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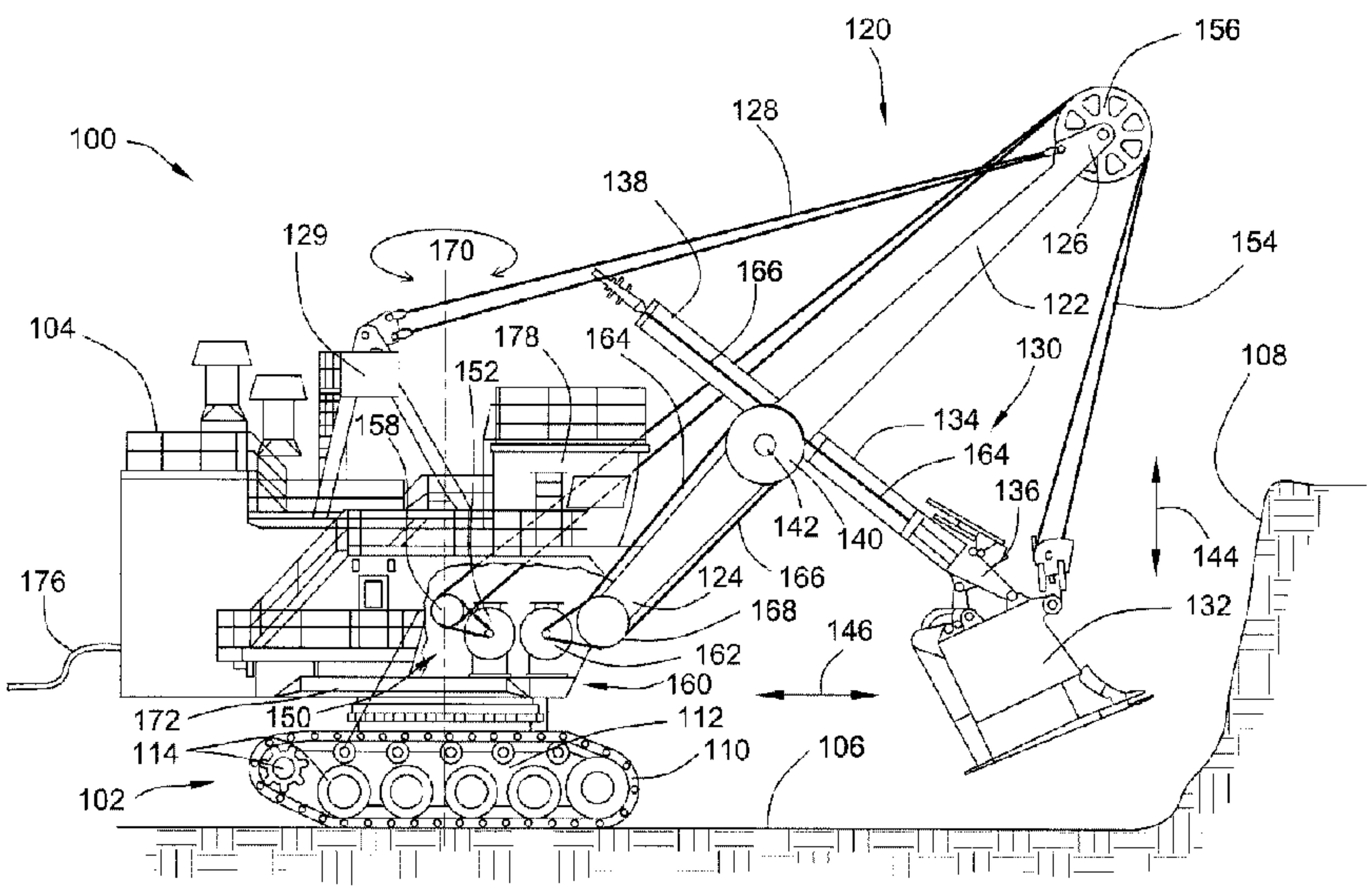

(57) Abrégé/Abstract:
A mining machine (100) such as a mining shovel includes a digging assembly (130) having an upward extending boom (122) and a dipper (132) generally horizontally supported by the boom (122). The dipper assembly (130) includes a dipper (132) disposed at one end of a dipper arm (134) that can slide in translation with respect to the boom (122) to crowd toward or retract from a vertical bank (108) at the mining site. To translate the dipper assembly (130), the mining machine (100) includes a crowd system (160) having a crowd motor (162) and a crowd actuator (164). An electronic controller (200) receives the crowd motor torque (266), a crowd speed (264) of the dipper assembly (130), and an inertia parameter (274) associated with the dipper assembly (130). The electronic controller (200) can determine an approximate location of the dipper (132) with respect to the bank (108) and, in a further aspect, can execute an anti-swing function (242) if the dipper (132) is in the bank (108).

Abstract

CONTROL SYSTEM FOR MINING MACHINE

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Description

CONTROL SYSTEM FOR MINING MACHINE

Technical Field

This patent disclosure relates generally to a mining machine such as a mining shovel and, more particularly, to a method of controlling and enabling the machine to dig material at a mine site.

Background

Of the various types of machines utilized in mining operations, mining shovels are responsible for digging material from a vertical bank face or other surface that may be located in a pit at the mine site and transferring the material such as mineral ore, coal, and overburden to a dump truck or other machine for transportation. Mining shovels include a boom that extends upwards into the air and at angle with respect to the bank and a dipper assembly that is supported by the boom. The dipper assembly includes a bucket-like dipper that scoops into, fills with, and removes material from the bank and that is supported by an elongated dipper arm or handle. To enable the dipper to swing upwardly into the bank, the dipper assembly is supported by the boom in a manner that allows the dipper arm to pivot and slide with respect to the boom, hence the dipper assembly has at least two degrees of freedom with respect to the boom. The pivoting motion of the dipper upwards or downwards with respect to the boom may be referred to as hoisting. The sliding translation of the dipper arm with respect to the boom may be referred to as crowding, when proceeding in the direction of outward extension from the mining shovel, or retraction when proceeding in the direction of inward retraction or motion back towards the mining shovel.

When the dipper impacts and penetrates into the bank filling with material, the mining shovel is subjected to severe forces and stresses. The magnitude of these forces and stresses may possibly damage the mechanical components and operational systems of the mining shovel. Further, if the dipper assembly strikes the bank at an incorrect angle of attack, "boom jacking" may occur in which the crowding dipper assembly is pushed back against the boom and may cause the boom to pivot upwardly then drop and bounce with respect to the mining shovel. To assist operators in controlling the mining shovel to accommodate these applied forces, manufacturers often configure mining shovels with computer-implemented control systems that regulate the motions and power outputs of the mining shovel during the digging operation.

One example of a control system is provided in U.S. Patent No. 6,466,850 ("the '850 patent"). The '850 patent describes a control system which monitors various parameters regarding the machine, including a crowd torque and a hoisting force used for lifting and lowering the dipper assembly into the bank. This information is used in part to control operation of a crowd motor that is responsible for crowding out and retracting in the dipper assembly to prevent the dipper assembly from becoming stalled within the bank during a digging operation. The present disclosure is directed to providing a control system for a mining shovel or similar machine to similarly assist operation of the machine when digging.

Summary

The disclosure describes, in one aspect, a mining machine for excavating material at a mine site or the like. The mining machine can include an undercarriage with one or more propulsion devices and an upper structure rotatably supported to swing with respect to the undercarriage. To perform the digging operation, a digging assembly is disposed on the upper structure which may include a boom connected to the upper structure at a lower end and which extends upwardly to an upper end. The digging assembly also includes a dipper assembly having a dipper arm slidably supported by the boom with a dipper disposed at the first end of the dipper arm. To enable the dipper assembly to

slidably translate in the crowd and retraction directions with respect to the boom, a crowd system is operatively associated with a crowd motor and a crowd actuator that are included with the digging assembly. The mining machine further includes an electronic controller operatively associated with the crowd system and in electronic communication with the crowd motor. The electronic controller may be configured to calculate a calculated crowd force and to determine an approximate location of the dipper with respect to a bank at the mine site based in part on the calculated crowd force.

In another aspect, the disclosure describes a method of operating a mining machine. According to the method, a dipper assembly may slide in translation with respect to a boom that is arranged in an upward orientation on the mining machine by operation of a crowd motor. The method obtains a crowd motor torque and a crowd speed from the crowd motor during the sliding translation of the dipper assembly. Additionally, an inertia parameter is assigned to the dipper assembly. The method then calculates a calculated crowd force based in part on the crowd motor torque, the crowd speed, and the inertia parameter. The method can then determine an approximate location of the dipper assembly based in part on the calculated crowd force.

In yet a further aspect, the disclosure describes an electronic controller for a mining machine having a dipper assembly slidably supported on an upward extending boom and a crowd motor responsible for sliding the dipper assembly with respect to the boom. The electronic controller may be configured to perform a crowd force function to determine a calculated crowd force based in part on a crowd motor torque, a crowd speed of the dipper assembly, and an inertia parameter associated with the dipper assembly. The crowd force function may further determine an approximate location of a dipper disposed on the dipper assembly based on the calculated crowd force. The approximate location may correspond to an in-bank condition and an out-of-bank condition. The electronic controller may further perform an anti-swing function to limit rotation of an upper structure with respect to an undercarriage during the in-bank condition.

Brief Description of the Drawings

Figure 1 is a side elevational view of a machine, in the embodiment of a mining shovel, including a boom, a dipper assembly, and a crowd system for digging material at a mine site and which is configured with an electronic controller to control the mining shovel according to the disclosure.

Figure 2 is a schematic diagram representing an electronic controller operatively associated with various other components of the mining shovel for implementing the control system executed by the electronic controller.

Figure 3 is a flowchart representing a possible process or routine for determining if a dipper assembly on the mining shovel is digging into a bank based on a calculated crowd force applied to the crowd system.

Figure 4 is a chart representing the crowd forces being generated and applied during a digging operation.

Detailed Description

This disclosure relates to mining machines for digging, moving, and unloading material about a mine site as part of a mining operation. Now referring to FIG. 1, wherein like reference numbers refer to like elements, there is illustrated a mining machine of the foregoing type and, in the particular embodiment, a mining shovel 100 which can be configured to crowd into, excavate, and remove material from a vertical face or bank of a pit mine. However, in addition to mining shovels, aspects of the disclosure may be applicable to other mining machines for digging and excavating such as excavators, draglines, and the like. The illustrated embodiment of the mining shovel 100 may be mobilized so that it can move about the mining site during operation but, in other embodiments, the mining shovel may be temporarily or permanently fixed in location. To allocate mobility and digging functions, the mining shovel 100 may include an undercarriage 102 and an upper structure 104 that is supported on the undercarriage. To propel the mining shovel 100 over the ground surface 106 of the mine site, that may be disposed below a vertical face of a bank 108 or pit wall, the undercarriage 102 may be configured with one or more propulsion devices such as continuous tracks 110, sometimes referred to as caterpillar tracks. The continuous tracks 110 form a closed loop that can translate with respect to a frame 112 of the undercarriage 102 that includes a drive sprocket, rollers, and/or idlers 114 to facilitate translation of the tracks in a manner to propel the mining shovel 100. The mining shovel 100 can thus propel itself in the forward or rearward directions or turn itself towards either side. In an embodiment, multiple continuous tracks 110 can be provided on each side of the undercarriage 102. In a further embodiment, the undercarriage 102 may include rotatable wheels or other propulsion devices.

To dig and remove material from the bank 108 or a similar vertical face at the mine site, a digging assembly 120 may be disposed at the front of the upper structure 104 and thus may be referred to as a front end. The digging assembly 120 can include a boom 122, which may be an elongated, beam-like structure that is pivotally connected with pins at its lower end 124 to the upper structure 104. The boom 122 can extend upwardly from the upper structure 104 to its upper end 126 and may be angled in the forward direction at, for example, a 60° angle. To support the boom 122 in its upward extending, angled orientation, one or more suspension ropes 128 can be attached to the upper end 126 and extend back down to a A-frame shaped backstay 129 disposed on the upper structure 104. The boom 122 can support a dipper assembly 130 that includes a bucket-like dipper 132 that can penetrate into and fill with material from the bank 108. The dipper 132 may be supported by a dipper arm 134 or dipper handle that may be an elongated, arm-like structure that extends between a first end 136 connected to the dipper and a distal second end 138. During a digging operation, the dipper assembly 130 can swing upwardly into the bank 108 while projecting forwardly, or crowding, into the bank. To enable the swinging or scooping motion of the dipper 132 into the bank 108, the dipper assembly 130 is configured to pivot and slide with respect to the boom 122.

To facilitate pivoting and sliding of the dipper assembly 130, a saddle block 140 connects the dipper arm 134 to the boom 122. The saddle block 140 can be pivotally connected to the boom 122 at a pivot point 142 located between the fixed lower end 124 and the free upper end 126. Hence, when the dipper arm 134 is supported in the saddle block 140, the dipper arm can pivot or articulate with respect to the boom 122, thereby moving the dipper 132 upwardly and downwardly in the vertical direction 144 in movements that may be referred to as hoisting or lowering. To allow the dipper assembly 130 to translate or slide with respect to the boom 122 in the forward-reverse direction 146, the saddle block 140 can form a sleeve or cradle supporting the dipper arm 134 and which engages the dipper arm via appropriate bearings, rollers, or the like. Extension of the dipper assembly 130 in the forward-reverse direction 146 toward the bank 108 may be referred to as crowding the dipper assembly and retraction of the dipper assembly away from the bank may be referred to as retraction or retracting the dipper assembly.

To cause relative movement of the components of the digging assembly 120, the mining shovel 100 can include various motors, actuators, and rigging that are operatively associated with each other. For example, to hoist or lower the dipper 132 in the vertical direction 144, the mining shovel 100 can include a hoist system 150 that is powered by an electric hoist motor 152. The hoist motor 152, which may be an alternating current ("AC") motor of suitable power to lift and lower the dipper assembly and the dipper 132 when filled with material, may be disposed in the upper structure 104. To transfer motive power from the hoist motor 152 to the dipper assembly 130, one or more hoist ropes 154 or cables can be attached to the dipper 132 and extend upwardly and around a sheave 156 or pulley rotatably disposed at the upper end 126 of the boom 122. The hoist ropes 154 wrap partially around the rotatable sheave 156 to generally reverse their direction and extend back down and wind around a hoist winch 158 or drum disposed in the upper structure 104. The hoist winch 158 is operatively coupled with the hoist motor 152. Hence, operation of the hoist motor 152 rotates the hoist winch 158 to wind up or pay out the hoist ropes 154 causing the dipper assembly 130 to pivot about the pivot point 142 up or down along the vertical direction 144. The weight of the dipper assembly 130 is partially supported by the hoist ropes 154 that also pull the boom 122 in tension against the suspension ropes 128.

To cause the dipper assembly 130 to translate with respect to the boom 122 by crowding out or retracting in along the forward-reverse direction 146, the mining shovel 100 can also be equipped with a crowd system 160. The crowd system 160 can also be powered by an electric crowd motor 162 disposed in the upper structure 104. To convert rotation of the crowd motor 162 to translation of the dipper assembly 130, the crowd system 160 can include an appropriate crowd actuator operatively interconnected with the dipper arm 134. In the illustrated embodiment, the actuator may be a rope system or rigging which includes a first crowd rope 164 and a second crowd rope 166. The first crowd rope 164 can attach to the dipper arm 134 proximate to the first end 136 and the second crowd rope 166 can attach to the dipper arm proximate to the second end 138. The first and second crowd ropes 164, 166 extend along the length of the dipper arm 134 back toward the saddle block 140 and can partially wrap around the saddle block 140 to be redirected toward one or more crowd winches 168 or drums disposed in the upper structure 104. The rotatable crowd winch 168 is operatively coupled to the crowd motor 162. Rotation of the crowd winch 168 in one direction will pay out the first crowd rope 164 while winding up the second crowd rope 166 causing the dipper assembly to crowd forward toward the bank 108. Rotating the crowd winch 168 in the opposite direction winds up the first crowd rope 164 while paying out the second crowd rope 166 thereby retracting the dipper assembly 130.

In a further embodiment, the mining shovel 100 may be configured as a hydraulic mining shovel in which the crowd system 160 is associated with one or more hydraulic cylinders that may be disposed proximate the saddle block 140 and that can be used to crowd and retract the dipper assembly 130 with respect to the boom 122. In such an embodiment, the hydraulic cylinder functionally replaces the first and second crowd ropes 164, 166. The hydraulic cylinder can be operatively associated with a hydraulic system in which hydraulic fluid is pressurized by operation of the crowd motor 162 to extend and retract the dipper assembly 130.

In addition to the crowding and hoisting motions used to dig material from the bank 108, the mining shovel 100 can be configured to swing the digging assembly 120 about a vertical axis170, as indicated by the arrow, so the dipper assembly 130 moves horizontally over the ground surface 106 to and from the bank 108. Swinging the mining shovel can be used to, for example, position the dipper 132 over the body of a dump truck and release the extracted material. To enable the swinging motion, the upper structure 104 has a rotatable platform 172 or turn table that rotatable with respect to the upper structure to the undercarriage 102. Hence, the upper structure 104 can swing in either direction over the ground surface 106 while the undercarriage 102 remains stationary on the ground surface. To provide power for the various motors, systems, continuous tracks, and the like, the mining shovel 100 includes an electrical system that receives three-phase electrical power through a trail cable 176 from an offboard electrical source and distributes the power to the motors and other components on the mining shovel. In an alternative embodiment, the mining shovel may include an onboard prime mover such as an internal combustion engine for combusting and converting a hydrocarbon based fuel to mechanical power. To accommodate an operator and the controls, gauges, and readouts for operating the mining shovel 100, an operator's station 178 can be disposed on the upper structure 104 at a location that provides a view towards the digging assembly 120.

Referring to FIG. 2, to facilitate and coordinate operation of the various components of the mining shovel, the mining shovel can include an electronic control unit ("ECU") or a computerized or electronic controller 200, which is represented schematically with the corresponding controllable components and devices of the mining shovel. The electronic controller 200 can have any suitable computer architecture and can be in electronic communication with the various components on the mining shovel to send and receive electronic signals in digital or analog form with the components that enable the electronic controller to monitor and regulate the operations and functions of the mining shovel. The electronic controller 200 may execute and process functions, steps, routines, control maps, data tables, charts, and the like saved in and executable from computer readable and writable memory or another electronically accessible storage medium to control the mining shovel. To perform these functions and operations, the electronic controller 200 can include a processor 202 such as a central processing unit or microprocessor or, in other embodiments, an application specific integrated circuit (ASIC) or other appropriate processing circuitry. The processor 202 may further include a control unit 206 that is responsible for regulating its internal and external operations, such as receiving and loading applications and programs, reading and writing data to and from memory, and communicating with the other electronic components of the mining shovel. The processor 202 can also include a processing unit 208 responsible for executing the instructions associated with the programs and applications. To enable digital processing of data and execution of applications and programs, the processing unit 208 can be made of any of various gates, arrays, and other digital logic components.

To store data for processing and the instructions associated with programs and applications, the electronic controller 200 may include memory 210 or other data storage capabilities. The memory 210 may be further separated into instruction memory 212 that stores the instructions associated with the applications and programs and data memory 214 that is responsible for storing the data processed by the applications and programs. The memory 210 can include any suitable type of electronic memory devices such as random access memory ("RAM"), read only memory ("ROM"), dynamic random access memory ("DRAM"), flash memory and the like. In addition to the foregoing types of electronic memory, in a different embodiment, the memory 210 may include magnetic or optical accessibility. For more permanent storage, the electronic controller 200 can also read and write information to and from a separate database 216. The database 216 can include tables, data structures, libraries, and the like for organizing information in a manner that can be readily utilized by the electronic controller 200. Although in the illustrated embodiment, the electronic controller 200 and its components are illustrated as a single, discrete unit, in other embodiments, the electronic controller and its functions and operations may be distributed among a plurality of distinct and separate components such as electronic control units ("ECUs"), programmable logic controllers ("PLCs"), etc.

To interface with an operator of the mining shovel, the electronic controller 200 can be operatively associated with and in electronic communication with one or more operator input devices such as a joystick 220 or the like. The operator can manipulate the joystick 220 to produce digital or analog signals that are used to steer the mining shovel and to control movement of the digging assembly during digging operations. The joystick 220 can include toggles, dials, or buttons 222 to enable further input from the operator. To provide the operator with visual information regarding the operation and performance of the mining shovel, the electronic controller 200 can also communicate with a human-machine interface ("HMI") that includes a visual display device 224 such as a liquid crystal display ("LCD") and may also include audio capabilities. The visual display device 224 can be part of a portable notebook computer 226 located in the operator's station of the mining shovel; however, in other embodiments, the visual display device may be provided as a permanent installation of the operator station. Examples of visual information can include machine speed, engine load, electric motor performance, and the positions and forces being applied to the digging assembly. The notebook computer 226 can also include a keyboard 228 to facilitate its function as a HMI by allowing the operator to enter information and directions to the electronic controller 200. It should be noted, however, that the operator controls, inputs, and displays illustrated in FIG. 2 are by way of example only and may include different arrangements or controls in different embodiments.

In addition to the operator controls, to receive information about the status and operation of the mining shovel, the electronic controller 200 can be in electronic communication with various sensors 230 disposed about the mining shovel and that monitor and measure different operating parameters. In particular, the sensors 230 can send digital or analog data to the electronic controller 200 and may include motion or displacement sensors, Hall effect sensors, strain or load gages, voltage meters, current meters, temperature sensors, pressure sensors, and the like. In the illustrated embodiment, the plurality of sensors 230 can include a crowd winch sensor 232 that measures the force or load being applied to the crowd winch and a saddle block sensor 234 that measures activity of the saddle block such as the pivoting or crowding movements of the dipper assembly. The sensors 230 can be arranged in networked communication with each other and with the electronic controller 200 in a controller area network ("CAN") via a bus that physically conducts the electronic signals; however in other embodiments, communication may occur wirelessly through Wi-Fi, Bluetooth, or other communication standards.

To direct and control operation of the digging assembly of the mining shovel, the electronic controller 200 can be operatively coupled to the electric motors associated with the digging assembly and specifically with the hoist motor 152 and crowd motor 162. The electronic controller 200 can process and interpret the control signals or commands input through the joystick 220 and the notebook computer 226 by the operator and thereby operate the hoist motor 152 and the crowd motor 162 accordingly to produce the desired motions on the crowd system and the hoist system. For example, the electronic controller 200 can switch the electrical power from a generator or the like to the hoist motor 152 and crowd motor 162 on and off and may reverse the directions of the motors to pay out or take in the hoist and crowd ropes as desired. To regulate power to the hoist and crowd motors 152, 162, one or more electrical power regulators 236 may be disposed between the electronic controller 200 and the motors that adjust the applied current and voltage levels based on signals from the electronic controller to achieve the desired output speed, torque, and motor direction. In further embodiments, the electronic controller 200 can also be operatively associated with the hoist winch and the crowd winch to rotatably engage and disengage the winches from the respective hoist and crowd motors 152, 162.

In addition to operating the hoist and crowd systems, the electronic controller 200 can be arranged to swing the upper structure with respect to the lower undercarriage. In particular, the electronic controller 200 can be coupled via a motorized arrangement to a gear structure 238 that is attached to the platform 172 and that can be configured to adjust the force ratios to accommodate rotating the weight of the upper structure. If the electronic controller 200 receives a swing command from the joysticks 220, it can motorize the gear structure 238 to horizontally swing the platform and the upper structure thereon in either direction. Bearings, rail systems, and the like can also be included to enable the upper structure to swing with respect to the undercarriage. As can be appreciated, the electronic controller 200 can be responsible for regulating and controlling other aspects of the mining shovel such as the continuous tracks used to propel the mining shovel and the electrical power system that functions as the primary power source for the mining shovel.

In an embodiment, the electronic controller 200 can be configured to assist the operator in controlling the mining shovel to limit or reduce the affect of the forces generated during the digging operation. In particular, these features can take the form of a function, routine, or application program including computer executable instructions that can be stored in the instruction memory 212 of memory 210 and that can be loaded and executed in the processing unit 208 of the processor 202. For example, to determine the approximate location of the dipper, whether the dipper is located in-bank or out-of-bank, which may or may not be easy to verify from the operator's station, these instructions can include a crowd force function 240. The crowd force function 240 can utilize the information input through and readily obtainable from the other systems of the mining shovel to calculate the actual forces the crowd system is experiencing in a manner that enables the electronic controller 200 to estimate the approximate location of the dipper with respect to the bank. Further, the electronic controller 200 can be programmed to take various actions to assist operation of the mining shovel depending on the determined location of the dipper assembly. For example, to prevent unintentional movement of the digging assembly while it is disposed in the bank, the instructions can include an anti-swing function 242 that limits the ability or capability of the upper structure to rotate with respect to the lower undercarriage.

Referring to FIG. 3, there is illustrated a flowchart of a possible computer executable process 250 or routine for conducting the crowd force function 240 and anti-swing function 242. Although FIG. 3 illustrates a possible sequence as order of steps, steps may be omitted or added and may be performed in any possible alternative order. The process 250 can start with an initialization step 252 in which the programming instructions are loaded into the processing unit of the processor for execution in the electronic controller. In an embodiment, the mining shovel can be configured to operate in various different modes including, for example, a digging mode 254 for conducting the digging operation and a propulsion mode 256 for propelling the mining shovel over the ground surface about the mine site. Since the process 250 needs to be active only during a digging operation, the process can perform a digging assessment step 258 to determine whether the operator has selected or enabled either the digging mode 254 or the propulsion mode 256. If the propulsion mode 256 or a different mode is currently selected, the digging assessment step 258 can return to the initialization step 252 until the digging mode 254 is enabled.

If, however, the digging assessment step 258 affirmatively confirms that the mining shovel is in the digging mode 254, the process 250 can proceed to a data retrieval or data collection step 260 in which various data inputs are collected by the electronic controller. These data inputs can be determined using the sensors operatively associated with the electronic controller and disposed about the mining shovel. The electronic controller may already collect these data inputs in conjunction with the routine operation of the mining shovel. Examples of these data inputs can include operator references, commands, or input signals 262 from the joystick, crowd speed 264 and crowd motor torque 266, and a swing action 268 associated with the rotation of the upper structure with respect to the undercarriage, and any other suitable inputs. In an embodiment, the swing action 268 may correspond to a commanded swing speed or swing displacement that the operator may be attempting to direct the mining shovel to undertake. The crowd speed 264 may correspond to the voltage drawn by the crowd motor and the crowd motor torque 266 may correspond to the current drawn by the crowd motor. As explained below, in other embodiments, the crowd speed 264 may be measured differently. The electronic controller may monitor the data inputs continuously on a real-time basis so that the process 250 is reflective of real-time conditions. The data inputs may be in digital or analog form.

To perform the crowd force function 240 and estimate the approximate location of the dipper with respect to the bank, the process 250 can conduct a calculation step 270 to determine a calculated crowd force 272 that can represent the forces being applied to the crowd system. In a particular embodiment, the calculated crowd force 272 may correspond to the actual forces and stresses acting on the crowd system, such as tension or lack of tension on the crowd ropes separated from other forces, stresses, or moments being applied or originating elsewhere on the mining shovel, and may therefore correspond to the forces acting with respect to the dipper at an instantaneous moment. The calculated crowd force 272 can therefore be evaluated to determine whether the dipper is actually in-bank or out-of-bank.

In an embodiment, the calculation step 270 can proceed using the physical law that force equals mass times acceleration, as determined according to the following equation:

(Eqn. 1) F = M*A

The variables of the equation, and thus the calculated crowd force 272, are isolated with respect to the crowd system. To provide the acceleration variable, the speed of the dipper assembly moving in translation with respect to the boom is determined based on the crowd speed 264 that represents how fast the crowd is paying out or taking up the crowd ropes. As can be appreciated, the crowd motor speed corresponds to and can be converted to dipper assembly speed or velocity using known geometric correlations and dimensions obtained from the structure of the mining shovel. In another embodiment, the crowd speed or velocity of the dipper assembly may be determined directly by, for example, measuring translation of the dipper arm with respect to the saddle block. Directly measuring the speed and/or displacement of the dipper arm with respect to the saddle block may be advantageous in those embodiments in which a hydraulic cylinder is utilized to crowd and retract the dipper assembly, as opposed to crowd ropes. The process 250 can convert the crowd speed 264 to the crowd acceleration by taking the derivative of the crowd speed, thereby determining the change in speed over time, according to the following equation:

(Eqn. 2) Acceleration = dv / dt

Hence, through Eqn. 2, the process 250 indirectly calculates the crowd acceleration of the dipper assembly as feedback from readily obtainable information such as crowd speed 264 rather than directly attempting to measure acceleration of the dipper assembly. The crowd speed 264, and thus the calculated hoist acceleration variable, can be positive or negative, depending upon whether the dipper assembly is crowding or retracting with respect to the boom and bank, and the units may be in meters per second^2 or m/s^2. To determine the mass variable of Eqn. 1, an inertia parameter 274 can be estimated or determined that is associated with the mass of the dipper assembly and other factors. In particular, the inertia parameter 274, representing the resistance to the change in motion of the dipper assembly with respect to the boom, can be estimated using known masses for the dipper assembly and the other components of the crowd system as determined during design and manufacture of the mining shovel. In some embodiments, the inertia parameter 274 may be a static value, while in other embodiments, it may vary based on operational characteristics, component location and the like. The units for the estimated inertia parameter 274 may be in kilograms per meter^2 or Kg/m^2.

The forces associated with the crowd system can be calculated according to Eqn. 1 above to determine an inertial crowd force 276, which may correspond to the total forces needed to accelerate the dipper assembly in either the crowd or the retraction directions. This can be done according to the following modified version of Eqn. 1:

(Eqn. 3) Inertial Crowd Force = Inertia Parameter * (dv/dt)

In the embodiments utilizing a hydraulic cylinder to actuate the crowd system, the inertial crowd force may be determined based on other factors, such as the fluid pressure differential in the hydraulic cylinder between the cap end and the head end of the cylinder instead of employing an inertia factor. This quantity may equate to the total forces being applied to the cylinder by the crowd motor and the dipper assembly. To further isolate the actual forces applied to the crowd ropes alone, the inertial crowd force 276 can be subtracted from other forces being applied to the crowd system from the other components of the crowd system. In particular, the other forces may correspond to the output torque being generated by the crowd motor. The output torque corresponds to the crowd motor torque 266 collected during the data collection step 260. This determination produces the calculated crowd force 272 according to the following equation:

(Eqn. 4) Calculated Crowd Force = Crowd Motor Torque – Inertia Parameter * Crowd Acceleration

or

(Eqn. 5) Calculated Crowd Force = Crowd Motor Torque – Inertia Parameter * (dv/dt)

The calculated crowd force 272 represents the actual forces being applied externally to the dipper assembly, as experienced by the crowd ropes, by engagement with the material of the bank, i.e., the net forces on the crowd system minus the torque applied to the crowd system from the crowd motor. In other words, the calculated crowd force 272 represents the portion of the net total force applied to the crowd system that arises from penetration of the dipper into the bank. The calculated crowd force 272 may therefore be a better representation of the effect of the bank material on the crowd system than the measurement of the crowd motor torque 266, where the output torque may be also utilized to overcome frictional resistance of the components of the crowd system rather than engaging the dipper into the bank.

To ensure that the dipper is actually located in-bank, the process 250 can conduct a comparison step 280 in which the calculated crowd force 272 is further compared to a crowd force threshold 282. The crowd force threshold 282 may be determined based on a predetermined value such as a minimum or maximum quantity or may be determined based on dynamic operational characteristics regarding the mining shovel and/or mine site. For example, the crowd force threshold 282 can correspond to a threshold value of net forces the crowd system may be anticipated to withstand, or it can be based on a capacity of the crowd motor. In an embodiment, the crowd force threshold 282 can be a percentage of the full motor torque capacity rating for the crowd motor, such as 100% of the maximum rated torque capacity or the maximum continuous stall torque of the crowd motor. The comparison step 280 can occur according to the following equation:

(Eqn. 6) Calculated Crowd Force > Crowd Force Threshold.

If the calculated crowd force 272 exceeds the crowd force threshold 282, the process 250 can make an in-bank determination 284 confirming the dipper is disposed within the bank, thereby completing the crowd force function 240. By setting the first crowd force threshold 282 to the maximum rated torque capacity of the crowd motor, the process 250 can disregard incidental or minimal impacts, such as setting the dipper on the ground surface, that are safely within the capabilities of the mining shovel.

In furtherance with the disclosure, in an embodiment, the process 250 may proceed with additional steps to perform the anti-swing function 242 to limit the operator's ability to swing the upper structure with respect to the lower undercarriage while the dipper is in-bank. In particular, the process 250 can perform a swing comparison step 290 in which the swing action 268 is compared to a swing threshold 292 received by the process. The swing threshold 292 may be a predetermined value such as a minimum or maximum quantity or may be based on dynamic operational characteristics associated with the mining shovel and/or mine site. In the embodiment where the swing action 268 corresponds to the swing speed, the swing threshold 292 can correspond to a speed limit or the like. If the swing comparison step 290 confirms that the swing action 268 exceeds the swing threshold 292, this may indicate the operator is attempting to swing the upper structure with the dipper in-bank in an undesirable manner such as at an undesirable speed. In another embodiment, if the swing action 268 is significantly above the swing threshold 292, indicating that the operator is intentionally trying to swing the mining shovel and the dipper is not likely in the bank, the swing comparison step allow the operator to continue swinging the mining shovel accordingly. In such a case, the swing comparison step 290 determines if the swing action 268 is below the swing threshold 292 and should be limited.

In such a case, the process 250 can perform a swing limitation step 294 in which the operator's ability to swing the upper structure can be limited or reduced below the normal capacity by, for example, a fixed percentage such at 5% or 10%. In addition, the process 250 may provide a visual warning 296 or other warning that may display on the visual display device informing the operator that the process is in the swing limitation step 294. Limiting rotation of the upper structure with the dipper located in-bank further reduces bending moments that would otherwise be applied to the digging assembly if the operator attempted to swing the upper structure a significant distance. Allowing limited swinging further enables limited movement of the dipper assembly in a side-to-side motion, such as may be desirable to assist filling the dipper with material or to free a dipper stuck in the bank. In another embodiment, the process 250 may completely lock or block the ability of the operator to swing the upper structure for the duration of the in-bank condition. When the process 250 is no longer making an in-bank determination, it can proceed to a termination step 296 in which the process returns full swing capability to the operator.

Industrial Applicability

The present disclosure describes a system and process for determining the approximate location of the dipper of a mining shovel or similar mining device including whether the dipper is located in-bank or in another surface at a mine site. Referring to FIG. 1 and to FIG. 4, the digging operation may be explained. FIG. 4, in particular, is a chart 300 with forces 302 in, for example, foot-pounds or Newton-meters, represented on the Y-axis and time 304, for example in seconds, represented on the X-axis. FIG. 4 illustrates a digging operation in which the estimated position of the dipper, as represented by a dipper location line 310, is made in relation to the calculated crowd force 320 according to the above equations. The positive and negative signs attributed to the forces 302 along the Y-axis, or the positive and negative regions of the chart, are made in reference to the direction the dipper assembly 130 is moving with the force increasing during retraction and decreasing during crowding. Hence, the positive and negative signs associated with the forces 302 should be interpreted as a change in the direction that the forces are applied to the crowd system 160 rather than a change in the absolute force applied to the crowd system.

During the digging operation, the mining shovel 100 may initially retract and then crowd the dipper assembly 130 toward the bank 108 by translating the dipper arm 134 in the saddle block 140 backward and forward with respect to the boom 122 along the forward-reverse direction 146. Prior to impacting the bank 108, the calculated crowd force 320, indicated in FIG. 4 as a rope force applied to the crowd ropes, may be positive, as indicated by the first upward curve 322. This may be because the hoist system 150 at that time may be moving the dipper assembly 130 in the vertical direction 144, thereby assisting the crowd system 160, and because the torque output of the crowd motor 162 is only moving the dipper assembly through the empty space before the bank 108. Accordingly, the electronic controller on the mining shovel 100 may recognize the upward curve 322 as indicating the dipper 132 has not impacted or penetrated into the bank 108, i.e., the dipper is out-of-bank. In FIG. 4, this out-of-bank condition may correspond to the first lower portion 312 of the dipper location line 310.

When the dipper 132 does impact the bank 108, the calculated crowd force 320, as represented by the rope force such as tension or lack of tension on the crowd ropes, sharply drops negative as indicated by the downward curve 324. This represents that the crowd system 160 is experiencing significant stresses that may even exceed the output torque of the crowd motor 162. This downward curve 324 may continue as the dipper 132 is disposed within and penetrates into the bank 108. In fact, the downward curve 324 may include a second downward peak 326 as the operator subsequently retracts and crowds the dipper assembly 130 into the bank to fill the dipper 132 with material. The operator may also be manipulating the crowd system 160 to assist filling the dipper 132 with material. The electronic controller, using the steps and calculations described above, interprets this as an in-bank condition as represented by the upper portion 314 of the dipper location line. For the duration of the upper portion 314, the electronic controller may implement the anti-swing function and restrict the ability to swing the upper structure 104 with respect to the undercarriage 102 while the dipper 132 is in-bank.

When the dipper 132 is filled and the mining shovel 100 retracts the dipper assembly 130 from the bank 108, the calculated crowd force 320 as applied to the crowd ropes may increase into the positive region of the chart 300 as indicated by the second upward curve 328. The electronic controller may interpret this as meaning the dipper 132 is no longer in bank, as indicted by the second lower portion 316 of the dipper location line 310. At this point, the electronic controller may release the anti-swing function and allow the upper structure 104 to swing about the vertical axis 170 to move the dipper 132 over a dump truck and unload the material. Hence, the present disclosure assists operation of the mining shovel 100 by determining the approximate location of the dipper 132 with respect to the bank 108 based on a calculated crowd force, rather than based on a different parameter such as crowd motor torque alone, which may not accurately correspond to the location of the dipper.

It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

The use of the terms “a” and “an” and “the” and “at least one” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term “at least one” followed by a list of one or more items (for example, “at least one of A and B”) is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B), unless otherwise indicated herein or clearly contradicted by context.

Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

Claims

1. A mining machine comprising:

an undercarriage;

an upper structure rotatably supported to swing with respect to the undercarriage;

a digging assembly disposed on the upper structure, the digging assembly including:

a boom connected to the upper structure at a lower end and extending upwardly to an upper end;

a dipper assembly including a dipper arm and a dipper disposed at a first end of the dipper arm, the dipper assembly slidably supported by the boom;

a crowd system for slidably moving the dipper assembly with respect to the boom in a crowd direction and in a retract direction, the crowd system including:

a crowd motor disposed in the upper structure,

a crowd actuator operatively associated with the crowd motor and arranged to slide the dipper arm with respect to the boom; and

an electronic controller operatively associated with the crowd system and in electronic communication with the crowd motor, the electronic controller configured to receive a crowd speed and a crowd motor torque and to calculate a calculated crowd force and to determine an approximate location of the dipper based on the calculated crowd force.

2. The mining machine of claim 1, wherein the electronic controller receives an inertia parameter associated with the dipper assembly and calculates the calculated crowd force based in part on the inertia parameter.

3. The mining machine of any one of claims 1-2, wherein the electronic controller converts the crowd speed to a crowd acceleration.

4. The mining machine of any one of claims 1-3, wherein the electronic controller calculates an inertial crowd force based on the inertia parameter and the crowd acceleration.

5. The mining machine of any one of claims 1-4, wherein the electronic controller calculates the calculated crowd force by subtracting the inertial crowd force from the crowd motor torque.

6. The mining machine of claim 1, wherein the electronic controller receives a crowd force threshold and compares the crowd force threshold with the calculated crowd force to determine the approximate location of the dipper.

7. The mining machine of claim 1, wherein the electronic controller is further configured with an anti-swing function to restrict a swing speed of the upper structure.

8. The mining machine of claim 7, wherein the approximate location of the dipper maybe either one of an in-bank condition or an out-of-bank condition and the anti-swing function restricts the swing speed during the in-bank condition only.

9. The mining machine of claim 8, wherein the electronic controller compares the calculated crowd force to a crowd force threshold to determine if the in-bank condition exists.

10. A method of operating a mining machine comprising:

sliding a dipper assembly in translation with respect to a boom arranged in an upward orientation on the mining machine by operation of a crowd motor;

receiving a crowd motor torque and a crowd speed;

receiving an inertia parameter associated with the dipper assembly;

calculating a calculated crowd force based in part on the crowd motor torque, the crowd speed, and the inertia parameter; and

determining an approximate location of a dipper disposed on the dipper assembly based on the calculated crowd force.

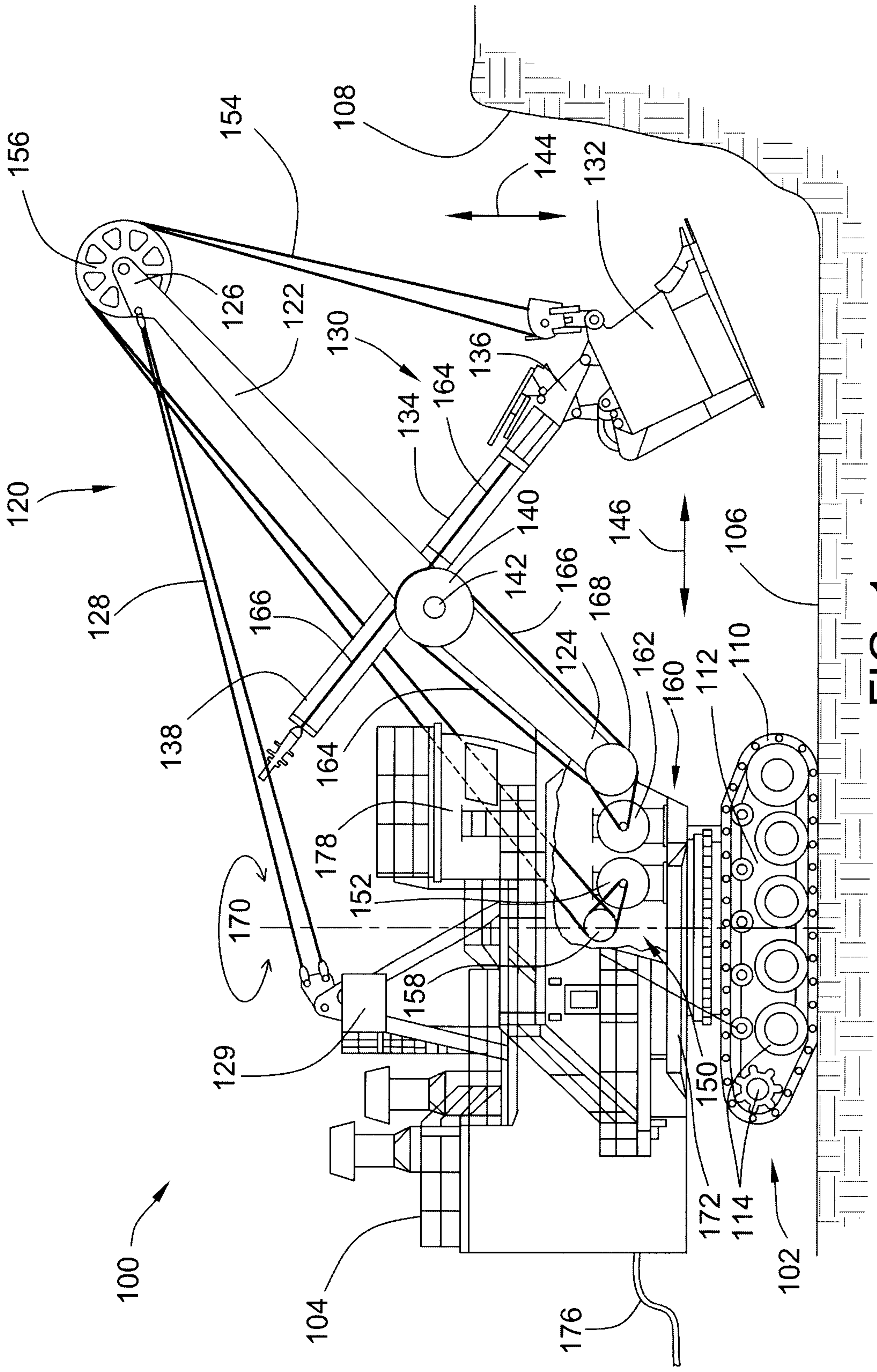
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FIG. 1

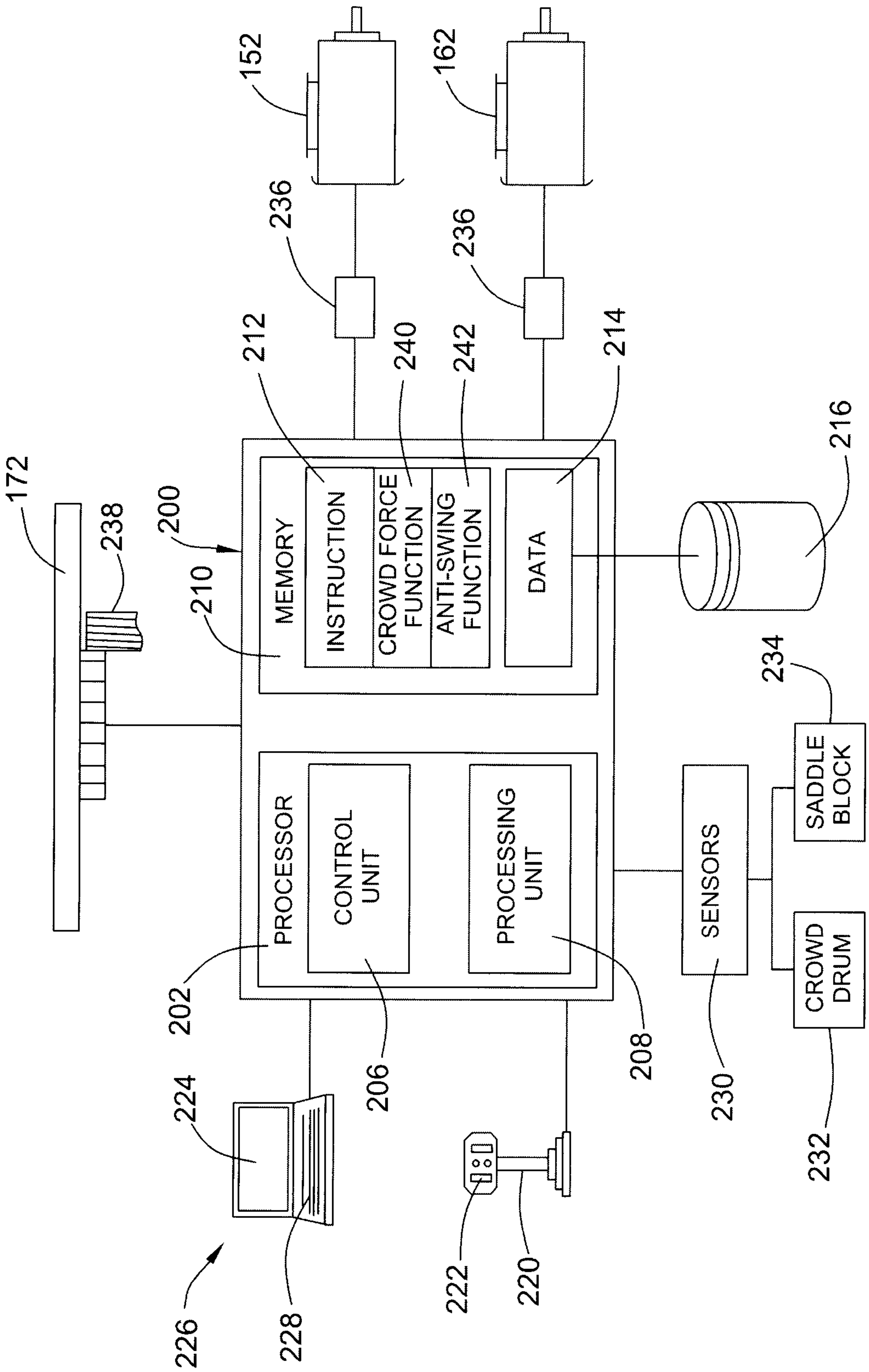
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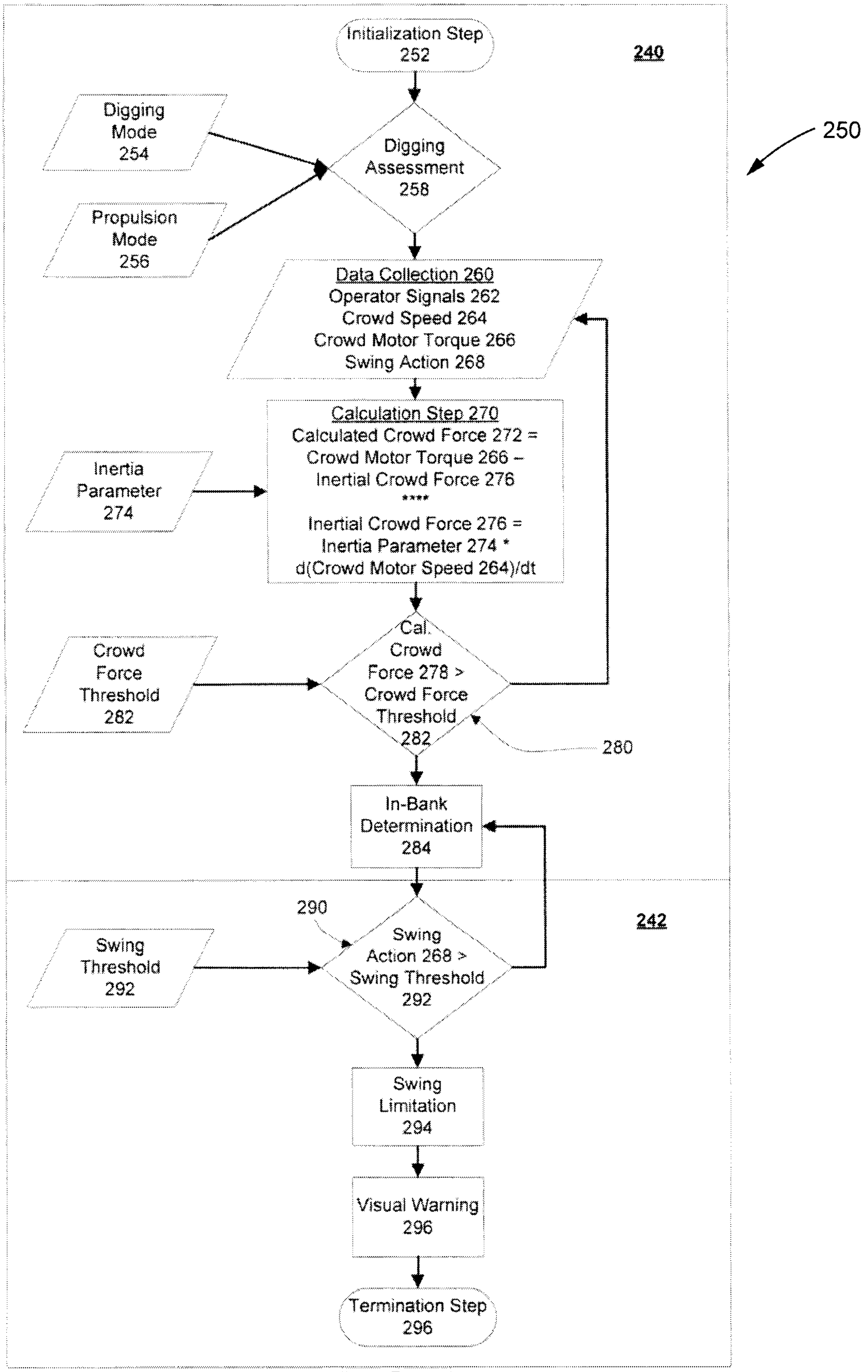
FIG. 2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Digging
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Propulsion
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Digging
Assessment
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Data Collection 260
Operator Signals 262
Crowd Speed 264
Crowd Motor Torque 266
Swing Action 268
Calculation Step 270
Calculated Crowd Force 272 =
Crowd Motor Torque 266 –
Inertial Crowd Force 276
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Inertial Crowd Force 276 =
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Limitation
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Visual Warning
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Termination Step
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FIG. 3

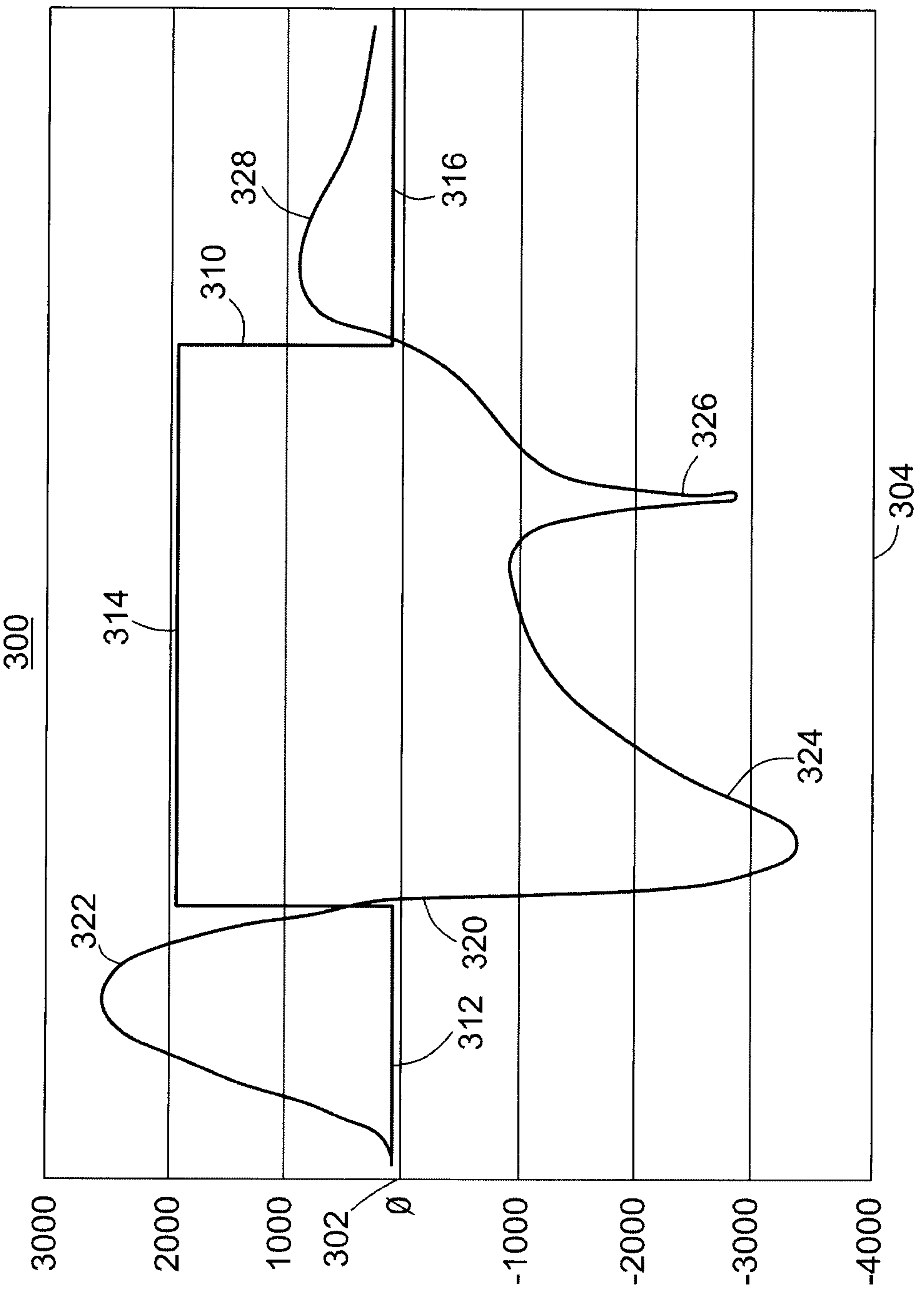
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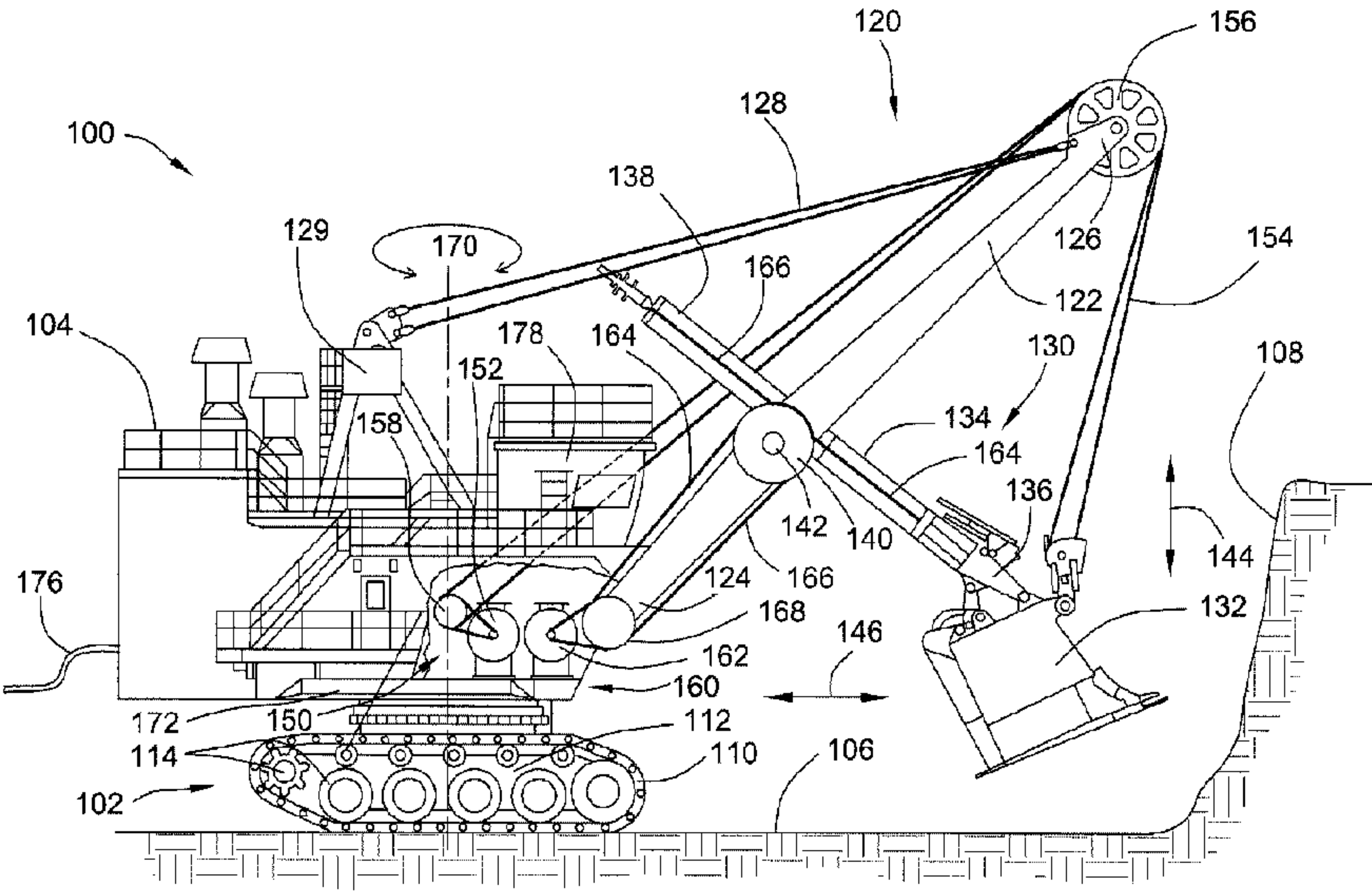
FIG. 4



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