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(54) **Title**: METHOD FOR CONTROLLING ROCK DRILLING

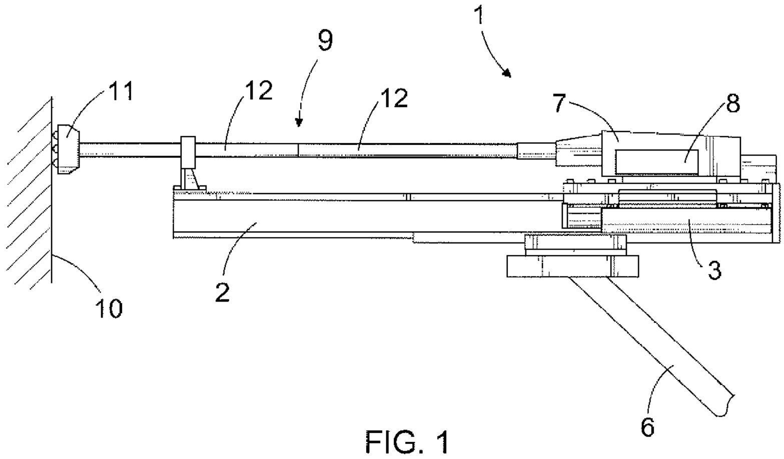

FIG. 1

(57) **Abstract**: A method for controlling rock drilling with a percussion device (7) belonging to a rock drill (1) to deliver impact pulses to rock through a tool (9) by pushing the tool against the rock by means of a feed device (3) and rotating simultaneously the tool by means of a rotation motor, whereby the maximum feed force is determined, pressure medium is fed to the feed device (3) and to the rotation motor and the feed force is controlled according to the drilling conditions. The feed force is controlled by using the feed speed as a first control parameter and the rotation torque as a second control parameter so that the feed force is controlled inversely proportionally to the feed speed and inversely proportionally to the rotation torque and the feed force is controlled using both the first and the second control parameter simultaneously.

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METHOD FOR CONTROLLING ROCK DRILLING

BACKGROUND OF THE INVENTION

The invention relates to a method for controlling rock drilling

wherein a percussion device belonging to a rock drill machine delivers impact pulses to rock through a tool; wherein the rock drill machine is simultaneously pushed against the rock by means of a feed actuator, and the tool is simultaneously rotated by means of a rotation motor;

the method comprising:

determining the maximum feed force;

feeding a pressure medium to the feed actuator along at least one feed channel;

feeding the pressure medium to the rotation motor along at least one rotation motor pressure channel; and

controlling the feed force according to the drilling conditions.

When holes are drilled into rock, the drilling conditions may vary in several ways. The rock may include voids and cracks, and rock layers having different hardness, which is why drilling parameters should be adjusted according to the drilling conditions.

Conventionally, an operator controls the operation of a rock drill machine on the basis of his or her personal experience. The operator sets certain drilling parameters on the basis of the presumed rock characteristics. During drilling, the operator checks the rotation and monitors the progress of the drilling. When necessary, he changes the feed force and/or the percussion power of the percussion device to suit a particular type of rock, thus trying to achieve a fast but still smooth drilling process. In practice, the operator is able to adjust one only drilling parameter and control its influence on the drilling process in several seconds or tens of seconds. When the quality of rock or the drilling characteristics thereof changes rapidly, even a qualified operator cannot adapt the drilling parameters quickly enough to suit the rock. It is thus obvious that the operator cannot ensure a good tool life if drilling conditions vary rapidly. Furthermore, it is practically impossible even for a qualified operator to monitor and control the operation of the rock drilling machine during an entire working shift such that the drilling progresses efficiently at every moment, simultaneously taking into account the stresses the tool is subjected to.

BRIEF DESCRIPTION OF THE INVENTION

An object of the invention is to provide a novel and improved method for controlling rock drilling.

The method of the invention is characterized by using the feed speed for controlling the feed force as a first control parameter for controlling the feed force;

controlling the feed force inversely proportionally to the feed speed;

using the rotation torque as a second control parameter for controlling the feed force;

controlling the feed force inversely proportionally to the rotation torque; and

controlling the feed force simultaneously using both the first and the second control parameter such that the control of the feed force is proportional to the combined control of both control parameters.

The idea underlying the invention is that a maximum feed force is first determined and set to the drilling control. The maximum feed force is in practice determined by setting the maximum pressure of the pressure fluid, which affects the feed cylinder. According to one embodiment of the invention the maximum feed force is affecting only, when the feed speed is zero. According to the idea of this invention the value of the feed speed is used to decrease the feed force, when the feed speed increases. Further according to the idea of the invention the rotation torque is used to control the feed force so that the feed force is decreased when the rotation torque is increased. As a summary the feed force is controlled simultaneously using both the feed speed and the rotation torque such that the control of the feed force is inversely relative to the combined effect of both the feed speed and the rotation torque. Correspondingly the feed force is increased when the feed speed and/or the rotation torque is decreased.

An advantage of the invention is that changes in the drilling conditions can be sensed and used in controlling the drilling effectively and automatically.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in closer detail in the accompanying drawings, in which:

Figure 1 is a schematic side view showing a rock-drilling unit, Figures 2 is a schematically presented hydraulic diagrams according to the invention,

Figure 3 is a schematically presented electrically controlled hydraulic diagrams according to the invention, and

Figure 4 is a schematic and sectional view showing the principle of the control method and

Figure 5 is a schematic diagram presenting still another embodiment of the invention.

For the sake of clarity, the figures show the invention in a simplified manner. Same reference numerals identify similar elements.

DETAILED DESCRIPTION OF THE INVENTION

The rock-drilling unit shown in Figure 1 comprises a rock drill machine 1 arranged on a feed beam 2. The rock drill machine 1 can be moved in the longitudinal direction of the feed beam 2 by means of a feed device 3. The feed actuator 3 is arranged to affect the rock drill machine 1 through a power transmission element, such as a chain or a wire. The feed actuator 3 may be a pressure medium cylinder or a pressure medium motor operated by pressure fluid in a manner known as such. The rock drill machine 1 and a tool 9 connected thereto are pressed against rock 10 by using a feed force of a desired magnitude. The feed beam 2 may be movably arranged at a free end of a drilling boom 6 belonging to the rock drilling apparatus. The rock drill machine 1 comprises at least a percussion device 7 and a rotating device 8. The percussion device is used for generating impact pulses to the tool 9 connected to the rock drill machine 1, the tool delivering the impact pulses to the rock 10. An outermost end of the tool 9 is provided with a drill bit 11, the bits therein penetrating the rock 10 due to the impact pulses, causing the rock 10 to break. Furthermore, the tool 9 is rotated with respect to its longitudinal axis, which enables the bits in the drill bit 11 always to be struck at a new point in the rock 10. The tool 9 is rotated by means of the rotating device 8, which may be e.g. a pressure medium operated device or an electric device. The tool 9 may comprise several drill rods 12 arranged on each other consecutively. Screw joints may be provided between the drill rods 12. In the solution of the invention, the percussion device 7 is a hydraulically operated. The percussion device 7 may comprise a percussion piston, which is moved to and fro by means of a pressure medium and which is arranged to strike upon a tool or a shank adapter arranged between a tool and a percussion piston. Of course, the invention may also be applied in connection with pressure medium operated percussion devices 7 wherein impact pulses are generated in a manner other than by means of a percussion piston moved to and fro.

Figure 2 shows a schematic presentation of this invention. A hydraulic circuit comprises a pump 20 pumping pressure fluid from reservoir 15 and for generating the necessary pressure and flow for the pressure medium. When necessary, the number of pumps 20 may be larger. Furthermore, the pump 20 may be a fixed displacement pump or a variable displacement pump. A pressure medium is conveyed from the pump 20 via a proportional feed control valve 21 to the feed device 3 which is connected to the rock drill 1 for feeding it forward during drilling and retracting it when necessary. Further the pressure medium is conveyed from the pump 20 via a rotation control valve 22 to a rotation device 8 for rotating tool 9 during drilling.

The hydraulic circuit of a feed cylinder can be connected as presented in the figure. Also it is possible to use a solution, in which the pressure fluid from the piston rod 3b side of the feed cylinder 3 is fed to the other side of the piston 3a when the piston 3a is pushed towards the piston rod 3b side of the feed cylinder 3. This kind of connection is commonly known as a differential connection.

The pressure channel 23 via which in the pressure medium is conveyed to the rotation device during drilling is connected via a control channel 24 to control the proportional feed control valve 21.

The spool of the proportional feed control valve 21 through which the pressure fluid flows to the feed device 3 and away from the other side of the piston 3a of the feed device 3 restricts the amount of the pressure medium flow with restrictors 25 and 26. The amount of restriction can be controlled by changing the spool position in relation to valve inlet and outlet channels. Thus the guiding edges of the spool control the flow. Restrictors 25 and 26 can be separate restrictors located into the valve 21. Alternately restrictors 25 and 26 can be created with the construction of the spool and the body of the valve 21.

When starting drilling the spool of the valve 21 is set to a position in which pressure fluid flows from pump 20 to channel 27. The pressure p_1 in channel 27 via which the pressure medium is conveyed to the feed device 3 for feeding rock drill 1 forward is set to a predetermined value, which defines the maximum feed force. The feed speed is dependent on the liquid volume flow to the feed device 3. If the drilling resistance is small the feed speed increases. Since the pressure medium flow increases through the proportional feed control valve 21 the pressure drop over the valve spool increases as a result of the flow increase through restrictor 25. As a result the pressure difference between the feed channel 27 and channel 28 via which pressure medium is removed from the feed device decreases and the feed force acting to the rock drill decreases correspondingly since the feed force is a result of the pressure acting on piston 3a. In case of soft material or broken stone or when drilling downwards and the weight of drill rods is big the feed may start rushing forward. This is, however, limited with the restrictor 26 in channel 28, which cause limited feed speed and also pressure decrease with increased fluid flow and thus decreases the feed speed and force. In case of drilling downwards and when the weight of drill rods is big you have to hold the mass of rods avoiding too high feed force.

Simultaneously the rotation torque, which is expressed as a pressure in the rotation device in channel 23 is used to control the feed control valve 21 if the rotation resistance increases, and thus the rotation pressure in channel 23 increases correspondingly in relation to the torque. This pressure affects the feed control valve 21 to restrict the flow of the pressure medium to feed device 3 and decrease the pressure in relation to the increase of the rotation pressure. Thus both feed speed and the rotation torque control the feed force in relation to their values. Correspondingly, if the feed speed decreases because of higher resistance the flow of the pressure medium decreases and the pressure acting the piston of the feed device increases thus increases the feed force. Again if the rotation resistance decreases the pressure acting the feed control valve 21 decreases and the restriction of the feed control valve 21 decreases thus raising the pressure in channel 27 and thus the feed force of the feed device.

Fig 2 also shows two valves 3b in channels 27 and 28. These are counterbalance valves, which close the channels tightly, when there is no fluid pressure in the channels. Thus the load formed by the rock drill and the tool cannot slide relative to the feed beam. Normal control valves are not so leakproof that they could stop the movement and therefore especially for this purpose designed valves are needed. There may be two counterbalance valves one in each channel or only one in one channel, if the drilling direction remains substantially similar either upwards or downwards. Normally these counterbalance valves are assembled to the feed device in order to avoid problems in hose breaks.

Fig. 3 shows schematically another embodiment of the invention with an electric control of the feed force. In this embodiment there is a control unit 30 controlling the drilling. The feed speed is sensed with the speed sensor 31, which is located to the feed device 3. The feed speed can be measured directly with a speed sensor or indirectly by measuring the liquid flow to the feed motor or cylinder, measuring the pressure drops in the feed liquid channel over a restrictor or any as such known method.

Further feed pressure is sensed in channel 27 with a pressure sensor 32. Also the rotation torque is measured in the rotation pressure medium channel 23 with a sensor 33. Since the spool of the feed control valve 21 can restrict the flow, the pressure of the return flow channel 28 must also be measured by sensor 34. Every sensor is connected to the control unit 30, which controls then the feed control valve electrically on the basis of the sensed values. The control wires or cables have been marked commonly with 35.

In this embodiment the control unit 30 senses the torque, feed speed and the feed force as a pressure difference between channels 27 and 28 and controls the feed control valve on the basis of the measured values. The controlling principle is the same as in the hydraulic solution in fig. 2. The control unit 30 controls the feed control valve 21 so that it restricts the flow of the pressure fluid and thus controlling the feed force relative to the measured feed speed and the rotation torque.

Fig. 4 shows schematically the control method described as a control surface in which feed force, rotation pressure and feed speed have been described as a three-dimensional figure. As it can be seen from the figure the feed force is at its maximum value when the feed speed is zero. Irrespective of the rotation torque the feed force still remains at its highest value as long as the feed speed is zero in this example. It is also possible to set the control so that the feed force remains in its highest value even until the feed speed exceeds a predetermined value and to start using the control only after this. When the feed starts the feed speed increases and the feed force starts decreasing. Depending on the rotation torque value the feed force follows some of the curves in relation to the feed speed and the rotation torque. If the rotation torque is zero the feed speed and the feed force follows curve A in this example. It may be preset to operate also so that the control starts when the rotation torque exceeds a predetermined value different from zero. If the rotation torque is at its maximum, in the fig in torque value 1,5, the feed force follows curve B in relation to feed speed. In practice the feed speed and rotation torque are somewhere between their extreme values and the feed force in relation to the feed speed and the rotation torque is somewhere between the curves A and B.

Fig. 5 discloses another embodiment of the invention. In this embodiment the control is implemented in connection with a load control valve 36. The load control valve 36 is normally automatically closed and will be opened only with a control signal. When control signal disappears the load control valve 36 closes the pressure fluid channel 28 of the feed device 3 which thus cannot move. In this embodiment however the load control valve 36 is used as a part of the feed force control. In this embodiment the load control valve is designed to operate also as a counterbalance valve. Thus without a control signal it prevents the load formed from the rock drill and the tool moving relative to the feed beam.

In this solution the feed pressures in channels 27 and 28 to the feed device 3 are measured similarly as in the embodiment of fig. 3. The feed speed and/or the feed position are measured with sensor 31, which is a position sensor or a speed sensor or both. The feed speed can be calculated on the basis of measured positions during the measuring time. Correspondingly the rotation torque is measured in the pressure line of the rotation motor 8 with sensor 33 as in fig. 3.

The measured values are fed to the control unit 30, which on the basis of these values controls the pressure control valve 37 and via that the pressure compensator 39 and the load control valve 36. The control unit is connected to the feed pressure control valve 37, which is electrically controlled. The feed pressure control valve 37 controls the pressure compensator 39, which controls the pressure in channel 27. In addition the pressure control valve 37 controls the load control valve 36. It is also possible to have separate pressure control valve to control load control valve 36. The normal feed speed is preset to a value, below which the feed speed normally is.

If the feed speed exceeds that preset value the control unit 30 controls the feed pressure control valve 37 so that it starts decreasing pressure in channel 27 via the pressure compensator 39 by controlling the pressure in channel 38.

Alternately the control unit 30 controls the feed pressure control valve 37 to restrict the flow from the feed device via the load control valve 36 thus increasing the pressure loss.

The operating order of the pressure compensator 39 and the load control valve 36 can be selected by presetting their operating pressure threshold values suitably different.

The control can be done so that either of the valves is controlled first and the other one it taken into use thereafter Also the control can be done by controlling both the pressure compensator 39 and the load control valve 36 all the time simultaneously.

As a result the pressure over the feed device 3 and thus the feed force is decreased.

Correspondingly, if sensor 33 measures an increase in torque of the rotation, the control unit 30 controls the feed pressure control valve 37 and via it the load control valve 36 to restrict the flow from the feed device thus increasing the pressure loss or controls the pressure compensator 39 for controlling the pressure or both.

In this embodiment feed control valve 21 is normal proportional valve which is also controlled by the control unit 30 either directly electrically as shown in fig. 3 or as shown in fig. 5 hydraulically by using electrically controlled pilot valves 40 and 41 between the control unit 30 and feed control valve 21. Valve 21 may restrict the maximum inlet flow to feed device 3 and controls the reverse feed of the system.

The invention has been described in the specification only schematically. In practice it can be implemented in many different practical ways and thus the protection area is defined by the claims of the application.

The drawings and the related description are only intended to illustrate the idea of the invention. In its details, the invention may vary within the scope of the claims.

CLAIMS

1. A method for controlling rock drilling

wherein a percussion device belonging to a rock drill machine delivers impact pulses to rock through a tool; wherein the rock drill machine is simultaneously pushed against the rock by means of a feed actuator, and the tool is simultaneously rotated by means of a rotation motor;

the method comprising:

- determining the maximum feed force;

feeding a pressure medium to the feed actuator along at least one feed channel;

feeding the pressure medium to the rotation motor along at least one rotation motor pressure channel; and

controlling the feed force according to the drilling conditions,

characterized by

using the feed speed for controlling the feed force as a first control parameter for controlling the feed force;

controlling the feed force inversely proportionally to the feed speed;

using the rotation torque as a second control parameter for controlling the feed force;

controlling the feed force inversely proportionally to the rotation torque; and

controlling the feed force simultaneously using both the first and the second control parameter such that the control of the feed force is proportional to the combined control of both control parameters.

2. A method as claimed in claim 1, characterized by using in controlling first the first control parameter and using the second control parameter as a supplementary control parameter.

3. A method as claimed in claim 1, characterized by using in controlling first the second control parameter and using the first control parameter as a supplementary control parameter.

4. A method as claimed in claim 1, characterized by using in controlling both the first control parameter and the second control parameter simultaneously all the time.

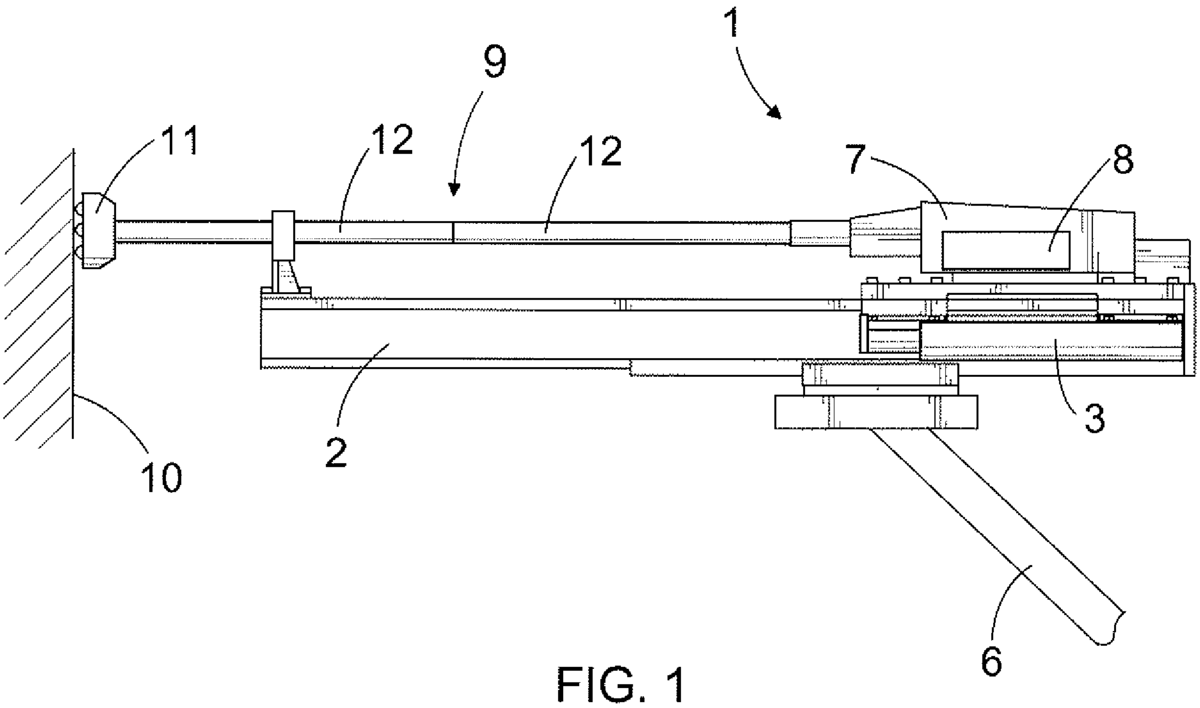
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FIG. 1

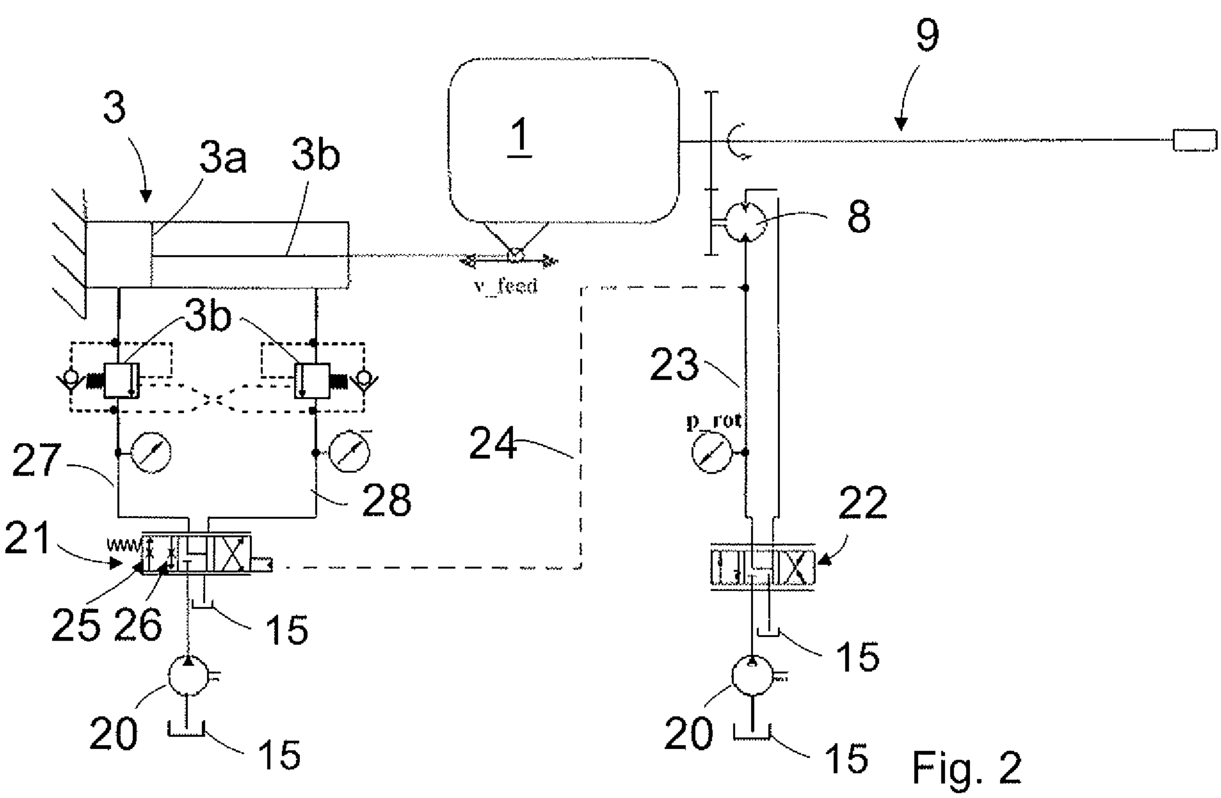
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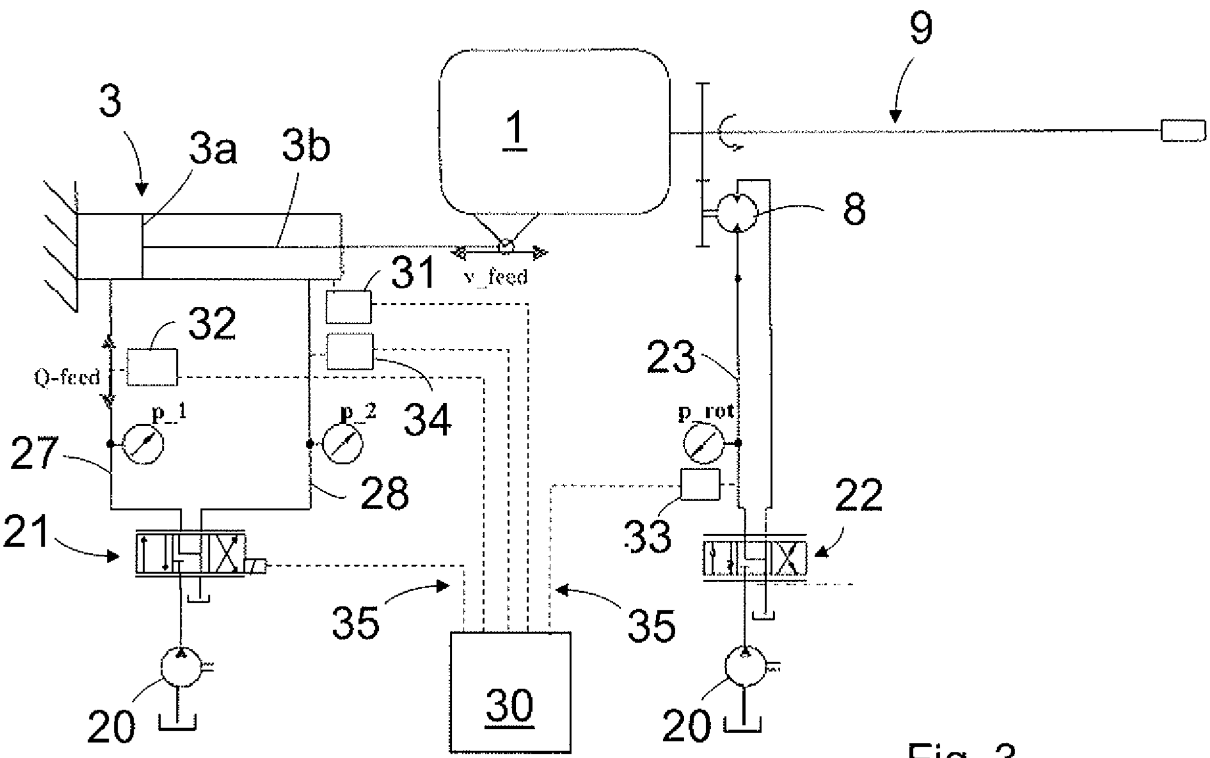
Fig. 2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p_2
p_rot
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Fig. 3

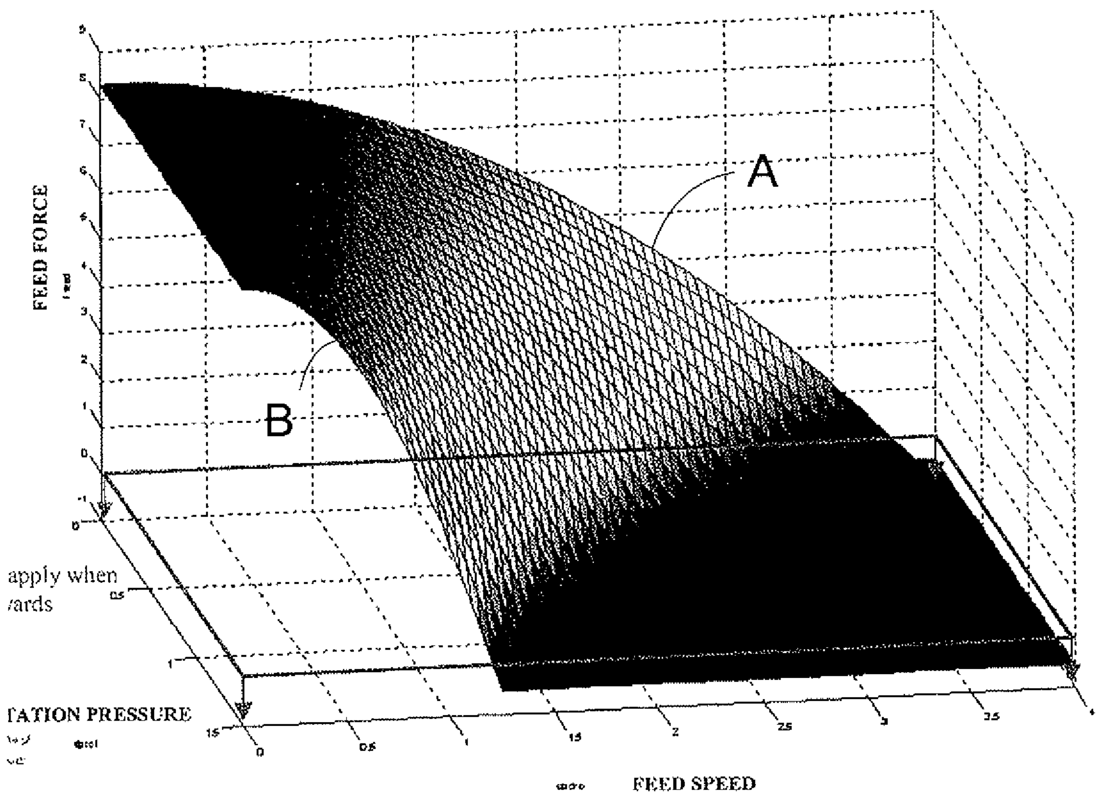
FEED FORCE
A
B
apply when
/ards
TATION PRESSURE
FEED SPEED

Fig. 4

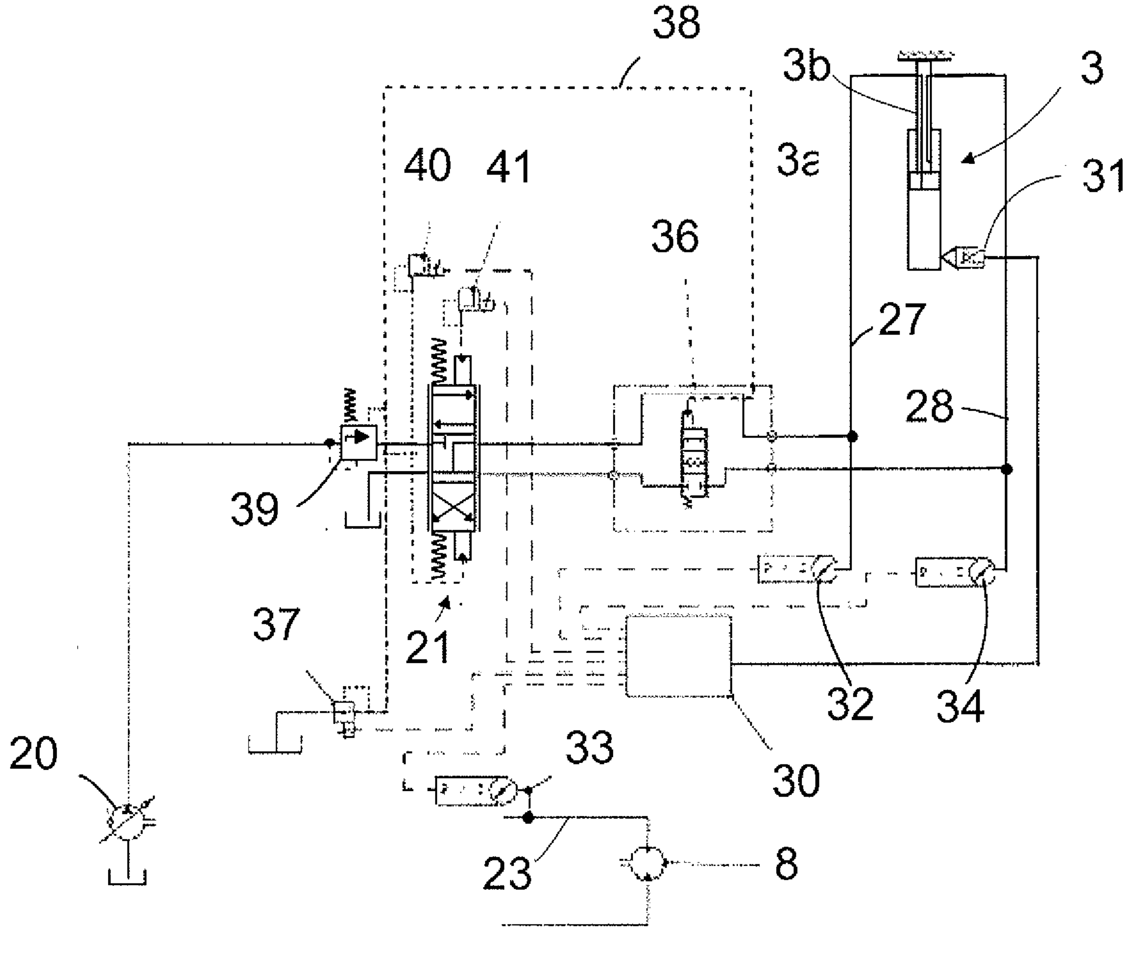

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2009/050579

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: E21B

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

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4440236 A (SHIIHARA TAKEO et al.) 03 April 1984 (03.04.1984) figure 2; column 5, lines 11-21	1-4
X	WO 2009002306 A1 (ATLAS COPCO ROCK DRILLS AB et al.) 31 December 2008 (31.12.2008) page 4, lines 18-21; page 5, lines 19-26; page 6, lines 1-7	1-4
A	US 3593807 A (KLIMA FRANK J) 20 July 1971 (20.07.1971) figure; column 1, lines 66-68; column 2, lines 7-15; column 3, lines 21-27 and 42-46	1-4
A	US 6029754 A (KATTENTIDT HINRICH et al.) 29 February 2000 (29.02.2000) figure 1; column 4, line 10	1-4

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

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Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/FI2009/050579

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
US 4440236 A	03/04/1984	JP 56046095 A JP 56046094 A	27/04/1981 27/04/1981
WO 2009002306 A1	31/12/2008	CA 2692027 A1 AU 2007355629 A1	31/12/2008 31/12/2008
US 3593807 A	20/07/1971	None	
US 6029754 A	29/02/2000	EP 0825329 A2 DE 19632401 A1	25/02/1998 19/02/1998

CLASSIFICATION OF SUBJECT MATTER

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E21B 44/02 (2006.01)