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(54) **DETERMINING THE EFFICIENCY OF A DRILLING PROCESS PERFORMED BY THE USE OF A MARX GENERATOR**

(57) According to an embodiment a method is disclosed for determining an efficiency of a drilling process performed by an electro pulse drill driven by a Marx generator (100) provided to produce an electric discharge current (200, 300) penetrating a medium, the current (200, 300) flowing between a drill tips and the electric discharge current (200, 300) originating from a high-voltage pulse generated by the Marx generator (100) comprising a set of spark gaps (110-113) between

capacitors (130-133), the method comprising the steps of capturing radiation at a Marx generator spark gap (110) being produced when the generator (100) discharges; filtering the captured radiation at a predefined wavelength; and measuring a duration of a time period during which the filtered radiation is above a predefined threshold when the electric discharge current flows between the drill tips; determining the efficiency of the drilling process based on the measured duration (201, 301).

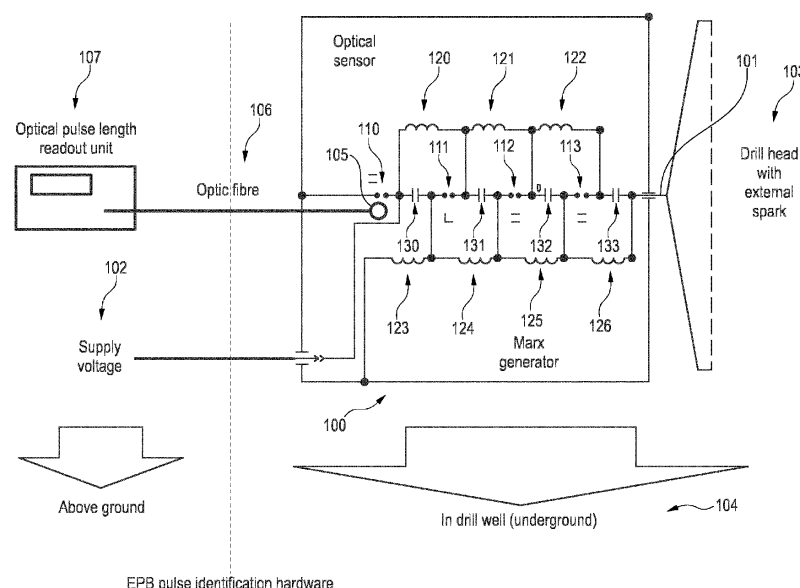


Fig. 1

Description

Field of the Invention

[0001] The present invention relates to a drilling process by use of a high voltage Marx generator. More in particular, the invention relates to a method for determining the efficiency of said drilling process.

[0002] It further relates to a data processing apparatus configured for performing said method. Additionally, the invention relates to a drilling apparatus comprising said data processing apparatus or configured to exchange and interact with said data processing apparatus.

Background

[0003] A Marx generator is an electrical circuit configured to generate a high-voltage pulse from a low-voltage DC supply. The high-voltage pulse is generated by the circuit by charging a number of capacitors in parallel, and subsequently connecting them in series. This connection into series is performed by spark gaps, which are used as switches. At first, a number of capacitors are charged in parallel to a voltage V_c by a DC power supply through resistors or coils. The spark gaps used as switches have the voltage V_c across them, but the gaps have a breakdown voltage greater than V_c . Hence, they all behave as open circuits while the capacitors charge. To create the high-voltage pulse, the first spark gap is caused to break down, thereby placing the first two capacitors in series and thus applying a voltage of $2V_c$ across the second spark gap. Consequently, the second gap breaks down to add the third capacitor to the stack. Each stage adds its voltage to the previous stage's voltage, resulting in a cumulative multiplication of the voltage. This makes the Marx generator capable of producing extremely high voltages. Due to their ability to generate extremely high voltages and deliver powerful electrical discharges, Marx generators are intricate and complex devices that require careful design, engineering, and safety considerations to operate effectively and safely.

[0004] WO2023/073114A1 discloses a high-voltage pulse generator of the Marx type and a method of operating such a high-voltage pulse generator. Such high-voltage generators have numerous possible applications, such as for instance electro-pulse drilling.

[0005] Electro-pulse drilling is a drilling method in which a medium, such as rock or concrete, is broken by a powerful high-voltage electric discharge current generated by a Marx generator. The current travels from one electrode to the other electrode through the medium. The electrodes are arranged in such a way that at least one of them is in contact with the medium. This way the discharge current may travel through the medium.

[0006] In WO2023/052412A1 a method and system for electro-pulse drilling is disclosed.

[0007] A disadvantage of the method disclosed in WO2023/052412A1 is that the current delivered at the

drill head may also travel through a surrounding medium, like for example air, water, and/or a flushing fluid. When this happens the part of the discharge current passing through the surrounding medium is not productive for the drilling process. This may give rise to a decreasing rate of penetration and/or the drilling process may even come to a standstill while consuming time and energy.

[0008] In a practical drilling operation, the drill head with electrodes is located within a bore hole when performing the electro-pulse drilling process, and the electrodes are not visible and not accessible for a drill head operator. Therefore, one needs to be able to determine the rate of penetration (ROP) from outside of the borehole. However, the ROP is in the order of magnitude of only a few meters per hour and the ROP is not constant but usually shows some variations over short time periods. Additionally, the movement of the drill head through the medium is not a straight constant movement, but may involve wagging, rocking or oscillating. As a result, in order to determine a usable, meaningful ROP, long measurement periods may be required, for example 10 minutes or more which is impractical in practice. Besides this the rocking of the drill head distance impedes an accurate measurement of the distance over which the drill head has progressed. As a result the measurement of the ROP when carried from outside the borehole is inaccurate and lengthy.

[0009] In US2016377389A1 a system and method are disclosed for providing a mobile means to produce a high voltage electric discharge capable of disabling or destroying electric devices, detecting conductors and/or initiating detonation of an explosive device. The Marx generator disclosed therein includes a luminance meter configured to monitor the relative luminance of one or more spark gaps for determining the efficiency of the drilling process. Since the drilling process is performed in a hostile, heavily polluted environment, the Marx generator becomes contaminated in the course of time. This is a disadvantage because it makes monitoring the relative luminance more complex.

[0010] There is thus a need for a method which is suitable for determining an efficiency of a drilling process performed by an electro pulse drill comprising a drill head driven by a Marx generator, in a polluted environment.

[0011] It is therefore an object of the present invention to alleviate the above and other disadvantages and to provide a method for determining an efficiency of a drilling process performed by an electro pulse drill comprising a drill head driven by a Marx generator.

Summary of the Invention

[0012] This object is achieved, in a first aspect, by the method according to the first claim for determining an efficiency of a drilling process performed by an electro pulse drill comprising a drill head driven by a Marx generator, wherein the drill head is provided to produce an electric discharge current penetrating a medium to be

drilled, the electric discharge current flowing between a first and second drill tip of a pair of drill tips and the electric discharge current originating from a high-voltage pulse generated by the Marx generator comprising a set of spark gaps between capacitors, the method comprising the steps of:

- capturing radiation at a Marx generator spark gap, the radiation being produced when the Marx generator discharges;
- filtering the captured radiation at a predefined wavelength; and
- measuring a duration of a time period during which the filtered radiation is above a predefined threshold when the electric discharge current flows between the drill tips;
- determining the efficiency of the drilling process based on the measured duration.

[0013] According to the present invention, the term *efficiency* is a concept that can not only be measured but can also be quantitatively determined by a ratio of useful output over total input or total useful input. It is a measurable parameter which permits minimising the risk to wasting materials, energy, efforts, money, and time while, in this case, performing or carrying out a drilling process. With the method of this invention the efficiency of the drilling process, in particular the ratio, can also be determined indirectly, meaning that the output as well as the input don't need to be quantified, and thus that the efficiency itself is also determined indirectly.

[0014] An object of the invention is to quantify the extent or amount to which the electric discharge current produced by the Marx generator is capable of penetrating the targeted medium. Another object of the invention is to provide real-time feedback on the efficiency or performance of the drill head. In the context of the invention the term *performance* refers to the efficiency, and thus to the amount of electric discharge current that is capable of penetrating the medium to be drilled, versus the amount of electric discharge current that travels through a medium surrounding the targeted medium to be drilled. The surrounding medium may for example be air, water, or a flushing medium, whereas the targeted medium may for example be a rock, underground soil, etc.

[0015] It is a further object of the invention, although the efficiency is measurable and therefore able to be expressed in a number, an amount, and/or a value, to provide an indication of the effectiveness of a drilling process, for example whether a drilling process is either running efficient or not without explicitly expressing this in a number, an amount, and/or a value, as will be further discussed below.

[0016] The drilling process is performed by an electro pulse drill comprising a drill head driven by a Marx generator. An electric discharge current that originates from a high-voltage pulse generated by the Marx generator is guided to the drill head comprising a first and second drill

tip. When drilling, the drill head is placed adjacent to the surface of the medium to be drilled, and the high-voltage pulse is applied between the drill tips. This results in the electric discharge current and subsequently in one or more electric arcs for breaking up the surface. Differently formulated, the electric discharge current flows between the first and second drill tip of a pair of drill tips and penetrates the medium to be drilled.

[0017] As explained in the background section, the high-voltage pulse is generated by the circuit by charging a number of capacitors in parallel, and subsequently connecting them in series performed by the spark gaps, which are used as switches. In the context of this invention, the Marx generator is therefore a known one. However, according to a new and inventive feature, the method of this invention further comprises the step of capturing radiation produced at at least one of the spark gaps and to determine the efficiency of the drilling process based on that captured radiation.

[0018] Said radiation is produced when the Marx generator discharges, thus when the electric discharge current is produced that originates from the high-voltage pulse generated by the Marx generator. Radiation means the emission or transmission of energy in the form of electromagnetic waves through the medium surrounding the spark gaps. The emitted radiation may have a wavelength of a certain band width, which may be narrower or broader. Radiation may however also be emitted in one single wavelength region, or in various wavelength regions. In the context of the invention, the emitted radiation can have a wavelength in the region of visible light, but instead or additionally the emitted radiation may have a different wavelength such as infrared or ultraviolet. The discharge current not only produces a spark at the drill tips, but also over the spark gaps of the Marx generator. As all spark gaps are connected in series at the time of discharge, the current is more or less identical in all sparks, including the spark or sparks involved in penetrating the medium in which drilling is carried out. It should however further be understood that small differences may occur between sparks due to parasitic capacitances and inductances of the Marx generator and drill head. However, in the context of this invention it is sufficient that radiation is captured at the location of at least one of the spark gaps.

[0019] In a next step, the captured radiation may be filtered at a predetermined wavelength or wavelength band width. This predetermined wavelength may be selected from a range of available wavelengths and is usually selected depending on the nature of the medium surrounding the spark gaps. Since the produced high-voltages need to be electrically isolated within the Marx generator, the Marx generator is commonly immersed in high pressure dielectric gas such as sulphur hexafluoride SF_6 , or nitrogen N . When the sparks are produced in the spark gaps, a plasma or electromagnetic radiation is generated, the wavelength of which varies with the nature of the dielectric gas. The plasma spectrum and the

wavelength of the radiation is therefore known in advance as it is known to depend on the nature of the dielectric gas. For example, when the dielectric gas comprises nitrogen, the spectrum of the plasma is stable over a predefined width at 550nm, such that the predefined wavelength of the sensor used to capture the radiation will correspond to this width at said wavelength.

[0020] Where the captured radiation is filtered at a certain wavelength width, the band wavelength with is preferably as small as possible to provide optimal reproducibility of the measurement. The inventors have observed that the broader the band with, the larger the variation. The broader the band with, the larger the duration of the time period may be. Examples of suitable band widths are 50-100 nm. Note however that the presence of a dielectric gas is not a prerequisite of the claimed invention. Although less preferred, the spark gaps may also be surrounded by air, and the radiation of ionized air when the spark gaps are broken down may be captured. Because air is composed of several gasses, the radiation thus produced may have a broader wavelength distribution. Yet, when the Marx generator is immersed in a dielectric gas, the predefined wavelength corresponds to the wavelength of the light that is emitted during relaxation of the dielectric gas that has been excited during discharging of the Marx generator.

[0021] In a next step, a duration of a time period is measured, during which the filtered radiation is produced and in which the intensity of the produced radiation exceeds a predefined threshold when the electric discharge current flows between the drill tips.

[0022] It has been observed by the inventors that the duration of said time period during which the filtered radiation is produced and in which the intensity of the produced radiation exceeds a predefined threshold is noticeably shorter when the current penetrates a solid targeted medium to be drilled compared to penetrating water, air, oil, and/or a flushing fluid. Thus, by looking at the duration of said time period during which the intensity of the filtered radiation exceeds a predefined threshold, it can be deducted therefrom if the discharge current is penetrating a targeted medium or not, or whether a combination of media is penetrated. In other words, the efficiency of the drilling process can be determined based on the measured duration during which the intensity of the filtered radiation exceeds a predefined threshold.

[0023] The threshold can be set arbitrarily and is determined by a calibrating step. Experimentally it has been noticed that there is a significant distinction between the duration of radiation emitted at the spark gaps when the electric current penetrates the targeted medium, versus the duration of radiation emitted at the spark gaps when the electric current does not penetrate the targeted medium but flows through a surrounding medium like air. It has been further observed that when executing successive tests the duration of radiation emitted at the spark gaps when the electric current pe-

netrates the targeted medium maintains the same characteristics. Thus prior to the drilling process, the steps of capturing and filtering can be performed by the drill operator by placing the drill head adjacent to the targeted medium to ascertain that the electric discharge current penetrates the medium to be drilled. Next, these steps are likewise performed by holding the drill head away from the medium to be drilled at a distance from the medium to be drilled, thus in the surrounding medium. The responses of the steps described above are processed such that a set of different time periods (reference time period) is obtained. Since the responses of the steps when holding the drill head adjacent to the targeted medium are different than the responses when the drill head is held away from the targeted medium, a set of reference time periods is obtained from which one part may be linked to an efficient drilling operation when penetrating the targeted medium, while the other part corresponds to an inefficient drilling operation linked to penetrating the surrounding medium to a certain extent. Based thereon the predefined duration for the measuring step, and therefore also for the determination of the efficiency can be assessed or a window within which the duration of the measurement should proceed can be determined or defined. Further note that due to this calibration step, it is not needed to obtain an exact value of the threshold, since the responses when penetrating the targeted medium remain identical. Differently formulated, there is no need to perform a measurement of absolute values. One only needs to set the threshold arbitrarily with the single restriction that sensor should capture the radiation. It should be understood that when the threshold is above a certain level of sensitivity, no radiation will be captured whatsoever, which needs to be avoided. Finally, the measured duration can be compared with the determined or reference duration which corresponds to the current penetrating the medium to be drilled. When the measured duration corresponds to the reference duration, it can be concluded that the drilling process is performed in an efficient manner. When the measured duration is longer than the one determined through the calibration step, the drilling process is not performed in an efficient manner. Further note that when the measured duration is significantly shorter than the one determined through the calibration step, it can also be deducted therefrom that the drilling process is not performed in an efficient manner and that, for example, a technical defect is present in the generator, like an internal short circuit.

[0024] It should be further noted that based on the measured duration it is also possible to determine the nature of the medium, i.e. whether it is granite, marble, mainly sand or any other medium. A database comprising a set of time periods and corresponding mediums could be created as a derivative of the claimed method.

[0025] Next, according to an embodiment, a warning sign can be produced when the measured duration deviates from a predefined window. This way, the drill

operator is triggered when the drilling process is not performed in an efficient manner as defined.

[0026] Different advantages are identified.

[0027] Firstly, the present invention relates to the drilling of holes or gaps or pipes or similar in a medium, in the course of the drilling process the drill head with the drill tip is usually situated/located in a bore hole. An advantage of the method of this invention is that the efficiency can be determined for every spark at any time during the drilling process. Thereby, the drill head does not have to be visible to the drill operator. Nevertheless a real time feedback on the performance of the drilling process is provided.

[0028] Further there is no need to measure the current flowing to and from the drill tips by using a current pulse transformer, as is done in the art. Such current pulse transformers are bulky as they need to provide sufficient electric isolation from the high-voltage line on which they are mounted. Further, as the Marx generator and the drill head are close to each other, this is inside the borehole, a long well electrical isolated cable would be required from the current pulse transformer to a data acquisition system outside the borehole. A bulky transformer is not an ideal solution for use in a bore hole being a hostile environment. An advantage of the claimed method is therefore that the current signal is converted into an optical signal, being the captured radiation. Optical signals provide excellent electric isolation and electromagnetic interference, EMI, and/or electrostatic discharge, ESD, immunity. Furthermore, some dielectric gasses give rise to the production of radiation having a wide spectrum. Hence no lens is needed for compressing the bandwidth. This is another advantage of the invention since this would be expensive and leads to losses.

[0029] A third advantage is that the efficiency may be measured inside the Marx generator by capturing the radiation within the device instead of at the drill head, although it is underground. Since, as already highlighted, the bore hole is a hostile environment, in particular the drill tips, such that a measurement at that location should be avoided.

[0030] According to a second aspect of the invention, a data processing apparatus is disclosed comprising means for carrying out the steps of:

- measuring a duration of a time period of filtered light being above or below a predefined duration, the filtered light obtained according to the steps of the method of the first aspect;
- performing the step of determining the efficiency of the drilling process according to the method of the first aspect.

[0031] This data processing apparatus can be placed remotely from the Marx generator and the drill head, such that the data can likewise be processed remotely. The captured light can thus be safely transported towards this data processing apparatus outside the borehole. This transport can for example be performed by an optic fibre.

It can then be decoded by a photo diode or photo transistor circuit and converted to a logic level. The discharge current may oscillate due to parasitic inductance of the setup but it is converted to a steady logic level by the spark's radiation. The duration of the time period of the filtered light can be measured by a pulse length measurement device providing a resolution of preferably at least 100ns. The pulse rate can also be measured and provides fast feedback on the drilling process when using the Marx generator without the need to wait for slower rate of penetration measurement.

[0032] Another advantage thereof is that it provides the ability to evaluate spark efficiency to the drill head operator in real time. This way, he can adjust settings for the drill head and/or Marx generator, for example by increasing or decreasing the spacing between the drill head and the targeted medium, to rotate the drill head, to adjust the ignition high-voltage, and/or to adjust the dielectric gas pressure inside the Marx generator. The result of one or more of these adjustments can be immediately evaluated and if successful the drill head can be repaired without the need for further observation and/or delays.

[0033] Furthermore, the space requirements in the borehole for a filter and optic fibre are very low compared to those of a current sensor.

[0034] According to an embodiment, the means are further configured to carrying out the step of triggering a warning sign according to the method of the first aspect, and/or comparing the measured duration with a set of reference durations obtained by the calibration step of the method of the first aspect.

[0035] According to a third aspect, a drilling apparatus is disclosed comprising:

- a Marx generator comprising a set of spark gaps between capacitors;
- a drill head comprising a first and second drill tip to an output of the Marx generator configured to cause breaking of a medium penetrated by an electric discharge current flowing between the drill tips;
- an optic fibre configured to capture light at a spark gap;
- connecting means for transmitting the captured light to the data processing apparatus according to the second aspect.

[0036] The connecting means allow to process the information obtained by the captured radiation remotely from the drilling apparatus itself, as already highlighted above.

[0037] According to an embodiment, the drilling apparatus further comprises an optical light filter between the optic fibre and the spark gap, the optical light filter configured to filter the captured light at a predefined wavelength. This way, no lens or transducer are needed. Furthermore, this setup is not sensitive to infrared glow.

[0038] According to embodiment, the drilling apparatus may also comprise the data processing apparatus

according to the second aspect of the invention.

Brief Description of the Figures

[0039] The invention will be further illustrated with reference to the figures, wherein:

Fig. 1 illustrates a one-wire diagram for the optical measurements for the determination of the efficiency of a drilling process using a Marx generator.

Fig. 2 illustrates graphs of a current respectively an optical signal derived from a spark penetrating a non-targeted medium; and

Fig. 3 illustrates graphs of a current respectively an optical signal derived from a spark penetrating a targeted medium.

Detailed Description of Embodiments

[0040] The present invention will be described with respect to certain embodiments and with reference to certain figures, but the invention is not limited thereto and is defined only by the claims. The figures described are only schematic and non-limiting. In the figures, the size of certain elements may be exaggerated and not drawn to scale for illustrative purposes. The dimensions and relative dimensions do not necessarily correspond to actual practical embodiments of the invention.

[0041] In addition, the terms first, second, third and the like are used in the specification and in the claims to distinguish between like elements and not necessarily to describe a sequential or chronological order. The terms are interchangeable under appropriate circumstances and the embodiments of the invention may be used in sequences other than those described or illustrated herein.

[0042] Furthermore, the terms top, bottom, over, below and the like in the specification and claims are used for illustrative purposes and not necessarily to describe relative positions. The terms so used are interchangeable under appropriate circumstances, and the embodiments of the invention described herein may be used in orientations other than those described or illustrated herein.

[0043] Further, although referred to as "preferred embodiments", the various embodiments are to be construed as exemplary in which the invention may be practiced rather than as a limitation on the scope of the invention.

[0044] The term "comprising", used in the claims, should not be construed as being limited to the means or steps set forth below; the term does not exclude other elements or steps. The term should be interpreted as specifying the presence of the named features, elements, steps, or components referred to, but does not exclude the presence or addition of one or more other

features, elements, steps or components, or groups thereof. The scope of the expression "a device comprising means A and B" should therefore not be limited to devices consisting only of the components A and B. The meaning is that with respect to the present invention only the components A and B of the device are listed, and the claim is further to be interpreted as including equivalents of these components.

[0045] Fig. 1 illustrates a one-wire diagram for the optical measurements for the determination of the efficiency of a drilling process using a Marx generator 100. The Marx generator 100 is an electrical circuit to generate a high-voltage pulse from a low-voltage DC supply 102. The high-voltage pulse is made available at location 101 such that it can further be guided towards the drill head 103. This drill head 103 comprises electrodes or drill tips. When performing an electro-pulse drilling process by use of the Marx generator, the drill head 103 is situated within a bore hole or drill well 104. The drill head 103 is placed adjacent to a medium targeted for cracking or bursting it.

[0046] The cracking or bursting occurs when an electric discharge current penetrates the targeted medium. This electric discharge current on its turn originates from the high-voltage pulse generated by the Marx generator 100. The latter is produced by a number of capacitors 130-133 charged in parallel to the voltage V_c 102 through the resistors R_c or coils L_c 120-126. Next spark gaps 110-113 used as switches have the voltage V_c 102 across them, while the gaps 110-113 have a breakdown voltage greater than this value V_c 102. Hence, they are open switches such that the capacitors 130-133 can be charged. To produce the high-voltage pulse and subsequently the electric discharge current, the first spark gap 110 is caused to break down which shortcuts this gap 110, thereby placing the first two capacitors 130 and 131 in series, and thus applying a voltage of $2V_c$ over the second spark gap 111. Consequently, the second spark gap 111 breaks down to add the third capacitor 131 to the chain, and the process continues to sequentially break down all the spark gaps 112-113, thereby connecting the capacitors 130-133 in series to create the high-voltage pulse.

[0047] The Marx generator 100 with the drill head 103 is placed in the bore hole or well 104 with the drill head adjacent to the targeted medium. By the created high-voltage pulse the electric discharge current follows and penetrates the medium. Next, energy therefrom is discharged when the current travels through the medium, whereby the current oscillates. The characteristics of the medium further determine the rate at which the oscillating current damps.

[0048] In Fig. 2 respectively Fig. 3 two currents are illustrated travelling through a non-targeted medium respectively a targeted medium. A non-targeted medium is for example air or water, while a targeted medium is for example rock or concrete.

[0049] Fig. 2 illustrates an oscillating current 200 with low damping because it travels through a non-targeted

medium, such as air. Fig. 3 illustrates an oscillating current 300 with high damping because it travels through a targeted medium, such as rock.

[0050] When the electric discharge current penetrates the target medium, the drilling process is running in an efficient manner. However, since the Marx generator 100 and drill head 103 are located in the bore hole or well 104, a drill operator cannot observe if this indeed the case. A possibility would be to monitor the current, and more in particular the damping thereof. However, this would acquire a current pulse transformer, which is bulky a need to be provided with sufficient electric isolation from the high-voltage line of the Marx generator 100. Furthermore, the current pulse transformer should also be placed within the bore hole 104, which is inconvenient.

[0051] Another way to monitor the efficiency of the drilling process is to monitor the radiation emitted by the current instead of looking at the current itself. In Fig. 2 and Fig. 3 besides the current 200, 300 there are also graphs which illustrates radiation originating from the damping current 200, 300 and being above a predefined threshold. In Fig. 2 graph 201 illustrates the radiation emitted by the current 200. In Fig. 3 graph 301 illustrates the radiation emitted by the current 300.

[0052] From these graphs 201 and 301 it can be observed that the length or time period of the radiation originating from an oscillating current 200 penetrating a non-targeted medium is significantly longer than radiation originating from an oscillating current 300 penetrating a targeted medium. In the first case the time period is 94 μ s, while the second case the time period is 11 μ s.

[0053] Again with reference to Fig. 1, an optical sensor 105 is placed at the first spark gap 110 to capture this radiation. Next, by use of an optical fibre 106 the radiation captured by the sensor 105 is transmitted to a data processing apparatus 107. Within this data processing apparatus 107 the duration of the captured radiation is measured. Based thereon, it can be derived if the drilling process is running in an efficient manner.

[0054] Further note that by capturing the radiation instead of monitoring the current, the processing thereof can be performed remotely from the Marx generator 100 and drill head 103. While the Marx generator 100 and drill head 103 are located in the drill well 104, the data processing unit 107 can be located on a safe and more convenient location.

Claims

1. A method for determining an efficiency of a drilling process performed by an electro pulse drill comprising a drill head (103) driven by a Marx generator (100), wherein the drill head (103) is provided to produce an electric discharge current (200, 300) penetrating a medium to be drilled, the electric discharge current (200, 300) flowing between a first and second drill tip of a pair of drill tips and the electric

discharge current (200, 300) originating from a high-voltage pulse generated by the Marx generator (100) comprising a set of spark gaps (110-113) between capacitors (130-133), the method comprising the steps of:

- capturing radiation at a Marx generator spark gap (110), the radiation being produced when the Marx generator (100) discharges;
- filtering the captured radiation at a predefined wavelength; and
- measuring a duration of a time period during which the filtered radiation is above a predefined threshold when the electric discharge current flows between the drill tips;
- determining the efficiency of the drilling process based on the measured duration (201, 301).

2. The method according to claim 1, further comprising the step of:

- producing a warning sign when the measured duration (201, 301) deviates from a predefined duration.

3. The method according to any of the preceding claims, wherein the Marx generator (100) is immersed in a dielectric gas, and wherein the predefined wavelength corresponds to the wavelength of the radiation that is emitted during relaxation of the dielectric gas that has been excited during discharging of the Marx generator (100).

4. The method according to claim 3, wherein the dielectric gas comprises nitrogen, and wherein the predefined wavelength corresponds to 550nm.

5. The method according to any of the preceding claims, further comprising a calibration step comprising the steps of:

- performing the capturing and filtering step when the drill head (103) is placed adjacent to a targeted medium respectively a surrounding medium;
- processing responses thereof thereby obtaining a set of time periods;

and wherein the predefined threshold for the measuring step is determined based on the set of time periods.

6. A data processing apparatus (107) comprising means for carrying out the steps of:

- measuring a duration of a time period of filtered radiation being longer or shorter than a prede-

fined duration, the filtered radiation obtained according to the steps of the method of claim 1;
- performing the step of determining the efficiency of the drilling process according to the method of claim 1.

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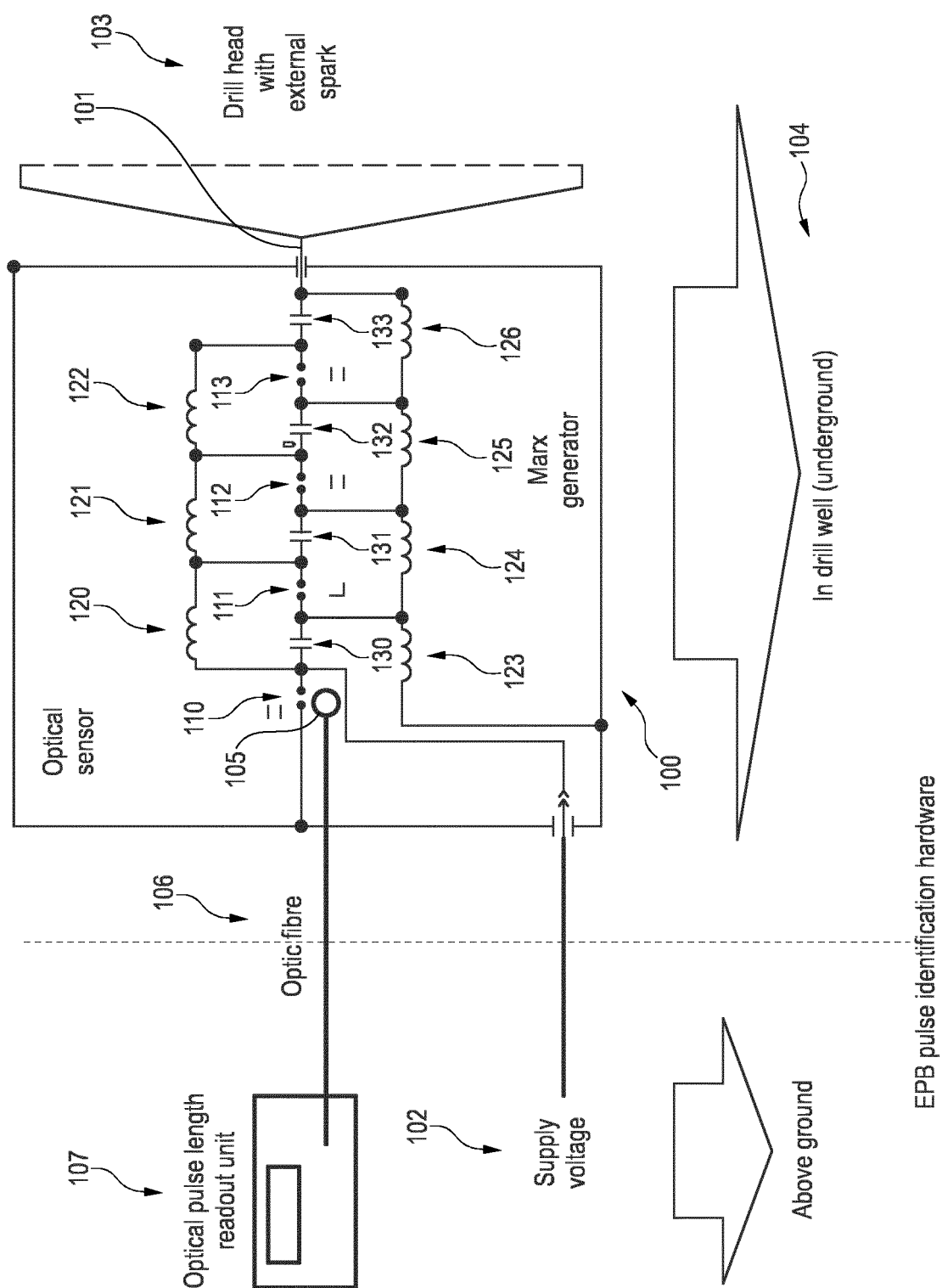
7. The data processing apparatus (107) according to claim 6, wherein the means are further configured to carrying out the step of triggering a warning sign according to the method of claim 2, and/or comparing the measured duration with a set of reference durations obtained by the calibration step of claim 5.
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8. A drilling apparatus (100, 103) comprising:
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- a Marx generator (100) comprising a set of spark gaps (110-113) between capacitors (130-133);
 - a drill head (103) comprising a first and second drill tip to an output of the Marx generator (100) configured to cause breaking of a medium penetrated by an electric discharge current (200, 300) flowing between the drill tips;
 - an optic fibre (105) configured to capture radiation at a spark gap (110);
 - connecting means (106) for transmitting the captured radiation to the data processing apparatus (107) according to one of the claims 6 or 7.
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9. The drilling apparatus (100, 103) according to claim 8, further comprising an optical light filter between the optic fibre (105) and the spark gap (110), the optical light filter configured to filter the captured radiation at a predefined wavelength.
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10. The drilling apparatus (100, 103) according to any of the claims 8 to 9 comprising the data processing apparatus (107) according to one of the claims 6 or 7.

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1. 9.

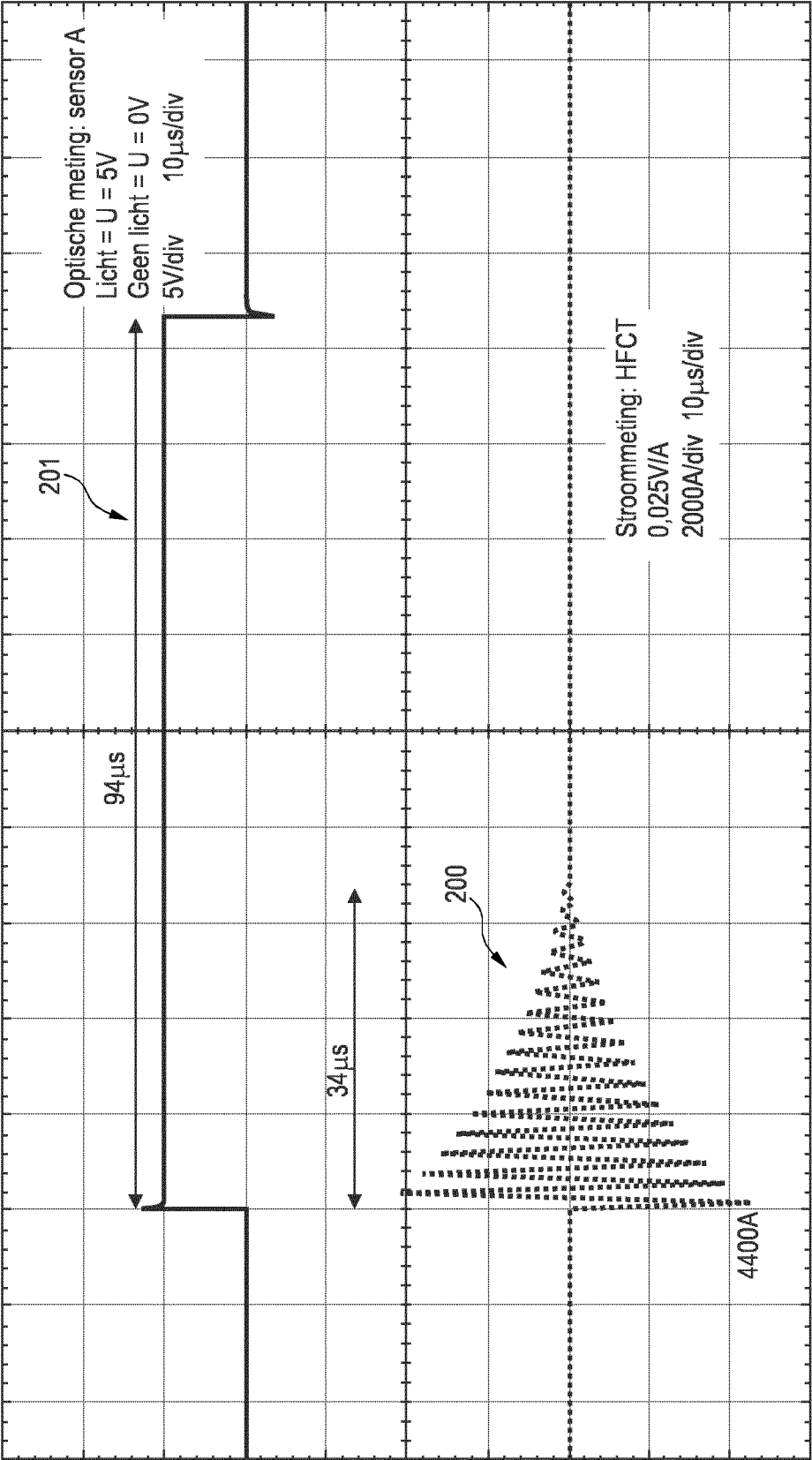


Fig. 2

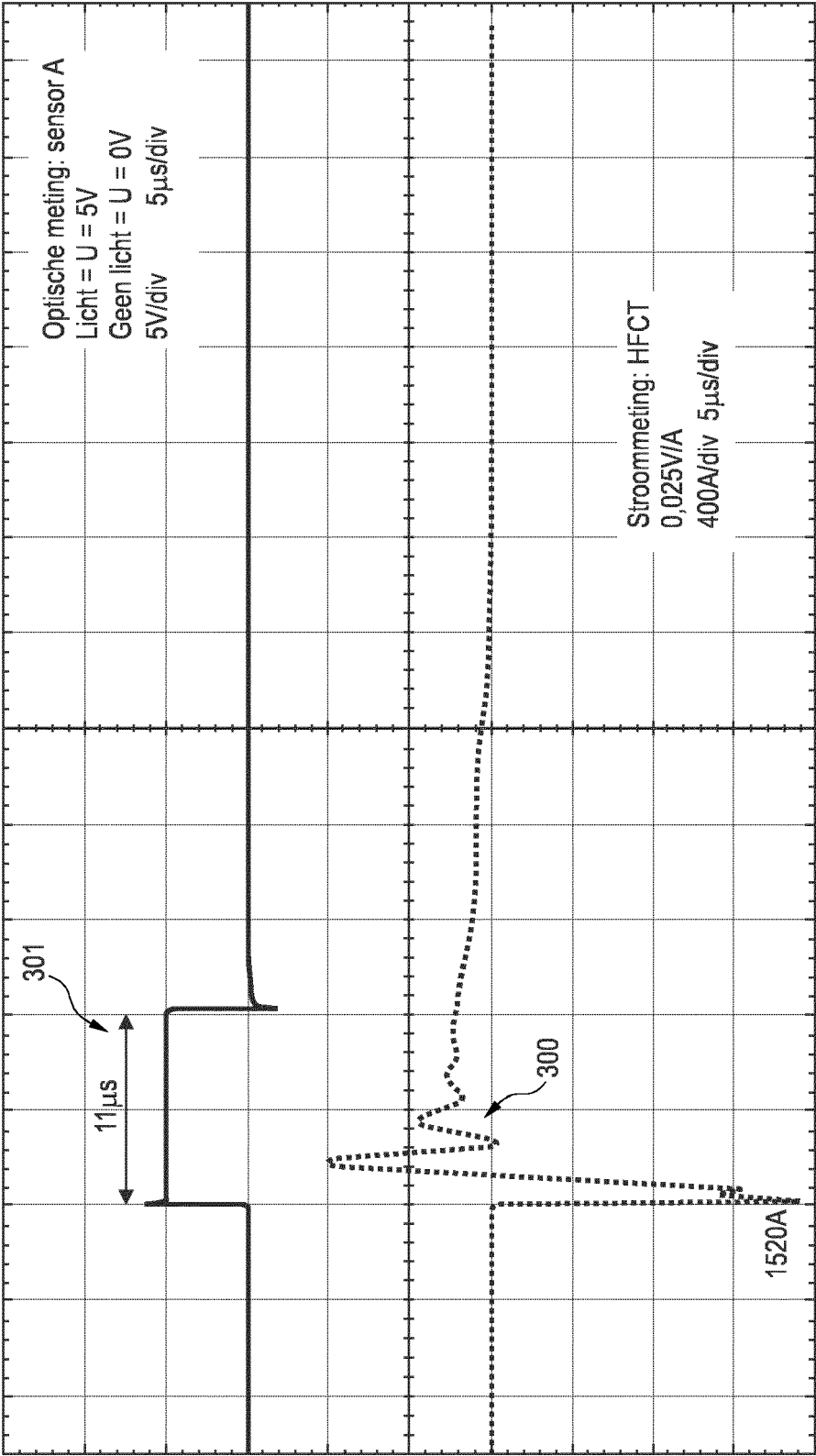


Fig. 3



EUROPEAN SEARCH REPORT

Application Number

EP 23 20 5584

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	US 2022/195807 A1 (CAMMACK MATTHEW EUGENE [US] ET AL) 23 June 2022 (2022-06-23)	1, 2, 5-7	INV. E21B7/15
A	* abstract * * figures 2, 3A-3B, 6-7 * * paragraphs [0001] - [0005], [0035] - [0038], [0044] - [0045] *	3, 4	
X	EP 4 159 970 A1 (VITO NV [BE]) 5 April 2023 (2023-04-05) * abstract * * figures 1, 3, 7 * * paragraphs [0039] - [0041], [0075] - [0076], [0108] - [0110] *	1, 8-10	TECHNICAL FIELDS SEARCHED (IPC) E21B B23K
A	US 2022/307323 A1 (CAMMACK MATTHEW EUGENE [US] ET AL) 29 September 2022 (2022-09-29) * the whole document *	1-10	
A	US 10 407 995 B2 (SDG LLC [US]) 10 September 2019 (2019-09-10) * the whole document *	1-10	
A	CA 2 896 335 A1 (SDG LLC [US]) 26 June 2014 (2014-06-26) * the whole document *	1-10	
A	US 2020/370375 A1 (GLEITMAN DANIEL D [US] ET AL) 26 November 2020 (2020-11-26) * the whole document *	1-10	
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 26 February 2024	Examiner Ing, James
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	

EPO FORM 1503 03.82 (P04C01)

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

EP 23 20 5584

5

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.

26-02-2024

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2022195807 A1	23-06-2022	US 2022195807 A1	23-06-2022
		WO 2022132293 A1	23-06-2022

EP 4159970 A1	05-04-2023	EP 4159970 A1	05-04-2023
		WO 2023052412 A1	06-04-2023

US 2022307323 A1	29-09-2022	BR 112023014514 A2	03-10-2023
		EP 4267832 A1	01-11-2023
		US 2022307323 A1	29-09-2022
		WO 2022203675 A1	29-09-2022

US 10407995 B2	10-09-2019	NONE	

CA 2896335 A1	26-06-2014	AU 2013361421 A1	23-07-2015
		BR 112015014670 A2	11-07-2017
		CA 2896335 A1	26-06-2014
		CA 3142102 A1	26-06-2014
		EP 2935754 A1	28-10-2015
		WO 2014100255 A1	26-06-2014
		ZA 201505070 B	26-10-2016

US 2020370375 A1	26-11-2020	US 2020370375 A1	26-11-2020
		US 2021324683 A1	21-10-2021
		WO 2020236189 A1	26-11-2020

15

20

25

30

35

40

45

50

55

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2023073114 A1 [0004]
- WO 2023052412 A1 [0006] [0007]
- US 2016377389 A1 [0009]