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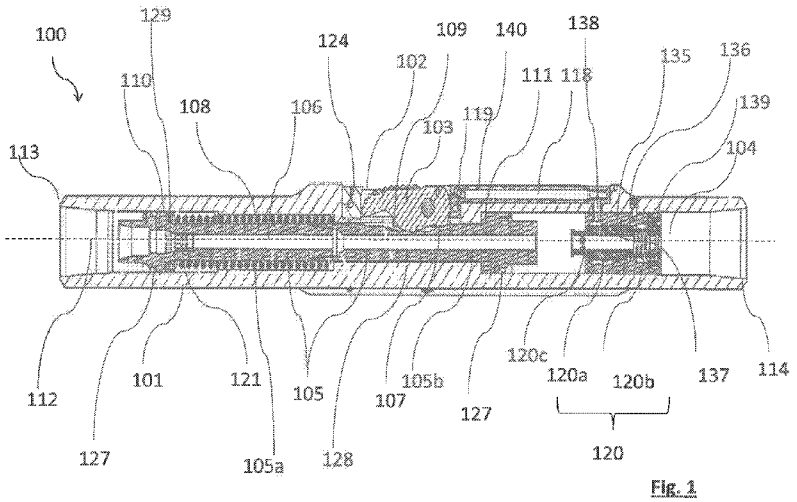

Fig. 1

(57) Abstract: This invention relates to a downhole tool (101), comprising a housing (101), at least one tool member (103) which can be activated and deactivated, an actuating member (105) which is movable between a first position and a second position in order to activate or deactivate said tool member (103), a circuit (104, 106) for the circulation of a fluid inside said housing arranged to apply a fluid pressure onto the actuating member (105) in order to move it from the first to the second position, a channel (118) connecting the circuit (104, 106) to a nozzle (119) for projecting a fluid from said circuit (104, 106) towards the outside of the housing, and a valve assembly (120) for closing or opening the path to said channel (118), said valve assembly (120) being operable by said actuating member (105).

Downhole tool and method for operating such a downhole tool

The present invention relates to a downhole tool comprising a housing, at least one tool member which can be activated and deactivated, an actuating member which is movable between a first position and a second position in order to activate or deactivate said tool member, a circuit for the circulation of a fluid inside said housing arranged to apply a fluid pressure onto the actuating member in order to move it from the first to the second position, and a channel connecting the circuit to a nozzle for projecting a fluid from said circuit towards the outside of the housing.

The present invention also relates to a method for operating such a downhole tool.

Drilling of a wellbore for oilfield exploration or oil and gas production is achieved with a drillstring typically made up of a drill pipe and a bottom hole assembly comprising a drill bit. The drillstring is generally provided by additional downhole apparatuses such as swivel means, under-reamers or cleaning tools. Some of these downhole tools comprise an actuating member which is moved when needed for performing an action. Generally these actuating members comprise a ball or dart catcher assembly and are moved by throwing a ball or a dart into the bore of the drillstring.

An under-reamer is a downhole apparatus which is generally provided in a drillstring for enlarging a borehole. An under-reamer comprises a main body provided with cutting blades movable between two positions:

- a retracted position wherein the cutting blades are contained within the main body of the under-reamer, and
- an extended position wherein the cutting blades are radially expanded to engage and cut the formation.

In use, the under-reamer is initially provided in a drillstring with the cutting blades in their retracted position, while passing through the wellbore until it is required to activate and start bore-hole enlargement, for example when the under-reamer enters in a swelling shales or salt formation. Activation of the under-reamer can be done hydraulically, mechanically or electrically. Upon completion of the required bore-hole enlargement, the under-reamer is then deactivated to pull the tool through the cased section and out of the hole.

Some under-reamers comprising hydraulic actuation mechanism are disclosed for example in documents US7703553, US7401666, US6360831, US7314099, and US7900717.

Basically, these reamers comprise a body having a longitudinal bore in which a fluid is allowed to circulate. A hydraulic mechanism for moving cutting blades or cutting blocks from a retracted position to an extended position is comprised inside the body. The hydraulic mechanism is activated by creation of a differential of pressure between the inside of the bore and the annulus comprised between the drillstring and the wall of the wellbore. For moving the cutting blades or blocks to the extended position, all of these mechanisms require that the flow pressure applied on the hydraulic mechanism from the inside of the bore be higher than the pressure applied on the hydraulic mechanism from the annulus comprised between the wall of the borehole and the drill string. The pressure applied on the hydraulic mechanism from the annulus is variable in function of some parameters including the depth of the wellbore or the position of the under-reamer in the drillstring. Therefore, it is difficult to predict a definite threshold of flow rate required for moving the cutting blades or block to their extended position.

Document US6615933 discloses a downhole cutting tool for mounting between first and second sections of a drill string, the tool comprising:

- a mandrel for coupling to a first section of drill string;

- a body axially movably mounted on the mandrel and for coupling to a second section of drill string whereby application of weight to the string induces axial movement of the body relative to the mandrel;
- fluid pressure responsive means for moving the body axially relative to the mandrel on application of a fluid pressure force between the body and mandrel and;
- at least one linearly radially extendable cutter mounted in the body and being operatively associated with the mandrel such that relative axial movement of the mandrel and body induces radial movement of the cutter, whereby application of weight to the string induces linear radial extension of the cutter.

Such a mechanism applying a weight to the string or a weight on bit (WOB) is not effective in soft formations or when re-reaming sections. Moreover the hydraulic pressure module used relies on pressure difference between annulus and bore, thus it is sensitive to whatever restrictions come after it as well as depth.

In US patent n° 8,028,763 it is attempted to solve the problem of pressure difference between annulus and bore when activation of the underreamer is required by providing an underreamer tool comprising:

- a main body having a longitudinal axis and having a conduit for flow of tubing fluid there through, at least one tool element movably mounted to the main body;
- a movable actuation device configured to urge the tool element radially with respect to the main body, the actuation device being configured to react to a pressure differential within the body and to urge the tool element in response to said pressure differential;
- a biasing mechanism, wherein the tool element is urged by the actuation device from a first configuration to a second configuration by a fluid pressure differential applied to the actuation device above a predetermined threshold, and is returned to the first position by the biasing mechanism when the pressure differential falls below the threshold value; and
- wherein the tool has a flow port for flow of tubing fluid between the conduit of the main body and a drive face of the actuation device.

However, this tool comprises a lot of components and actuation of the tool elements is rendered independent of well pressure condition by the fact that actuation of the tool elements is readily controlled by switching on and/or switching off flow through the conduit.

Most of the tools described above have a large number of components which adds to cost, complexity and increased possibility of failures.

Most of these tools described above comprise shear pin solutions for avoiding accidental triggering of the tool. However, shear pin solutions are sometimes not preferred because it can happen that the shear pins don't shear.

It is an object of the first invention to provide a tool which doesn't have the disadvantages of the tools of the prior art. It is desirable to provide a downhole tool having an actuating member, wherein actuation and deactivation of the actuating member is easily controllable. It is further desirable to provide a downhole tool in which a flow of fluid is permitted to circulate across the bore of the downhole tool without interruption during a drilling operation or reaming while drilling operation. It is further desirable to provide a downhole tool in which the actuating member can be actuated and deactivated several times. It is further desirable to provide an downhole tool providing a high bore hole quality.

It is further desirable to reduce the number of components and the complexity of a downhole tool in order to reduce costs of manufacturing and to reduce possibilities of failure.

There is a need for a means for monitoring actuation and deactivation of the downhole tool.

According to a first aspect, the present invention relates to a downhole tool comprising the features indicated in the first paragraph of this description, in which, according to this invention, it further comprises a valve assembly for closing or opening the path to said channel, said valve assembly being operable by said actuating member.

Preferably, the path to said channel is opened when the actuating member is in the position activating the tool member, providing cleaning of the tool member. When the valve assembly is opened simultaneously with the actuation of the tool member, an increase of flow resulting from the opening of the valve assembly is visible at the surface of the wellbore and provides a monitoring means for monitoring that the tool member is actuated. The valve assembly is further closed simultaneously with the retraction of the tool member.

In a preferred embodiment of this invention, the valve assembly comprises a tubular part movable inside the housing between a closing position closing the path to said channel and an opening position opening said path, and means for applying a retaining force onto the tubular part urging it towards said closing position, said actuating member being arranged to move said tubular part to its opening position, when it is moved towards its second position.

When said nozzle is directed towards said tool member, the fluid projected from the nozzle cleans the activated tool member in a very efficient way.

Preferably, the housing comprises a groove or a cavity on its external surface and said channel is at least partially included in an insertable housing which is inserted into said groove or cavity. Such an arrangement provides an easier machining of the housing and allows location of the nozzle closer to the cutting member allowing an improved cleaning of the cutting member.

Alternatively, the channel is built-in in the housing.

In this downhole tool, the housing further may comprise a pocket comprising a tool member which is movable between a retracted position inside said pocket and an extended position in which at least a portion of the tool member is outside said pocket and protrudes from said housing.

Preferably, the actuating member further comprises a cam profiled for moving the tool member between said retracted position and said extended position.

In a very advantageous embodiment said tool member is rotatably connected to the housing and the tool comprises motion transfer means for converting the movement of the actuating member into rotational movement of said tool member, said motion transfer means being adapted such that said tool member is held in the retracted position and in the extended position when the actuating member is in a first position and in a second position respectively.

In such a downhole tool, the extension as well as the retraction of the tool members is very easily controllable and is very reliable.

In a very preferred embodiment, the actuating member further comprises

- a first pressure surface and a second pressure surface exposed to a first pressure and a different second pressure of the circulating fluid, respectively, resulting in a first force and a different second force acting on the actuating member in opposite directions, and
- a third pressure surface and a fourth pressure surface exposed to an external pressure of the fluid outside the housing, resulting in a third force and a fourth force acting on the actuating member in opposite directions.

In such a downhole tool, actuation of the actuating member is less dependent or even more or less independent of the differential pressure between the inside and the outside of the downhole tool's housing. Therefore, the force to apply on the actuating member does not vary much in function of the depth of the downhole tool. This force can even be substantially identical for any depth of the downhole tool in the wellbore. Actuation of the actuating member is also less sensitive to the existence of any pressure-drop devices below the downhole tool. The fluid force acting on the actuating member is primarily determined by the internal pressure drop between the location of the first pressure and the location of the second pressure. For example the first and the second pressures are the fluid pressures in two

different locations in the circuit, spaced apart from one another in the direction of flow of the fluid, for example on both sides of a channel or bore through which the fluid is circulating. No drop-ball activation is needed.

When it is needed to move back the actuating member in its first position, it is possible to reduce the fluid force by reducing the fluid flow rate and/or the fluid density or both fluid parameters, or any combination of one of these parameters and any other fluid parameter, to such an extent that the actuating member is moved to its first position under the influence of the retaining force.

Advantageously, the third and fourth forces are substantially equal. This can be obtained by an actuating member comprising third and fourth surfaces with substantially equal projected areas. In this way, the external pressure results in substantially equal forces acting on the actuating member in opposite directions. Actuation of the actuating member is then substantially independent of the differential pressure between the inside and the outside of the downhole tool's housing.

The expression 'projected area' refers to the area of a projection of a pressure surface on a plane perpendicular to the flow direction of the fluid.

Preferably, also the first and second pressure surfaces of the actuating member have substantially equal projected areas.

In a preferred embodiment of the downhole tool, the actuating member is movable in a fluid channel of said circuit and comprises a first piston head and a second piston head which are spaced apart from one another in the direction of flow of the fluid, said piston heads having respective pressure surfaces facing away from one another and respective pressure surfaces facing one another, said pressure surfaces facing away from one another forming said first and

second pressure surfaces, and said facing pressure surfaces forming said third and fourth pressure surfaces.

Advantageously, the space in between said facing pressure surfaces is in communication with the outside of the housing through an opening in the fluid channel.

Preferably, the housing comprises a longitudinal fluid channel, the actuating member is movable in this fluid channel between its first and second position, and the actuating member comprises a longitudinal bore, so that the fluid channel and the bore form a circuit through which the fluid is permitted to flow.

In a very advantageous embodiment of this invention, the retaining means is provided to retain the actuating member in said first position as long as the fluid force does not exceed a predetermined threshold. When the fluid force exceeds said treshold, the actuating member will be moved to its second position.

Preferably the tool member is deactivated when the actuating member is in its first position, and the tool member is activated when the actuating member is in its second position.

A very practical downhole tool according to this invention has a top end comprising connection means for connecting it to an upper part of a string, and a bottom end comprising connection means for connecting it to a lower part of a string.

Preferably, the housing comprises a longitudinal fluid channel, the actuating member is movable in this fluid channel between its first and second position, and the actuating member comprises a longitudinal bore, so that the fluid channel and the bore form a circuit through which the fluid is permitted to flow.

Preferably, the cam and the tool member are further profiled such that the cam is able to lock the tool member in its retracted position, and/or to lock the tool member in its extended position. In particular, when the actuating member is in the first position and in the second position, the tool member abuts against the cam surface in such a way that it prevents the movement of the tool member from its retracted position or its extended position to the other of said positions.

In a particular embodiment, the tool member comprises a cutting section. In that case, the downhole tool is preferably an under-reamer.

In a very advantageous embodiment, the retaining means is provided to retain the actuating member in said first position as long as the fluid force does not exceed a predetermined threshold.

The downhole tool according to this invention preferably has a top end and a bottom end, and said tool member is arranged such that, when the tool member is in its extended position, the distance between the surface of the cutting section and its central longitudinal axis decreases towards the bottom end of the tool. The tool member may comprise a gauge section.

Preferably, the downhole tool has a top end and a bottom end, and said tool member comprises a backreaming section arranged such that when the tool member is in its extended position, the distance between the surface of the backreaming section and the longitudinal axis decreases towards said top end.

Preferably, the retaining means for retaining the actuating member in the first position is a spring. This spring may be connected to the housing, preferably a wall of a fluid channel in the housing.

The means for applying a retaining force onto this tubular part may be a spring.

Preferably, said actuating member comprises an nozzle for creating a sufficient pressure drop across the actuating member at a predetermined threshold of fluid flow rate. In particular, the nozzle is placed in the fluid channel of the housing or in the longitudinal bore of the actuating member.

Preferably said nozzle is interchangeable. The size of the nozzle can be determined in function of the pressure drop required in a particular tool and in particular circumstances.

In a preferred embodiment of the downhole tool according to this invention said housing comprises a groove or a cavity on its external surface and said channel connecting the longitudinal bore of said actuating member to said nozzle, is at least partially included in an insertable housing which is inserted into said groove or cavity.

In a preferred embodiment of the downhole tool according to the invention, the housing is a one-part body. Preferably, the actuating member is an assembly of at least two parts.

In a second aspect, this invention relates to a downhole tool comprising the features indicated in the first paragraph of this description, in which, according to this invention, said housing comprises a groove or a cavity on its external surface, and said channel is at least partially included in an insertable housing which is inserted into said groove or cavity.

Preferably, said housing further comprises a pocket and a tool member which is movable between a retracted position inside said pocket and an extended position in which at least a portion of the tool member is outside said pocket and protrudes from said housing. A very advantageous downhole tool according to this second aspect is obtained when the actuating member further comprises a cam profiled for moving said tool member between said retracted position and said extended position. Preferably, the nozzle is directed towards said tool member.

The downhole tool according to this second aspect may be combined with any feature or combination of features of the downhole tool according to the first aspect.

In a third aspect, the present invention relates to a method for operating a downhole tool according to the first and the second aspect of the invention, comprising the steps of :

i) providing said downhole tool in a string,

ii) circulating a fluid in said circuit (104, 106) of the downhole tool, and

iii) activating said tool member (103) by exerting a fluid pressure on said actuating member, such that the valve assembly opens the path to said channel and a fluid is projected outside of the housing through said nozzle towards the activated tool member.

In this method, the tool member preferably is activated by increasing the flow rate and/or density of the fluid so that the fluid force exerted on said actuating member is increased and such that the actuating member is moved to its second position.

In a preferred method according to this invention, the fluid force is influenced such that it does not exceed a predetermined treshold to keep or bring the tool member in a deactivated status, and the fluid force is influenced such that it exceeds said treshold to keep or bring the tool member in an activated status.

Preferably the method includes

- a step first during which a fluid is circulating through a fluid channel inside the housing and a bore in the actuating member such that the fluid force exerted by said fluid on the actuating member is not exceeding a predetermined threshold, such that the actuating member is retained in its first position, and

- a step during which the flow rate and/or the density of the fluid is increased such that said fluid force is exceeding said predetermined threshold, such that the actuating member moves axially towards the bottom end of the tool within said housing.

Preferably,

- the housing of this downhole tool comprises a pocket, a tool member movable between a retracted position inside said pocket and an extended position wherein at least a portion of the tool member is outside said pocket,
- the actuating member further comprises a cam profiled for moving said tool member between said retracted position and said extended position,
- said string is a drillstring,
- said tool member comprises a cutting section,
- said step of circulating a fluid in said circuit is performed while rotating said drillstring into a borehole and while applying a weight on bit, and
- said weight on bit is removed before the tool member is moved to its extended position.

Preferably, the tool member is moved to its extended position in order to enlarge the borehole.

The method preferably also comprises one or both of the following steps:

- monitoring the pressure of fluid at the surface of the wellbore for acknowledging that said tool member has moved to its extended position;
- monitoring the torque on said drillstring for acknowledging that said tool member has moved to its extended position.

Preferably, these steps include acknowledging that the tool member has completely moved to its extended position.

Preferably, the method comprises one or more of the following further steps:

- applying a weight on bit once it is acknowledged that the tool member has completely moved to its extended position;
- keeping a weight on bit while reducing the flow rate of the fluid such that said at least one tool member is kept in its extended position;
- moving said tool member back into its retracted position by decreasing the flow rate under a predetermined threshold and by removing said weight on bit.

The invention will now be explained in more detail by means of the following more detailed description of a possible embodiment of a downhole tool according to the present invention. The described embodiment is only an example and can therefore by no means be seen as a limitation of the scope of protection or of the area of application of the invention.

Reference numerals are used in this detailed description to refer to the attached figures, in which:

- Figure 1 is a cross-sectional view of a possible embodiment of an under-reamer according to the invention of which the tool members are placed in their retracted position,
- Figure 2 is a cross-sectional view of the under-reamer of figure 1 having its tool members in their extended position,
- Figures 3 and 4 are a conceptual view of a cam of an actuating member in contact with a tool member of the under-reamer of figures 1 and 2, the tool member being in a retracted position (fig. 3) and an extended position (fig. 4) respectively,
- Figure 5 is a conceptual view of an actuating member in a housing of an under-reamer according to an embodiment of the present invention, and
- Figure 6 is an enlarged cross-sectional view of a top portion of the under-reamer of figures 1 and 2, showing in particular the actuating member comprising an interchangeable nozzle.

The under-reamer (100) shown on figures 1 and 2 comprises a housing (101) having a longitudinal central axis (112). A fluid channel (104) crosses this housing (101) and extends

through said housing from the top end (113) to the bottom end (114) along said longitudinal axis (112).

The top end (113) of the housing (101) is provided with upper connection means (not represented on the drawings) for connecting the tool (100) to an upper part of a drill string. The bottom end (114) of the housing (101) is provided with lower connection means (not shown on the drawings) for connecting the tool (100) to a lower part of a drill string.

An actuating member (105) having an elongate body is provided in the fluid channel (104) inside the housing (101) and is axially movable in this fluid channel (104) between the first position shown on figure 1 and the second position shown on figure 2. The elongate body of the actuating member (105) is crossed by a longitudinal bore (106) extending through this body along said longitudinal axis (112). When the tool is in use as part of a drill string, the fluid channel (104) and the longitudinal bore (106) form a circuit through which the drilling fluid is flowing towards the bottom end of the tool.

A spring (108) of which one end (the left end on figures 1 and 2) is attached to or seated against the housing (101), and the other end (the right end on figures 1 and 2) is attached to or seated against the actuating member (105), exerts a spring force on the actuating member (105), urging this actuating member towards its first position shown on figure 1. The spring force retains the actuating member (105) in its first position as long as the fluid force exerted by the circulating drilling fluid is below a predetermined threshold.

The elongate body of the actuating member (105) comprises a first piston head (110) in the vicinity of its top end (the left end on figures 1 and 2) and a second piston head (111) in the vicinity of its bottom end (the right end on figures 1 and 2).

Advantageously, the downhole tool according to the present invention is characterized in that said housing 101 is a one-part body and said actuating member 105 is an assembly of at least two parts.

Preferably, the housing (101) is machined such that the internal diameter of the housing comprises a first section of large diameter, a second section of a reduced diameter, and a third section of large diameter separated from the first section of large diameter by the second section of reduced diameter. The actuating member (105) is made of a first part (105a) and a second part (105b).

In a first embodiment, both first part (105a) and second part (105b) of the actuating member comprise :

- a first section having an external diameter fitting with one of the large inner diameter section of the housing, and
- a second section having an external diameter fitting with the reduced inner diameter section of the housing.

In an alternative embodiment, the first part (105a) or the second part (105b) of the actuating member (105) comprise:

- a first section having an external diameter fitting with one of the large inner diameter section of the housing, and
- a second section having an external diameter fitting with the reduced inner diameter section of the housing, and

the other part of the actuating member (105) has a section having an external diameter fitting with the other large inner section of the housing (101).

The first part (105a) of the actuating member is introduced in the fluid channel (104) of the housing (101) from a first end of the housing and the second part (105b) of the actuating

member is assembled, for example by means of threaded connections, with the first part (105a) by introducing the second part (105b) of the actuating member (105) into the fluid channel (104) of the housing (101) from the opposite end of the housing. The second section of reduced diameter of the housing forms a shoulder part (128) which bears the actuating member (105). Preferably, the second section of reduced diameter comprises openings (109), for allowing retraction or extension of tool members (103), as presented in figure 1 and 2.

Preferably, a spring (108) is provided between the shoulder part (128) and the first section of the actuating member or the first piston head. More preferably, the top end of the actuating member (105) comprises a coupling section, for example a polygonal coupling section for inserting a fastening means and screwing the first part (105a) of the actuating member (105) with the second part (105b) of the actuating member (105).

In an embodiment of the invention, the bottom end of the second part (105b) of the actuating member (105) comprises a coupling section for inserting a fastening means and screwing the first part (105a) of the actuating member (105) with the second part (105b) of the actuating member (105).

In another embodiment of the invention, the second part (105b) of the actuating member (105) preferably comprises a cam having a cam surface (107) which cooperates with at least a tool member (103) such that the tool member (103) prevents any rotational movement of the second part (105b) of the actuating member.

More preferably, a bearing (129) is provided at one extremity of the spring, for example at the extremity facing the first piston head (110), for facilitating the screwing of the first part (105a) of the actuating member (105) with the second part (105b) of the actuating member.

The fluid channel (104) in the housing (101) is in communication with the outside of the housing 101 through an opening (109) made in this shoulder part (128). The piston heads (110), (111) of the actuating member (105) are fitted into the fluid channel (104) on both sides of the shoulder part (128). As the piston heads (110), (111) cannot pass the channel section having a reduced diameter, the shoulder part (128) always remains in between the piston heads (110),

(111) during the movement of the actuating member (105) in the fluid channel (104). So, for any position of the actuating member (105), the piston heads (110), (111) are always located on both sides of the opening (109).

The piston heads (110), (111) have respective pressure surfaces (110a), (111a) facing away from one another (referred to as the first pressure surface and the second pressure surface). The first (110a) pressure surface (111a) is exposed to the pressure of the drilling fluid in the circuit (104, 106) at a first location in the circuit, near the top end (113) of the tool (100), whereas the second pressure surface (111a) is exposed to the pressure of the drilling fluid at a second location in the circuit, near the bottom end (114) of the tool. The pressure applied on the first pressure surface (110a) and the pressure applied on the second pressure surface (111a) act in opposite directions.

The first piston head (110) and the second piston head (111) also have respective pressure surfaces (110b), (111b) facing one another (referred to as the third pressure surface and the fourth pressure surface). These pressure surfaces (110b), (111b) are exposed to the external pressure of the drilling fluid outside the housing (101), as will be explained hereinafter with reference to the conceptual view of the under-reamer represented in figure 5.

The housing (101), the cam surface (107) of the actuating member (105), the first piston head (110) and the second piston head (111) delimit a chamber which is isolated from the circuit formed by the fluid channel (104) of the housing (101) and the bore (106) of the actuating member (105), and which is connected to the outside of the housing (101) through the opening (109). Preferably, both piston heads (110), (111) comprise a recess for lodging a sealing element (127) for isolating said chamber.

Each pistons head (110), (111) comprises a respective piston head surface (110a), (111a) exposed to an internal pressure (P_i) from the fluid channel (104) of the housing (101). These surfaces (110a), (111a) are the surfaces faced away from one another which have been

referred to as the first (110a) and second pressure surface (111a). The first and second pressure surfaces have substantially equal projected areas, hereinafter referred to as A_{110a} and A_{111a} respectively.

Each piston head (110), (111) also has a respective second piston head surface (110b), (111b) exposed to an external pressure (P_e) from the outside of the housing. These are the surfaces (110b), (111b) facing one another which have been referred to as the third and fourth pressure surfaces. The third and fourth pressure surfaces have substantially equal projected areas, hereinafter referred to as A_{110b} and A_{111b}, respectively.

When the downhole tool (100) is run within a string into a borehole, a fluid having a predetermined density generally referred to as a "drilling fluid" is circulated with a predetermined flow rate through the string, including the circuit formed by the fluid channel (104) of the housing (101) and the bore (106) of the actuating member (105), until the fluid reaches the bottom of the string. Then the fluid is projected outside the housing and flows through the annulus comprised between the wall of the borehole and the string and comes back to the surface of the wellbore.

While running the string into the borehole, the drilling fluid is circulated with a predetermined density under a predetermined flow rate threshold through the string. When the drilling fluid arrives at the bottom of the wellbore, it flows back to the surface of the well through the annulus comprised between the wall of the borehole and the string. The fluid is allowed to fill the chamber delimited by the housing (101), the cam surface (107) and the facing piston head surfaces (110b), (111b) of the piston heads (110),(111), through the opening (109).

When the actuating member (105) is in its first position, the forces applied on the actuating member (105) are given by equation (1) and (2):

$$F = F_d - F_s - F_f \qquad (1)$$

$$F = P_{i110a}A_{110a} - P_{e110b}A_{110b} + P_{e111b}A_{111b} - P_{i111a}A_{111a} - F_s - F_f \quad (2)$$

wherein

F_d s the force on the actuating member provided by the drilling fluid circulating through the bore of the drillstring and the annulus between the drillstring and the wall of the borehole,

F_s is the force which opposes to force F_d and which is provided by the spring (108) for retaining the actuating member (105) in its first position,

F_f are the friction forces between the piston heads (110), (111) and the internal surface of the fluid channel (104) of the housing (101), that are preferably minimized by lubrication,

P_{i110a} is the internal pressure on the area A_{110a} of the first pressure surface (110a) on the first piston head (110)

P_{i111a} is the internal pressure on the area A_{111a} of the second pressure surface (111a) on the second piston head (111),

P_{e110b} is the external pressure on the area A_{110b} of the third pressure surface (110b) on the first piston head (110),

P_{e111b} is the external pressure on the area A_{111b} of the fourth pressure surface (111b) on the second piston head (111)

Inside the chamber, $P_{e110b} = P_{e111b}$, $A_{110b} = A_{111b}$ and $A_{110a} = A_{111a}$

Therefore, equation (2) becomes:

$$F = P_{i110a}A_{110a} - P_{i111a}A_{111a} - F_s - F_f \quad (3)$$

According to equation (3), the required force for moving the actuating member (105) from its first position towards its second position is given by expression $P_{i110a}A_{110a} - P_{i111a}A_{111a}$ and has to be superior to the force (F_s) retaining the actuating member (105) in its first position.

According to the present invention, the required force for moving the actuating member only depends on variations of the flow rate or variation of the fluid density and is independent from the external pressure.

As the first pressure surface (110a) on the first piston head (110) and the second pressure surface (111a) on the second piston head (111) have the same projected area, equation (3) can be simplified into equation (4):

$$F = A_{1110a} (P_{i110a}-P_{i111a}) -F_s - F_f = A_{1110a}(\Delta P_{i105}) - F_s - F_f \qquad (4)$$

where ΔP_{i105} is the pressure drop across actuating member (105). This pressure drop depends only on the flow rate of the drilling fluid flowing across the actuating member (105).

Therefore, the required force for moving the actuating member (105) has to exceed a predetermined threshold which is defined by a combination of forces $F_s + F_f$ which are specific for the downhole tool.

Actuation of the actuating member (105) in the downhole tool is insensitive to differential pressure between the inside and the outside of the downhole tool's housing (101). Therefore, the force to apply on the actuating member (105) is the same for any depth of the downhole tool in the wellbore. Actuation of the actuating member (105) is also substantially independent from the presence of any pressure-drop devices below the downhole tool.

The actuation of the actuating member is primarily dependent on the internal pressure drop across the bore (106) of the actuating member (105). No drop-ball activation is needed.

When it is needed to move the actuating member (105) back to its first position, the fluid flow rate or the fluid density or both parameters is/are reduced so that the force exerted by the

fluid is no longer exceeding the predetermined threshold, and so that the retaining force (F_s) exerted by the spring (108) pushes the actuating member (105) back to its first position, the friction forces (F_f) being negligible.

In the under-reamer shown in figures 1 and 2, the housing (101) further comprises a pocket (102) comprising a cutting member (103) movable between a retracted position inside the pocket (102) and an extended position wherein at least a portion of the cutting member (103) is outside the pocket (102).

The actuating member (105) further comprises a cam (107) profiled for moving the cutting member (103) between the retracted position and the extended position.

The opening (109) putting the fluid channel (104) of the housing (101) in communication with the outside of the housing (101) is located in the bottom part of the pocket (102).

Preferably, the housing (101) comprises one or more pockets (102) distributed along the circumference of the housing (101). The opening (109) at the bottom of the pocket (102) allows the cam (107) to be in contact with the cutting member (103). Small clearances between the pocket (102) and the cutting member (103) are provided so as to allow fluid to flow through the opening (109) while preventing cuttings from entering into the pocket (102) during drilling. Various sizes of cutting members (103) can be provided in the pocket (102) in combination with a suitable sizing block (124) fitted in the pocket (102).

The spring (108) for retaining the actuating member (105) in its first position is preferably connected to the wall of the fluid channel (104) of the housing (101). Preferably, the spring (108) is seated on the edge formed by the thicker shoulder part (128) of the wall surrounding the fluid channel (104). A bearing (129) can be positioned between the first piston head (110) and the spring (108). The spring can also be seated on other locations as for example on a valve assembly (120) that will be described thereinafter.

In this embodiment of the present invention, said cam (107) and said cutting member (103) are further profiled such that said cam (107) is able to lock said tool member (103) when said cutting member (103) is in said retracted position and to lock said tool member (103) when said tool member (103) is in said extended position. When the actuating member (105) is in the first position, the tool member (103) abuts against the cam surface (107) in such a way that it prevents the movement of the tool member from its retracted position to its extended position. When the actuating member (105) is in the second position, the tool member (103) abuts against the cam surface (107) in such a way that it prevents the movement of the tool member from its extended position to its retracted position.

A cutting member (103) and a cam (107) are represented more in detail on figure 3 in a configuration wherein the cutting member 103 is in a retracted position, and on figure 4 in a configuration wherein the cutting member (103) is in an extended position.

The cutting member (103) comprises an outer side (125a) oriented towards the outside of the housing (101) so that it can be put in contact with the wall of the borehole when the cutting member (103) is placed in its extended position, an inner side (125b) facing the cam (107), a lateral side (134), and a pivot means (126) comprising for example a transverse hole for housing a large diameter pin (not shown) about which the cutting member (103) can rotate.

The cutting member (103) comprises a lateral protrusion (131) that acts as rest support while the cutting member (103) is in its extended position and the downhole tool is rotating. When the cutting member (105) is extended and when the drillstring rotates, it is submitted to stresses from the bore hole. Upon such a load, the protrusion (131) contacts the side of the pocket (102) and reduces the load on the pivot means (126).

The cam (107) is also represented in more detail in figures 3 and 4. The profile of the cam (107) is preferably divided in a few sections along the longitudinal axis (112) :

- a first flat section C1 at a first distance from the longitudinal axis (112) and substantially parallel to the longitudinal axis (112);
- a second flat section C2 at a second distance from the longitudinal axis (112) and substantially parallel to the longitudinal axis;
- a third flat section C3 located between said first C1 and second flat sections C2 substantially parallel to the longitudinal axis (112) and at a third distance from the longitudinal axis (112), said third distance being smaller than said first distance and said second distance;
- a first tapered portion T1 joining the first flat section C1 to the third flat section C3 and ;
- a second tapered portion T2 joining the third flat section C3 to the second flat section C2.

The profile of the inner side (125b) of the cutting member (103) comprises a convex portion with an apex A1 on a first side of the pivot means (126), a second substantially flat surface A2 extending from the apex A1 to a location under the pivot means (126), and a third substantially flat surface A3 on the second side of the pivot means (126) forming an angle with the second substantially flat surface A2.

As shown in figure 3, when the cutting member (103) is in its retracted position, the second flat section C2 of the cam (107) abuts the third substantially flat surface A3 of the cutting member (103), and said third flat section C3 of the cam (107) abuts the apex A1 of the convex portion of the cutting member (103). The surface of the second flat section C2 of the cam (107) prevents the rotation of the cutting member (103) towards the extended position, and the surface of the third flat section C3 stabilizes and immobilizes the cutting member (103) in its retracted position.

When the actuating member (105) moves to the second position, the second flat section C2 of the cam (107) moves away from the flat surface A3 of the cutting member (103) and the cutting member becomes free to rotate. The apex A1 of the cutting member (103) slides on the tapered section T1 of the cam (107) which induces a rotation to the cutting member (103) such that the cutting member (103) rotates towards its extended position until the third

substantially flat surface A3 of the tool member (103) abuts the tapered section T1 of the cam (107).

When the cutting member (103) is in its extended position, as shown in figure 4, the first section C1 of the cam (107) abuts the substantially flat surface A2 of the cutting member (103). The first section C1 prevents rotation of the cutting member (103) towards the retracted position and blocks the cutting member (103) in the extended position. Any small fluid flow fluctuation is absorbed by said first section C1 without affecting the gauge of the downhole tool.

The gauge of a downhole tool is the greatest external diameter of the tool which in this case is provided by the cutting members in their extended position. Since the cutting members are locked in this extended position, the gauge of the tool is not disturbed or changed as a result of any changes of one or more fluid flow parameters.

When it is desired to move the cutting member (103) in its retracted position, the flow rate across the string and the downhole tool is decreased under the predetermined threshold, and the spring (108) moves the actuating member (105) to its first position. The first section C1 of the cam (107) moves away from the second substantially flat surface A2 of the cutting member (103), which allows the rotation of the tool member (103). The lateral side (134) of the cutting member 103 then slides on the tapered section T2 of the cam (107) which rotates the cutting member (103) towards its retracted position until the apex A1 of the cutting member (103) abuts the third flat section C3 of the cam (107).

The man skilled in the art can conceive any kind of downhole tools with an actuating member that doesn't necessarily present all the features of the present invention but having the same cam profile disclosed herein above and combined with a tool member having the same inner side profile as disclosed herein above.

In another embodiment, the downhole tool (100) of the present invention comprises :

- a nozzle (119) located at the external surface of the housing (101) for projecting a fluid from said longitudinal bore (106) of the actuating member (105) towards the outside of the housing when said actuating member is moved towards its second position,
- a channel (118) connecting the longitudinal bore (106) of the actuating member (105) to the nozzle (119), and
- a valve assembly (120) for closing or opening the path to said channel (118), said valve assembly (120) being operable by said actuating member (105).

Preferably, the valve assembly (120) comprises a tubular part (120a) movable inside the fluid channel (104) of said housing (101) between a closing position closing the path to the channel (118) and an opening position opening the path to the channel (118), means (120b) for retaining said tubular part (120a) in said closing position (for example a spring 120b), said actuating member (105) and said tubular part (120a) are arranged such that the tubular part (120a) is moved to said opening position, opening the path to said channel (118), when said actuating member (105) is moved to its second position.

In the under-reamer represented in figures 1 and 2, the valve assembly (120) further comprises a valve housing (135) fixed by fasteners (136) into the fluid channel (104) of the housing (101). The valve housing (135) comprises a port (137) aligned with a port (138) made in the housing (101) of the downhole tool and connected to the channel (118).

The tubular part (120a) comprises a port (120c) that can be brought into alignment with the port (137) of the valve housing (135) for connecting the bore (106) of the actuating member (105) with the channel (118). The tubular part (120a) is maintained at an upper position by a spring (120b) seated on a seat (139) at the base of the valve housing (135). Therefore, when the actuating member (105) is pushed to its second position, it pushes the tubular part (120a) towards a lower position, against the spring force exerted by said spring (120b), and aligns the port (120c) of the tubular part (120a) with the port (137) of the valve housing (135). The ports

(120c), (137), (138) convey the fluid to the channel (118). The fluid flows through the channel (118) and is projected outside of the housing (101).

Activation of the means for cleaning the outer side (125a) of the cutting member (103) provides a pressure drop at the same flow rate. This pressure drop can be viewed at the surface of the wellbore and indicates to the user that the cutting member (103) has been moved to its extended position. Advantageously, the spring (120b) of the valve assembly (120) gives an additional push to the spring (108) when the actuating member (105) has to be moved back to its first position.

The man skilled in the art can conceive any other kind of downhole tool that doesn't necessarily present all the features of the present invention but which comprises a valve assembly (120) as disclosed herein above wherein the tubular part (120a) is pushed upon actuation of an ordinary actuating member (105). For example, the valve assembly can be included in a downhole tool without cutting members (103) or any other tool members, such as a cleaning tool.

The nozzle (119) is directed towards the cutting member (103) for cleaning the cutting member (103) when these are in their extended position.

The channel (118) is at least partially included in an insertable housing (140). The housing (101) of the downhole tool comprises a groove or a cavity on its external surface in which is inserted the insertable housing (140). Such an arrangement provides an easier machining of the housing (101) and allows location of the nozzle (119) closer to the cutting member (103) allowing an improved cleaning of the cutting member 103.

Alternatively, the channel (118) is built-in in the housing (101).

In an embodiment of the present invention, as shown in figure 6, the actuating member (105) comprises an interchangeable nozzle (121) preferably located at the top end of the actuating member (105) such that the fluid is passing this nozzle and sized for creating a sufficient pressure drop across the actuating member (105) when the circulating fluid is under a predetermined flow rate threshold.

In this embodiment, the actuating member (105) also comprises an internal fishing profile (130) machined preferably near the top of the actuating member (105) for allowing a fishing tool to grip the actuating member (105) when a cutting member (103) is stuck in its extended position. The housing (101) preferably also comprises a portion of larger external diameter in which grooves are provided (not shown) in order to provide a passage for the drilling fluid. Preferably this portion of larger external diameter comprises the pockets (102).

In a preferred embodiment of the invention, the downhole tool is an under-reamer (100) for enlarging or reaming a borehole in a subterranean formation. However this embodiment does not limit the scope of protection of the present invention, and the man skilled in the art can conceive other downhole tools than a reamer apparatus that comprise the characterizing features of the invention, such as for example a cleaning tool, a swivel means, a brake tool or a fishing tool.

An embodiment of an under-reamer according to the present invention is represented in fig. 1 in a deactivated configuration, and fig.2 in an activated configuration for enlarging or reaming the borehole. The under-reamer preferably comprises all the features disclosed herein above wherein at least a tool member (103) comprises cutting elements or inserts (123) such as for example polycrystalline diamond compact (PDC) cutters or diamond impregnated inserts. These examples of inserts are not limitative and other kind of inserts can be envisaged by the man skilled in the art.

The outer side (125a) of the tool member (103) preferably comprises a cutting section (115) and a gauge section (116). The gauge section is the most external part of the cutting member (103), which is in contact with the wall of the bore hole. When the cutting members are in their extended position, it is important that the gauge (the most external diameter of the tool provided by the extended cutting members) is kept constant so that the bore hole quality is improved, i.e. the bore hole is smooth, without doglegs.

The tool member (103) further may comprise a backreaming section (117). More preferably, the cutting section (115) is longer than the gauge section (116) and the backreaming section (117). The back reaming section (117) advantageously maintains the size and the shape, i.e. hole quality, of the enlarged borehole while pulling out of the hole. During a backreaming operation, the circulation of drilling fluid is needed with a flow rate larger than the predetermined threshold to maintain the under-reamer activated since there is no weight on bit during pulling out of the hole.

More preferably, the cutting section (115), the gauge section (116) and the backreaming section (117) have flat surfaces forming an angle between each other as shown in the embodiment of figures 3 and 4.

In a preferred embodiment of an under-reamer according to this invention, the pivot means (126) of the cutting member (103) is arranged such that when the cutting member (103) is in its extended position, the cutting section (115) is inclined with respect to said longitudinal axis (112) towards the bottom end (114) of the reamer apparatus, i.e. the cutting section (115) approaches the axis (112) in the direction towards the bottom end (114) of the tool.

Thanks to this arrangement, it is possible to provide cutting members (103) with a longer cutting section (115) when compared to the devices of the prior art. The life of the cutting members (103) is then increased. Thanks to this arrangement, it is further possible to allow the cutting member (103) in its extended position to grip on the cam (107) under weight on bit. Hence, when sufficient weight on bit is applied, the reduction in flow of the drilling fluid will not cause the actuating member (105) to move back to its first position, and the reamer

apparatus can continue drilling with low fluid flow. When it is desired to retract the cutting members, the weight on bit is removed while the fluid flow rate is under the predetermined threshold, which allows the actuating member (105) to move back to its first position for retracting the cutting member (103).

The under reamer apparatus according to the present invention and the use of this apparatus for reaming or enlarging a wellbore provides the following main advantages:

- extension of cutting members (103) from the housing (101) of the under reamer apparatus is substantially independent of the pressure differential between the inside and the outside of the under reamer apparatus;
- possible activation and deactivation of the actuating member several times,
- less components and complexity inside the under reamer apparatus that allows reduction of costs and maintenance;
- avoiding accidental triggering of the actuating member (105);
- avoiding the use of a drop ball activation system for extending or retracting the cutting members (103);
- providing an indication at the surface of the wellbore that the cutting member has been moved to its extended position;
- providing a high bore hole quality thanks to the long stabilization section directly below the cutting members (103); and
- others advantages that may be apparent for the man skilled in the art.

The present invention also relates to a method for operating a downhole tool, in particular a method for operating a tool member (103) by moving an actuating member (105) of a downhole tool.

A possible method according to this invention, only given by way of example, comprises the steps of :

i) providing a string comprising a downhole tool (100) according to this invention, said tool (100) comprising a housing (101) which comprises :
   - a longitudinal fluid channel (104),
   - an actuating member (105) having a longitudinal bore (106) forming with said fluid channel (104) a circuit through which a fluid is permitted to circulate, said actuating member (105) being movable inside the fluid channel (104) of the housing (101) between a first position and a second position in order to activate or deactivate a tool member (103),
   - a means (108) for retaining the actuating member (105) in the first position, when the fluid force exerted on the actuating member (105) is under a predetermined threshold,
   - a top end (113) comprising a connection means for an upper part of a string, and
   - a bottom end (114) comprising a connection means for a lower part of a string,

   wherein said fluid channel (104) of the housing (101) is in communication with the outside of the housing (101) through an opening (109) formed in the housing (101), and the actuating member (105) comprises a first piston head (110) and a second piston head (111) fitted into said fluid channel (104) such that both piston heads (110), (111) are always on both sides of the opening (109), each piston head (110), (111) comprising
   - a respective first piston-head surface (110a), (111a), said surfaces facing away from one another and being exposed to a different internal pressure from the fluid channel (104), and having equal projected areas, and
   - a respective second piston-head surface (110b), (111b), said surfaces facing one another and being exposed to an external pressure from the outside of the housing and having equal projected areas;

ii) circulating a fluid through said fluid channel (104) and said bore (106) of the actuating member (105), such that the force exerted by said fluid on the actuating member (105) is under a predetermined threshold, so as to bring or keep the actuating member (105) in its first position, which places the tool member (103) in a deactivated status,

iii) increasing the flow rate and/or the density to increase said fluid force such that it exceeds said predetermined threshold, such that the actuating member (105) moves axially in the

housing (101) towards the bottom end (114) of the tool, which moves the actuating member (103) to its second position, which places the tool member (103) in an activated status.

In this method, it is preferred that the downhole tool comprises a pocket (102) and a cutting member (103) which is movable between a retracted position inside the pocket (102) and an extended position wherein at least a portion of the cutting member (103) is outside the pocket 102, that the actuating member (105) further comprises a cam (107) profiled for moving the cutting member (103) between the retracted position and the extended position, that the string is drillstring, that the cutting member (103) comprises a cutting section (115), that the step of circulating the fluid is performed while rotating the drillstring into a borehole and while applying a weight on bit, and that the weight on bit is removed before the flow rate and/or density of the fluid is increased in order to place the tool member (103) in its activated status.

During this method the fluid pressure at the surface of the wellbore and/or the torque on the drillstring may be monitored for acknowledging that the cutting member (103) has been moved completely in its extended position.

The method may also comprise a further step of applying a weight on bit once it is acknowledged that the cutting member (103) has completely moved to its extended position. Said weight on bit can be maintained while reducing the flow rate such that the cutting members (103) are kept in their extended position. In a possible further method step the cutting member (103) is moved back in its retracted position by decreasing the flow rate under a predetermined threshold and by removing the weight on bit.

CLAIMS

1. A downhole tool comprising a housing (101), at least one tool member (103) which can be activated and deactivated, an actuating member (105) which is movable between a first position and a second position in order to activate or deactivate said tool member (103), a circuit (104, 106) for the circulation of a fluid inside said housing arranged to apply a fluid pressure onto the actuating member (105) in order to move it from the first to the second position, and a channel (118) connecting the circuit (104, 106) to a nozzle (119) for projecting a fluid from said circuit (104, 106) towards the outside of the housing, **characterized in that** it further comprises a valve assembly (120) for closing or opening the path to said channel (118), said valve assembly (120) being operable by said actuating member (105).

2. A downhole tool according to claim 1 characterized in that the path to said channel (108) is opened when the actuating member (105) is in the position activating the tool member (103).

3. A downhole tool (100) according to claim 1 or 2 characterized in that said valve assembly (120) comprises a tubular part (120a) movable inside the housing (101) between a closing position closing the path to said channel (118) and an opening position opening said path, and means (120b) for applying a retaining force onto the tubular part (120a) urging it towards said closing position, and that said actuating member (105) is arranged to move said tubular part (120a) to its opening position, when it is moved towards its second position.

4. A downhole tool according to any of claims 1 to 3 characterized in that said nozzle (119) is directed towards said tool member (103).

5. A downhole tool (100) according to any of the preceding claims characterized in that said housing (101) comprises a groove or a cavity on its external surface and that said channel

(118) is at least partially included in an insertable housing (140) which is inserted into said groove or cavity.

6. A downhole tool according to any of the preceding claims characterized in that said housing (101) further comprises a pocket (102) comprising a tool member (103) movable between a retracted position inside the said pocket (102) and an extended position in which at least a portion of the tool member(103) is outside said pocket (102) and protrudes from said housing (101).

7. A downhole tool according to any of the preceding claims characterized in that the housing (101) comprises a longitudinal fluid channel (104), that the actuating member(105) is movable in this fluid channel (104) between its first and second position, that the actuating member (105) comprises a longitudinal bore (106), so that the fluid channel (104) and the bore (106) form a circuit through which the fluid is permitted to flow.

8. A downhole tool according to any of the preceding claims characterized in that said retaining means (108) is provided to retain the actuating member (105) in said first position as long as the fluid force does not exceed a predetermined threshold.

9. A downhole tool according to any of the preceding claims characterized in that said tool member (103) comprises a cutting section (115).

10. A downhole tool according to any of the preceding claims characterized in that it has a top end (113) and a bottom end (114), and that said tool member (103) is arranged such that when the tool member (103) is in its extended position, the distance between the surface of the cutting section (115) and its central longitudinal axis (112) decreases towards the bottom end (114) of the tool.

11. A downhole tool according to any of the preceding claims characterized in that it has a top end (113) and a bottom end (114), and that said tool member (103) comprises a backreaming section (117) arranged such that when the tool member (103) is in its extended position, the distance between the surface of the backreaming section (117) and the longitudinal axis (112) decreases towards said top end (113).

12. A downhole tool comprising a housing (101), at least one tool member (103) which can be activated and deactivated, an actuating member (105) which is movable between a first position and a second position in order to activate or deactivate said tool member (103), a circuit (104, 106) for the circulation of a fluid inside said housing arranged to apply a fluid pressure onto the actuating member (105) in order to move it from the first to the second position, and a channel (118) connecting the circuit (104, 106) to a nozzle (119) for projecting a fluid from said circuit (104, 106) towards the outside of the housing, **characterized in that** said housing (101) comprises a groove or a cavity on its external surface and that said channel (118) is at least partially included in an insertable housing (140) which is inserted into said groove or cavity.

13. A downhole tool according to claim 12 characterized in that said housing (101) further comprises a pocket (102) and a tool member (103) which is movable between a retracted position inside the said pocket (102) and an extended position in which at least a portion of the tool member(103) is outside said pocket (102) and protrudes from said housing (101) and wherein said nozzle (119) is directed towards said tool member (103).

14. A method for operating a downhole tool according to any of the claims 1 to 11, characterized in that it comprises the steps of
    i) providing said downhole tool in a string,
    ii) circulating a fluid in said circuit (104, 106) of the downhole tool, and
    iii) activating said tool member (103) by exerting a fluid pressure on said actuating member (105) such that the valve assembly (120) opens the path to said channel (118)

and a fluid is projected outside of the housing through said nozzle (119) towards the tool activated member (103).

15. A method for operating a downhole tool according to claim 14, characterized in that the flow of fluid coming back to the surface of the wellbore is monitored to acknowledge that the said tool member (103) has been activated.

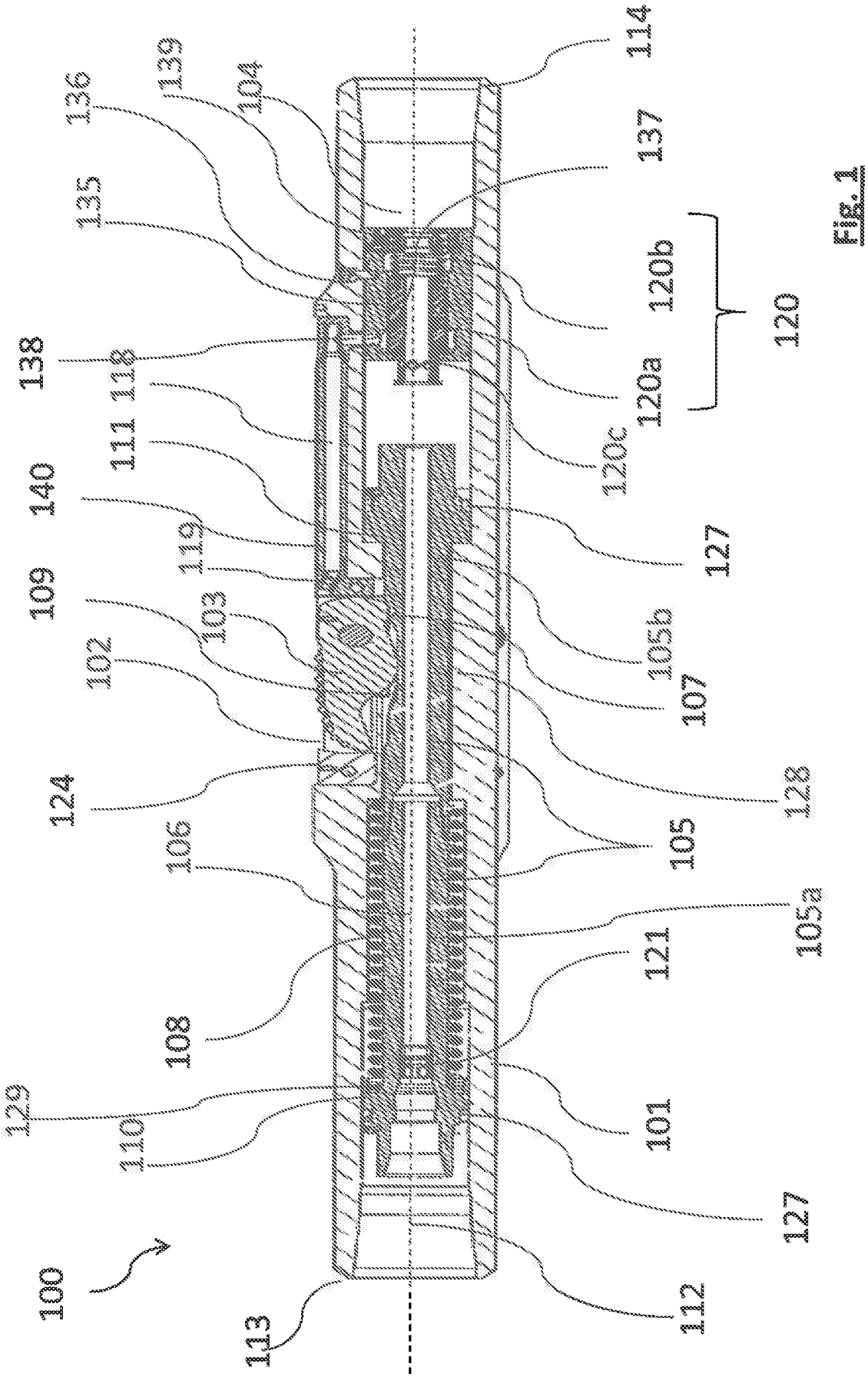
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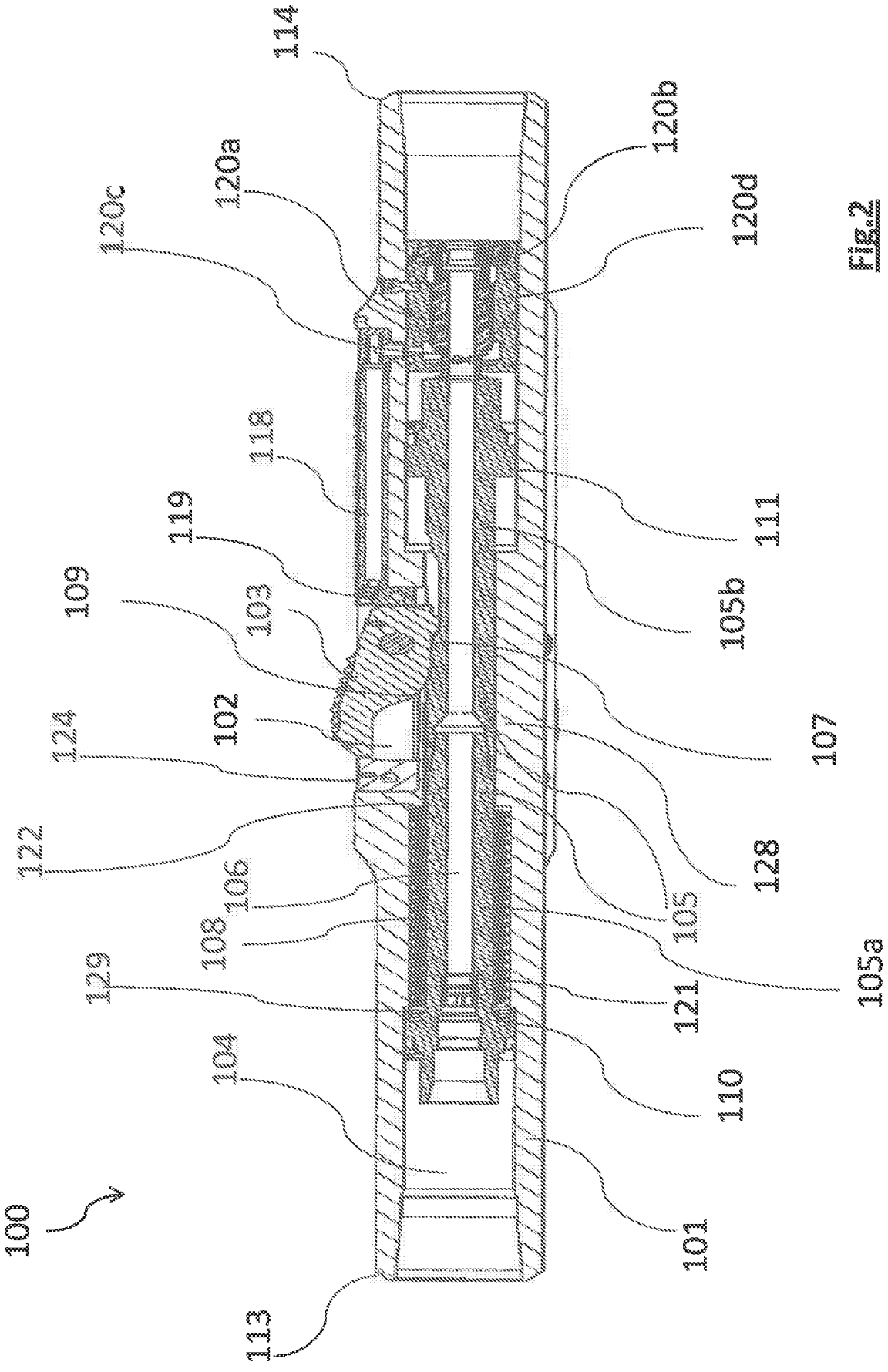
Fig. 1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113

Fig.2

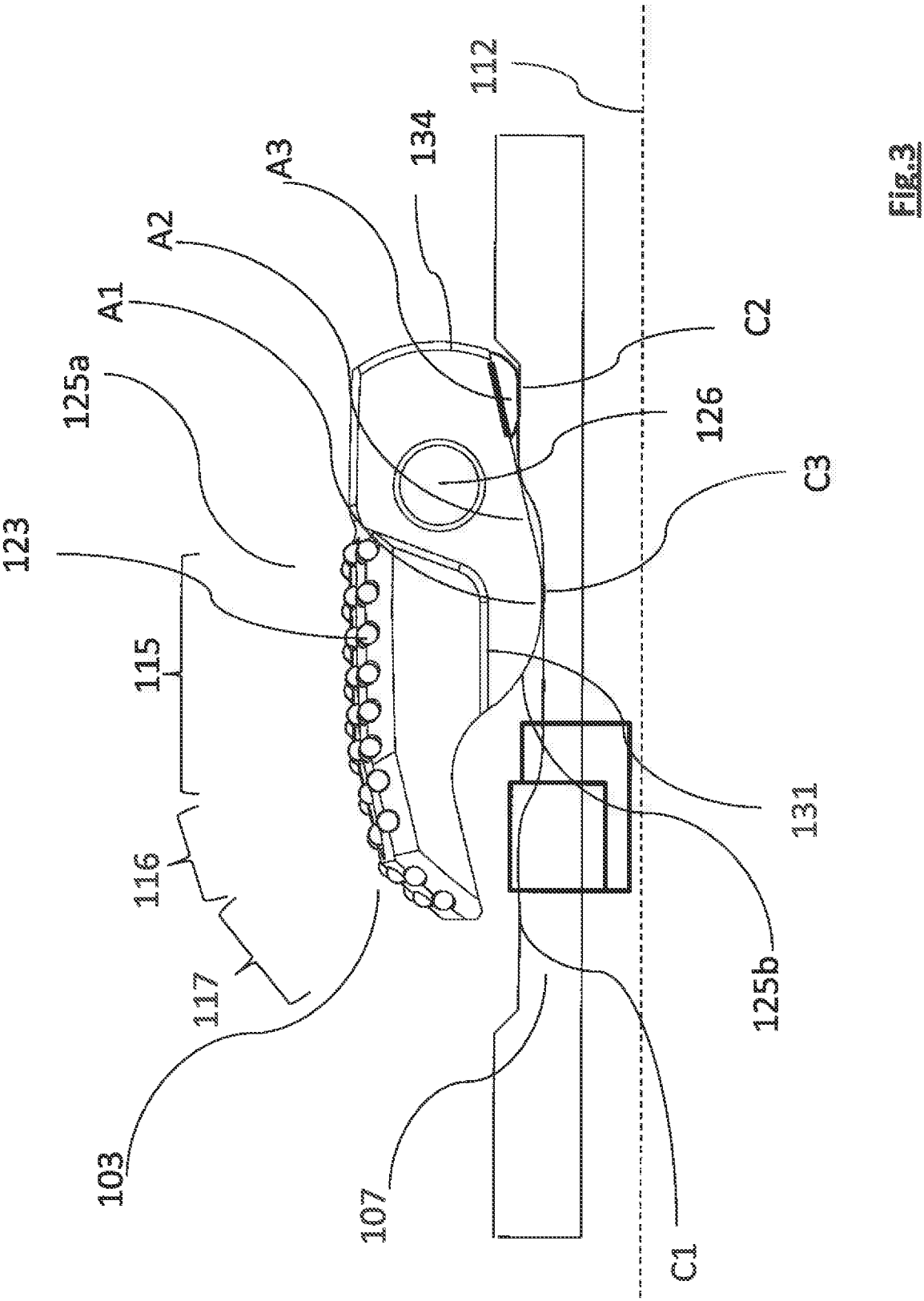
112
134
A3
A2
A1
125a
123
115
116
117
103
107
C1
125b
131
C3
126
C2

Fig.3

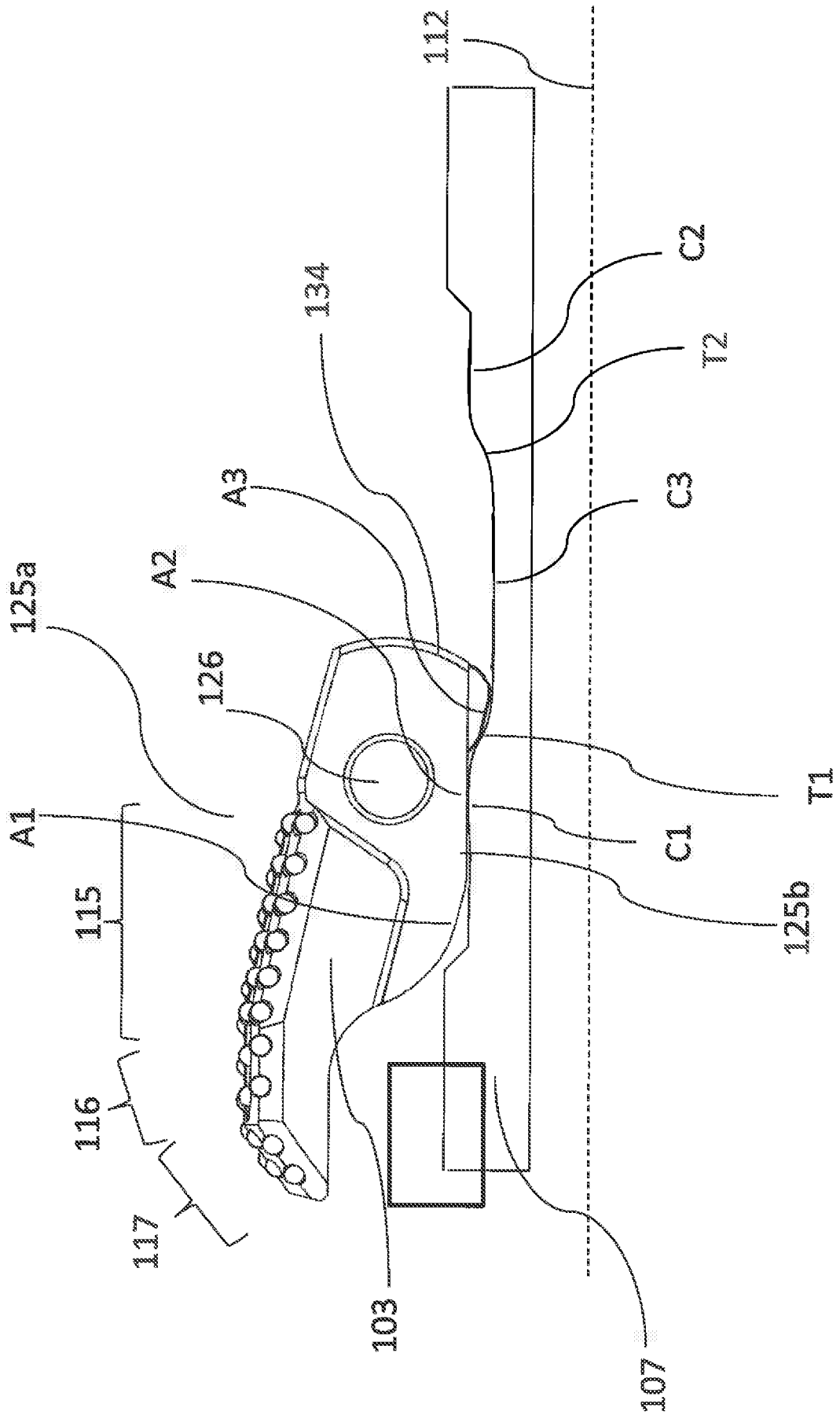

Fig.4

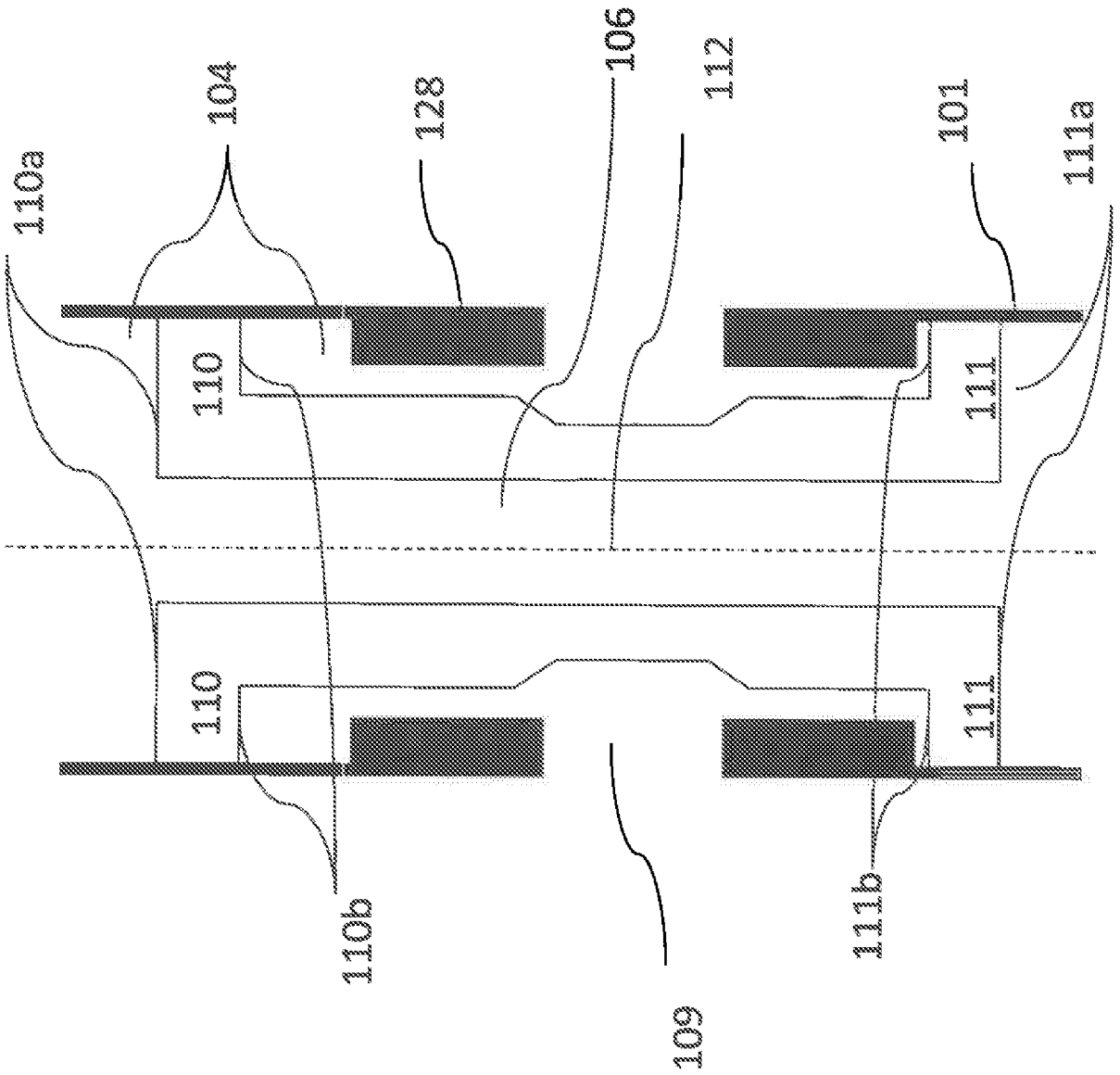

Fig.5

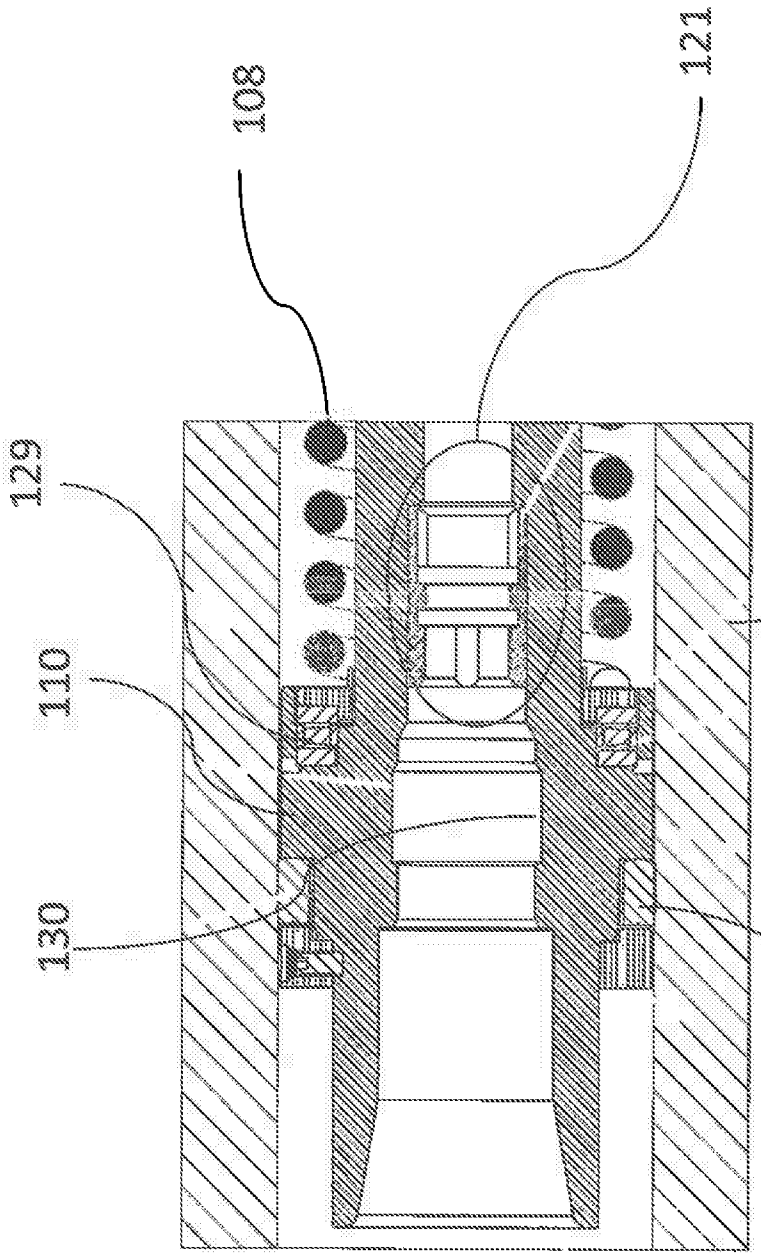

Fig.6

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/058699

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B41/00 E21B10/32
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/175095 A1 (DEWEY CHARLES H [US] ET AL) 11 July 2013 (2013-07-11) page 2, paragraph 18; figures 2a,2B page 2, paragraph 23 - page 3, paragraph 26; figures 3A,3B	1-3,6-15
X	US 2012/080183 A1 (RADFORD STEVEN R [US] ET AL) 5 April 2012 (2012-04-05) page 8, paragraph 74; figures 3,12A-12C	1-3,6-14
A	US 2013/206401 A1 (BHOITE SAMEER P [US] ET AL) 15 August 2013 (2013-08-15) figures 6,7	1-15
A	US 2013/133949 A1 (XU WEI JAKE [US] ET AL) 30 May 2013 (2013-05-30) figures 10C,10D	1-15

-/--

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

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 February 2015	12/02/2015

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/058699

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/284233 A1 (WU JIAN [US] ET AL) 24 November 2011 (2011-11-24) figure 8A -----	1-15

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Information on patent family members

International application No
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