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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 January 2016 (28.01.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/014571 A1

(51) International Patent Classification:
E21B 17/10 (2006.01) *B32B 5/26* (2006.01)

(21) International Application Number:
PCT/US2015/041385

(22) International Filing Date:
21 July 2015 (21.07.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/026,794 21 July 2014 (21.07.2014) 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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, 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,

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(54) Title: COMPOSITE BOW SPRING CENTRALIZER

(57) Abstract: Laminated composite bow-springs for use in a centralizer have a plurality of layers. A mid-plane separates a first portion and a second portion of the plurality of layers. The first portion and the second portion each have a matrix including a plurality of reinforcements, and each have an average angular orientation of their respective reinforcements in relation to the longitudinal axis. The average angular orientation of the first portion is less than the average angular orientation of the second portion.

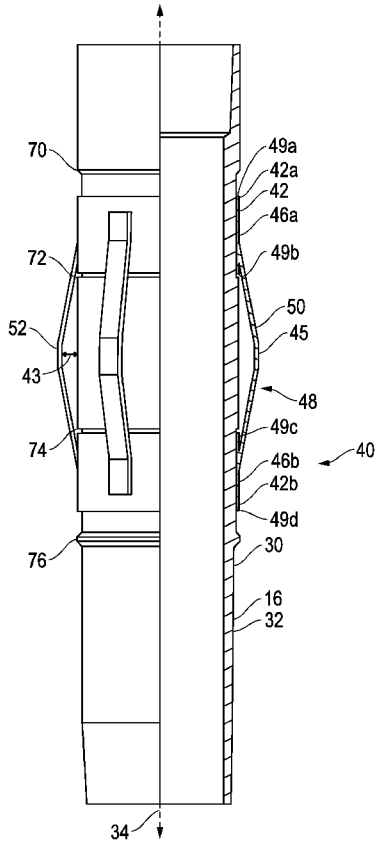


FIG. 2

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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, RW, SD, SL, ST, 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))*

— *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))*

TITLE: Composite Bow Spring Centralizer

BACKGROUND

[0001] Technical Field: Bow-spring centralizers are used in holes and in tubulars in the petroleum and in other industries.

[0002] The bow-spring centralizers must have sufficient ductility to collapse yet sufficient strength to centralize a mandrel according to the given application within a hole and/or casing/tubular.

[0003] US Patent Nos. US 5575333, US 4787458, and US 3749168 are incorporated herein by reference for all purposes in its entirety.

BRIEF SUMMARY

[0004] The exemplary embodiments relate to laminated composite bow-springs for use in a centralizer having a plurality of layers. A mid-plane separates a first portion and a second portion of the plurality of layers. The first portion and the second portion each have a matrix including a plurality of reinforcements, and each have an average angular orientation of their respective reinforcements in relation to the longitudinal axis. The average angular orientation of the first portion is less than the average angular orientation of the second portion.

[0005] The terms “a first portion”, “an outer portion”, or “a first or outer portion” as used herein each shall mean at least one layer(s) or ply(ies), wherein if there is more than one layer then such layers shall be stacked, positioned or arranged consecutively, and further wherein the first portion is, relative to a second portion, further from the longitudinal axis of a mandrel or centralizer.

[0006] The terms “a second portion”, “an inner portion”, or “a second or inner portion” as used herein each shall mean at least one layer(s) or ply(ies), wherein if there is more than one layer then such layers shall be stacked, positioned or arranged consecutively, and further wherein the second portion is, relative to the first portion, nearer to the longitudinal axis of the mandrel or centralizer.

[0007] The term “midplane” or “mid-plane” as used herein shall mean a plane between or contiguous with both the first portion and the second portion (alternatively, between the outer portion and the inner portion).

[0008] This application claims the benefit of US Provisional Application No. 62/026,794 filed 21 July 2014 the disclosure of which is hereby incorporated by reference.

BRIEF DESCRIPTION OF THE FIGURES

[0009] The exemplary embodiments may be better understood, and numerous objects, features, and advantages made apparent to those skilled in the art by referencing the accompanying drawings. These drawings are used to illustrate only exemplary embodiments, and are not to be considered limiting of its scope, for the disclosure may admit to other equally effective exemplary embodiments. The figures are not necessarily to scale and certain features and certain views of the figures may be shown exaggerated in scale or in schematic in the interest of clarity and conciseness.

[0010] Figure 1 depicts a schematic view of a well site having a drilling system with an exemplary embodiment of a centralizer.

[0011] Figure 2 depicts an enlarged schematic view of the exemplary embodiment of the centralizer of Figure 1.

[0012] Figure 3 depicts a perspective view of an exemplary embodiment of a centralizer collar.

[0013] Figure 4 depicts a cross section view of the exemplary embodiment of the centralizer collar of Figure 3.

[0014] Figure 5 depicts an exploded view of an exemplary embodiment of a bow spring of a centralizer.

[0015] Figure 6 depicts a schematic view of an exemplary embodiment of a layer of composite material having a matrix with unidirectional reinforcements within.

[0016] Figure 7 depicts a sectional view of an alternate exemplary embodiment of a centralizer bow spring of uncured laminate composite.

[0017] Figure 8 depicts a sectional view of the alternate exemplary embodiment of the centralizer bow spring of Figure 7 having undergone a curing process.

[0018] Figure 9 depicts an exploded view of an alternate exemplary embodiment of a bow spring of a centralizer.

[0019] Figure 10 depicts an exploded view of an alternate exemplary embodiment of a bow spring of a centralizer.

[0020] Figure 11 depicts a top view of an alternate exemplary embodiment of a woven or matted reinforcement, layer and/or composite material.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENT(S)

[0021] The description that follows includes exemplary apparatus, methods, techniques, and instruction sequences that embody techniques of the inventive subject matter. However, it is understood that the described exemplary embodiments may be practiced without these specific details.

[0022] Figure 1 depicts a schematic view of a well site 20 having a drilling system 10. Although the depicted drilling system 10 is a terrestrial system in Figure 1, it is to be appreciated that the disclosed embodiments may be practiced in alternate environments, including, but not limited to, offshore drilling units as well. For example, the wellbore 22 may be subsea having a wellhead located adjacent to the waterline and may have a drilling system 10 located on a platform adjacent the wellhead. Further, although wellbore 22 is depicted as a vertical wellbore, it is to be appreciated that the exemplary embodiments disclosed herein may be utilized with any cased or uncased wellbores 22, including curved, deviated and horizontal wellbores 22.

[0023] In Figure 1, the well site 20 may have a wellbore 22 formed in the earth and may be optionally lined with a casing 24. The wellbore 22 may define an inner diameter 23, and the casing 24 may define an inner diameter 25. The drilling system 10 may include a derrick 12, pressure control devices 14, casing 24, a centralizer 40 and oilfield equipment 16. The one or more pressure control devices 14 at the well site 20 may control pressure in the wellbore 22. The pressure control devices 14 may include, but are not limited to, blow out preventers (BOPs), rotating control devices (RCDs), and the like. The pressure control device 14 is a drill-through

device with a rotating seal that contacts and seals against a piece of oilfield equipment 16 for the purposes of controlling the pressure or fluid flow to the surface. The oilfield equipment 16 may be any suitable equipment to be sealed by the pressure control device 14 including, but not limited to, a mandrel 30, a drill string, a bushing, a bearing, a bearing assembly, a test plug, a snubbing adaptor, a docking sleeve, a sleeve, sealing elements, a drill pipe, a tool joint, and the like. The oilfield equipment 16 or mandrel 30 may define an axis or longitudinal axis 34 about which the centralizer 40 is longitudinally oriented. The centralizer 40 may have a plurality of collars or bodies 42 to which bow springs 50 are attached. The collars or bodies 42 may surround, engage, mount or couple to the outer diameter 32 of the piece of oilfield equipment 16.

[0024] Figure 2 depicts an enlarged schematic view of the exemplary embodiment of the centralizer 40 of Figure 1. As depicted, the centralizer 40 has collars 42 which define a void 41 (see Figures 3 and 4) through which the piece of oilfield equipment 16 or mandrel 30 may travel therethrough. The exemplary embodiment of the centralizer 40 of Figure 2 has two bodies or collars 42, a top collar 42a and a bottom collar 42b. A plurality of bow springs 50 may connect the top collar 42a and bottom collar 42b. Each bow spring 50 may have end portions 46, for example a top end portion 46a and a bottom end portion 46b, to couple to the bodies 42a, 42b, and one or more arced portions 48, with each arc 48 having an apex 45. The plurality of arcs 48 and their apexes 45 may be arranged concentrically about the longitudinal or mandrel axis 34 to define an outer diameter 52 and a height 43 of the bow springs 50. The outer diameter 52 and/or height 43 of the bow springs 50 may contact or engage the inner diameters 23 or 25 or the wellbore or hole 22 or casing/tubular 24, respectively, for the purpose of centralizing the piece of oilfield equipment 16 or mandrel 30 within the wellbore 22 or casing 24. The outer diameter 52 and/or height 43 of the bow springs 50 may be adjusted or modified as necessary by one of ordinary skill in the art to centralize the mandrel 30 or piece of oilfield equipment 16 within a particular wellbore 22 or casing 24.

[0025] Moreover, the top collar 42a may end in a top abutment 49a and a bottom abutment 49b. Likewise, the bottom collar 42b may have ends as a top abutment 49c and a bottom abutment 49d. The mandrel 30, upon which the centralizer 40 is

mounted, may feature a top shoulder 70, a bottom shoulder 76, a top ridge 72, and a bottom ridge 74. The top shoulder 70, bottom shoulder 76, top ridge 72, and bottom ridge 74 all have outer diameters (such as indicated and shown at 76 exceeding the diameter 32) which extend beyond the diameter of the void or space 41 (see Figures 3 and 4) defined within collars 42a, 42b. The top shoulder 70 on the mandrel 30 is located above the top abutment 49a of the top collar 42a and the top ridge 72 on the mandrel 30 is located below the bottom abutment 49b of the top collar 42a, such that the range of axial movement of the top collar 42a along the mandrel 30 is limited by the distance defined between the top shoulder 70 and the top ridge 72. In a similar fashion, the bottom ridge 74 of the mandrel 30 is located above the top abutment 49c of the bottom collar 42b, and the bottom shoulder 76 of the mandrel 30 is located below the bottom abutment 49d of the bottom collar 42b. Accordingly, the range of axial movement of the bottom collar 42b is limited to the distance defined between the bottom ridge 74 and the bottom shoulder 76. The abutting interaction between abutments 49a, 49b, 49c, 49d and respective shoulders 70, 76 and ridges 72, 74 help to ensure proper positioning of and prevent damage to the centralizer 40 when moving or adjusting the position of the mandrel 30 and centralizer 40 downhole in the wellbore 22.

[0026] Figure 3 depicts a perspective view of an exemplary embodiment of a collar 42 of a centralizer 40. Figure 4 depicts a cross-section view of the exemplary embodiment of the body or collar 42 of Figure 3. The collar or body 42 may be generally cylindrical in shape and define a void 41 which may attach to, mount to, couple to, engage or surround the mandrel 30 or piece of oilfield equipment 16. The collar 42 may be filament wound, compression molded, transfer molded, cast, or machined. In one exemplary embodiment, the collar 42 may be formed from a composite material 60 similar to that of the composite material 60 which forms the bow spring 50. In alternate exemplary embodiments, the collar 42 may be constructed of any suitable material, including metal. The collar or body 42 may also define one or more engagement mechanisms 44 to which the end portion 46 of the bow spring 50 may attach. The engagement mechanism 44 may be a notch, groove, slit or slot 44a as depicted, and/or the bow springs 50 may attach or couple to the collar 42 in any other manner known in the art including: integrally forming the bow springs 50 and the collars 42 as a single unit; mechanical fastening such as welding

or bolting; adhesive fastening; or other techniques as known in the art. Holes may be drilled through the top end 46a and bottom end 46b of bow spring 50 for enhancing attachment, and the collars 42 may have counter-holes 44c (connected to and/or intersecting the slot 44a) for respectively bolting down, securing, attaching, fastening, or fixing the top end 46a and bottom end 46b of the bow spring 50 to the collars 42. By way of example only, the engagement mechanism 44 may be angled at an offset angle 44b to the longitudinal or mandrel axis 34.

[0027] Figure 5 depicts an exploded view of an exemplary embodiment of a bow spring 50 of the centralizer 40. The bow spring 50 may be made up of a plurality of layers or plies 54. The layers or plies 54 may be grouped into a first portion 51 of layers or plies 54 and a second portion 61 of layers or plies 54. The plurality of layers or plies 54 together form a laminate or laminated composite 47 which has undergone a curing process to become cured laminated composite 57. As illustrated in Figure 6, the layer or ply 54 in the embodiment shown is created from a unidirectional composite material 60 having a matrix 58 and a plurality of fibers or reinforcements 59. Within each layer or ply 54, a proportion of fibers or reinforcements 59 are oriented in the same particular direction with respect to axis 34 while suspended within the matrix 58. By way of example only, the matrix 58 may be a thermoplastic (e.g. PEEK, PTFE, PEK, PEKK, HDPE, PEI, nylon, polypropylene, LDPE, polycarbonate, PVC, ABS etc.), or a thermoset (e.g. epoxy, vinylester, polyester, phenolic, polyamide, bismaleimide, polyurethane, polyimide, cyanate ester, polyamidimide, etc.), or any other suitable substance. Further, the reinforcements 59 may be, by way of example only and not limited to, glass fibers, carbon fibers, aramid fibers, and/or synthetic fibers. Further, the composite material 60 may optionally take, by way of example only, the following forms: preform, pre-impregnated, mat, woven, fabric, tow, yarn, or ¼" to 3" (0.635 to 7.62 cm) chopped fiber.

[0028] The layer 54 represented in Figure 6 contains unidirectional reinforcements 59 as part of the laminated composite 47 and layers 54 are primarily unidirectional in the exemplary embodiments shown. However, it is to be understood that layers 54 are not limited to containing unidirectional reinforcements 59 and may contain matted/woven reinforcements or composite material 60a (see Fig. 11), be void of

reinforcements 59, or contain reinforcements of others shapes such as rods, spheres or crystalline (impregnated, blended in or separate from unidirectional reinforcements 59). The outer portion 51 preferably, but not necessarily, has greater than or equal to layer(s) 54 containing unidirectional reinforcements 59 as compared to layer(s) 54 making up the inner portion 61.

[0029] Referring to Figures 5 and 6, each layer or ply 54 has reinforcements or fibers 59 oriented at an angle (inclusive of zero degrees or parallel) with respect to the axis 34. Although illustrated with six layers 54 in Figure 5, the laminate or laminated composite 47 may be composed of any number of layers or plies 54, as long as more than one layer or ply 54 is utilized, and the first portion 51, having at least one layer or ply 54, is asymmetric about the midplane 62 to the second portion 61, having at least one layer or ply 54.

[0030] By way of example only, as shown in Figures 5 and 6, one or more layers or plies 54 may have a proportion of the reinforcements or fibers 59 oriented in parallel (i.e. at an angle equal to 0, 180 or 360 degrees) to the axis 34. In addition, by way of example, one or more layers or plies 54 may have a proportion of the reinforcements or fibers 59 oriented asymmetric (i.e. at any angle other than 0, 180 or 360 degrees) to the axis 34 (including one or more layers 54 having reinforcements/fibers 59 perpendicular, i.e. at an angle equal to 90 or 270 degrees, to the axis 34). While Figure 5 illustrates the layers 54 in the first portion 51 having fibers 59 with the same parallel orientation in an exemplary embodiment, it is to be appreciated that layers or plies 54 in the first portion 51 may have any orientation of fibers 59 so long as the average fiber 59 orientation of the first portion 51 is less than the second portion 61. In other words, the first portion 51 and the second portion 61 may be conceptually divided by a mid-plane 62, and the absolute values of the fiber 59 orientation with respect to the longitudinal axis 34 of each respective layer 54 within the first portion 51 may be summed. Next, such first portion sum is divided by the number of layers or plies 54 of the first portion 51 in order to determine an average angular fiber 59 orientation of the first portion 51. Likewise, the absolute values of the fiber 59 orientation with respect to the longitudinal axis 34 of each respective layer 54 within the second portion 61 may be summed. Then, such second portion sum is divided by the number of layers or plies 54 of the second portion 61 in order to determine an

average angular fiber 59 orientation of the second portion 61. And, in the preferred embodiment, the average angular fiber 59 orientation of the first portion 51 will be less than average angular fiber 59 orientation of the second portion 61. As the average angular fiber 59 orientation of the first portion 51 will be less than average angular fiber 59 orientation of the second portion 61, by definition the two said averages shall be asymmetric with respect to each other. Moreover, one or both of said averages may be asymmetric with respect to the longitudinal axis 34. The laminated composite 47 may also have a coating 56 which may be a low-friction coating added to a surface of the bow springs 50.

[0031] As used in the bow spring 50, the laminated composite 47 is a cured laminate 57. In an exemplary embodiment, the layers 54 are laid up in an asymmetric fashion wherein the first portion 51, with layers 54 having a proportion of fibers 59 with an average orientation of fibers 59 less than the second portion 61, are placed or arranged farthest from the mandrel 30; and the second portion 61 with layers 54 having a proportion of fibers 59 with an average orientation greater than the first portion 51, will be placed or arranged on the side nearest to the mandrel 30.

[0032] Figure 7 depicts a side cross-section view of an alternate exemplary embodiment of a bow spring 50 of a centralizer 40, as uncured laminated composite 55. In this alternate exemplary embodiment, the laminated composite 47 has twelve layers or plies 54. Of the twelve layers or plies 54, there are six layers or plies 54 forming the first portion 51. The layers 54 in the first portion 51 may have a proportion of reinforcements/fibers 59 oriented axial, parallel or at zero degrees (0º) to the axis 34. However, the individual layers 54 in the first portion 51 may have any fiber 59 orientation so long as the average orientation of the fibers 59 in the first portion 51 is less than the average orientation of the fibers 59 in the second portion 61. This first or outer portion 51 is arranged to be farthest from the mandrel 30 or piece of oilfield equipment 16 and will warp the least during the curing process.

[0033] Of the twelve layers or plies 54 in Figure 7, there are six layers or plies 54 forming the second portion 61. The layers 54 in the second portion 61 may have a proportion of reinforcements/fibers 59 oriented in less than total alignment with the axis 34. Although the exemplary embodiment of layers 54 in the second portion 61 is illustrated in Figure 7 with fibers 59 oriented at positive forty-five degrees (+45º),

negative forty-five degrees (-45º) and at ninety degrees (90º), it is to be appreciated that the proportion of fibers 59 in the second portion 61 may occupy any orientation so long as the average orientation of the fibers 59 in the second portion 61 is greater than the average orientation of the fibers 59 in the first portion 51. This second or inner portion 61 is arranged to be nearest to the mandrel 30 or piece of oilfield equipment 16 and may be separated from the first portion 51 by a midplane 62. The midplane 62 may not necessarily have equal numbers of layers 54 on either side of the midplane 62, although it is illustrated as such in Figures 7 and 8. Of the second portion 61, there may be a portion 53, as seen in Figure 7, wherein the layers 54 in the portion 53 which have a proportion of reinforcements/fibers 59 oriented perpendicular, or ninety (90º) to the axis 34. The layers 54 in the portion 53 are arranged to warp the most during the curing process as a result of the perpendicular orientation of the reinforcements/fibers 59.

[0034] Figure 8 depicts a side cross-section view of the alternate exemplary embodiment of the bow spring 50 in Figure 7, wherein the laminate composite 47 has undergone a curing or manufacturing process to become a cured laminate or cured laminate composite 57. Such manufacturing or curing processes to cure a laminate composite 47 may include compression/heat curing, autoclave curing, infusion, resin transfer molding, Vacuum Assisted Resin Transfer Molding (VARTM), filament winding, thermoforming or other known methods to produce an asymmetric cured laminated composite 57 with a thermoplastic or thermoset matrix 58 (or other matrices 58).

[0035] Each layer or ply 54 of composite material 60 may have transverse Coefficients of Thermal Expansion (CTEs) approximately seven times (e.g. E-Glass fiber) to approximately twenty times (e.g. carbon fibers) of the longitudinal CTE. As a result, when the layers 54 of the asymmetric laminate composite 47 are cured/manufactured through one of the aforementioned processes, the laminate composite 47 will warp due to unbalanced CTE changes through the thickness of the laminate 47 following cure at elevated temperatures.

[0036] As the uncured laminated layup or composite 55 of Figure 7 undergoes the manufacturing or cure cycle and returns to room temperature, the bottom six layers 54 forming the second portion 61 nearest to the mandrel 30 will contract or warp

substantially more than the top six layers 54 forming the first portion 51 furthest from the mandrel 30 due to the difference in CTEs. As a result, the substantially larger contraction of the inner portion 61 will deform the entire laminate composite or layup 47 inward to form a curve or an arc 48 while maintaining an amount of flex to the bow spring 50. The load of centralizing the mandrel 30 or piece of oilfield equipment 16 may be at least partially borne or carried by the flex or spring of the cured laminate 57. The internal and/or hygrothermal stresses which result in warpage act to increase the spring rate of the cured laminate composite 57. Furthermore, the cured laminated composite 57 does not take a permanent set following deformation (i.e. a constant spring rate is maintained for a longer period than steel during fatigue or multiple loadings). The amount of flex or deformation and spring rate of cured asymmetric laminate 57 can be approximated by equations, formulas and constants known in the art.

[0037] The residual internal stresses of the cured asymmetric laminated composite or laminate layup 57 may result in higher spring rate-to-weight ratio than is achievable with similarly sized symmetric laminates. Moreover, the bow springs 50 created from cured laminate composites 57 may be lightweight, low friction, non-scoring, drillable, tailorable, and have a constant spring rate.

[0038] Figure 9 depicts an exploded view of an alternate exemplary embodiment of a bow spring 50 of a centralizer 40. The alternate exemplary embodiment of the bow spring 50 in Figure 9 has two layers or plies 54 which make up the cured laminated composite 57: a first or outer portion 51, having a single layer 54 with fibers 59 oriented parallel to the longitudinal or mandrel axis 34; and a second or inner portion 61, having a single layer 54 wherein the fibers 59 are oriented perpendicular to the axis 34.

[0039] Figure 10 depicts an exploded view of an alternate exemplary embodiment of a bow spring 50 of a centralizer 40. In Figure 10, the first portion 51 and second portion 61 are separated by an internal layer, layers or segment 63. The internal segment 63 may be any suitable material, including materials which are not composites, composite materials having non-unidirectional reinforcements (e.g. a matted/woven reinforcement, layer and/or composite material 60a, see Fig. 11), and further, may or may not be one or more layers in a laminate. Either side of the

midplane 62 may contain layers 54 oriented from -90 degrees to +90 degrees (as measured in the X, Y plane with the longitudinal/mandrel axis 34 indicating 0, 180 and -180 degrees), as long as the average orientation of the fibers in the first portion 51 is less than the average orientation of fibers in the second portion 61. Further, the first portion 51 is asymmetric to the second portion 61 about the midplane 62. In the alternate exemplary embodiment in Figure 10, the first portion 51 and second portion 61 may each be a single layer or ply 54, having different average orientations as detailed above.

[0040] While the exemplary embodiments are described with reference to various implementations and exploitations, it will be understood that these exemplary embodiments are illustrative and that the scope of the inventive subject matter is not limited to them. By way of example only, it is to be appreciated that not all the bow springs 50 of the centralizer 40 may necessarily be formed with asymmetric laminated composite 47. For example, a centralizer 40 may have several bow springs 50 which may be at least partially made of cured laminated composite 57, and several bow springs which may be more conventional bow springs, such as those made from entirely unlaminated materials. Additionally, aside from reinforcement/fiber 59 orientation, each layer 54 may be formed from combinations of matrices 58 and fibers 59 distinct from one or more layers 54 in the laminate composite 47. Further, the width and thickness throughout the length of the bow spring 50, as well as the length and shape of the bow spring 50, may be varied as optimal for the situation desired by the operator of the drilling system 10. Layers or plies 54 may be grouped such that there are greater than two portions 51, 61 (with each additional contiguous portion separated by a mid-plane). Many variations, modifications, additions and improvements are possible.

[0041] Plural instances may be provided for components, operations or structures described herein as a single instance. In general, structures and functionality presented as separate components in the exemplary configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements may fall within the scope of the inventive subject matter.

CLAIMS:

1. A bow-spring apparatus for use in a centralizer, wherein the centralizer defines a longitudinal axis and further wherein the bow-spring comprises a laminated composite having a plurality of layers and wherein the laminated composite defines a midplane, further comprising:

    a first portion of the plurality of layers contiguous with the midplane, wherein the first portion comprises a first matrix including a first plurality of reinforcements and wherein the first portion has a first average angular orientation of the first plurality of reinforcements in relation to the longitudinal axis;

    a second portion of the plurality of layers contiguous with the midplane, wherein the second portion comprises a second matrix including a second plurality of reinforcements and wherein the second portion has a second average angular orientation of the second plurality of reinforcements in relation to the longitudinal axis; and

    wherein the first average angular orientation is less than the second average angular orientation.

2. The bow-spring apparatus according to claim 1, further comprising a mandrel wherein the centralizer is mounted on the mandrel, and wherein the second average angular orientation of the second plurality of reinforcements is asymmetric relative to the longitudinal axis.

3. The bow-spring apparatus according to claim 1, further comprising a layer of friction reducing coating adjacent the first portion.

4. The bow-spring apparatus according to claim 1, wherein the reinforcements are fibers.

5. The bow-spring apparatus according to claim 1, wherein the type of the reinforcements are selected from the group consisting of glass fibers, carbon fibers, aramid fibers, synthetic fibers, and mixtures thereof.

6. The bow-spring apparatus according to claim 1, wherein the form of the reinforcements are selected from the group consisting of filament, tow, yarn, chopped, and mixtures thereof.

7. The bow-spring apparatus according to claim 1, wherein the first matrix is a thermoplastic material.

8. The bow-spring apparatus according to claim 1, wherein the first matrix is a thermoset material.
9. The bow-spring apparatus according to claim 1, wherein the second matrix is a thermoplastic material.
10. The bow-spring apparatus according to claim 1, wherein the second matrix is a thermoset material.
11. The bow-spring apparatus according to claim 7, wherein the thermoplastic material is selected from the group consisting of PEEK, PTFE, PEK, PEKK, HDPE, PEI, nylon, polypropylene, LDPE, polycarbonate, PVC, and ABS.
12. The bow-spring apparatus according to claim 8, wherein the thermoset material is selected from the group consisting of epoxy, vinylester, polyester, phenolic, polyamide, bismaleimide, polyurethane, polyimide, cyanate ester, and polyamidimide.
13. The bow-spring apparatus according to claim 2, further comprising a first collar mounted to the mandrel, wherein the first collar is configured for receiving one end of the bow-spring; and a second collar mounted to the mandrel, wherein the second collar is configured for receiving another end of the bow-spring.
14. The bow-spring apparatus according to claim 13 wherein the first collar and the second collar are configured for production by molding.
15. The bow-spring apparatus according to claim 13 wherein the first collar and the second collar are configured for production by filament winding.
16. The bow-spring apparatus according to claim 13, wherein the first collar defines a slit offset from the axial orientation of the mandrel and further defines a first counter-hole connected to the slit, wherein the first counter-hole is configured for securing the first collar to one end of the bow-spring; and wherein the second collar defines another slit offset from the axial orientation of the mandrel and further defines a second counter-hole connected to the other slit, wherein the second counter-hole is configured for securing the second collar to the other end of the bow-spring.

17. A method for centralizing a mandrel within a hole, wherein the mandrel defines a longitudinal axis, which comprises the steps of mounting a centralizer having a plurality of bow-springs around the mandrel and centralizing the mandrel with the plurality of bow-springs comprising:

a laminated composite having a plurality of layers wherein a first portion of the plurality of layers includes a first matrix including a first plurality of reinforcements, wherein the first portion has a first average angular orientation of the first plurality of reinforcements in relation to the longitudinal axis;

wherein a second portion of the plurality of layers includes a second matrix including a second plurality of reinforcements, wherein the second portion has a second average angular orientation of the second plurality of reinforcements in relation to the longitudinal axis

wherein the first average angular orientation is less than the second average angular orientation.

18. A method of making a bow-spring for a centralizer, comprising the steps of:

forming a laminated composite having a plurality of layers and wherein the laminated composite defines a midplane comprising:

a first portion of the plurality of layers contiguous with the midplane, wherein the first portion comprises a first matrix including a first plurality of reinforcements, wherein the first portion has a first average angular orientation of the first plurality of reinforcements in relation to a longitudinal axis;

a second portion of the plurality of layers contiguous with the midplane, wherein the second portion comprises a second matrix including a second plurality of reinforcements, wherein the second portion has a second average angular orientation of the second plurality of reinforcements in relation to the longitudinal axis; and

wherein the first average angular orientation is less than the second average angular orientation.

19. The method according to claim 18, wherein the first average angular orientation and the second average angular orientation differ by greater than zero to less than or equal to ninety degrees.

20. The method according to claim 18, further comprising curing the composite.

21. The method according to claim 18, further comprising machining the composite.

22. A bow-spring apparatus for use in a centralizer wherein the bow-spring comprises a laminated composite having a plurality of layers, further comprising:

a first ply of the plurality of layers, wherein the first ply comprises a first matrix including a first plurality of reinforcements, wherein the first plurality of reinforcements are axially aligned in a first orientation;

a second ply of the plurality of layers, wherein the second ply comprises a second matrix including a second plurality of reinforcements, wherein the second plurality of reinforcements are axially aligned in a second orientation; and

wherein the first orientation is asymmetric with respect to the second orientation.

23. The bow-spring apparatus according to claim 22, wherein the centralizer is mounted on a mandrel and wherein the mandrel is axially aligned in the second orientation.

24. The bow-spring apparatus according to claim 22, further comprising:

a third ply of the plurality of layers, wherein the third ply comprises a third matrix including a third plurality of reinforcements, wherein the third plurality of reinforcements are axially aligned in a third orientation.

25. The bow-spring apparatus according to claim 24, wherein the third orientation is asymmetric with respect to the second orientation.

26. The bow-spring apparatus according to claim 25, wherein the third orientation is asymmetric with respect to first orientation.

27. The bow-spring apparatus according to claim 26, further comprising:

a fourth ply of the plurality of layers, wherein the fourth ply comprises a fourth matrix including a fourth plurality of reinforcements, wherein the fourth plurality of reinforcements are axially aligned in a fourth orientation.

28. The bow-spring apparatus according to claim 27, wherein the fourth orientation is asymmetric with respect to the first, second and third orientations.

29. The bow-spring apparatus according to claim 22, wherein the first ply comprises one of a group of plies arranged consecutively together with each having the first orientation.

30. The bow-spring apparatus according to claim 29, wherein the second ply comprises one of a second group of plies arranged consecutively together with each having the second orientation.
31. The bow-spring apparatus according to claim 22, further comprising a layer of a friction reducing coating adjacent the second ply.
32. The bow-spring apparatus according to claim 22, wherein the reinforcements are fibers.
33. The bow-spring apparatus according to claim 22, wherein the type of the reinforcements are selected from the group consisting of glass fibers, carbon fibers, aramid fibers, synthetic fibers, and mixtures thereof.
34. The bow-spring apparatus according to claim 22, wherein the form of the reinforcements are selected from the group consisting of filament, tow, yarn, chopped, and mixtures thereof.
35. The bow-spring apparatus according to claim 22, wherein the first matrix is a thermoplastic material.
36. The bow-spring apparatus according to claim 22, wherein the first matrix is a thermoset material.
37. The bow-spring apparatus according to claim 22, wherein the second matrix is a thermoplastic material.
38. The bow-spring apparatus according to claim 22, wherein the second matrix is a thermoset material.
39. The bow-spring apparatus according to claim 35, wherein the thermoplastic material is selected from the group consisting of PEEK, PTFE, PEK, PEKK, HDPE, PEI, nylon, polypropylene, LDPE, polycarbonate, PVC, and ABS.
40. The bow-spring apparatus according to claim 36, wherein the thermoset material is selected from the group consisting of epoxy, vinylester, polyester, phenolic, polyamide, bismaleimide, polyurethane, polyimide, cyanate ester, and polyamidimide.

41. The bow-spring apparatus according to claim 23, further comprising:
    a first collar mounted to the mandrel, wherein the first collar defines a slit offset from the axial orientation of the mandrel for receiving one end of the bow-spring; and
    a second collar mounted to the mandrel, wherein the second collar defines another slit offset from the axial orientation of the mandrel for receiving another end of the bow-spring.
42. The bow-spring apparatus according to claim 41, wherein the first collar and the second collar are configured for production by molding.
43. The bow-spring apparatus according to claim 41, wherein the first collar and the second collar are configured for production by filament winding.
44. The bow-spring apparatus according to claim 41, wherein the first collar further defines a first counter-hole connected to the slit, wherein the first counter-hole is configured for securing the first collar and one end of the bow-spring; and wherein the second collar further defines a second counter-hole connected to the other slit, wherein the second counter-hole is configured for securing the second collar and the other end of the bow-spring.
45. A method for centralizing a mandrel within a hole, which comprises the steps of mounting a centralizer having a plurality of bow-springs around the mandrel and centralizing the mandrel with the plurality of bow-springs comprising:
    a laminated composite having a plurality of layers wherein a first ply of the plurality of layers includes a first matrix including a first plurality of reinforcements, wherein the first plurality of reinforcements are axially aligned in a first orientation which is asymmetric with respect to an axial orientation of the mandrel.

46. A method of making a bow-spring for a centralizer, comprising the steps of:

laminating a composite having a plurality of layers comprising:

a first ply of the plurality of layers, wherein the first ply comprises a first matrix including a first plurality of reinforcements, wherein the first plurality of reinforcements are axially aligned in a first orientation;

a second ply of the plurality of layers, wherein the second ply comprises a second matrix including a second plurality of reinforcements, wherein the second plurality of reinforcements are axially aligned in a second orientation; and

wherein the first orientation is asymmetric with respect to the second orientation.

47. The method according to claim 46, wherein the first orientation and the second orientation are separated by an angle ranging from zero degrees to ninety degrees.

48. The method according to claim 46, further comprising curing the composite.

49. The method according to claim 46, further comprising drilling the composite.

50. The method according to claim 46, further comprising machining the composite.

51. A bow-spring apparatus for use in a centralizer, comprising:

a collar configured for mounting to a mandrel, wherein the collar defines a slit offset from an axial orientation of the mandrel for receiving one end of a bow-spring; and wherein the collar further defines a counter-hole connected to the slit, wherein the counter-hole is configured for securing the collar and one end of the bow-spring.

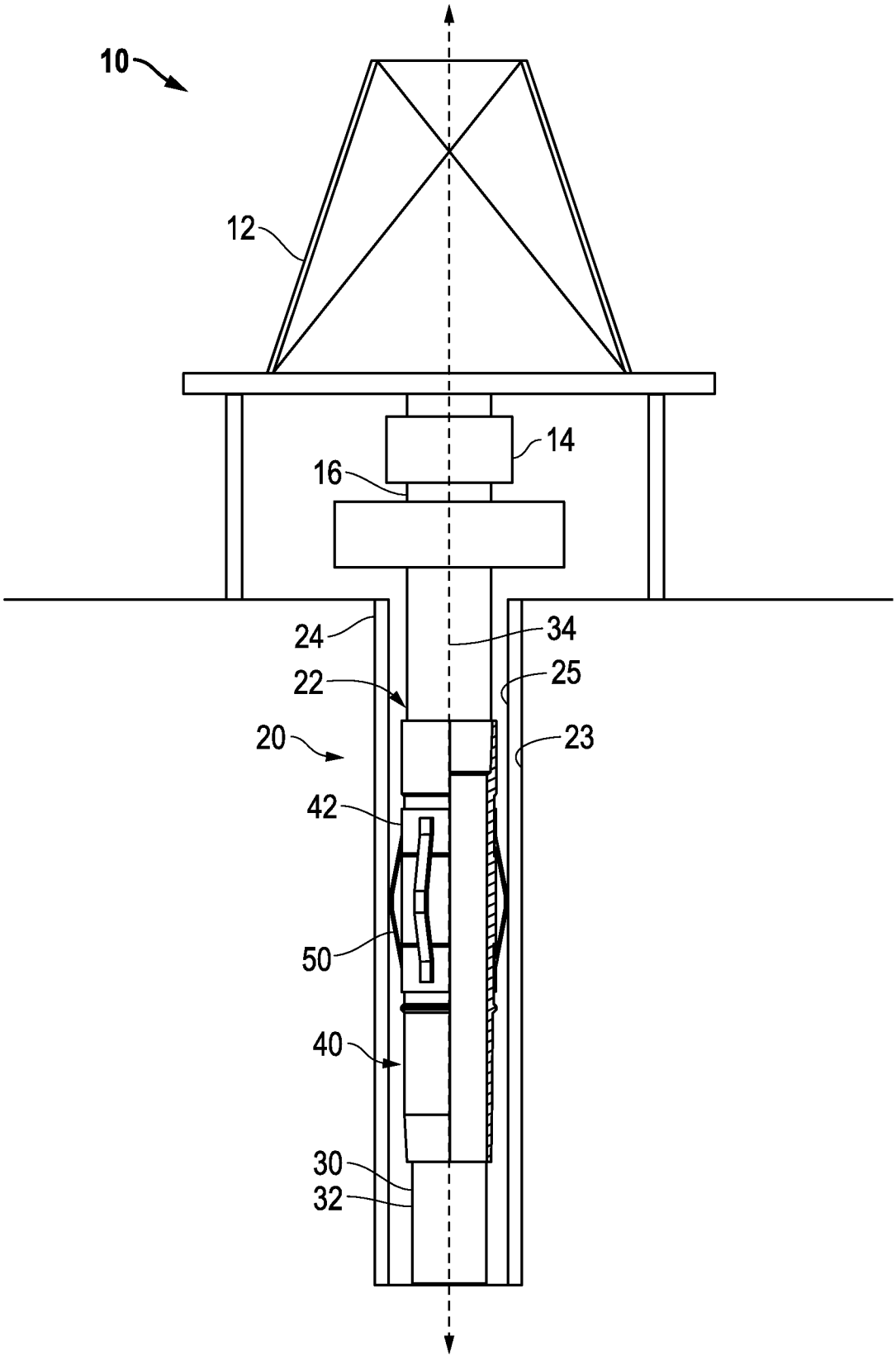


FIG. 1

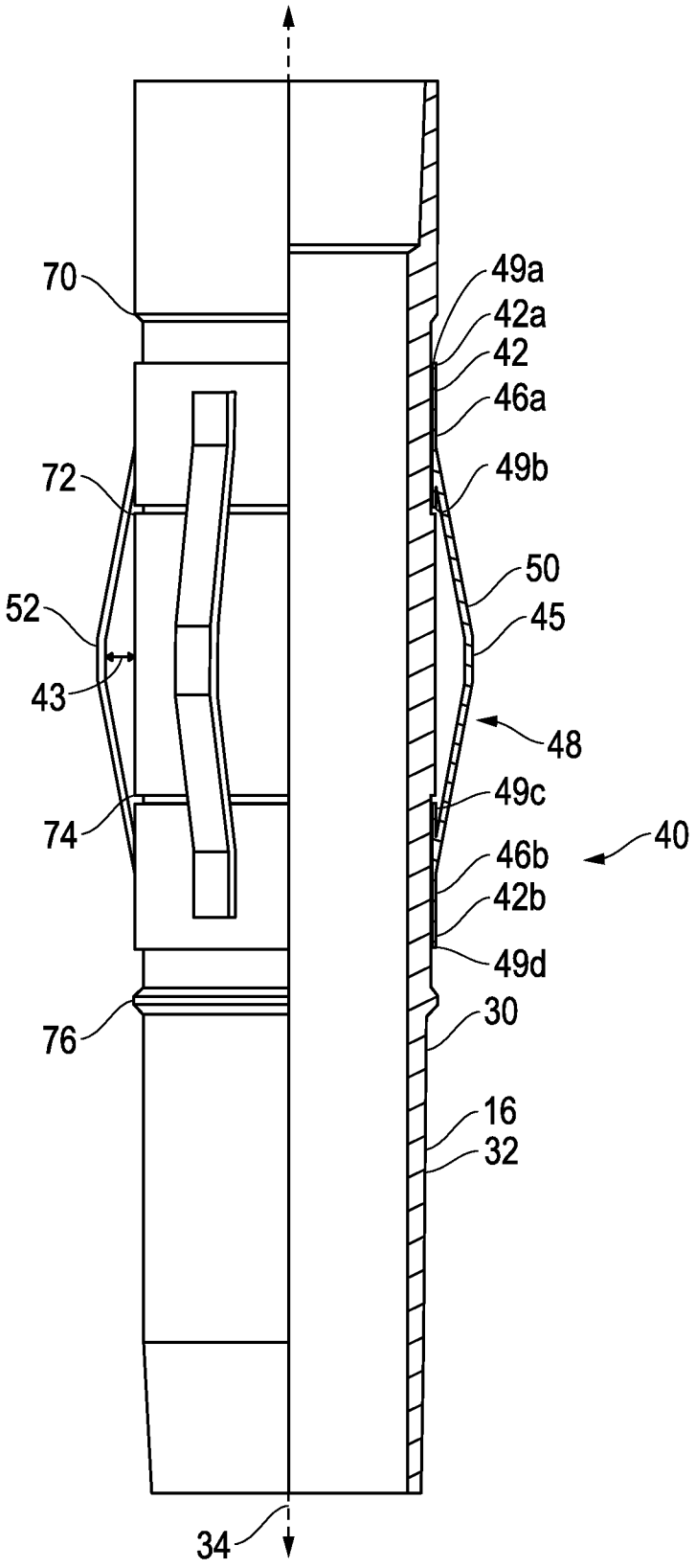

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FIG. 2

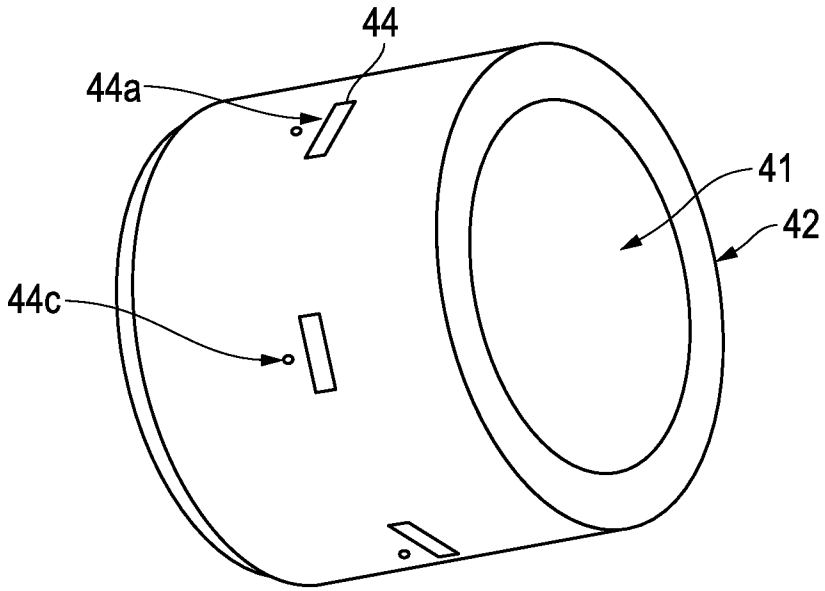


FIG. 3

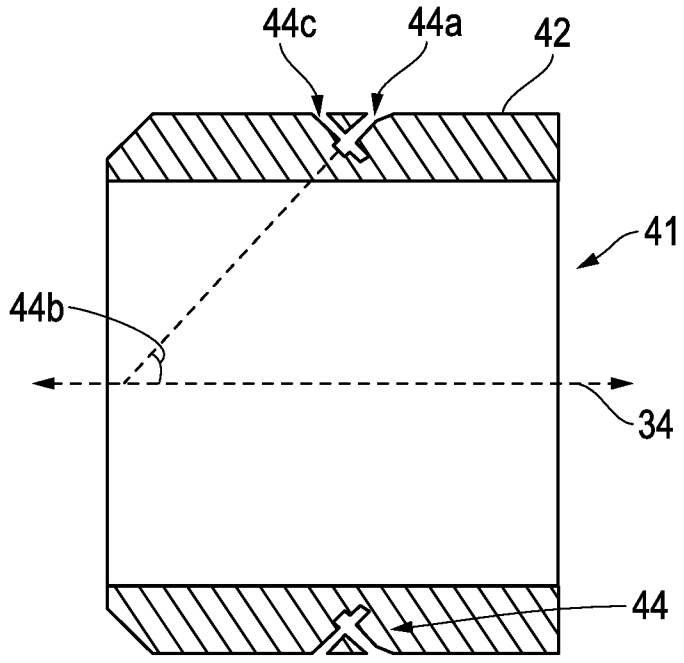


FIG. 4

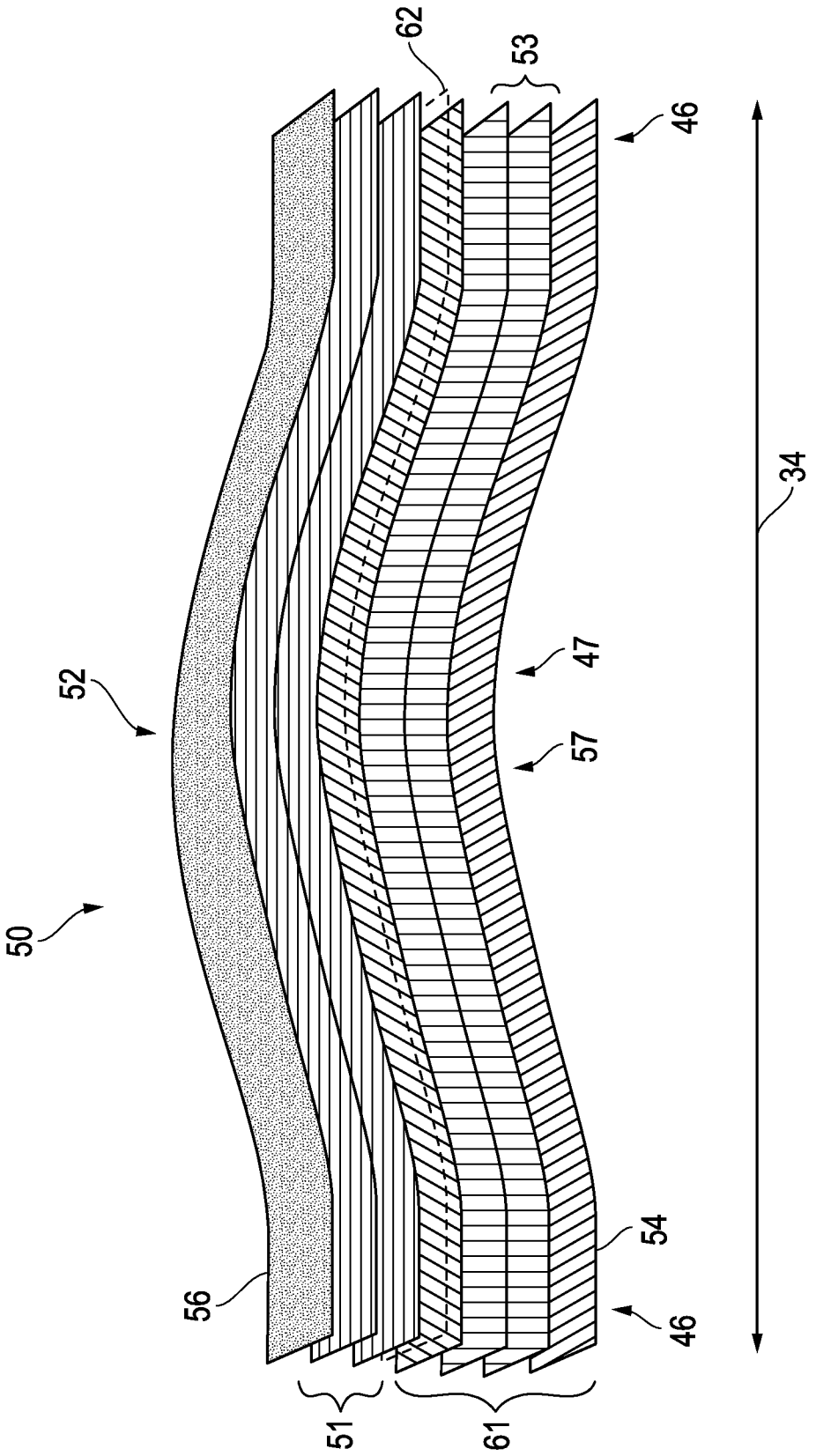


FIG. 5

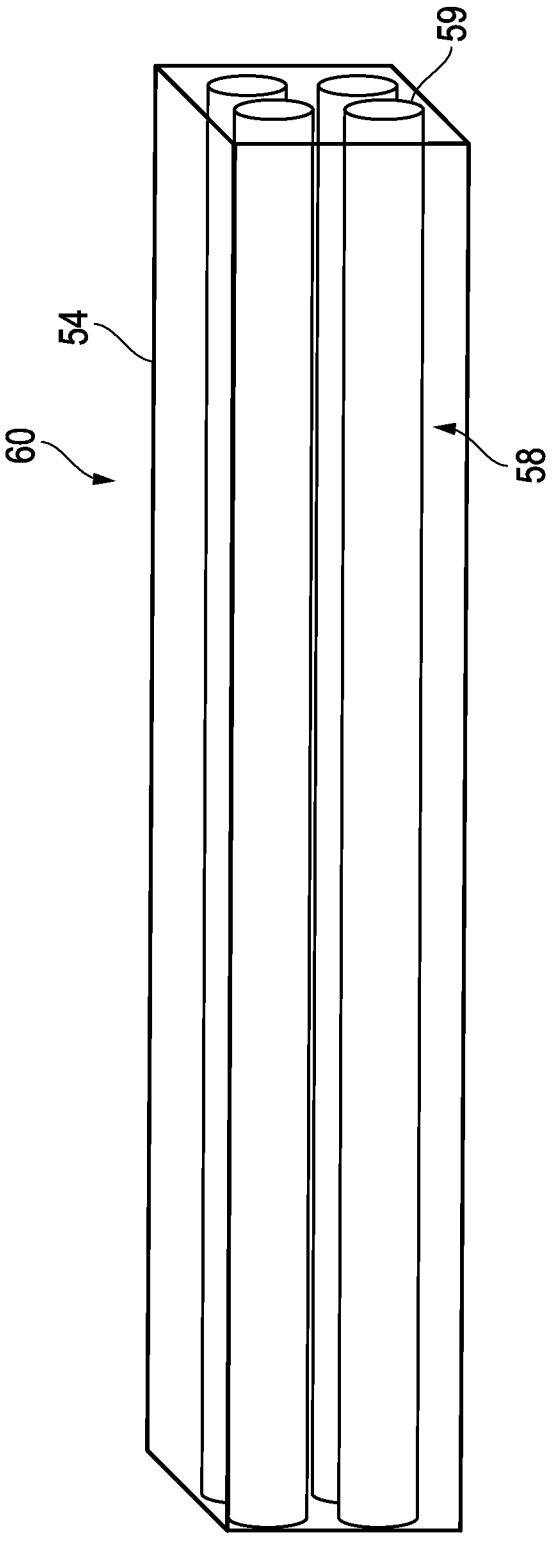


FIG. 6

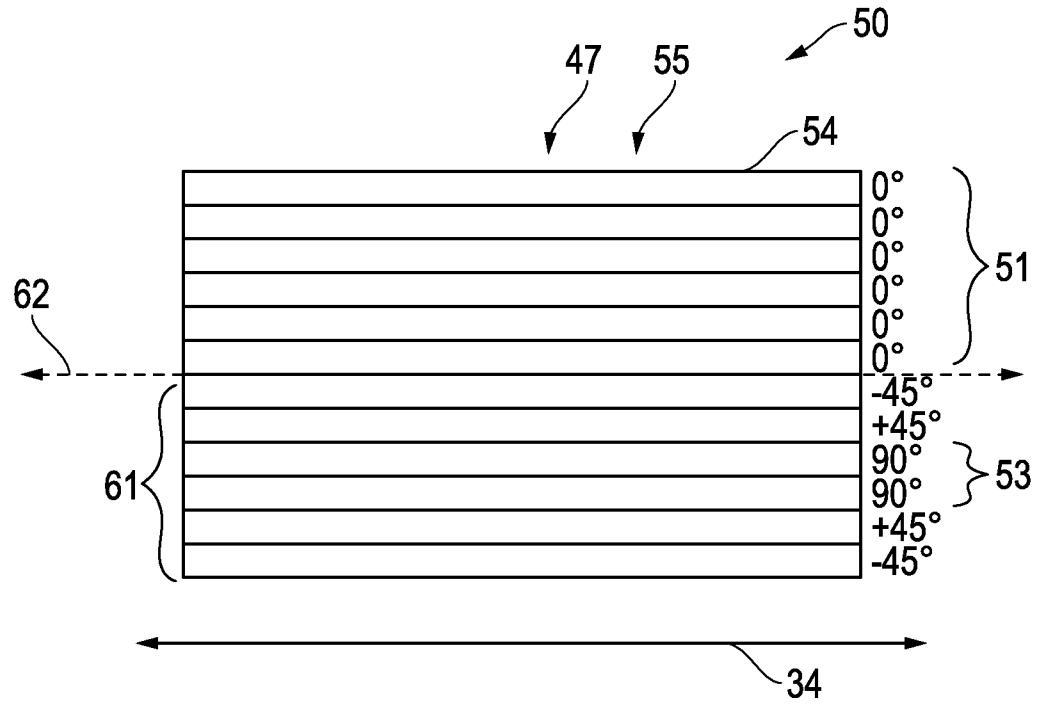

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FIG. 7

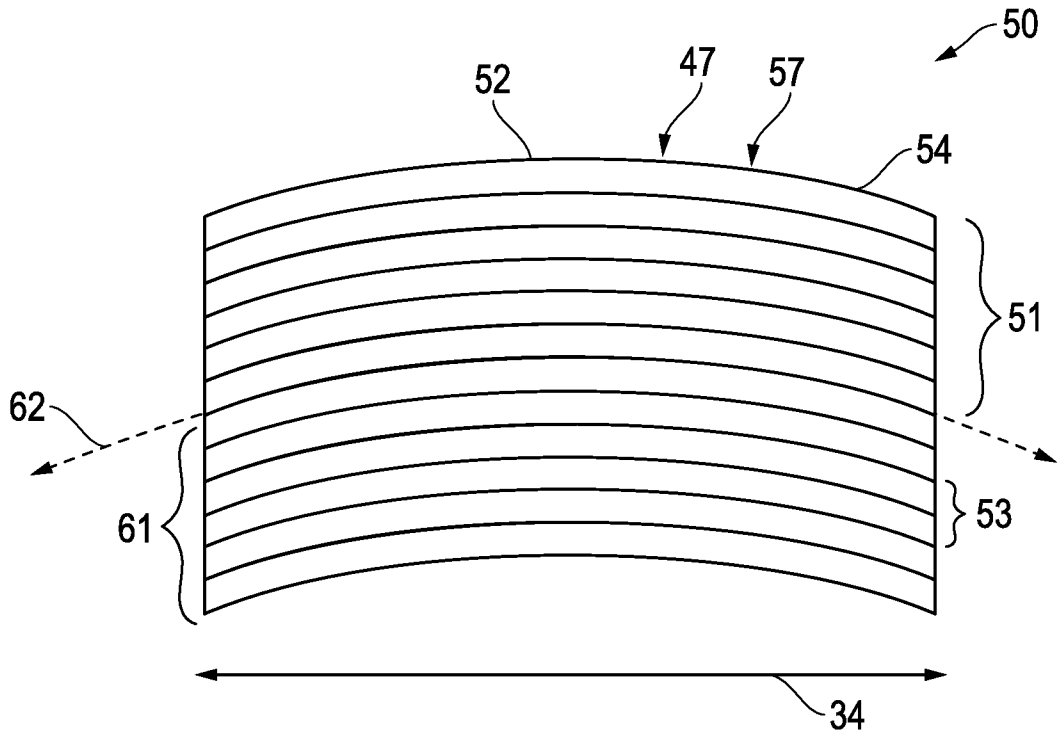

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FIG. 8

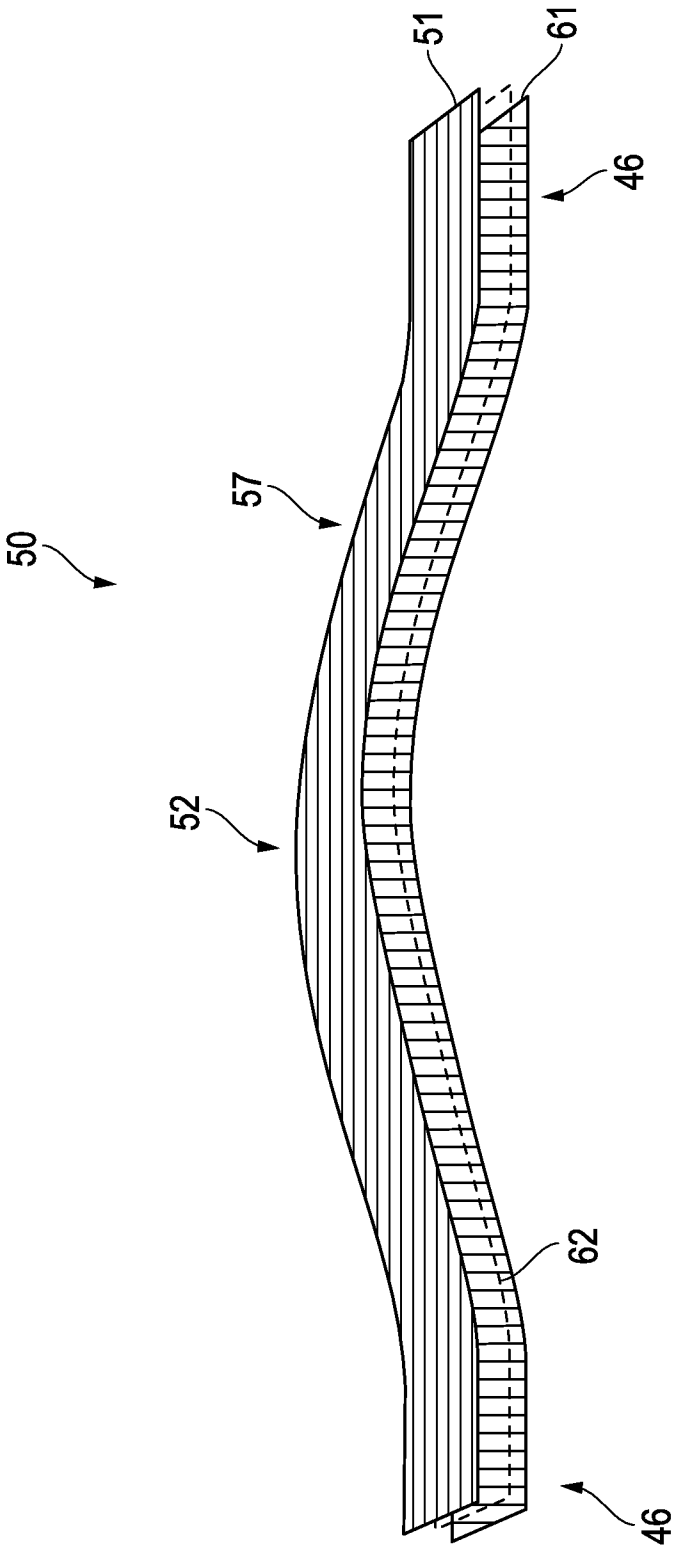


FIG. 9

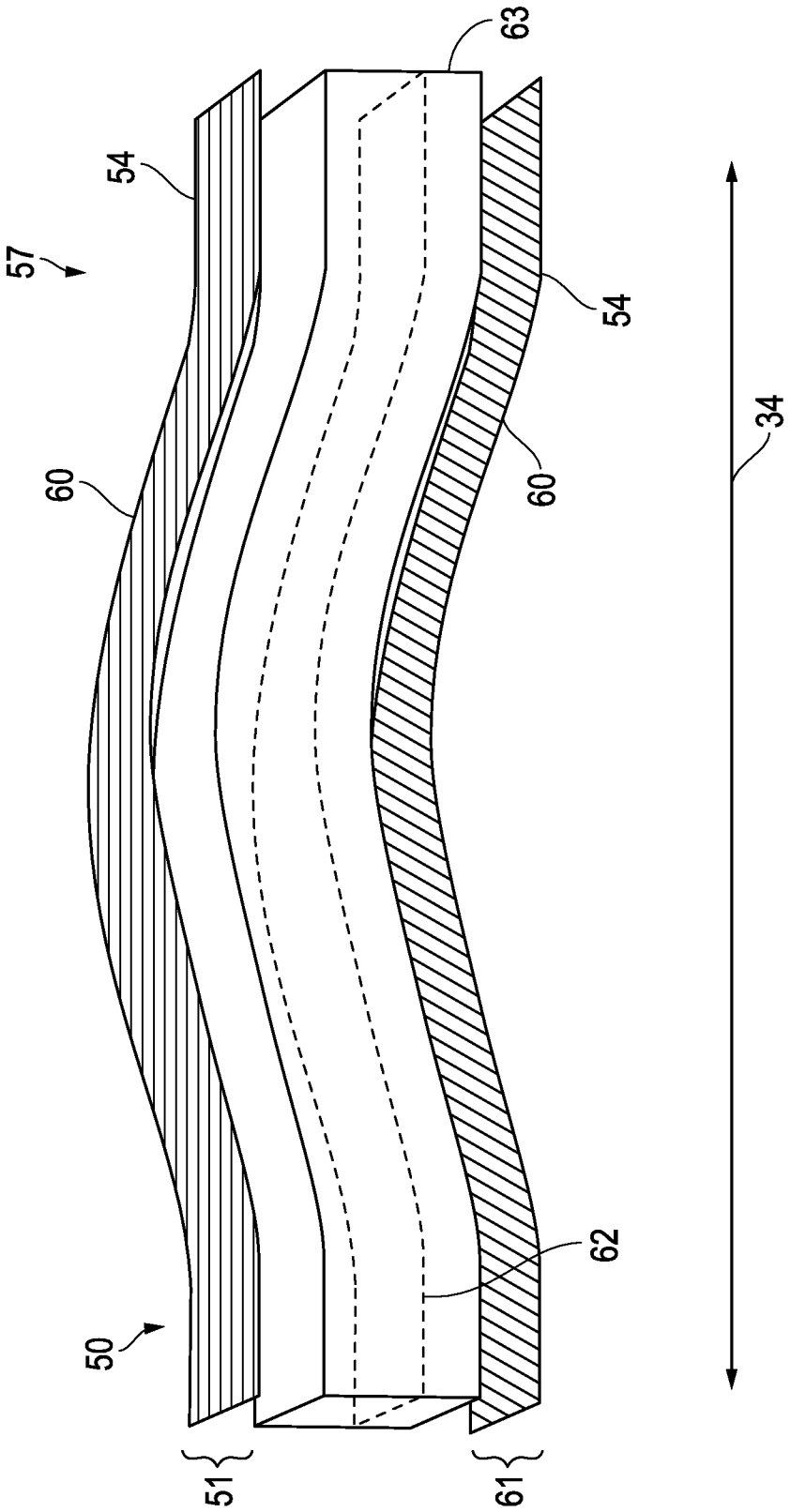


FIG. 10

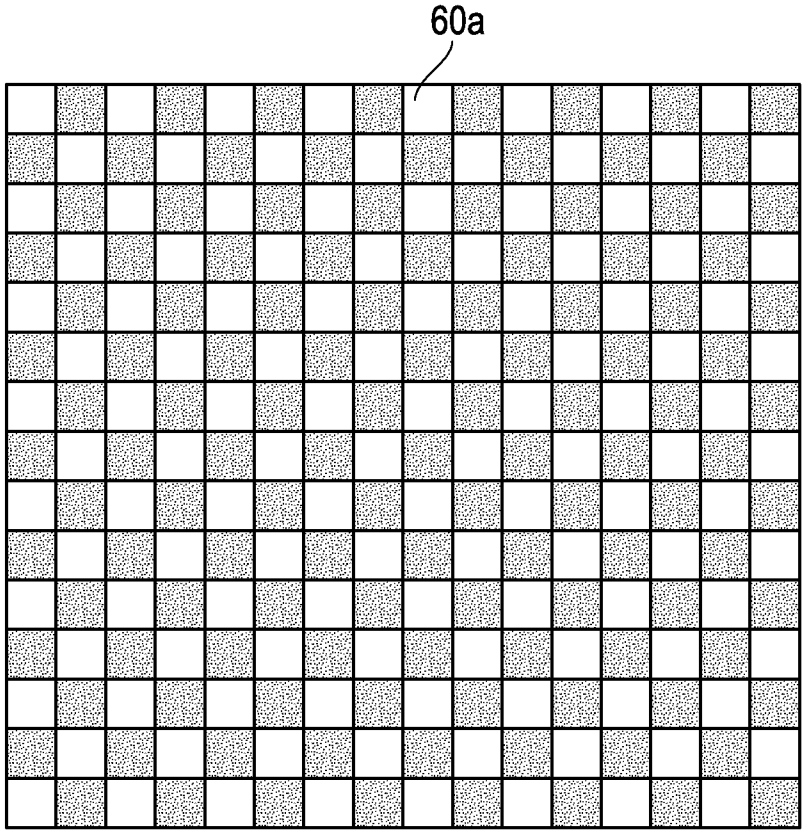


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/041385

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B17/10 B32B5/26
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 B32B

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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/319690 A1 (LEVIE WILLIAM IAIN ELDER [US] ET AL) 5 December 2013 (2013-12-05) paragraph [0031] paragraphs [0039] - [0041] paragraphs [0048], [0049], [0052] figures 1-10	1-50
Y	EP 2 671 707 A1 (BOEING CO [US]) 11 December 2013 (2013-12-11) paragraphs [0005] - [0008] paragraphs [0026] - [0028] figures 5, 8	1-50

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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	Date of mailing of the international search report
26 November 2015	02/12/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kecman, Ivan

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	paragraph [0028] paragraphs [0031] - [0032] paragraphs [0034] - [0035] figures 2-4	16,41,44

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A	US 4 363 360 A (RICHEY VERNON T) 14 December 1982 (1982-12-14) column 4, lines 10-60 figures 1-4	51

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International application No
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