



- (51) International Patent Classification:
E21B 7/06 (2006.01) *E21B 29/06* (2006.01)
- (21) International Application Number:
PCT/US2015/039661
- (22) International Filing Date:
9 July 2015 (09.07.2015)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
62/022,504 9 July 2014 (09.07.2014) 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, 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).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

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

(54) Title: CASING EXIT MILLS AND APPARATUS AND METHODS OF USE

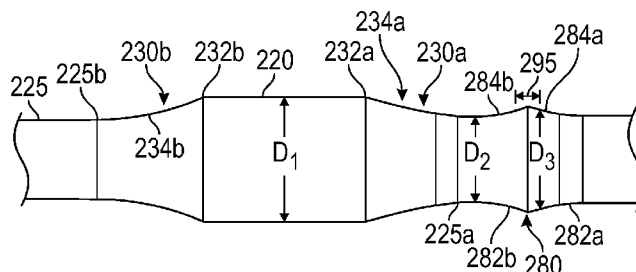


FIG. 2

(57) Abstract: A mill for use in milling a section in a wellbore is disclosed that includes a first concave curved section followed by a substantially flat section and a second concave curved section following the substantially flat section and a number of blades attached to the first concave curved section, substantially flat section and the second concave curved section, wherein each such blade includes a first convex curved portion that corresponds to the first concave curved section and a second convex curved portion that corresponds to the second concave curved section.

CASING EXIT MILLS AND APPARATUS AND METHODS OF USE

CROSS-REFERENCES TO RELATED APPLICATION

This application claims the benefit of U.S. Application No. 62/022504, filed on July 9, 2014, which is incorporated herein by reference in its entirety.

BACKGROUND1. Field of the Disclosure

[0001] The present disclosure is related to a milling apparatus for milling casing exits and to perform other cutting operations in wellbores.

2. Background Of The Art

[0002] Conventional cylindrical mills are commonly utilized for milling windows (or sections) in metal casings (such as pipes) placed in wellbores to provide exits for forming lateral wellbores and to perform other downhole cutting operations. Often, three mills (a window mill, a lower mill and an upper mill) are used on a bottomhole assembly (BHA) to perform the milling operations. Such mills generally include an enlarged pipe section (larger diameter section) that transitions to a smaller diameter pipe on both sides at a taper angle, typically 15°, with a small blending radius at both ends of the taper. Blades are welded over the tapered sections and the enlarged section. Although such tapers or tapered sections along with the small blending radiuses appear to provide a smooth transition between the two diameters to avoid stress concentration, the analysis and operational experience show a relatively high concentration of stress at such transitions. Additionally, the lower mill is the most highly stressed member of the bottomhole assembly (BHA). During milling operations, as the window mill moves down the ramp and laterally through the casing wall, the lower mill body is bent. High stress concentration occurs at the end of the blades, causing cracks to first appear near the ends of such blades. The lower mill is also subject to the substantial torque required to drive the mill, and to torsional impacts from the blades engaging (hitting) the side of the window and the cut slot. The torsional stress is sufficiently high to promote crack growth.

[0003] The disclosure herein provides a milling apparatus that addresses at least some of the above-described deficiencies of the mills.

SUMMARY OF THE DISCLOSURE

[0004] In one aspect, the present disclosure provides a mill for use in milling a section of a casing in a wellbore that in one embodiment includes a first concave curved section followed by a substantially flat section and a second concave curved section following the substantially flat section and a number of blades attached to the first concave curved section, substantially flat section and the second concave curved section, wherein each such blade includes a first convex curved section that corresponds to the first concave curved section and a second convex curved section that corresponds to the second concave curved section.

[0005] In another aspect, a method of milling a section of a casing in a wellbore is disclosed that in one embodiment includes: placing a ramp at a selected location in the casing; conveying a bottom hole assembly in the wellbore, the bottom hole assembly including a mill that contains a plurality of blades attached to a blade body, wherein at least one blade in the plurality of blades includes a tapered curved section attached to a corresponding curved tapered section along downhole side of the blade body for reducing stress on an end of the such blade; and milling a section of the casing above the ramp by the mill. In another aspect, one or more blades may further be attached to a curved tapered section on an uphole side of the blade body and wherein each such blade includes a curved section that corresponds to the curved section on the uphole side of the blade body. In another aspect a one or more bosses may be provided downhole and/or uphole of the blades to reduce the stresses on and extend the fatigue life of the blades.

[0006] Examples of certain features of the apparatus and method disclosed herein are summarized broadly in order that the detailed description thereof that follows may be better understood. There are, of course, additional features of the apparatus and method

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The disclosure herein is best understood with reference to the accompanying figures in which like numerals have generally been assigned to like elements and in which:

FIG. 1 (Prior Art) shows a line diagram of a prior art mill having a larger diameter (raised) section that tapers on both sides to a smaller diameter pipe and a blade attached to the tapered and larger diameter sections;

FIG. 2 shows a line diagram of a blade body that includes a raised section on a pipe with curved tapered sections on both sides of the pipe having a curved outer surface, according to one embodiment of the disclosure;

FIG. 3 shows a blade attached to the curved tapered sections and the raised section of the blade body shown in **FIG. 2**, wherein the underside of the blade profile matches or substantially matches the curved tapered sections;

FIG. 4 shows a bottom hole assembly carrying one or more mills made according to an embodiment of the disclosure;

FIG. 5 shows results of an analysis showing concentration of stress in and in front of a blade on a mill made according to the prior art embodiment shown in **FIG. 1**; and

FIG. 6 shows results of an analysis showing stress concentration on a blade of a mill made according to the embodiment shown in **FIG. 3**;

DESCRIPTION OF THE EMBODIMENTS

[0008] **FIG. 1** shows a line drawing of a partial prior art mill **100** that includes a body (also referred to as the “blade body”) **110** that includes a raised section **120** having a diameter **D1** and a first tapered section or lower tapered section **130a** that transitions or extends from an end **132a** of the raised section **120** to a point **115a** on a pipe **115** having a diameter **D2** toward a downhole side of the mill **100** (in this example, the right side). A second tapered section (or upper tapered section or ramp) **132b** transitions or extends from the second end **132b** of the raised section **120** to a point **115b** on the tapered section **130b** toward an uphole side (in this example, the left side) of the mill **100**. The diameter **D1** is greater than the diameter **D2**. The tapered sections **130a** and **130b** have respectively straight or flat outer surfaces **134a** and **134b**. A number of blades, such as blades **150a** and **150n** are attached circumferentially on surface **134a**, the raised section **120** and the surface **134b**. It is known that the ends **154a** and **154n** of blades **150a** and **150n** at the pipe **115** are subject to damage during milling of an opening in a casing. In some cases the prior art mills, such as mill **100**, provide a relief radius (not shown) covered with a wear resistant material to limit wear during milling. The application of the wear resistant material, typically tungsten carbide, is a high temperature process that can reduce the strength of the steel pipe, such as pipe **115**. During milling operations, the lower tapered section, such as section **130a**, moves the mill **100** laterally into the casing, bending the blade body **110**, which develops a high stress concentration at the end of the blades, such as end **154n** of blade **154**. Therefore, cracks typically first appear near the ends of the blades. The mill, such as mill **100**, is also subject to the substantial torque required to drive the mill and torsional impacts from the blades hitting the side of the window and the slot cut in the casing. The cracks formed are typically formed at an angle or even turn as they propagate or grow.

[0009] FIG. 2 shows a line diagram of a blade body **200**, according to a non-limiting embodiment of the disclosure. The blade body **200** includes a raised section **220** having a diameter or an outer dimension **D1** and a first or lower tapered section **230a** that transitions or extends from a first end **232a** of the raised section **220** to a point **225a** on a pipe **225** having a diameter or an outer dimension **D2** toward the lower or downhole side of the blade body **200** (in this example, the right side). A second or upper tapered section **230b** transitions or extends from the second or upper end **232b** of the raised section **220** to a point **225b** of the pipe **225** toward an upper or uphole side (in this example, the left side) of the blade body **200**. The diameter **D1** is greater than the diameter **D2**. The tapered sections **230a** and **230b** include curved surfaces (also referred to herein as “radiused” surfaces”) **234a** and **234b** respectively. The tapered section **230a** may include more than one curved surfaces, such as surfaces with the same or different curvatures. In one aspect, the radius or curvature of surface **234a** may be made as large as possible before it approaches a straight line in nature such that the stress reducing benefits are compromised. Up to a point as the curvature on the downhole or front side of the raised section is made larger, the stress in the blades and body near the end of the blades placed on such surface is reduced. Large radius surfaces, such as surfaces **234a** and **234b** provide additional length on the outer surface (compared to the flat surfaces **134a** and **134b**, FIG. 1) that elongate when the blade body **200** is bent, without excessive stretching and stress. A curved or radiused surface provides more surface length compared to a non-radiused surface. The relatively greater surface length prevents bending stress accumulation as the radiused surface is bent into a straight surface, compared to a non-radiused surface exposed to bending, since the area near the blade will experience stress from the cumulative stretching along the blade surface. In one aspect, a computer model is used to determine the optimum contour for minimum or optimal bending stress on the curved surface **234a**. The computer modes or equations for determining torsional stress concentration are similar to the bending stress models and thus a low bending stress concentration will have a low torsional stress concentration as well. Such models are known in the art and are not described herein. In one aspect, the blade body **200** may further include an enlarged section or boss **280**, on downhole side (in this example, the right side) of the raised section **220**, having a tapered section **282a** on the downhole or lower side and section **282b** on the upper or uphole side. The surfaces **284a** and **284b** of sections **282a** and **282b** may be curved. The curvature or radius **284a** of section **282a** and curvature or radius **284b** of section **282b** may be same or different. The diameter **D3** of boss **280** is between the diameters **D1** and **D2**. In another aspect, the boss **280** may be a cusp or may have a flat surface. The diameter or outer

dimension of the boss **280** is between the diameters **D1** and **D2**. In another aspect, the outer most surface of the boss **280** may have a length less than half the diameter **D2**. In yet another aspect, another boss (not shown) may be provided uphole of the upper tapered section **230b** to reduce bending stresses. In yet another aspect, more than one boss may be provided on one or both sides of the raised section **220**. A boss on the upper side of the raised section **220** is more useful in reducing bending stress in larger mills.

[0010] **FIG. 3** show the blade body **200** of **FIG. 2** with a blade **250** attached, such as by welding, on the upper curved surface **234b**, raised section **220** and the lower curved surface **234a**. In one aspect, the underside **252a** of the lower blade section **256a** includes a curved surface **254a** that matches or conforms or substantially matches or conforms to the contours of curved surface **234a** of section **230a** and the underside surface **252b** of the upper section **256b** of the blade **250** matches or conforms or substantially matches or conforms to the contour of the surface **234b** of the curved section **230b**.

[0011] Referring to **FIGS. 2** and **3**, as discussed above in reference to **FIG. 1**, the prior art mills provide a relief radius covered with a wear resisting material to prevent grooves from being worn in the pipe. The application of the wear resisting material, typically tungsten carbide, is a high temperature process which compromises the strength of the steel pipe, such as pipe **225**. In one aspect, the disclosure herein addresses such a problem by providing the enlarged section or boss **280** adjacent to the radiused section **230a**. In one aspect, such an enlargement holds the mill **200** away from the casing being milled to avoid damage to the ends of the blades, such as end **288a** of blade **250**. In another aspect, the boss **280** may have a narrow width or outside diameter surface **284**. Thus, in the non-limiting configuration shown in **FIG. 3**, the mill includes a narrow diameter enlargement or boss **280** formed by a continuation of the neck radius **284b** on one side, and radius **284a** on the other side. Forming one side with the neck radius, such as radius **284b**, near the blade ends reduces the stress on the blades during milling compared to the mills, such as mill **100** shown in **FIG. 1**. In one aspect, the surface width **284** of the enlarged section **280** is relatively small. In another aspect, the width **284** may be a point (cusp), as shown in **FIGS. 2** and **3**. In another aspect, the “point” **284** may be about .060”. In another aspect, the upset **295** protects the front ends of the blades, which alleviates the need for applying wear resisting material, such as carbide to the radiused section of the mill. Consequently, there is less reduction in the strength of the steel in the maximum stress area, as shown in reference to **FIG. 6**.

[0012] **FIG. 4** shows a wellbore system **400** with a bottom hole assembly **420** utilizing a lower mill **430** and a mill **450** made according to one or more embodiments of this

disclosure for milling a casing section and forming a lateral wellbore from the milled section. The system **400** shows a wellbore **401** that is lined with a casing **410**, such as a casing made from steel sections. A ramp **480** containing a whipstock **482** is shown anchored in the casing **410** by an anchor **484** at a location **485** where a window is to be milled in the casing **410**. A drill string **412** containing a conveying member **414** and a bottomhole assembly **420** is shown placed inside the casing **410**. The bottom hole assembly **420** includes a cutting device **425**, a lower mill **430** above the cutting device **425** and a second mill **450** above the mill **430**. Mill **430** or both mills **430** and **450** are made according to an embodiment of this disclosure. In the particular bottom hole assembly of **FIG. 4**, mills **430** and **450** are respectively shown to include blades **432a-432n** and **452a-452n** attached to a respective blade body, such as body **200** shown in **FIG. 2**. To form a window or mill a section **460** in the casing, **410**, the cutting device **425** travels along the whipstock **482** and makes an initial cut in the casing **410** at location **485**. The mill **430** then mills the window **460** as shown in **FIG. 4**. The stresses introduced in the mill **430** are reduced, compared to prior art mills, such as shown in **FIG. 1** due to the boss, such as boss **280** shown in **FIG. 2** and corresponding radiused tapered surfaces (such as surface **234a**) on the blade body **200** and radiused underside surfaces on the blades (such as blade **254a**), as described above in reference to **FIGS. 2** and **3**. The bottom hole assembly may be further used to form a lateral wellbore, as known in the art.

[0013] **FIG. 5** shows results of a FEA stress analysis for a prior art mill **500**, similar to the mill **100** shown in **FIG. 1**. For this FEA analysis, the mill **500** was constrained at the back end **510** and on the gage, and the front end **520** bent to the side as dictated by the whipstock geometry. The results shows high stress **530** in front **535a** of the blade **540** on the gage at the point of contact with the casing wall **535c**, and at the back **535b** of the blade, as shown in **FIG. 5**. In this analysis, the maximum stress was 34,000 psi just in front of the blade **540**.

[0014] **FIG. 6** shows results of a stress analysis for a mill **600** made according to an embodiment of the present disclosure, similar to the mill **300** shown in **FIG. 3**. The analysis shown in **FIG. 6** was performed in a manner similar to the analysis performed for mill **500** of **FIG. 5**. The results show a relatively lower stress **630** in front **635a** of the blade **640** on the gage at the point of contact with the casing wall **635b**, and at the back **635c** of the blade **640**, as shown in **FIG. 6**. The results show that the stress reduced from 34,000psi to 16,000 psi in front of the blade **640**. Also, the results show that the stress in mill **600** is more uniformly distributed compared to the mill **500**. While the concepts of the mill are described herein in reference to a window cutting or casing exit mill design and application, a mill made as

described herein or with obvious modifications, is equally applicable in various other applications, including, but not limited to, reaming tools and operations.

[0015] While the foregoing disclosure is directed to the certain exemplary embodiments of the disclosure, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.

CLAIMS

What is claimed is:

1. A mill for use in a wellbore, comprising:
a blade body that includes a raised section of a first diameter and a first tapered section extending from a first end of the raised section to a first reduced section of the blade body that has a second diameter that is less than the first diameter, wherein the first tapered section includes a curved surface .
2. The mill of claim 1, wherein the blade body includes a second tapered section that extends from a second end of the raised section to a second reduced section of the blade body that has a third diameter that is less than the first diameter, wherein the second tapered section includes a curved surface.
3. The mill of claim 1 or 2 further comprising:
a blade attached to the raised section and the first tapered section, wherein a surface of the blade includes a curved surface that substantially corresponds to the curved surface of the first tapered section.
4. The mill of claim 1 or 2 further comprising a boss disposed a selected distance from the first end of the raised section, wherein the boss has a diameter that is between the first diameter and the second diameter.
5. The mill of claim 4 further comprising a curved tapered section between at least one of: the first reduced section and the boss; and the boss and a third reduced section.
6. The mill of claim 2 further comprising a blade attached to the raised section, the first tapered section and the second tapered section and wherein the blade includes a first curved surface that substantially corresponds to the curved surface of the first tapered section and a second curved surface that substantially corresponds to the curved surface of the second tapered section.
7. The mill of claim 4 wherein an outer most surface of the boss has a length less than half the second diameter.
8. The mill of claim 4, wherein the diameter of the boss is less than twenty percent greater than the second diameter.
9. The mill of claim 1 or 2 further comprising a boss disposed on the second reduced section of the blade body.
10. The mill of claim 6, wherein the curved surfaces of the first and second tapered sections are concave and the curved surfaces of the blade are convex.

11. A method of milling a casing in a wellbore, comprising:
placing a ramp in the casing at a selected location in the casing;
conveying a bottom hole assembly in the wellbore, the bottom hole assembly including a mill that contains a plurality of blades attached to a body, wherein each blade in the plurality of blades includes a tapered convex portion attached to a corresponding concave tapered portion along a downhole side of the blade body for reducing stress on a downhole end of each such blade; and
milling a section of the casing above the ramp utilizing the mill.
12. The method of claim 11, wherein each blade in the plurality of blades is further attached to a tapered section on an uphole side of the body and wherein each blade in the plurality of blades includes a curved portion that corresponds to the curved section on the uphole side of the body.
13. The method of claim 11 or 12, wherein the body further comprises a boss on downhole side of each blade in the plurality of blades for reducing stress on the blades.
14. The method of claim 11, wherein the body includes a boss on an uphole side of each of the blades.
15. The method of claim 11 or 12, wherein the bottom hole assembly further includes a cutting device below the mill and wherein the method further comprises cutting with the cutting device a first section of the casing above the ramp followed by milling a section of the casing above the first section with the mill.

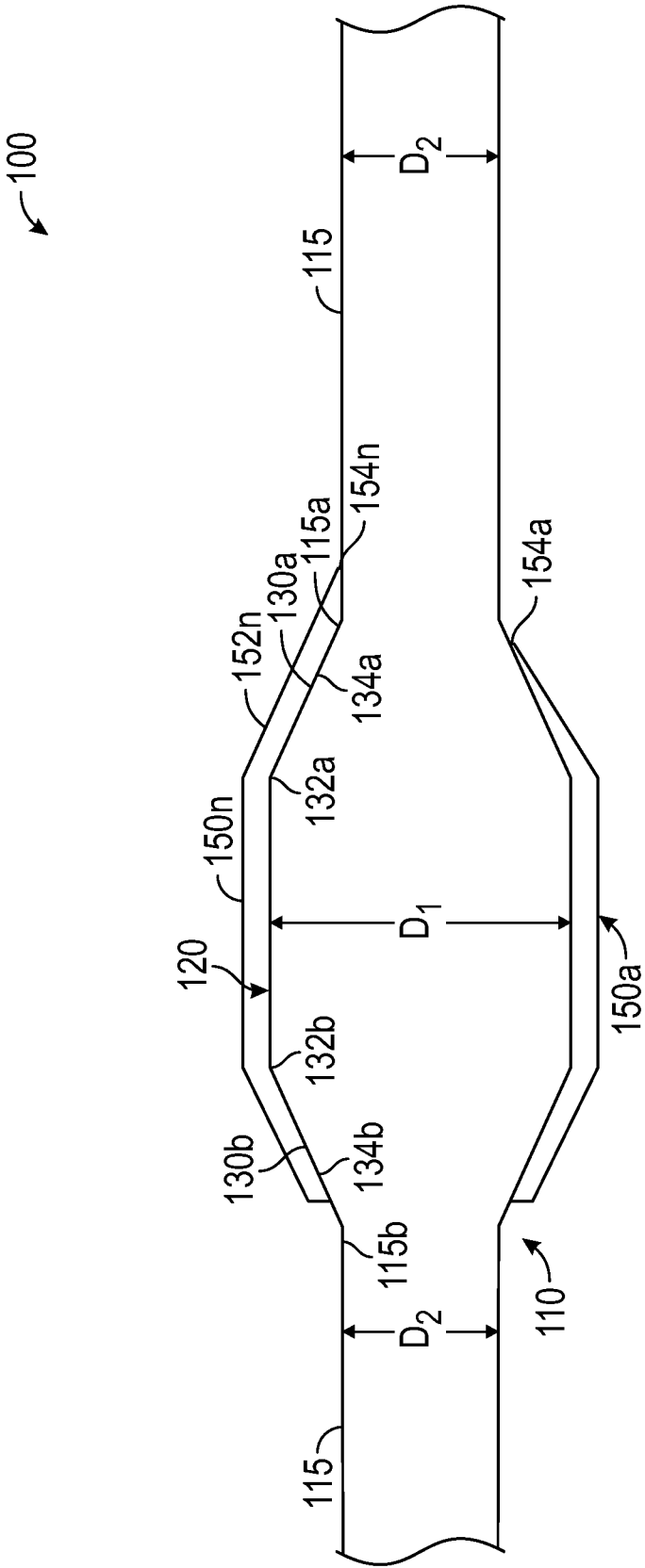


FIG. 1
(Prior Art)

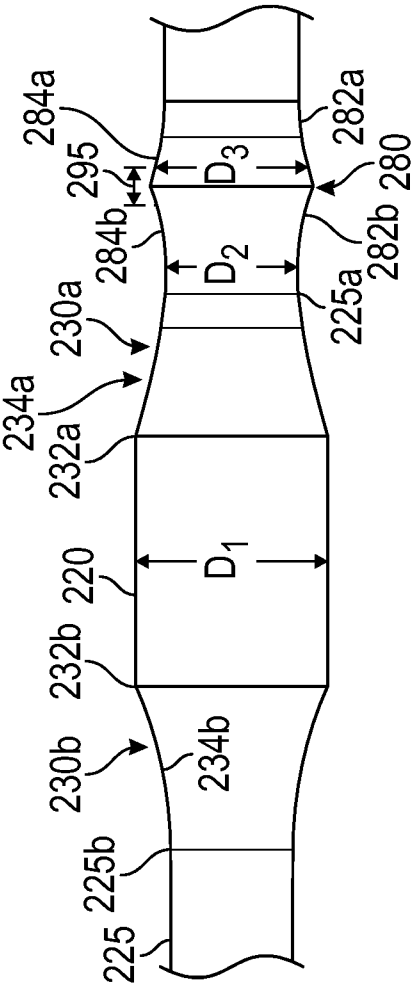


FIG. 2

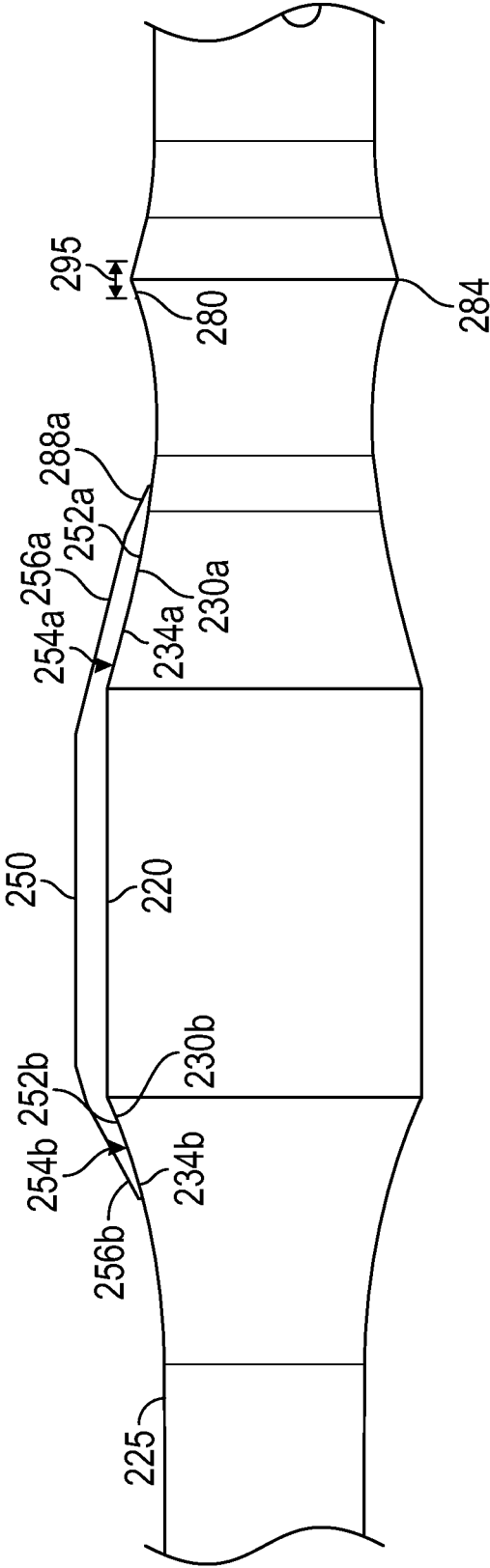


FIG. 3

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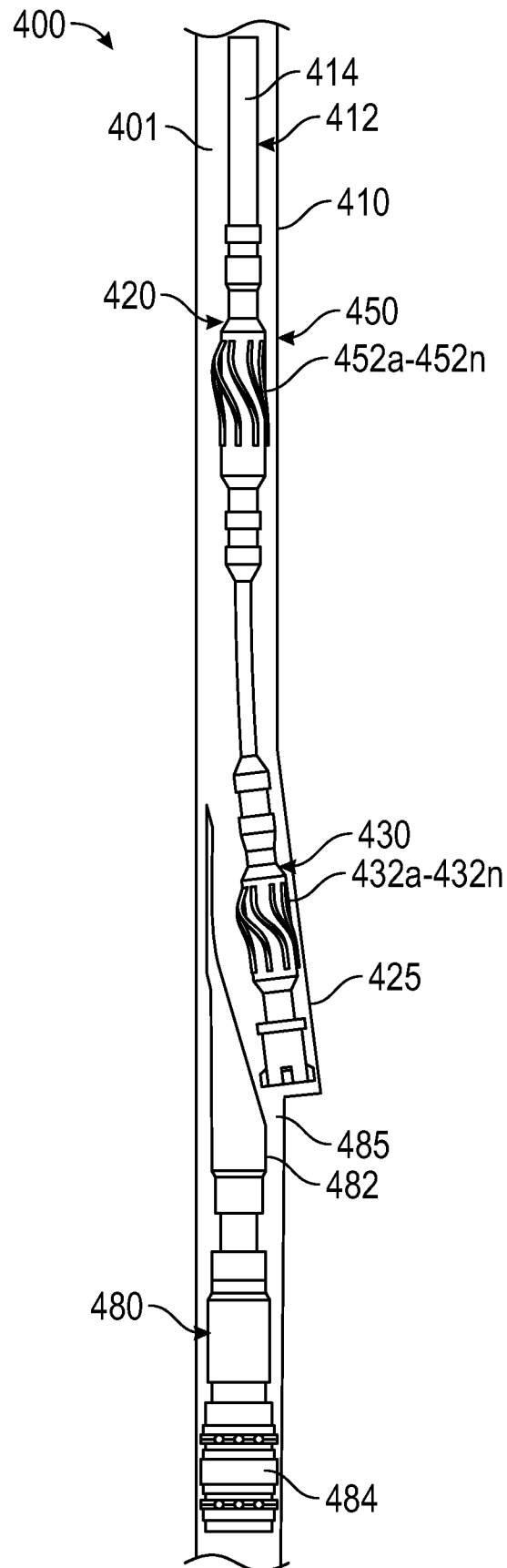


FIG. 4

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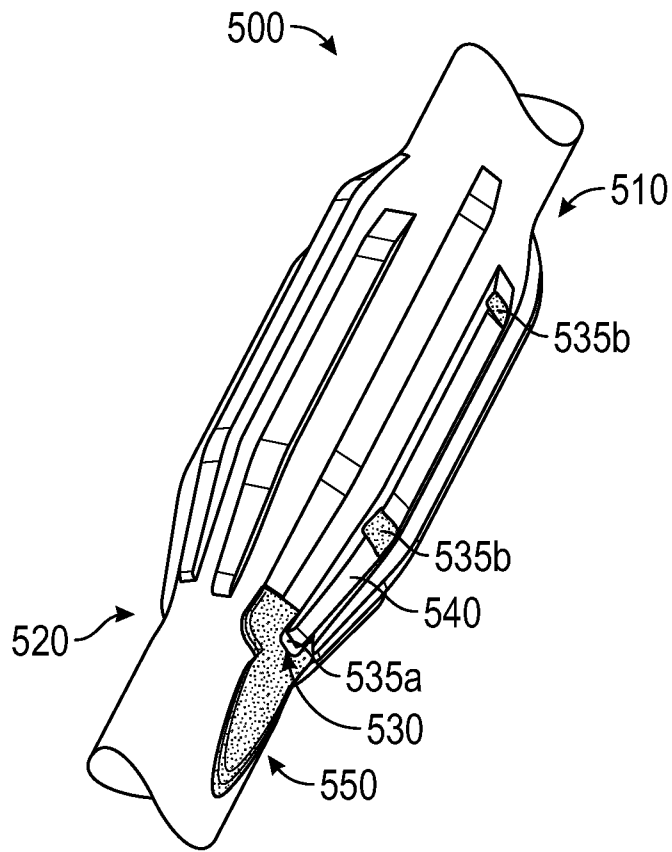


FIG. 5

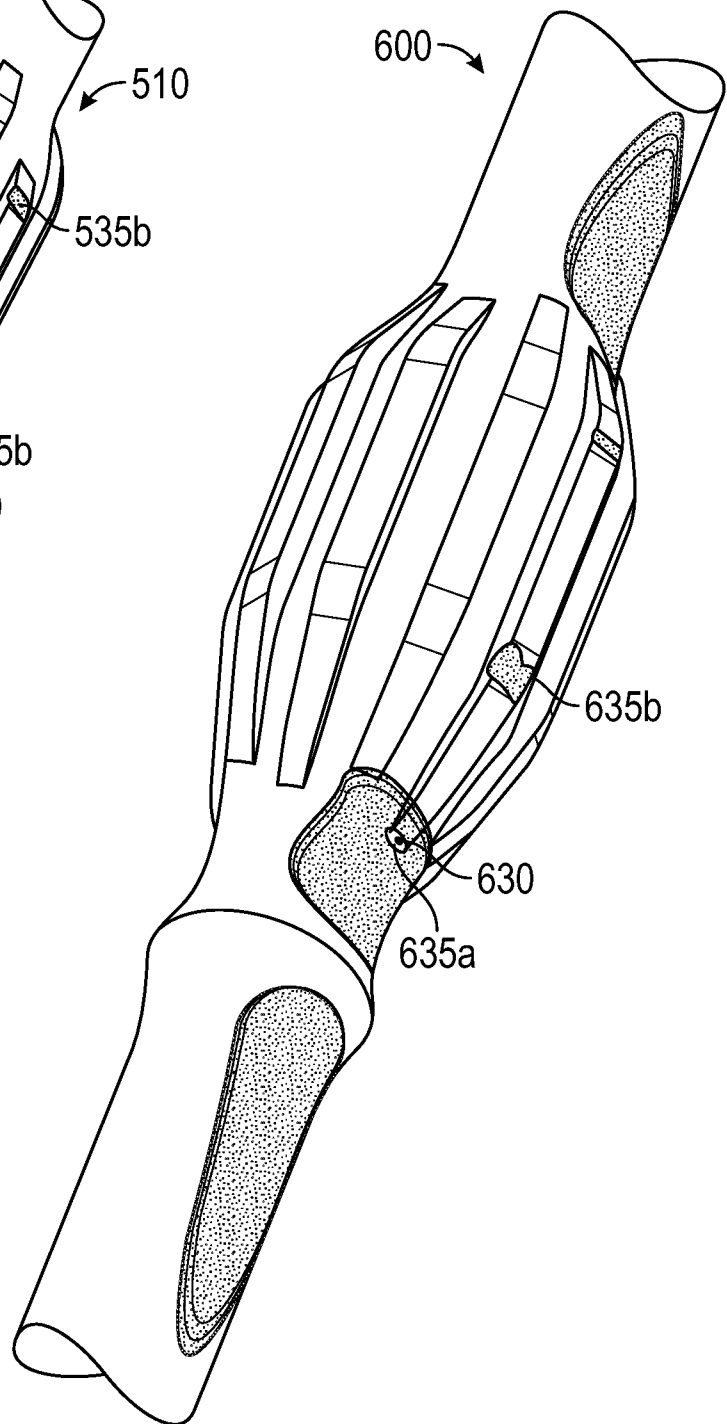


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/039661**A. CLASSIFICATION OF SUBJECT MATTER****E21B 7/06(2006.01)i, E21B 29/06(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 7/06; E21B 10/26; E21B 29/06; E21B 7/08; E21B 29/00

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: mill, blade, raised section, tapered section, curved surface, diameter, boss, and ramp

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6926100 B1 (ANTHONY et al.) 09 August 2005	1-10
Y	See abstract, column 8, line 35 - column 9, line 45, and figure 3.	11-15
Y	US 2011-0174477 A1 (VERMA et al.) 21 July 2011	11-15
	See abstract, paragraph [0024], and figure 2.	
A	US 2009-0133877 A1 (NEFF, MICHAEL CLAUDE) 28 May 2009	1-15
	See abstract, paragraphs [0035]-[0037], and figures 2, 5.	
A	US 5551509 A (BRADDICK, BRITT O.) 03 September 1996	1-15
	See abstract, column 7, line 45 - column 8, line 38, and figures 6-7.	
A	US 2013-0199784 A1 (SWADI et al.) 08 August 2013	1-15
	See abstract, paragraph [0026], and figure 2A.	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"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

23 September 2015 (23.09.2015)

Date of mailing of the international search report

23 September 2015 (23.09.2015)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/039661

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