 2006/021801 A1 (HUGHES JOHN [CA] ET AL) 2 February 2006 (2006-02-02) figure 1A ----- -/-	1-3,12, 13,15
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.												
X	US 2010/252331 A1 (HIGH ANGELA D [US] ET AL) 7 October 2010 (2010-10-07) paragraphs [0024], [0029]; figure 1 -----	1-3,12, 13,15												
A	WO 01/83932 A1 (BBL DOWNHOLE TOOLS LTD [GB]; BAIN JAMES [GB]; HAITES BINNERT RUERD [GB]) 8 November 2001 (2001-11-08) page 6, lines 10-12, 21-26; figure 2 -----	1-3,12, 13,15												
A	US 2006/021801 A1 (HUGHES JOHN [CA] ET AL) 2 February 2006 (2006-02-02) figure 1A ----- -/-	1-3,12, 13,15												
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.														
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family														
Date of the actual completion of the international search 17 November 2015		Date of mailing of the international search report 07/12/2015												
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Georgescu, Mihnea												

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/064273

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/127233 A2 (BAKER HUGHES INC [US]; MARVEL TIM KING [US]; MEINERS MATTHEW J [US]; E) 4 November 2010 (2010-11-04) page 3, lines 16-18, 22-25; figures 1C, 1D, 4 page 8, lines 22-25 page 17, lines 21-22, 27-29 page 18, lines 12-15 -----	1-3, 6-9
A	US 2006/185855 A1 (JORDAN JOHN C [US] ET AL) 24 August 2006 (2006-08-24) paragraphs [0038], [0053], [0054], [0056]; figures 2A, 2E, 4A -----	1-3, 6-10, 12, 13, 15
A	US 3 159 219 A (SCOTT LYLE B) 1 December 1964 (1964-12-01) figures 4, 5, 11-14 -----	1-3, 6-10, 12, 13, 15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/064273

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US 2010252331 A1	07-10-2010	GB 2480957 A US 2010252331 A1 WO 2010120567 A2	07-12-2011 07-10-2010 21-10-2010
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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 12, 13, 15

A shoe for a tubular element in a borehole extending into an earth formation, the shoe comprising: a body adapted to be connected to a downhole end of the tubular element, the body being provided with:

- a fluid channel;
- at least one nozzle for jetting fluid into the borehole, each nozzle being in fluid communication with the fluid channel, and
- an additional fluid outlet for pumping fluid from the fluid channel into the borehole, the fluid outlet being closed by a closure device arranged to open at a selected fluid overpressure in the fluid channel relative to a fluid pressure in the borehole;
- characterized in that the additional fluid outlet has a flow area larger than each nozzle.

2. claims: 4, 5

The shoe of claim 1, wherein (potential special technical feature of claim 4) the fluid outlet has a flow area between about 2 to 3 square inch (12 to 20cm²).

Technical problem: how to optimise the flow according to the purpose.

3. claims: 6-10

The shoe of claim 1, wherein (potential special technical feature of claim 6) the fluid channel is provided with a seat for receiving a plug for closing the fluid channel. Technical problem: how to prevent flow.

4. claim: 11

The shoe of claim 1, wherein (potential special technical feature of claim 11) the body includes a flange provided with at least one radially extending rib, each rib being arranged to prevent rotation of the flange during drilling-out of the shoe in the borehole.

Technical problem: how to improve the removal of the shoe.

5. claim: 14

The shoe of claim 12 or 13, wherein (potential special technical feature of claim 14) the reamer has a nose section arranged eccentrically relative to a central longitudinal axis of the tubular element when the shoe is connected to

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

the tubular element.

Technical problem: how enlarge the bore during the advancing of the tubular.
