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(54) **DOWNHOLE CUTTING TOOL**

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(56) References cited:
JP-A- 2007 224 549
US-A- 4 978 260
US-A- 5 012 863
US-A1- 2007 079 995
US-A1- 2008 093 076
US-A1- 2010 276 201
US-A1- 2012 325 480

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Description

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present document is based on and claims priority to GB Non-Provisional Application Serial No.: 1513927.2 , filed August 6, 2015.

BACKGROUND

[0002] Oil and gas wells are usually lined with steel tubing which is cemented in place and forms a casing. Other steel tubing may be located inside the casing. Some operations carried out within a well require the removal of a length of steel tubing which has been secured within the borehole. This is customarily carried out using a tool referred to as a mill which is used to mill out a length of tubing at a subterranean position which may be some distance from the surface. The mill cuts into the tubing and comminutes it to swarf.

[0003] Various types of mill are used in boreholes. A mill for removing a length of tubing is commonly referred to as a section mill. It has the characteristic that it cuts away tubing as it moves along the tubing. Parts of the tool, or parts of the tool string which incorporates the tool, may extend into the tubing which has not yet been removed and thereby guide the tool to progress axially along the tubing as it is advanced. This functionality contrasts with a window mill whose function is to cut outwardly through tubing and start a new borehole branching from an existing borehole.

[0004] A section mill which is able to mill out a length of tubing may have a rotatable body with one or more projecting or expandable parts which may be referred to by various names including blades and knives. These projecting or expandable parts carry cutters of hard material, often tungsten carbide, which cut into the tubing. The cut swarf is customarily entrained in the circulating flow of drilling fluid which carries it to the surface. However, pieces of swarf can become entangled within the borehole and form a blockage, sometimes referred to as a "bird’s nest", which can necessitate time-consuming interruption of the milling operation and removal of tools from the borehole in order to clear the blockage.

[0005] Another problem which can arise is damage to the cutters fitted to the tool. Wear of cutters during use of the milling tool is normal but it is possible for cutters to become chipped or broken which reduces the efficiency and working life of the tool.

[0006] When a hard cutting tool acts on a workplace, the cutting surface may be held perpendicular to the direction of traverse of the tool relative to the workpiece or at an angle to the perpendicular. This angle to the perpendicular is referred to as a rake angle. A rake angle may be referred to as forward or back, positive or negative, and the literature is not consistent in use of this terminology. In the present disclosure, when the edge of the cutting surface which is in contact with the workpiece is trailing behind the remainder of the cutting surface, the cutter is said to have a back rake also sometimes referred to as a positive rake.

[0007] US2008/0093076 is concerned with a window mill, intended to be used in conjunction with a wedge, termed a whipstock, to start a sidetrack from a well by cutting a window through existing well casing.

[0008] US2007/0079995 describes a drill bit for drilling through an obstacle and then continuing through formation rock. It has cutting elements 36 intended to cut through a metallic obstacle. These are positioned with a back rake of 5°.

[0009] US4978260 discloses a cutting tool for removing materials from a wellbore. The tool has a body with projecting elements which carry hard cutters. These elements and the cutters on them are at a backrake of between 3 and 15°.

[0010] US5012863 describes a milling tool having a main structure which houses extensible elements which carry hard cutters. Cutting surfaces have a backrake angle which does not exceed 20° and there is a preference for an angle less than 20°.

SUMMARY

[0011] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to be used as an aid in limiting the scope of the claimed subject matter.

[0012] In a first aspect of the present disclosure, a rotary tool which is a section mill for milling tubing in a borehole comprises a structure with a plurality of cutters thereon configured for milling the tubing while a part of the tool extends into tubing which has not yet been removed by the cutters, wherein at least one cutter has a cutter body and a cutting surface on the cutter body, where the cutter is shaped and positioned on the tool such that:

at least part of the cutting surface is back raked, that is to say it is inclined relative to the direction of rotation with an edge where the cutting surface cuts furthest into the tubing being a trailing edge of the cutting surface relative to the direction of rotation,

at least part of the back raked cutting surface extends from the said edge with a back rake angle which is from 25 to 60 degrees and at the said edge has an angle greater than 90 degrees included between the cutting surface and the surface of the cutter body following the cutting surface.

[0013] Because the rake angle between the cutting surface or part of the cutting surface and a perpendicular to the direction of traverse relative to the workpiece (i.e. direction of rotation relative to the tubing) lies in a range from 25 to 60 degrees, the angle between the cutting surface or part thereof and the direction of rotation lies in a range from 30 to 65 degrees.

[0014] We have found that a cutting surface with a significant back rake angle leads to the formation of swarf with less rigidity. It may be in the form of short pieces weakly connected together, or sometimes not connected at all. Changing the nature of the swarf reduces the risk of entangled swarf forming a "birds nest" blockage in the borehole. A significant back rake may require the cutter to be pressed against the tubing with more force than would be required with less back rake or none. In a machine-shop context, a requirement for increased force between a cutting tool and workpiece would be a disadvantage, but we have recognized that when operating a cutting tool in a wellbore, a requirement for greater force is beneficial. More force can be provided by increasing the weight on the tool and control of the cutting speed by varying the weight on the tool becomes easier. Increasing the included angle between the cutting surface and a surface of the body behind the cutter surface makes the cutter more robust and reduces the risk of the cutter being chipped or broken.

[0015] The angle of the back rake may be such that the rake angle between the cutting surface or part thereof and a perpendicular to the direction of motion relative to the tubing is in a range from 25 degrees to 45 or 50 degrees. In this case the angle between the cutting surface and the direction of rotation will lie in a range from 40 or 45 degrees to 65 degrees. The surface of the cutter body trailing back from the edge of the cutting surface may be aligned with the direction of rotation or may be at a small angle to the direction of rotation. Thus it may be at an angle of 0 to 10 or 15 degrees to the direction of rotation. In this case, the angle included between this surface of the cutter body and the cutting surface will be at least 95 degrees.

[0016] The cutter body may be dimensioned such that the at least part of the back raked cutting surface extends at least 1mm from the said edge where the cutting surface cuts furthest into the tubing and the cutter body's surface trailing back from the said edge extends at least 2 mm possibly at least 3mm or at least 5mm back from the said edge.

[0017] An individual cutter body may be formed from a hard material other than diamond. The hardness may be defined as a hardness of 1800 or more on the Knoop scale or a hardness of 9 or more on the original Mohs scale (where diamond has a Mohs hardness of 10).

[0018] The rotary tool may comprise one or more supporting structures, each having a plurality of cutters partially embedded in one of the supporting structures. A cutter body may have a front which is exposed and a thickness extending into the support behind the exposed front. The thickness dimension may be at least half, or at least three-quarters of any distance across the cutter body transverse to the thickness. The portion of the body which is embedded in the support structure may be greater than the volume of any portion projecting forwardly from the support structure. The cutting surface may extend as a bevel between side and front faces, at an angle (other than a right angle) to both and of course such that the rake angle between the cutting surface or part thereof and a perpendicular to the direction of motion relative to the tubing is in the range from 25 to 60 degrees.

[0019] Such a supporting structure may be an element which projects or is extensible outwardly from a central structure of the tool. The rotary tool may be constructed with a central structure for insertion axially into the tubing, and at least one element which carries at least one said cutter and which projects outwardly from the central structure to bring the at least one cutter into contact with the tubing. There may be a plurality of such elements which are distributed azimuthally around a longitudinal axis of the tool.

[0020] In some embodiments the at least one element is expandable outwardly, by operation of a mechanism within the tool structure. This can allow the tool to be inserted to a desired depth into a borehole and then expanded to begin cutting into tubing.

[0021] In another aspect of the present disclosure, a method of removing a length of tubing in a borehole comprises inserting into the tubing a rotary milling tool which is a section mill comprising a structure extending axially within the tubing with a plurality of cutters on the structure for milling the tubing while a part of the tool extends into tubing which has not yet been removed by the cutters, where at least one cutter has a cutter body and a cutting surface on the cutter body and the at least one cutter is shaped and positioned such that at least part of the cutting surface is back raked relative to the direction of rotation so that the cutting surface cuts furthest into the tubing at an edge which is a trailing edge of the cutting surface relative to the direction of rotation,, and then advancing the tool axially while rotating the tool with the at least one cutter cutting into the tubing completely around the tubing, wherein at least part of the back raked cutting surface extends from the said edge with a rake angle between the cutting surface and a perpendicular to the direction of rotation which is in a range from 25 to 60 degrees, and wherein, at the said edge (26, 62) of the cutting surface, an included angle between the cutting surface(24, 60, 65, 66) and the surface (22) of the cutter body following the cutting surface is greater than 90 degrees.

[0022] The cutter may cut into a sidewall of the tubing or into an end face created by an initial cut through the tubing.

BRIEF DESCRIPTION OF DRAWINGS

[0023]

Fig1 diagrammatically illustrates a hard cutter carried on a rotary tool and in contact with tubing;

Fig 2 shows equivalent stress distributed within a workpiece, in the direction of traverse of a cutter, as predicted by finite element analysis, when the cutter has zero rake angle;

Fig 3 shows equivalent stress distributed within a workpiece when the cutter has a rake angle of 30 degrees and when overall force between workpiece and cutter is maximum;

Fig 4 is similar to Fig 3 but shows the distribution of equivalent stress when overall force between workpiece and cutter is minimum;

Figs 5 and 6 are similar to Figs 3 and 4, with a cutter rake angle of 45 degrees;

Fig 7 is similar to Fig 3 with a cutter rake angle of 15 degrees;

Fig 8 is similar to Fig 4 with a cutter rake angle of 15 degrees, but shown at a larger scale;

Fig 9 diagrammatically shows a piece of swarf produced by a cutter with rake angle of 45 degrees;

Fig 10 is an enlarged cross section through a piece of swarf produced by a cutter with rake angle of 45 degrees;

Fig 11 is an enlarged cross section through a piece of swarf produced by a cutter with zero rake angle;

Figs 12 to 15 show distribution of principal tensile stress within cutters with rake angles of zero, 15, 30 and 45 degrees respectively, as predicted by finite stress analysis;

Figs 16, 17 and 18 are front and side views of cutters;

Fig 19 shows a section mill with a cutter assembly retracted;

Fig 20 is a cross section on line A-A of Fig 19;

Fig 21 shows the section mill of Fig 19 with the cutter assembly extended;

Fig 22 is a cross-sectional elevation view of another embodiment of expandable tool, showing its expandable cutter blocks in retracted position;

Fig 23 is a cross-sectional elevation view of the expandable tool of Fig. 19, showing the cutter blocks in expanded position;

Fig 24 is a perspective view of a cutter block for the expandable tool of Figs 22 and 23;

Fig 25 shows the cutter block of Fig 24 in use;

Fig 26 is a cross section on line B-B of Fig 25; and

Fig 27 is an enlarged detail from Fig 25.

DETAILED DESCRIPTION

[0024] Fig 1 shows part of the body of a cutter 10 which is carried on supporting structure (not seen in this enlarged diagram) which is part of a rotary tool and brings the cutter body 10 into contact with the inside wall of tubing 12 so that part of the tubing is cut away as the cutter is driven in the direction of rotation of the tool around its axis, indicated by the chain dotted arrow 14. The direction of rotation is of course perpendicular to a radius 16 extending from the tool axis.

[0025] The cutter body has a flat front face 20 and a side surface 22 which extends backwards relative to the direction of rotation, connected by bevelled face 24 which constitutes the cutting surface. The edge 26 of the cutting surface, cutting most deeply into the tubing 12, is trailing relative to the parts of the cutting surface 24 which are not in contact with tubing 12. The cutting surface 24 is thus positioned with a back rake angle. The rake angle between the cutting surface 24 and the radius 16 is indicated 34. The angle between the cutting surface 24 and the direction of rotation 14 is indicated 32.

[0026] The side surface 22 of the cutter body 10, extending back from the edge 26 of the cutting surface 24, is inclined so as to diverge from the newly-cut surface at a small angle 36 to the direction of rotation 16, so that the parts of the cutter body 10 behind the cutting surface 24 do not contact the freshly cut surface 28 on the tubing 12. The overall included angle between the cutting surface 24 and the side surface 22 extending back from the edge 26 is the sum of the angles 34 and 38.

[0027] In accordance with the concepts set out above, the angle between the cutting surface 24 and the radius 16 lies in a range from 25 to 60 degrees. The sum of the angles 32 and 34 is a right angle, because the direction of rotation 14 and the radius 16 are perpendicular. Thus the angle 32 lies in a range from 30 to 65 degrees. In the embodiment illustrated the rake angle 34 lies in a narrower range from 25 to 50 degrees and may be approximately 30 degrees.

[0028] The behaviour of a cutter made of hard material cutting into steel, with variations in rake angle, was investigated by finite element analysis, which is a computational modelling procedure, assuming a constant depth of cut of 0.25mm and a constant speed of traverse of the tool relative to the steel workpiece of 1metre/sec. The analysis ran for a period of 1millisecond corresponding to a distance traversed of 1mm which is four times the depth of cut. This analysis predicted that as the rake angle of the tool is increased (and consequently the angle between the cutting surface and the direction of traverse decreases) the force required to drive the tool increases and moreover with angles of 15 degrees or more the force oscillates between upper and lower values. The values predicted by this procedure were:

Rake angle	In direction of traverse		Perpendicular to traverse		Mean period of oscillation
	Mean force (kN)	Amplitude of oscillation (kN)	Mean force (kN)	Amplitude of oscillation (kN)	
zero	1.9	0.1	0.2	0.1	<0.1
15	2.3	0.2	0.8	0.2	0.1
30	2.6	0.5	1.75	0.25	0.2
45	2.75	0.75	2.8	0.8	0.6

[0029] This analysis also provided visual maps of the workpiece showing internal distribution of the equivalent stress in the direction of traverse. Such maps are shown by Figs 2 to 8. In Figs 2 to 7 areas 40 with lighter shading have equivalent stress between 730MPa and 1150MPa, areas with heavier shading have equivalent stress in a range from 1150MPa to 1250MPa and areas of the workpiece shown without shading are subjected to equivalent stress of less than 730MPa. (Fig 8 has larger scale and slightly different presentation as will be mentioned below). The stress results in strain and these maps of the workpiece show deformation of material by the cutter.

[0030] Fig 2 exemplifies the distribution of stress when the rake angle of the cutter 10 is zero. The distribution of stress varied during the length of time covered by the analysis, but a region 42 of highest stress between the arrows 44 was present throughout the duration of the analysis.

[0031] Figs 3 and 4 show the predicted distribution of stress when the rake angle was 30 degrees. Fig 3 shows the predicted distribution when applied force in the direction of traverse was at the maximum (2.6 + 0.5 = 3.1 kN) and Fig 4 shows the predicted distribution when applied force was at the minimum (2.6 - 0.5 = 2.1kN). As shown in Fig 3, when the force in the direction of traverse is at a maximum, there is a region 42 of highest stress between the areas 44. By contrast, when the force in the direction of traverse is at a minimum, not only is the stress within the workpiece 12 generally lower, there is also a localised region 46 of stress below 730MPa along a line between arrows 44.

[0032] The interpretation of the oscillation in applied force, tabulated above, and the finite element analysis shown by Figs 2-4 is that with zero cutter rake angle, equivalent stress in the workpiece 12 remains fairly constant and the material which is cut from the workpiece (the so-called chip) remains as a continuous strand even though it undergoes plastic deformation as it is cut. By contrast, with the 30 degree rake angle, stress and strain in the region of the workpiece 12 between arrows 44 increase until thermal softening of the material (resulting from plastic deformation causing a localised increase in temperature within the workpiece) enables a region of reduced stress between arrows 44 to propagate from the edge of the cutter to the free surface of the workpiece. When this thermally softened region has fully propagated, the chip being cut is displaced. This gives a temporary reduction of stress in the workpiece 12 and the region 46 of low stress between the arrows 44. Thus the chip becomes separated from the workpiece along the line between arrows 44.

[0033] Fig 5 and 6 show the predicted distribution of stress when the cutter rake angle was 45 degrees and applied force in the direction of traverse was at the maximum (3.5 kN) and minimum (2.0 kN) respectively. Fig 5 shows a region 42 with the high level of stress located between the arrows 44 when the applied force in the direction of traverse is at the maximum, and (similarly to Fig 4) a region 47 with low level of stress extending along the line between arrows 44, which is where the chip separates from the workpiece 12.

[0034] Figs 7 and 8 show the distribution of stress predicted by finite element analysis when the cutter rake angle was 15 degrees and applied transverse force between cutter and workpiece was maximum and minimum respectively. There was qualitative similarity to the maps at cutter rake angles of 30 and 45 degrees. As shown by Fig 7, when applied force in the direction of traverse was at the maximum (2.3 + 0.2 =2.5kN) there was a region of high equivalent stress 42 between the arrows 44. Fig 8 shows the distribution of stress when the applied force in the direction of traverse was at the minimum (2.3 - 0.2 =2.1 kN). This drawing is at a larger scale than Figs 2 to 7. Areas of light shading 41 have stress between 730MPa and 1000MPa. Areas 43 have stress between 1000MPa and 1150MPa. Areas 42 have stress between 1150MPa and 1250MPa. Fig 8 shows that when applied force in the direction of traverse was at the minimum, a region 48 of stress not exceeding 1000MPa extends along the line between the arrows 45, in between areas 43 of stress exceeding 1000MPa within which there were regions 42 of higher stress. Levels of stress within the region 48 were almost all below 900MPa.

[0035] The predictions of finite element analysis shown by Figs 5 and 6 were confirmed by experiment. A cutter as illustrated by Fig 1, with a rake angle of 45 degrees was used to cut material from a steel workpiece. The chip took the form shown diagramatically by Fig 9. It consisted of a ribbon of short sections 50 weakly joined one to the next along lines 52. Each of these lines 52 correspond to the instant when a section 50 detached from the workpiece 12 and the localised heating of the displaced material allowed a weak weld to form between adjacent sections 50. A piece of the swarf was embedded in rigid resin, then cut through, polished and photographed under high magnification. This photograph showed a cross section of the swarf along a line such as line X-X in Fig 9. The photograph was digitally manipulated to show the edge of the swarf: the result is shown as Fig 10. A double headed arrow shows a distance of 0.1mm. As a comparison, a piece of swarf obtained with a cutter of zero rake angle was likewise embedded in rigid resin, cut through, polished and photographed under high magnification. This photograph was likewise digitally manipulated to show the edge of the swarf: the result is shown as Fig 11. It can be seen that the swarf in Fig 11 was a continuous strip whereas the swarf in Fig 10 consisted of a number of sections 50, partially separated by gaps 54 so that the joins between the sections 50 do not extend across the full thickness of the piece of swarf.

[0036] Finite element analysis was also applied to stress within the cutters, as shown by Figs 12 to 14. Each of these illustrates the distribution of maximum principal tensile stress (the scalar value of maximum tensile stress regardless of direction). Regions 56 where the tensile stress exceeds 100MPa are shown with shading. In the case of the cutter with zero rake angle shown by Fig 12 the region 56 included a small region 58 adjoining the cutting surface in which the principal stress was from 300MPa up to 370MPa. For the cutter with rake angle of 15 degrees so that the included angle at edge 26 is 100 degrees, the area 56 as shown by Fig 13 had maximum stress of 230MPa. In the case of the cutters with 30 and 45 degree cutter rake angles, such that the included angles at the edge 26 were 115 and 130 degrees the principal stress in the areas 56 did not exceed 170MPa and 130MPa respectively. Cutter breakage is likely to start where material is under tension and so the lowering of tensile stress with increasing rake angle is valuable because it reduces the risk of cutter breakage during use. In addition, a larger included angle results in a stronger edge and longer tool life.

[0037] Figs 16, 17 and 18 show three embodiments of cutters. Figs 16a, 17a and 18a are front views, Figs 16b, 17b and 18b are side views. The cutter of Fig 16 is rectangular. A cutting surface 60 at an angle of 30 degrees to the front face 61 extends to the edge 62 which, when the cutter is mounted on a tool, is the edge where the cutter is furthest into the material being cut. The angle included at edge 62 is 120 degrees. The cutter of Fig 17 has a cylindrical body 63 and a front face 64 with smaller diameter surrounded by an annular surface 65 at an angle of 45 degrees to the front face 64. When mounted on a tool, part of this annular surface 65 is the cutting surface. The angle included between the side wall of the cutter body 63 and the surface 65 is 135 degrees, as shown. The thickness of the cutter behind the front face is indicated at 66 and the cross section transverse to the thickness, which in this case is the diameter of the cylindrical cutter body 63, is indicated 67. In this embodiment shown here, the thickness dimension 66 is about 0.8 of the cross section 67.

[0038] Fig 18 shows a cutter which also has a cylindrical body, but has a front face 64 which is eccentric relative to the main body. The widest part 68 of the annular surface around the front face 64 is at an angle of 45 degrees to the front face 64 but the narrowest part 69 is at a different angle, as can be seen in the drawing. This cutter is mounted in a tool so that wider parts of the annular surface provide the cutting surface.

[0039] These cutters are made of a hard material which may be tungsten carbide. This hard material may be provided as a powder which is compacted into the shape of the cutter and then sintered. Manufacturers of sintered tungsten carbide cutters include Cutting and Wear Resistant Developments Ltd, Sheffield, England and Hallamshire Hard Metal

Products Ltd, Rotherham, England.

[0040] Tungsten carbide is commonly used for cutters because it is very hard and also has good thermal stability. Other hard materials which may be used are carbides of other transition metals, such as vanadium, chromium, titanium, tantalum and niobium. Silicon, boron and aluminium carbides are also hard carbides. Some other hard materials are boron nitride and aluminium boride. A hard material (which is other than diamond) may have a hardness of 1800 or more on the Knoop scale or a hardness of 9 or more on the original Mohs scale (where diamond has a Mohs hardness of 10).

[0041] Figs 19 to 21 show a section mill used to remove a length of tubing, starting at a subterranean location which is some way down a borehole. An existing borehole is lined with tubing 72 (the wellbore casing) and cement 74 has been placed between the casing and the surrounding rock formation. The tubing and cement may have been in place for some years. It is now required to remove a length of tubing, starting at a point below ground. One possible circumstance in which this may be required is when a borehole is to be abandoned, and regulatory requirements necessitate removal of a length of tubing and surrounding cement in order to put a sealing plug in place.

[0042] Figs 19 and 21 are cross-sectional elevations showing part of the tool to the right of chain dotted centre line CL-CL. Fig 20 is a schematic cross section looking along the tool axis at the level of the arrows A-A in Fig 19, with plunger head 91 omitted. As shown by Fig 19, the tool has a cylindrical body with an outer wall 80. Three slots are formed in this body at positions which coincide axially and distributed azimuthally around the tool axis. At either side of each slot there is a plate 81 extending inwardly from the wall 80. A cutter assembly, which comprises cutters attached to an arm 82 made of steel plate, is accommodated within each slot. As can be seen from Fig 19, each arm 82 is pivoted to swing around a pin 83 supported by the plates 81. Each arm 82 can swing from a retracted position shown in Fig 19 to an expanded position shown in Fig 21. Expansion is brought about by a hydraulic cylinder and piston, not shown, operated by pressure of drilling fluid and connected to drive plunger shaft 89. Pressure of drilling fluid causes the plunger shaft 89 to move downwardly. A domed plunger head 91 on the end of shaft 89 acts on the inside edges of arms 82, forcing each arm to pivot outwardly towards the position shown in Fig 21. Outward expansion is limited by prolongations 92 of the arms 82 when these prolongations abut the inside face of the tool wall 80 as indicated at 93 on Fig 21.

[0043] Each arm 82 has cutters 86, 87 of the type shown by Fig 16 attached to its front face as seen in Figs 19 and 21 with the edges 62 of these cutters aligned with the edges 84, 85 of the arm 82. The cutters 86, 87 may be attached to the arm 82 by brazing and when attached to the arm 82 the cutting surfaces 60 of the cutters have a back rake of 30 degrees. At the corner of the arm 82 there is a cutter 88 which extends around the curve between the edges 84, 85 of the arm 82 and has a cutting surface with the same back rake of 30 degrees which also follows around the curve.

[0044] For use the section mill is included in a drill string and lowered to the point within the borehole tubing 72 where milling is to begin. The drill string is then rotated and the plunger head 91 is driven downwards forcing the arms 82 outwards towards the position shown by Fig 21. The cutters 87 on the outer edges 85 of the arms 82 cut radially outwards into and through the tubing 72 until the arms are fully extended as shown in Fig 21. The tool is then advanced axially downwards and the cutters 86 on the edge 84 progressively cut downwards into an end face on the tubing 72, destroying a length of the tubing by milling it to swarf.

[0045] As the cutters 86 on an arm 82 cut into the tubing 72, their cutting surfaces are at an angle of 30 degrees to the plane of the arm 82. This arm extends axially and the axial direction is perpendicular to the rotational direction of the tool and to the end face of the tubing 72 which is being cut. The cutters therefore are at a back rake of 30 degrees as they cut into the tubing 72. Previously, as the cutters 87 were cutting into the inside face of the tubing 72, they also were at a back rake relative to the inside surface of the tubing, although the back rake angle relative to this surface will vary as the arms swing around their pivots 83.

[0046] Figs 22 to 26 show a rotary tool which is an expandable milling tool, utilising an expansion mechanism which is already used in reamers. Fig 22 shows the tool with its expandable cutter blocks with the blocks in retracted position. Fig 23 is a corresponding view with the blocks in expanded position.

[0047] This expandable tool comprises a generally cylindrical tool body 106 with a central flowbore 108 for drilling fluid. The tool body 106 includes upper 110 and lower 112 connection portions for connecting the tool into a drilling assembly. Intermediately between these connection portions 110, 112 there are three recesses 116 formed in the body 106 and spaced apart at 120 degrees intervals azimuthally around the axis of the tool.

[0048] Each recess 116 accommodates a cutter block 122 in its retracted position. The three cutter blocks may be identical in construction and dimensions. One such cutter block 122 is shown in perspective in Fig 24. Each block 122 is formed of a steel inner block part 124 with a projecting lug 125 along its outer surface and an outer block part 126 astride the lug 125 and bolted to the inner part 124 by bolts (not shown) inserted through the apertures 128 into threaded holes in the inner part 124. Details of the outer part 126 are not shown in Figs 22 and 23 and will be described in more detail below. The radially outer face 129 of the outer block part 126 is indicated without detail in Figs 22 and 23.

[0049] The inner block part 124 has side faces with protruding ribs 117 which extend at an angle to the tool axis. These ribs 117 engage in channels 118 at the sides of a recess 116 and this arrangement constrains motion of each cutter block such that when the block 122 is pushed upwardly relative to the tool body 106, it also moves radially outwardly towards the position shown in Fig 23 in which the blocks 122 project outwardly from the tool body 106. The ribs 117 in channels 118 allow each cutter block to move bodily upwardly and outwardly in this way without changing its orientation (i.e. without changing its angular position) relative to the tool axis.

[0050] A spring 136 biases the block 122 downwards to the retracted position seen in Fig 22. The biasing spring 136 is disposed within a spring cavity 138 and covered by a spring retainer 140 which is locked in position by an upper cap 142. A stop ring 144 is provided at the lower end of spring 136 to keep the spring in position.

[0051] Below the moveable blocks 122, a drive ring 146 is provided that includes one or more nozzles 148. An actuating piston 130 that forms a piston cavity 132 is attached to the drive ring 146. The piston 130 is able to move axially within the tool. An inner mandrel 150 is the innermost component within the tool, and it slidingly engages a lower retainer 170 at 172. The lower retainer 170 includes ports 174 that allow drilling fluid to flow from the flowbore 108 into the piston chamber 132 to actuate the piston 130.

[0052] The piston 130 sealingly engages the inner mandrel 150 at 152, and sealingly engages the body 106 at 134. A lower cap 180 provides a stop for the downward axial movement of piston 130. This cap 180 is threadedly connected to the body 106 and to the lower retainer 170 at 182, 184, respectively. Sealing engagement is provided at 186 between the lower cap 180 and the body 106.

[0053] A threaded connection is provided at 156 between the upper cap 142 and the inner mandrel 150 and at 158 between the upper cap 142 and body 106. The upper cap 142 sealingly engages the body 106 at 160, and sealingly engages the inner mandrel 150 at 162 and 164.

[0054] In order to expand the blocks 122, drilling fluid is directed to flow downwards in flowbore 108. It flows along path 190, through ports 174 in the lower retainer 170 and along path 192 into the piston chamber 132. The differential pressure between the fluid in the flowbore 108 and the fluid in the borehole annulus surrounding tool causes the piston 130 to move axially upwardly from the position shown in Fig 22 to the position shown in Fig 23. A portion of the flow can pass through the piston chamber 132 and through nozzles 148 to the annulus as the cutter blocks start to expand. As the piston 130 moves axially upwardly, it urges the drive ring 146 axially upwardly against the blocks 122. The drive ring pushes on all the blocks 122 simultaneously and moves them all axially upwardly in recesses 116 and also radially outwardly as the ribs 150 slide in the channels 118. The blocks 122 are thus driven upwardly and outwardly in unison towards the expanded position shown in Fig 23.

[0055] The movement of the blocks 122 is eventually limited by contact with the spring retainer 140. When the spring 136 is fully compressed against the retainer 140, it acts as a stop and the blocks can travel no further. There is provision for adjustment of the maximum travel of the blocks 122. This adjustment is carried out at the surface before the tool is put into the borehole. The spring retainer 140 connects to the body 106 via a screwthread at 186. A wrench slot 188 is provided between the upper cap 142 and the spring retainer 140, which provides room for a wrench to be inserted to adjust the position of the screwthreaded spring retainer 140 in the body 106. This allows the maximum expanded diameter of the reamer to be set at the surface. The upper cap 142 is also a screwthreaded component and it is used to lock the spring retainer 140 once it has been positioned.

[0056] The outer part 126 of each cutter block is a steel structure with side face 200 which is the leading which is the leading face in the direction of rotation. An area 204 of this face is slanted back. This steel outer part 126 incorporates cylindrical pockets which receive the cylindrical bodies of cutters of the type shown in Fig 17. The cutters are held in place by brazing. The front faces 63 and the surrounding surfaces 66 are exposed within the area 204.

[0057] The outward facing surface of the outer block part 126 comprises a part-cylindrical outward facing surface 221 with a radius such that the surface 221 is centred on the tool axis when the cutter blocks are fully extended. The cutter 211 is positioned so that its radially outer edge is at the same distance from the tool axis as the surface 221. There is also a part-cylindrical outward facing surface 222 which is further out from the tool axis and again is centred on the tool axis when the cutter blocks are fully extended. The edge of cutter 212 is at the same distance from the tool axis as the surface 222. This pattern of a cutter and a part-cylindrical outward facing surface where the surface and the radial edge of the cutter are both at the same distance from the tool axis is repeated along the block by cutter 213 and surface 223, cutter 214 and surface 224 and so on at progressively greater radial distances from the tool axis. Transitional surfaces 227 connecting adjacent surfaces 221 and 222, similarly 222 and 223 and so on, have the same curvature as, and are aligned with, the curved edges of cutters 211-216.

[0058] For use as a section mill, the tool is attached to a drill string and lowered into the borehole tubing 68 to the required depth. The drill string is then rotated and the tool is expanded by pumping fluid into flowbore 108 as described above. The radially outer edge of cutter 216 contacts the interior face of the tubing 68 and cuts into it. This allows expansion to continue and the cutters 215 to 211 contact the inside face of the tubing in sequence, cutting into and through the tubing until the fully expanded position of the blocks is reached. The tool is then advanced axially. This is illustrated by Fig 25 which shows the outer part 126 of a cutter block in use to remove tubing 68 within a borehole. Numeral 107 indicates an edge of the outer wall of the tool body 106, exposed at the side of a recess 116. The tool is now advancing axially in the downward direction shown by arrow D. The leading cutters 211 on each cutter block are positioned to any corrosion or deposits 252 and also remove some material from the inside wall of the tubing 250, thus exposing a new inward facing surface 254.

[0059] The amount of expansion of the tool is arranged such that when the cutter blocks are fully expanded, the surfaces 221 and the outer extremities of the leading cutters 211 are at a radial distance from the tool axis which is slightly greater than the inner radius of the tubing 250 but less than the outer radius of the tubing. If necessary, the amount of expansion is limited by adjusting the screwthreaded spring retainer 140 in the body 106, using a wrench in the wrench slot 188 while the tool as at the surface so that expansion goes no further than required.

[0060] The new internal surface 254 is at a uniform radius which is the radial distance from the tool axis to the extremities of the leading cutters 211. Because the part-cylindrical outward facing surfaces 221 of the three blocks have a curvature which is centred on the tool axis and at the same radial distance from the tool axis as the extremities of the leading cutters 211, they are a close fit to this surface 254 created by the cutters 211, as is shown in Fig 25, and act as guide surfaces which slide over this new internal surface 254 as the tool rotates. The tool axis is thus positioned relative to the tubing 250.

[0061] As the tool advances axially, the cutters 212 which extend outwardly beyond the surfaces 221 remove the remainder of the tubing indicated at 256 outside the new surface 254 so that the full thickness of the tubing 250 has been removed. The cutters 213 to 216 cut through any cement or other material which was around the outside of the tubing.

[0062] Because the part-cylindrical surface 221 is centred on the tool axis when the cutter blocks are fully expanded, the tool is configured for removing tubing of a specific internal diameter. However, the tool can be used to remove tubing within a range of internal diameters by preparation at the surface, before it is put into a borehole. The tool is configured by fitting the cutter blocks with outer parts 124 dimensioned so that the radius of curvature of the surface 221 is the same as or slightly larger than the original (i.e. as manufactured) internal radius of the tubing to be removed. Also, at the surface, spring retainer 140 is adjusted, using a wrench in slot 188, so that expansion of the tool is limited to the extent required, at which the cutters 211 create the new internal surface on line 254 and the surfaces 221 are a close fit against this surface.

[0063] Fig 26 is a cross section showing the cutter 211. As can be seen the part of the face 66 close to the inside wall of the tubing is the cutting surface and is at a back rake angle of about 50 degrees. Fig 27 is an enlarged view of the face of the cutter 211. The cutting surface is an arc of the face 66 of the cutter, approximately between the chain dotted lines.

[0064] It will be appreciated that the embodiments and examples described in detail above can be modified and varied within the scope of the concepts which they exemplify. Proportions may be varied and in particular back raked cutting surfaces may be larger or smaller than shown in the drawings. Features referred to above or shown in individual embodiments above may be used together in any combination as well as those which have been shown and described specifically. More particularly, where features were mentioned above in combinations, details of a feature used in one combination may be used in another combination where the same feature is mentioned. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

Claims

1. A rotary tool which is a section mill for milling tubing in a borehole, comprising a structure with a plurality of cutters (86-88, 211-216) thereon configured for milling the tubing while a part of the tool extends into tubing which has not yet been removed by the cutters,
   wherein at least one cutter (86-88, 211-216) has a cutter body and a cutting surface (24, 60, 65, 66,) on the cutter body, where the cutter is shaped and positioned on the tool such that at least part of the cutting surface (24, 60, 65, 66) is back raked relative to the direction of rotation so that the cutting surface (24, 60, 65, 66)cuts furthest into the tubing at an edge (26, 62) which is a trailing edge of the cutting surface relative to the direction of rotation,
   wherein at least part of the back raked cutting surface (24, 60, 65, 66) extends from the said edge (26, 62) with a rake angle between the cutting surface and a perpendicular to the direction of rotation which is in a range from 25 to 60 degrees and, at the said edge (26, 62) of the cutting surface (24, 60, 65, 66), has an angle greater than 90 degrees included between the cutting surface (24, 60, 65, 66) and the surface of the cutter body (22) following the cutting surface (24, 60, 65, 66).

2. A rotary tool according to claim 1 wherein the at least part of the back raked cutting surface (24, 60, 65, 66) extends from the said edge (26, 62) with a rake angle which is in a range from 25to 50 degrees.

3. A rotary tool according to claim 1 or claim 2 wherein, at the said edge (26, 62), the surface (22) of the cutter body following the at least part of the back raked cutting surface (24, 60, 65, 66) diverges from the cut surface (28) at an angle of between 0 and 15 degrees to the direction of rotation.

4. A rotary tool according to claim 1 wherein the at least part of the back raked cutting surface (24, 60, 65, 66) extends

from the said edge (26, 62) with an angle of at least 100 degrees included between the back raked cutting surface at the said edge and the surface (22) of the cutter body following the cutting surface.

5. A rotary tool according to any one of the preceding claims wherein the at least one cutter (86-88, 211-216) is a body of a hard material.

6. A rotary tool according to claim 5 wherein the at least one cutter (86-88, 211-216) is a body of a hard material with a Knoop hardness of 1800 or more.

7. A rotary tool according to any one of the preceding claims wherein the tool comprises a central structure for insertion axially into the tubing, and at least one element (82, 122) which carries at least one said cutter (86-88, 211-216) and which projects or is extensible from the central structure to bring the at least one cutter into contact with the tubing.

8. A rotary tool according to claim 7 wherein the at least one element (82, 122) is configured to bring the at least one cutter into contact with the internal surface of the tubing to cut radially outwardly into the tubing.

9. A rotary tool according to claim 7 or claim 8 wherein the at least one element (82, 122) has the at least one said cutter partially embedded therein and partially exposed, such that the embedded portion of the cutter body is of greater volume than the exposed portion.

10. A rotary tool according to claim 9 wherein the at least one said cutter has an exposed front and a partially embedded thickness following the said front with an extent which is at least half the length of any dimension across the body, perpendicular to the said thickness.

11. A rotary tool according to any one of claims 7 to 10 wherein the milling tool has a plurality of elements (82, 122) which each carry at least one said cutter (86-88, 211-216) formed of hard material, which project or are extensible from the tool body and which are distributed azimuthally around a longitudinal axis of the tool.

12. A method of removing a length of tubing in a borehole, comprising
inserting into the tubing a rotary milling tool which is a section mill comprising a structure extending axially within the tubing with a plurality of cutters (86-88, 211-216) on the structure for milling the tubing while a part of the tool extends into tubing which has not yet been removed by the cutters,
where at least one cutter has a cutter body and a cutting surface (24, 60, 65, 66) on the cutter body and the at least one cutter is shaped and positioned such that at least part of the cutting surface (24, 60, 65, 66) is back raked relative to the direction of rotation so that the cutting surface cuts furthest into the tubing at an edge (26, 62) which is a trailing edge of the cutting surface relative to the direction of rotation, and
advancing the tool axially while rotating the tool with the at least one cutter cutting into the tubing completely around the tubing,
wherein at least part of the back raked cutting surface extends from the said edge (26, 62) with a rake angle between the cutting surface (24, 60, 65, 66) and a perpendicular to the direction of rotation which is in a range from 25 to 60 degrees and, at the said edge (26, 62) of the cutting surface, an included angle between the cutting surface (24, 60, 65, 66) and the surface (22) of the cutter body following the cutting surface is greater than 90 degrees.

13. A method according to claim 12 wherein
the rotary tool comprises at least one element (82, 122) which carries the at least one cutter (86-88, 211-216),
the at least one element projects or is extensible from the central structure to bring the at least one cutter into contact with the tubing, and
part of the tool extends axially ahead of the cutters into tubing which has not yet been removed by the cutters (86-88, 211-216),

14. A method according to claim 12 or claim 13 wherein the at least one element (82, 122) is configured to bring the at least one cutter (86-88, 211-216) into contact with the internal surface of the tubing, whereby the at least one cutter cuts radially outwardly into the internal surface completely around the tubing.

Patentansprüche

1. Drehwerkzeug, das eine Trägerstraße zum Fräsen einer Rohrleitung in einem Bohrloch darstellt, umfassend eine

Struktur mit einer Vielzahl von Schneidern (86-88, 211-216) darauf, die zum Fräsen der Rohrleitung konfiguriert sind, während sich ein Teil des Werkzeugs in einen Abschnitt der Rohrleitung erstreckt, der noch nicht durch die Schneider entfernt wurde,

wobei zumindest ein Schneider (86-88, 211-216) einen Schneiderkörper und eine Schneidfläche (24, 60, 65, 66) an dem Schneiderkörper aufweist, wobei der Schneider derart geformt und an dem Werkzeug positioniert ist, dass zumindest ein Teil der Schneidfläche (24, 60, 65, 66) bezogen auf die Drehrichtung zurück gespannt wird, sodass die Schneidfläche (24, 60, 65, 66) an einer Kante (26, 62), bei der es sich um eine Hinterkante der Schneidfläche bezogen auf die Drehrichtung handelt, am weitesten in die Rohrleitung schneidet,

wobei sich zumindest ein Teil der zurück gespannten Schneidfläche (24, 60, 65, 66) in einem Spannwinkel zwischen der Schneidfläche und einer senkrecht zu der Drehrichtung, der in einem Bereich zwischen 25 und 60 Grad liegt, von der Kante (26, 62) erstreckt und an der Kante (26, 62) der Schneidfläche (24, 60, 65, 66) einen Winkel größer 90 Grad aufweist, der zwischen der Schneidfläche (24, 60, 65, 66) und der Fläche des Schneiderkörpers (22) hinter der Schneidfläche (24, 60, 65, 66) eingeschlossen ist.

2. Drehwerkzeug nach Anspruch 1, wobei sich der zumindest eine Teil der zurück gespannten Schneidfläche (24, 60, 65, 66) in einem Spannwinkel, der in einem Bereich zwischen 25 und 50 Grad liegt, von der Kante (26, 62) erstreckt.

3. Drehwerkzeug nach Anspruch 1 oder 2, wobei die Fläche (22) des Schneiderkörpers hinter dem zumindest einen Teil der zurück gespannten Schneidfläche (24, 60, 65, 66) an der Kante (26, 62) in einem Winkel zwischen 0 und 15 Grad zu der Drehrichtung von der Schneidefläche (28) abweicht.

4. Drehwerkzeug nach Anspruch 1, wobei sich der zumindest eine Teil der zurück gespannten Schneidfläche (24, 60, 65, 66) in einem Winkel von zumindest 100 Grad, der zwischen der zurück gespannten Schneidfläche an der Kante und der Fläche (22) des Schneiderkörpers hinter der Schneidfläche eingeschlossen ist, von der Kante (26, 62) erstreckt.

5. Drehwerkzeug nach einem der vorangehenden Ansprüche, wobei der zumindest eine Schneider (86-88, 211-216) einen Körper aus einem harten Material darstellt.

6. Drehwerkzeug nach Anspruch 5, wobei der zumindest eine Schneider (86-88, 211-216) einen Körper aus einem harten Material mit einer Knoop-Härte von 1.800 oder mehr darstellt.

7. Drehwerkzeug nach einem der vorangehenden Ansprüche, wobei das Werkzeug eine zentrale Struktur zum axialen Einsetzen in die Rohrleitung und zumindest ein Element (82, 122) umfasst, das zumindest einen des Schneiders (86-88, 211-216) trägt und das von der zentralen Struktur hervorsteht oder davon ausgezogen werden kann, um den zumindest einen Schneider in Berührung mit der Rohrleitung zu bringen.

8. Drehwerkzeug nach Anspruch 7, wobei das zumindest eine Element (82, 122) konfiguriert ist, um den zumindest einen Schneider mit der Innenfläche der Rohrleitung in Berührung zu bringen, um radial nach außen in die Rohrleitung zu schneiden.

9. Drehwerkzeug nach Anspruch 7 oder Anspruch 8, wobei der zumindest eine Schneider zumindest teilweise in dem zumindest einen Element (82, 122) eingebettet ist und zumindest teilweise davon freiliegt, sodass der eingebettete Abschnitt des Schneiderkörpers ein größeres Volumen aufweist als der freiliegende Abschnitt.

10. Drehwerkzeug nach Anspruch 9, wobei der zumindest eine Schneider eine freiliegende Vorderseite und eine teilweise eingebettete Dicke in einem Ausmaß, das zumindest die Hälfte der Länge einer beliebigen Abmessung des Körpers senkrecht zu der Dicke ausmacht, hinter der Vorderseite aufweist.

11. Drehwerkzeug nach einem der Ansprüche 7 bis 10, wobei das Fräswerkzeug eine Vielzahl von Elementen (82, 122) aufweist, die zumindest einen des Schneiders (86-88, 211-216) tragen, der aus hartem Material gebildet ist, die von dem Werkzeugkörper hervorstehen oder von diesem ausgezogen werden können und die azimutal entlang einer Längsachse des Werkzeugs verteilt sind.

12. Verfahren zum Entfernen einer Rohrleitungslänge in einem Bohrloch, umfassend:

Einsetzen eines Drehfräswerkzeugs in die Rohrleitung, das eine Trägerstraße darstellt, umfassend eine Struktur, die sich axial in der Rohrleitung erstreckt, mit einer Vielzahl von Schneidern (86-88, 211-216) an der Struktur

zum Fräsen der Rohrleitung, während sich ein Teil des Werkzeugs in einen Abschnitt der Rohrleitung erstreckt, der noch nicht durch die Schneider entfernt wurde,
wobei zumindest ein Schneider einen Schneiderkörper und eine Schneidfläche (24, 60, 65, 66) an dem Schneiderkörper aufweist und der zumindest eine Schneider derart geformt und positioniert ist, dass zumindest ein Teil der Schneidfläche (24, 60, 65, 66) bezogen auf die Drehrichtung zurück gespannt wird, sodass die Schneidfläche an einer Kante (26, 62), bei der es sich um eine Hinterkante der Schneidfläche bezogen auf die Drehrichtung handelt, am weitesten in die Rohrleitung schneidet, und
axiales Vorrücken des Werkzeugs, während das Werkzeug gedreht wird, wobei zumindest ein Schneider vollständig um die Rohrleitung in die Rohrleitung schneidet,
wobei sich zumindest ein Teil der zurück gespannten Schneidfläche in einem Spannwinkel zwischen der Schneidfläche (24, 60, 65, 66) und einer senkrecht zu der Drehrichtung, der in einem Bereich zwischen 25 und 60 Grad liegt, von der Kante (26, 62) erstreckt und an der Kante (26, 62) der Schneidfläche ein eingeschlossener Winkel zwischen der Schneidfläche (24, 60, 65, 66) und der Fläche (22) des Schneiderkörpers hinter der Schneidfläche größer 90 Grad ist.

13. Verfahren nach Anspruch 12, wobei:

das Drehwerkzeug zumindest ein Element (82, 122) umfasst, das den zumindest einen Schneider (86-88, 211-216) trägt,
wobei das zumindest eine Element von der zentralen Struktur hervorsteht oder davon ausgezogen werden kann, um den zumindest einen Schneider in Berührung mit der Rohrleitung zu bringen, und
wobei sich ein Teil des Werkzeugs axial vor die Schneider in einen Abschnitt der Rohrleitung erstreckt, der noch nicht durch die Schneider (86-88, 211-216) entfernt wurde,

14. Verfahren nach Anspruch 12 oder Anspruch 13, wobei das zumindest eine Element (82, 122) konfiguriert ist, um den zumindest einen Schneider (86-88, 211-216) in Berührung mit der Innenfläche der Rohrleitung zu bringen, wodurch der zumindest eine Schneider vollständig um die Rohrleitung radial nach außen in die Innenfläche schneidet.

Revendications

1. Outil rotatif qui est une fraise de section pour fraiser une colonne de production dans un trou de forage, comprenant une structure avec une pluralité de dispositifs de taille (86-88, 211-216) sur celle-ci configurée pour fraiser une colonne de production tandis qu'une partie de l'outil s'étend dans la colonne de production qui n'a pas encore été retirée par les dispositifs de taille,
dans lequel au moins un dispositif de taille (86-88, 211-216) a un corps de dispositif de taille et une surface de taille (24, 60, 65, 66) sur le corps de dispositif de taille, où le dispositif de taille est formé et positionné sur l'outil de sorte qu'au moins une partie de la surface de taille (24, 60, 65, 66) est inclinée vers l'arrière par rapport au sens de rotation de sorte que la surface de taille (24, 60, 65, 66) coupe le plus loin dans la colonne de production au niveau d'un bord (26, 62) qui est un bord de fuite de la surface de taille par rapport au sens de rotation,
dans lequel au moins une partie de la surface de taille inclinée (24, 60, 65, 66) s'étend à partir dudit bord (26, 62) avec un angle d'inclinaison entre la surface de taille et une perpendiculaire au sens de rotation qui est dans une plage de 25 à 60 degrés et, au niveau dudit bord (26, 62) de la surface de taille (24, 60, 65, 66), a un angle supérieur à 90 degrés compris entre la surface de taille (24, 60, 65, 66) et la surface du corps de taille (22) suivant la surface de taille (24 , 60, 65, 66) .

2. Outil rotatif selon la revendication 1, dans lequel l'au moins une partie de la surface de taille inclinée vers l'arrière (24, 60, 65, 66) s'étend à partir dudit bord (26, 62) avec un angle d'inclinaison qui est compris dans une plage de 25 à 50 degrés.

3. Outil rotatif selon la revendication 1 ou la revendication 2, dans lequel, au niveau dudit bord (26, 62), la surface (22) du corps de dispositif de taille suivant l'au moins une partie de la surface de taille inclinée vers l'arrière (24, 60, 65, 66) diverge de la surface de taille (28) selon un angle compris entre 0 et 15 degrés par rapport au sens de rotation.

4. Outil rotatif selon la revendication 1, dans lequel l'au moins une partie de la surface de taille inclinée vers l'arrière (24, 60, 65, 66) s'étend à partir dudit bord (26, 62) avec un angle d'au moins 100 degrés compris entre la surface de taille inclinée vers l'arrière au niveau dudit bord et la surface (22) du corps de taille suivant la surface de taille.

5. Outil rotatif selon l'une quelconque des revendications précédentes, dans lequel l'au moins un dispositif de taille (86-88, 211-216) est un corps constitué d'un matériau dur.

6. Outil rotatif selon la revendication 5, dans lequel l'au moins un dispositif de taille (86-88, 211-216) est un corps constitué d'un matériau dur avec une dureté Knoop de 1 800 ou plus.

7. Outil rotatif selon l'une quelconque des revendications précédentes, dans lequel l'outil comprend une structure centrale pour une insertion axiale dans la colonne de production, et au moins un élément (82, 122) qui porte au moins un dit dispositif de taille (86-88, 211-216) et qui fait saillie ou est extensible à partir de la structure centrale pour mettre l'au moins un dispositif de taille en contact avec la colonne de production.

8. Outil rotatif selon la revendication 7, dans lequel l'au moins un élément (82, 122) est configuré pour mettre l'au moins un dispositif de taille en contact avec la surface interne de la colonne de production afin de couper radialement vers l'extérieur dans la colonne de production.

9. Outil rotatif selon la revendication 7 ou la revendication 8, dans lequel l'au moins un élément (82, 122) a l'au moins un dit dispositif de taille partiellement intégré à l'intérieur et partiellement exposé, de sorte que la partie intégrée du corps de dispositif de taille est d'un plus grand volume que la portion exposée.

10. Outil rotatif selon la revendication 9, dans lequel l'au moins un dit dispositif de taille a une partie avant exposée et une épaisseur partiellement intégrée suivant ladite partie avant avec une étendue qui est au moins la moitié de la longueur de toute dimension à travers le corps, perpendiculaire à ladite épaisseur.

11. Outil rotatif selon l'une quelconque des revendications 7 à 10, dans lequel l'outil de fraisage a une pluralité d'éléments (82, 122) qui portent chacun au moins un dit dispositif de taille (86-88, 211-216) constitué d'un matériau dur, qui font saillie ou sont extensibles à partir du corps d'outil et qui sont répartis de manière azimutale autour d'un axe longitudinal de l'outil.

12. Procédé de retrait d'une longueur de colonne de production dans un trou de forage, comprenant
l'insertion dans la colonne de production d'un outil de fraisage rotatif qui est une fraise de section comprenant une structure s'étendant axialement à l'intérieur de la colonne de production avec une pluralité de dispositifs de taille (86-88, 211-216) sur la structure pour fraiser la colonne de production tandis qu'une partie de l'outil s'étend dans la colonne de production qui n'a pas encore été retirée par les dispositifs de taille,
où au moins un dispositif de taille a un corps de dispositif de taille et une surface de taille (24, 60, 65, 66) sur le corps de dispositif de taille et l'au moins un dispositif de taille est façonné et positionné de sorte qu'au moins une partie de la surface de taille (24, 60, 65, 66) est inclinée vers l'arrière par rapport au sens de rotation de sorte que la surface de taille coupe le plus loin dans la colonne de production au niveau d'un bord (26, 62) qui est un bord de fuite de la surface de taille par rapport au sens de rotation, et
l'avancement axial de l'outil tout en faisant tourner l'outil avec l'au moins un dispositif de taille coupant dans la colonne de production complètement autour de la colonne de production, dans lequel au moins une partie de la surface de taille inclinée vers l'arrière s'étend à partir dudit bord (26, 62) avec un angle d'inclinaison entre la surface de taille (24, 60, 65, 66) et une perpendiculaire au sens de rotation qui est compris dans une plage de 25 à 60 degrés et, au niveau dudit bord (26, 62) de la surface de taille, un angle inclus entre la surface de taille (24, 60, 65, 66) et la surface (22) du corps de taille suivant la surface de taille est supérieur à 90 degrés.

13. Procédé selon la revendication 12, dans lequel
l'outil rotatif comprend au moins un élément (82, 122) qui porte l'au moins un dispositif de taille (86-88, 211-216), l'au moins un élément fait saillie ou est extensible à partir de la structure centrale pour mettre l'au moins un dispositif de taille en contact avec la colonne de production, et
une partie de l'outil s'étend axialement en avant des dispositifs de taille dans la colonne de production qui n'a pas encore été retirée par les dispositifs de taille (86-88, 211-216),

14. Procédé selon la revendication 12 ou la revendication 13, dans lequel l'au moins un élément (82, 122) est configuré pour mettre l'au moins un dispositif de taille (86-88, 211-216) en contact avec la surface interne de la colonne de production, moyennant quoi l'au moins un dispositif de taille coupe radialement vers l'extérieur dans la surface interne complètement autour de la colonne de production.

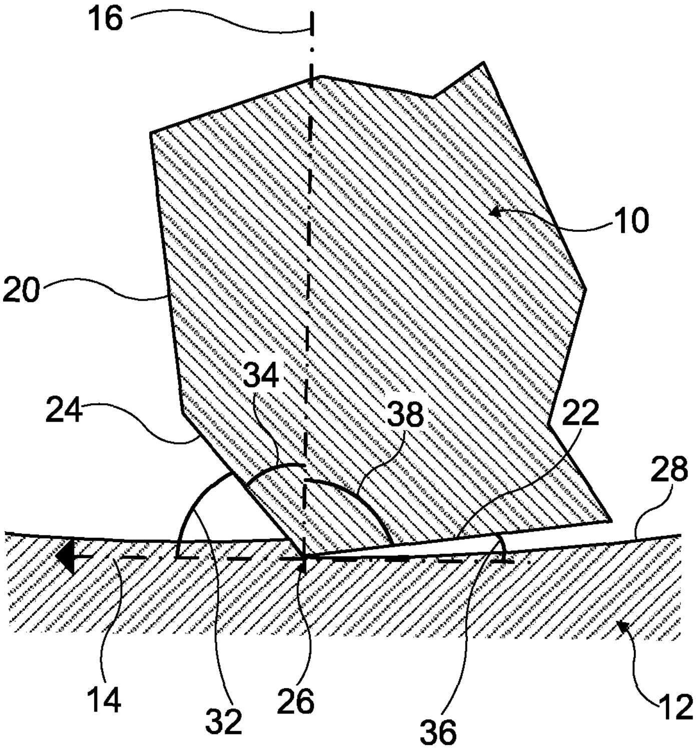


Fig 1

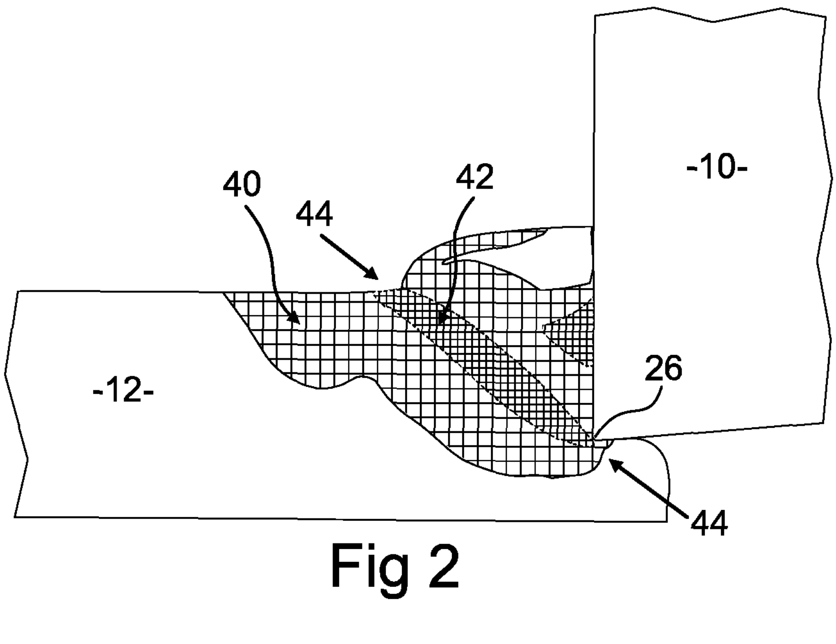
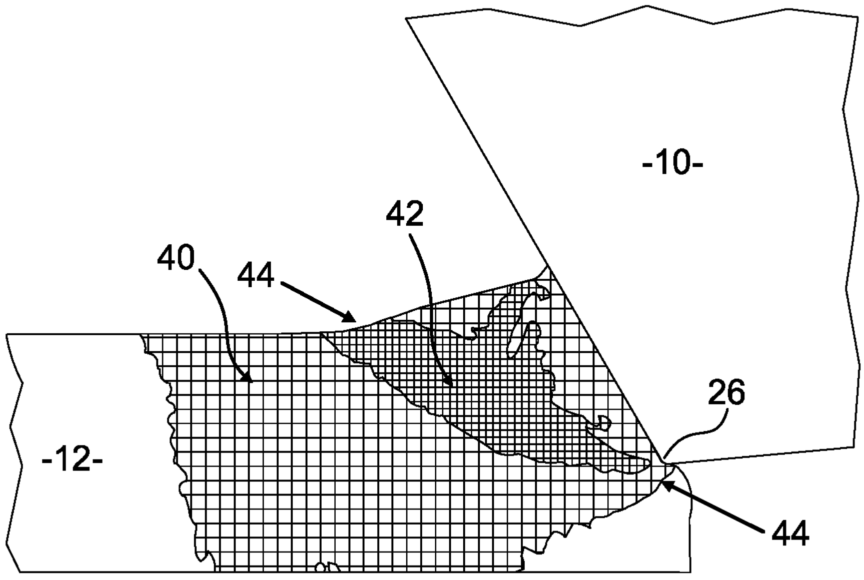


Fig 2



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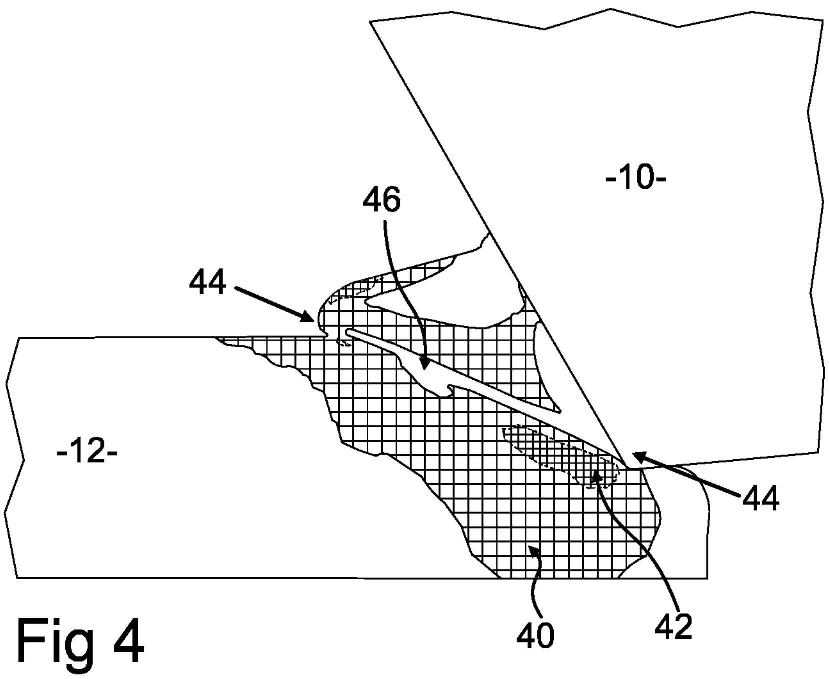

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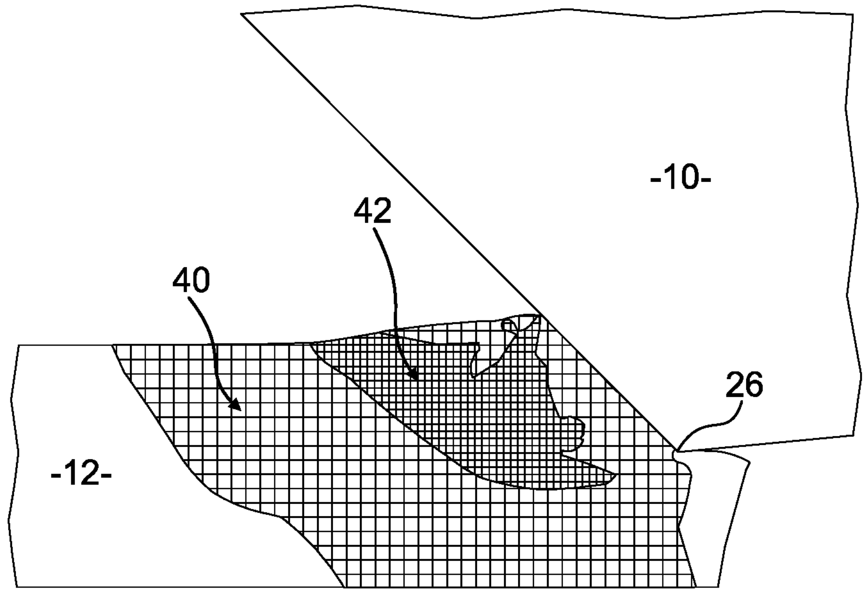

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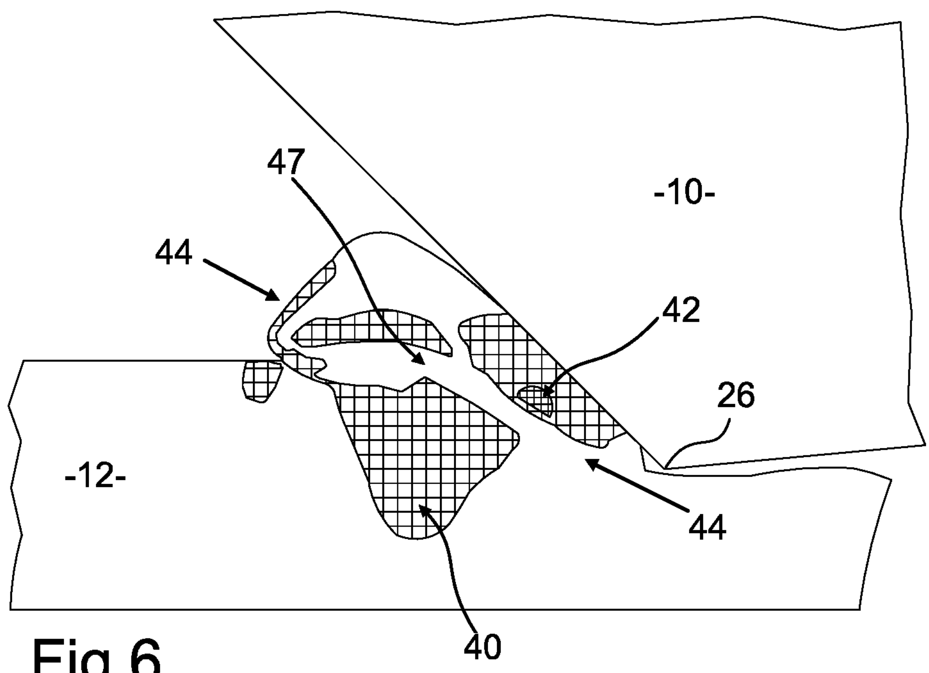

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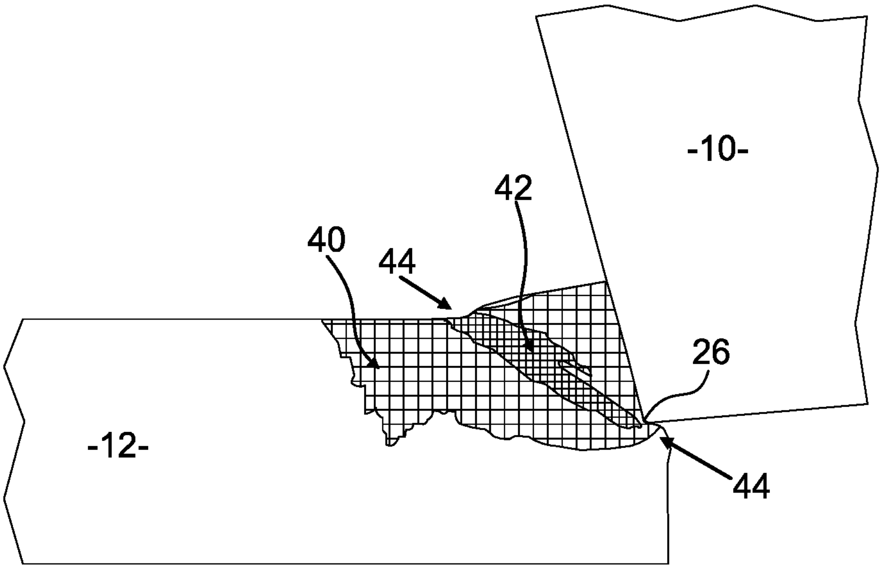

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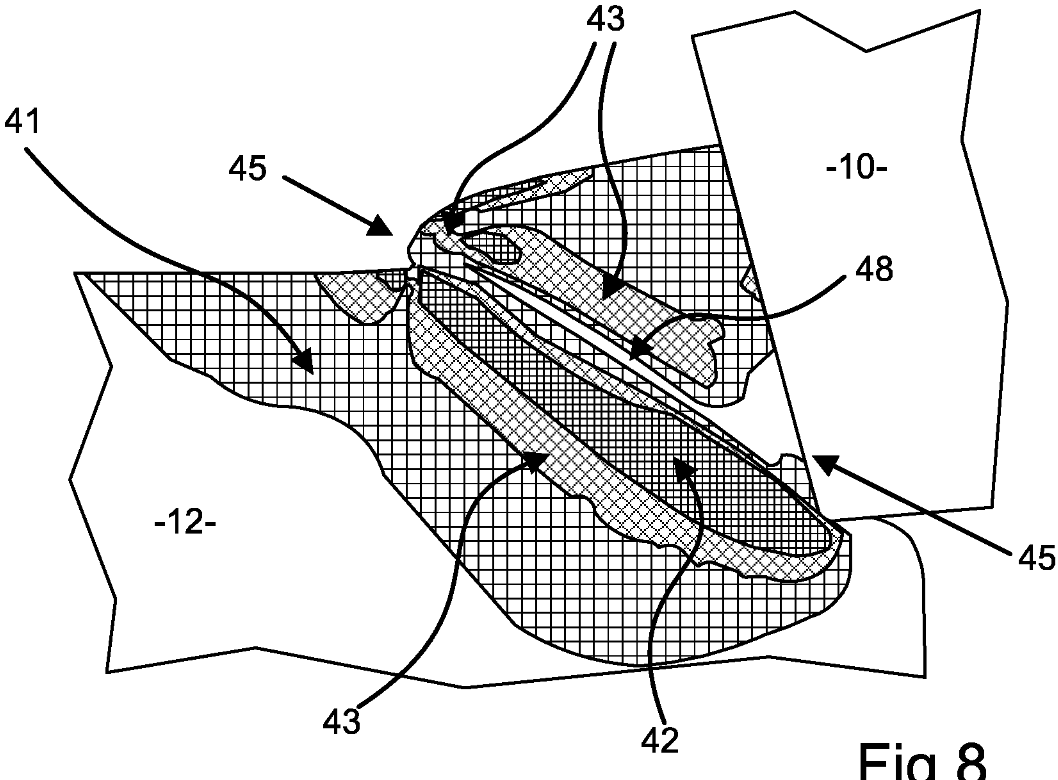

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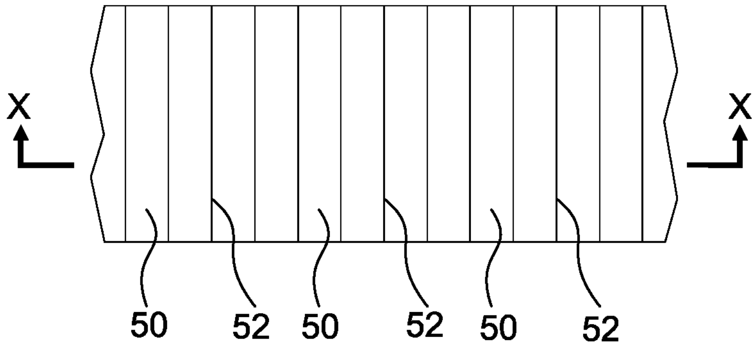

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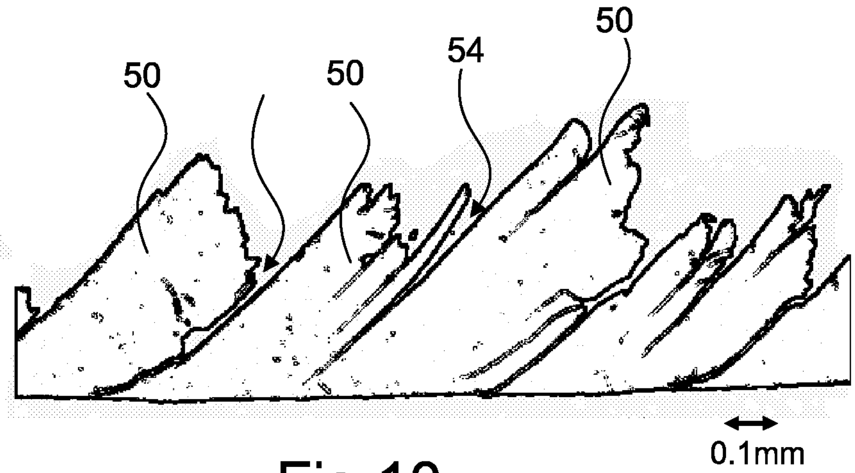
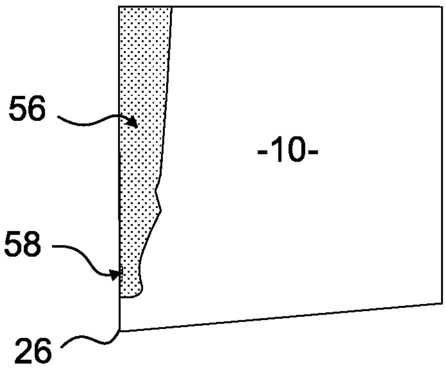


Fig 10

Fig 11



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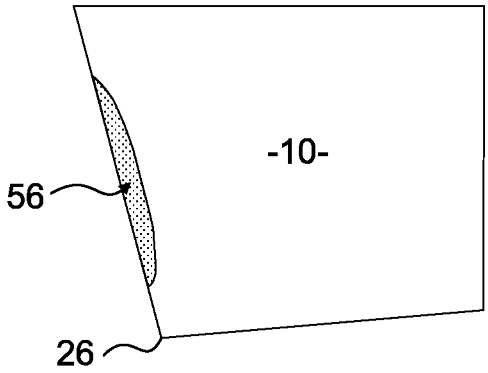


Fig 13

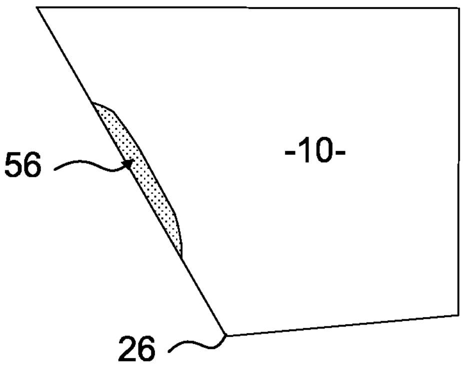
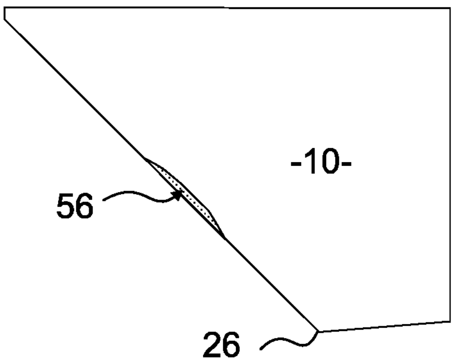


Fig 14



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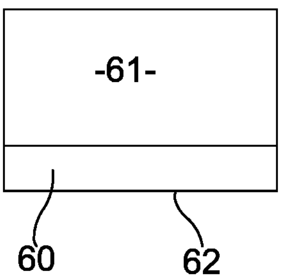


Fig 16a

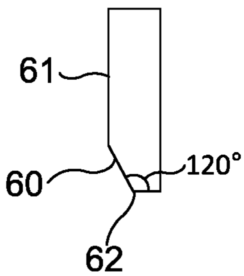
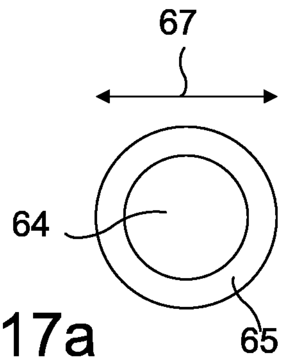


Fig 16b



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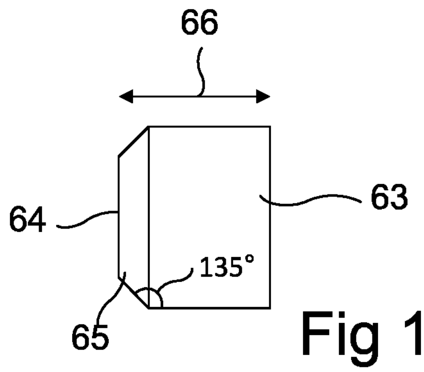
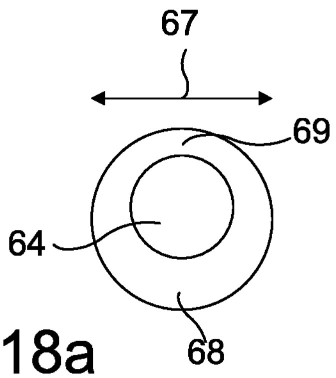


Fig 17b



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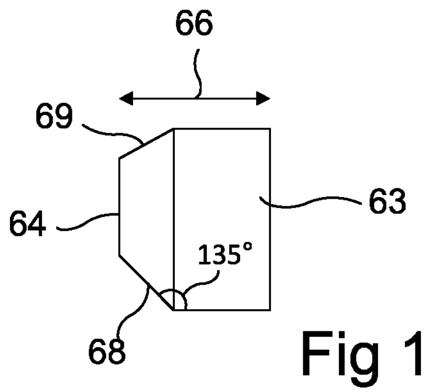
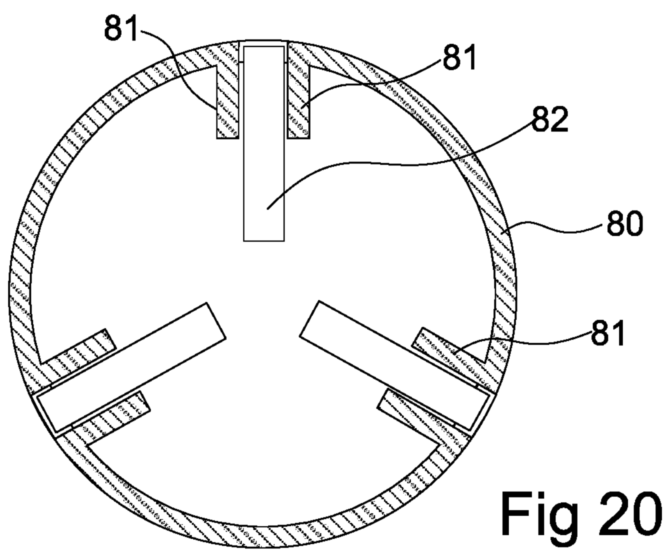


Fig 18b



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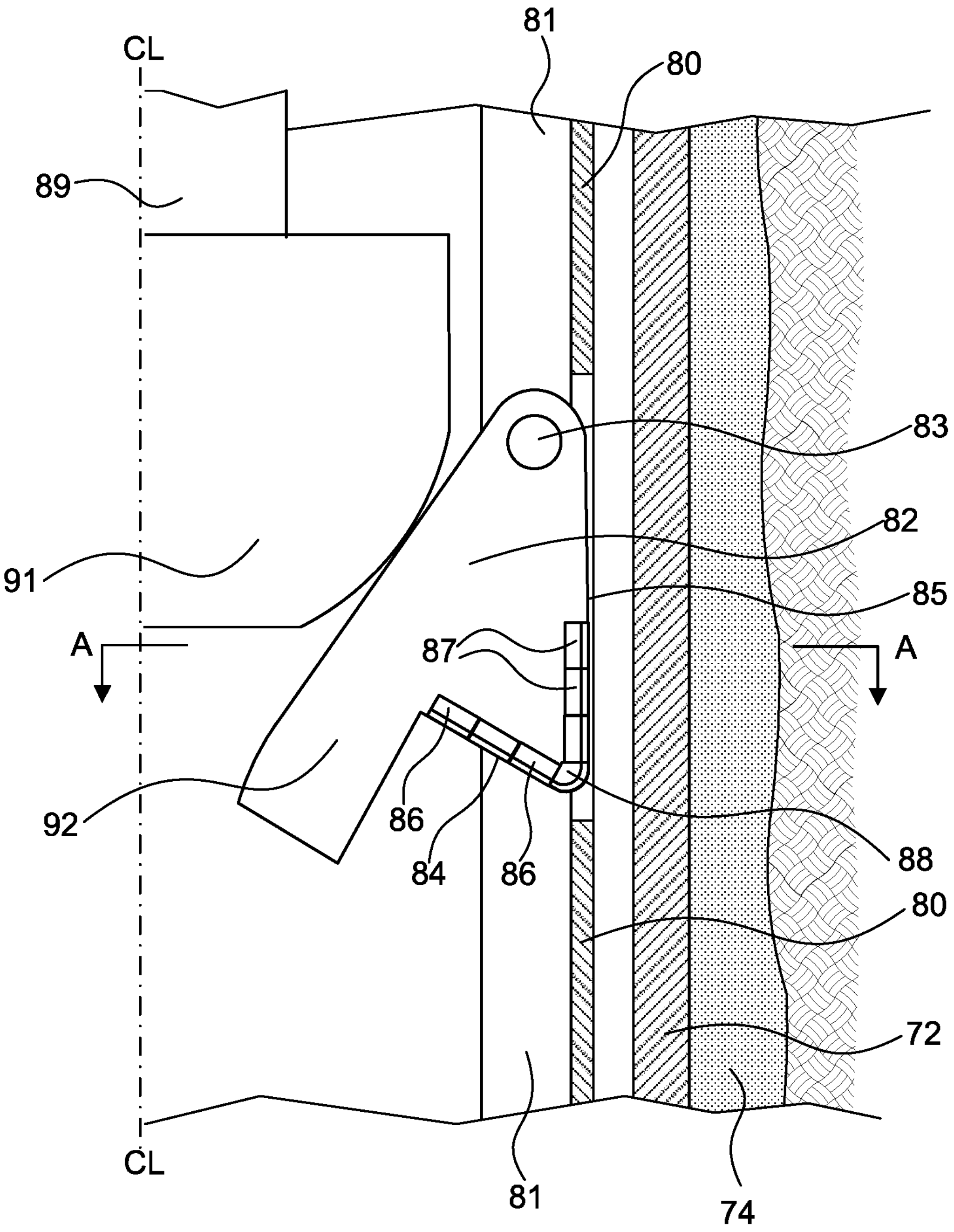

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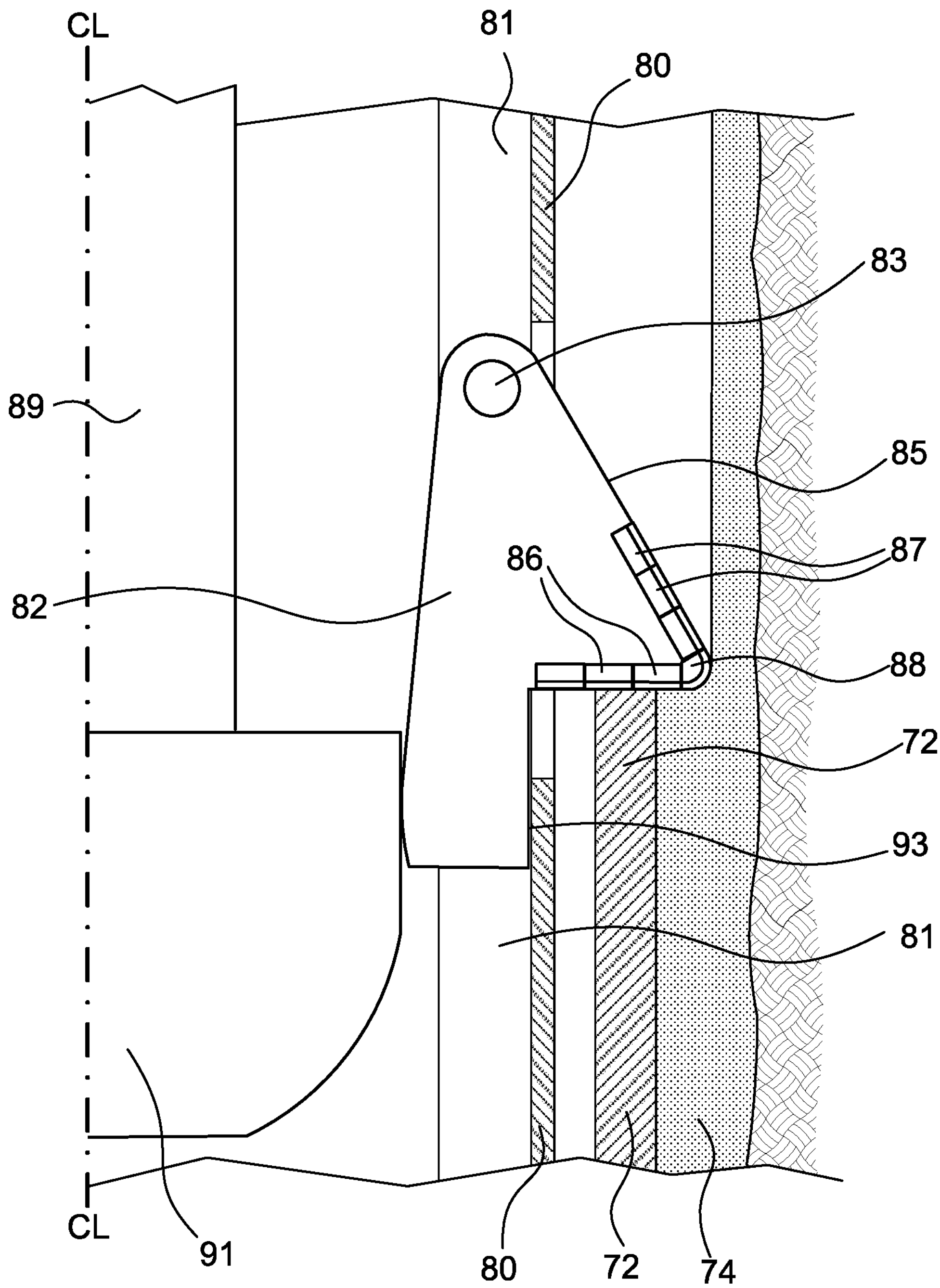

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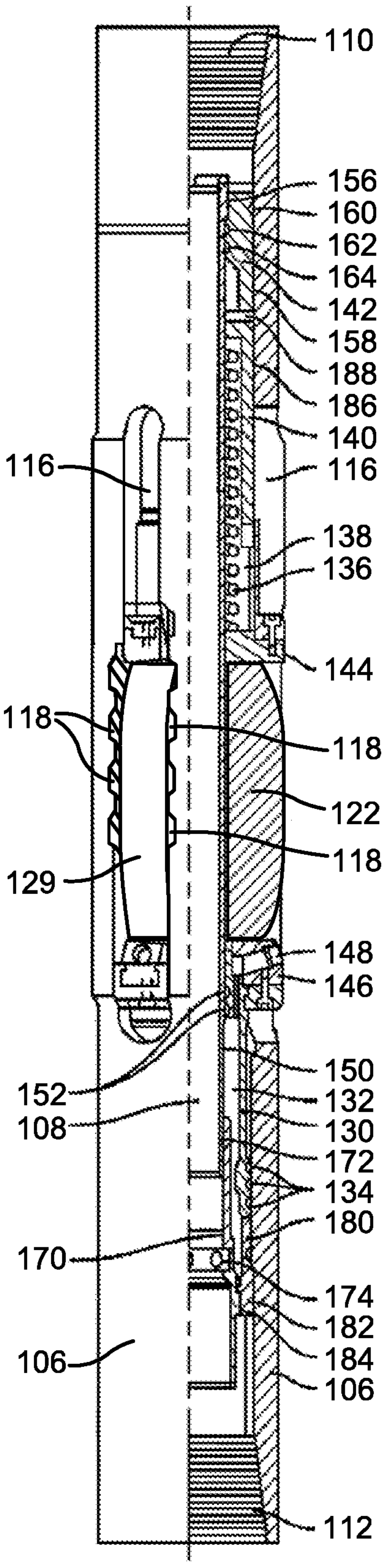
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Fig 22

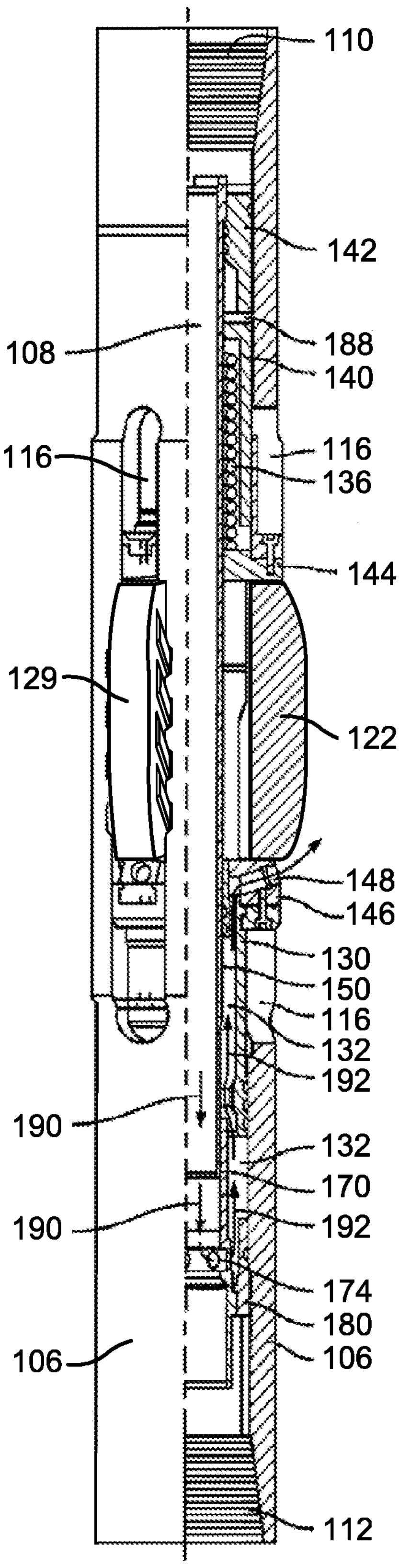
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Fig 23

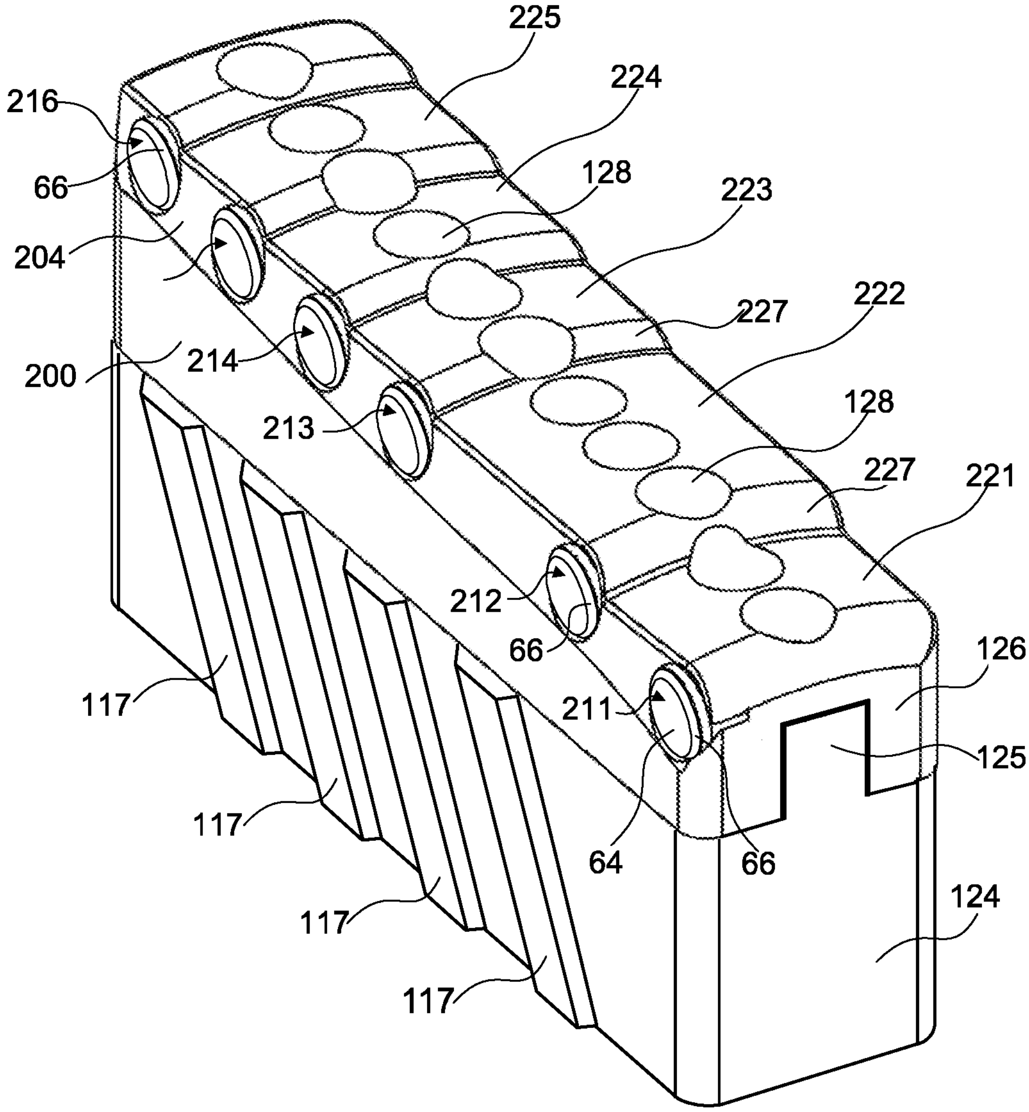
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Fig 24

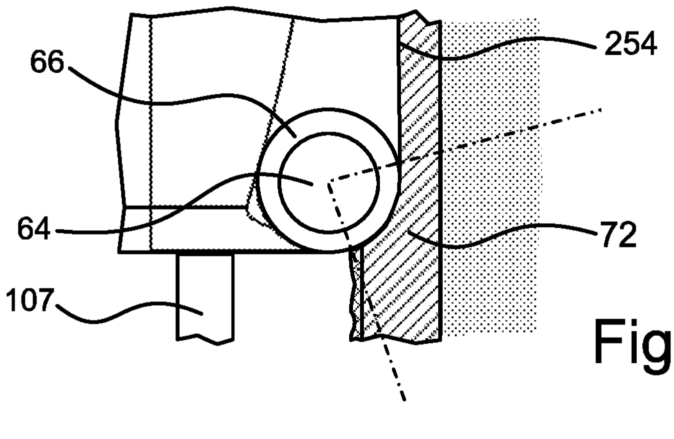
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Fig 27

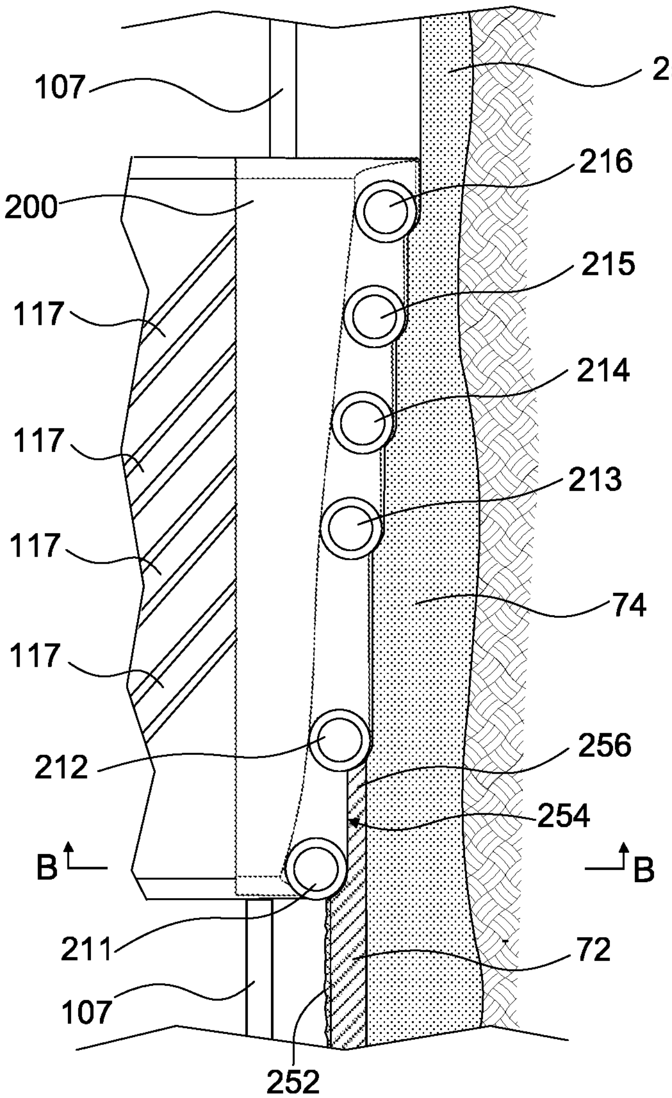
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Fig 25

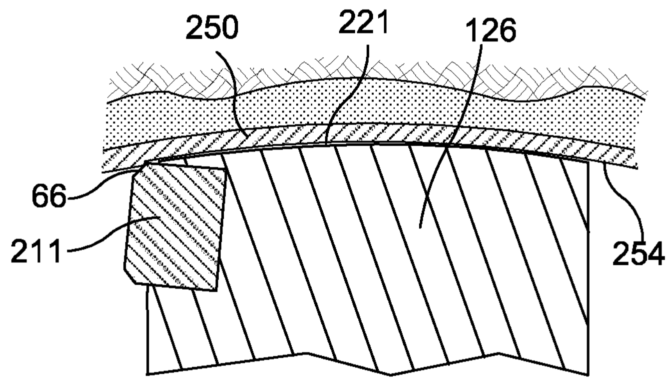
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Fig 26

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- GB 1513927 A **[0001]**
- US 20080093076 A **[0007]**
- US 20070079995 A **[0008]**
- US 4978260 A **[0009]**
- US 5012863 A **[0010]**