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(54) **A METHOD AND SYSTEM FOR ELECTRO-PULSE DRILLING**

(57) The method relates to a method and system for drilling by means of a drill head with an end portion, wherein at least two electrodes are arranged at the end portion, the method comprising: moving, by means of an actuation system, the drill head adjacent to a surface to be broken up; applying, by means of a voltage generator, a voltage between the electrodes resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface; and wherein a gap distance is provided between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs.

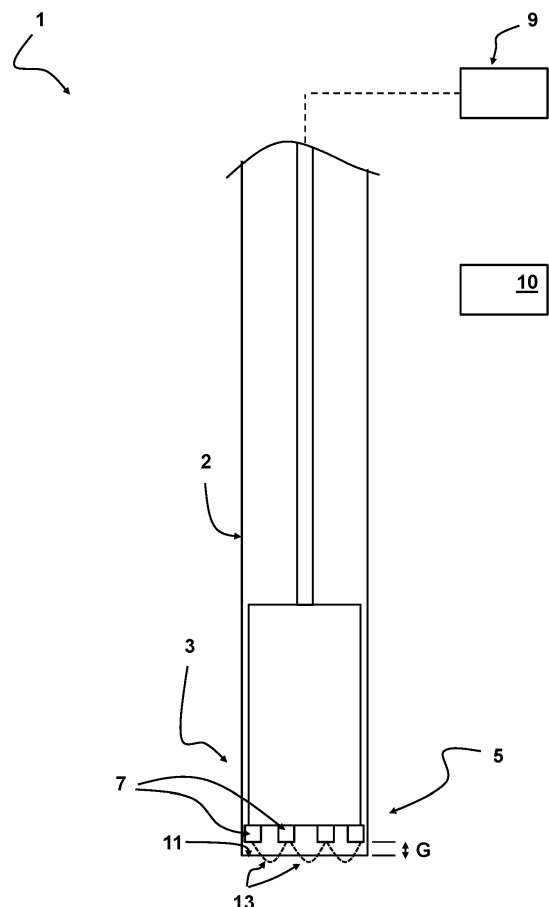


FIG 1

Description

FIELD OF THE INVENTION

[0001] The invention relates to a method for drilling by means of a drill head with an end portion, wherein at least two electrodes are arranged at the end portion. The invention also relates to a system for performing pulsed drilling operations. Furthermore, the invention relates to an optical sensor for use in a system for performing pulsed drilling operations. Additionally, the invention relates to a computer program product.

BACKGROUND TO THE INVENTION

[0002] Electro-pulse drilling employs pulsed-power technology for drilling into materials such as rock formations, mineral lumps, etc. A conduction path is created inside the material which can result in breaking of the material.

[0003] Typically, the electro-pulse drill head has at least two electrodes. An electrical potential is applied across the electrodes which contact the material, generating a high electric field, which results in the formation of an arc or plasma inside the material (e.g. rock). The arc travels from a high voltage electrode to a low voltage electrode of the electro-pulse drill head. The electrical current flows through the conduction path, or arc, through the surface and inside the material, and results in the expansion inside the material which can create high stress or pressures. These induced high pressures and generated tensions can result in structural failure of the material, thus effectively fracturing the surrounding material and creating fragments (e.g. fragmented rock). The fragments can be carried away from the drill head, for instance by means of drilling fluid, and the drill head can be advanced further in the borehole. The arcs may be repeatedly generated arcs for incremental fracturing of the material during the drilling process.

[0004] Existing solutions may have a low efficiency and rate of penetration. Often, only smaller fragments are produced during electro-pulse drilling, which can have a detrimental effect on the rate of penetration or drilling/boring speed achieved by the electro-pulse drill head. There is a strong desire to improve the fracturing of the material during the electro-pulse drilling process.

[0005] Since the drilling efficiency of existing electro-pulse drilling systems is often too low, the technology is regularly regarded as less attractive compared to alternative systems which utilize alternative boring/drilling techniques.

SUMMARY OF THE INVENTION

[0006] It is an object of the invention to provide for a method and a system that obviates at least one of the above mentioned drawbacks.

[0007] Additionally or alternatively, it is an object of the

invention to improve drilling/boring speed achieved by the electro-pulse drill head.

[0008] Additionally or alternatively, it is an object of the invention to improve the rate of penetration achieved by the electro-pulse drill head.

[0009] Additionally or alternatively, it is an object of the invention to break off larger parts of fragments from a surface during electro-pulse drilling.

[0010] Thereto, the invention provides for a method of drilling by means of a drill head with an end portion, wherein at least two electrodes are arranged at the end portion, the method comprising: moving, by means of an actuation system, the drill head adjacent to a surface to be broken up; applying, by means of a voltage generator, a voltage between the electrodes resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface; and wherein a gap distance is provided between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs.

[0011] By leaving an open space (cf. gap distance) between the electrodes of the drill head and the surface to be broken up, the electro-pulse boring/drilling can be significantly improved. The drill head is better capable of breaking up the surface opposite to the drill head. Advantageously, as a result of the open space between the electrodes of the drill head, larger debris broken off of the surface may be obtained. Moreover, the separation between the extending electrodes of the drill head and the opposite surface to be broken up, enables more easy removal of larger pieces of the surface broken off (i.e. debris). As a result, the boring/drilling speed and/or the rate of penetration achieved by the electro-pulse drill head can be significantly improved. The rate of penetration can be seen as the speed at which the drill head can be moved forward during drilling/boring. The rate of penetration provides an indication of the efficiency of the drill head in drilling/boring rock or the like, which can be improved by providing a gap distance between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs.

[0012] By providing a split or void between the electrodes of the drill head and the surface to be broken up (e.g. drilling fluid in the split/void), less force may be applied on the surface. The weight of the drill head is not resting on the surface. As a result, less energy may be needed to break off pieces from the surface. When a piece of the surface has broken off, it may be immediately flushed away since the gap distance is provided during the electro-pulse boring process. If the piece is too large to immediately flush away, it may be further broken in pieces by subsequently generated electric arcs. Advantageously, a similar or same drilling/boring effect can be obtained with less energy. Hence, the energy efficiency of the drill head can be significantly improved in this way.

[0013] Optionally, the method comprises: measuring, by means of a sensor measurement system, at least one

value indicative of a property of the generated one or more electric arcs; and controlling, by means of a control system, one or more operational parameters of the actuation system such as to adjust the gap distance between the drill head and the surface based on the at least one value.

[0014] Advantageously, the sensor measurement system may be used for determining the effectiveness of the electro-pulse drilling/boring. This provides a way faster approach than for instance measuring a value indicative of debris (e.g. weighing debris), since flushing debris may be a slower process, making it less interesting for use for control. For example, it can take some time for the debris to be flushed away out of the drill hole.

[0015] Optionally, the sensor measurement system comprises an optical sensor configured to measure a value indicative of a length of time of the one or more electric arcs.

[0016] The length of time (cf. duration) of an electric arc provides an efficient way of determining whether the electric arc has passed through the surface (e.g. rock) properly. The duration of the electric arc can be measured in different ways. The gap distance may be in a predetermined range, and within said predetermined range, one or more operational parameters may be further adjusted to obtain better electric arcs. For this a feedback loop may be provided. For instance, the gap distance may be variably adjusted within the predetermined range, further taking into account values provided by the sensor measurement system, such as for instance a value indicative or related to a duration of the generated individual electric arcs.

[0017] A longer pulse duration may be an indication that the arc has travelled through the drilling fluid. Hence, a shorter pulse duration may indicate that the arc has travelled through the surface (e.g. rock) being bored.

[0018] In some cases, the pulse duration is very small, for example smaller than 1 microsecond. This may be difficult to measure. However, an optical sensor may provide the ability to accurately measure such small lengths of time.

[0019] Optionally, the pulse durations may be in a range between 100-3000 nanoseconds, more preferably between 300-2000 nanoseconds.

[0020] In some examples, the gap distance is not measured, but it is checked whether the generated electric arcs or pulses have certain properties, providing an indication of the gap distance. The gap distance may be optimal in a predetermined range. In this way, by monitoring parameters indicative of properties of the generated electric arcs or pulses, it can indirectly be determined whether the electrodes are suitable distanced from the surface being drilled.

[0021] It may pose significant difficulty to directly measure the gap distance with an accuracy of mm as the broken rock surface is very rough. However, indirect measurement through the determination of values indicative of the pulse length may not be influenced by the rough-

ness of the surface, providing significant advantages.

[0022] Optionally, the control system is configured to operate one or more actuators to dynamically optimize the gap distance based on the sensory data obtained by means of the sensor measurement system.

[0023] Optionally, the optical sensor is arranged at the voltage generator.

[0024] Advantageously, properties related to the generated arcs at the electrodes of the drill head can be effectively measured at the voltage generator. This may provide in more robust and reliable monitoring.

[0025] Additionally or alternatively, the control system may be configured to control electrical parameters in the voltage generator based on the at least one value indicative of the property of the generated one or more electric arcs. Additionally or alternatively, the control system may be configured to control the flushing speed based on the at least one value. Since, it can be expected that less debris are produced due to the generated arcs, when the generated arcs fail to travel through the surface being drilled.

[0026] Optionally, the voltage generator is integrated with the drill head.

[0027] Optionally, the optical sensor is arranged at the drill head.

[0028] The generated arcs at the electrodes of the drill head can be sensed by means of the optical sensor. It is also possible to have multiple optical sensors, for example arranged at the voltage generator and at the electrodes of the drill head.

[0029] It will be appreciated that combinations with other sensors are also possible. For instance, additionally or alternatively, an acoustic sensor and/or a vibrational sensor (e.g. accelerometer) can be used.

[0030] The use of an optical sensor may provide significant advantages. During generation of the one or more electric arcs, an aggressive electromagnetic interference (EMI) environment may be obtained. This can make it challenging to effectively use sensors with electronics, such as electronic sensors. In some examples, additional shielding is provided in order to protect such sensors against the electromagnetic radiation. Additionally or alternatively, the effect of electromagnetic interference may be reduced by placing the sensors at a sufficient distance from the source of electromagnetic radiation. Advantageously, the optical sensors are not affected by the aggressive EMI environment and may thus not require such additional measures. The signals measured by means of the optical sensor may be measured without interference, even when employed in the aggressive EMI environment.

[0031] Optionally, the voltage generator charges and discharges sequentially, wherein the one or more electric arcs are generated during discharge.

[0032] Optionally, the voltage generator is a Marx generator. Such a voltage generator can create high-voltage pulse from a low voltage DC supply. The Marx generator may have a circuit which generates a high-voltage pulse

by charging a number of capacitors in parallel, then suddenly connecting them in series. It will be appreciated that other types of high voltage generators for producing an arc/pulse may be used.

[0033] Optionally, the sensor operates synchronous with the voltage generator.

[0034] Optionally, the sensor is selectively disconnected based on the operation of the voltage generator.

[0035] Optionally, in case the voltage generator is charging, the sensor is operated such as to perform measurements, and in case the voltage generator is discharging (cf. generation of the one or more electric arcs), the sensor is disconnected. This may be performed by a switching circuit. In this way, electromagnetic interference resulting from the generated electric arcs may be effectively reduced or even prevented. Such embodiments may be particularly advantageous when sensors are employed which comprise electronics, e.g. electronic sensors which may be affected by electromagnetic interference.

[0036] Optionally, the value indicative of the length of time of the one or more electric arcs is associated to the traveled path of said one or more electric arcs.

[0037] For example, the pulse duration can be determined based on the sensory data, providing an indication of the path of the arcs.

[0038] Optionally, the control system is configured to determine based on the value indicative of the length of time whether the one or more electric arcs have travelled into the surface to be broken up.

[0039] Measuring a value indicative of the length of time of the one or more electric arcs, i.e. pulse duration, can be done in different ways. Optionally, a value indicative of the pulse duration is determined by means of a sensor at the voltage generator. This can be advantageous, since more accurate determinations may be achieved. Additionally or alternatively, it is also possible to determine a value indicative of the pulse duration by means of a sensor at the drill head, for instance arranged at or proximate to the electrodes.

[0040] The arcs going through the surface may result in effective fragmentation of the material, resulting in a more effective drilling process.

[0041] Optionally, the sensor measurement system comprises an electric sensor configured to measure a voltage and/or a current during generation of the one or more electric arcs. The voltage and/or current can be indicative of the travel path of the one or more electric arcs. In this way, it can be determined whether the one or more electric arcs or pulses pass through the surface properly.

[0042] Optionally, the control system is configured to determine whether the length of time of the one or more electric arcs is smaller than a threshold value, wherein one or more operational parameters of the actuation system are adjusted for changing the gap distance between the drill head and the surface when the length of time of said one or more electric arcs is larger than the threshold

value.

[0043] Providing a split distance between each electrode and the opposite surface to be broken up, may result in improved debris forming. Direct contact between the electrodes and the surface may cause for smaller debris, which has detrimental effect on the efficiency and the rate of penetration and/or drilling speed.

[0044] As a result of the interspace between the at least one electrode and the surface to be broken up, opposite to the end portion of the drill head, the efficiency and the drilling/boring speed can be significantly enhanced. In some cases, the drill speed can be increased with a factor of at least 5, even at least 10 or more.

[0045] Optionally, a drilling fluid is used during pulsed drilling operation, wherein the drilling fluid has a dielectric constant which is higher than a dielectric constant of the surface to be broken up.

[0046] Advantageously, by carefully selecting the drilling liquid, it can be better guaranteed that the electric pulse (cf. spark) goes through the substrate surface to be broken up, instead of solely between the drilling fluid from one electrode to another electrode. Even if there is no direct contact between the electrode and substrate surface to be broken up, the electric pulse or spark will still pass through the substrate surface and result in breaking thereof, forming debris which can be easily flushed.

[0047] Optionally, the dielectric constant of the drilling fluid is at least 5 times larger than the dielectric constant of the surface to be broken up, more preferably at least 10 times larger, even more preferably at least 20 times larger.

[0048] Advantageously, the drilling fluid can act as a capacitor dielectric, resulting in the electric pulses or sparks going through the substrate surface, even with an interspace between the electrodes and said substrate surface.

[0049] Optionally, the drilling fluid is water based.

[0050] By employing a drilling fluid with water, the drilling liquid between the drill head and the surface to be broken up can be charged with an amount of energy without the voltage getting too high, thus acting as a capacitor. The permittivity is lower in the surface (e.g. rock, substrate, soil, etc. has a lower permittivity). For example, the permittivity of a rock surface to be drilled may be 10 to 50 times lower than that of the drilling fluid (e.g. water), which causes the sparks or electric pulses to go through the rock surface.

[0051] Water as drilling fluid may have far greater electric conductivity than oil. Additionally, water may result in less contamination of the environment, compared to the use of oil.

[0052] Optionally, it is prevented that any electrode of the at least two electrodes touches the surface to be drilled, at least during the generation of the electric arcs. A non-zero gap distance may be provided between the electrodes and the surface.

[0053] Smaller gap distances may provide improved

drilling. However, too small gap distances may result in detrimental effects, resulting in less efficient boring. Optionally, the gap distance is kept above 1 millimeter, more preferably above 2 millimeter. By approaching the surface and maintaining such minimal gap distance, the optimal gap distance can be automatically reached. Therefore, it is possible to significantly simplify control during the electro-pulse drilling process.

[0054] Optionally, the gap distance is kept between 1 to 30 millimeter, more preferably between 2 to 10 millimeter, even more preferably between 2 to 5 millimeter.

[0055] In some cases, the gap distance may be selected independent of the dimensions of the drill head, such as the diameter of the drill head. The gap distance may also be selected independent of characteristics of the ground to be drilled/bored, such as for instance material properties. This is advantageous, since often the characteristics and the properties of the surface/substrate are not well known. For example, the rock may have heterogeneous properties.

[0056] Advantageously, no insulation may need to be arranged between the electrodes, as the generated electric arcs can travel into the surface. This may improve the flushing capabilities since the debris can more easily be flushed away.

[0057] Optionally, a spacing unit is provided for mechanically distancing the at least two electrodes of the drill head and the surface to be broken up.

[0058] Optionally, the spacing unit is preset.

[0059] Optionally, the drill head is continuously moved into the drill hole. The movement of the drill head into the drill hole may be carried out at a boring speed. For example, the drill head may be continuously lowered in the drill hole.

[0060] Optionally, the drill head is moved into the drill hole with a boring speed, wherein the boring speed is adjusted based on the at least one value indicative of the property of the generated one or more electric arcs.

[0061] Optionally, the spacing unit is configured to keep a minimum distance between the drill head and the surface to be broken up.

[0062] Advantageously, a self-regulating operation can be obtained with a rather simple design. Therefore, a more robust and reliable operation of the drill head control can be obtained. When the electrodes of the drill head are approach the surface to be drilled/bored, an optimal distance may be achieved since a minimal gap distance is always maintained such as to avoid direct contact between the electrodes and the surface. In this way, the electro-pulse drill head will efficiently bore/drill into the surface, causing pieces of the surface (e.g. rock) being broken off. By flushing the debris, the distance of the electrodes to the surface (cf. gap distance) is effectively increased, which may result in less efficient boring/drilling. However, reducing the gap distance, for example by means of an actuator allowing the drill head to go deeper in the drill hole, the optimal distance will again be automatically reached, without requiring complex control sys-

tems for accurately determine the gap distance. This process can be facilitated by providing a spacing unit.

[0063] Optionally, the spacing unit is adjustable to allow variable minimal distances between the at least two electrodes and the surface to be drilled. In some examples, the spacing unit has one or more mechanical fingers which extend from the end portion of the drill head towards the surface to be drilled. In this way, the mechanical fingers can contact the surface when the distance between the electrodes and the surface is reduced, preventing further reduction of the distance. In some examples, a plurality of mechanical fingers are used for maintaining a minimum distance. It is also possible to employ braces or skirts for keeping the distance. The skirts may be shaped such as to facilitate flushing. Advantageously, the flushing can be improved whilst maintaining a minimum distance between the electrodes and the surface. The spacing unit may avoid that the electrodes directly rest on the surface during electric pulse drilling operation.

[0064] The fingers may have various configurations, shapes and/or dimensions. For instance, feeler pens may be employed which can also measure a distance by contact. This distance can be used by the control system. In some examples, the fingers have springs reducing mechanical shocks. The fingers may include one or more sensors for detecting contact and/or the forces applied.

[0065] Optionally, at least one distance sensor is provided, wherein the at least one distance sensor is configured to provide data indicative of a distance of the electrodes from the surface to be broken up. In some examples, the at least one distance sensor is configured to measure data indicative of the distance at least at a central portion of the on the front portion of the drill head. In some examples, the at least one distance sensor is configured to measure data indicative of the distance at a plurality of points on the front portion of the drill head. In some examples, the plurality of points may for instance be evenly distributed on the front portion of the drill head. The at least one distance sensor may measure from a surface of the drill head from which the at least two electrodes extend. The sensors may thus be calibrated to take into account the distance at which the electrode extends from the surface of the drill head, such as to be able to provide data indicative of the distance of the electrodes with respect to the surface to be broken up (cf. sample surface). Optionally, the drill head has at least one distance sensor arranged at its front portion facing the surface to be broken up.

[0066] Optionally, the at least one distance sensor is a sonar sensor. The sonar sensor may use sound propagation in the liquid surrounding the drill head to measure distances (ranging). In some examples, the sonar sensor employs active sonar by emitting pulses of sounds and listening for echoes, based on which data indicative of the distance of the electrodes to the surface to be broken up is calculated.

[0067] Optionally, the at least one distance sensor is configured to employ electro-magnetic radiation for de-

termining the distance to the surface to be broken up. Optionally, the at least one distance sensor is a laser sensor which is configured to use a laser beam to determine the distance to the surface to be broken up. Various types of laser distance sensors can be employed. In some examples, the drill head has at least one or more laser rangefinders. Other types of distance sensors, such as radar, lidar, sonar, etc.

[0068] Optionally, the at least one distance sensor is an electro-mechanical sensor.

[0069] Optionally, the at least one distance sensor is integrated in the spacing unit. For instance, the spacing unit may have a biasing member, such as a spring, wherein the spacing unit has a first state, in which the spring is not compressed, and a second state, in which the spring is maximally compressed as a result of contact of the spacing unit with the surface to be broken up. In such an example, data indicative of the distance can be measured between the first state and the second state.

[0070] Optionally, a calibration step is performed for determining the boring speed. The calibration step may include: starting with an initial boring speed; measuring, by means of the sensor measurement system, the at least one value indicative of a property of the generated one or more electric arcs; calculating a continuous boring speed which would allow continuous drilling without the need of interrupting the movement. Such continuous drilling speed may enable the drill head to efficiently break off the surface during drilling, whilst maintaining an optimal gap distance range (hotspot range) which results in good electric arc formations going through the surface for breaking off surface pieces.

[0071] Optionally, the method may include flushing to guide broken off debris away from the separation between the electrodes and the surface.

[0072] Optionally, insulating material is provided between at least two electrodes such as to avoid arcs forming directly between the at least two electrodes. In this way, the direction of the arcs may be better controlled. It can be better guaranteed that the arcs extend at a front portion of the drill head. However, examples without insulating material are also possible.

[0073] According to an aspect, the invention provides for a system for performing pulsed drilling operations, the system comprising: a drill head with an end portion, wherein at least two electrodes are arranged at the end portion; an actuation system configured for moving the drill head adjacent to the surface to be broken up, wherein a gap distance is provided between the drill head and the surface; a voltage generator configured for applying a voltage between the electrodes resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface; and a distancing unit for providing a gap distance between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs.

[0074] It will be appreciated that different gap distances

may be employed. The gap distance may also depend on other parameters, such as but not limited to: the electrical actuation of the electro-pulse drill head, the liquid used during drilling/boring, the properties of the surface to be broken up (e.g. rock, substrate, soil, etc.), etc. In some cases the drilling liquid includes water.

[0075] Water based drilling fluid may for example have a dielectric constant around 80. Such a relatively high dielectric constant results in a high (relative) permittivity, which can be beneficial as the water based drilling fluid between the electrodes and the surface being drilled can act as a capacitor, better enabling the generated arcs or electric pulses to go through the surface such as to break pieces off.

[0076] The values indicative of length of time of the one or more electric arcs or pulse duration may be determined in various ways. In some advantageous embodiments, an optical sensor is employed, providing a reliable and robust way of determining values indicative of said length of time or pulse duration.

[0077] Optionally, the values indicative of the length of time of the one or more electric arcs may be determined electrically. In some examples, an electric sensor is used which is configured to measure at least one of a voltage or current. Since large electric currents, for instance higher than 10000 ampere or even higher than 15000 ampere) may be induced, it may be beneficial to employ a voltage sensor. In this way, a more accurate indication of the values indicative of the length of time of the one or more electric arcs can be obtained. Also, a more cost-effective solution may be provided in this way.

[0078] Although the optical sensor may provide accurate characteristics, such as the pulse duration, of the generated arcs, it is also possible to employ, additionally or alternatively, other sensors, such as for example electrical sensors, vibration sensors, accelerometers, acoustic sensors, electro-mechanical sensors, etc. It will be appreciated that a combination of sensors may also be used. For example, an optical sensor may be combined with a vibrational sensor (e.g. accelerometer) for obtaining a more accurate determination of the pulse duration. This may provide a very robust determination of properties associated to the generated arcs. Additionally or alternatively, an acoustic sensor may be used which can calculate the pulse duration based on sound.

[0079] Optionally, the determined values indicative of the length of time of a generated electric arc (cf. pulse duration) is related to a path followed by the generated electric arc. The controller may be configured to link the pulse duration to the path. In this way, the controller may determine an indication of the followed/travelled path of the generated electric arc. Hence, it can be determined whether the electric arc has gone through the surface to be broken up.

[0080] In some examples, the electrodes are arranged on a periphery (e.g. circle) of the drill head, wherein for example positive and negative electrodes alternate along said periphery, or wherein for example at least one first

electrode is arranged at an outside periphery of the drill head, and at least one second electrode of opposite polarity is arranged at or near a central portion of the drill head. The at least one second electrode may for instance be one electrode arranged centrally, a circular electrode, or a plurality of individual electrodes. Various other configurations are possible.

[0081] According to an aspect, the invention provides for an optical sensor for use in a system for performing pulsed drilling operations, wherein the optical sensor is attachable at a generator and/or a drill head of the system, the optical sensor being configured to measure a value indicative of a length of time of the one or more electric arcs generated by electrodes of the drill head of the system.

[0082] According to an aspect, the invention provides for a computer program product containing a set of instructions stored thereon that, when executed by a control system of the system according to the invention, results in the system performing a method according to the invention.

[0083] Advantageously, it is possible to use less energy and/or lower voltages for performing the electro-pulse boring as a higher efficiency is obtained. The drilling speed can also be improved.

[0084] According to an aspect, the invention provides for a use of the system according to the invention, for performing pulsed drilling operations.

[0085] According to an aspect, the invention provides for a method of drilling by means of a drill head with an end portion, wherein at least two electrodes are arranged at the end face, the method comprising: moving, by means of an actuation system, the drill head adjacent to the surface to be broken up, wherein a gap distance is provided between the drill head and the surface; applying, by means of a voltage generator, a voltage between the electrodes resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface; measuring, by means of a sensor measurement system, at least one value indicative of a property of the generated one or more electric arcs; and controlling, by means of a control system, one or more operational parameters of the actuation system such as to adjust the gap distance between the at least two electrodes of the drill head and the surface based on the at least one value.

[0086] It will be appreciated that the gap distance may be considered as an interspace, a separation, a clearance, a split, a spacing, or a void between the electrodes of the drill head and the surface to be broken up. In use, said gap distance prevents contact between any of the electrodes on the drill head and the surface being drilled. A minimal gap distance may be guaranteed at least during the generated of the electric arcs.

[0087] It will be appreciated that the (substrate) surface may be seen as a material which is to be drilled by means of the drill head. For this purpose the drill head may be directed towards the surface, with the electrodes facing

towards the surface. The electric arcs generated by the electrodes of the drill head can be used for breaking off pieces of the surface, which can be subsequently flushed or guided away. The electro-pulse drilling apparatus can be used for drilling in a borehole, wellbore, etc. The surface may for instance be a rock formation, mineral lumps or the like. However, any other type of material may be used, such as geological materials, geological bodies, ore bodies, stone, minerals, concrete, soil, etc.

[0088] It will be appreciated, that during a drilling process using the electro-pulse drill head, the surface in which the drill head is boring/drilling may be relatively uneven. The surface may have irregularities (cf. non-flat), for instance as a result of earlier boring/drilling in which debris have broken off. Even with an interspace between the at least two electrodes of the drill head and the surface (i.e. without direct contact), the electric arc can travel through and below the surface.

[0089] It will be appreciated that any of the aspects, features and options described in view of the method apply equally to the system and the described device, sensor(s) and the computer program product. It will also be clear that any one or more of the above aspects, features and options can be combined.

BRIEF DESCRIPTION OF THE DRAWING

[0090] The invention will further be elucidated on the basis of exemplary embodiments which are represented in a drawing. The exemplary embodiments are given by way of non-limitative illustration. It is noted that the figures are only schematic representations of embodiments of the invention that are given by way of non-limiting example.

[0091] In the drawing:

Fig. 1 shows a schematic diagram of an embodiment of an electro-pulse drilling system;

Fig. 2a, 2b show a schematic diagram of an embodiment of a drill head;

Fig. 3 shows a schematic diagram of an embodiment of a drill head;

Fig. 4 shows a schematic diagram of an embodiment of a discharge tube;

Fig. 5 shows a schematic diagram of an embodiment of a discharge tube;

Fig. 6 shows a schematic diagram of an embodiment of a drill head;

Fig. 7 shows a schematic diagram of an embodiment of an optical sensor at the drill head;

Fig. 8a, 8b show a schematic diagram of an embodiment of drill head; and

Fig. 9 shows a schematic diagram of a method.

DETAILED DESCRIPTION

[0092] Fig. 1 shows a schematic diagram of an embodiment of an electro-pulse drilling system 1. The drilling

system 1 comprises a controller 10 configured for operating the electro-pulse drilling system. The system 1 comprises a drill head 3 with an end portion 5, wherein at least two electrodes 7 are arranged at the end portion 5 of the drill head 3. The system 1 further includes an actuation system 9 configured for moving the drill head adjacent to the surface 11 to be broken up. The system 1 also includes a voltage generator configured for applying a voltage between the electrodes 7 resulting in one or more electric discharges between the electrodes 7, the one or more discharges resulting in one or more electric arcs 13 for breaking up the surface 11. A distancing unit is provided for providing a gap distance D between the at least two electrodes 7 of the drill head 3 and the surface 11 during generation of the one or more electric arcs 13. In some examples, the controller acts as the distancing unit, maintaining the gap distance D by means of controlling the actuation system 9. Additionally or alternatively, a member such as a spacer is provided for maintaining a (minimum) gap distance G between the electrodes 7 of the drill head 3 and the surface 11. Advantageously, the formation of relatively larger debris can be better guaranteed, resulting in a more efficient electro-pulse drilling.

[0093] In the shown example, the drill head 3 is positioned in a drill hole 2. In some cases the voltage generated (not shown in this figure) is separated from the drill head 3. However, it is also envisaged that the voltage generated is attached to or integrated in the drill head. In some examples, the drill head 3 and the voltage generator form a unitary device, directly coupled to each other. In some examples, the drill head 3 and the voltage generator are separated and can be positioned remotely with respect to each other, for instance coupled by means of wiring. In some examples, the drill head 3 and the voltage generator are separated such as to allow movement with respect to each other. Many types of arrangements are possible.

[0094] It will be appreciated that the front end of the drill head 3 is not necessarily a flat face containing electrodes 7 extending therefrom. The front end may only include protruding electrodes (e.g. rods with electrode end portions). Between the protruding electrodes 7, sufficient spacing may be provided to as to allow debris to be evacuated by means of flushing. Additionally, a gap distance G is provided between the electrodes 7 and the surface 11 being drilled, such that a significantly improved electro-pulse drilling can be achieved.

[0095] In some examples, sensors (not shown) are arranged at at least one of: at least one of the at least two electrodes or the voltage generator, for determining a value indicative of the pulse duration.

[0096] Fig. 2a, 2b show a schematic diagram of an embodiment of a drill head 3. A gap distance G is provided between the electrodes of the drill head 3 and the surface 11 during generation of the one or more electric arcs. A mechanical spacing unit 15 is provided for mechanically distancing the electrodes of the drill head and the surface

to be broken up. In these examples, the spacing units 15 are protruding from an end face of the drill head 3. However, various other mechanical arrangements are possible for keeping the electrodes of the drill head distanced with respect to the surface 11. In the example shown in fig. 2A, the spacing unit 15 comprises one finger 17a, which is arranged centrally on the drill head 3, for providing a minimum distance M between the electrodes of the drill head 3 and the surface 11 when the drill head 3 approaches said surface 11. In the example shown in fig. 2B, the spacing unit 15 comprises two fingers 17a, 17b extending from the drill head towards the surface 11. When the drill head approaches the surface 11, at a certain point, a minimum distance may be provided by means of the two fingers 17a, 17b. Advantageously, the fingers 17a, 17b may better guarantee a minimum distance M.

[0097] Optionally, the gap distance G is maintained within a predetermined range. Optionally, the minimal gap distance is at least 1 millimeter. Larger minimal gap distances are also possible, such as at least 2 millimeter and/or at least 3 millimeters may also be employed.

[0098] The gap distance G may provide for an advantageous space or opening between the at least two electrodes 7 of the drill head 3 and the surface 11 to broken up. In use, the at least two electrodes 7 may be positioned such as to face the surface 11, and a minimum distance is provided such as to prevent direct contact between the surface 11 (e.g. rock in the bore hole) and any of the at least two electrodes 7. With other words, all electrodes 7 arranged on the drill head 3 may be spaced apart from the surface 11 during generation of the electric arcs. In this way, the arcs can be better guaranteed to travel into the surface, such as to have improved fragmentation of the surface material during drilling. It can be prevented that any one of the electrodes at which the arc is generated contacts the surface. In case of an uneven surface to be broken up, for instance obtained as a result of drilling, the gap distance G can be understood as the smallest distance between any one of the electrodes of the drill head and the surface. With other words, the gap distance G may be seen as the distance between the part of the surface being closest to any one of the at least two electrodes and said any one of the at least two electrodes. In some examples, the gap distance G is measured in a longitudinal direction L of the drill head 3.

[0099] In some examples, the drill head 3 is lowered in the drill/bore hole during the drilling/boring process. The drill head 3 may be actuated by means of an actuation unit for inducing movement of the drill head 3. In some examples, the drill head 3 can descend aided by its own weight. The speed in which the drill head is drilling/boring (cf. speed of lowering) can be determined by means of cables and/or flushing pipes. In some examples, the speed is adjusted for keeping the gap distance G between the electrodes 7 of the drill head 3 and the surface 11 within a desired predetermined range.

[0100] By employing the spacing unit 15, a self-regu-

lating system may be achieved, wherein initially a minimum distance is maintained, for example falling within a predetermined range. For example, the gap distance between the electrodes of the electro-pulse drill head and the surface may be kept at a minimum distance of 1 millimeter, avoiding any contact between the electrodes and the surface. During drilling, the distance may be increased, since some pieces of the surface are broken off and debris are flushed away. However, if the distance is too large, the electric pulses or sparks will not go through the surface. Therefore, the system may automatically lower the drill head, for example at a constant pace or periodically (intermittently), whilst maintaining a predetermined minimum distance. In this way, the distance will automatically decrease over time, resulting in continued drilling/boring as the distance will fall within the range in which the electric pulse or electrical arcs travel through the surface. The minimum distance may for instance be achieved by a mechanical spacing unit, providing the ability for a simple control system. However, additionally or alternatively, it is also envisaged to provide for a control system for maintaining at least the minimum distance. Such control system may also be configured to keep the distance/separation between the electrodes of the drill head and the surface within a predetermined range. In some cases, the predetermined range may be adjusted, for instance taking into account properties of the drilling fluid, the surface, the pulse actuation, etc.

[0101] Fig. 3 shows a schematic diagram of an embodiment of a drill head 3. A perspective view is shown. The drill head 3 may have a first set of electrodes 7a and a second set of electrodes 7b, the first set of electrodes 7a used with a first polarity (e.g. positive), and the second set of electrodes 7b used with a second polarity (e.g. negative), i.e. opposite polarity. In this example, the drill head has ten electrodes 7a, 7b arranged at the end portion 5. Each polarity (positive, negative) has five electrodes. It will be appreciated that other configurations, numbers, dimensions, shapes, arrangements, etc. are also possible. The electrodes may have various shapes, dimensions and arrangements on the drill head 3. In this exemplary embodiment, the first set of electrodes 7a has electrodes which are smaller than the electrodes in the second set of electrodes 7b.

[0102] In some examples, at least a subset of electrodes is arranged along a periphery of the drill head. In some examples, at least one electrode has a ring shape. For example, a first ring may form one or more positive electrodes and a second ring may form one or more negative electrodes, wherein the first ring is inside the second ring, or vice versa. The electrodes 7a, 7b may have various forms and shapes and many alternative arrangements are envisaged. The drill head 3 may have various dimensions.

[0103] Contact between any electrode of the at least two electrodes 7 of the drill head 3 and the surface 11 which is to be drilled may be prevented at least during generation of the one or more electric arcs. A gap dis-

tance may be provided such as to have no contact. Contact, and thus no gap distance (i.e. a gap distance equal to zero), may have a significant detrimental effect on the efficiency of the electro-pulse boring/drilling.

[0104] Fig. 4 shows a schematic diagram of an embodiment of a discharge tube 20 of a voltage generator. Within the discharge tube a first spark 21 and a second spark 23 are arranged. The sparks 21, 23 may be arranged in a tube 22. In this example, an optical sensor 25 is arranged at the discharge tube 20 of the voltage generator. The sensory data retrieved by the optical sensor provides an indication of the property of the generated arc between the at least two electrodes 7 of the drill head 3. Based on the sensory data, for instance the pulse duration (i.e. length of time), or a value indicative thereof, can be determined. The controller 10 can determine whether the one or more electric arcs have travelled into the surface to be broken up, based on the value indicative of the length of time. For example, the controller 10 can be configured to calculate whether the length of time of the one or more electric arcs is smaller than a threshold value, wherein one or more operational parameters of the actuation system 9 are adjusted for changing the gap distance G between the drill head and the surface when the length of time of said one or more electric arcs is larger than the threshold value.

[0105] The use of optical sensor 25 clearly has an advantage over other sensors, which would require much more effort and extra measures to make it function properly in the aggressive electromagnetic interference environment during generation of the one or more electric arcs, for example by extensive shielding against electromagnetic interference.

[0106] At the drill head 3, debris (e.g. rock fragments resulting from the drilling process) may influence the optical sensing. The drill head 3 may be completely submerged in a drilling fluid (e.g. liquid such as water), which can make optical detection more difficult. Additionally, as a result of the relatively rough conditions, the optical sensor may be more prone to damage. Hence, arranging the optical sensor at the voltage generator may provide important benefits. Optionally, optical sensors are arranged at the drill head and the voltage generator. By performing optical measurements at the generator and the drill head it is also possible to make the results even more accurate.

[0107] Fig. 5 shows a schematic diagram of an embodiment of a discharge tube 20, similar to the example shown in fig. 4. The discharge tube 20 may be transparent, allowing the optical sensor 25 to be arranged outside of the discharge tube 20. In this way, a very robust and reliable sensory arrangement can be obtained.

[0108] Fig. 6 shows a schematic diagram of an embodiment of a drill head 3 comprising an optical sensor 25. The optical sensor 25 is integrated in the drill head 3. Such an integrated design can increase the reliability and robustness. The optical sensor 25 is arranged at the end portion 5 of the drill head 3 facing the surface 11. The optical sensor 25 is employed for directly sensing

light induced by the one or more arcs generated between the electrodes 7 during the electro-pulse drilling. Based on the sensed light, an indication of the pulse duration can for example be determined or calculated.

[0109] Optionally, a permittivity of the drilling fluid F is larger than a permittivity of the surface 11 (e.g. rock or mineral). In this way, it can be avoided that the electric arc travels only through the drilling fluid (not going through the surface). Optionally, the drilling fluid F is chosen such that its permittivity is at least 5 times larger than that of the material of the surface, preferably at least 10 times larger, even more preferably at least 20 times larger. A water based liquid F, can be a polarized liquid, resulting in higher permittivity.

[0110] Fig. 7 shows a schematic diagram of an embodiment of an optical sensor 25 integrated in the drill head 3. The optical sensor 25 has a housing 26 and is arranged adjacent the electrodes 7 with its sensory portion 28 facing a region where arcs are generated between electrodes. Although one optical sensor 25 is shown, a plurality of optical sensors 25 may be used in some examples. In this way, for example, the pulse duration can be more accurately determined, whilst providing a more reliable configuration.

[0111] The invention enables improved control during electro-pulse drilling. When the gap distance between the electrodes and the surface to be broken up is within the predetermined range, the surface may be more efficiently broken up in pieces. Larger debris may be obtained, which can thereby result in higher boring/drilling speeds achievable by means of the drill head. If the distance is too small, for instance smaller than 500 micrometer, for instance due to contact between at least one electrode of the at least two electrodes of the drill head and the surface, then the surface may break too slowly as a result of the generated electric pulses/sparks. Advantageously, the system may be configured to provide a gap distance/interspace between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs.

[0112] Fig. 8a, 8b show a schematic diagram of an embodiment of drill head 3. In fig. 8a, a voltage generator 30 is integrated within the drill head 3. In fig. 8B, the voltage generator 30 is distanced from the drill head. The distance between the voltage generator 30 and the drill head 3 may be variable in this example, for example the distance may be increased when the drill head 3 is lowered further in the bore hole. The voltage generator 30 and the drill head 3 may be coupled by means of a coupling member 40.

[0113] In some examples, an optical sensor is employed at the voltage generator 30 and/or at the drill head 3. Advantageously, the operation of the optical sensor is not sensitive to electromagnetic interference resulting from the operation of the electro-pulse system. This may be an important advantage with respect to other types of sensors, such as for example electronic sensors.

[0114] Fig. 9 shows a schematic diagram of a method

100 of drilling by means of a drill head with an end portion, wherein at least two electrodes are arranged at the end portion. In a first step 101, the drill head is moved adjacent to a surface to be broken up by means of an actuation system. In a second step 102, a gap distance is provided between the at least two electrodes of the drill head and the surface. In a third step 103, a voltage is applied between the electrodes, by means of a voltage generator, resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface, wherein the gap distance is maintained at least during generation of the one or more electric arcs. The gap distance may be actively, e.g. by controlling the actuation, or passively, e.g. by providing one or more mechanical spacing units, maintained

[0115] It will be appreciated that electro-pulse drilling may also be understood as electrical-pulse drilling, electrical arc drilling, electro-crushing drilling, pulsed arc plasma drilling, pulsating arc drilling, plasma arc drilling, plasma pulse drilling, plasma pulse geo-drilling, etc. The term "drilling" along with its derivatives, may be replaced with "boring" and vice versa. The term can be interpreted as an action of making a hole, cutting or making an indentation or the like, in some surface or material. The term drilling or boring may imply that pieces of the surface or material are broken up and are removed from the drilling zone during the drilling process.

[0116] It will be appreciated that the method may include computer implemented steps. All above mentioned steps can be computer implemented steps. Embodiments may comprise computer apparatus, wherein processes performed in computer apparatus. The invention also extends to computer programs, particularly computer programs on or in a carrier, adapted for putting the invention into practice. The program may be in the form of source or object code or in any other form suitable for use in the implementation of the processes according to the invention. The carrier may be any entity or device capable of carrying the program. For example, the carrier may comprise a storage medium, such as a ROM, for example a semiconductor ROM or hard disk. Further, the carrier may be a transmissible carrier such as an electrical or optical signal which may be conveyed via electrical or optical cable or by radio or other means, e.g. via the internet or cloud.

[0117] Some embodiments may be implemented, for example, using a machine or tangible computer-readable medium or article which may store an instruction or a set of instructions that, if executed by a machine, may cause the machine to perform a method and/or operations in accordance with the embodiments.

[0118] Various embodiments may be implemented using hardware elements, software elements, or a combination of both. Examples of hardware elements may include processors, microprocessors, circuits, application specific integrated circuits (ASIC), programmable logic devices (PLD), digital signal processors (DSP), field pro-

grammable gate array (FPGA), logic gates, registers, semiconductor device, microchips, chip sets, et cetera. Examples of software may include software components, programs, applications, computer programs, application programs, system programs, machine programs, operating system software, mobile apps, middleware, firmware, software modules, routines, subroutines, functions, computer implemented methods, procedures, software interfaces, application program interfaces (API), methods, instruction sets, computing code, computer code, et cetera.

[0119] Herein, the invention is described with reference to specific examples of embodiments of the invention. It will, however, be evident that various modifications, variations, alternatives and changes may be made therein, without departing from the essence of the invention. For the purpose of clarity and a concise description features are described herein as part of the same or separate embodiments, however, alternative embodiments having combinations of all or some of the features described in these separate embodiments are also envisaged and understood to fall within the framework of the invention as outlined by the claims. The specifications, figures and examples are, accordingly, to be regarded in an illustrative sense rather than in a restrictive sense. The invention is intended to embrace all alternatives, modifications and variations which fall within the scope of the appended claims. Further, many of the elements that are described are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location.

[0120] In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word 'comprising' does not exclude the presence of other features or steps than those listed in a claim. Furthermore, the words 'a' and 'an' shall not be construed as limited to 'only one', but instead are used to mean 'at least one', and do not exclude a plurality. The mere fact that certain measures are recited in mutually different claims does not indicate that a combination of these measures cannot be used to an advantage.

Claims

1. A method of drilling by means of a drill head with an end portion, wherein at least two electrodes are arranged at the end portion, the method comprising:

moving, by means of an actuation system, the drill head adjacent to a surface to be broken up, applying, by means of a voltage generator, a voltage between the electrodes resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface, and

wherein a gap distance is provided between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs.

2. The method according to claim 1, wherein the method comprises:

measuring, by means of a sensor measurement system, at least one value indicative of a property of the generated one or more electric arcs, and
controlling, by means of a control system, one or more operational parameters of the actuation system such as to adjust the gap distance between the drill head and the surface based on the at least one value.

3. The method according to claim 1 or 2, wherein the sensor measurement system comprises an optical sensor configured to measure a value indicative of a length of time of the one or more electric arcs.

4. The method according to claim 3, wherein the optical sensor is arranged at the voltage generator.

5. The method according to claim 3 or 4, wherein the optical sensor is arranged at the drill head.

6. The method according to claim 3, 4 or 5, wherein the value indicative of the length of time of the one or more electric arcs is associated to the traveled path of said one or more electric arcs.

7. The method according to any one of the preceding claims 3-6, wherein the control system is configured to determine based on the value indicative of the length of time whether the one or more electric arcs have travelled into the surface to be broken up.

8. The method according to any one of the preceding claims 3-7, wherein the control system is configured to determine whether the length of time of the one or more electric arcs is smaller than a threshold value, wherein one or more operational parameters of the actuation system are adjusted for changing the gap distance between the drill head and the surface when the length of time of said one or more electric arcs is larger than the threshold value.

9. The method according to any one of the preceding claims, wherein a drilling fluid is used during pulsed drilling operation, wherein the drilling fluid has a dielectric constant which is higher than a dielectric constant of the surface to be broken up.

10. The method according to claim 9, wherein the dielectric constant of the drilling fluid is at least 5 times

larger than the dielectric constant of the surface to be broken up, more preferably at least 10 times larger, even more preferably at least 20 times larger.

11. The method according to claim 9 or 10, wherein the drilling fluid is water based. 5

12. The method according to any one of the preceding claims, wherein the gap distance is kept between 1 to 30 millimeter, more preferably between 2 to 10 millimeter, even more preferably between 2 to 5 millimeter. 10

13. The method according to any one of the preceding claims, wherein a spacing unit is provided for mechanically distancing the at least two electrodes of the drill head and the surface to be broken up. 15

14. The method according to claim 13, wherein the spacing unit is configured to keep a minimum distance between the drill head and the surface to be broken up. 20

15. A system for performing pulsed drilling operations, the system comprising: 25
 - a drill head with an end portion, wherein at least two electrodes are arranged at the end portion; an actuation system configured for moving the drill head adjacent to the surface to be broken up; 30
 - a voltage generator configured for applying a voltage between the electrodes resulting in one or more electric discharges between the electrodes, the one or more discharges resulting in one or more electric arcs for breaking up the surface; and 35
 - a distancing unit for providing a gap distance between the at least two electrodes of the drill head and the surface during generation of the one or more electric arcs. 40

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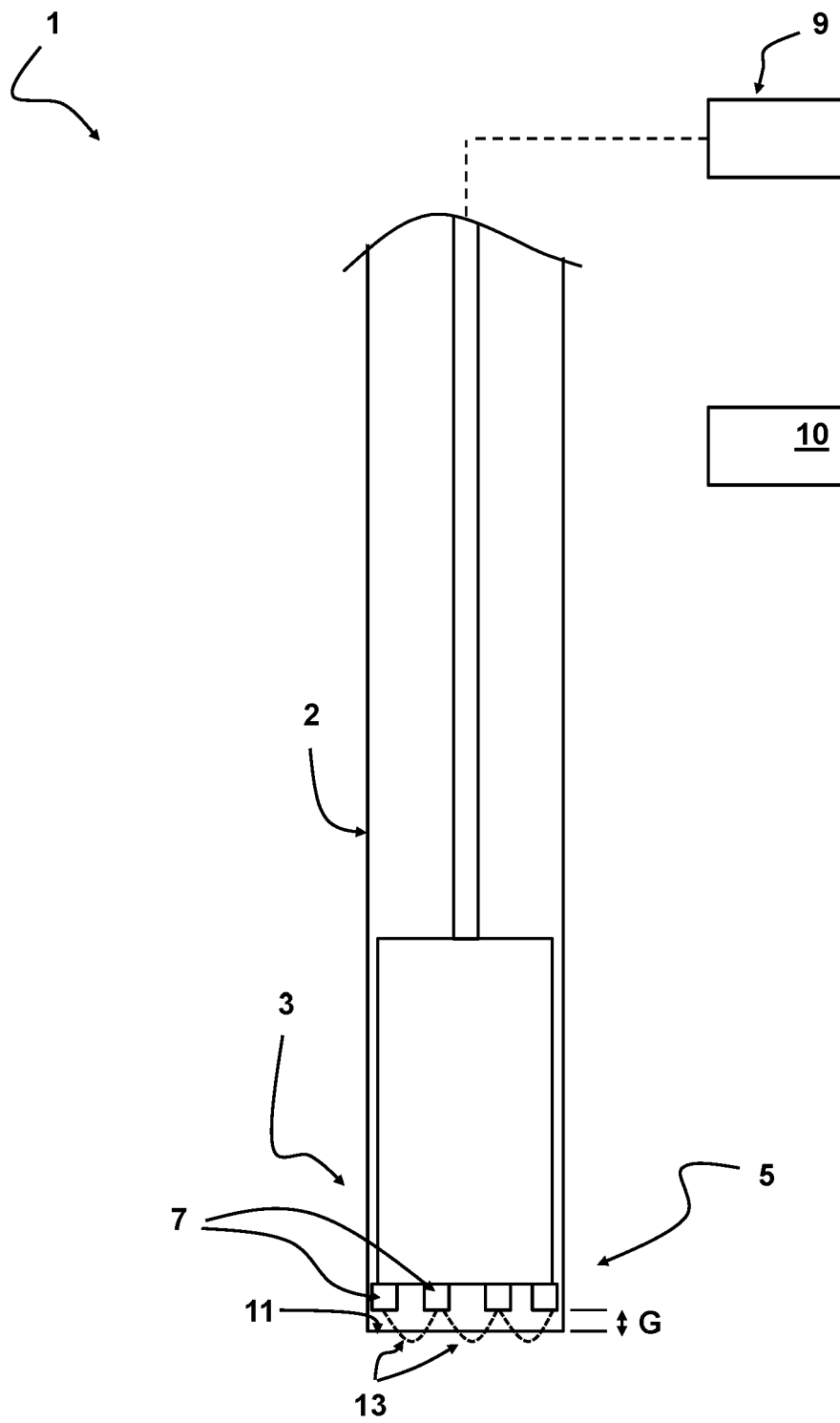


FIG 1

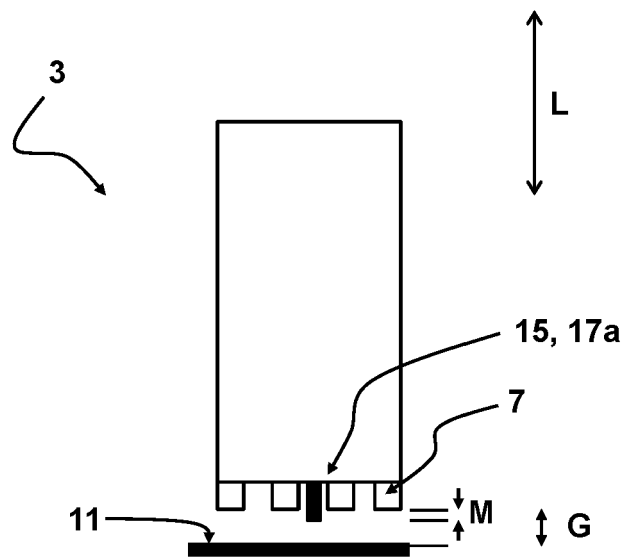


FIG 2A

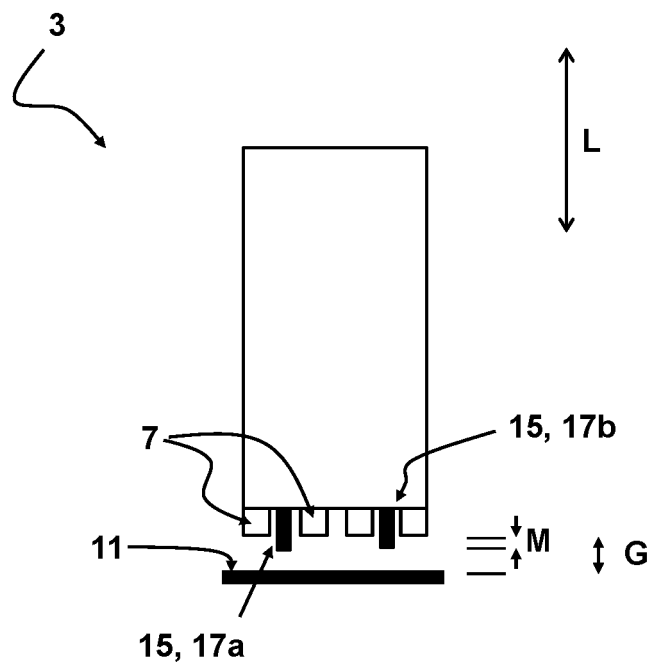


FIG 2B

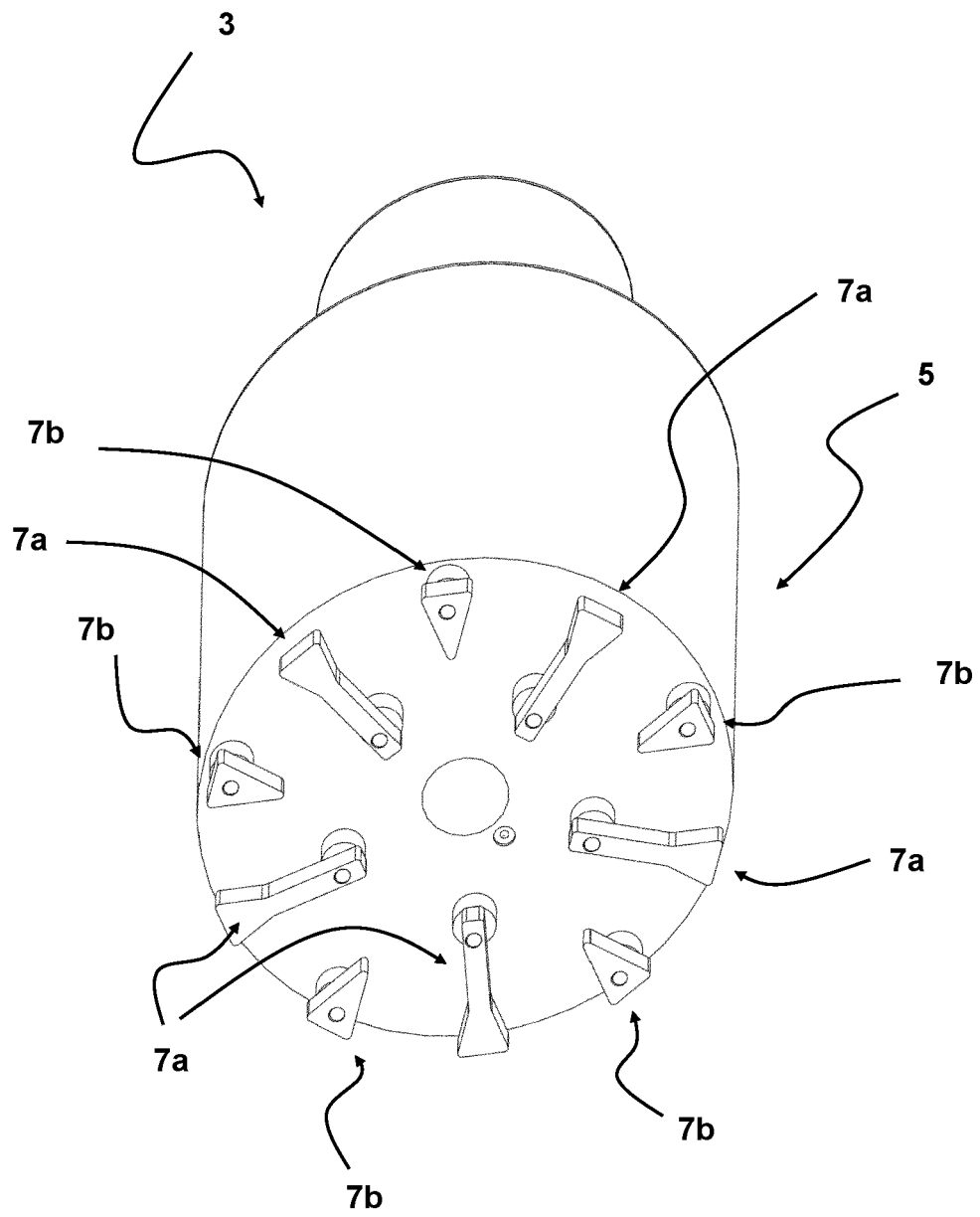


FIG 3

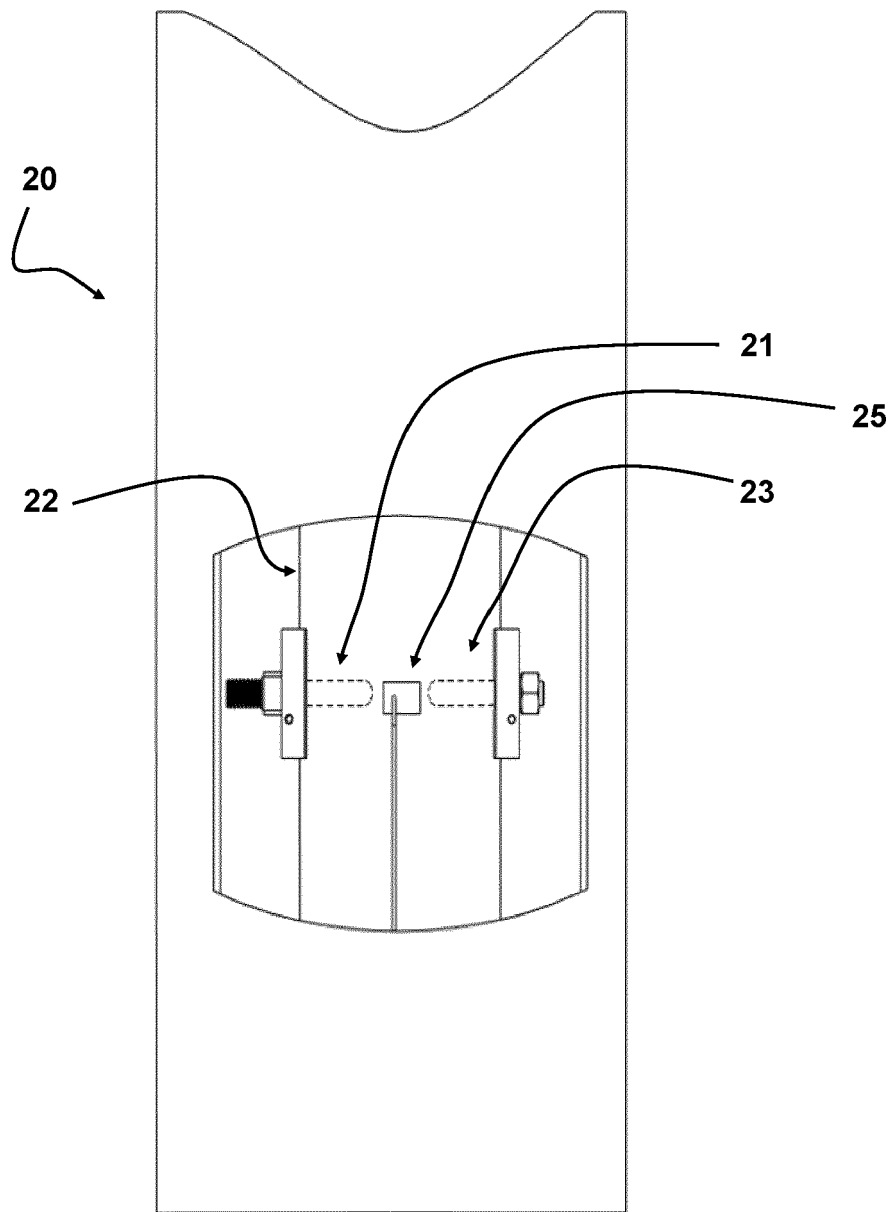


FIG 4

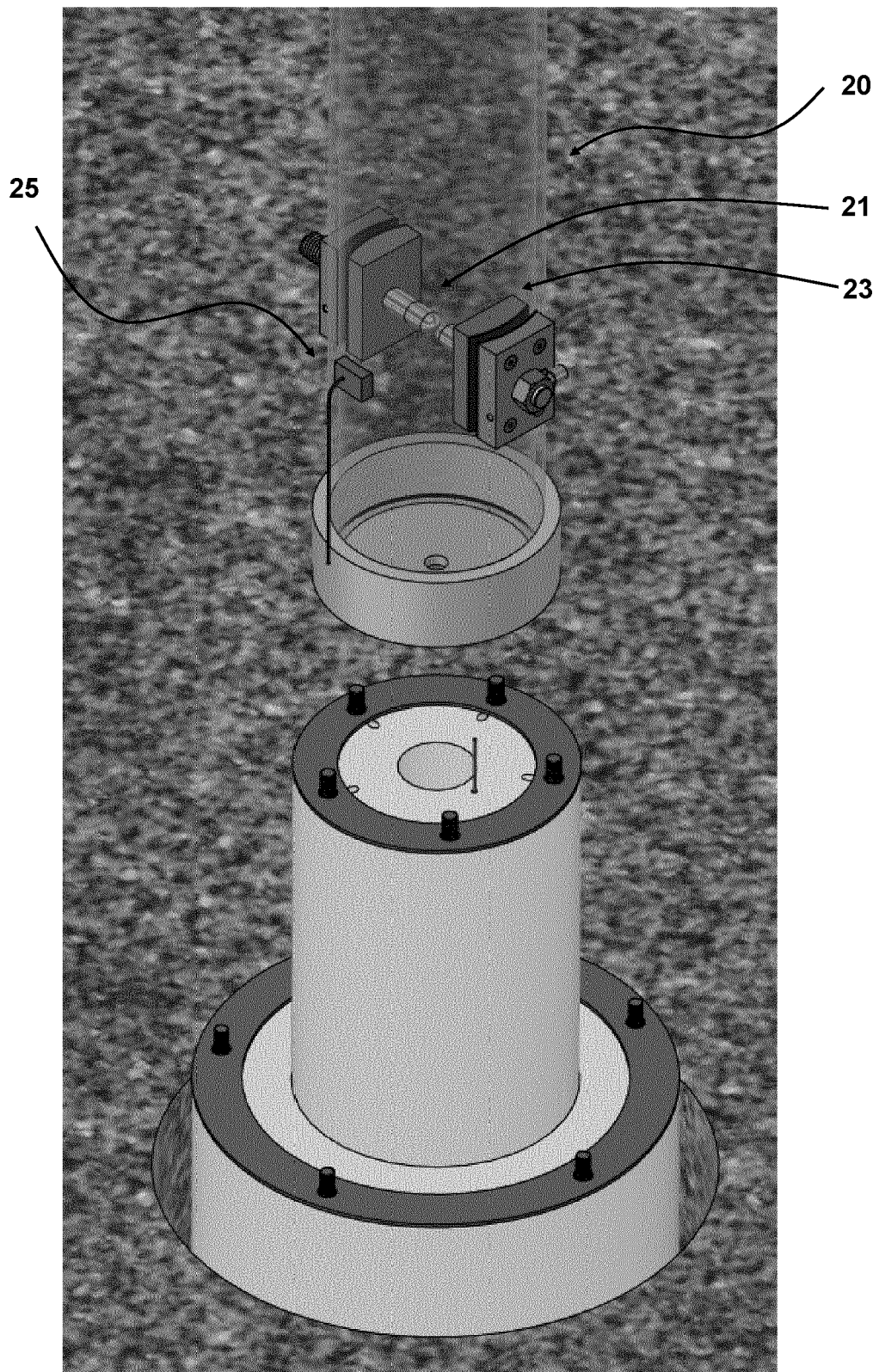


FIG 5

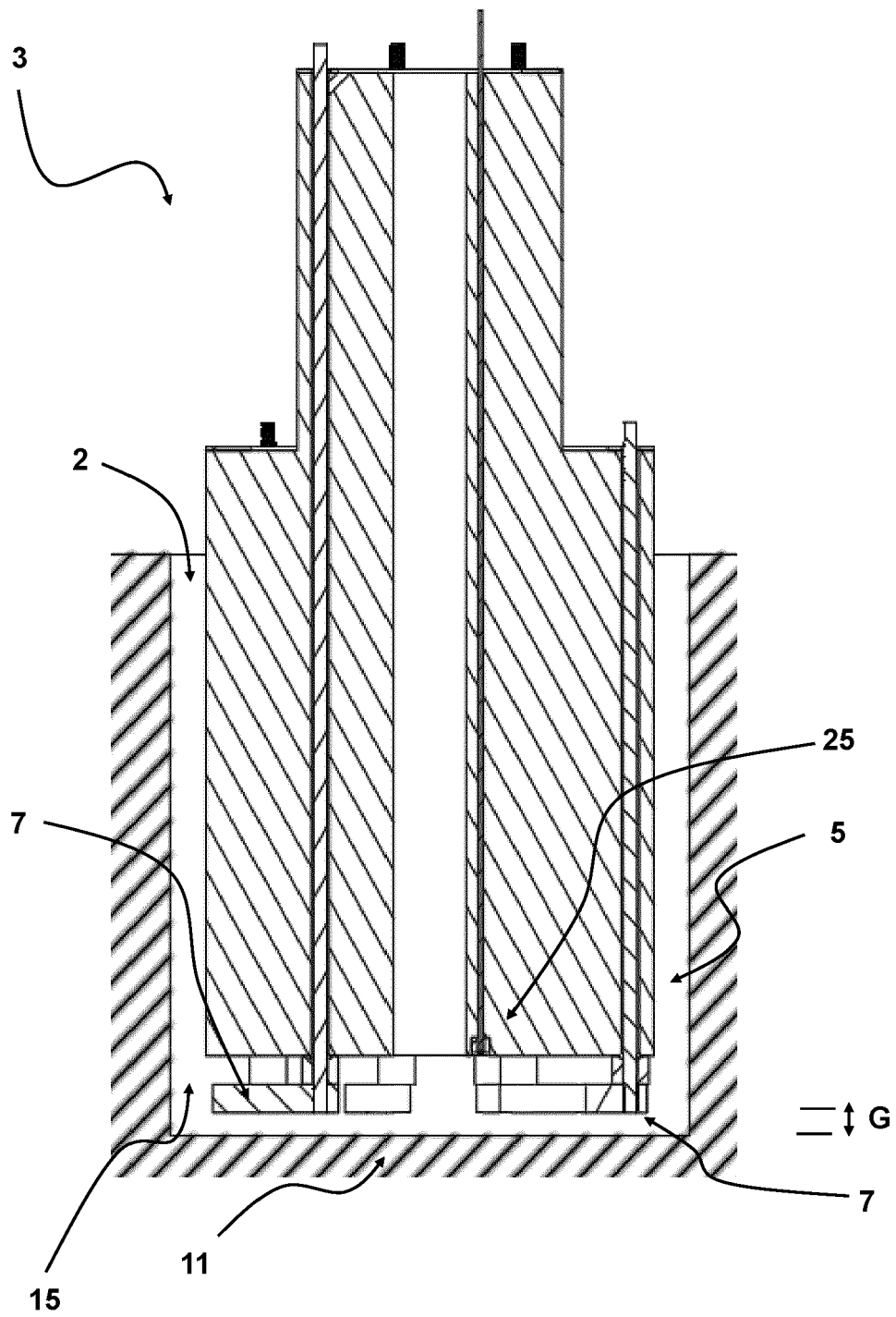


FIG 6

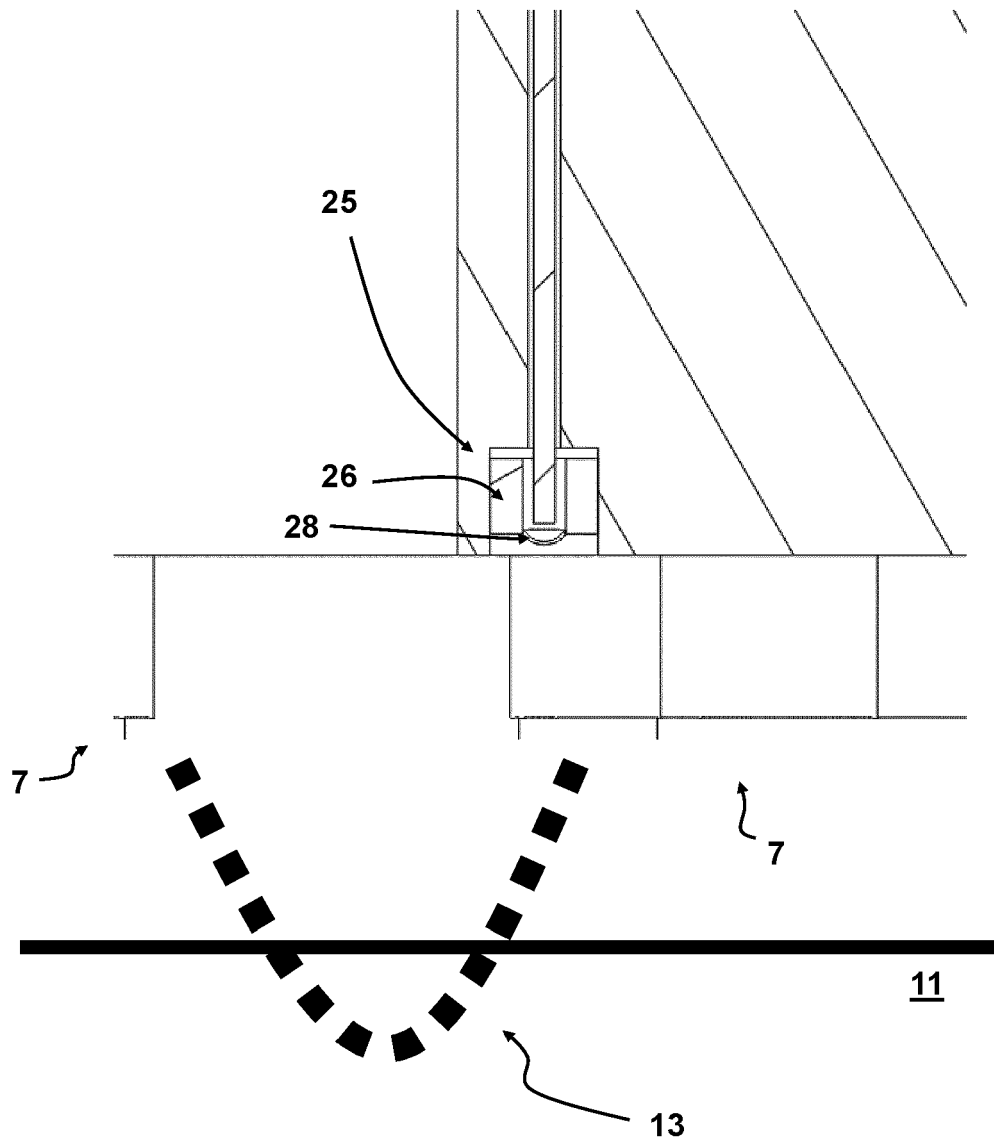


FIG 7

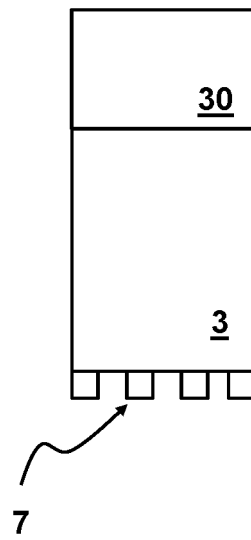


FIG 8A

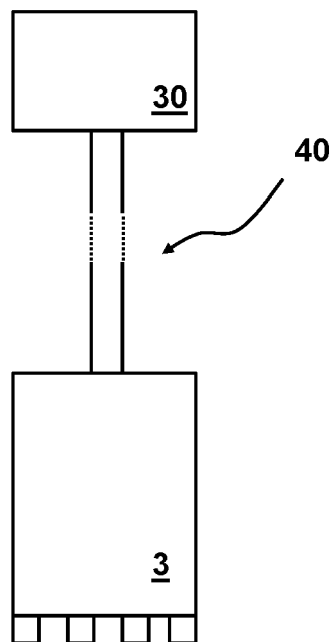


FIG 8B

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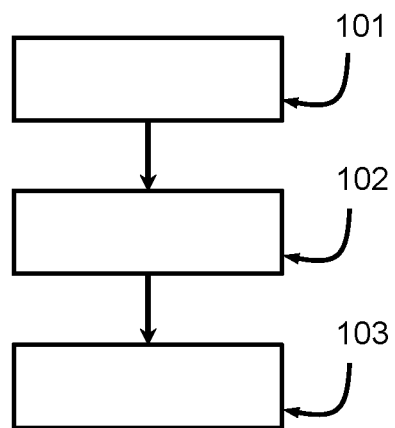


FIG 9



EUROPEAN SEARCH REPORT

Application Number

EP 21 19 9973

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2014/098776 A2 (GA DRILLING AS [SK]) 26 June 2014 (2014-06-26) * paragraphs [0015], [0063], [0064], [0070], [0076], [0077]; figure 1 * -----	1, 2	INV. E21B7/00 E21B7/15 B02C19/18 E21C37/18
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X	US 2019/177944 A1 (MAGNOTTI FRANK A [US] ET AL) 13 June 2019 (2019-06-13) * paragraphs [0028], [0029], [0042]; figures 2A, 6 * -----	1, 13-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			E21B B04C B02C E21C
The present search report has been drawn up for all claims			

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EPO FORM 1503 03.82 (P04C01)

Place of search	Date of completion of the search	Examiner
Munich	11 May 2022	Georgescu, Mihnea
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document		



Application Number

EP 21 19 9973

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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☒ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

1-8, 12-15

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

**LACK OF UNITY OF INVENTION
SHEET B**

Application Number

EP 21 19 9973

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-8, 12

A method of drilling (as in claim 1, with following features of claim 3) wherein the sensor measurement system comprises an optical sensor configured to measure a value indicative of a length of time of the one or more electric arcs.

2. claims: 9-11

A method of drilling (as in claim 1, with following features of claim 9), wherein a drilling fluid is used during pulsed drilling operation, wherein the drilling fluid has a dielectric constant which is higher than a dielectric constant of the surface to be broken up.

3. claims: 13-15

A method of drilling (as in claim 1, with following features of claim 13), wherein a spacing unit is provided for mechanically distancing the at least two electrodes of the drill head and the surface to be broken up.

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 21 19 9973

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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