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(54) Title: DOWNHOLE TOOL AND METHOD OF FORMING THE SAME

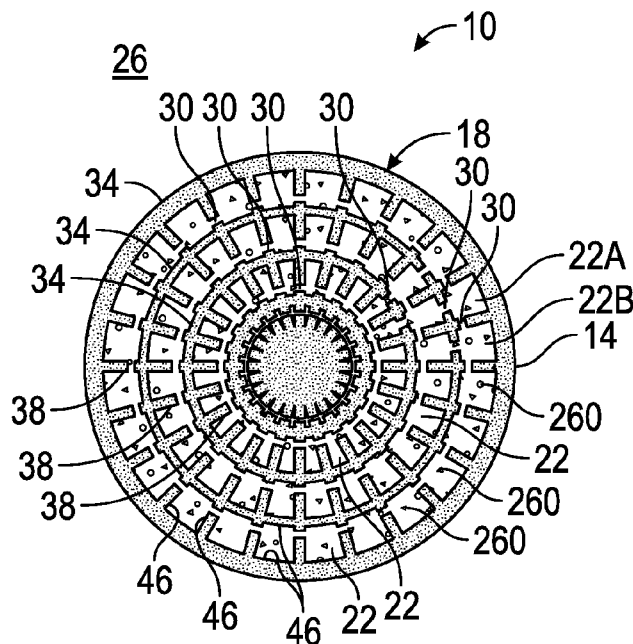


FIG. 2

(57) Abstract: A downhole tool, including at least one body defining a surface, the at least one body having a plurality of cavities sealed from an outside of the at least one body by the surface. A plurality of the plurality of cavities being in fluidic communication with others of the plurality of cavities through a plurality of openings. A method of forming a downhole tool.





SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG). **Published:**

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Declarations under Rule 4.17:

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

DOWNHOLE TOOL AND METHOD OF FORMING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Application No. 14/639581, filed on March 5, 2015, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Tools employed in fluidic systems have various characteristics that affect how well suited they are for the specific applications in which they are employed. Control of effective density of a tool may be important in one application while flexibility and sealing integrity thereof might be of importance in another application. Many different manufacturing techniques have been developed to fabricate tools. Each technique has advantages over some techniques while having disadvantages when compared to others. Which manufacturing technique is used to make a particular tool is often selected based on the desired final characteristics that the tool needs to have. Industry is therefore receptive to new tool designs and new manufacturing techniques that may have advantages to those currently available.

BRIEF DESCRIPTION

[0003] Disclosed herein is a downhole tool. The downhole tool includes at least one body defining a surface, the at least one body having a plurality of cavities sealed from an outside of the at least one body by the surface, and a plurality of the plurality of cavities being in fluidic communication with others of the plurality of cavities through a plurality of openings.

[0004] Further disclosed herein is a method of forming a downhole tool. The method includes creating a three-dimensional computer model of the downhole tool of the foregoing paragraph, and forming the downhole tool with an additive manufacturing process from the three-dimensional computer model.

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 depicts a side view of a downhole tool disclosed herein;

[0007] FIG. 2 depicts a cross sectional view of the downhole tool of FIG. 1 taken at arrows 2-2;

[0008] FIG. 3 depicts a cross sectional view of the downhole tool of FIG. 1 taken at arrows 3-3;

[0009] FIG. 4 depicts a cross sectional view of another embodiment of a downhole tool disclosed herein;

[0010] FIG. 5 depicts a partial cross sectional view of a valve incorporating a downhole tool disclosed herein;

[0011] FIG. 6 depicts another partial cross sectional view of the valve of FIG. 5;

[0012] FIG. 7 depicts a magnified view of a portion of the valve of FIG. 5; and

[0013] FIG. 8 depicts another magnified view of a portion of the valve of FIG. 5.

DETAILED DESCRIPTION

[0014] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0015] Figures 1-3 illustrate an embodiment of a downhole tool disclosed herein at 10. The downhole tool 10 includes, at least one body 14 defining a surface 18 with a plurality of cavities 22 sealed from an outside 26 of the at least one body 14 by the surface 18. A plurality of the cavities 22 being in fluidic communication with others of the plurality of cavities 22 through a plurality of openings 30. The geometry of the downhole tool 10 is such that it is only formable from an additive manufacturing process. Additive manufacturing as referred to herein is defined by the industry standard term (ASTM F2792) for all applications of the technology. It is defined as the process of joining materials to make objects from three-dimensional (computer) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms include additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.

[0016] In this illustrated embodiment the body 14 is a single element and has the shape of a sphere, or ball although any shaped object could be employed in other embodiments. The body 14 can act as a plug when run in a tubular against a seat (not shown) positioned within the tubular, for example. The body 14 includes a plurality of spherical shells 34 that are concentric to one another as best shown in Figure 2. The surface 18 is defined by the outer portion of the outermost shell 34. Each of the shells 34 is connected to

other of the shells 34 radially adjacent thereto by webs 38. Depending upon the orientation where a section view is taken the webs 38 may be a planar surface 42 like the one shown in Figure 3 that is taken at arrows 3-3 in Figure 1. The planar surface 42 shows a plurality of the openings 30 formed therein that fluidically connect cavities 22A and 22B on opposing sides of the planar surface 42.

[0017] The effective density of the downhole tool 10, that is the mass of the tool 10 divided by the volume of the tool 10, is controllable by the design of the tool 10. For example, by selecting more and larger of the cavities 22, with thinner webs 38 for a given material and size of the body 14 the effective density of the tool 10 can be reduced. In contrast, by selecting fewer and smaller of the cavities 22 with thicker webs 38 for a given material and size of the body 14 the effective density of the tool 10 can be made greater. In other words the effective density of the tool is selected by adjusting a ratio of volume of the material of the body 14 to that of the cavities 22. Alternately, by just changing the material that the body 14 is made of the effective density of the body 14 can be altered without changing any other parameter. Additionally, two or more materials can be employed during the fabrication of the body 14. By selecting the two or more materials having different densities and adjusting proportions of the body 14 made by each of the two or more materials the effective density can be controlled even further. Possible materials for use in constructing the body 14 include polymer, metal, ceramic or combinations of two or more of the foregoing. Controlling the effective density of the body 14 can be desirable in some applications. For example, in an earth formation borehole application such as in the hydrocarbon recovery or the carbon dioxide sequestration industries altering the effective density of a body 14 runnable within the borehole can allow for easier pump out and later retrieval of the body 14 from the borehole.

[0018] In one embodiment the downhole tool 10 is made of a material that can disintegrate or degrade when exposed to a target environment. Such materials can include a high strength controlled electrolytic metallic material and is degradable by brine, acid, or aqueous fluid. For example, a variety of suitable materials and their methods of manufacture are described in United States Patent Publication No. 2011/0135953 (Xu et al.), which Patent Publication is hereby incorporated by reference in its entirety.

[0019] The geometric configuration of the body 14, when made of a disintegratable material, provides a user of the tool 10 with greater control over a rate of disintegration of the body 14 in comparison to typical disintegratable tools made with conventional manufacturing techniques. This is due to the control of a rate of exposure of various internal portions of the

tool 10 to the fluid after the fluid has breached the outer surface 18. The plurality of openings 30 allow fluid that has breached the surface 18 to readily flow to many or even all of the cavities 22 thereby exposing walls 46 that define each of the cavities 22 to the fluid. While the walls 46 in this embodiment are defined by the shells 34 and the webs 38, other embodiments may have the walls 46 defined by feature other than the shells 34 and the webs 38. Exposing multiple of the walls 46 create a large exposure of surface area of the internal portions of the body 14 to the fluid thereby allowing disintegration thereof to happen at a faster rate than conventional bodies that do not have the large amount of surface area of the tool 10 or the number of openings of the tool 10 made possible by the additive manufacturing process employed herein. Additionally, the webs 38, the shells 34 and the cavities 22 of the body 14 allow designers to intentionally concentrate stress (be it mechanical stress or chemical stress) experienced by the body 14 to facilitate rupturing at selected loads. Such rupturing can allow even greater control of a rate of exposure to internal portions of the body 14 and subsequent disintegration thereof.

[0020] Referring to Figure 4, an alternative embodiment of the downhole tool 110 disclosed herein includes more than one body 114A-114E, with the five separate bodies 114A-114E being illustrated. The outermost body 114A includes a surface 118A on an outermost shell 134A. The other bodies 114B-114E include surfaces 118B-118E on shells 134B-134E respectively. Openings 130 in the shells 134B-134E allow for radial fluid communication, while gaps 132 between webs 138 and the surfaces 118B-118E allow for fluidic communication in perimetrical directions. The bodies 114A-114E being completely separate from one another are able to move around within the space provided by the gaps 132.

[0021] In alternate embodiments the bodies 114A-114E could be attached to one another as manufactured by a small sprue (not shown), for example, then separated from each other in response to loads imparted on the tool 110. Such loads could be impact loads or slower applied loads that deform the one of the bodies 114A-114D sufficiently to cause separation to the body 114B-114E internally adjacent thereto.

[0022] The additive manufacturing process allows the bodies to be made as separate components from one another. The gaps 132 can be sized to allow the shell 134A to deform under load to a point where the webs 138 attached to the shell 134A make contact with the surface 118B. This amount of deformation can be sized to be within an elastic range of the body 114A such that the shell 134A is recoverable to its undeformed shape after withdrawal of the load that caused it to deform. The foregoing configuration allows the body 114B to

provide support to the body 114A. The deformation of the shell 134A also allows the surface 118A to seal to a seat (not shown) around imperfections or contaminations on the seat that would prevent sealing if the shell 134A were not allowed to deform. The seal created by the deformed shell 134A also can occur at lower loads against a seat than would be required if the shell 134A were not allowed to deform. Additionally, a volume of the body 114A can be decreased when deformed in comparison to a volume of the body 114A in the undeformed configuration. Such a condition allows pressure within the shell 134A to increase when the shell 134A is deformed to resist increases in deformation thereof.

[0023] Figures 5-8 show an alternate embodiment of a downhole tool disclosed herein generally at 210. The downhole tool 210 is a movable body 214 of a ball valve 216. The movable body 214 has a partially spherical surface 218 that sealingly engages with a seat surface 220 of a seat 224 within which the movable body 214 is movably engaged. The movable body 214 is rotatable at least through 90 degrees of rotation relative to the seat 224. In the position shown in Figures 5 and 6 the movable body 214 occludes flow through a through bore 228 in the seat 224 and the movable body allows flow through the through bore 228 and through a bore 232 through the movable body 214 when rotated 90 degrees from the position shown in Figures 5 and 6. The rotation of the movable body 214 is about a rotational axis 236.

[0024] Referring to Figures 7 and 8 specifically, a portion of the ball valve 216 is shown magnified with the movable body 214 in partially cross section in Figure 8. The cross section shows a cavity 222 that is positioned below the surface 218 of the movable body 214. The cavity 222 is sized, shaped and configured to allow a portion 240 of the movable body 214 that is between the surface 218 and the cavity 222 to deform under load. Such deformation allows a volume of the cavity 222 to be reduced as the surface 218 is locally dented in response to being loaded by an imperfection 244 or piece of contamination located between the surfaces 218 and 220. The deformation of the portion 240 allows the surface 218 to seal to the surface 220 at lower contact loads between the two surfaces 218, 220 than it would had the surface 218 not be allowed to deform. One or more trusses 248 can be positioned within the cavity 222 to provide greater control to what amount of deformation occurs at what loads. The movable body 214 and cavity 222 can be shaped and further configured nonsymmetrically relative to the surface 218 to provide varying levels of resistance to deformation of the portion 240 to account for differences in loads anticipated during sealing.

[0025] In Figure 7 a cavity 252 is shown within the seat 224. This is an option that could be included in the ball valve 216 such that both the seat 216 and the movable body 214 include the respective cavities 252, 222. In embodiments wherein the seat 216 includes the cavity 252 the movable body 214 could be employed without the cavity 222. In embodiments wherein the seat 224 includes the cavity 252 the seat 224 serves as a downhole tool disclosed herein.

[0026] The downhole tools 10, 110, 210 are made with an additive manufacturing process. One embodiment of an applicable process includes small particles 260 (shown in Figure 2 only) that are adhered together one layer at a time. This adherence can be through the application of heat via a laser, for example. Some of the small particles 260, however, are not adhered to the tools 10, 110, 210 and can be removed from the cavities 22, 222, 252 or optionally left and sealed within the cavities 22, 222, 252 as the formation of the tools 10, 110, 210 is completed. In such a case the cavities 22, 222, 252 are not filled only with a gas present during the manufacturing process but are also at least partially filled with the unadhered particles 260. Leaving the unadhered particles 260 inside the cavities 22, 222, 252 can allow them to provide structural support to the shells 34, 134A and the surfaces 18, 118A or the portion 240 and the surface 218, for example, while allowing for dissipation of the particles 260 upon breaching of the shells 34, 134A and portion 240. Such dissipation can allow for a very fast removal of the downhole tool 10, 110, 210 in comparison to conventional downhole tools.

[0027] Although the tools 10, 110, 210 are illustrated as balls and movable bodies other possible embodiments include but are not limited to downhole tools that are a single component, such as, hold down dogs and springs, screen protectors, seal bore protectors, electric submersible pump space out subs, full bore guns, chemical encapsulations, slips, dogs, springs and collet restraints, liner setting sleeves, timing actuation devices, emergency grapple release, chemical encapsulation containers, screen protectors, beaded screen protectors, whipstock lugs, whipstock coatings, pins, set screws, emergency release tools, gas generators, mandrels, release mechanisms, staging collars, C-rings, components of perforating gun systems, disintegrable whipstock for casing exit tools, shear pins, dissolvable body locking rings, mud motor stators, progressive cavity pump stators, shear screws. Or the downhole tool is configured to inhibit flow without being pumpable, such as, seals, high pressure beaded frac screen plugs, screen basepipe plugs, coatings for balls and seats, compression packing elements, expandable packing elements, O-rings, bonded seals, bullet seals, sub-surface safety valve seals, sub-surface safety valve flapper seal, dynamic seals, V-

rings, back up rings, drill bit seals, liner port plugs, atmospheric discs, atmospheric chamber discs, debris barriers, drill in stim liner plugs, inflow control device plugs, flappers, seats, ball seats, direct connect disks, drill-in linear disks, gas lift valve plug, fluid loss control flappers, electric submersible pump seals, shear out plugs, flapper valves, gaslift valves, sleeves. Or the downhole tool is configured to inhibit flow and be pumpable, such as, plugs, direct connect plugs, bridge plugs, wiper plugs, frac plugs, components of frac plugs, drill in sand control beaded screen plugs, inflow control device plugs, polymeric plugs, disappearing wiper plugs, cementing plugs, balls, diverter balls, shifting and setting balls, swabbing element protectors, buoyant recorders, pumpable collets, float shoes, and darts.

[0028] While the invention has been described with reference to an exemplary embodiment or 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 may be made to adapt a particular 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, but that the invention will include all embodiments falling within the scope of the claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

[0029] The teachings of the present disclosure may be used in a variety of well operations. These operations may involve using one or more treatment agents to treat a formation, the fluids resident in a formation, a wellbore, and / or equipment in the wellbore, such as production tubing. The treatment agents may be in the form of liquids, gases, solids, semi-solids, and mixtures thereof. Illustrative treatment agents include, but are not limited to, fracturing fluids, acids, steam, water, brine, anti-corrosion agents, cement, permeability modifiers, drilling muds, emulsifiers, demulsifiers, tracers, flow improvers etc. Illustrative well operations include, but are not limited to, hydraulic fracturing, stimulation, tracer injection, cleaning, acidizing, steam injection, water flooding, cementing, etc.

CLAIMS

What is claimed is:

1. A downhole tool (10), comprising at least one body (14) defining a surface (18), the at least one body (14) having a plurality of cavities (22) sealed from an outside (26) of the at least one body (14) by the surface (18), a plurality of the plurality of cavities (22) being in fluidic communication with others of the plurality of cavities (22) through a plurality of openings (30).
2. The downhole tool (10) of claim 1, wherein the at least one body (14) is formed by an additive manufacturing process.
3. The downhole tool (10) of claim 2, wherein the additive manufacturing process adheres together particles (260) of a material that forms the at least one body (14) and some of the particles (260) of the material are left unadhered within the plurality of cavities (22).
4. The downhole tool (10) of claim 3, wherein the unadhered particles (260) of the material provide structural support to the surface (18).
5. The downhole tool (10) of claim 1, wherein the plurality of cavities (22) are set to an effective density of the at least one body (14) by setting ratios of volumes of the plurality of cavities (22) relative to that of a balance of the at least one body (14).
6. The downhole tool (10) of claim 1, wherein the at least one body (14) comprises polymer, metal, ceramic or combinations of two or more of the foregoing.
7. The downhole tool (10) of claim 1, wherein the at least one body (14) is disintegratable in a target fluid.
8. The downhole tool (10) of claim 1, wherein the plurality of cavities (22) are positioned below the surface (18) to allow the surface (18) to deform under loads applied to the surface (18).
9. The downhole tool (10) of claim 8, wherein deformation of the surface (18) is elastic deformation.
10. The downhole tool (10) of claim 1, wherein the at least one body (14) and the plurality of cavities (22) are configured nonsymmetrically relative to the surface (18).
11. The downhole tool (110) of claim 1, wherein the at least one body (114A, 114B) comprises, a first body (114A) and a second body (114B), the first body (114A) defining the surface (118A) and the second body (114B) being sealingly encapsulated within the first body (114A).

12. The downhole tool (10) of claim 1, wherein the at least one body (14) is a portion of a downhole tool (10) selected from the group consisting of seals, high pressure beaded frac screen plugs, screen basepipe plugs, coatings for balls and seats, compression packing elements, expandable packing elements, O-rings, bonded seals, bullet seals, sub-surface safety valve seals, sub-surface safety valve flapper seal, dynamic seals, V-rings, back up rings, drill bit seals, liner port plugs, atmospheric discs, atmospheric chamber discs, debris barriers, drill in stim liner plugs, inflow control device plugs, flappers, seats, ball seats, direct connect disks, drill-in linear disks, gas lift valve plug, fluid loss control flappers, electric submersible pump seals, shear out plugs, flapper valves, gaslift valves, sleeves.

13. The downhole tool (10) of claim 1, wherein the downhole tool (10) is pumpable within a downhole environment and is selected from the group consisting of plugs, direct connect plugs, bridge plugs, wiper plugs, frac plugs, components of frac plugs, drill in sand control beaded screen plugs, inflow control device plugs, polymeric plugs, disappearing wiper plugs, cementing plugs, balls, diverter balls, shifting and setting balls, swabbing element protectors, buoyant recorders, pumpable collets, float shoes, and darts.

14. The downhole tool (10) of claim 1, wherein the downhole tool (10) is selected from the group consisting of seals, high pressure beaded frac screen plugs, screen basepipe plugs, coatings for balls and seats, compression packing elements, expandable packing elements, O-rings, bonded seals, bullet seals, sub-surface safety valve seals, sub-surface safety valve flapper seal, dynamic seals, V-rings, back up rings, drill bit seals, liner port plugs, atmospheric discs, atmospheric chamber discs, debris barriers, drill in stim liner plugs, inflow control device plugs, flappers, seats, ball seats, direct connect disks, drill-in linear disks, gas lift valve plug, fluid loss control flappers, electric submersible pump seals, shear out plugs, flapper valves, gaslift valves, sleeves.

15. A method of forming a downhole tool (10), comprising:
creating a three-dimensional computer model of the downhole tool (10) of claim 1;
and
forming the downhole tool (10) with an additive manufacturing process from the three-dimensional computer model.

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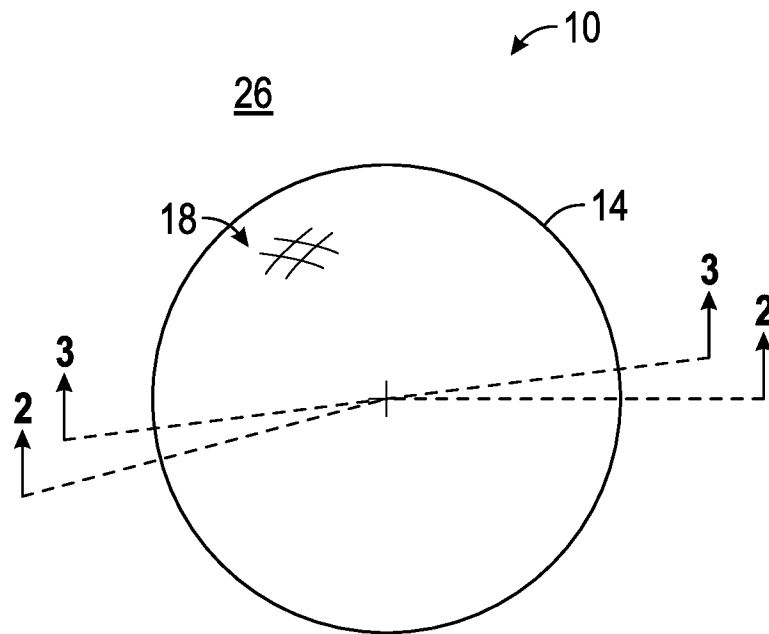


FIG. 1

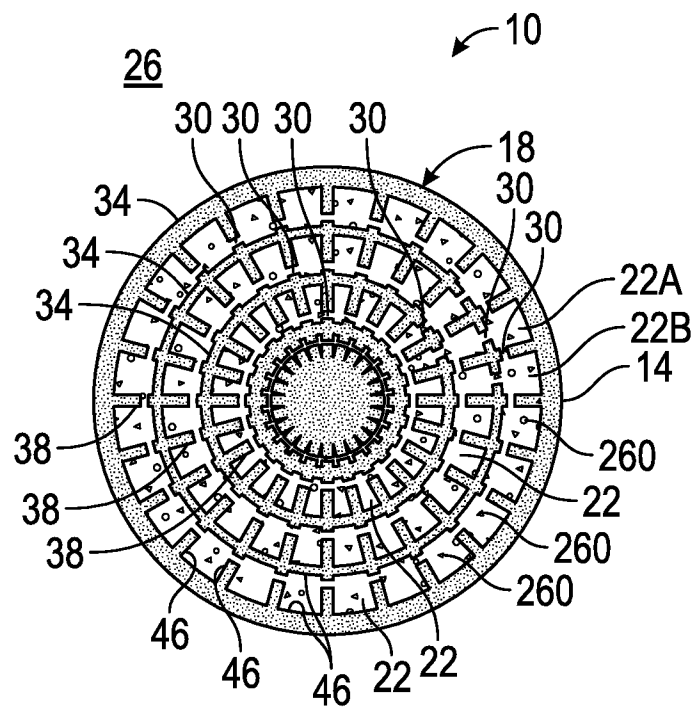


FIG. 2

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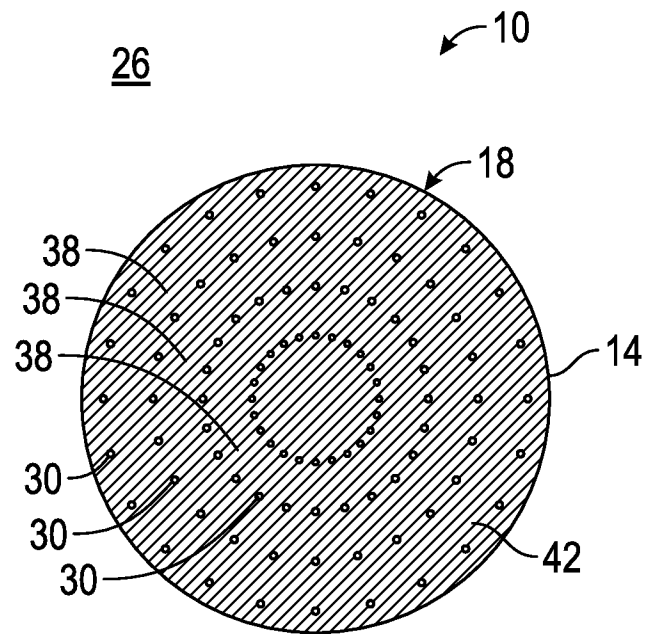


FIG. 3

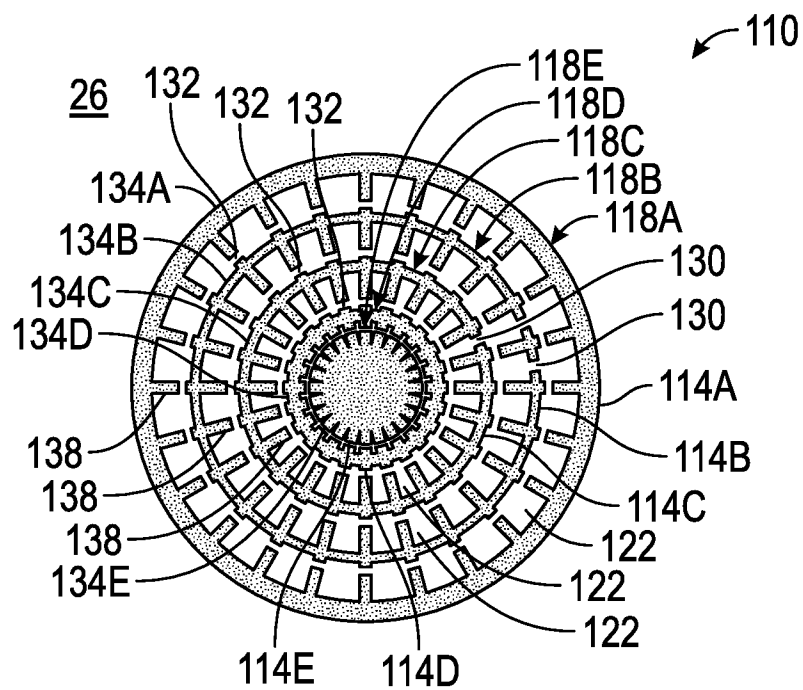


FIG. 4

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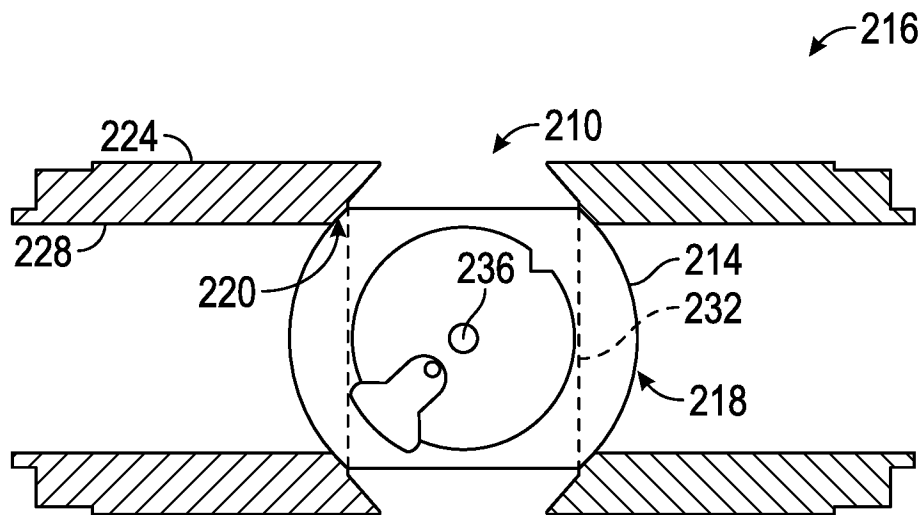


FIG. 5

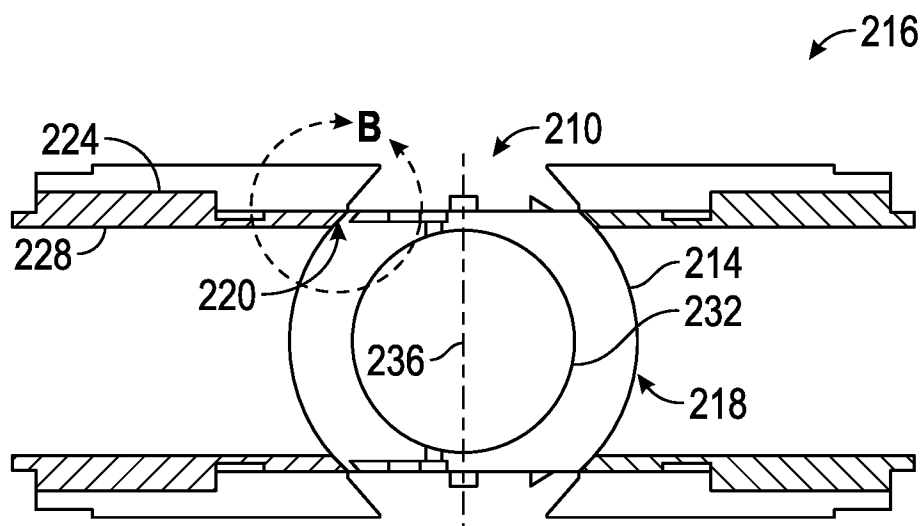


FIG. 6

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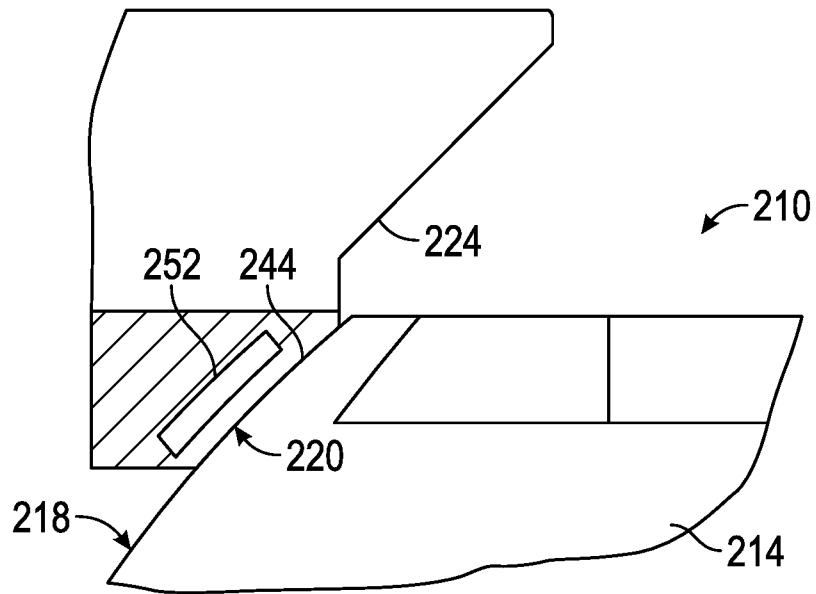


FIG. 7

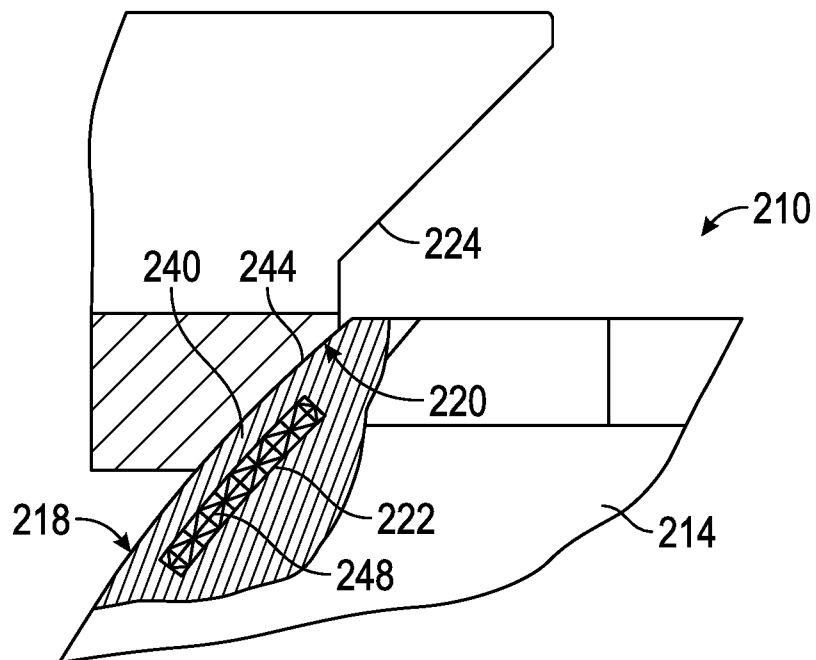


FIG. 8

A. CLASSIFICATION OF SUBJECT MATTER**E21B 33/12(2006.01)i, E21B 41/00(2006.01)i, B22F 3/105(2006.01)i, B33Y 50/00(2015.01)i, B33Y 80/00(2015.01)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 33/12; E21B 43/12; E21B 33/10; G06F 17/50; E21B 34/00; E21B 43/119; E21B 33/13; E21B 43/26; E21B 41/00; B22F 3/105; B33Y 50/00; B33Y 80/00

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: body, surface, cavity, opening, density, volume, particle, disintegratable, deform, additive manufacturing process

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014-0332231 A1 (PACKERS PLUS ENERGY SERVICES INC.) 13 November 2014 See paragraphs [0021]-[0022], [0033]-[0038], [0047]-[0049], [0058]-[0059]; and figures 2, 6a-6b, 7a-7b, 8a-8b.	1, 6-7, 10-14
Y		2-5, 8-9, 15
Y	US 2013-0310961 A1 (SCHLUMBERGER TECHNOLOGY CORPORATION) 21 November 2013 See paragraphs [0032]-[0041]; and figure 4.	2-4, 15
Y	US 2013-0068461 A1 (1069416 AB LTD.) 21 March 2013 See paragraphs [0026]-[0027], [0036], [0040]; and figures 3a-3c, 4a-4f.	5, 8-9
A	WO 2012-071449 A2 (DRILL MASTER INC. et al.) 31 May 2012 See paragraphs [0012]-[0014], [0037]-[0048], [0060]; and figure 8.	1-15
A	WO 91-11587 A1 (CONOCO INC. et al.) 08 August 1991 See page 8, line 21 - page 12, line 13; and figures 2-3.	1-15



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

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Date of the actual completion of the international search

23 April 2016 (23.04.2016)

Date of mailing of the international search report

03 May 2016 (03.05.2016)

Name and mailing address of the ISA/KR

International Application Division

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/015948

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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