



- (51) **International Patent Classification:**
E21B 12/00 (2006.01) *E21B 10/00* (2006.01)
F16J 15/10 (2006.01)
- (21) **International Application Number:**
PCT/US2013/058136
- (22) **International Filing Date:**
5 September 2013 (05.09.2013)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/696,950 5 September 2012 (05.09.2012) US
14/018,165 4 September 2013 (04.09.2013) 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, BN, 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, 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, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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.

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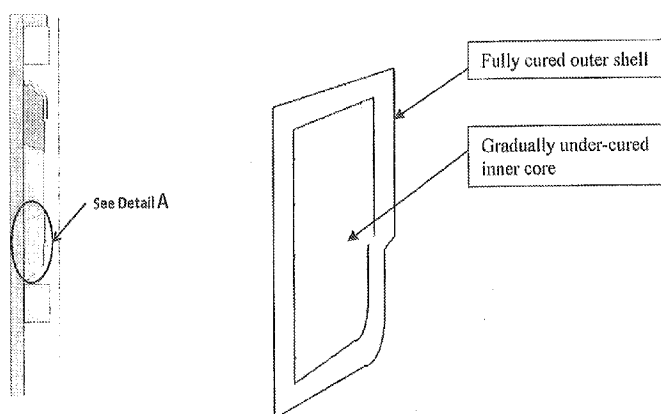
(54) **Title:** FUNCTIONALLY GRADIENT ELASTOMER MATERIAL FOR DOWNHOLE SEALING ELEMENT

Fig. 1

(57) **Abstract:** A sealing device of enhanced configuration for use in downhole in a well. The device may include an element of elastomeric and unitary construction. At the same time, however, the element may include a substantially cured outer shell disposed about a substantially under-cured inner core. Thus, enhanced robustness and durability may be provided to the device in light of downhole conditions without sacrifice to sealable function of the device.



(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, KM, ML, MR, NE, SN, TD, TG).

Published:

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

FUNCTIONALLY GRADIENT ELASTOMER MATERIAL FOR DOWNHOLE SEALING ELEMENT

BACKGROUND

[0001] Exploring, drilling and completing hydrocarbon and other wells are generally complicated, time consuming, and ultimately very expensive endeavors. As a result, over the years, a significant amount of added emphasis has been placed on maximizing hydrocarbon recovery for every well drilled. Along these lines, well monitoring and maintenance have become critical to effective well management throughout the life of the well. Additionally, overall well completions and architecture design are directed at enhancing overall recovery.

[0002] Well completions as well as management of the well throughout the life thereof, often involve the utilization of downhole sealing elements. For example, the well may be partitioned off into different productive and non-productive zones through the use of zonal isolation packers. Such isolation may be undertaken at the outset of well completions, over the course of the life of the well, or for sake of temporary interventional applications. Regardless, effective sealing in the often extreme conditions of a downhole environment may be sought for some substantial duration.

[0003] Unfortunately, sealing devices and device features such as swell packers, mechanical packer elements, and others, are often prone to extrude, degrade and otherwise fail. That is, whether due to the downhole conditions themselves, or added stress imparted due to the nature of the deployment, such isolating devices are unlikely to maintain an effective seal for extended periods of time such as the life of the well.

SUMMARY

[0004] A sealing device is disclosed for downhole use in a well. The device includes a structurally supportive mandrel platform. Thus, a seal element may be

disposed thereabout. Further, the seal element includes a substantially cured outer shell about a substantially under-cured inner core.

[0005] In some embodiments, the present invention is directed to a sealing device for downhole deployment in a well. The device includes a mandrel, a first sealing element coupled to the mandrel and being cured to a first curing level, and a second sealing element coupled to the mandrel and being cured to a second curing level different from the first curing level. The first and second sealing elements are operatively coupled together.

[0006] In other embodiments the first and second sealing elements each have a radial cross-sectional shape. The radial cross-sectional shape of the first and second sealing elements is generally similar but the radial cross-sectional shape of the first sealing element is smaller than the radial cross-sectional shape of the second sealing element such that the second sealing element surrounds the first sealing element with a uniform thickness.

[0007] In still further embodiments, the present invention is directed to a functionally gradient elastomer material for use with a packer including a first element having a first characteristic configured to resiliently seal against an exterior surface and a second element having a second characteristic configured to resist extrusion. The second element resiliently seals against an exterior surface to a lesser degree than the first element, and the first element resists extrusion to a lesser degree than the second element. The first and second elements are coupled together such that, when actuated, pressure causes the first and second elements to deform together to form a seal. The device also includes a mandrel coupled to at least one of the first or second elements and configured to support the first and second elements as the functionally gradient elastomer material forms the seal.

[0008] In still further embodiments the present invention is directed to a method of forming a sealing device for use with a downhole tool, including forming a first elastomeric sealing element having a first physical property, forming a second elastomeric sealing element having a second physical property, wherein the first physical property causes the first elastomeric sealing element to be comparatively more resilient than the second elastomeric sealing element and the second physical characteristic causes the second elastomeric sealing element to be comparatively better at resisting extrusion stresses than the first elastomeric sealing element. The method also includes coupling the first and second elastomeric sealing elements together, and coupling the first and second elastomeric sealing elements to a mandrel configured to support the elastomeric sealing elements as pressure is exerted upon the elastomeric sealing elements to form a seal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Fig. 1 includes side and enlarged sectional views of an embodiment of a functionally gradient material sealing element.

[0010] Fig. 2 is a chart summarizing modulus data for the material of Fig. 1 upon exposure to varying temperatures.

[0011] Fig. 3 is a side view of an alternate embodiment of the material employed in an O-ring seal configuration.

[0012] Fig. 4 is an alternate embodiment of the material employed in a T-seal configuration.

[0013] Fig. 5 is an alternate embodiment of the material employed in a V-seal configuration.

[0014] Fig. 6 is an alternate embodiment of the material employed as cased hole hydraulic packer elements.

[0015] Fig. 7 is an alternate embodiment of the material employed as open hole hydraulic packer elements.

[0016] Fig. 8 an alternate embodiment of the material employed as open hole hydraulic packer elements.

DETAILED DESCRIPTION

[0017] Embodiments herein are described with reference to certain types of downhole sealing devices. For example, conventional packers are shown for zonal isolation in a well. However, more unique types of packers and a host of other sealing devices may take advantage of embodiments of functionally gradient elastomer materials as detailed herein. Regardless, the sealing device may include an element utilizing an elastomer with a substantially cured outer shell about a substantially under-cured inner core.

[0018] Referring now to Fig. 1, side and enlarged sectional views of an embodiment of a functionally gradient material sealing element are shown. In this embodiment, the sealing element is incorporated into a downhole isolation packer disposed about a tubular. The downhole sealing element in a borehole annulus includes an elastomeric material (e.g. a rubber) molded in ring shape and installed into the metal mandrel. The element can energize and/or swell when an activating system (mechanical loads or fluids) is in place. Conventional sealing element is made from homogeneously mixed polymer compounds and then cured to a uniform part. The present invention relates, in general, to a seal element that were intentionally made with non-uniformly distributed property to achieve better sealing performance by minimizing seal failures associated with extrusion, temperature cycles, and degradation.

[0019] The Packer sealing element consists of 1 to 3 pieces of elastomeric rings installed in a metal mandrel. When activated, the elements provide a seal in annulus space between the mandrel and casing. Once sealed, the elements undergo pressure

differential from both above and below the seal, as well as temperature cycles due to downhole temperature and fluid injection from surface.

[0020] In the case when packer element is energized by mechanical force pushing the gage ring, hyper-elastic strain energy is stored in the packing elements due to large compressive deformation within the elements. This stored strain energy results in contact pressure at the sealing surfaces (casing ID and mandrel OD) thus provides seals. In a defined setting load case, the lower modulus (softer) element generates more stored elastic energy. When temperature decrease occurs due to fluid injection, the decrease of contact force is proportional to the modulus of element (G), the coefficient of thermal expansion (α), and the temperature drop (ΔT) as was stated in the following expression:

$$P \propto G \cdot \alpha \cdot \Delta T$$

[0021] Therefore, a softer elastomer compound is favored by maintaining a better seal with less loss in sealing force when cooling down. However, most of the downhole seal failure attributes to extrusion of the sealing elements under differential pressure. Higher modulus material generally provides better extrusion resistance. So to combine those two requirements, a functionally gradient elastomer material (FGEM) is presented in this invention where a softer inner core is embedded in the harder outer shell. The modulus differential can be achieved by adjusting curing characteristic of the part during molding process.

[0022] Figure 1 illustrates the design of the FGEM material in a downhole packer element. The harder shell is mainly for extrusion resistant purpose and the overall softer material will help with sealing capability. Tests were performed using side-by-side comparison between homogeneous material and FGEM in system level.

[0023] With added reference to Fig. 2 a chart summarizing modulus data for the material of Fig. 1 upon exposure to varying temperatures is depicted. More specifically, Figure 2 shows the FGEM element being used for the test. Test follows ISO 14310 V3 standard and the pressure holding results for the two element systems are summarized in the following two tables. The FGEM elements exhibit better differential pressure capability, especially when a larger ΔT is present. Due to the nature of this particular FGEM element design with soft inner core extends to element ID, excessive amount of rubber was extruded from the OD of mandrel.

Homogeneously cured material: ET201104959
2.590" stroke

50,000 lbf setting force;

Pressure holds summary								
	Above				Below			
Temperature	5ksi	10ksi	15ksi	20ksi	5ksi	10ksi	15ksi	20ksi
450F (1, 2, 3)			√	√			√	√
200F				√		√	√	√
175F			√	√	X	X	X	
150F		√	X			X	X	

Functionally gradient material (FGEM): ET201111659 **50,000 lbf setting force;**
2.553" stroke

Pressure holds summary				
	Above		Below	
Temperature	15ksi	20ksi	15ksi	20ksi
450F (1, 2)	√		√	
150F	√	√	√	√
450F (3, 4)		√		√

[0024] In addition to the uses noted hereinabove, the embodiments of the seal element material construction detailed hereinabove may be utilized in any bottom hole assembly where packers and/or seals may be employed. The sealing element of the present invention maybe O-ring seals, T-seals, V-seals, and packing elements for cased hole packers, open hole packers, and swell packers. The polymer material may

comprise elastomer such as NBR, HNBR, EPDM, FEPM, FKM, FFKM. The seal element may further include a reinforcement material such as a powder material, a fiber material, or nanoparticles with scale range from 1 nanometer to approximately 500 nanometers. Depend on application, the property/functionality in the FGEM that varies spatially may include modulus, hardness, strength, elongation, volume swell, degradation temperature. The gradient of those properties can also be in all directions (radial, angular, and axial).

[0025] With specific reference to the alternate embodiments of Figs. 3-8, Fig. 3 depicts a side view of an alternate embodiment of the material employed in an O-ring seal configuration. Meanwhile, Fig. 4 depicts an alternate embodiment of the material employed in a T-seal configuration. Similarly, Fig. 5 is an alternate embodiment of the material employed in a V-seal configuration.

[0026] Continuing with added reference to Figs. 6-8, packer embodiments are depicted. Specifically, Fig. 6 depicts an alternate embodiment of the material employed as cased hole hydraulic packer elements. Alternatively, Fig. 7 is an embodiment of the material employed as open hole hydraulic packer elements whereas Fig. 8 is an embodiment of the material employed as open hole hydraulic packer elements.

[0027] Embodiments detailed hereinabove provide elastomeric material seals and construction configured for enhanced sealing capability in conjunction with extended life even upon exposure to extreme and/or harsh downhole environmental conditions. The preceding description has been presented with reference to presently preferred embodiments. Persons skilled in the art and technology to which these embodiments pertain will appreciate that alterations and changes in the described structures and methods of operation may be practiced without meaningfully departing from the principle, and scope of these embodiments. Furthermore, the foregoing description

should not be read as pertaining only to the precise structures described and shown in the accompanying drawings, but rather should be read as consistent with and as support for the following claims, which are to have their fullest and fairest scope.

CLAIMS

We Claim:

1. A sealing device for downhole deployment in a well, the device comprising:
a mandrel;
a first sealing element coupled to the mandrel and being cured to a first curing level; and
a second sealing element coupled to the mandrel and being cured to a second curing level different from the first curing level, wherein the first and second sealing elements are operatively coupled together.
2. The sealing device of claim 1, wherein the first and second sealing elements are formed from a homogeneous material wherein the first sealing element is cured to the first curing level and the second sealing element is cured to the second curing level.
3. The sealing device of claim 1, wherein the first and second sealing elements are discrete pieces of material mechanically coupled together and to the mandrel.
4. The sealing device of claim 3 wherein the first sealing component is nested within the second sealing component.
5. The sealing device of claim 1, wherein first and second sealing elements each have a radial cross-sectional shape, wherein the radial cross-sectional shape of the first and second sealing elements is generally similar but the radial cross-sectional shape of the first sealing element is smaller than the radial cross-sectional shape of the second sealing element such that the second sealing element surrounds the first sealing element with a uniform thickness.
6. The sealing device of claim 5 wherein the first curing level is lower than the second curing level such that the inner portion defined by the first sealing element has a lower modulus than the second sealing element.
7. The sealing device of claim 1 wherein the first curing level is lower than the second curing level such that the first sealing element is configured to improve the sealing characteristics of the sealing device and the second sealing element is configured to resist extrusion.

8. The sealing device of claim 1, wherein the device comprises three or more sealing elements, each cured to a curing level, and wherein at least two of the curing levels of the sealing elements are different.
9. The sealing device of claim 1 wherein the first sealing element is an O-ring seal, a T-seal, or a V-seal, and the second sealing element at least partially surrounds the first sealing element.
10. The sealing device of claim 1 wherein the first or second sealing element is made of an elastomer such as NBR, HNBR, EPDM, FEPM, FKM, or FFKM.
11. The sealing device of claim 1, further comprising a reinforcement material such as a powder material, fiber material, or a nanoparticle material.
12. The sealing device of claim 1, wherein the first sealing element and second sealing element are formed of an integral material and the curing level varies substantially continuously throughout at least a portion of the elements, such that there is a gradient region within the sealing device.
13. The sealing device of claim 12, wherein the gradient region varies substantially linearly in a predetermined direction throughout the sealing device.
14. The sealing device of claim 12, wherein the gradient region encompasses all of the first sealing element and all of the second sealing element.
15. The sealing device of claim 12, wherein the sealing device is configured for use in a cased hole packer, an open hole packer, or a swell packer.
16. A functionally gradient elastomer material for use with a packer, the functionally gradient elastomer material comprising:
 - a first element having a first characteristic configured to resiliently seal against an exterior surface;
 - a second element having a second characteristic configured to resist extrusion, wherein the second element resiliently seals against an exterior surface to a lesser degree than the first element, and wherein the first element resists extrusion to a lesser degree than the second element, and further wherein the first and second elements are coupled together such that,

when actuated, pressure causes the first and second elements to deform together to form a seal; and

a mandrel coupled to at least one of the first or second elements and configured to support the first and second elements as the functionally gradient elastomer material forms the seal.

17. The functionally gradient elastomer material of claim 16, wherein the first and second elements are formed integrally, the functionally gradient elastomer material further comprising a gradient region between the first and second elements in which the first and second characteristics vary.

18. The functionally gradient elastomer material of claim 17, wherein the gradient varies spatially at least one of linearly, radially, angularly, or axially.

19. The functionally gradient elastomer material of claim 16, wherein the first and second elements are formed of discrete materials.

20. The functionally gradient elastomer material of claim 16, wherein the first characteristic and second characteristic are different levels of curing, reinforcement material, modulus, hardness, strength, elongation, volume swell, or degradation temperature.

21. A method of forming a sealing device for use with a downhole tool, the method comprising:

forming a first elastomeric sealing element having a first physical property;

forming a second elastomeric sealing element having a second physical property, wherein the first physical property causes the first elastomeric sealing element to be comparatively more resilient than the second elastomeric sealing element and the second physical characteristic causes the second elastomeric sealing element to be comparatively better at resisting extrusion stresses than the first elastomeric sealing element;

coupling the first and second elastomeric sealing elements together; and

coupling the first and second elastomeric sealing elements to a mandrel configured to support the elastomeric sealing elements as pressure is exerted upon the elastomeric sealing elements to form a seal.

22. The method of claim 21, wherein forming the first elastomeric sealing element comprises curing the elastomeric sealing element to a first level and wherein forming the second elastomeric sealing element comprises curing the elastomeric sealing element to a second level different from the first level.

23. The method of claim 21, wherein forming the first and second elastomeric sealing element comprises integrally forming the first and second elastomeric sealing elements.

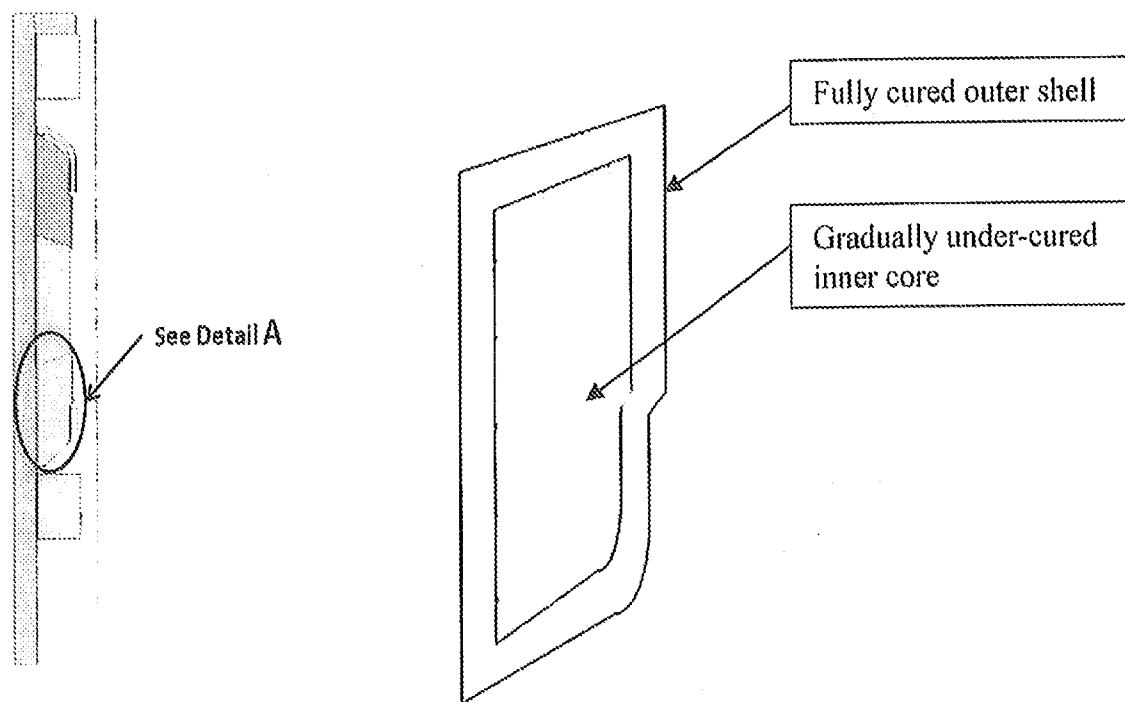


Fig. 1

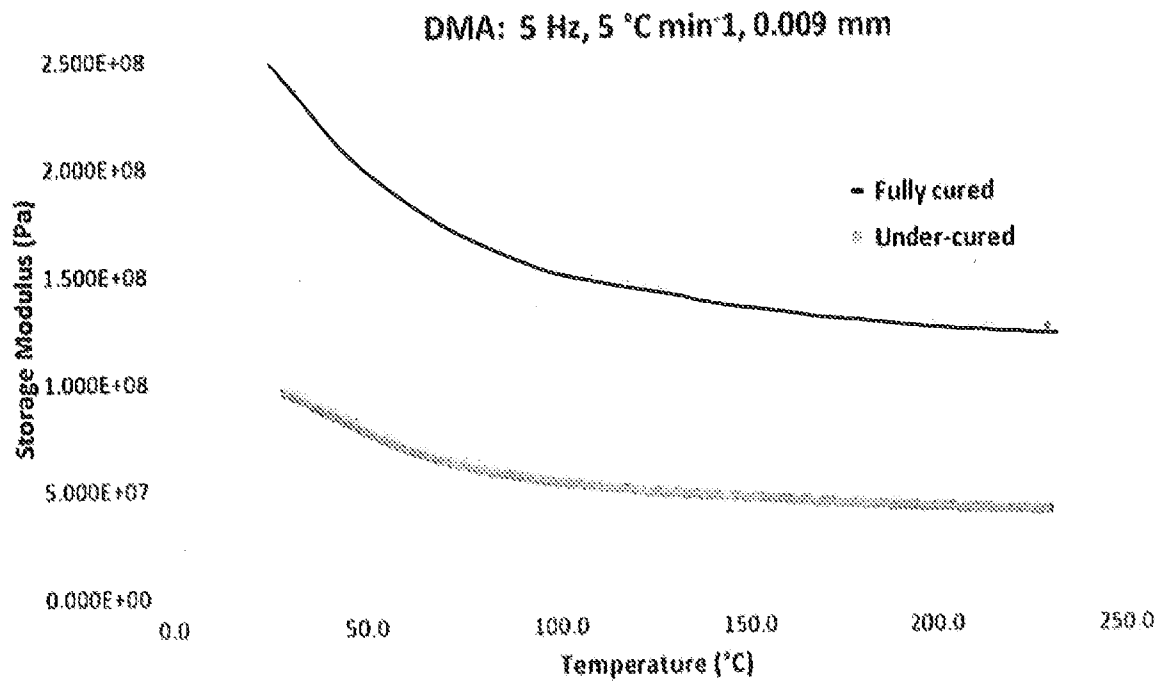


Fig. 2

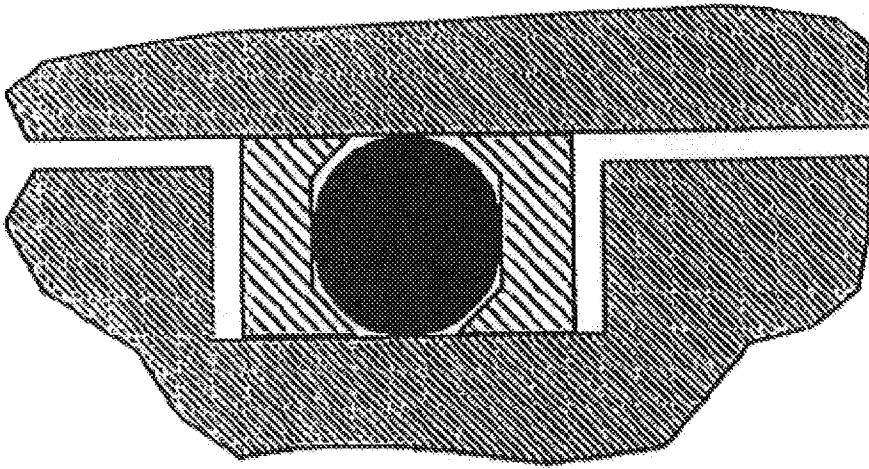


Fig. 3

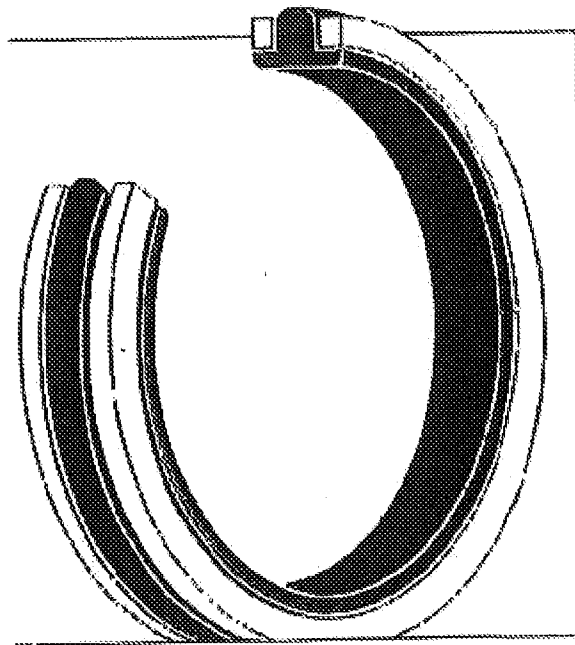


Fig. 4

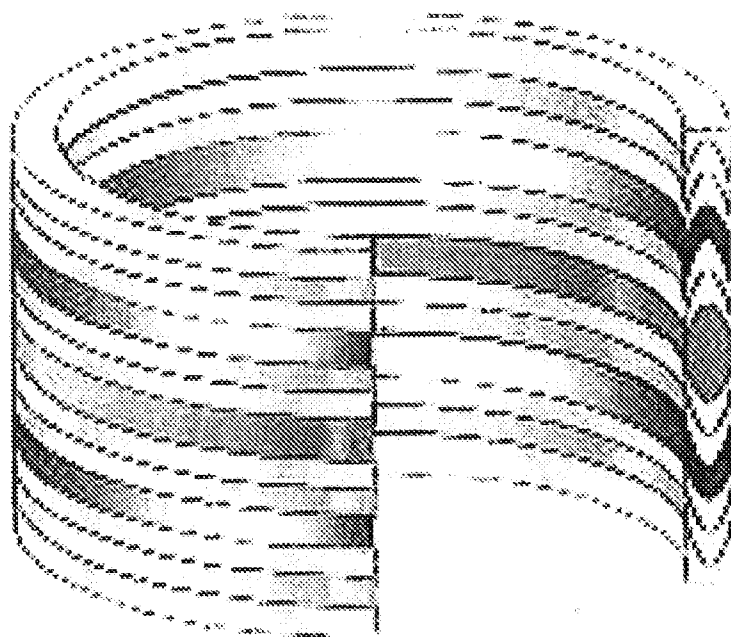


Fig. 5

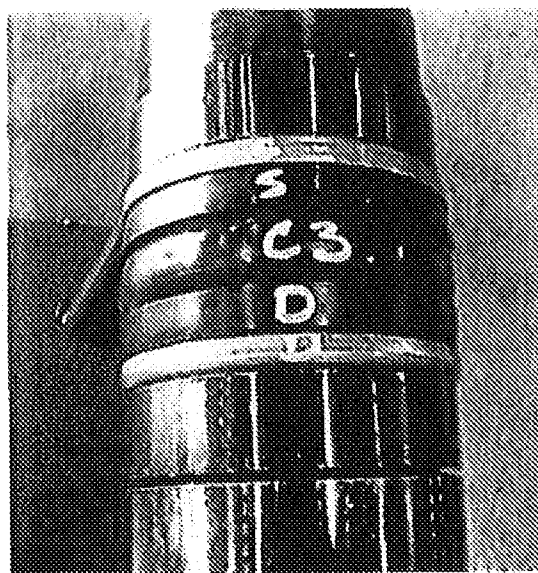


Fig. 6

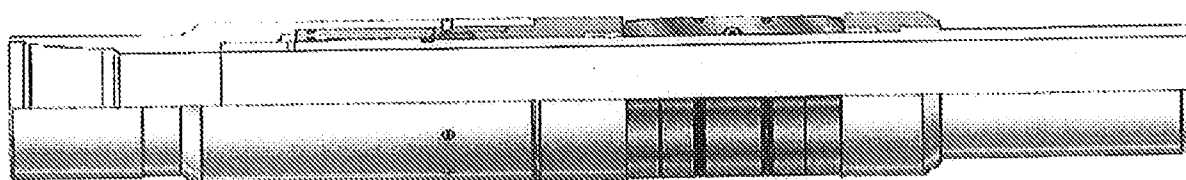


Fig. 7

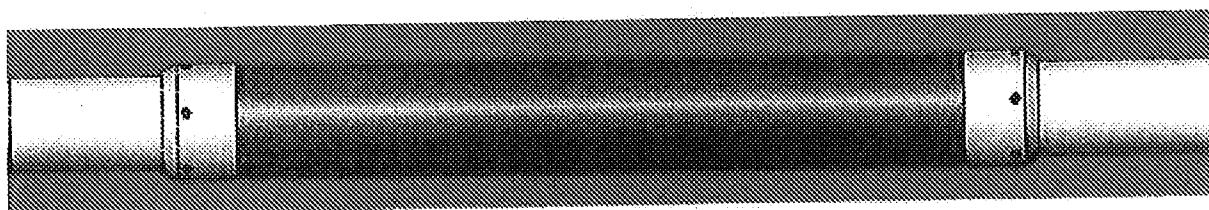


Fig. 8

A. CLASSIFICATION OF SUBJECT MATTER**E21B 12/00(2006.01)i, F16J 15/10(2006.01)i, E21B 10/00(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 12/00; E21B 23/04; E21B 34/06; C09K 7/02; E21B 33/13; E21B 23/00; F16J 15/10; E21B 10/00

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: downhole, mandrel, sealing element, curing level, and gradient elastomer material

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7304098 B2 (LI, YANMEI et al.) 04 December 2007 See column 3, line 4 - column 5, line 34, claims 1-2, and figures 1-7.	1-23
A	US 2004-0031605 A1 (MICKEY, CLINT E.) 19 February 2004 See paragraphs [0012]-[0013], claim 1, and figure 4.	1-23
A	US 6508305 B1 (BRANNON, HAROLD D. et al.) 21 January 2003 See column 25, lines 15-56 and figures 4-5.	1-23
A	US 2009-0178800 A1 (KORTE, JAMES R. et al.) 16 July 2009 See paragraphs [0007]-[0013], claims 1-2, 6-10, and figure 1.	1-23
A	US 2005-0284642 A1 (WONG, FREDRICK SUN-VEOW) 29 December 2005 See paragraphs [0042]-[0055] and figures 1A-9.	1-23



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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"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

21 November 2013 (21.11.2013)

Date of mailing of the international search report

21 November 2013 (21.11.2013)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/058136

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 7304098 B2	04/12/2007	CA 2556250 A1 NO 20063886 A US 2005-0171248 A1 US 2006-0047028 A1 US 2006-0278391 A1 WO 2005-073501 A1	11/08/2005 31/08/2006 04/08/2005 02/03/2006 14/12/2006 11/08/2005
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