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(54) **ELLIPTICAL DESIGN FOR HEXAGONAL SHANKS**

ELLIPTISCHES DESIGN FÜR SECHSECKIGE SCHÄFTE

CONCEPTION ELLIPTIQUE POUR TIGES HEXAGONALES

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DescriptionField of invention

5 **[0001]** The present invention relates to a hexagonal shank for rock drill components in particular, although not exclusively, to a hexagonal shank configured to minimise stress concentrations.

Background art

10 **[0002]** Percussion drilling is used to create a long borehole via a plurality of elongate drill string rods. The well-established technique breaks rock by hammering impacts transferred from the rock drill bit, mounted or forged at one end of the drill string, to the rock at the bottom of the borehole. Typically, the energy required to break the rock is generated by a hydraulically or pneumatically driven piston that contacts the end of the drill string to create a stress (or shock) wave that propagates through the drill string and ultimately to the base rock level.

15 **[0003]** Rock drill components having a hexagonal shank are commonly used in less powerful rock drills and in particular for drilling smaller holes. However, these rock tools are typically subjected to bending moments during drilling. These bending moments fatigue the rock tools and may lead to breakage within the joint. An example of a rock drill component having a hexagonal shank is disclosed in document US 3876319 A.

20 **[0004]** In particular, the transition between the different diameters of shoulder on the rock drill component and the hexagonal shank provides a region for potentially high stress concentrations due to bending moments and tensile loads. Conventionally, the outside diameter of the rock drill component at the transition axially between the hexagonal shank and the shoulder is flared radially outward with a curved shape profile having a single radius curvature that is as large as can be accommodated between the two regions. The problem is with this profile is that high levels of stress can build up in this region. Fatigue and possible breakage are therefore very likely which causes significant disruption to a drilling operation. There is therefore a need for a hexagonal shank design that addresses these problems.

Summary of the Invention

30 **[0005]** It is an objective of the present invention to provide a rock drill component having a hexagonal shank that is optimised to minimise the likelihood of stress concentrations at the transition region between the shoulder and the hexagonal shank to extend the operational lifetime of the rock drill component and minimise fatigue and the risk of breakage in use. It is a further specific objective to provide a rock drill component that is compatible with existing drilling apparatus and methods that comprises an enhanced capacity to withstand large bending moments and tensile loads.

35 **[0006]** The objectives are achieved by specifically configuring the transition region that is positioned axially at the interface between the annular shoulder and the hexagonal shank. The present invention provides a rock drill component that has a hexagonal shank that exhibits reduced stress concentrations compared to known designs at the junction of the shoulder and the hexagonal shank resultant from incident bending moments or tensile loads.

40 **[0007]** According to a first aspect of the present invention there is a rock drill component to form part of a drilling assembly, the rock drill component comprising: a main body; a hexagonal shank provided at one end of the rock drill component; a radially projecting shoulder positioned axially between the main body and the hexagonal shank; wherein the transition section has an outside diameter that increases in diameter in a direction from the hexagonal shank to the shoulder; wherein the cross-sectional shape profile of the outer surface of the transition section in the plane of the longitudinal axis comprises a segment of an ellipse having semi-major axis (a); a semi-minor axis (b) and an exponential factor (n) according to the equation:

$$\left| \frac{x}{a} \right|^n + \left| \frac{y}{b} \right|^n = 1$$

45 characterised in that the ratio of the semi-major to semi-minor axes (a:b) is within the range $2b < a < 8b$.

50 **[0008]** Advantageously, this provides a coupling to hexagonal shank exhibiting enhanced stiffness and that is more resilient to bending moments and tensile forces. The transition section is configured to eliminate or at least minimise stress concentrations at the section where spigot projects axially from shoulder. If the ratio of the lengths of the semi-major to semi-minor axes are above or below this the stress concentrations increase. Consequently, the risk of breakage is reduced and so the operation lifetime of the rock drill component is increased. Optionally, the transition section may also comprise segments wherein the shape profile is straight and / or different curved profile.

55 **[0009]** Preferably, the ratio of the semi-major to semi-minor axes (a:b) is within the range $2.5b < a < 6b$, even more

preferably $2.5 < a < 4b$. Advantageously, within the narrowed ratio range the stress concentrations at the section where the hexagonal shank projects axially from the shoulder are further reduced meaning that there is enhanced capacity to withstand large bending moments and tensile stresses.

[0010] Preferably, the exponential factor (n) is in the range $1 \leq n \leq 3$. Advantageously, this provides a transition section having an elliptical profile with the lowest stress concentration.

[0011] Optionally, a vertex of the ellipse is positioned at a tangent with the annular side surface of the shoulder. Alternatively, the vertex of the ellipse undercuts the annular side surface of the shoulder. Different load cases may benefit from different forms of the ellipse.

[0012] Optionally, the x-axis of the ellipse is parallel to the longitudinal axis. Alternatively, the x-axis of the ellipse is tilted with respect to the longitudinal axis. Different load cases may benefit from different forms of the ellipse.

[0013] Optionally, the profile of the outer surface of the transition section in the plane of the longitudinal axis comprises a quarter segment of an ellipse. Alternatively, the cross-sectional shape profile of the outer surface of the transition section in the plane of the longitudinal axis comprises greater than a quarter segment of an ellipse. Alternatively, the cross-sectional shape profile of the outer surface of the transition section in the plane of the longitudinal axis comprises a less than quarter segment of an ellipse. Different load cases may benefit from different forms of the ellipse.

[0014] Within the specification, reference to 'curvature' encompasses a smooth or gradual change in surface profile and a plurality of sequential linear increases (or decreases) in diameter that collectively may be regarded as a 'curved' shape profile. For example, the term 'curvature' encompasses relatively small linear step changes such that an edge or middle region of each step may be considered to collectively define a curve.

[0015] Preferably, the rock drill component comprises a shoulder projecting radially from the main length section wherein an outside diameter of the shoulder is greater than an outside diameter of the main length section and the transition section of the shank. Such a configuration allows for the conventional 'shoulder contact' coupling between the male spigot and the female sleeve that is preferred over the alternative 'bottom contact' due to the larger diameter and surface area contact between the male and female parts.

[0016] Preferably, a side surface of the shoulder that is in contact with the transition section comprises an annular radially outer region that is aligned substantially perpendicular to the longitudinal axis. The curved transition section therefore does not continue over the full radial length of the annular side surface to provide a flat annular surface for contact by the annular end face of the female sleeve.

[0017] In one embodiment, the rock drill component is a shank rod.

[0018] In another embodiment, the rock drill component is a taper rod.

[0019] In another embodiment, the rock drill component is an integral drill steel (IDS).

[0020] According to a second aspect of the present invention there is provided a drilling assembly comprising a rock drill component as claimed herein.

Brief description of drawings

[0021] A specific implementation of the present invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 is an external view of a rock drill component having a hexagonal shank.

Figure 2a is an external side view of one end of the rock drill component of Figure 1 showing the transition region between the shoulder and the hexagonal shank wherein the main body has a cylindrical external surface.

Figure 2b is an external side view of one end of the rock drill component of Figure 1 showing the transition region between the shoulder and the hexagonal shank wherein the main body has a hexagonal external surface.

Figure 3 is a magnified view of a rock drill component in the region of the transition section according to one embodiment of the invention wherein the vertex of the elliptical profile of the transition section is at a tangent to the shoulder;

Figure 4 is a magnified view of a rock drill component in the region of the transition section according to an alternative embodiment of the invention wherein the elliptical profile of the transition section undercuts the annular side surface of the shoulder.

Figure 5 is a magnified view of a rock drill component in the region of the transition section according to an alternative embodiment of the invention wherein the elliptical profile of the transition section is tilted.

Figure 6 is an example wherein the rock drill component is a shank rod.

Figure 7 is an example wherein the rock drill component is a taper rod.

Figure 8 is an example wherein the rock drill component is an integral drill steel (IDS)

Figure 9 is an example wherein the rock drill component is a plug hole IDS.

Figures 10a-c are von Mises effective stress images.

Detailed description of preferred embodiment of the invention

[0022] Figure 1 shows a rock drill component 100 having a hexagonal shank 102. The hexagonal shank 102 is positioned between a trailing end 103 and a shoulder 110 (or collar). The hexagonal shank 102 has a hexagonally shaped cross section. The hexagonal shank 102 is mounted in a percussive hammer (not shown) such that the hammer engages with the hexagonal shank 102 and the shoulder 102. The hammer is operated and rotates the rock drill component whilst simultaneously applying axial percussive loads to the trailing end 103 of the rock drill component.

[0023] Figures 2a and 2b shows that a main body 101 of the rock drill component comprises a cylindrical or hexagonal external surface 200 that is flared radially outward at the shoulder 110 to provide an annular concave region 201 that terminates at a cylindrical surface 202 located at the shoulder 110. The cylindrical external surface 200 is shown in figure 2a and the hexagonal external surface is shown in figure 2b. Subsequent drawings all shown the cylindrical option for the external surface 200, but it should be understood that in any embodiment the hexagonal external surface could be used instead. The shoulder 110, in particular the cylindrical surface 202 is terminated at the hexagonal shank side by an annular side surface 203 aligned perpendicular to the axis 204. The hexagonal shank projects axially from a radially inward region of the surface 203 and is aligned coaxial with the main body 101 and the annular shoulder 110. A curved transition section 206 is positioned axially between the side surface 203 and the main length of the hexagonal shank 102. The transition section 206 tapers radially outward in a direction from the hexagonal shank 102 to contact against the annular side surface 203

[0024] Figure 3 shows an expanded view of the transition section 206. The transition section 206 increases in diameter and cross-sectional area from hexagonal shank 102 to the shoulder 110, such that the external surface profile of the transition section 206 in a plane along axis 204 is curved according to a gradual curvature having a profile corresponding to quarter segment of a perimeter of an ellipse 214, or slightly more or slightly less than a quarter segment of an ellipse 214. The ellipse 214 has a semi-major axis (x) and a semi-minor axis (y). Preferably, there is no abrupt change along the length of the transition section 206 from a first radius to a second radius, instead there is a continuous and gradual change in the radius along the length of the transition section 206. Optionally, the transition section 206 may also comprise segments wherein the shape profile is straight and / or has a different curved profile, which could be positioned at either end of the elliptical profile or as an interruption part way along the elliptical profile.

[0025] The equation of an ellipse is defined by a Lamé curve when n=2:

$$\left| \frac{x}{a} \right|^n + \left| \frac{y}{b} \right|^n = 1$$

Wherein:

x is the co-ordinate on the x axis;

y is the co-ordinate on the y axis;

a is the semi-major axis (x);

b is the semi-minor axis (y);

n determines the shape of the curve. n=2 defines an ordinary ellipse. n<2 a hypoellipse and n>2 a hyperellipse.

[0026] In the present invention the ratio of the major to minor axes, (a: b) is within the range $2b < a < 8b$, preferably, $2b < a < 6b$, more preferably $2.5b < a < 6b$, even more preferably $2.5b < a < 4b$.

[0027] Preferably, the semi-minor axis (b) is as large as possible.

[0028] Preferably, the exponential factor n is in the range $1 \leq n \leq 3$, preferably $1.8 \leq n \leq 2.2$, most preferably 2.

[0029] The equation of the elliptical profile of the transition section 206 can be measured using a contour measuring machine. The contour measuring machine drags a needle over the surface of the transition section 206, then the

equipment will try to fit different geometries and then output the equation of shape profile measured.

[0030] At each endpoint of the semi-major axis (x) is a vertex 215 of the ellipse 214 and at each endpoint of the minor axis (y) there is a co-vertex 216 of the ellipse 214. Optionally, the vertex 215 of the ellipse is positioned at a tangent with the annular side surface 203 of the shoulder 110, as shown in Figure 3.

[0031] Figure 4 shows an alternative design, where the vertex 215 of the ellipse 214 undercuts the annular side surface 203 of the shoulder 110.

[0032] Optionally, the x-axis of the ellipse 214 is parallel to the longitudinal axis 204, as shown in Figure 3.

[0033] Figure 5 shows an alternative wherein the x-axis of the ellipse 214 is tilted with respect to the longitudinal axis of 204.

[0034] It should be appreciated that any combination of the position of the vertex 215 can be combined with any orientation of the x-axis with respect to the longitudinal axis 204 as described hereinabove.

[0035] The profile of the transition section 206 provides a male shank end exhibiting enhanced stiffness and that is more resilient to bending moments and tensile forces with respect to conventional hexagonal shank designs. Additionally, the transition section 206 is configured to eliminate or at least minimise stress concentrations at the section where hexagonal shank 102 projects axially from shoulder 110.

[0036] Figure 6 shows that in one embodiment, the rock drill component 100 is a shank rod 250 having a threaded section 251 at the axially opposite end compared to the hexagonal shank 102 for connection to a coupling or directly to a threaded drill bit (not shown).

[0037] Figure 7 shows that in another embodiment, the rock drill component 100 is a taper rod 260 having a tapered joint 261 at the axially opposite compared to the hexagonal shank 102 for connection to a drill bit (not shown).

[0038] Figure 8 shows that in another embodiment, the rock drill component 100 is an integral drill steel (IDS) 270 having a forged bit end 271 at the axially opposite end to the hexagonal shank for drilling into the rock.

[0039] Figure 9 shows that the IDS 270 could for example be a plug hole IDS.

[0040] The rock drill component 100 could also be any component that has a hexagonal shank 102 and a shoulder 110.

[0041] Figures 10a-c show the maximum value of the von Mises effective stress using rotating bending as the load case for different transition section 206 profiles as shown in Table 1:

Table 1: Description of transition section profiles used in the von Mises effective stress images.

Figure	Transition section profile	Von Mises stress
10a (prior art)	Single radius = 4.5 mm	361 MPa
10b (invention)	Elliptical: a = 7.0 mm and b = 2.3 mm	327 MPa
10c (invention)	Elliptical: a = 10.0 mm and b = 3.5 mm	291 MPa

[0042] The risk for failure is increased as the value of the von Mises effective stress increases. Thus, darker colours mean higher risk for failure. By comparing figure 10a (prior art) to figures 10b-c (embodiments of the present invention) it can be seen that the von Mises effective stress has decreased for the inventive profiles. The stress images were captured using implicit analysis in LS-Dyna and the von Mises stress images are extracted using the Hyperview software. Table 1 also shows the maximum value of the von Mises effective stress measured from this equipment. It can be seen from the results in Table 1 that all the inventive samples have lower von Mises stress compared to the prior art version.

Claims

1. A rock drill component (100) to form part of a drilling assembly, the rock drill component (100) comprising:

a main body (101);

a hexagonal shank (102) provided at one end of the rock drill component (100);

a radially projecting shoulder (110) positioned axially between the main body (101) and the hexagonal shank (102);

wherein there is a transition section (206) increasing in diameter in a direction from the hexagonal shank (102) to the shoulder (110);

wherein the cross-sectional shape profile of the outer surface of the transition section (206) in the plane of the longitudinal axis (204) comprises a segment of an ellipse (214) having semi-major axis (a); a semi-minor axis (b) and an exponential factor (n) according to the equation:

$$\left|\frac{x}{a}\right|^n + \left|\frac{y}{b}\right|^n = 1$$

5

characterised in that:

the ratio of the semi-major to semi-minor axes (a:b) is within the range $2b < a < 8b$.

- 10
2. The rock drill component (100) according to claim 1, wherein the ratio of the semi-major to semi-minor axes (a:b) is within the range $2.5b < a < 6b$.
3. The rock drill component (100) according to claim 1 or claim 2, wherein the exponential factor (n) is in the range $1 \leq n \leq 3$.
- 15
4. The rock drill component (100) according to any preceding claim, wherein a vertex (215) of the ellipse (214) is positioned at a tangent with the annular side surface (203) of the shoulder (110).
5. The rock drill component (100) according to any of claims 1-3, where the vertex (215) of the ellipse (214) undercuts the annular side surface (203) of the shoulder (110).
- 20
6. The rock drill component (100) according to any preceding claim, wherein the x-axis of the ellipse (214) is parallel to the longitudinal axis (204).
7. The rock drill component (100) according to any of claims 1-5, wherein the x-axis of the ellipse (214) is tilted with respect to the longitudinal axis (204).
- 25
8. The rock drill component (100) according to any of the preceding claims, wherein the cross-sectional shape profile of the outer surface of the transition section (206) in the plane of the longitudinal axis (204) comprises a quarter segment of an ellipse (214).
- 30
9. The rock drill component (100) according to any of claims 1-7, wherein the cross-sectional shape profile of the outer surface of the transition section (206) in the plane of the longitudinal axis (204) comprises greater than a quarter segment of an ellipse (214).
- 35
10. The rock drill component (100) according to any of claims 1-7, wherein the cross-sectional shape profile of the outer surface of the transition section (206) in the plane of the longitudinal axis (204) comprises less than a quarter segment of an ellipse (214).
- 40
11. The rock drill component (100) according to any of the preceding claims wherein the rock drill component (100) is a shank rod (250).
12. The rock drill component (100) according to any of the preceding claims wherein the rock drill component (100) is a taper rod (260).
- 45
13. The rock drill component (100) according to any of the preceding claims wherein the rock drill component (100) is an integrated rock drill (IDS) (270).
14. A drilling assembly comprising a rock drill component (100) according to any preceding claim.

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Patentansprüche

1. Gesteinsbohrkomponente (100) zur Bildung eines Teils einer Bohranordnung, wobei die Gesteinsbohrkomponente (100) umfasst:

55

einen Hauptkörper (101);
 einen hexagonalen Schaft (102), der an einem Ende der Gesteinsbohrkomponente (100) vorgesehen ist;
 eine radial vorstehende Schulter (110), die axial zwischen dem Hauptkörper (101) und dem hexagonalen Schaft

(102) angeordnet ist;

wobei es einen Übergangsabschnitt (206) gibt, dessen Durchmesser in einer Richtung von dem hexagonalen Schaft (108) zu der Schulter (110) zunimmt;

wobei das Querschnittsformprofil der Außenfläche des Übergangsabschnitts (206) in der Ebene der Längsachse (204) ein Segment einer Ellipse (214) umfasst, die große Halbachse (a); eine kleine Halbachse (b) und einen Exponentialfaktor (n) gemäß der Gleichung aufweist:

$$\left| \frac{x}{a} \right|^n + \left| \frac{y}{b} \right|^n = 1$$

dadurch gekennzeichnet, dass:

das Verhältnis der großen Halbachse zu der kleinen Halbachse (a:b) innerhalb des Bereichs von $2b < a < 8b$ liegt.

2. Gesteinsbohrkomponente (100) nach Anspruch 1, wobei das Verhältnis der großen Halbachse zu der kleinen Halbachse (a:b) innerhalb des Bereichs $2,5b < a < 6b$ liegt.
3. Gesteinsbohrkomponente (100) nach Anspruch 1 oder Anspruch 2, wobei der Exponentialfaktor (n) innerhalb des Bereichs $1 \leq n \leq 3$ liegt.
4. Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche, wobei ein Scheitelpunkt (215) der Ellipse (214) an einer Tangente mit der ringförmigen Seitenfläche (203) der Schulter (110) positioniert ist.
5. Gesteinsbohrkomponente (100) nach einem der Ansprüche 1-3, wobei der Scheitelpunkt (215) der Ellipse (214) die ringförmige Seitenfläche (203) der Schulter (110) hinterschneidet.
6. Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche, wobei die x-Achse der Ellipse (214) parallel zur Längsachse (204) ist.
7. Gesteinsbohrkomponente (100) nach einem der Ansprüche 1-5, wobei die x-Achse der Ellipse (214) in Bezug auf die Längsachse (204) geneigt ist.
8. Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche, wobei das Querschnittsformprofil der Außenfläche des Übergangsabschnitts (206) in der Ebene der Längsachse (204) ein Viertelsegment einer Ellipse (214) umfasst.
9. Gesteinsbohrkomponente (100) nach einem der Ansprüche 1-7, wobei das Querschnittsformprofil der Außenfläche des Übergangsabschnitts (206) in der Ebene der Längsachse (204) mehr als ein Viertelsegment einer Ellipse (214) umfasst.
10. Gesteinsbohrkomponente (100) nach einem der Ansprüche 1-7, wobei das Querschnittsformprofil der Außenfläche des Übergangsabschnitts (206) in der Ebene der Längsachse (204) weniger als ein Viertelsegment einer Ellipse (214) umfasst.
11. Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche, wobei die Gesteinsbohrkomponente (100) eine Schaftstange (250) ist.
12. Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche, wobei die Gesteinsbohrkomponente (100) eine Kegelstange (260) ist.
13. Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche, wobei die Gesteinsbohrkomponente (100) ein integrierter Gesteinsbohrer (IDS) (270) ist.
14. Bohranordnung, umfassend eine Gesteinsbohrkomponente (100) nach einem der vorstehenden Ansprüche.

Revendications

1. Composant de forage de roches (100) pour former une partie d'un ensemble de forage, le composant de forage de roches (100) comprenant :

un corps principal (101) ;
 un fleuret hexagonal (102) prévu à une extrémité du composant de forage de roches(100) ;
 un épaulement faisant saillie radialement (110) positionné axialement entre le corps principal (101) et le fleuret hexagonal (102) ;
 dans lequel il y a une section de transition (206) dont le diamètre augmente dans une direction allant du fleuret hexagonal (108) à l'épaulement (110) ;
 dans lequel le profil de forme de section transversale de la surface extérieure de la section de transition (206) dans le plan de l'axe longitudinal (204) comprend un segment d'une ellipse (214) présentant un axe semi-majeur (a) ; un axe semi-mineur (b) et un facteur exponentiel (n) selon l'équation :

$$\left| \frac{x}{a} \right|^n + \left| \frac{y}{b} \right|^n = 1$$

caractérisé en ce que :

le rapport des axes semi-majeur à semi-mineur (a:b) est compris dans la plage $2b < a < 8b$.

2. Composant de forage de roches (100) selon la revendication 1, dans lequel le rapport des axes semi-majeur à semi-mineur (a:b) est dans la plage $2,5b < a < 6b$.
3. Composant de forage de roches (100) selon la revendication 1 ou la revendication 2, dans lequel le facteur exponentiel (n) est dans la plage $1 \leq n \leq 3$.
4. Composant de forage de roches (100) selon une quelconque revendication précédente, dans lequel un sommet (215) de l'ellipse (214) est positionné au niveau d'une tangente avec la surface latérale annulaire (203) de l'épaulement (110).
5. Composant de forage de roches (100) selon l'une quelconque des revendications 1-3, dans lequel le sommet (215) de l'ellipse (214) coupe la surface latérale annulaire (203) de l'épaulement (110).
6. Composant de forage de roches (100) selon une quelconque revendication précédente, dans lequel l'axe x de l'ellipse (214) est parallèle à l'axe longitudinal (204).
7. Composant de forage de roches (100) selon l'une quelconque des revendications 1-5, dans lequel l'axe x de l'ellipse (214) est incliné par rapport à l'axe longitudinal (204).
8. Composant de forage de roches (100) selon l'une quelconque des revendications précédentes, dans lequel le profil de forme de section transversale de la surface extérieure de la section de transition (206) dans le plan de l'axe longitudinal (204) comprend un quart de segment d'une ellipse. (214).
9. Composant de forage de roches (100) selon l'une quelconque des revendications 1-7, dans lequel le profil de forme de section transversale de la surface extérieure de la section de transition (206) dans le plan de l'axe longitudinal (204) comprend plus d'un quart de segment d'une ellipse (214).
10. Composant de forage de roches (100) selon l'une quelconque des revendications 1-7, dans lequel le profil de forme de section transversale de la surface extérieure de la section de transition (206) dans le plan de l'axe longitudinal (204) comprend moins d'un quart de segment d'une ellipse (214).
11. Composant de forage de roches (100) selon l'une quelconque des revendications précédentes dans lequel le composant de forage de roches (100) est une tige de fleuret (250).
12. Composant de forage de roches (100) selon l'une quelconque des revendications précédentes dans lequel le

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composant de forage de roches (100) est une tige conique (260).

13. Composant de forage de roches (100) selon l'une quelconque des revendications précédentes dans lequel le composant de forage de roches (100) est un foret de roche intégré (IDS) (270).

14. Ensemble de forage comprenant un composant de forage de roches (100) selon une quelconque revendication précédente.

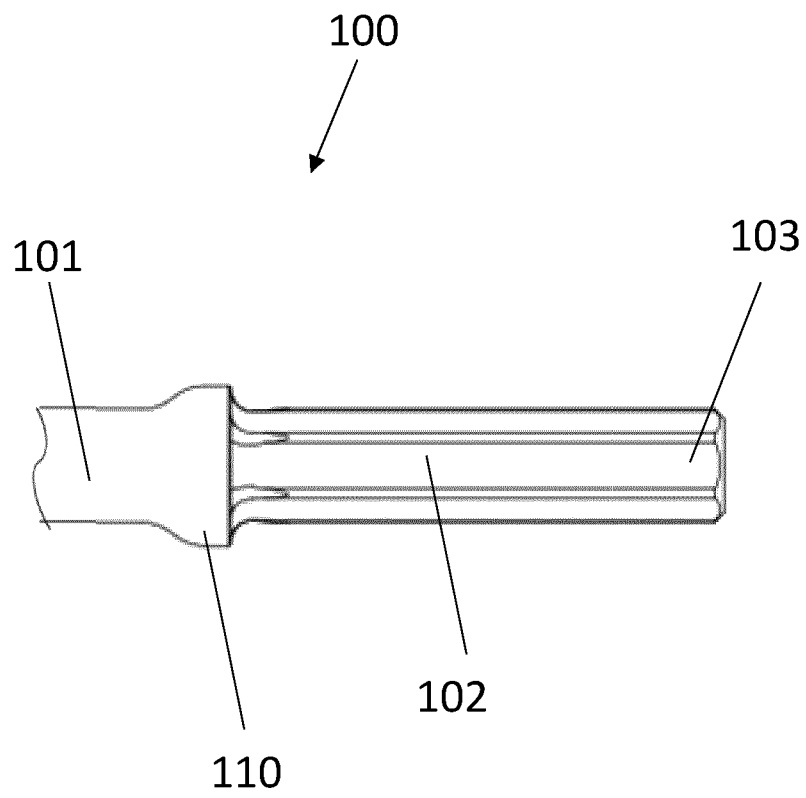
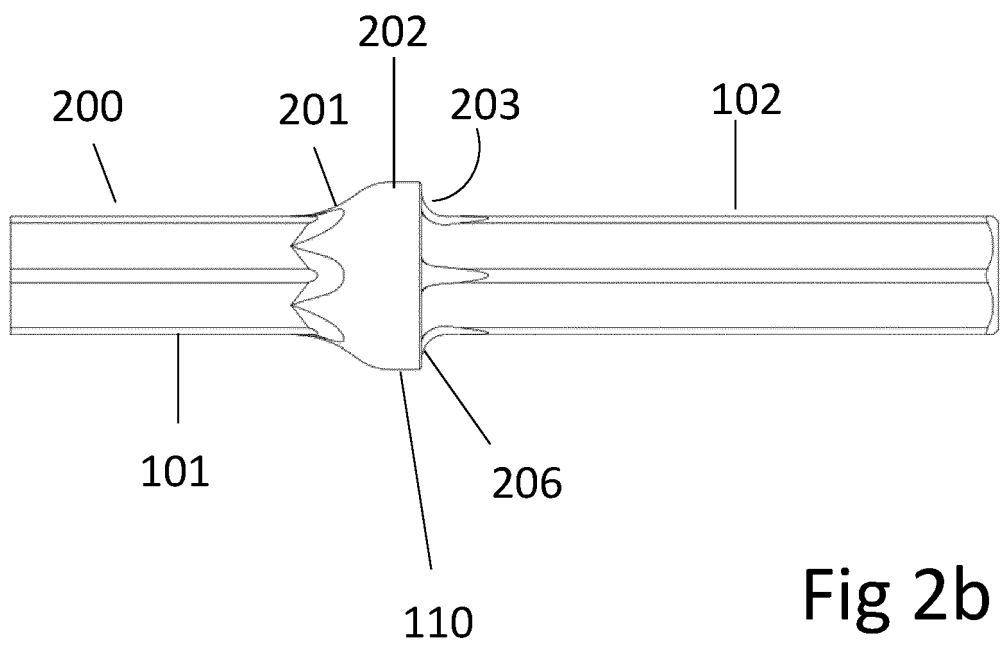
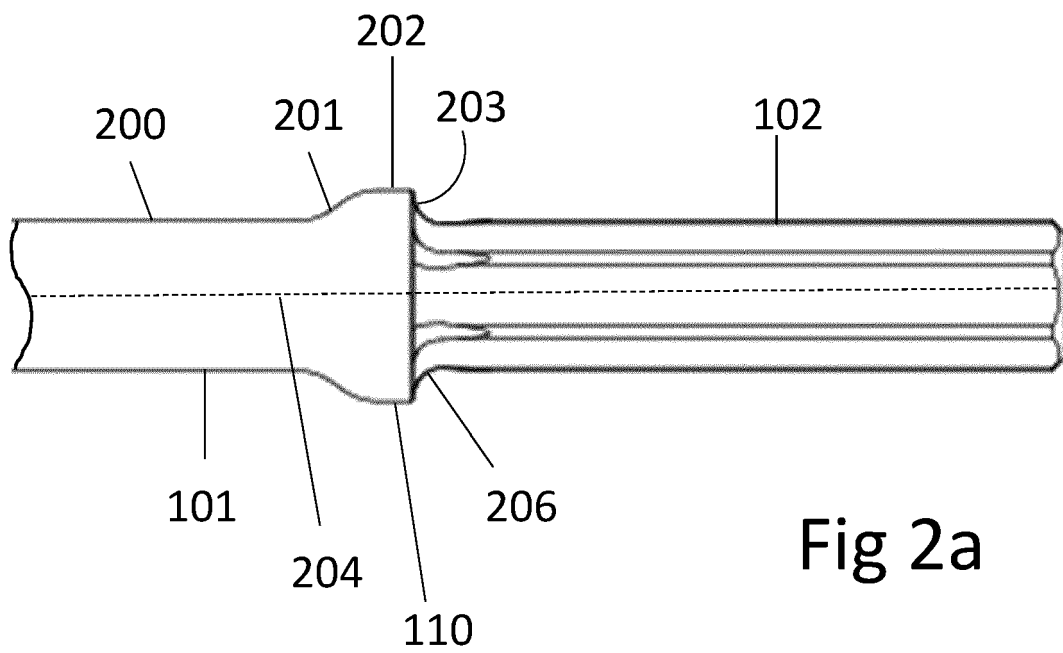


Fig 1



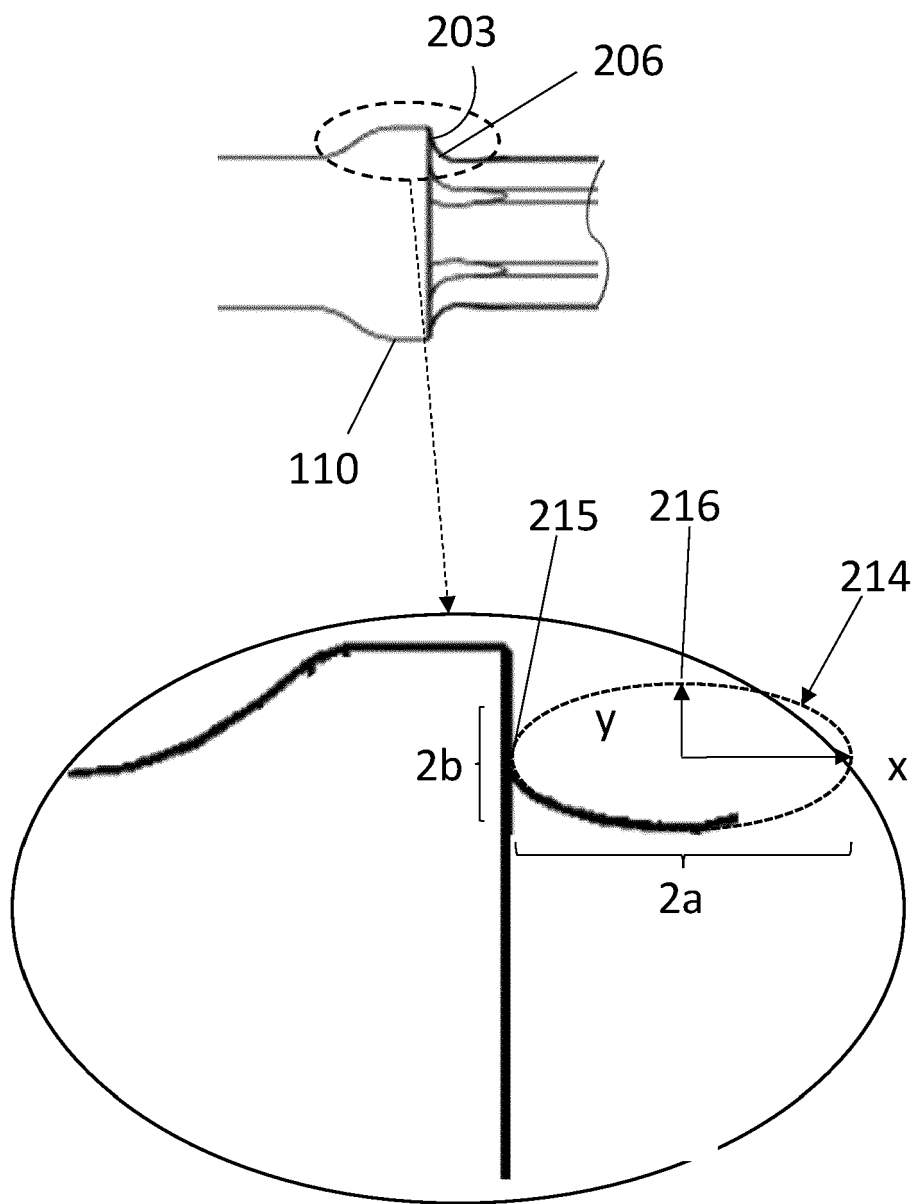


Fig 3

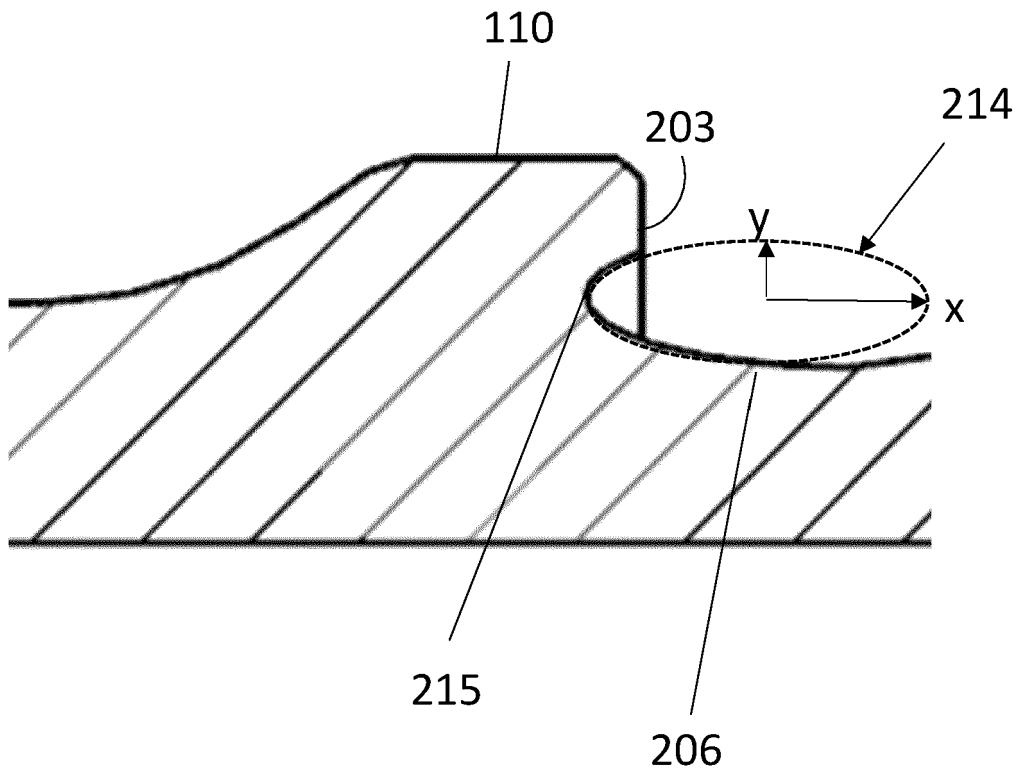


Fig 4

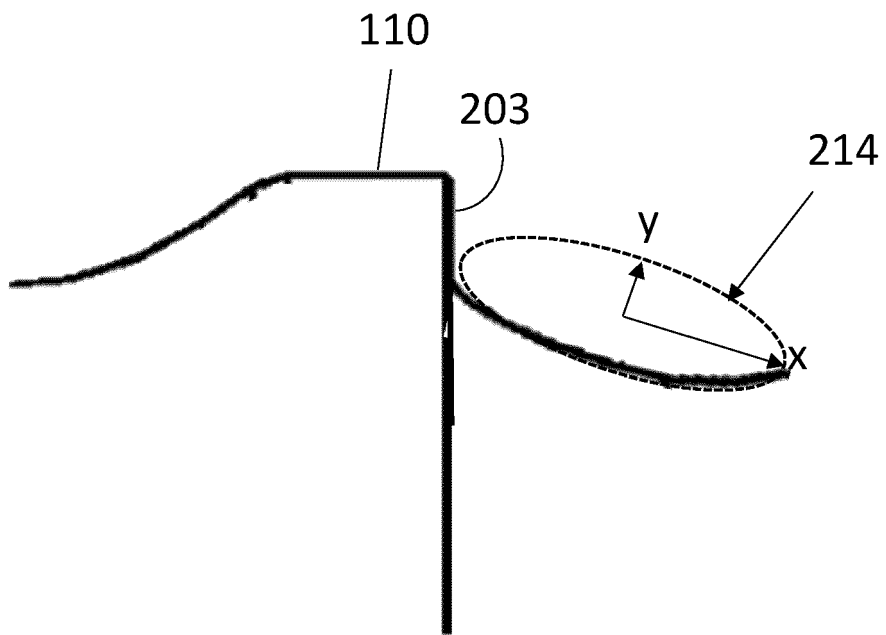


Fig 5

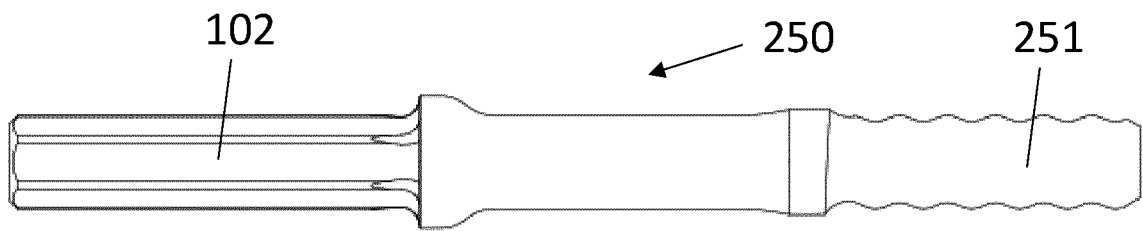


Fig 6

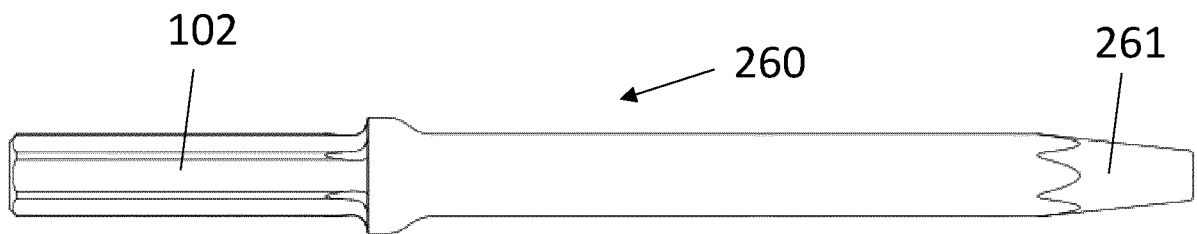


Fig 7

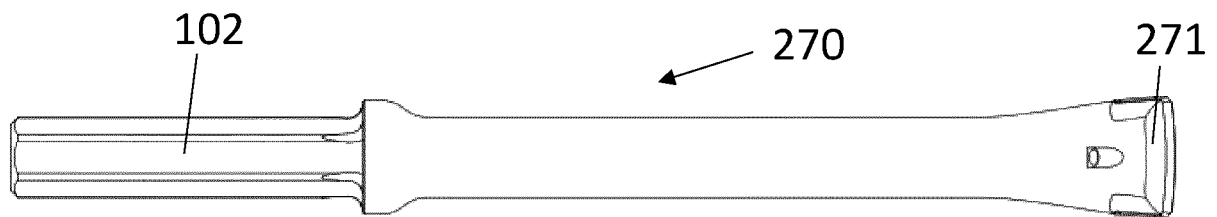


Fig 8

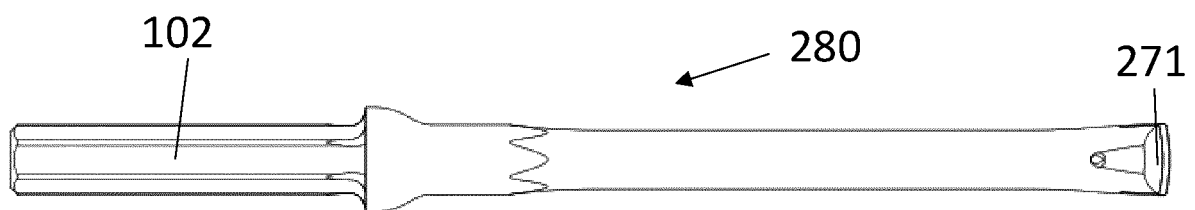


Fig 9

Contour Plot
Stress(vonMises)
Analysis system
Simple Average

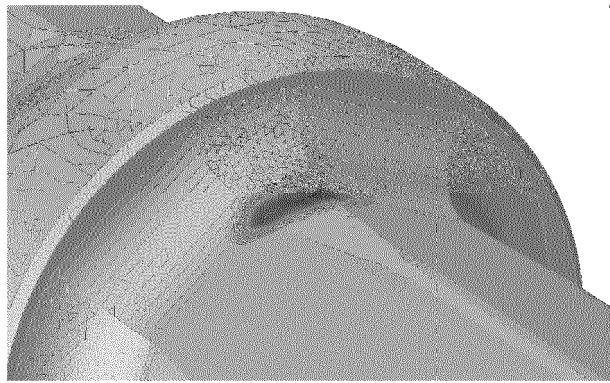
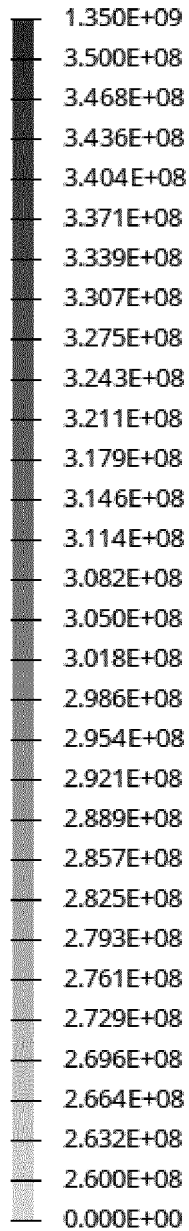


Fig 10a

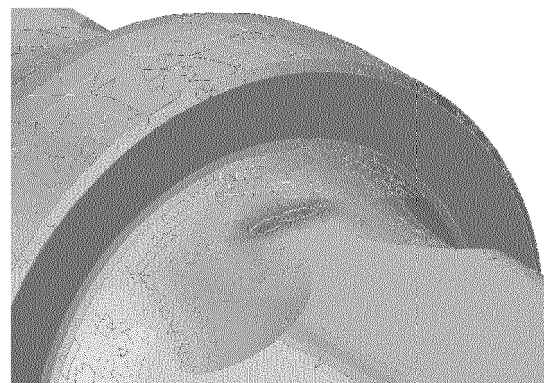


Fig 10b

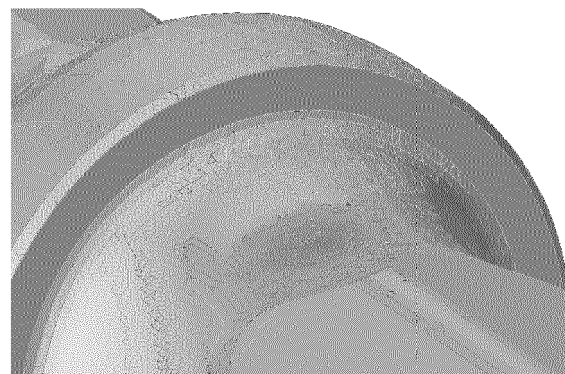


Fig 10c

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 3876319 A [0003]