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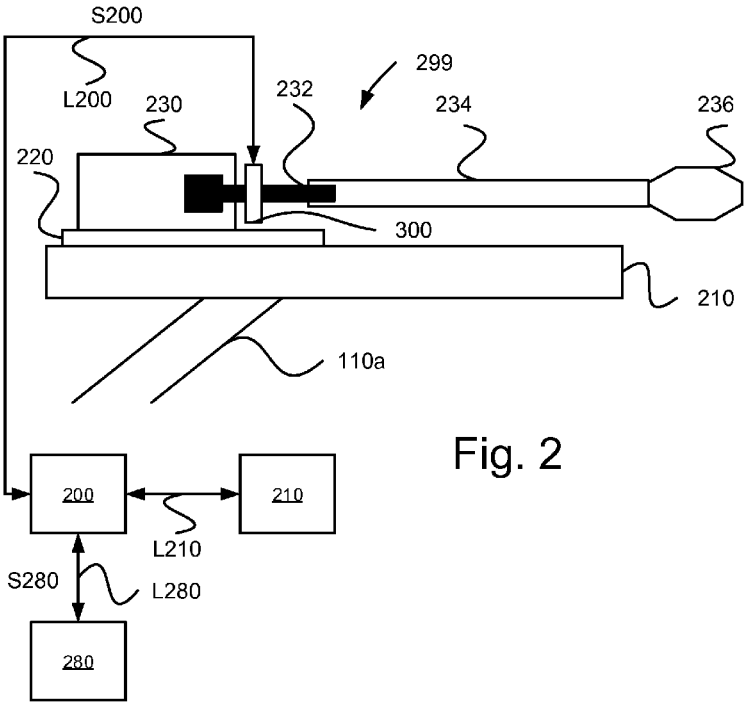


Fig. 2

(57) Abstract: The invention related to a method for determining efficiency of a drilling process comprising the steps of: transferring (s510) energy via a tool member (232, 234) to the material in which drilling is to be performed by means of a drilling configuration (299); - detecting (s520) waves which are propagating in said tool member (232, 234) of said drilling configuration (299) during drilling as a result of energy provision; - detecting (s520) said waves by means of at least two sensor means (310:1; 310:2) arranged on mutually opposite sides of said tool member (232, 234) adjacent to, on a certain distance from, said tool member (232, 234), which sensor means (310:1; 310:2) are based on inductive and/or capacitive detection of said waves in said tool member (232, 234); and - based on results of said detection, determining (s530) said efficiency of said drilling process. The invention also relates to a computer program product comprising program code (P); a system (299), a drilling rig (100) which is equipped with the system and a detection device of such

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System and method for determining efficiency of a drilling process

TECHNICAL FIELD

The present invention relates to a method for determining an excavating efficiency of a drilling process. The invention also relates to a computer program product comprising program code for a computer for implementing the method. The invention also relates to a system for determining an excavating efficiency of a drilling process and a drilling rig which is equipped with such system. The invention also relates to a detecting unit of a system for determining excavating efficiency of a drilling process.

BACKGROUND

When excavating rocks, or other hard materials, various kinds of drilling rigs or machines can be used. A drilling rig can comprise a number of booms wherein each one has a drilling machine arranged slidable on a sledge of a feeder (arm) of the rig. The feeder will be arranged so as to apply pressure in a controlled way onto a drilling steel provided with a cutter and therefore against the rock which is to be excavated. Further, said drilling machine may be arranged for excavating rocks by rotational movement of the drilling steel cutter, as well as impact cutting effected by striking the drilling steel end opposite the cutter. It is desired that an operator of a drilling rig may adapt operation of each drilling machine so as to excavate rocks in an optimal way, for example when mining or preparing tunnels.

The form and energy content of shock waves cause by drilling steel striking can be shown to be proportional to efficiency of excavating. As shock waves are generated by means of said striking, it is of interest to determine excavating efficiency regarding the drilling process so as to be able to adapt operation of a corresponding drilling machine. Today there are various techniques for determining efficiency of a drilling process.

According to a first example, strain meters are used, which are rigidly arranged by means of fastening means on the drilling steel of the drilling machine. This variant is however in practice only useful for a laboratory environment, for many reasons. Firstly, the total

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operational time of strain meters of today is relatively short. Secondly, a wire arranged between the strain meter and the meter system is required, which as such disqualifies this first example for use in field operation. It has been proved to be detrimental to mount the required electronics for the strain meter on the drilling steel as shock waves cause degradation of the electronics. Applications wherein wireless techniques are used for transferring information from the strain meters to remotely located electronics provide unsatisfying performance too.

According to a second example, an inductive coil member with its winding(s) arranged about the drilling steel of the drilling machine can be used. Said drilling steel extend hereby through said coil. This example functions acceptably but delivers very noisy signals, which contributes to this measuring method not providing accurate results.

SUMMARY OF THE INVENTION

It would be beneficial to provide a method for determining excavating efficiency of a drilling process which does not present or at least ameliorates some of the disadvantages mentioned above involving application of wire-connected sensors directly onto a drilling steel of the drilling machine and which also provides high accuracy of detected shock waves and/or tensile waves in said drilling steel.

It would also be advantageous to provide a novel system for determining excavating efficiency of a drilling process, as well as an implementation by way of a processor-executable computer program for determining excavating efficiency of a drilling process.

Advantageously, the present invention could also be embodied in a detecting unit of a system for determining excavating efficiency of a drilling process.

Such a method, system and computer program could enhance secure and user-friendly operation of a drilling machine by an operator, with improved efficiency on the basis of determined excavation efficiency of a drilling process.

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Preferably, a method, a system and a computer program should be devised which allow accurate continuous determination of excavation efficiency of a drilling process.

Advantageously, a relatively cheap and during operation cost effective system for determining excavation efficiency of a drilling process should be made available.

According to one aspect of the present invention there is provided a method for determining excavating efficiency of a drilling process, comprising the steps of:

- transferring energy, via a tool member used in the drilling process, to the material in which drilling is to be performed by means of a drilling configuration;
- detecting waves which propagate in said tool member during drilling as a result of energy transfer;
- wherein detecting said waves is done by at least two pairs of sensor means symmetrically arranged in the detection unit, wherein each pair of sensor means comprises two sensors located on mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member, which sensor means are configured for inductive and/or capacitive detection of said waves in said tool member; and
- determining said excavating efficiency of said drilling process based on comparisons between original pressure waves and reflected tensile waves in said tool member, or based on characteristics of a few reoccurring tensile waves in said tool member.

Hereby is achieved a versatile and cost effective method for determining said efficiency of said drilling process. The method is versatile in that both tensile waves and shock waves are detected in a reliable way by the at least two pairs of sensor means (i.e. at least four sensors located with spacing from each other about the tool member. This renders that the method is applicable to a set of different drilling configurations/drilling machines, regarding a drilling rig as well as hand-held or stand-alone drilling configurations/drilling machines. By arranging the two individual sensors of the at least two pairs of sensor means on mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member, a very accurate detection of said waves is achieved.

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It is advantageous to be able to measure waves of said tool member without the need of having a sensor mounted on said tool member, e.g. a drilling steel of the drilling configuration.

Advantageously, said drilling process may be continuously optimized on the basis of said determined excavating efficiency of said drilling process regarding e.g. minimization of rock-reflected waves or a ratio between tensile waves and pressure waves.

It is also possible to determine if connections are loose at said tool member as well as detecting erroneous function of striking arrangements of said drilling configuration.

The method further comprises the step of:

- processing results from said sensor means pairwise as a basis for said determination. Hereby said four sensor means are advantageously used pairwise, whereby detected "interferences" may be reduced or eliminated. These interferences may be constituted by flexing (or bending) waves, wobbling tool members and broken fixtures. By processing waves detected by the sensor means by means of mathematical models of an electronic control unit, a correct continuous state of the tool member may be provided. By arranging sensor means pairwise on opposite sides of said tool member flex waves components of pressure waves and tensile waves can be filtered out in an accurate manner.

The method may further comprise the step of:

- positioning said sensor means at a preferred position along said tool member where lateral movements of said tool member are relatively small. One such position may advantageously be at a neck adapter of the drilling configuration, i.e. the portion which is connecting the drilling machine to a drilling steel. This position allows an easy connecting procedure regarding the detecting device comprising said sensor means. By positioning said sensor means at said neck adapter, flex waves will be appearing to a lesser extent. Alternatively, said sensor means may be arranged at one end of said drilling steel, i.e. at said cutter or at a position close to said neck adapter of said drilling steel.

The method may comprise the step of:

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- providing said energy by means of strikes on and/or rotation of the drilling steel. Hereby a versatile method is achieved. The method is thus applicable to machines using striking energy for breaking rocks. The method is thus also applicable to machines using energy generated by rotational movement (during feeding) of the drilling steel for breaking rocks. According to one embodiment, the inventive method is applicable to machines using a combination of strikes by and rotational movement of the drilling string cutter for breaking rocks.

In accordance with the invention, the sensor mean pairs comprise oppositely arranged coil members comprising at least one permanent magnet as coil core. Said at least one permanent magnet is arranged to generate a substantially constant magnetic field about said tool member, which tool member is vibrating/moving during operation. Such movements influence said magnetic field, whereby changes in said magnetic field may be detected by means of said at least two sensor mean pairs. An electrical signal from said sensor means is representing the movement of said tool member, the content of said signal is the basis for said assessment of said drilling process. Alternatively another unit than a permanent magnet may be used for generating a substantially constant magnetic field about said tool member, for example a direct current electromagnet.

The coil members will exhibit a substantially elliptic configuration, having the shorter ellipse axis substantially parallel with a longitudinal direction of said tool member. Hereby an accurate and reliable detection of said waves of said tool member is achieved.

As noted above, the method comprises the step of:

- determining said excavating efficiency of said drilling process on the basis of comparisons between original pressure waves and reflected tensile waves in said tool member; or
- determining said excavating efficiency of said drilling process on the basis of characteristics of a few reoccurring reflected tensile waves in said tool member.

By comparing original pressure/shock waves and corresponding tensile waves/reflected waves in said tool member, the effective work may be determined. In a case where rotational movement of a cutter applied under pressure against a rock during breaking

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generates tensile waves, these may be analysed for determining efficiency of said drilling process without comparison with shock waves.
According to one embodiment said excavating efficiency of said drilling process may be determined on the basis of characteristics of reflected pressure waves.

The method may comprise the further step of:
- detecting additional waves in said tool member by means of additional sensor means oriented in a symmetrical configuration, the additional sensors rotated in relation to the at least two pairs of sensor means such that these additional sensor means specifically detect torsion waves in said tool member. By providing sensor means having another orientation compared to an already provided configuration of sensor means it is possible to detect said torsion waves in an effective way.

The method may comprise the further step of continuously controlling said drilling process based on such determined excavating efficiency for an efficiency optimization. Hereby, for example feeding pressure, rotational speed, striking frequency, striking power etc. may be adapted during operation for achieving an improved rock breaking process and thus a more efficient drilling process.

Herein described is also a method for determining excavating efficiency of a drilling process where no striking is present and where drilling is performed by means of a drilling configuration having a tool member, comprising the steps of:
- detecting waves which propagate in said tool member of said drilling configuration during drilling, which waves are generated by the material in which drilling is performed;
- detecting said waves by means of at least two sensor means arranged on mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member, which sensor means are based on inductive and/or capacitive detection of said waves in said tool member; and
- based on results of said detection, determining said excavating efficiency of said drilling process.

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According to another aspect of the present invention, there is provided a system for determining excavating efficiency of a drilling process, comprising:

- a drilling configuration arranged for transferring energy via a tool member to a material in which drilling is to be performed;
- a detection unit for detecting waves which propagate in said tool member of said drilling configuration during drilling as a result of energy transfer, wherein the detection unit comprises at least two pairs of sensor means symmetrically arranged in the detection unit about the tool member and configured for inductively and/or capacitively detecting said waves, with each pair of sensor means comprising two sensors arranged on mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member; and
- at least one control unit configured to receive the inductive and/or capacitive detection results from the detection unit and to perform pairwise processing of the detection results for each pair of sensors of the at least two pairs of sensor means, wherein the at least one control unit is further configured for determining said excavating efficiency of said drilling process based on comparisons of original pressure waves with reflected tensile waves propagating in said tool member, or based on characteristics of a few reoccurring tensile waves propagating in said tool member.

By detecting waves of said tool member during (field) operation, a drilling process may be optimized to a substantially ideal rock breaking, efficiency, total operational time of the drilling steel, or a combination of said parameters.

The technical effects and the advantages which are presented by features of the inventive method are also valid for corresponding features of the system depicted herein.

The system thus has at least four sensors symmetrically pairwise arranged at mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member, wherein the system further comprises means for processing results of said sensors pairwise as a basis for said determination.

Said sensor means can advantageously be provided at a preferred position along said tool member at which lateral movements of said tool member are relatively small.

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The system may comprise means for providing said energy by means of strikes and/or rotation of a drilling string of the tool member.

As previously noted, each of the at least two pairs of sensor means comprises oppositely arranged coil members comprising at least one permanent magnet as a coil core for inductively detecting said waves.

The coil members have a substantially elliptic configuration having a shorter ellipse axis arranged substantially parallel with a longitudinal direction of said tool member.

The system may further comprise additional sensor means for detecting torsion waves in said tool member.

The system may further comprise means for continuously controlling said drilling process based on such determined excavating efficiency for an efficiency optimisation.

The detecting unit of the system may be installed afterwards to an existing drilling configuration. Hereby software/electronics/other equipment for processing information regarding said waves determined by the detecting unit may be installed afterwards at an existing drilling configuration.

The inventive method and the inventive system may advantageously be used at a drilling rig. Accordingly, another aspect of the present invention provides a drilling rig which comprises the system for determining excavating efficiency of a drilling process as described above. The drilling rig may be intended for mining. According to another aspect of the present invention there is provided a drilling rig comprising the inventive detecting unit.

According to yet another aspect of the invention there is provided a computer program for determining excavating efficiency of a drilling process, wherein said computer program comprises program code, preferably stored on a non-volatile computer readable medium,

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for causing an electronic control unit or a computer connected to the electronic control unit to perform the steps of the invention's method referenced above.

Further advantages and preferred and/or optional features of the present invention will become apparent to one skilled in the art from the following detailed description of non-limiting embodiments of the invention, provided with reference to the accompanying drawings, and also by putting the invention into practice. Whereas embodiments of the invention are described below, it should be noted that it is not limited to the specific details described. One skilled in the art, having access to the teachings herein, will recognise further applications, modifications and incorporations in other fields, which are within the scope of the invention.

In the figures of the accompanying drawings, the same reference notations denote functionally or constructionally similar items in the various diagrams.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 schematically illustrates a drilling rig, according to an embodiment of the invention;

Figure 2 schematically illustrates a drilling machine arranged on a boom of a drilling rig, according to an embodiment of the invention;

Figure 3a schematically illustrates a detecting unit, according to an embodiment of the invention;

Figure 3b schematically illustrates a cross-section of the detecting unit of fig. 3a;

Figure 3c schematically illustrates a detecting unit, according to another embodiment, but not in accordance of the invention as defined in the claims;

Figure 3d schematically illustrates a detecting unit, according to another embodiment of the invention;

Figure 3e schematically illustrates a sensor means as used, for example, in the detecting units of figures 3a and 3d according to an embodiment of the invention;

Figure 4a schematically illustrates a diagram of wave propagation in a drilling steel in a first operational state;

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Figure 4b schematically illustrates another diagram of wave propagation in a drilling steel in a second operational state;

Figure 5a schematically illustrates a flow chart of a method according to an embodiment of the invention;

Figure 5b illustrates in greater detail schematically a flow chart of a method according to an embodiment of the invention; and

Figure 6 schematically illustrates a computer with computer-readable code for use in an embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

With reference to Figure 1 a drilling rig 100 is illustrated. The exemplified drilling rig is according to one embodiment adapted for mining. The drilling rig 100 is equipped with the invented system, which is depicted in greater detail with reference to, for example, Figures 2 and 3a-3d herein.

The drilling rig 100 may be controlled by an operator, whereby one or more operators may be on-board during propulsion and/or operation of drilling rig. According to an alternative the drilling rig 100 is remotely controlled, whereby one or more operators may be located in a control centre above ground. According to an alternative the drilling rig is arranged for autonomous control and operation of the inventive system.

Herein the term “link” refers to a communication link which may be a physical wire, such as an opto-electronic communication wire, or a non-physical connection, such as a wireless connection, for example a radio or microwave link.

Figure 2 schematically illustrates a drilling configuration 299 comprising a drilling machine 230 and a drilling steel 234 with a cutter 236, where said drilling steel 234 is detachably arranged to said drilling machine 230 by means of a neck adaptor 232. Said drilling steel 234 may comprise multiple pieces which are attached by means of a respective thread configuration at so called connections. Herein the units neck adaptor 232, drilling steel 234 and cutter 236 are denoted tool member.

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Operation of said tool member for mining of rocks or other materials is herein denoted drilling process.

Said drilling machine 230 can be arranged to rotate said drilling steel 234 at a suitable rotational speed for breaking a rock or other materials. Said drilling machine 230 can also comprise a striking arrangement for generating shockwaves that propagate through said drilling steel 234 for mining of rocks or other materials. According to a variant said drilling machine 230 is arranged for achieving both rotational movement of said drilling steel 234 as well as providing power pulses by means of said striking arrangement. Said drilling configuration 299 may be a stand-alone handheld drilling configuration.

According to this example said drilling configuration 299 is arranged on a sledge device 220 which is slidably arranged on a feeder 210. Said feeder 210 is fixedly secured at an arm 110a, which is illustrated with reference to Figure 1. Herein a feed pressure of said drilling steel 234 is achieved against the rock which is to be mined.

A detection unit 300 is arranged about said neck adaptor 232. Said detection unit is depicted in greater detail with reference to, for example, the Figures 3a to 3e below. Said detection unit 300 may be arranged at a suitable position in a longitudinal direction about said neck adapter 232 or said drilling steel 234. Preferably, said detection unit 300 is positioned at a suitable position along said tool member where lateral movements of said tool member are relatively small. A position where the movement of said tool member is relatively small may be adjacent to said cutter 236 or about said drilling steel 234 in contiguity of said neck adaptor 232 or about said drilling steel 234 adjacent to said neck adapter. Since said detection unit 300 comprises sensor means which are sensitive to magnetic interference, it will be advantageous to position said detection unit at a suitable distance from said drilling machine 230 or at a suitable distance from other members of the drilling rig 100 which are generating a magnetic field.

For arranging said detection unit 300 at said tool member in a robust way, suitable support means may be used. Further, suitable magnetic shielding devices may be mounted at said

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detection unit 300 so as to, where applicable, reduce magnetic affection of said detection unit 300.

Said detection unit 300 is signal-connected to a first control unit 200 via a link L200. Said detection unit 300 is arranged to send signals S200 to said first control unit 200 via said link L200. Said signals S200 will comprise information about waves generated at said tool member and detected by means of said detection unit 300.

Said first control unit 200 is arranged for communication with presentation means 280 via a link L280. Said first control unit 200 is arranged to send signals S280 comprising information based on, or related to, said determination of excavating efficiency of said drilling process. According to an embodiment, instructions for an operator on the drilling rig 100 may be presented, where said instructions are generated on the basis of said determination for optimizing operation of said drilling configuration 299. Said instructions may be presented in the shape of alphanumerical signs or suitable signals/colour coding, etc.

A second control unit 210 is arranged for communication with the first control unit 200 via a link L210. The second control unit 210 may be detachable connected to the first control unit 200. The second control unit 210 may be an external control unit of the drilling rig 100. The second control unit 210 may be arranged to perform the innovative method steps according to the invention. The second control unit 210 may be used for downloading software to the first control unit 200, in particular software for performing the innovative method. The second control unit 210 may alternatively be arranged for communication with the first control unit 200 via an internal communications network in a drilling rig. The second control unit 210 may be arranged to perform substantially the same functions as the first control unit 200, such as for example determining said excavating efficiency of said drilling process.

Figure 3a schematically illustrates a detecting unit 300, according to an embodiment of the invention. Said detection unit 300 may be in a form having a substantially circular cross section and comprising a hole IH. Said hole IH has dimensions suitable for receiving the tool member which it surrounds / encloses. The detection unit 300 may be arranged about said neck adaptor 232 or said drilling steel 234.

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According to an embodiment said detection unit 300 comprises four sensor means (or simply: sensors) 310:1, 310:2, 310:3 and 310:4 in the form of inductive coils with suitable wires. Hereby the four sensor means 310:1, 310:2, 310:3 and 310:4 are arranged pairwise, with the sensor means of each pair arranged on mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member 232, 234. A first sensor pair hereby comprises the first coil member 310:1 and the second coil member 310:2. A second sensor pair hereby comprises the third coil member 310:3 and the fourth coil member 310:4. The coil members' central axis is hereby arranged vertically to a longitudinal axis of said tool member 232, 234. According to an embodiment said coil members 310 are arranged for inductive measurements of said waves in said tool member 232, 234.

Said detection unit 300 comprises a processing unit 350. Said processing unit 350 is arranged for communication with a respective one of the sensor means 310:1, 310:2, 310:3 and 310:4 via suitable electrical wires. Hereby said processing unit 350 may receive electrical signals from the respective sensor means 310:1, 310:2, 310:3 and 310:4 and forward these to said first control unit 200 via said link L200. Said electrical signals comprise information about the waves in said tool member 232, 234 which have been detected by means of said sensor means 310. Theses electrical signals present variations in voltage as a function of (i.e. representing) said detected waves.

According to an embodiment, said processing unit 350 is arranged to only receive said signals from the various sensor means 310 and forward these to said first control unit 200 for processing an analysis and determination of excavating efficiency of said drilling process. According to an embodiment, said processing unit 350 is arranged with necessary electronics/software for processing said received signals and perform said determination of excavating efficiency of said drilling process. Hereby said determination of said drilling process may thus be performed at only said processing unit 350, only at said first control unit 200 (or second control unit 210), or partly in said processing unit 350 and partly in said first control unit 200.

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According to an embodiment, said detection of variations in magnetic fields caused by waves of said tool member 232, 234 is performed without an external magnetic field. Hereby permanent magnets of said sensor means are used for amplification.

According to another embodiment, said detection of variations in magnetic fields caused by waves of said tool member 232, 234 is performed with applied external magnetic fields. Hereby permanent magnets of said sensor means are used for amplification. This is depicted in greater detail with reference to Figure 3e.

According to another embodiment, said sensor means 310 comprise capacitor members, such as for example plate capacitors, arranged for capacitive sensing of said waves in said tool member 232, 234. This may be arranged in a suitable way so as to in a corresponding way as inductive members detecting waves of said tool member 232, 234.

The first control unit 200 is arranged to determine excavating efficiency of said drilling process on the basis of detected waves of said tool member. The first control unit 200 is according to an embodiment arranged to control operation of said drilling configuration on the basis of said determined efficiency. Hereby, for example, feeding pressure of the drilling configuration 299 may be controlled. Hereby, for example, rotational speed of said drilling steel 234 may be controlled. Hereby, for example, striking frequency of said drilling machine 230 may be controlled. Also other functions may hereby be controlled, such as for example flushing of said drilling process. According to an embodiment, said first control unit 200 is arranged for automatically controlling operation of said drilling configuration on the basis of said determined excavating efficiency. According to another embodiment, said control unit 200 is arranged for continuously or intermittently present information, by means of said presentation means 280, for an operator of the drilling configuration 299 regarding adaption of operation of said drilling configuration 299 on the basis of said determined excavating efficiency.

Controlling operation of said drilling configuration 299 may involve minimizing the shock wave reflections from the rock in said tool member. Where minimum energy of reflected waves is presented, a maxium of energy is transferred in to the rock. Controlling of

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operation of said drilling configuration 299 may aim for optimizing towards a certain proportion between tensile waves and pressure waves of said tool member. Further, analysis of said detected waves may be used for determining whether any or some of the connections of said drilling steel 234 are loose. Further, detected shock waves of the tool member may be used for determining a prevailing state of a striking arrangement of said drilling machine 230. Further, detected shock waves of the tool member may be used for determining a prevailing state of a damping system of the drilling configuration 299. Hereby, a measure of the performance of the damping system may be determined.

Figure 3b schematically illustrates a cross section view of said detection unit 300, such as that of figure 3a, according to an embodiment of the invention. Said detection unit 300 may comprise an outer enclosure consisting of for example plastics or other suitable material. Said detection unit 300 may comprise a suitable shock damping material enclosing the sensor means 310:1, 310:2, 310:3 and 310:4 and the processing unit 350. Said shock damping material may for example comprise a gel that is functioning as electrically and thermally insolating and presents good shock damping properties.

Figure 3c schematically illustrates a detection unit 300 which comprises only two sensor means in the form of inductive coil members 310:1 and 310:2, for comparative purposes with the sensor arrangement proposed by the present invention. The two inductive coil members are positioned diametrically opposite with a respective central axis perpendicular to a longitudinal axis of said tool member 232, 234. Whilst a method for determining excavating efficiency may work with only two sensor members, accuracy of the detection of waves of said tool member 232, 234 is severely diminished as compared with that of the present invention as defined in the appended claims. It should be noted that it is advantageous to arrange sensor members pairwise, i. e. multiples of 2, for example 4, 6 or 8 sensor members. The sensor means of the respective pairs will hereby be arranged opposite to each other, which is exemplified with reference to Figure 3d. In Figure 3d four pairs of sensor means are arranged rotationally off-set to each other about the axis of the tool member 232, 234 extending through the detection unit 300 with an internal angle V of 45 degrees to each other. It should be noted that the inventive method is applicable also where an odd number of sensor members are provided, as for such of example three, five or seven

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senor members, even though it is computational more complicated to determine excavating efficiency of said drilling process. By processing sensor means pairwise, determination of characteristics of said detected waves may be processed with higher accuracy. This is because detected amplitudes of waves of two opposite positioned sensor means can be normalized. This is an advantageous way of determining energy content of detective waves.

According to an embodiment not illustrated here, additional sensors oriented in a symmetrical configuration corresponding to a certain rotation relative to an already existing configuration of sensor means (as per the above embodiments) for detecting torsion waves in said tool member. These additional sensor means may be substantially identical with existing sensor means 310:1 etc. The additional sensor means may also be arranged pairwise in a corresponding way as the already provided said sensor means. By arranging these additional sensor means (for example inductive coil members) with a different orientation than the existing sensor means, torsion waves of the tool member 232, 234 may be detected in an efficient manner. Hereby, the additional coil members present not only a central axis which is parallel to a radial direction of said tool member 232, 234. In other words the additional coil members do not present a central axis which is perpendicular to a longitudinal direction of said tool member 232, 234.

Figure 3d schematically illustrates a detection device 300, according to another embodiment of the invention. According to this embodiment four pairs of sensor means 310:1 to 310:8 are symmetrically arranged on mutually opposite sides of said tool member 234, 234 adjacent to, but at a certain distance from, said tool member 232, 234. The sensor means 310:1 and 310:2 constitute a first pair, the sensor means 310:3 and 310:4 constitute a second pair, the sensor means 310:5 and 310:6 constitute a third pair and the sensor means 310:7 and 310:8 constitute the fourth pair.

By first determining amplitudes of a wave detected by means of the sensor means in one of said pairs and normalizing these, an accurate determining of characteristics of said wave is achieved. Hereby normalized amplitudes are determined for the relevant detected wave, after which adding and mean value determination of all detected amplitudes is performed. This is performed by means of the first control unit 200.

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Figure 3e schematically illustrates a coil member 310:1 of said detection unit 300, according to an embodiment of the invention. According to this example, said coil member 310:1 comprises four permanent magnets 310:1a, 310:1b, 310:1c and 310:1d arranged within the wiring of the coil member for amplifying changes generated by waves of the tool member 232, 234. An arbitrary number of permanent magnets may be arranged at said coil member 310:1. Preferably all coil members of the detection device 300 comprise substantially similar sets of permanent magnets.

According to an example, the coil members of the detection device present an elliptical cross section. Said elliptic form is advantageous for more accurate detecting flanks of the waves which are propagating in said tool member. The higher ratio between the axes of the ellipse, the more accurate said flaks may be detected. It should be noted that said coil members also may present a circular cross section according to an embodiment of the present invention. According to alternative embodiments, the coil members of the detection device 300 may present other forms than elliptical, for example rectangular.

Figure 4a schematically illustrates a diagram of wave propagation in said tool member 232, 234. In this diagram, the cutter of the tool is not in contact with the material which should be mined. The tool member hereby presents a free end (cutter) and a secured end at the neck adaptor 232. Hereby a quantity Q as function of time T given in seconds is presented. Q is a representation of a quantity which is associated with and proportional to strain in said tool member 232, 234. Amplitude Q for waves may hereby be measured by means of said detection device. The quantity Q is proportional to amplitude of the waves which are detected. According to this example it is illustrated how a shock wave, generated by a striking arrangement of the drilling machine 230, is detected at a first point of time T1. The duration of the wave is T2-T1. This shock wave is reflected in the cutter of the tool member and a tension wave (propagating in a direction opposite of the corresponding shock wave) appears at a point of time T3 and has a duration T4-T3.

Figure 4b schematically illustrates a diagram of wave propagation in said tool member 232, 234 where said cutter 236 is positioned against the material which is to be mined. Said tool

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member is hereby rotated. In a corresponding way, a shock wave is hereby appearing, generated by a striking arrangement of the drilling machine 230, which is detected at a first point of time T1. The duration of the wave is T2-T1. This shock wave causes breaking of said material and a corresponding tensile wave (propagating in a direction opposite the corresponding compressive shock wave) appears at a point of time T3 and has a duration T4-T3.

By analysing energy content of said shock wave and a corresponding tensile wave it may be determined how effective said drilling process really is. There are different ways of analysing this. According to one example, an amplitude of each respective wave may be integrated over the time T, for obtaining a respective measure of energy content.

Figure 5a schematically illustrates a flowchart of a method for determining excavating efficiency of a drilling process, according to an embodiment of the invention. The method comprises a first method step s501. The step s501 comprises the steps of:

- transferring energy via tool member 232, 234 to the material in which drilling is to be performed by means of the drilling configuration 299;
- detecting waves which propagate in said tool member 232, 234 of said drilling configuration 299 during drilling by energy transfer;
- detecting said waves by means of at least four sensor means arranged pairwise on mutually opposite sides of said tool member 232, 234 adjacent to, but at a certain distance from, said tool member 232, 234, which sensor means configured for inductive and/or capacitive detection of said waves in said tool member 232, 234; and
- based on results of said detection, determining said excavating efficiency of said drilling process.

After the step s501 the method is ended/returned.

Figure 5a schematically illustrates a flowchart of a method for determining excavating efficiency of the drilling process, in more detail, where both striking and rotational movement of the tool member is affected.

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The method comprises a first method step s510. The step s510 comprises the step of transferring energy via the tool member 232, 234 to the material in which drilling is to be performed by means of the drilling configuration 299. Said energy may be provided by means of strikes of said drilling machine and/or rotational movement of said tool member 232, 234. It should be noted that a feeder pressure is applied to said drilling configuration 299. After the step s510 a subsequent step s520 is performed.

The step s520 comprises the step of detecting waves which are propagating in said tool member 232, 234 of said drilling configuration 299 during drilling by the energy transfer. These waves may be pressure waves and corresponding waves reflected by the rock. These waves may also comprise torsion waves. Detection of these waves is performed by means of the inventive detection device 300. Said waves may be detected by at least two sensor mean pairs, wherein the sensor means of each pair are arranged at mutually (diametrically) opposite sides of said tool member 232, 234 adjacent to, but at a certain distance from, said tool member (232, 234), which sensor means are based on inductive and/or capacitive detection of said waves in said tool member 232, 234.
After the step s520 a subsequent step s530 is performed.

The step s530 comprises the step of, based on results of said detection, determining said excavating efficiency of said drilling process. This may be performed in various ways. According to one embodiment said excavating efficiency of the drilling process is determined on the basis of comparisons between original (compressive) pressure waves and reflecting tension waves in said tool member 232, 234. Hereby a difference regarding energy content between the waves may be determined. Such difference indicates excavating efficiency of the drilling process. According to another embodiment, said excavating efficiency of said drilling process may be determined on the basis of characteristics of a few reoccurring tension waves in said tool member. This is applicable when no strikes are provided by the drilling configuration 299.
In a case where said waves are detected by means of four sensor means 310:1; 310:2; 310:3; 310:4 symmetrically arranged on mutually opposite sides of said tool member 232, 234, detection results from said sensor means 310:1; 310:2; 310:3; 310:4 will be processed pairwise as basis for said determination.

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After the step s530 a subsequent step s540 is performed.

The step s540 comprises the step of continuously controlling said drilling process based on such determined excavating efficiency for an efficiency optimization. This can, according to one embodiment, be performed automatically by means of said first control unit 200. According to one embodiment, an operator of the drilling configuration 299 can control said drilling process on basis of instructions presented by means of said presentation means 280. After the step s540 the method is ended/returned.

With reference to Figure 6 there is illustrated a diagram of one version of a device 600. The control units 200 and 210 described with reference to Figure 2 may in one version comprise the device 600. The device 600 comprises a non-volatile memory 620, a data processing unit 610 and a read/write memory 650. The non-volatile memory 620 has a first memory element 630 in which a computer program, e.g. an operating system, is stored for controlling the function of the device 600. The device 600 further comprises a bus controller, a serial communication port, I/O means, an A/D converter, a time and date input and transfer unit, an event counter and an interruption controller (not depicted). The non-volatile memory 620 has also a second memory element 640.

There is provided a computer program P comprising routines for determining efficiency of a drilling process where energy is transferred via a tool member 232, 234 to the material in which drilling is to be performed by means of a drilling configuration 299.

The computer program P may comprise routines for detecting waves which are propagating in said tool member 232, 234 of said drilling configuration 299 during drilling as a result of energy provision.

The computer program P may comprise routines for detecting said waves by means of at least two sensor means 310:1; 310:2 arranged on mutually opposite sides of said tool member 232, 234 adjacent to, on a certain distance from, said tool member 232, 234, which sensor means 310:1; 310:2 are based on inductive and/or capacitive detection of said waves in said tool member 232, 234.

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The computer program P may comprise routines for, based on results of said detection, determining said efficiency of said drilling process.

The computer program P may comprise routines for detecting said waves by means of four sensor means 310:1; 310:2, 310:3; 310:4 symmetrically arranged at mutually opposite sides of said tool member 232, 234 adjacent to, on a certain distance from, said tool member 232, 234.

The computer program P may comprise routines for processing results from said sensor means 310:1; 310:2, 310:3; 310:4 pairwise (310:1, 310:2; 310:3, 310:4) as basis for said determination.

The computer program P may comprise routines for detecting said waves wherein said sensor are positioned at a preferred position along said tool member 232, 234 where lateral movements of said tool member 232, 234 are relatively small.

The computer program P may comprise routines for controlling operation of said tool member 232, 234 whereby said energy is provided by means of strikes and/or rotation.

The computer program P may comprise routines for inductively detecting said waves by means of oppositely arranged coil members 310:1, 310:2 comprising at least one permanent magnet 310:1a as coil core.

The computer program P may comprise routines for determining said efficiency of said drilling process on the basis of comparisons between original pressure waves and reflecting tensile waves in said tool member 232, 234.

The computer program P may comprise routines for determining said efficiency of said drilling process on the basis of characteristics of a few reoccurring tensile waves in said tool member 232, 234.

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The computer program P may comprise routines for detecting waves in said tool member 232, 234 by means of additional sensor means oriented in a symmetrical configuration corresponding to a certain rotation relatively an already provided configuration of sensor means for detection of torsion waves in said tool member 232, 234.

The computer program P may comprise routines for continuously controlling said drilling process based on such determined efficiency for an efficiency optimization.

The program P may be stored in an executable form or in compressed form in a memory 660 and/or in a read/write memory 650.

Where it is stated that the data processing unit 610 performs a certain function, it means that it conducts a certain part of the program which is stored in the memory 660 or a certain part of the program which is stored in the read/write memory 650.

The data processing device 610 can communicate with a data port 699 via a data bus 615. The non-volatile memory 620 is intended for communication with the data processing unit 610 via a data bus 612. The separate memory 660 is intended to communicate with the data processing unit 610 via a data bus 611. The read/write memory 650 is arranged to communicate with the data processing unit 610 via a data bus 614. The links L200, L210 and L280, for example, may be connected to the data port 699 (see Figure 2). When data are received on the data port 699, they are stored temporarily in the second memory element 640. When input data received have been temporarily stored, the data processing unit 610 will be prepared to conduct code execution as described above. According to one embodiment, the signals received on the data port 699 comprises information about energy content of pressure waves and tensile waves in said tool member. According to one embodiment, the signals received on the data port 699 comprises information about torsion waves in said tool member. The signals received on the data port 699 may be used by the device 600 for determining said efficiency of said drilling process.

Parts of the methods herein described may be conducted by the device 600 by means of the data processing unit 610 which runs the program stored in the memory 660 or the read/write

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memory 650. When the device 600 runs the program, method steps described herein are executed.

The foregoing description of the preferred embodiments of the present invention is provided for illustrative and descriptive purposes. It is not intended to be exhaustive, nor to limit the invention to the variants described. Modifications and variations will suggest themselves to one skilled in the art. The embodiments have been chosen and described in order to explain the principles of the invention and their practical applications and thereby make it possible for one skilled in the art to understand the invention for different embodiments and with the various modifications appropriate to the intended use.

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Claims

1. A method for determining excavating efficiency of a drilling process, comprising the steps of:

- transferring energy, via a tool member used in the drilling process, to the material in which drilling is to be performed by means of a drilling configuration;

- detecting waves which propagate in said tool member during drilling, as a result of energy transfer, wherein detecting said waves comprises inductive and/or capacitive detection by at least two pairs of sensor means symmetrically arranged in the detection unit, wherein each pair of sensor means comprises two sensors located on mutually opposite sides of said tool member adjacent to, but at a certain distance from, said tool member, wherein each of the sensors comprises an inductive coil member with at least one permanent magnet as a coil core, wherein the coil members have a substantially elliptic configuration and are arranged at said tool member such that a shorter ellipse axis extends substantially parallel with a longitudinal direction of said tool member, and wherein detecting said waves comprises pairwise processing signals representative of said detection from each pair of sensors of the at least two pairs of sensor means; and

- determining said excavating efficiency of said drilling process based on comparisons between original pressure waves and reflected tensile waves in said tool member, or based on characteristics of a few reoccurring tensile waves in said tool member.

2. The method according to claim 1, wherein the sensors of the at least two pairs of sensor means are positioned at a defined position along a longitudinal direction of said tool member where lateral movements of said tool member during drilling are relatively small.

3. The method according to claim 1 or 2, wherein transferring said energy is by means of strikes and/or rotation of the tool member.

4. The method according to anyone of claims 1 to 3, comprising the further step of:

- continuously controlling said drilling process based on such determined excavating efficiency for an efficiency optimization.

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5. A system for determining excavating efficiency of a drilling process, comprising:

-a drilling configuration arranged for transferring energy via a tool member to a material in which drilling is to be performed;

- a detection unit arranged about the tool member of the drilling configuration, wherein the detection unit comprises at least two pairs of sensor means configured for inductively and/or capacitively detecting waves propagating in said tool member during drilling as a result of energy transfer, wherein the at least two pairs of sensor means are symmetrically arranged in the detection unit with each pair of sensor means comprising two sensors located on mutually opposite sides of said tool member, adjacent to, but at a certain distance from, said tool member, wherein each of the pair of sensor means comprises two oppositely arranged coil members having at least one permanent magnet as a coil core for inductively detecting said waves, and wherein the coil members have a substantially elliptic configuration with a shorter ellipse axis arranged substantially parallel with a longitudinal direction of the tool member; and

- at least one control unit configured to receive the inductive and/or capacitive detection results from the detection unit and to perform pairwise processing of the detection results for each pair of sensor means of the at least two pairs of sensor means, wherein the at least one control unit is further configured for determining said excavating efficiency of said drilling process based on comparisons of original pressure waves with reflected tensile waves propagating in said tool member, or based on characteristics of a few reoccurring tensile waves propagating in said tool member.

6. The system according to claim 5, wherein the at least two pairs of sensor means are located at a position along said tool member at which lateral movements of said tool member are relatively small.

7. The system according to claim 5 or 6, wherein the drilling configuration is configured for providing said energy by means of strikes and/or rotation.

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8. The system according to anyone of claims 5 to 7, wherein the at least one control unit is further configured for continuously controlling said drilling process based on such determined excavating efficiency for an efficiency optimisation.

9. A drilling rig comprising a system according to anyone of claims 5 to 8.

10. A computer program product, comprising a computer-readable storage medium and program code stored on the computer-readable medium, the program code loadable into an electronic control unit or a computer connected to the electronic control unit and coding to execute the method steps according to anyone of claims 1 to 4 with a drilling rig when said program code is run on the electronic control unit or the computer connected to the electronic control unit.

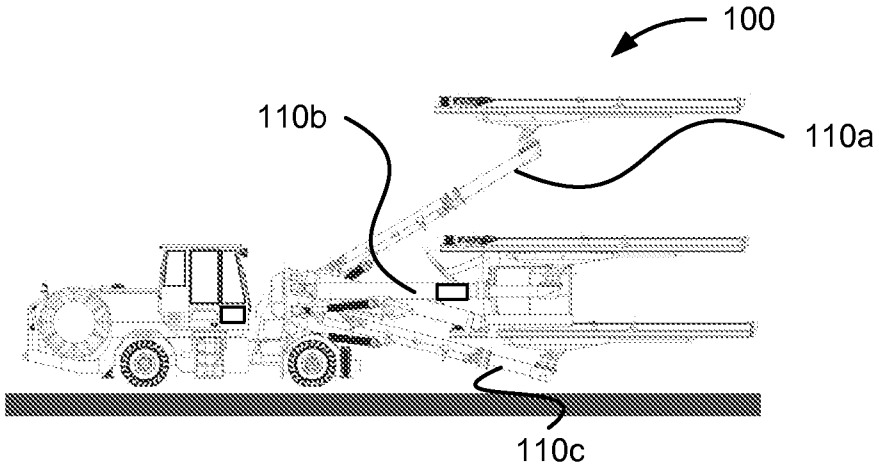

100
110b
110a
110c

Fig. 1

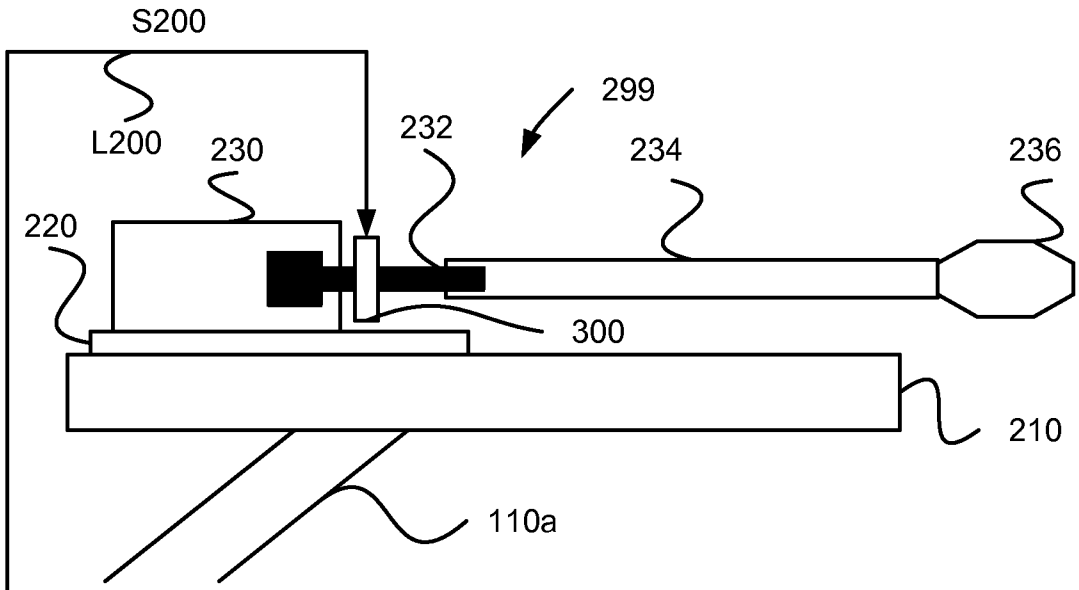
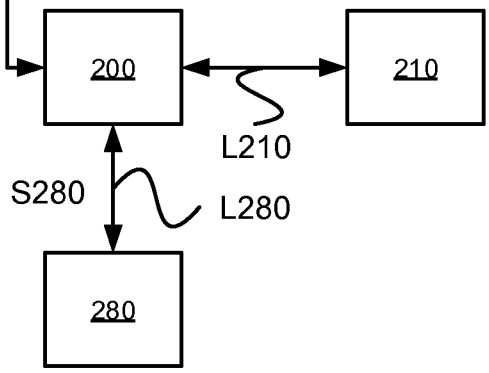

S200
L200
230
232
299
234
236
220
300
210
110a

Fig. 2


200
210
L210
S280
L280
280

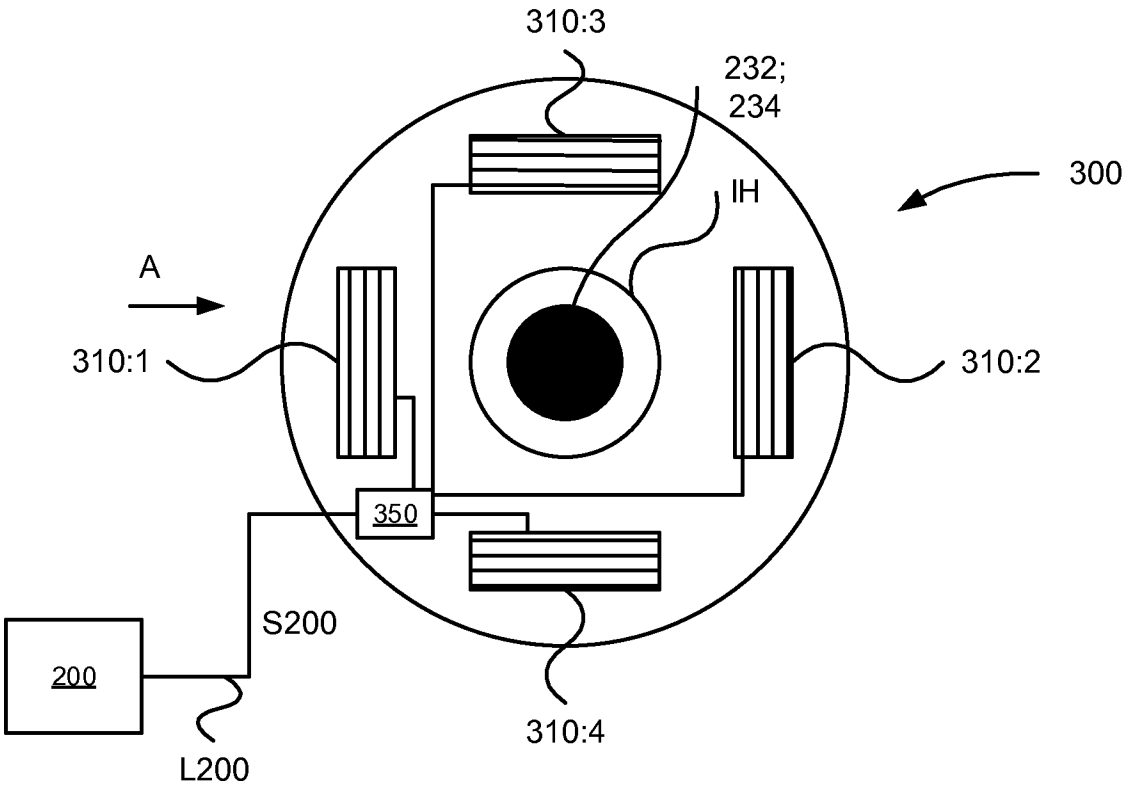

310:3
232;
234
300
IH
A
310:1
310:2
350
S200
200
L200
310:4

Fig. 3a

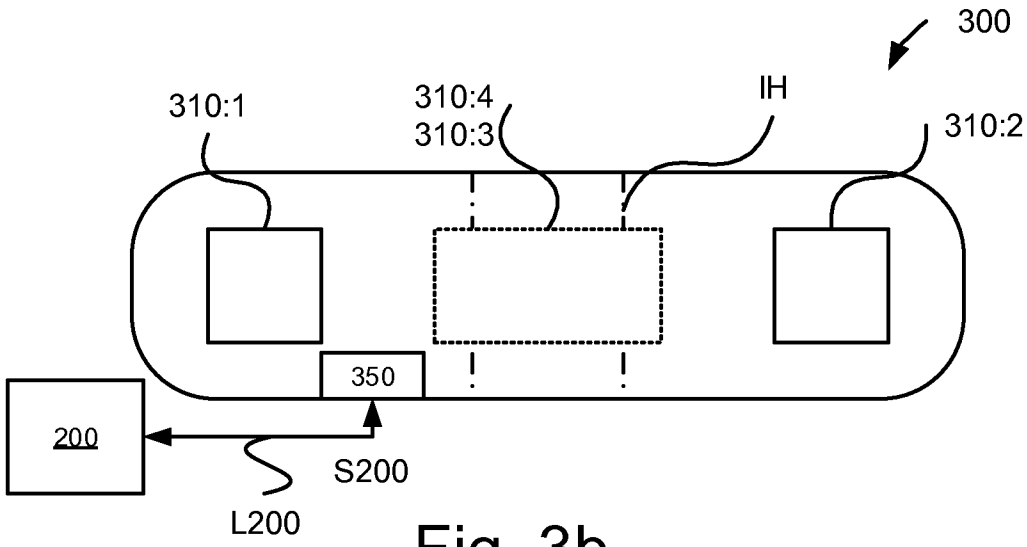

300
310:1
310:4
310:3
IH
310:2
350
200
S200
L200

Fig. 3b

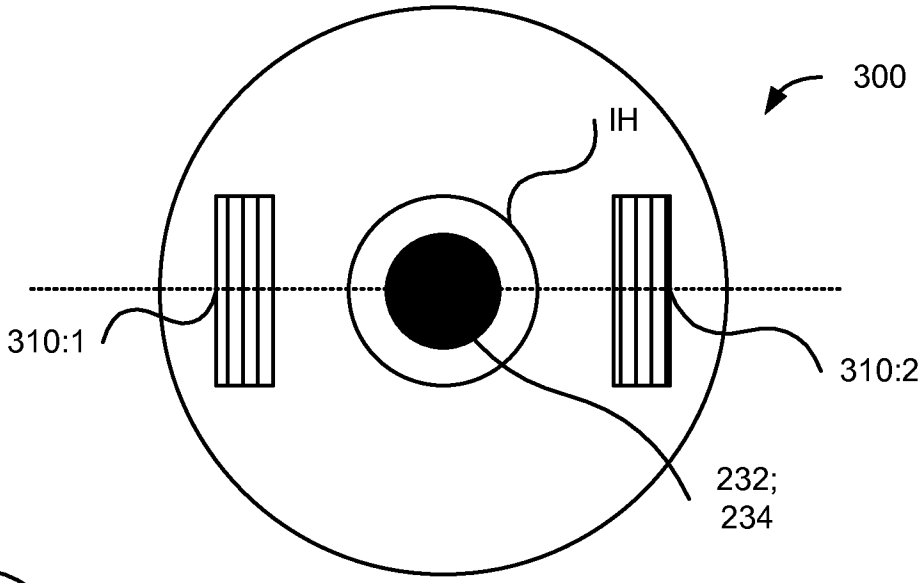


Fig. 3c

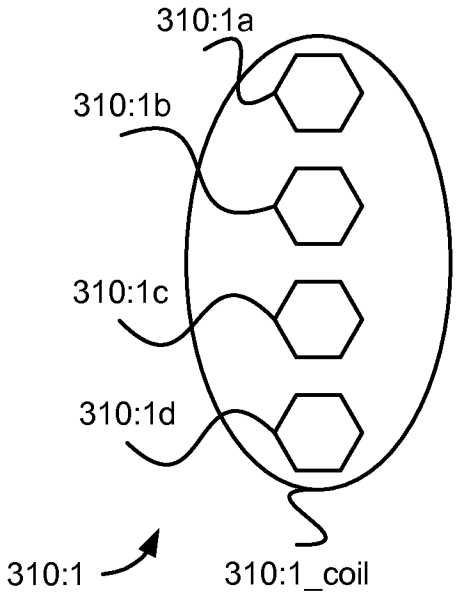


Fig. 3e

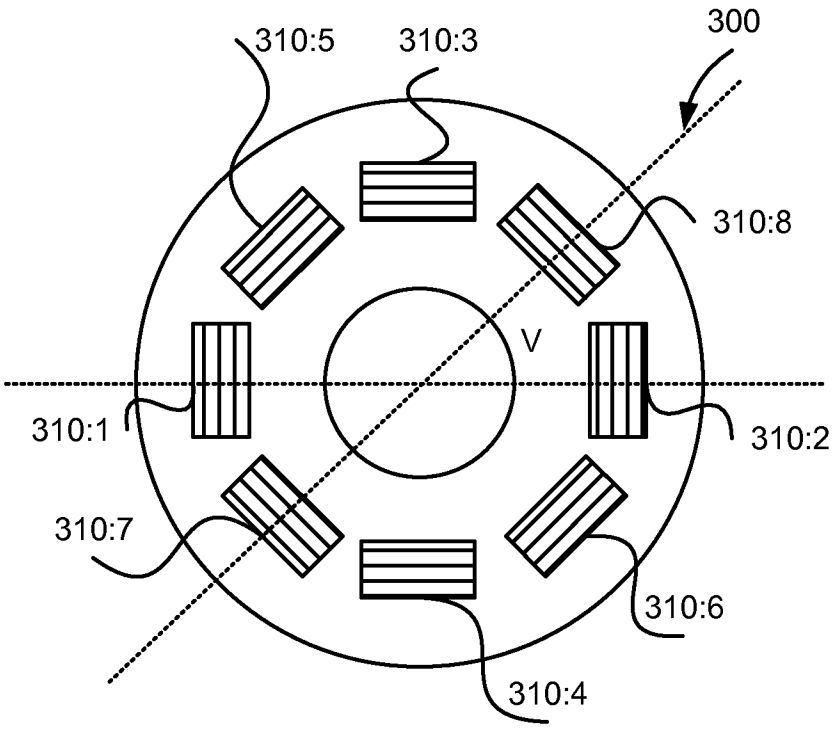


Fig. 3d

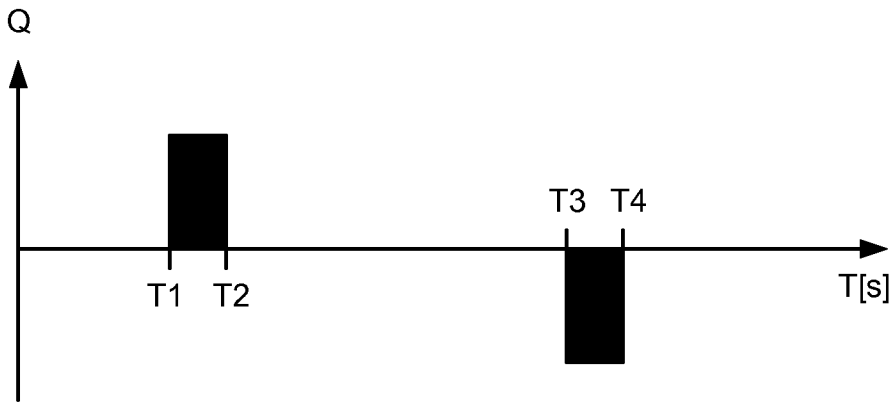


Fig. 4a

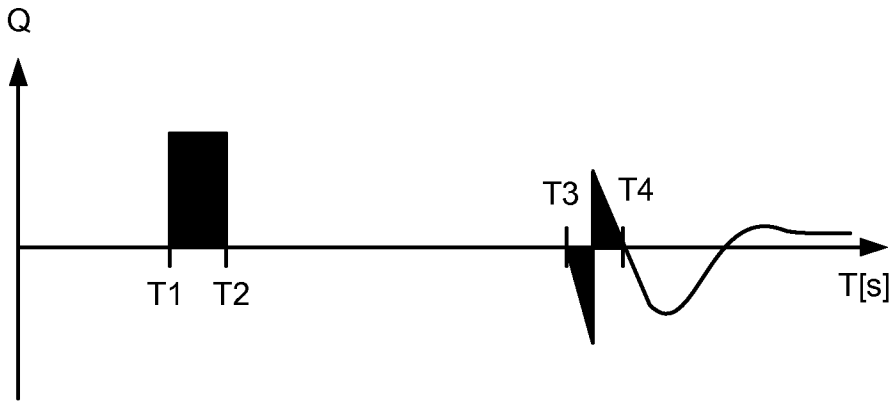


Fig. 4b

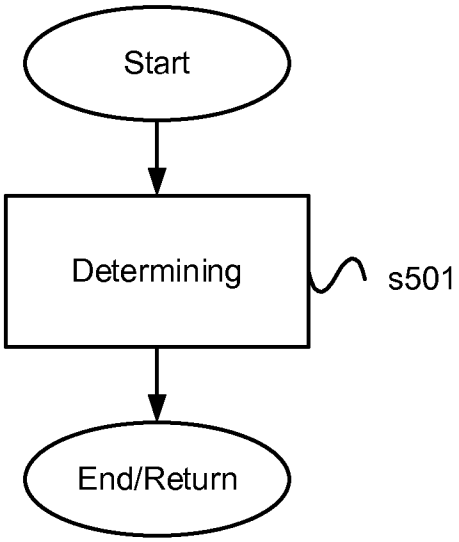

Start
Determining
s501
End/Return

Fig. 5a

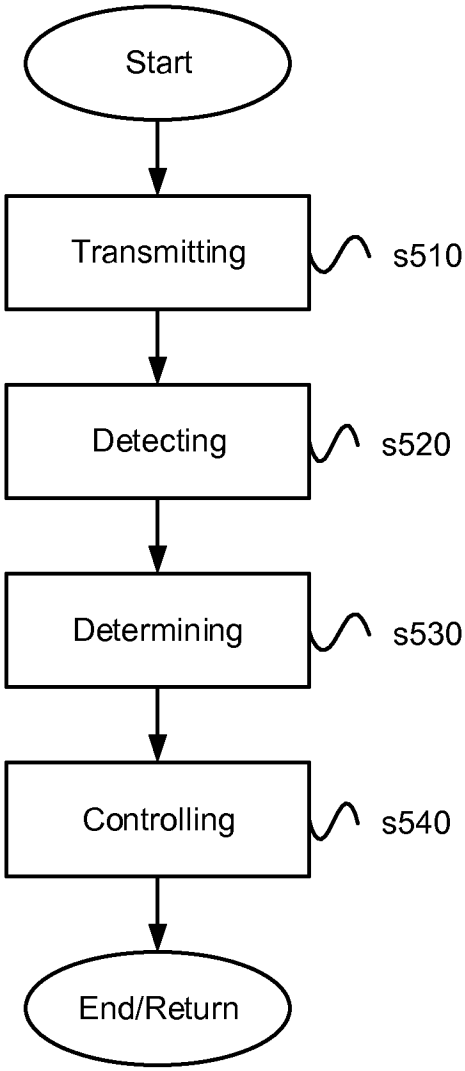

Start
Transmitting
s510
Detecting
s520
Determining
s530
Controlling
s540
End/Return

Fig. 5b

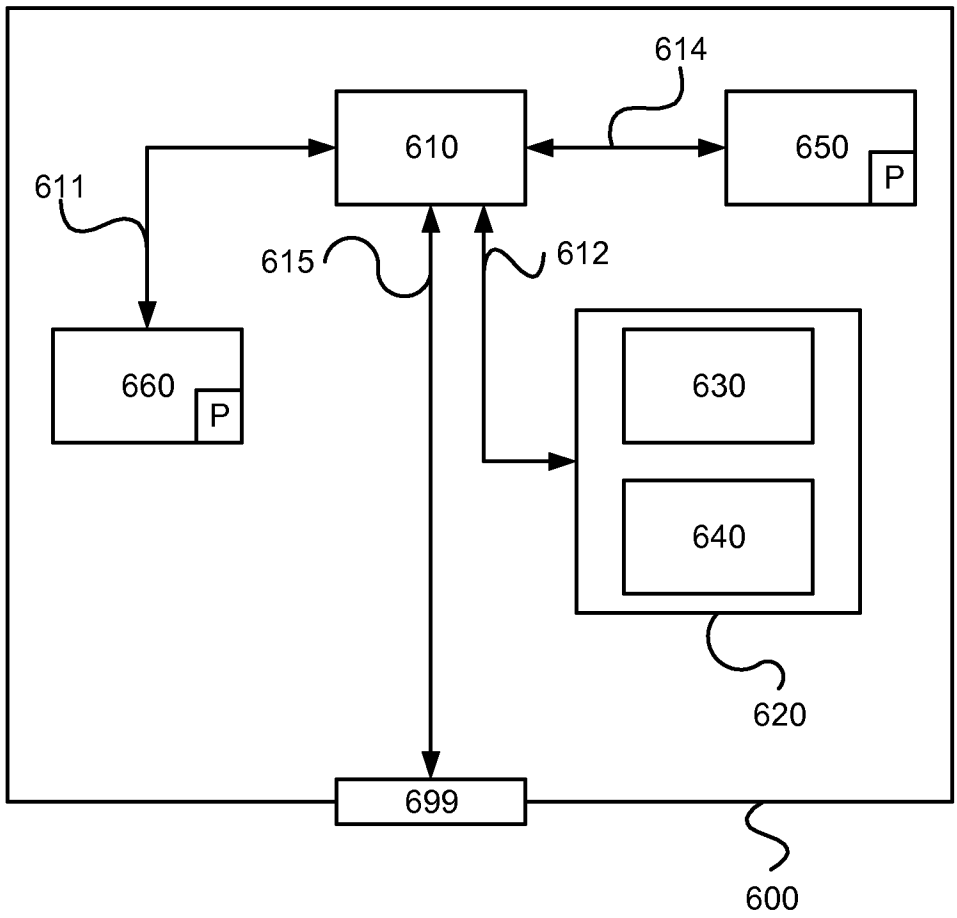


Fig. 6