(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 March 2012 (22.03.2012)

PCT

(10) International Publication Number
WO 2012/036774 A1

(51) International Patent Classification:
*E21B 34/06* (2006.01) *E21B 34/14* (2006.01)

(21) International Application Number:
PCT/US2011/043039

(22) International Filing Date:
6 July 2011 (06.07.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/880,853 13 September 2010 (13.09.2010) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Declarations under Rule 4.17:**

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

**Published:**

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) **Title**: BALL-SEAT APPARATUS AND METHOD

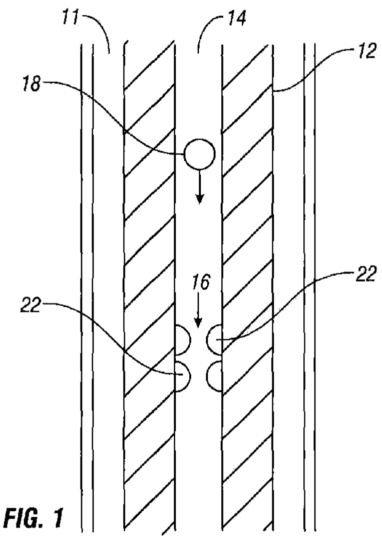


*FIG. 1*

(57) **Abstract**: An apparatus for restricting fluid flow includes: a ball receiving element disposed in a fluid conduit and configured to receive a ball that has been advanced through the fluid conduit and at least partially restrict fluid flow, the fluid conduit having a longitudinal axis; and at least one feature disposed at the fluid conduit and configured to at least one of reduce a rate of deceleration of the ball due to actuation of the apparatus and reduce pressure waves generated by an impact between the ball and the ball receiving element.

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# BALL-SEAT APPARATUS AND METHOD

## CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Application No. 12/880,853, filed on September 13, 2010, which is incorporated herein by reference in its entirety.

## BACKGROUND

[0001] In the drilling and completion industry and for example in hydrocarbon exploration and recovery operations, a variety of components and tools are lowered into a borehole for various operations such as production operations, for example. Some downhole tools utilize ball-seat assemblies to act as a valve or actuator. Ball-seat assemblies are used with, for example, hydraulic disconnects, circulating subs and inflatable packers.

[0002] Actuation of a ball-seat assembly generally includes releasing a ball or other plug into a fluid conduit and allowing the ball to drop or be pumped onto the ball seat and restrict fluid flow therein. The impact between the ball and the ball seat can produce pressure waves, which can cause wear and/or damage to components of the assembly, vibrations and tubing failure. For example, fluid in downhole applications can be pumped at rates of up to about 80 bbl/min, which can cause an enormous pressure surge upon impact of a plug or ball on a seat, which causes wear and potential damage to downhole components.

## SUMMARY

[0003] An apparatus for restricting fluid flow includes: a ball receiving element disposed in a fluid conduit and configured to receive a ball that has been advanced through the fluid conduit and at least partially restrict fluid flow, the fluid conduit having a longitudinal axis; and at least one feature disposed at the fluid conduit and configured to at least one of reduce a rate of deceleration of the ball due to actuation of the apparatus and reduce pressure waves generated by an impact between the ball and the ball receiving element.

[0004] A method of restricting fluid flow includes: releasing a ball into a fluid conduit and receiving the ball in a ball receiving element disposed at the fluid conduit and at least partially restricting fluid flow, the fluid conduit having a longitudinal axis; and at least one of reducing a rate of deceleration of the ball due to actuation of the apparatus and reducing pressure waves generated by an impact between the ball and the ball receiving element by at least one feature disposed at the fluid conduit.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0006] FIG. 1 is a cross-sectional view of an embodiment of a ball-seat assembly;

[0007] FIG. 2 is a partial cross-sectional view of an embodiment of the ball-seat assembly of FIG. 1;

[0008] FIG. 3 is a perspective view of another embodiment of the ball-seat assembly of FIG. 1; and

[0009] FIG. 4 is a flow diagram depicting a method of restricting fluid flow in a conduit.

## DETAILED DESCRIPTION

[0010] The apparatuses, systems and methods described herein provide for the reduction of a ball-seat impact and the mitigation of pressure waves caused by actuation of a ball-seat assembly. A ball seat assembly includes a ball receiving element such as a ball seat. The ball seat includes a plurality of axially offset ball seat assemblies or seating components disposed at a fluid conduit and protruding at least partially into the fluid conduit. In one embodiment, each seating component has a cross-sectional shape that is contoured to create one or more fluid passageways when a ball contacts the seating component. The contoured seating components may be circumferentially offset so that a portion of the fluid in the conduit flows through the ball seat as the ball contacts each seating component. In one embodiment, one or more of the seating components is axially contoured and/or compliant to reduce the impact of the ball on each component and control the reduction in velocity resulting from contact with each seating component. The configuration of the seating components acts to incrementally slow the ball as it engages the ball seat and may also incrementally reduce fluid flow as the ball is seated to reduce impact on the ball seat assembly and reduce pressure waves resulting from the ball-seat impact.

[0011] Referring to FIG. 1, a downhole tool 10, such as a ball seat sub, configured to be disposed in a borehole 11, includes a housing 12 having a longitudinal bore or fluid conduit 14. A ball seat assembly includes a ball seat 16 included in the conduit 14 to retain a ball 18 that is released into the conduit 14. In one embodiment, the ball 18 is a spherical metal or plastic plug, although "ball" may refer to any type of moveable or droppable plugging element, such as a drop plug, and may take any desired shape or size. Actuation of the ball seat assembly includes releasing the ball into the fluid conduit 14, for example by dropping the ball 18 into and/or pumping the ball 18 through the fluid conduit 14 from a surface or downhole location. The ball 18 falls and/or is advanced by downhole fluid toward the ball seat 16 and is seated on the ball seat 16 to restrict fluid flow through the conduit 14. As described herein, "axial" refers to a direction that is at least generally parallel to a central longitudinal axis of the conduit 14. "Radial" refers to a direction along a line that is orthogonal to the longitudinal axis and extends from the longitudinal axis. As described herein, "downstream" refers to the direction of movement of the ball and/or the downhole fluid, and "upstream" refers to a direction opposite the direction of movement of the ball and/or the downhole fluid.

[0012] Referring to FIG. 2, the ball seat 16 includes a plurality of axially offset seating members or seating components 22 disposed at the conduit 14 and protruding radially into the conduit 14. The plurality of seating components 22 include one or more upstream seating components, such as seating component 24, axially disposed relative to a downstream seating component, such as seating component 26, to create an axial contouring that reduces the overall deceleration of the ball 18 and brings the ball 18 to a relatively gentle stop. This in turn reduces the amplitude of pressure waves due to an incremental or fractional change in velocity of the ball 18. The reduction in amplitude reduces impact loading between the ball 18 and the ball seat 16, which reduces pressure waves, wear on the ball seat assembly and the potential for damage to the ball seat assembly. In one embodiment, the ball seat 16 and/or seating components 22 are directly disposed on and/or attached to the inner surface of the conduit 14 or is formed from a reduced diameter portion of the conduit 14. In one embodiment, the ball seat 16 is disposed on or is part of a movable component such as a sliding sleeve or other movable seat carrier 20 for use, for example, as an actuator or valve.

[0013] The plurality of seating components 22 reduces the total rate of deceleration and increases the time rate of ball seat assembly closure during actuation of the ball seat assembly. Seating loads can thereby be reduced as they depend on the time rate of velocity change. In one embodiment, the ball 18 is slowed in several increments, defined by the initial velocity of the ball 18, the resistance to movement of the seating components 22, and the axial as well as any radial offset between the components. The number of increments can be represented by:

$$\Delta v = \Sigma \Delta v_i,$$

where "$\Delta v$" is the total change in velocity, and "$\Delta v_i$" is the change in velocity for each incremental closure "i" of the flow passage. Each closure may correspond to one or more seating components 22 contacting the ball 18. Since the ball impact load and the surge pressures are proportional to change in velocity, the loading occurs in this embodiment in small increments, resulting in smaller pressure waves, instead of the total loading being applied all at once.

[0014] In one embodiment, at least one seating component 22 has a cross-sectional profile, i.e., a profile in a plane at least partially orthogonal to the longitudinal axis of the conduit 14, so that contact between the ball 18 and the seating component only partially stops fluid flow as the ball 18 moves downstream. In one embodiment, one or more of the seating components 22 has a cross sectional shape configured to form one or more conduits, or passageways upon contact with the ball 18. The passageways are configured to allow fluid flow therethrough when the ball is in contact with a respective seating component 22. In this way, as the ball 18 contacts each seating component 22, fluid voids are formed that allow a portion of the fluid to pass through, thereby disrupting or otherwise reducing the effect of pressure waves produced during ball-seat impact.

[0015] For example, as shown in FIG 3, seating components 24 and 26 each include a plurality of circumferentially arrayed protrusions or members extending into the conduit 14. The separation between adjacent members forms a fluid void formed when the ball 18 contacts each assembly.

[0016] In one embodiment, as shown in FIG. 3, the assemblies 24 and 26 are circumferentially offset so that contact with the upstream seating component 24 forms a fluid void, and as the ball 18 advances further along the ball seat 16 and contacts the downstream component 26, the fluid voids may be closed to fully cut off fluid flow through the ball seat 16. The fluid voids in each seating component 24, 26 are circumferentially offset or otherwise arranged relative to other seating components so that in each successive contact closure the flow velocity and volume reduces fractionally rather than all at once.

[0017] In one embodiment, the ball seat 16 includes at least one additional seating component 28 axially offset at least one of the other seating components 24, 26. Each component 24, 26 and 28 is sequentially contacted by the ball 18 during actuation, and the ball 18 is thus incrementally slowed until it comes to a stop and is seated. In one embodiment, each seating component is circumferentially offset from an axially adjacent seating component, so that the fluid voids formed become incrementally smaller as the ball 18 advances through the ball seat 16. In one embodiment, the ball 18 has a circumference sufficient so that the ball 18 remains in contact with each seating component 22 as it advances through the ball seat 16. In one embodiment, the seating components are circumferentially offset so that when the ball 18 comes to a rest and is seated, the ball 18 is in continuous circumferential contact with the seating components 22 so that fluid flow is completely cut off.

[0018] Each successive seating component can be configured to control the incremental reduction in velocity of the ball 18. For example, each seating component 22 may have a selected resistance to movement that causes the ball 18 to reduce its velocity by a desired amount. “Resistance to movement” may include a stiffness, compliance or elasticity of each component or constituent member, a mechanical resistance generated by a spring or other device, or an axial shape of the seating component. In one example, a seating component 22 may include an internal spring. In another example, a seating component 22 may have a selected axial contour, such as a gradual increase in radial extension as the seating component (e.g., an elliptical shape as shown in FIGS. 1-3) extends axially downstream. The resistance to movement and/or contour may be selected so that the seating components 22 have the same or varying resistances to movement to control the incremental velocity changes. The reduction of velocity may depend on the geometrical profiles of the seating components 22 and the ball 18 (or other plugging device), the axial and angular spacing of the seating components 22, the load-deformation behavior of the contacting bodies, and/or fluid flow rates.

[0019] The seating components 22 are not limited to the embodiments described herein, and may take any shape or configuration suitable for gradually or incrementally slowing the ball as it engages the ball seat 16. Examples of such configurations include a ring-shaped or toroidal elastic seat disposed on an interior surface, resilient flaps, and resistant mechanisms such as spring loaded and/or articulated member that protrude into the conduit 14 and having a selected resistance to movement. In other embodiments, the seating components may be formed from an axial contour or shape of a single seating component.

[0020] The downhole tool 10 is not limited to that described herein. The downhole tool 10 may include any tool, carrier or component that includes a ball seat assembly. The carriers described herein, such as a production string and a screen, are not limited to the specific embodiments disclosed herein. A "carrier" as described herein means any device, device component, combination of devices, media and/or member that may be used to convey, house, support or otherwise facilitate the use of another device, device component, combination of devices, media and/or member. Exemplary non-limiting carriers include borehole strings of the coiled tube type, of the jointed pipe type and any combination or portion thereof. Other carrier examples include casing pipes, wirelines, wireline sondes, slickline sondes, drop shots, downhole subs, bottom-hole assemblies, and drill strings. In addition, the tool 10 is not limited to components configured for downhole use.

[0021] FIG. 4 illustrates a method 40 of restricting fluid flow in a component. The method includes, for example, actuating a valve or packer in a downhole assembly. The method 40 includes one or more stages 41-43. Although the method is described in conjunction with the tool 10 and the ball seat 16, the method can be utilized in conjunction with any device or system (configured for downhole or surface use) that utilizes a ball-seat assembly.

[0022] In the first stage 41, in one embodiment, the tool 10 is disposed at a downhole location, via for example a borehole string or wireline. In the second stage 42, the ball-seat assembly is actuated by releasing the ball 18 into the conduit 14, for example by dropping the ball 18 into the conduit 14 and/or pumping the ball 18 through the conduit 14. The ball 18 advances through the conduit 14 and engages the ball seat 16. In the third stage 43, the ball 18 is incrementally slowed by the seating components 24, 26 and/or 28. Upon contact with the most downstream seating component (e.g., seating component 26 or 28), the ball 18 comes to a stop, and fluid flow is completely cut off or reduced by a selected amount.

[0023] The systems and methods described herein provide various advantages over existing processing methods and devices. The systems and methods result in a more gradual reduction in impact velocity versus instantaneous arrest and reduces pressure waves formed by ball-seat impact. This in turn reduces damage to the ball seat assembly and improves reliability, and can enable the use of a wider range of construction materials and reduce the complexity of ball-seat design, for example by reducing the need for relatively complex ball seat designs to reduce impact. Reduced pressure wave loading can also reduce the burst or collapse loading on downhole tubing. Furthermore, the apparatuses described herein provide an alternative lower complexity design relative to prior art applications such as embedded springs.

[0024] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention.

CLAIMS

1. An apparatus for restricting fluid flow, comprising:

a ball receiving element disposed in a fluid conduit and configured to receive a ball that has been advanced through the fluid conduit and at least partially restrict fluid flow, the fluid conduit having a longitudinal axis; and

at least one feature disposed at the fluid conduit and configured to at least one of reduce a rate of deceleration of the ball due to actuation of the apparatus and reduce pressure waves generated by an impact between the ball and the ball receiving element.

2. The apparatus of claim 1, wherein the at least one feature is included in the ball receiving element, and the at least one feature includes:

at least one first seating component disposed at the conduit and protruding radially into the conduit, the at least one first seating component configured to contact the ball and reduce a velocity of the ball; and

a second seating component protruding radially into the conduit and disposed at a downstream location relative to the first seating assembly, the second seating assembly configured to prevent downstream movement of the ball.

3. The apparatus of claim 2, wherein the at least one first seating component has a cross-sectional shape configured to form one or more first fluid passageways therethrough upon contact with the ball.

4. The apparatus of claim 3, wherein the at least one first seating component includes a plurality of axially successive circumferentially offset seating components.

5. The apparatus of claim 4, wherein respective fluid passageways in each of the plurality of seating components are offset from one another so that a total cross-sectional area of the fluid passageways successively decreases as the ball advances through the ball receiving element.

6. The apparatus of claim 3, wherein the second seating component has a cross-sectional shape configured to form one or more second fluid passageways therethrough upon contact with the ball, and the second fluid passageways are circumferentially offset relative to the one or more first fluid passageways.

7. The apparatus of claim 6, wherein the ball forms a complete fluid seal with the first and second seating components when seated.

8. The apparatus of claim 3, wherein the at least one first seating component includes a plurality of first axially tapered members, each first axially tapered member

arranged circumferentially and forming a first fluid passage with an adjacent first tapered member.

9. The apparatus of claim 8, wherein the second seating component includes a plurality of second axially tapered members circumferentially offset relative to the plurality of first members, each second axially tapered member arranged circumferentially and forming a second fluid passage with an adjacent second tapered member.

10. The apparatus of claim 2, wherein each of the first and second seating components have an axial contour that increases gradually in the downstream direction.

11. The apparatus of claim 2, wherein each of the at least one first seating component and the second seating component include at least one of a selected resistance to movement and axial contour configured to reduce a velocity of the ball by a selected amount upon contact with the ball.

12. The apparatus of claim 11, wherein at least one of the resistance to movement and the axial contour of the second seating component is sufficient to stop the ball after contact with the first seating component.

13. A method of restricting fluid flow, comprising:

releasing a ball into a fluid conduit and receiving the ball in a ball receiving element disposed at the fluid conduit and at least partially restricting fluid flow, the fluid conduit having a longitudinal axis; and

at least one of reducing a rate of deceleration of the ball due to actuation of the apparatus and reducing pressure waves generated by an impact between the ball and the ball receiving element by at least one feature disposed at the fluid conduit.

14. The method of claim 13, wherein the at least one feature is included in the ball receiving element, and the at least one feature includes:

at least one first seating component disposed at the conduit and protruding radially into the conduit, the at least one first seating component configured to contact the ball and reduce a velocity of the ball; and

a second seating component protruding radially into the conduit and disposed at a downstream location relative to the first seating component, the second seating component configured to prevent downstream movement of the ball.

15. The method of claim 14, further comprising reducing a velocity of the ball in successive increments by successively contacting the first seating component and the second seating component by the ball as the ball engages the ball receiving element.

16. The method of claim 14, wherein the at least one first seating component has a cross-sectional shape configured to form one or more first fluid passageways therethrough upon contact with the ball.

17. The method of claim 16, further comprising reducing a fluid flow through the ball seat in successive increments by successively contacting the first seating component and the second seating component by the ball as the ball engages the ball receiving element.

18. The method of claim 17, wherein the ball forms a complete fluid seal with the first and second seating components when seated.

19. The method of claim 16, wherein the at least one first seating component includes a plurality of axially successive circumferentially offset seating components, and respective fluid passageways in each of the plurality of seating components are offset from one another so that a total cross-sectional area of the respective fluid passageways successively decreases as the ball advances through the ball receiving element.

20. The method of claim 16, wherein the second seating component has a cross-sectional shape configured to form one or more second fluid passageways therethrough upon contact with the ball, and the one or more second fluid passageways are circumferentially offset relative to the one or more first fluid passageways.

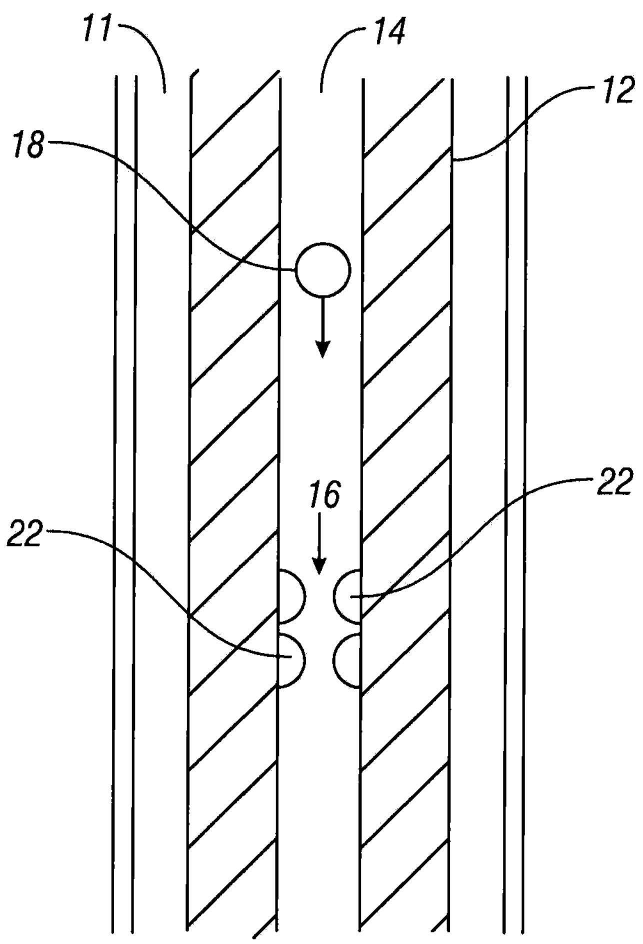


FIG. 1

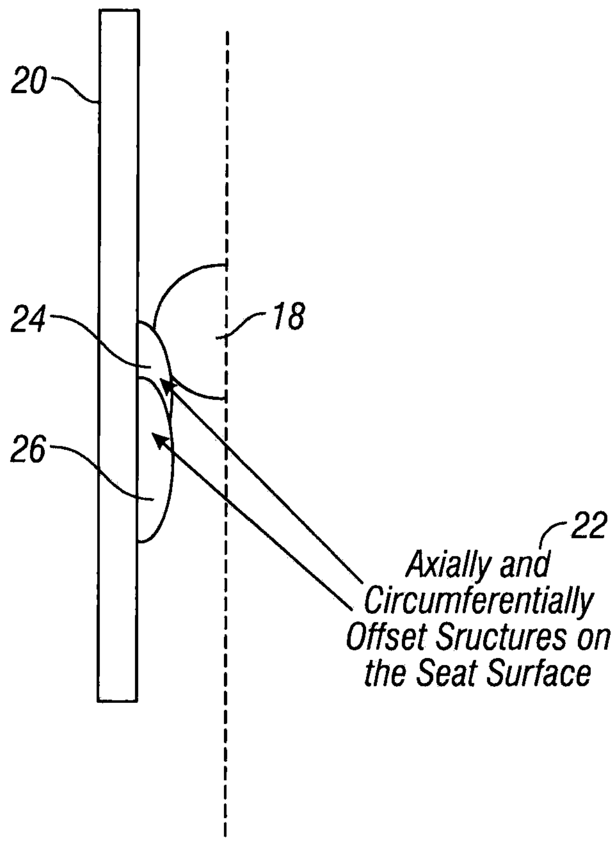
20
24
26
18
22
Axially and
Circumferentially
Offset Sructures on
the Seat Surface

FIG. 2

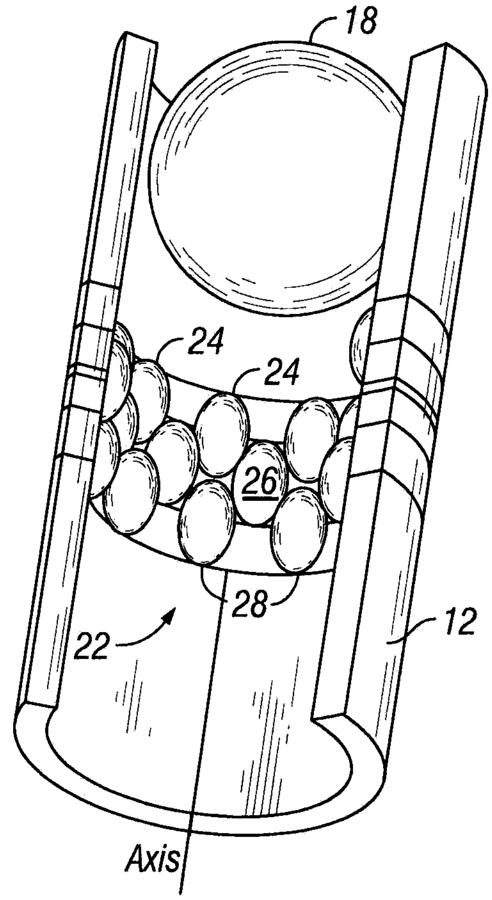
18
24
24
26
28
22
12
Axis

FIG. 3

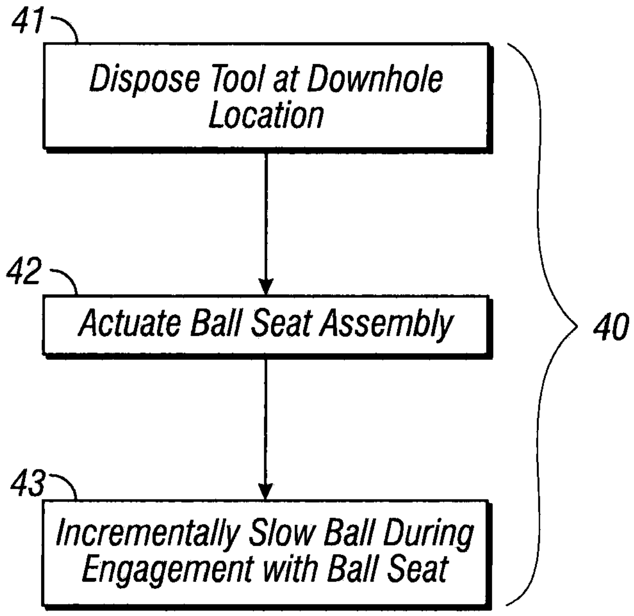
41
Dispose Tool at Downhole Location
42
Actuate Ball Seat Assembly
43
Incrementally Slow Ball During Engagement with Ball Seat
40

FIG. 4

**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/US2011/043039**

**A. CLASSIFICATION OF SUBJECT MATTER**

***E21B 34/06(2006.01)i, E21B 34/14(2006.01)i***

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 34/06; E21B 33/12; E21B 34/14; E21B 36/00; E21B 34/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: ball, dart, plug, spheric, drop, release, discharge, passage, internal, path, seat, receive, protrusion, pressure wave, impact, shock, deceleration, reduce, decrease, absorb, restrict, flow, fluid

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| A | US 2009-0044948 A1 (AVANT MARCUS A. et al.) 19 February 2009<br>See abstract, paragraphs 27,29,31 and figures 1,2 | 1-20 |

☐ 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
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"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 | Date of mailing of the international search report |
|---|---|
| 22 FEBRUARY 2012 (22.02.2012) | **23 FEBRUARY 2012 (23.02.2012)** |

| Name and mailing address of the ISA/KR | Authorized officer |
|---|---|
| Korean Intellectual Property Office<br>Government Complex-Daejeon, 189 Cheongsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea<br>Facsimile No. 82-42-472-7140 | BAHNG, Seung Hoon<br>Telephone No. 82-42-481-8444 |

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