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(54) **MINING MACHINE AND METHOD FOR CONTROLLING MOVEMENT OF A MOVABLE ELEMENT OF A MINING MACHINE**

(57) A method (1000) for controlling movement of a movable element of a mining machine is provided. The method comprises providing (1010) a relation between control values for a hydraulic valve arranged to affect a movement of the movable element and a parameter representative of the (resulting) movement of the movable element. The method further comprises receiving (1020) an input representative of a desired movement of the movable element. The method further comprises obtaining (1030) a control value for the hydraulic valve based on the relation and using a parameter value corresponding to the desired movement and operating (1040) the hydraulic valve with a control signal using the obtained control value. The method further comprises obtaining (1050), from a feedback mechanism, a feedback relative to the movement of the movable element resulting from operating the hydraulic valve with the control signal, determining (1060) a correction value based on said desired movement and the feedback, and updating (1090) at least a part of the relation based on the correction value.

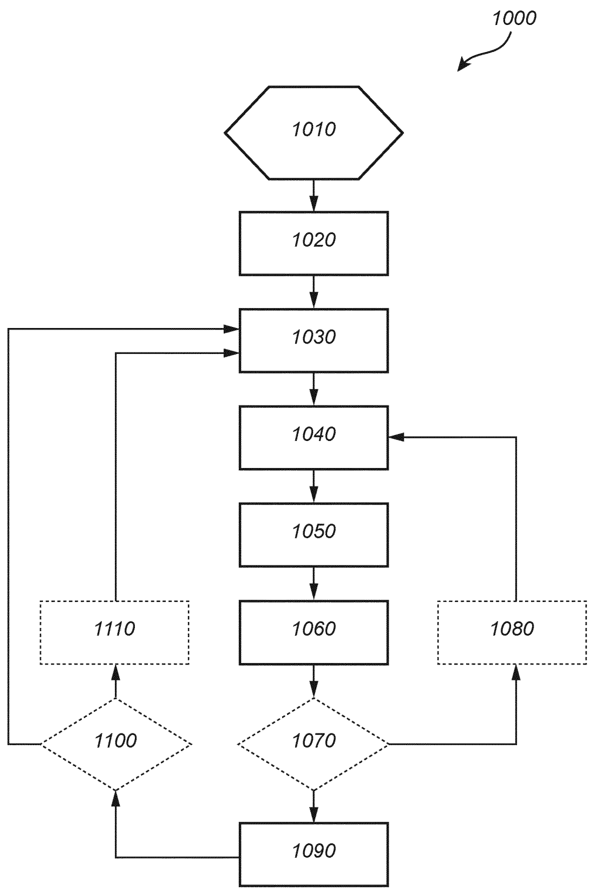

Fig. 1

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Description

Technical field

[0001] The present disclosure relates generally to the field of work machines. More specifically, it relates to controlling movement of a movable element of a mining machine.

Background

[0002] Various mining vehicles or machines, such as rock drilling equipment, loading equipment and transport equipment, are used in a mine and other work sites. Mining vehicles/machines may be manned or unmanned. Unmanned mining vehicles may be remote controlled by an operator from a control station or operated automatically. Operation of a mining machine may be carried out in a surface or underground operating area.

[0003] In mining machines, hydraulic valve systems are often used to control movement of different elements, such as e.g. wheels or crawler tracks, booms, etc. In such systems, factors like manufacturing tolerances, spool temperature, oil leaks or wear may result in a time varying behaviour of the system. Traditional controllers may have difficulties dealing with such effects. In many cases, they either have to be tuned imperfectly, which may lead to slow response times and/or use of a large set of control parameters, such as in gain scheduling, or they may be prone to unwanted oscillations. These systems are notoriously difficult to tune.

[0004] There is therefore a need to develop control methods which provide a fast response time and are not prone to oscillations.

Summary

[0005] It is therefore an object of the present invention to overcome at least some of the above-mentioned drawbacks, and to provide an improved method for controlling movement of a movable element of a mining machine.

[0006] This and other objects are achieved by means of a method, a mining machine and a storage medium comprising instructions for a controller as defined in the appended independent claims. Other embodiments are defined by the dependent claims.

[0007] According to a first aspect of the present disclosure, a method for controlling movement of a movable element of a mining machine is provided. The method comprises providing (or alternatively initializing) a relation between control values for a hydraulic valve arranged to affect movement of the movable element and a parameter representative of the movement of the movable element. The method further comprises receiving an input representative of a desired movement of the movable element and, obtaining a control value for the hydraulic valve based on the relation and using a parameter value corresponding to the desired movement. The method further comprises operating the hydraulic valve with a control signal using the obtained control value and obtaining, from a feedback mechanism, a feedback relative to the movement of the movable element resulting from operating the hydraulic valve with the control signal. Further, the method comprises determining a correction value based on the desired movement and the feedback and updating at least a part of the relation based on the correction value.

[0008] Many different mining machines (or vehicles) are used in a mine, such as an underground mine, or at a work site. Examples of such mining machines include drilling machines, bolting machines, apparatuses for roof and ground support, and many more. These machines/vehicles often comprise movable elements which movement is generated, controlled, and/or affected by at least a hydraulic valve. For example, a movable element may be a (cutting) boom, or a means of propulsion of the mining machine, such as wheels or crawler tracks, or a manipulator used for drilling and bolting.

[0009] Parameters related to the movement of the movable element may for example be a linear or rotational speed, a position, an angle (e.g. defining a travel direction of the machine or a tilt of the machine, or an angle between the movable element and another portion of the mining machine), a linear or rotational acceleration, the pressure in a valve, a flow etc.

[0010] The relation may be understood as a one-to-one mapping between the control values and values of the parameter representative of the resulting movement. The relation may comprise stored data or a stored data model. The relation is stored such that it can be updated and accessed at a later time instance. In particular, the relation may define how a control value corresponds to, is associated with or results in a value of the parameter. For a parameter value representative of a desired movement, the relation may provide a control value (related to the parameter value) which is predicted to bring the movable element to perform the desired movement.

[0011] Preferably the initially provided relation may be based on prior knowledge of the movable element.

[0012] The input representative of a desired movement may for example represent a desired speed or a desired position for the movable element. The input may for example be provided by an operator of the mining machine, or by a processor controlling automatic operation of the mining machine. The input may be in the form of a signal or a set point value.

[0013] In some embodiments, the received input may directly correspond to a parameter value corresponding to the desired movement. In other embodiments, a parameter value may be derived or extracted from the received input. For example, a parameter value representing a velocity may be derived from an input comprising information representing a position.

[0014] A feedback mechanism may comprise one or more sensors for measuring one or more properties related to the movement of the movable element. For example, a sensor may measure a speed or position of the movable element, or a pressure in e.g. a valve affecting the movement of the movable element. The feedback may for example comprise a measurement or a combination of different measurements.

[0015] The correction value is determined based on the desired movement and the feedback representing the (actual/measured) movement of the movable element. Thus, the correction value may be determined based on, and/or compensate for, a difference between the desired (or reference) movement and the actual movement, such that the relation, after being updated with the correction value, may provide a new control value with which the controller may operate the hydraulic valve. The control signal using the new control value may provide that the movement of the movable element better corresponds to the desired movement.

[0016] The difference between the desired (or reference) movement and the actual (or measured) movement may be referred to as the error. For example, the correction value may comprise a function of the error, such as a product of the error and a predefined or variable coefficient. For example, a feedback controller, such as a PID controller, may be used to generate the correction value.

[0017] Updating at least a part of the known relation based on the correction value may include updating the control value associated with the parameter value using, or based on, the correction value. For example, the correction value may be added to a presently stored control value associated with the parameter value representative of the desired movement. Alternatively, the stored control value may be altered with an increment or decrement of a predetermined size based on the sign of the correction value.

[0018] As the relation is updated, the stored relation between control values and parameter values may better and better represent the actual relation between control values and parameter values for the specific hydraulic valve and movable element used. Therefore, the response of the hydraulic valve and the movable element to a control value extracted from the relation may be improved. The method according to the first aspect may thus provide self-learning. Further, the need for an initial calibration may be reduced, as the method may provide self-calibration during operation. The method may also allow for adaptation to changes in the mining machine, for example due to changes in operating conditions or due to wear.

[0019] According to some embodiments, the method may further comprise adjusting the control signal based on the correction value.

[0020] Updating the control signal based on the correction value may provide an improved control signal. An improved control signal may bring the hydraulic valve to affect the movable element such that the movement of the movable element becomes closer to the desired movement. The resulting feedback may therefore be used to determine an improved correction value, based on which the relation may be updated.

[0021] Updating the control signal based on the correction value may reduce the number of operations or calculations necessary to reach the desired movement and/or improve the relation, as the relation may be updated less frequently.

[0022] According to some embodiments, the relation may be implemented as a look-up table. Updating the relation based on the correction value may comprise updating one or more values within the look-up table.

[0023] For example, updating the relation may comprise updating the control value related to the parameter corresponding to the desired movement. Control values related to parameter values in a range surrounding, e.g. above and below, the parameter corresponding to the desired movement may also be updated, preferably using a weight function to determine the correction value for each of the affected/updated control values. For example, inverse distance weighting may be used.

[0024] In some embodiments, the method may further comprise, after the relation has been updated a predefined number of times, smoothing the relation.

[0025] Alternatively, or additionally, the relation may be smoothed upon detection of irregularities (such as large peaks or values that are out of bounds) in the updated relation.

[0026] Smoothing may comprise updating one or more control values such that a small change in the value of the parameter representing the desired movement does not cause an abrupt or large change in the control value. Smoothing may comprise removing outliers from a data set. A smoother, less irregular relation may allow for a more stable control of the device.

[0027] According to some embodiments, the relation may be implemented as an analytic function. Updating the relation based on the correction value may comprise updating one or more parameters of the analytic function.

[0028] In some implementations, there may be a known physical or empirical relation between the control values for the hydraulic valve and the parameter representative of the (resulting) movement. In such implementations, the relation may use an analytic function describing the physical or empirical relation.

[0029] According to some embodiments, the method may further comprise, before updating the relation based on the correction value, verifying whether at least one update condition is fulfilled.

[0030] An update condition is a condition to be fulfilled for an update of the relation to take place. Updating the relation when certain conditions are met may allow for a more efficient method, as the relation may not be unnecessarily updated. For example, the number of required operations (or calculations) may be lowered.

[0031] According to some embodiments, updating the relation may be prevented if it is detected that the mining machine is in a predefined state.

[0032] In a mine, the operating conditions may vary significantly. If the mining machine, and thereby the hydraulic valve, is at the limits of its normal operating range, for example if it is subject to a high torque load or it is operating at a speed close to the nominal speed of the device, the response of the movable element to a control signal may not be representative of the normal performance/operation. An update under such conditions may result in a faulty relation which may lead to issues during subsequent normal operation. A predefined state may reflect such conditions in which an update may affect the relation in a negative way.

[0033] According to some embodiments, the method may further comprise monitoring the updated relation. If a control value of the updated relation exceeds a first threshold value, the method may comprise providing an operator of the mining machine with a warning message. If a control value of the updated relation exceeds a second threshold value, the method may comprise resetting the relation to the initially provided relation.

[0034] A control value being lower or higher than expected may be an indication of an abnormal condition or a potential fault in the system. A warning message may indicate which parameter values are related to the out of bounds control values, such that operation of the mining machine may be adapted.

[0035] Further, a large increase or decrease in control value between two adjacent parameter values may also be indicative of a fault. Therefore, warning messages, or resetting, may also be provided when such conditions are detected.

[0036] According to some embodiments, the mining machine may comprise wheels. The movable element may be a first wheel, and the parameter may be a speed of the first wheel.

[0037] The mining machine may comprise a plurality of wheels, such as four or six wheels, which allow the mining machine to move around. The hydraulic valve may activate one or more of the wheels. Further, the mining machine may comprise crawler tracks, or continuous track, where the vehicle runs on a continuous band of treads or track plates driven by two or more wheels.

[0038] In such embodiments, each wheel may be treated as a separate movable element, and a separate relation between control values and resulting parameter values may be implemented. Alternatively, if movement of two or more wheels are affected by the same hydraulic valve, they may be treated as a single movable element for which a relation is implemented.

[0039] According to some embodiments, the movable element of the mining machine may be a rotatable cutter boom. The parameter may be a rotational speed of the rotatable cutter boom relative to a chassis of the mining machine.

[0040] In some embodiments, the feedback relative to the movement of the movable element comprises at least a measured angular position of the cutter boom relative to the chassis. The hydraulic valve may activate the cutter boom and thereby affect its movement.

[0041] According to a second aspect of the present disclosure, a mining machine is provided. The mining machine comprises a movable element and a hydraulic valve arranged to affect a movement of the movable element. The mining machine further comprises a feedback mechanism configured to provide a feedback relative to movement of the movable element. The mining machine further comprises a controller configured to control operation of the hydraulic valve.

[0042] The controller is configured to receive an input representative of a desired movement of the movable element. The controller is further configured to obtain a control value for the hydraulic valve, based on a stored relation between control values for the hydraulic valve and a parameter representative of the (resulting) movement of the movable element, and using a parameter value corresponding to the desired movement. The controller is further configured to operate the hydraulic valve with a control signal using the obtained control value. The controller is further configured to obtain a feedback relative to the movement of the movable element from the feedback mechanism and determine a correction value based on the desired movement and the feedback. Further, the controller is configured to update at least a part of the relation based on the correction value.

[0043] According to some embodiments, the controller may be further configured to adjust the control signal based on the correction value.

[0044] According to some embodiments, the mining machine may further comprise a communication system. The communication system may be adapted to allow interaction with an operator of the mining machine. The communication system may be configured to transmit an input representative of a desired movement set by an operator to said controller.

[0045] According to some embodiments, the mining machine may further comprise wheels arranged for propulsion of the mining machine. The movable element may be a first wheel, and the parameter may be a speed of the first wheel. As previously described with reference to the first aspect of the disclosure, the mining machine may comprise a plurality of wheels arranged for propulsion of the mining machine. The wheels may form part of crawler tracks.

[0046] According to some embodiments, the mining machine may further comprise a cutter boom rotatably attached to a chassis of the mining machine. The movable element may be the cutter boom. The parameter may be a rotational speed of the rotatable boom relative to the chassis of the mining vehicle.

[0047] In some embodiments, the feedback relative to the movement of the movable element may comprise at least a measured angular position of the cutter boom relative to the chassis.

[0048] In other embodiments, the movable element may be another movable element of a mining machine which activated or actuated by (or which movement is affected by) a hydraulic valve of the mining machine. The movable element may be separate (or distinct) from a hydraulic system of the mining machine.

[0049] According to a third aspect of the present disclosure, a storage medium comprising instructions for a controller to control operation of a hydraulic valve of a mining machine is provided.

[0050] The instructions comprise, receiving an input representative of a desired movement of a movable element of the mining machine. The instructions further comprise obtaining a control value for the hydraulic valve based on a stored relation between control values for the hydraulic valve and a parameter representative of the (resulting) movement of the movable and using a parameter value corresponding to the desired movement. The instructions further comprise operating the hydraulic valve with a control signal using the obtained control value. The instructions further comprise obtaining a feedback relative to the movement of the movable element from a feedback mechanism, determining a correction value based on the desired movement and the feedback, and updating the relation based on the correction value.

[0051] It is noted that other embodiments using all possible combinations of features recited in the above described aspects and embodiments may be envisaged. Thus, the present disclosure also relates to all possible combinations of features mentioned herein.

Brief description of drawings

[0052] Exemplifying embodiments will now be described in more detail, with reference to the following appended drawings:

Figure 1 is a flowchart illustrating a method, in accordance with some embodiments;

Figure 2 is a graphic representation of a relation implemented as a look-up table, in accordance with some embodiments;

Figure 3 is a graphic representation of a relation implemented as an analytic function, in accordance with some embodiments;

Figure 4 is a block diagram illustrating the internal operation of a controller, in accordance with some embodiments;

Figure 5 is an illustration of a mining machine having a cutter boom and wheels, in accordance with some embodiments;

Figure 6 is an illustration of a different mining machine having a cutter boom and wheels, in accordance with some embodiments.

Detailed description

[0053] Exemplifying embodiments will now be described more fully hereinafter with reference to the accompanying drawings in which currently preferred embodiments are shown. The invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided for thoroughness and completeness, and fully convey the scope of the invention to the skilled person.

[0054] With reference to Figure 1, a method 1000 for controlling movement of a movable element of a mining machine, in accordance with some embodiments, will be described.

[0055] Figure 1 is a flow-chart showing a method 1000 for controlling movement of a movable element of a mining machine, in accordance with some embodiments. In the method 1000, optional steps are illustrated with dashed outlines.

[0056] First, in the illustrated method 1000, a relation between control values for a hydraulic valve arranged to affect movement of the movable element, and a parameter representative of the (resulting) movement of the movable element is provided at step 1010. Examples of such relations will be described below with reference to Figures 2 and 3.

[0057] The provided (or initial) relation may be stored, such that it may be accessed at a later stage.

[0058] Next, the method 1000 comprises receiving 1020 an input representative of a desired movement of the movable element.

[0059] The input representative of a desired movement may for example represent a desired speed, or a desired position for the movable element. The input may for example be provided by an operator of the mining machine, or by a processor controlling automatic operation of the mining machine. The input may be in the form of a signal or a set point value.

[0060] For example, the input may be observed or monitored at regular intervals, such that the method may return to step 1020. Alternatively, a change in the input may automatically trigger a return to step 1020.

[0061] A control value for the hydraulic valve is obtained, at step 1030, based on the relation and using a parameter value corresponding to the desired movement.

[0062] A control value may be obtained for example by identifying a parameter value corresponding to the desired movement and finding the control value related to this parameter value using the relation between control values and (resulting) movement of the movable element.

[0063] For example, the relation may relate control values for the hydraulic valve, such as valve actuation, with a resulting rotational or translational speed of the movable element. Obtaining the control value may then comprise deriving a desired speed from the input signal, locating the desired speed in the relation, and finding the corresponding control value related to the desired speed.

[0064] The method 1000 further comprises operating 1040 the hydraulic valve with a control signal using the obtained control value.

[0065] For example, the control signal may be adapted based on a current (present) value of the control signal and the obtained control value to provide a smooth transition between the current value of the control signal and the (new) obtained control value.

[0066] Next, at step 1050, a feedback relative to the movement of the movable element is obtained from a feedback mechanism. The feedback may for example be a measured value, such as a speed or a position of the movable element.

[0067] Based on the desired movement and the feedback, a correction value is determined, at step 1060.

[0068] A correction value based on the desired movement and the feedback may for example be based on a difference between the desired movement and the actual (measured) movement of the movable element. For example, the parameter representative of the desired movement and the feedback relative to the movement of the movable element may be related such that they can be compared. For example, a speed or a position may be derived from both the desired movement and the feedback. Then, the correction value may be based on a difference between the desired speed and the speed derived from the feedback. For example, a feedback controller, such as a PID controller, may be used to generate the correction value.

[0069] After obtaining the correction value, one or more conditions may (optionally) be tested at step 1070 to decide whether the relation should be updated or to continue control of the hydraulic valve without adjusting the relation. The optional step 1070 of testing a condition may comprise one or several update or stop conditions.

[0070] If the condition is fulfilled/approved, the method continues to step 1090, in which the relation is updated based on the correction value. If the condition is not fulfilled, the method instead proceeds either with optional step 1080, in which the control signal is adjusted based on the correction value, or straight back to operating the hydraulic valve at step 1040.

[0071] In embodiments including the optional step 1080 of adjusting the control signal based on the correction value, followed by operating the hydraulic valve with the adjusted control signal, the movement of the movable element may be improved at a faster rate, as the control signal may be more adaptable.

[0072] It will be appreciated that the optional step 1080 of adjusting the control signal may also be combined with updating 1090 the relation such that the two steps are performed concurrently or one after the other.

[0073] For example, an update condition may be that the desired movement (derived from the input) has remained substantially constant, or within a predefined interval, for a predetermined period of time. The response of the movable element may not be instantaneous or even fast. If the desired movement has been (almost) constant for a period of time, the hydraulic valve and the movable element may have had sufficient time to respond to the control signal comprising the control value. Therefore, a correction value based on the feedback at such a time may provide a more relevant contribution to the relation.

[0074] For example, an update condition may be that the feedback relating to the movement of the movable element indicates that the desired movement has been achieved, or that the movement of the movable element is closer to the desired movement.

[0075] For example, such an update condition may be combined with the optional step 1080 of updating the control signal based on the correction value. In such embodiments, the movement of the movable element may be adjusted without updating the relation, to become closer to the desired movement. The feedback relative to the movement of the movable element may thus be updated, and a new correction value may be determined. When the movement of the movable element is within a specified interval from the desired movement, the control signal may be close to the true control signal for providing the desired movement. Therefore, a correction value based on the feedback at such a time may provide a more relevant contribution to the relation.

[0076] For example, in embodiments in which the control signal is updated (at step 1080) based on the control value, an update condition may be that the control signal has been updated a predetermined number of times, or for a predetermined period of time.

[0077] After a predetermined time or number of updates of the control signal, the control signal may have been improved. Updating the stored relation may thus result in an improved relation, closer to the true relation. Updating at regular intervals may result in a regular adjustment of the relation to the current behavior of the mining machine.

[0078] A condition may also be a stop condition, which prevents updates of the relation. This may be beneficial in case the mining machine is in such a state that an update would be detrimental.

[0079] At step 1090, at least a part of the relation is updated based on the correction value. Examples of how such an update may affect a relation such as one of the relations that will be described below with reference to Figures 2 and 3.

[0080] Updating the relation may be referred to as a learning event, as the relation is adapting to (or learning) the behaviour of the hydraulic valve. After the update, the (updated) relation may better describe how control values applied to the hydraulic valve affects the movable element. The control value corresponding to a desired movement in the updated relation may thus result in a movement of the movable element which is closer to the desired movement than a control value corresponding to the desired movement in the old (non-updated) relation.

[0081] After the update 1090 of the relation, one or more conditions relating to the relation may be checked at optional monitoring step 1100. If the condition is met, the method may proceed with optional reaction step 1110 and, if not, the method proceeds directly with step 1030 of obtaining a new control value based on the updated relation.

[0082] For example, the condition of the monitoring step 1100 may comprise checking whether the relation causes any control values to be out of bounds or exceed a threshold value (a warning threshold). If so, the reaction step 1110 may comprise sending a warning message to an operator of the mining machine. If the control value exceeds a second threshold (an error threshold), the reaction step 1110 may comprise resetting the relation to the initially provided relation.

[0083] As another example, the monitoring step 1100 may comprise observing whether there are peaks or irregularities in the control values of the relation. If so, the reaction step 1110 may comprise smoothing the relation. As an alternative, smoothing may be performed at regular intervals, such as after a certain number of updates.

[0084] After the update of the relation at step 1090, and optionally any monitoring step 1100 and/or any optional reaction at step 1110, the method proceeds to step 1030. At step 1030, a (new) control value is obtained based on the desired movement and the updated relation. The method then proceeds as described above using the new control value for operating the hydraulic valve.

[0085] With reference to Figure 2, a method in which the relation 100 is implemented as a look-up table will be described.

[0086] Figure 2 is a graphic representation of values in a look-up table describing the relation 100 between a target rotational speed in degrees/second, along the horizontal x axis, and the corresponding valve actuation in mA, along the vertical y axis. In other words, the parameter indicative of the desired movement is the target speed, and the control value for the hydraulic valve is the value corresponding to the valve actuation. In order to obtain a control value for a specific desired speed, the desired speed is located, and the corresponding control value read in the look-up table. If the desired speed is between two stored values in the look-up table, the closest value may be selected, or interpolation between the closest speeds and the corresponding control values may be performed.

[0087] The initially provided relation 102 is a straight line, indicating that a linear relation between the target speed and the valve actuation was assumed when providing the relation.

[0088] Certain values in the relation are fixed 104 and can therefore not be changed. In the present example, the maximum control value has been limited, such that target speeds over 5 deg/s do not result in an increased control value.

[0089] Further, alarm thresholds 106 are illustrated with dashed lines. There is an upper threshold and a lower threshold for each target speed. If a control value would exceed the upper threshold, or be lower than the lower threshold, an alarm (or warning message) would be sent (provided) to an operator.

[0090] As shown in figure 2, the relation has been updated a number of times, thereby resulting in the relation 100 (which is different than the initially provided relation 102). The current desired speed 108 is marked by a vertical dashed line, at 3.1 deg/s. During the current learning event, the correction value is positive, meaning that a higher control value than the one in the present relation 100 is needed to achieve the current desired speed. The updated relation 110 is illustrated with a dotted line. A triangular weighing function is used to update the relation such that control values corresponding to desired speeds within a range centring on the current desired speed are increased. The size of the increase is related to the inverse distance between the speed corresponding to the control value and the current desired speed. The size of the increase, i.e. the change between the present relation 100 and the updated relation 110, is exaggerated for illustrative purposes. In practice, the change may be much smaller.

[0091] With reference to Figure 3, a method in which the relation 200 is implemented as an analytic function will be described.

[0092] Figure 3 is a graphic representation of a look-up table describing the relation 200 between a target speed in degrees/second, along the horizontal x axis, and the corresponding valve actuation mA, along the vertical y axis. In other words, the parameter indicative of the desired movement is the target speed, and the control value for the hydraulic valve is the value corresponding to the valve actuation.

[0093] The present relation between target speeds and valve actuation is a square root function, that is the relation can be described by:

$$y = a + b\sqrt{x}$$

wherein y is the valve actuation, or control value, x is the desired/target speed, or parameter representative of the (resulting) movement of the movable element, a is the offset, defining the starting value of the relation, and b is the root term or gain.

[0094] In the present embodiment, when a learning event takes place at low speeds, updating the relation may comprise adjusting the offset a. For higher speeds, updating the relation may comprise adjusting the root term b. For example, low speeds may correspond to the lower third of the range of input values. High speeds may, for example, correspond to the higher two thirds of the range of input values.

[0095] Figure 3 illustrates an example of an analytic function describing the relation between target (desired) speeds and valve actuation, which can be manipulated by observing pressures on a hydraulic axis. In other words, when using this example of a relation, the feedback may comprise information (measurements) of the pressure of a hydraulic axis.

[0096] Like in the example described with reference to Figure 2, thresholds 206 are also implemented for the analytic relation 200. In case a control value goes outside the range delimited by the lower and upper thresholds 206, an alarm or warning message may be sent to an operator.

[0097] With reference to Figure 4, a controller 320 and a control loop, in accordance with some embodiments, will be described.

[0098] Figure 4 is a block diagram illustrating the internal operation of a controller 320, as well as control signals and feedback signals.

[0099] The controller 320 receives an input r, which is representative of a desired movement of a movable element 332 in the work machine of which the controller 320 forms part or to which the controller 320 is connected. The input r is put into the relation 300 which outputs a control value *u*. The control value u is related, via the relation 300, to a parameter corresponding to the desired movement represented by the input r.

[0100] The control value u is input into a treatment block 322, which outputs a control signal $\hat{u}$. The treatment block 322 may provide a signal $\hat{u}$, which may optionally be a continuous signal, it may also limit the control signal to a predetermined range or smooth the control signal.

[0101] The control signal $\hat{u}$ is the output of the controller 320. It is used to operate a hydraulic valve 330 of the work machine. The hydraulic valve affects a movement of a movable element 332 of the work machine.

[0102] Measurements y of movement of the movable element 332 are performed. The measurements y are treated by a feedback mechanism 334. The feedback mechanism provides a feedback y to the controller 320. The feedback y relates to the movement of the movable element 332 which results from operating the hydraulic valve 330 with said control signal $\hat{u}$.

[0103] The feedback y is provided into a correction value calculator 324. The correction value calculator 324 uses the feedback y and the input (or reference value) r to determine a correction value c. The correction value c is used to update the relation 300. Further, the correction value calculator 324 may optionally provide a further correction value c, based on the correction value c, to the treatment block 322. The further correction value $\hat{c}$ may optionally be used to update the control signal $\hat{u}$.

[0104] With reference to Figure 5, a mining machine (or vehicle) 450 in accordance with an embodiment will be described.

[0105] Figure 5 is an illustration of a mining machine 450. As an illustrative example, the mining machine 450 is a continuous miner. Continuous miners are used for example to cut coal in coal mines.

[0106] The mining machine 450 comprises a chassis 452. A boom 454 is rotatably attached to the chassis such that the boom can perform a pivoting motion in a direction/plane which is substantially vertical direction when the mining machine 450 is standing on horizontal ground/floor. A cutting head 458, or cutter drum, is connected to the boom 454. The cutting head 458 is rotatably attached to the boom, such that it can perform a rotational cutting movement (revolve) around a central axis of the cutting head 458.

[0107] The mining machine 450 further comprises crawler tracks 460, which comprise wheels 462. The crawler tracks 460 are arranged for propulsion of the mining machine 450 and are driven by the wheels 462.

[0108] The crawler tracks 460 may move the miner (mining machine, mining vehicle) 450 forward and backward, and allow the mining machine 450 to turn. The boom 454 may perform a pivoting motion, and optionally a translating motion in the direction of travel of the mining machine, such that the cutting head 458 may sump into a wall of material in front of the mining machine 450, while rotating/revolving, to cut material from the wall.

[0109] Movement of a wheel 462, which drives a crawler track 460, is affected or activated by a hydraulic valve 430. Operation of the hydraulic valve 430 is controlled by a controller 420. The controller 420 is configured to control movement of the movable element (i.e. the wheel 462 or the crawler track 460) in accordance with the method 1000 described above with reference to Figure 1. The controller 420 may be equivalent to the controller 320 described above with reference to Figure 4.

[0110] In order to receive an input, for example from an operator or a processor controlling automatic operation of the mining machine 450, the mining machine 450 may comprise, a communication system 456 connected to the controller 420.

[0111] Further, the controller 420 comprises, or is connected to, a storage unit (not shown) in which a relation between control values for the hydraulic valve 430 and a parameter representative of the movement of the movable element (i.e. wheel 462 or crawler track 460) is stored, such that the controller 420 can obtain a control value for the hydraulic valve 430 based on the stored relation and a parameter value corresponding to the desired movement. The controller 420 is also configured to update the stored relation.

[0112] Operation of the hydraulic valve 430 affects movement of the wheel 462, which in turn affects the movement of the crawler track 460. A feedback mechanism 434, comprising at least one sensor measuring the movement of the wheel 460 or the crawler track 462, is configured to send a feedback relative to the movement of the wheel 460 or the crawler track 462 to the controller 420.

[0113] With reference to Figure 6, a mining machine 550 in accordance with another embodiment will be described.

[0114] Figure 6 is an illustration of a mining machine 550. As an illustrative example, the mining machine 550 is a road header. Road headers are used for example for cutting and excavating rock, such as when forming a tunnel.

[0115] The chassis 552, wheels 562 and crawler tracks 560 of the mining machine 550 in Figure 6 may be equivalent to those described above with reference to Figure 5.

[0116] A boom 554 is rotatably attached to the chassis 552, such that the boom can perform pivoting motion in both horizontal and vertical directions/planes. A cutting head 558, or cutter drum, is connected to the boom. The cutting head 558 is rotatably attached to the boom 554, such that it can perform a rotational cutting movement (revolve) around a central axis of the cutting head 558.

[0117] Movement of the boom 554 is affected or activated by a hydraulic valve 530. Operation of the hydraulic valve 530 is controlled by a controller 520. The controller 520 is configured to control movement of the boom 554 (i.e. the movable element) in accordance with the method 1000 described above with reference to Figure 1.

[0118] The controller 520 may be equivalent to the controller 320 described above with reference to Figure 4, and/or to the controller 420, described above with reference to Figure 5. For example, it may comprise/be connected to a communication system 556 and/or a storage unit. The feedback mechanism 534 comprises at least one sensor for measuring the movement of the boom 554. For example, the feedback mechanism 534 may measure an angle of the boom relative to the chassis 552. The feedback mechanism is configured to send a feedback relative to the movement of the boom 554 to the controller 520.

[0119] The person skilled in the art realizes that the present invention by no means is limited to the preferred embodiments described above. On the contrary, many modifications and variations are possible within the scope of the appended claims.

[0120] Although features and elements are described above in particular combinations, each feature or element can be used alone without the other features and elements or in various combinations with or without other features and elements.

[0121] Additionally, variations to the disclosed embodiments can be understood and effected by the skilled person in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain features are recited in mutually different dependent claims does not indicate that a combination of these features cannot be used to advantage.

Claims

1. A method (1000) for controlling movement of a movable element of a mining machine, the method comprising:

   providing (1010) a relation between control values for a hydraulic valve arranged to affect a movement of said movable element and a parameter representative of the movement of the movable element;
   receiving (1020) an input representative of a desired movement of said movable element;
   obtaining (1030) a control value for the hydraulic valve based on said relation and using a parameter value corresponding to the desired movement;
   operating (1040) said hydraulic valve with a control signal using the obtained control value;
   obtaining (1050), from a feedback mechanism, a feedback relative to the movement of the movable element resulting from operating said hydraulic valve with said control signal;
   determining (1060) a correction value based on said desired movement and said feedback; and
   updating (1090) at least a part of said relation based on said correction value.

2. The method of claim 1, further comprising adjusting (1060) said control signal based on said correction value.

3. The method of any of the preceding claims, wherein said relation is implemented as a look-up table (100) and wherein updating said relation based on said correction value comprises updating one or more values within said lookup table.

4. The method of any of claims 1-2, wherein said relation is implemented as an analytic function (200) and wherein updating said relation based on said correction value comprises updating one or more parameters of said analytic function.

5. The method of any of the preceding claims, further comprising, before updating said relation based on said correction value, verifying (1070) whether at least one update condition is fulfilled.

6. The method of any of the preceding claims, wherein said updating is prevented if it is detected that the mining machine is in a predefined state.

7. The method of any of the preceding claims, further comprising monitoring (1100) the updated relation; and

   if a control value of the updated relation exceeds a first threshold value, providing an operator of the mining machine with a warning message; and/or
   if a control value exceeds a second threshold value resetting said relation to the initially provided relation.

8. The method of any of the preceding claims, wherein said mining machine comprises wheels, said mova-

ble element is a first wheel, and wherein said parameter is a speed of said first wheel.

9. The method of any of claims 1-7, wherein said movable element of said mining machine is a rotatable cutter boom, and wherein said parameter is a rotational speed of said rotatable boom relative to a chassis of the mining machine.

10. A mining machine (450, 550) comprising:

a movable element (332);
a hydraulic valve (330) arranged to affect a movement of said movable element;
a feedback mechanism (334) configured to provide a feedback relative to movement of the movable element; and
a controller (320) configured to control operation of the hydraulic valve, said controller being configured to:

receive an input representative of a desired movement of said movable element;
obtain a control value for the hydraulic valve based on a stored relation between control values for the hydraulic valve and a parameter representative of the movement of the movable element, using a parameter value corresponding to the desired movement;
operate the hydraulic valve with a control signal using the obtained control value;
obtain, from the feedback mechanism, a feedback relative to the movement of the movable element resulting from operating said hydraulic valve with said control signal;
determining a correction value based on said desired movement and said feedback; and
update at least a part of said relation based on said correction value.

11. The mining machine of claim 10, wherein said controller is further configured to adjust said control signal based on said correction value.

12. The mining machine of any of claims 10-11, further comprising a communication system (456) for interaction with an operator of the mining machine, said communication system being configured to transmit an input representative of a desired movement set by an operator to said controller.

13. The mining machine of any of claims 10-12, further comprising wheels (462) arranged for propulsion of said mining machine, wherein said movable element is a first wheel, and wherein said parameter is a speed of said first wheel.

14. The mining machine of any of claims 10-12, further comprising a cutter boom (554) rotatably attached to a chassis (550) of said mining machine, and wherein said movable element is said cutter boom, said parameter is a rotational speed of said rotatable boom relative to the chassis of the mining vehicle.

15. A storage medium comprising instructions for a controller to control operation of a hydraulic valve of a mining machine, wherein said instructions comprise:

receiving an input representative of a desired movement of a movable element of said mining machine;
obtaining a control value for the hydraulic valve based on a stored relation between control values for the hydraulic valve and a parameter representative of the movement of the movable element, using a parameter value corresponding to the desired movement;
operating the hydraulic valve with a control signal using the obtained control value;
obtaining, from a feedback mechanism, a feedback relative to the movement of the movable element resulting from operating said hydraulic valve with said control signal;
determining a correction value based on said desired movement and said feedback; and
updating said relation based on said correction value.

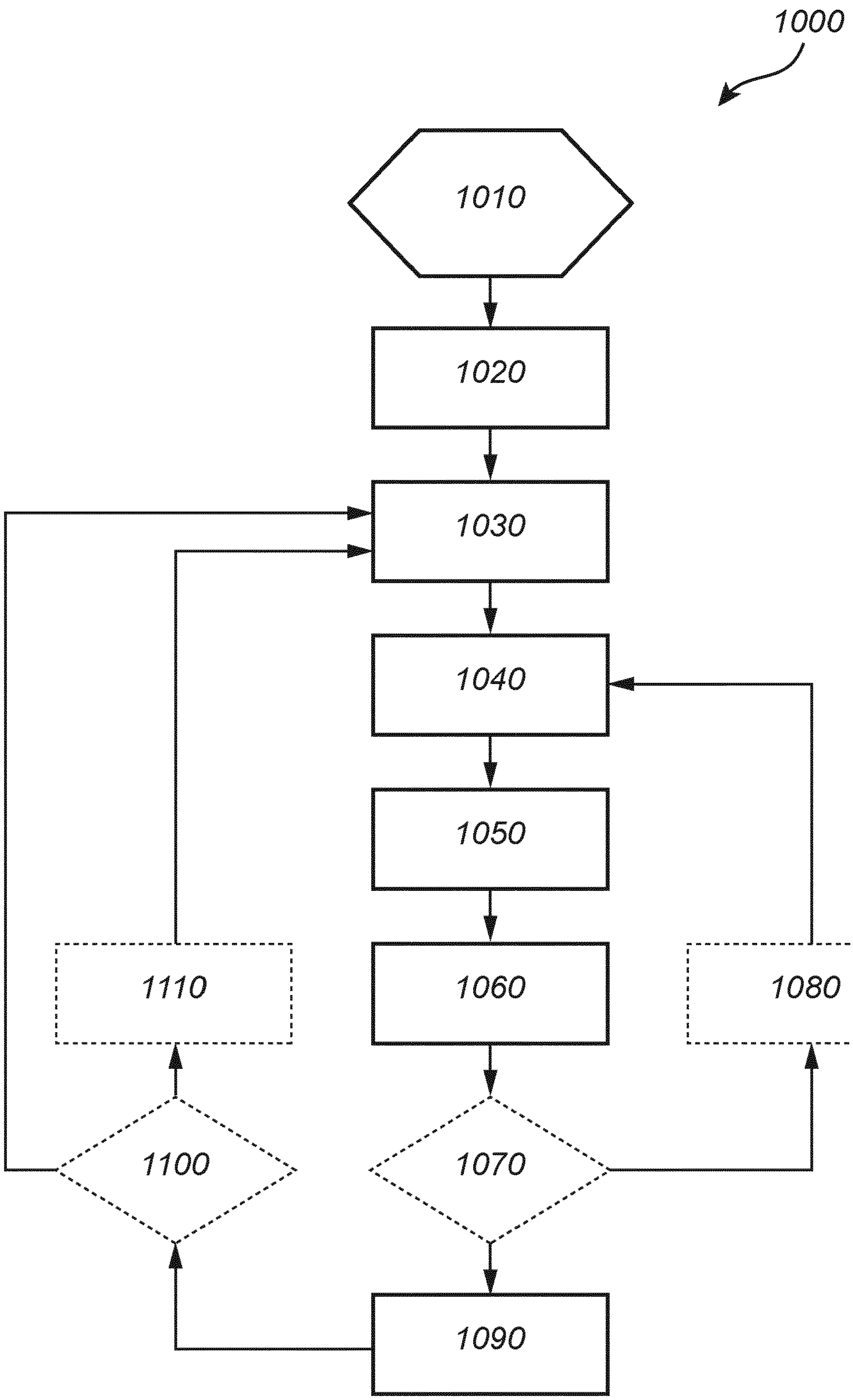


Fig. 1

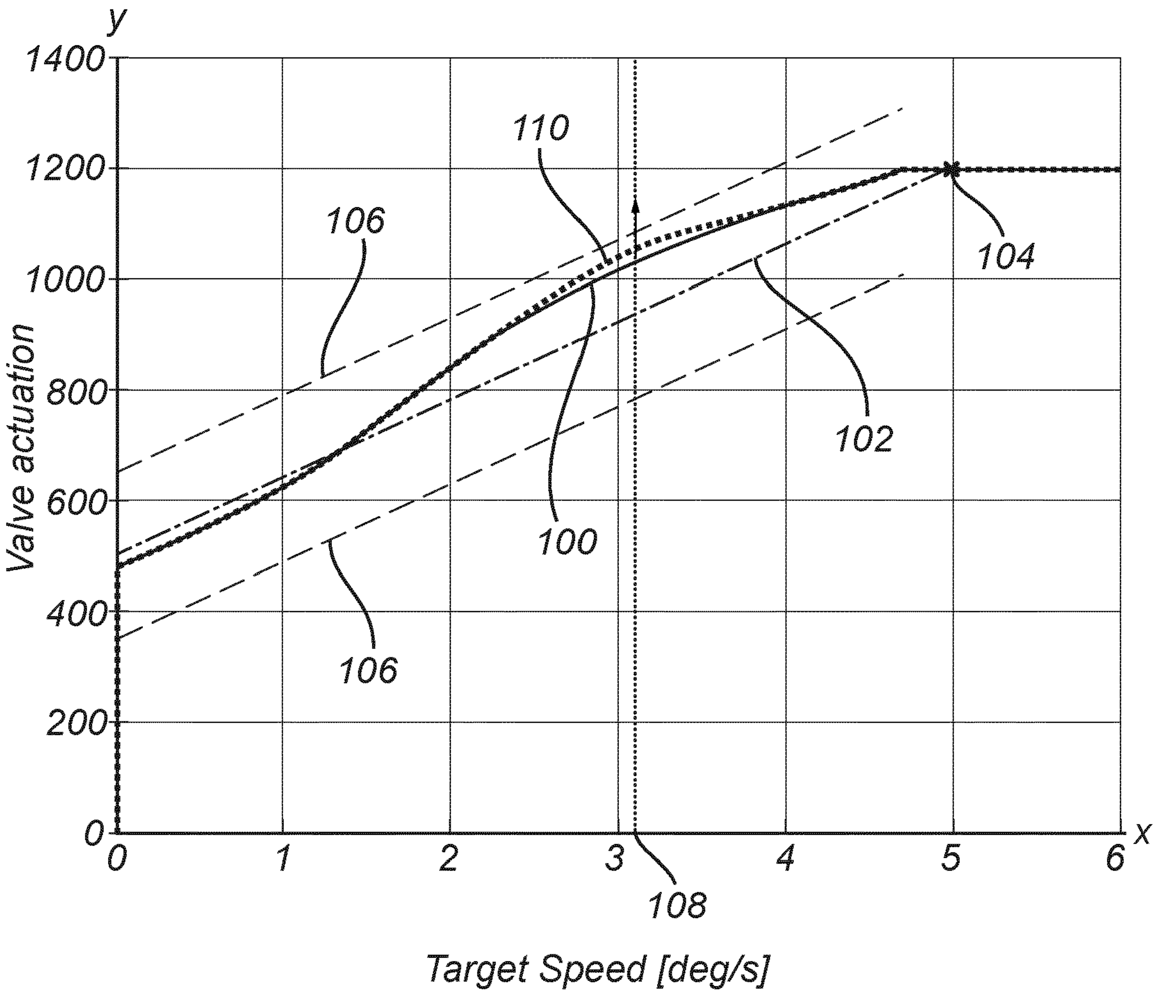
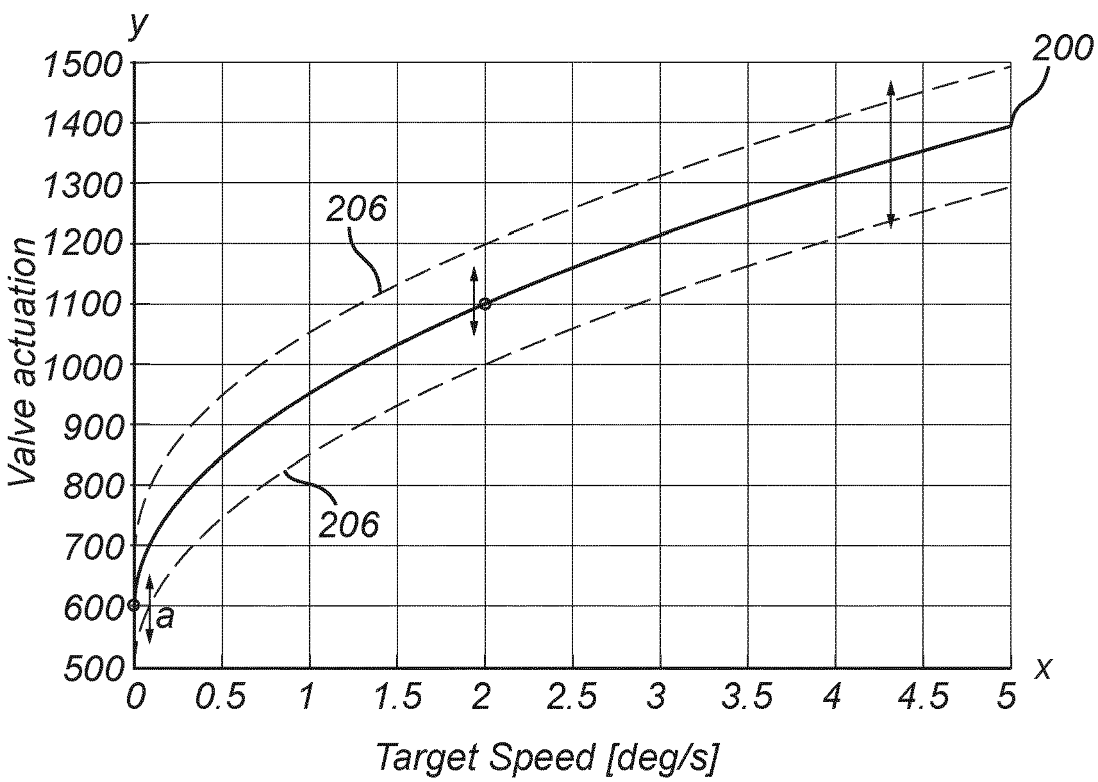

y
1400
1200
1000
800
600
400
200
0
Valve actuation
110
106
104
102
100
106
x
0
1
2
3
4
5
6
108
Target Speed [deg/s]

Fig. 2


y
1500
1400
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1200
1100
1000
900
800
700
600
500
Valve actuation
200
206
206
a
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
x
Target Speed [deg/s]

Fig. 3

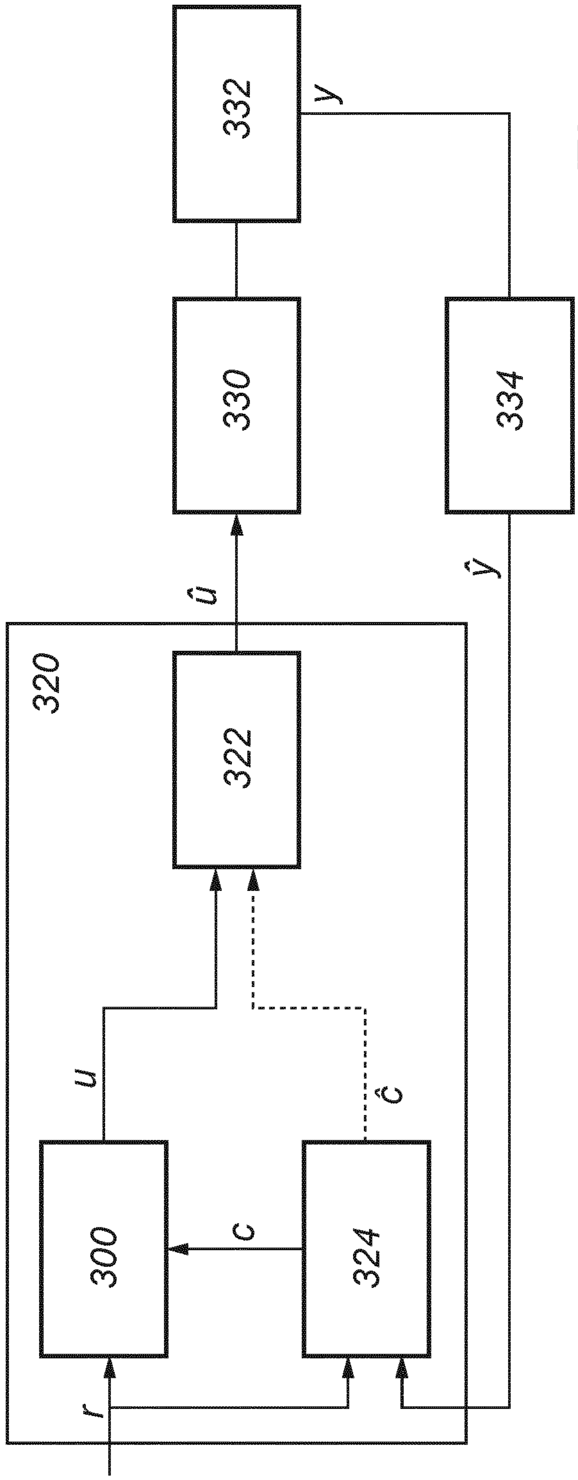

Fig. 4

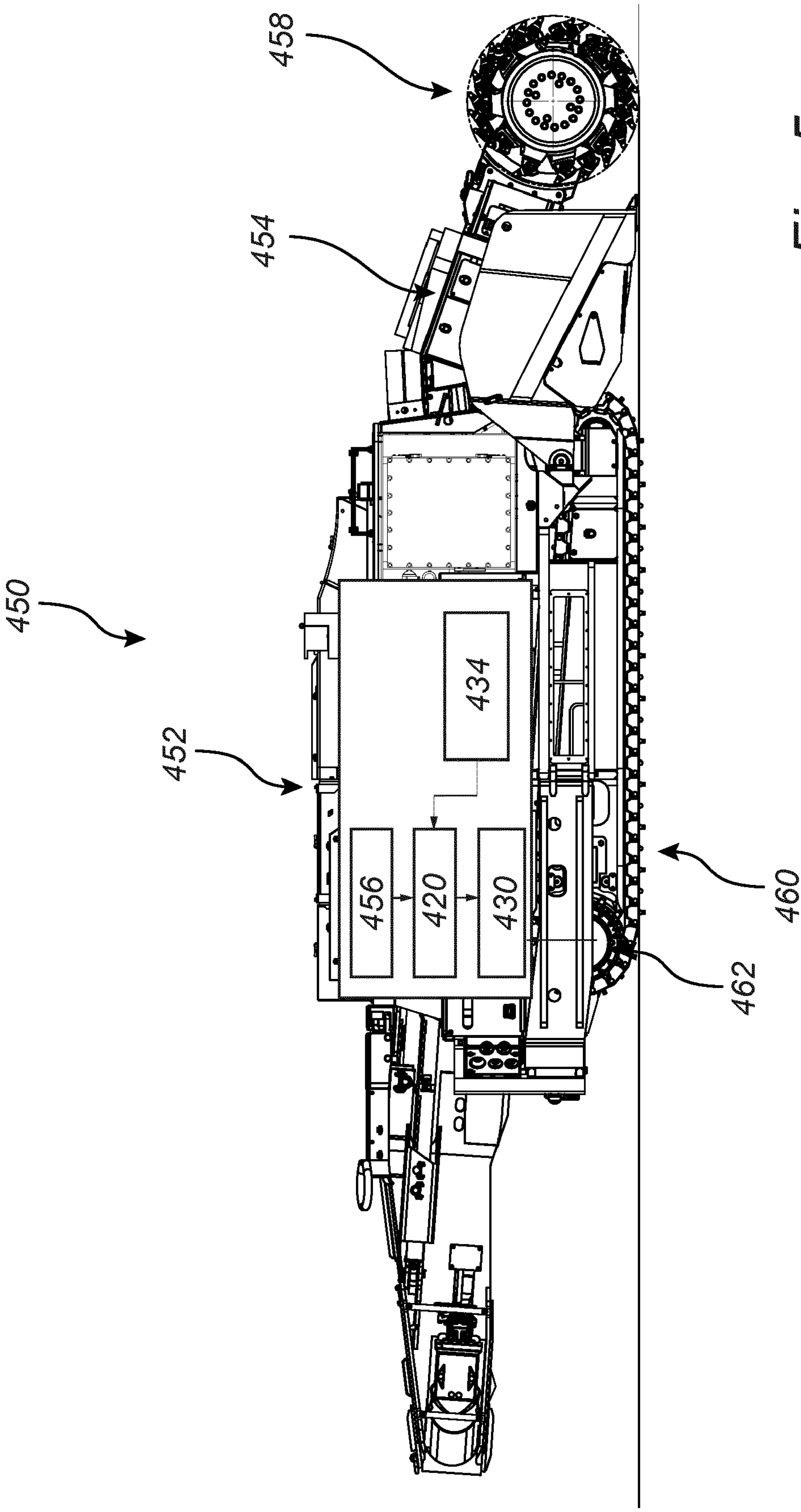

Fig. 5

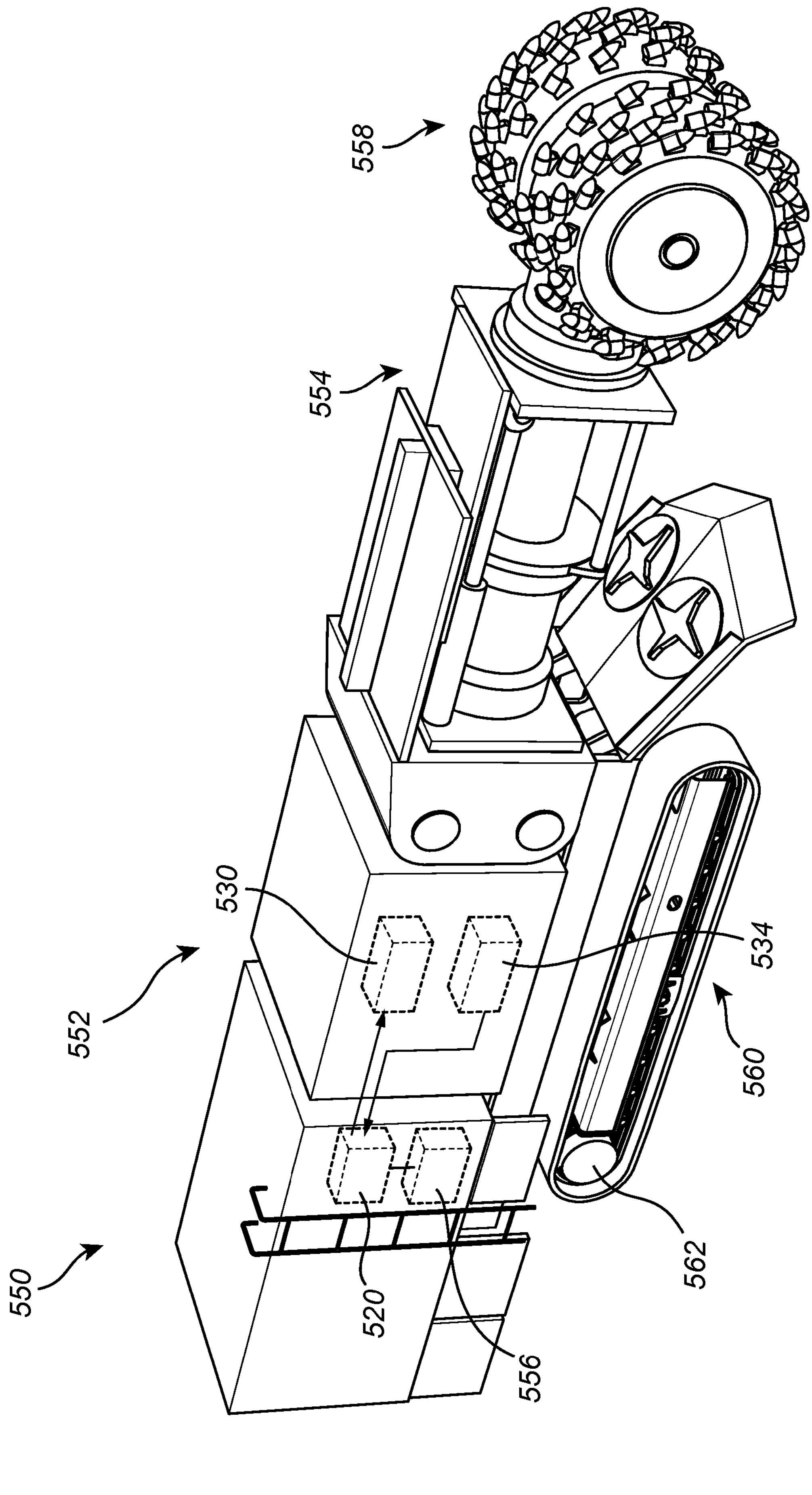

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 21 15 4175

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	10 June 2021	Morrish, Susan

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