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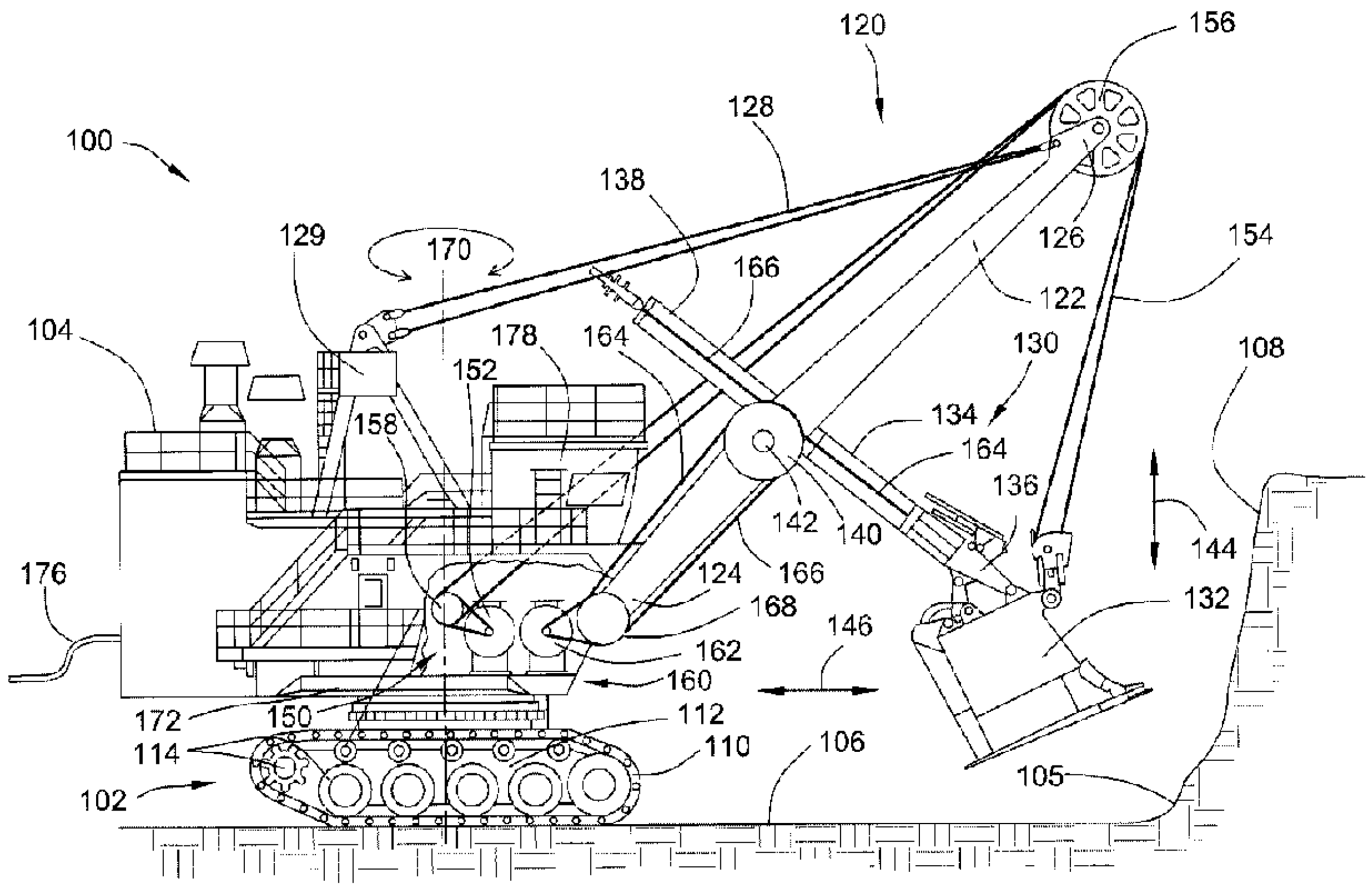
(54) **Titre :** MECANISME DE COMMANDE DE VEHICULE D'EXPLOITATION MINIERE
(54) **Title:** CONTROL SYSTEM FOR MINING MACHINE



(57) **Abrégé/Abstract:**
A mining machine (100) such as a mining shovel includes a digging assembly (120) having an upward extending boom (122) and a dipper assembly (130) with a dipper (132) that is generally horizontally supported by the boom (122). A hoist system (150) including hoist ropes (154) attached to the dipper (132) may be used to vertically pivot the dipper assembly (130) with respect to the boom (122). To determine if the hoist ropes (154) are properly supporting the weight of the dipper assembly (130), an electronic controller (200) can calculate a calculated hoist rope force (332) based on a hoist speed (312) associated with the hoist ropes (154) and a hoist motor torque (314) from a hoist motor (152). If the calculated hoist rope force (332) indicates that slack exists in the hoist ropes (154), the electronic controller (200) can execute a slack reduction function to increase tension in the hoist ropes (154) attached to the dipper (130).

Abstract

CONTROL SYSTEM FOR MINING MACHINE

A mining machine (100) such as a mining shovel includes a digging assembly (120) having an upward extending boom (122) and a dipper assembly (130) with a dipper (132) that is generally horizontally supported by the boom (122). A hoist system (150) including hoist ropes (154) attached to the dipper (132) may be used to vertically pivot the dipper assembly (130) with respect to the boom (122). To determine if the hoist ropes (154) are properly supporting the weight of the dipper assembly (130), an electronic controller (200) can calculate a calculated hoist rope force (332) based on a hoist speed (312) associated with the hoist ropes (154) and a hoist motor torque (314) from a hoist motor (152). If the calculated hoist rope force (332) indicates that slack exists in the hoist ropes (154), the electronic controller (200) can execute a slack reduction function to increase tension in the hoist ropes (154) attached to the dipper (130).

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.

Various actuators are used to actuate the hoisting and crowding movements of the dipper assembly that, in some embodiments, may include ropes or cables that extend about the boom and dipper assembly. By paying out or taking up the ropes, the dipper can be made to crowd into or retract from the bank. However, crowding the dipper into the bank subjects the mining shovel to severe forces and stresses that may attempt to dislocate the parts of the digging assembly including the ropes. 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. 8,355,847 ("the '847 patent"). The '847 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 with respect to the bank to reduce or prevent rearward tipping forces moments imparted back to the mining shovel. 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 includes an undercarriage and an upper structure rotatably supported on the undercarriage. To perform the digging operation, the mining machine includes a digging assembly that has a fixed boom connected to the upper structure at a lower end an extending upwardly to an upper end and a dipper assembly including a dipper arm and a dipper pivotally supported by the boom. To pivot the dipper assembly with respect to the boom, a hoist system is provided including a hoist motor in the upper structure and a hoist rope anchored at a hoist winch operated by the hoist motor. The hoist rope runs from the hoist winch upwards about the upper end of the boom and downwards to attach to the dipper. To monitor slack in the hoist rope, electronic controller is configured to receive a hoist speed and a hoist motor torque and to determine a calculated hoist rope force indicative of tension in the hoist rope based in part on the hoist speed and the hoist motor torque.

In another aspect, the disclosure describes a method of operating a mining machine having a hoist system for hoisting a dipper assembly pivotally supported on an upward extending boom of the mining machine. According to the method, a hoist motor pays out or winds in a hoist rope to pivot the dipper assembly with respect to the boom. To assess tension in the hoist rope, the method calculates a calculated hoist rope force based on received values for a hoist motor torque and a hoist speed associated with the hoist system. The method further compares the calculated hoist rope force with a hoist force threshold to determine if the hoist speed should be reduced to reduce slack in the hoist rope.

In yet a further aspect, the disclosure describes an electronic controller for a mining machine having a dipper assembly pivotally supported on an upward extending boom. To pivot the dipper assembly, the mining machine may have a hoist system including a hoist motor arranged to pay out or wind in a hoist rope extending over the boom and attached to the dipper assembly. The electronic controller can execute a hoist force function to determine a calculated hoist rope force associated with tension in the hoist rope. The calculated hoist rope force is based in part on a hoist motor torque generated by a hoist motor, a hoist speed associated with the hoist rope, and an inertia parameter associated with the dipper assembly. The hoist force function further determines the presence of a rope slack condition indicative of slack in the hoist rope by comparing the calculated hoist rope force with a hoist force threshold. If the slack rope condition is present, the electronic controller is further configured to execute a slack reduction function to reduce the hoist speed during the rope slack 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 is being supported by a hoist system of the mining shovel.

Figure 4 is a flowchart representing a possible process for reducing slack in one or more hoist ropes of the hoist system used to pivot the dipper assembly.

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 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.

Due to the angled orientation of the boom 122, the sheave 156 disposed at the upper end 126 may be directed over and above the horizontal path of translation for the dipper assembly 130. 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 crowd 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 a 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 as the crowd actuator. 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 axis 170, 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 is 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 a onboard prime mover such as an internal combustion engine for combusting and converting a hydro-carbon 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 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's 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 hoist winch sensor 232 that measures the force or load being applied to the hoist 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 172 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 during the digging operation. In particular, these configured 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, referring to FIGS. 1 and 2, these instructions may execute a process to determine if the weight of the dipper assembly 130 is being properly supported by the hoist system 150, instead of by another cause such as the ground surface 106 or material in the bank 108. To make the determination, the electronic controller 200 may execute a hoist force function 240 from instruction memory 212 that can utilize information from the sensors 230 and other systems disposed about the mining shovel 100 to calculate the actual forces applied to the hoist system 150 and, in particular, the forces or tension on the hoist ropes 154. The tension on the hoist ropes 154 is indicative of the whether the hoist system 150 is bearing the weight of the dipper assembly 130 or if is being carried elsewhere and the hoist ropes are relatively slack. Because slackness in the hoist ropes 154 may have adverse consequences for operation of the mining shovel 100 and the hoist system 150 in particular, the electronic controller 200 can further execute a slack reduction function 242 retrieved from instruction memory 212 to reduce or eliminate slack in the hoist ropes.

Referring to FIGS. 3 and 4, there is illustrated a flowchart of a possible computer executable process 300 or routine for conducting the hoist force function 240 and the slack reduction function 242. Although FIGS. 3 and 4 represents a possible sequence or order of steps, various steps may be omitted or added and may be performed in any possible alternative order. The process 300 can start with an initialization step 302 in FIG. 3 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 304 for conducting the digging operation and a propulsion mode 306 for propelling the mining shovel over the ground surface about the mine site. Since the process 300 needs to be active only during a digging operation when the dipper assembly is being raised or lowered, the process can perform a digging assessment step 308 to determine whether the operator has selected or enabled either the digging mode 304 or the propulsion mode 306. If the propulsion mode 306 or a different mode is currently selected, the digging assessment step 308 can return to the initialization step 302 until the digging mode 304 is enabled.

If, however, the digging assessment step 308 affirmatively confirms that the mine shovel is in the digging mode 304, the process 300 can proceed to a data retrieval or data collection step 310 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. Examples of these data inputs can include a hoist speed 312 and a hoist motor torque 314; a swing command 316 associated with the rotation of the upper structure with respect to the undercarriage such as a commanded swing speed; and a hoist position 318 and a crowd position 319 representing the relative positions of the dipper assembly based on operation of the hoist and crowd systems. The hoist speed 312 may be the speed of the hoist motor and may correspond to the voltage drawn by the hoist motor while the hoist motor torque 314 may correspond to the current drawn by the hoist motor. However, in other embodiments, the hoist speed 312 may be measured indirectly, such as by sensing the velocity of the hoist rope moving past a fixed location. The hoist position 318 and the crowd position 319 can be determined indirectly by calculation using information from the hoist and crowd systems such as how much rope had paid out or taken in. The electronic controller may monitor the data inputs continuously on a real-time basis so that the process 300 is reflective of real-time conditions. The data inputs may be in digital or analog form.

Prior to assessing whether the hoist system is responsible for bearing the weight of the dipper assembly, the process 300 can conduct a swing assessment step 320. If operator is swinging the upper structure with respect to the undercarriage, the dipper assembly has likely been removed from the bank and complications or negative consequences with respect to operation of the hoist system are lessened. Accordingly, the hoist force function 240 can terminate itself based on the swing assessment step 320. To perform the swing assessment step 320, a swing threshold 322 can be received that may be related to a swing reference or a swing command 316 directed by the operator. The swing threshold may be a percentage or fraction of the potentially available swing speed of the upper structure with respect to the lower structure, or it may be based on an angular distance or commanded swing in degrees or radians. The swing assessment step 320 compares the swing command 316 to the swing threshold 322 to determine if the operator is attempting to swing the mining shovel and as a prerequisite, if so, can terminate the hoist force function 240 and return to the data collection step 310.

However, if mine shovel is not swinging, the hoist force function 240 can proceed to a calculation step 330 to determine a calculated hoist rope force 332 representing the tension or force applied to the hoist ropes. If the hoist ropes are not taut or under tension, or if slack is developing in the hoist ropes, the weight of the dipper assembly is likely being carried by the ground surface or bank material and not by the hoist system as intended. Further operation of the digging assembly and movement of the dipper assembly may result in possible boom jacking, shock loading of the hoist and/or crowd systems, or dislocation of the dipper assembly with respect to the boom. Hence, the hoist force function 240 calculates the calculated hoist rope force 332 and evaluates the calculation to determine if hoist ropes are properly tensioned and can proceed to corrective measurements if there is slack in the hoist ropes.

In an embodiment, the calculation step 330 can proceed using the physical law that force equals mass times acceleration, as determined according to the following equation:

(Eqn. 1) $F = M*A$

To provide the acceleration variable, the speed of the dipper assembly is vertically moving with respect to the boom, either by hoisting or lower, is determined based on the hoist speed 312 that may represent how fast the hoist motor is paying out or taking up the hoist ropes. As can be appreciated, the hoist speed 312 corresponds to and can be converted to dipper assembly speed or velocity using known geometric correlations and dimensions of the mining shovel. In another embodiment, the hoist speed 312 and thus the speed or velocity of the dipper assembly may be determined directly by, for example, measuring the angular rotation of the dipper assembly pivoting with respect to the boom in the saddle block. The hoist force function 240 can convert the hoist speed 312 to the hoist acceleration variable by taking the derivative of the hoist speed, thereby determining the change in speed over time, according to the following equation:

(Eqn. 2) $\text{Acceleration} = dv / dt$

Hence, through Eqn. 2, the hoist force function 240 indirectly calculates the hoist acceleration of the dipper assembly using readily obtainable information such as hoist speed 312 rather than directly attempting to measure acceleration of the dipper assembly. The hoist speed 312, and thus the calculated hoist acceleration, can be positive or negative, depending upon whether the dipper assembly is being hoisted or lowered with respect to the boom, and the units may be in meters per second^2 or m/s^2.

To determine the mass variable for Eqn. 1, an inertia parameter 336 can be estimated or determined that is associated with the mass of the dipper assembly and other factors. In particular, the inertia parameter 336, 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 336 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 336 may be in kilograms per meter^2 or Kg/m^2.

The forces associated with the hoist system can be calculated according to Eqn. 1 above to determine an inertial hoist force 334, which may correspond to the total forces needed to accelerate the dipper assembly in vertical direction. This can be done according to the following modified version of Eqn. 1:

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

The inertial hoist force 334 may represent the total forces being applied to the hoist to the dipper assembly from the hoist system and due to gravity, impact and penetration into the bank, etc. To further isolate the actual forces applied to the hoist ropes, the inertial hoist force 334 can be subtracted from other forces being applied to the hoist system from the other components of the hoist system. In particular, the other forces may correspond to the output torque being generated by the hoist motor. The output torque corresponds to the hoist motor torque 314 collected during the data collection step 310. This determination produces the calculated hoist rope force 332 according to the following equation:

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

or

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

The calculated hoist rope force 332 represents the actual force or tension applied to the hoist ropes supporting the dipper assembly the material of the bank, i.e., the net forces on the hoist system minus the torque applied to the hoist motor. It is believed that determining the calculated hoist rope force 332 in the foregoing manner may provide a more direct representation of the tension force in the hoist ropes than, for example, using the hoist motor torque alone. The calculated hoist rope force 332 may also provide a better assessment of whether the hoist system is primarily supporting the dipper assembly or whether it is grounded on either the ground surface or in the bank. To make the determination, the hoist force function 240 performs a hoist force comparison step 340 in which the calculated hoist rope force 332 is compared to a hoist force threshold 342. The hoist force threshold 342 may be a predetermined value, such as a minimum or maximum quantity, or may be based on a dynamic operational characteristics associated with the mining shovel. The hoist force comparison step 340 may assess or evaluate whether the calculated hoist rope force 332 is above or below the hoist force threshold 342 according to the following equation.

(Eqn. 6) Calculated Hoist Rope Force < Hoist Force Threshold.

If the calculated hoist rope force 332 is below the hoist force threshold 342, the hoist force comparison step 340 can make positive determination of a rope slack condition 344 confirming that the hoist ropes are not properly tensioned and that slack may exist within the hoist ropes. The electronic controller can further understand the rope slack condition 344 indicates that the weight of the dipper assembly is not properly supported by the hoist system by way of a recognition step 348, and can further respond as described below to adjust operation of the hoist system accordingly.

Industrial Applicability

The present disclosure describes a system and process for determining whether the hoist system of a rope shovel or similar mining machine is properly supporting the weight of the dipper assembly including any material received in the dipper or if the weight is being carried elsewhere and the hoist ropes are relatively slack. Referring to FIG. 1, if the operator of the mining shovel 100 rests the dipper 132 disposed at first end 136 of the dipper assembly 130 adjacent the ground surface 106, or if dipper assembly has crowded and penetrated into the bank 108, the weight of the dipper assembly may no long be fully supported by the hoist system 150. This condition may mean that the hoist ropes 154 are not under proper tension and may cause the hoist ropes to go slack, which may adversely affect a digging operation. For example, the hoist motor 152 and the hoist winch 158 may rapidly wind up the slack hoist ropes 154 prior to assuming the weight of the dipper assembly 130 and any material held in the dipper 132. This may result in a possible overwrap of the hoist ropes 154 about the hoist winch 158 and the sudden assumption of large, heavy loads of the dipper assembly 130 by the hoist ropes and hoist motor 152, thereby mechanically and electrically stressing those components. Additionally, if the dipper assembly 130 crowding into the bank encounters significant reactionary forces, those forces may initiate a boom jack kicking the dipper assembly and boom 122 backwards and causing the hoist ropes 154 and suspension ropes 128 to go slack and then suddenly being stretched taut as the dipper assembly and boom fall again.

Accordingly, to assist in operation of the mining shovel during such conditions, the electronic controller can execute the slack reduction function to reapply tension to the hoist ropes and possibly to the crowd ropes 164, 166 and reduce any slack. Referring to FIGS. 1 and 4, where the slack reduction function 242 is depicted as a possible series of steps, slack reduction can be accomplished through a speed reduction step 350 that reduces or limits the speed or velocity at which the hoist system 150 and/or the crowd system 160 may operate. In an embodiment, the speed reduction step 350 can receive a hoist speed limit 352 and a crowd speed limit 354 that can be applied to hoist motor 152 and the crowd motor 162 respectively to reduce or limit the speed at which the motors can rotate the associated hoist and crowd winches 158, 168. The hoist speed limit 352 and the crowd speed limit 354 may be a static, absolute value based on, for example, a fixed percentage or fraction of the full rated motor speed for the respective hoist and crowd motors 152, 162 and may be in units like RPM, radian per second, etc. In other embodiments, the hoist speed limit 352 and the crowd speed limit 354 may be variable values dynamically determined in proportion to perceived amount of slack in the hoist ropes 154.

In an embodiment, the hoist speed limit 352 and the crowd speed limit 354 may outright limit the speed output of the respective hoist motor 152 and/or the crowd motor 162, for example, as a fixed percentage or fraction of the available full motor speed. In particular, the hoist speed limit 352 and crowd speed limit 354 may regulate the voltage the motors may draw to limit speed. In another embodiment, the hoist speed limit 352 and the crowd speed limit 354 may limit the directional commands or references input from the operator, for example, they may be applied to the hoist speed command 356 and hoist speed command 358 the operator direct of the hoist motor 152 and crowd motor 162. In such an embodiment, the hoist speed limit 352 and the crowd speed limit 354 may proportionally reduce the crowd speed command 356 or hoist speed command 358, for example, as a percentage of those commands.

With reference to FIG. 1, by conducting speed reduction step 350, the hoist system 150 may slowly recover the slack hoist ropes 154 and increase tension to gradually assume the load of the dipper assembly 130. In contrast to the sudden assumption of the full weight of the dipper assembly 130, especially if the dipper 132 is full, the slack reduction function 242 avoids shock loading the hoist ropes 154 and the hoist motor 152 and may prevent overrides on the hoist winch 158. In addition, by sensing slack in the hoist ropes 154 that may indicate a potential boom jack condition coming, the speed reduction step 250 reduces the speed or velocity of the hoist system 150 and/or crowd system 160 to preemptively reduce reactionary forces that may otherwise propagate through the digging assembly 120 and mine shovel 100. Hence, present disclosure assists operation of the mining shovel 100 by sensing whether the hoist system 150 is supporting the weight of the dipper assembly 130, in particular by calculating the forces in the hoist ropes 154, and by executing the slack reduction function 242 to accordingly.

Referring again to FIGS. 1 and 4, the slack reduction function 242 may perform other steps associated with tensioning the hoist ropes 154. For example, the process 300 carried through in the slack reduction function 242 may provide a visual warning 360 or other warning to the operator that may display on the visual display device in the operator station 178 that the process is presently performing the speed reduction command 350 reducing the speed of the systems.

The process 300 may also perform a log command 362 in which the rope slack condition 344 is logged for, for example, maintenance records or performance evaluation. To terminate the slack reduction function 242 and restore full speed operator to the hoist system 150 and crowd system 160, a timing assessment step 370 may track the occurrence time of the slack reduction function and compare that with a time limit 372. It may be appreciated that slack may be reduced and tension restored to the hoist ropes 154 in seconds or less and, accordingly, a short time limit 372 may sufficient to complete the slack reduction function 242. In another embodiment, conclusion of the rope slack condition 344 assessed by the hoist force function may terminate the slack reduction function 242. Upon the termination step 374, operation of the hoist system 150 and crowd system 160 may return to normal.

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 supported on 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 pivotally supported by the boom;

a hoist system for pivoting the dipper assembly with respect to the boom in a generally vertical direction, the hoist system including:

a hoist motor disposed on the upper structure;

a hoist rope operatively associated with the hoist motor and running from a hoist winch upwards about the upper end of the boom and downwards to attach to the dipper;

an electronic controller operatively associated with the hoist system and in electronic communication with hoist motor, the electronic controller configured to receive a hoist speed and an hoist motor torque and to determine a calculated hoist rope force indicative of tension in the hoist rope based in part on the hoist speed and the hoist motor torque.

2. The mining machine of claim 1, wherein the electronic controller receives an inertia parameter associated with the dipper assembly and calculates the calculated hoist rope 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 hoist speed to a hoist acceleration.

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

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

6. The mining machine of any one of claims 1-5, wherein the electronic controller compares the calculated hoist rope force to a hoist force threshold to assess a rope slack condition.

7. The mining machine of any one of claims 1-6, wherein the electronic controller reduces the hoist speed if the rope slack condition is assessed.

8. The mining machine of any one of claims 1-7, further comprising a crowd system for slidably moving the dipper assembly with respect to the boom, the crowd system including a crowd motor disposed in the upper structure and a crowd actuator operatively associated with the crowd motor and arranged to slide the dipper arm with respect to the boom, and the electronic controller reduces a crowd speed of the crowd actuator if electronic controller assesses the rope slack condition.

9. The mining machine of any one of claims 1-8, wherein the upper structure is rotatably mounted to the undercarriage; and the electronic controller monitors a swing command directing the upper structure to rotatably

swing with respect to the undercarriage, and the electronic controller compares the swing command to a swing threshold and only assesses a rope slack condition if the swing command is below the swing threshold.

10. A method of operating a mining machine comprising:

operating a hoist motor to pay out or wind in a hoist rope;

pivoting a dipper assembly pivotally supported on a boom arranged in an upward orientation on the mining machine with the hoist rope by operation of the hoist motor;

receiving a hoist motor torque and a hoist speed;

calculating a calculated hoist rope force based in part on the hoist motor torque and the hoist speed, the calculated hoist rope force representative of tension in the hoist rope;

comparing the calculated hoist rope force to a hoist force threshold; and

reducing the hoist speed if the calculated hoist rope force is below the hoist force threshold.

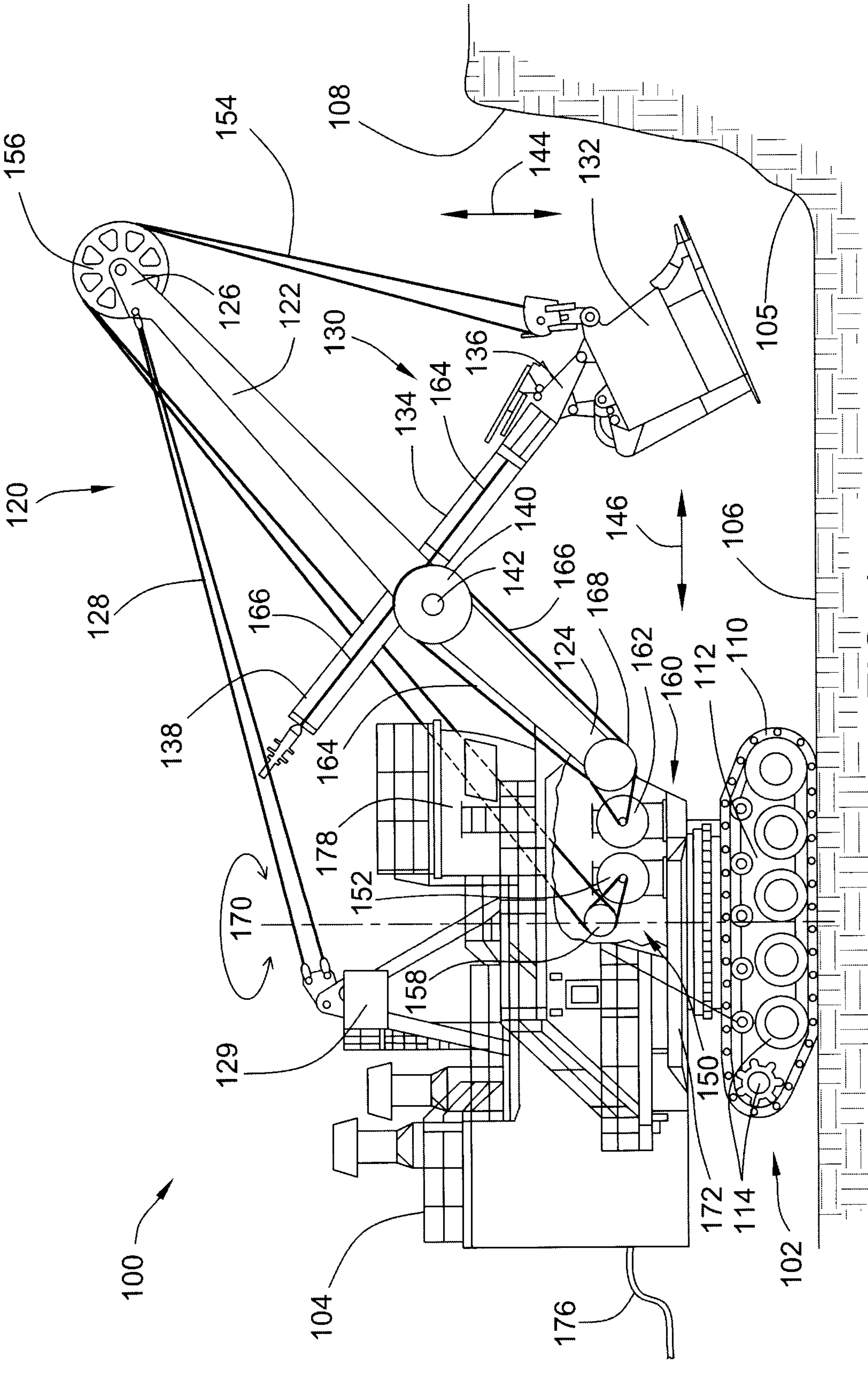

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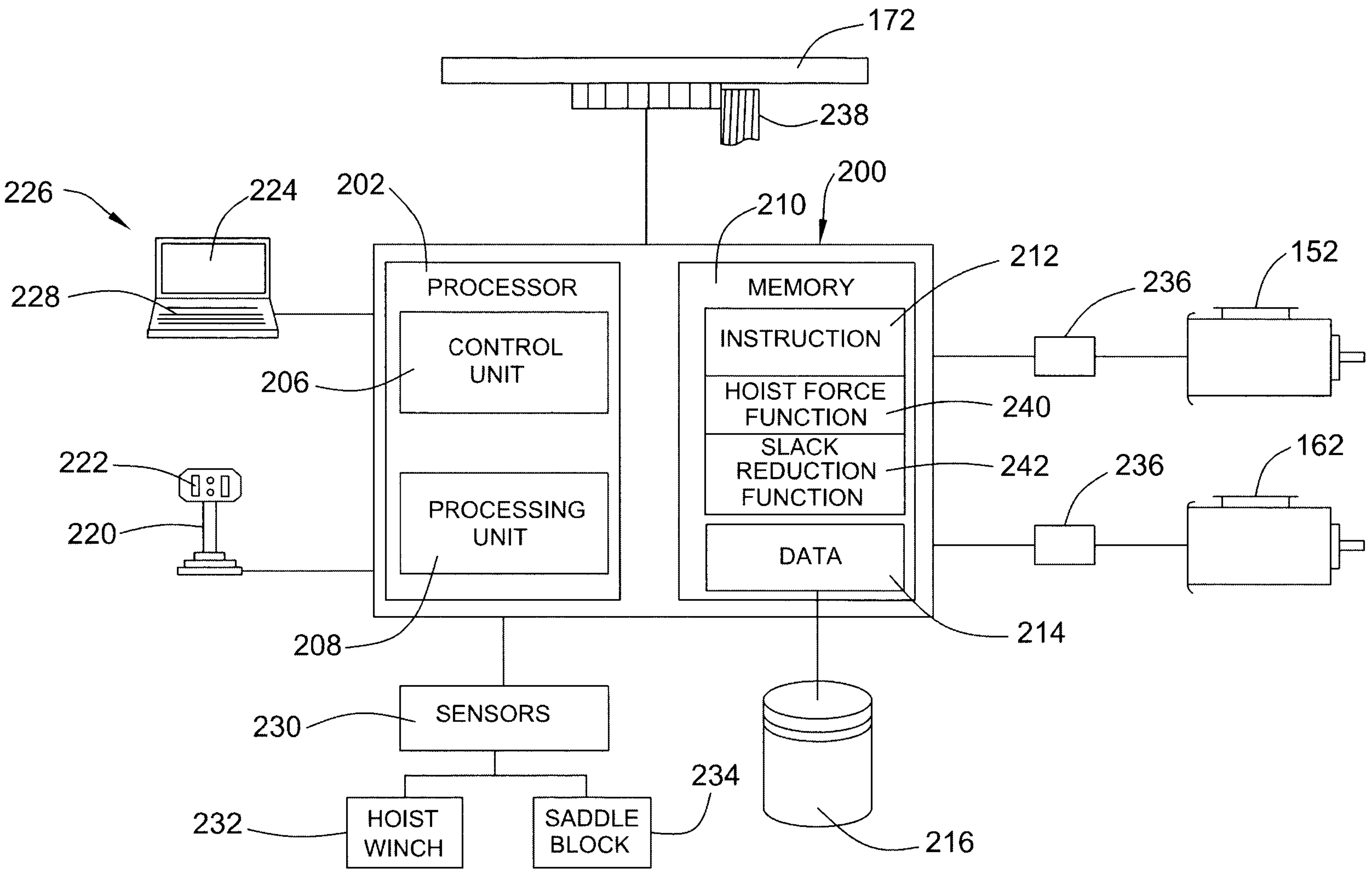
FIG. 1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MEMORY
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CONTROL UNIT
INSTRUCTION
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HOIST FORCE FUNCTION
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222
SLACK REDUCTION FUNCTION
242
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162
PROCESSING UNIT
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DATA
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SENSORS
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HOIST WINCH
SADDLE BLOCK
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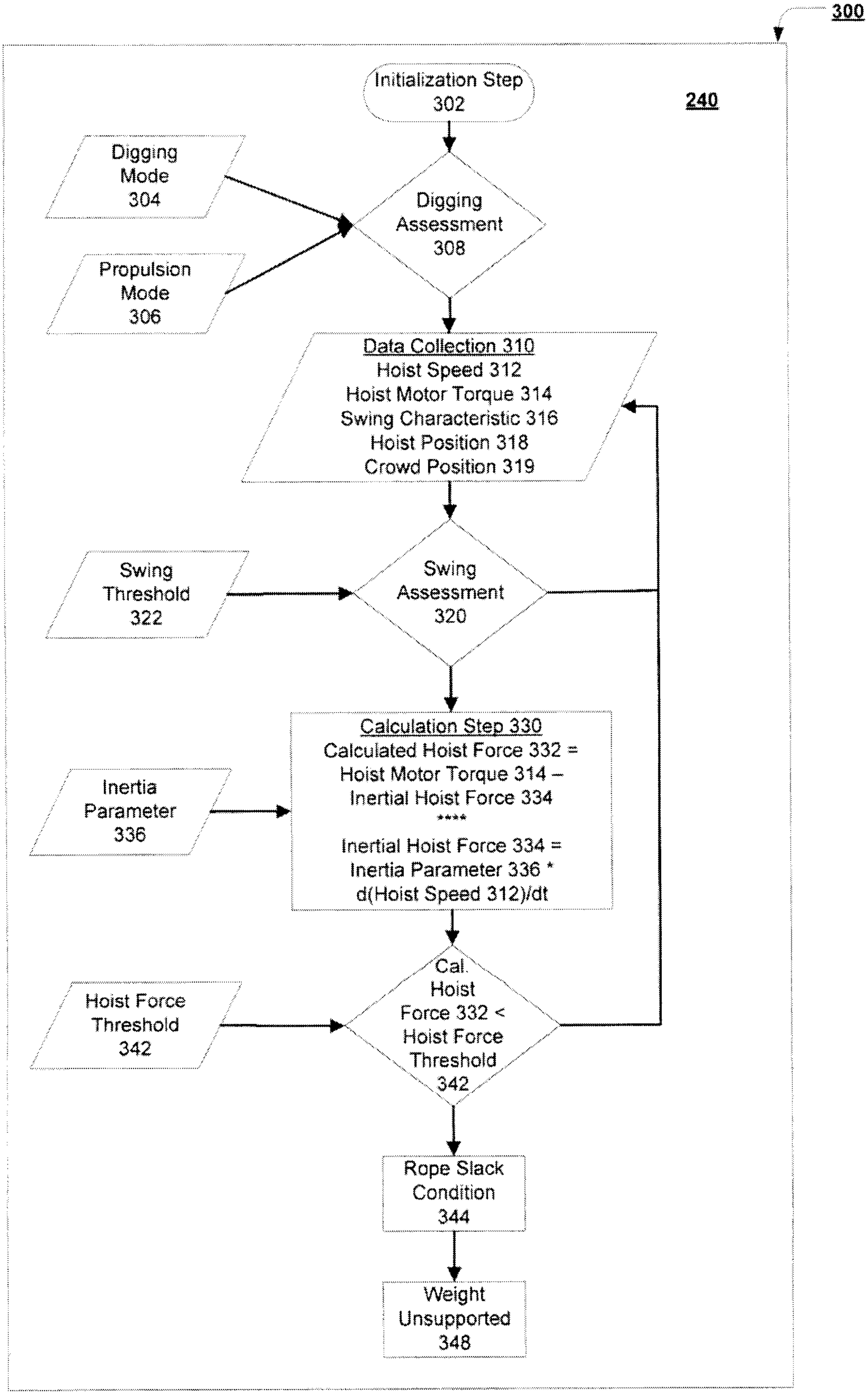
FIG. 2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Initialization Step 302
Digging Mode 304
Propulsion Mode 306
Digging Assessment 308
Data Collection 310
Hoist Speed 312
Hoist Motor Torque 314
Swing Characteristic 316
Hoist Position 318
Crowd Position 319
Swing Threshold 322
Swing Assessment 320
Inertia Parameter 336
Calculation Step 330
Calculated Hoist Force 332 = Hoist Motor Torque 314 – Inertial Hoist Force 334
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Inertial Hoist Force 334 = Inertia Parameter 336 * d(Hoist Speed 312)/dt
Hoist Force Threshold 342
Cal. Hoist Force 332 < Hoist Force Threshold 342
Rope Slack Condition 344
Weight Unsupported 348

FIG. 3

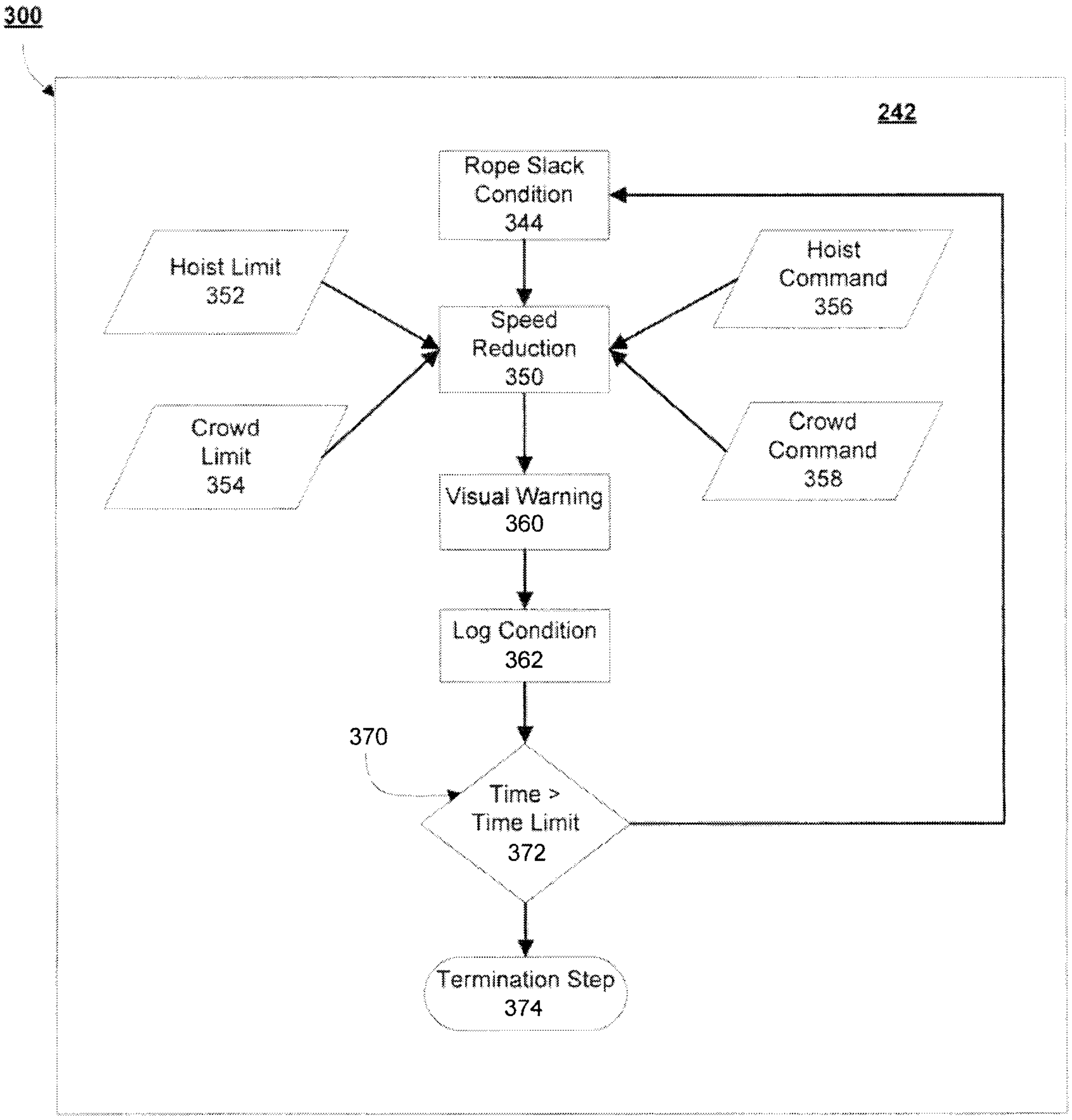
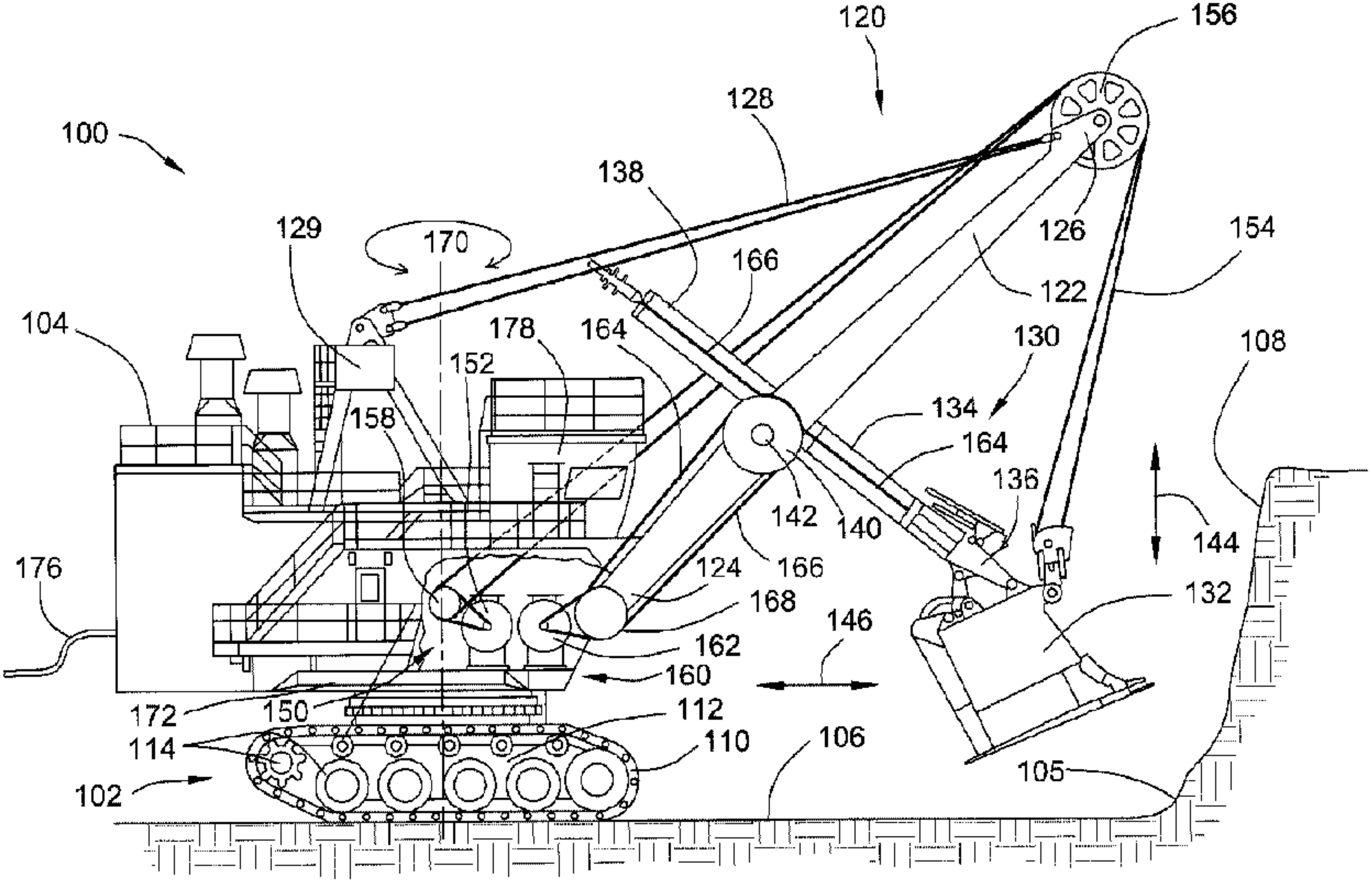

300
242
Rope Slack Condition 344
Hoist Limit 352
Hoist Command 356
Speed Reduction 350
Crowd Limit 354
Crowd Command 358
Visual Warning 360
Log Condition 362
370
Time > Time Limit 372
Termination Step 374

FIG. 4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