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(54) **Title**: AUTOMATIC DEPTH AND TRACTION CONTROL FOR RIPPING MACHINES

(57) **Abstract**: A system and method of controlling a ripping operation is disclosed. The method includes lowering a ripper (18) of a machine (10) to a depth under a work surface (12). The method determines when a drawbar pull of the machine (10) is at a drawbar pull target for the machine. When the drawbar pull is greater than the drawbar pull target, the method reduces the power source torque of the machine from a first power source torque to a second power source torque.

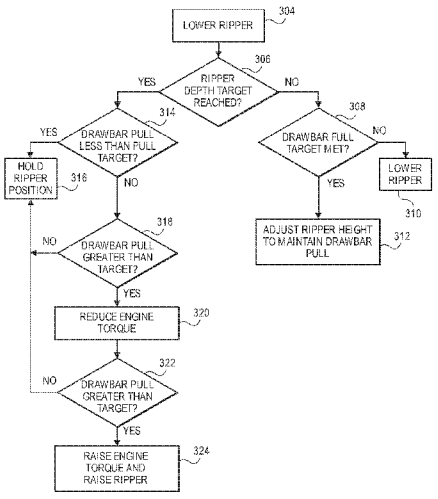


FIG. 3

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Description

AUTOMATIC DEPTH AND TRACTION CONTROL FOR RIPPING MACHINES

Technical Field

The present disclosure relates to an automatic digging system and, more particularly, to a ripper automatic digging system that implements machine acceleration and ripper control.

Background

Mobile excavation machines, such as, dozers, agricultural tractors, and scrapers, often include one or more material engaging implements utilized to cultivate, dig, rip or otherwise disturb a ground surface. The ground surface can include non-homogenous loose soil or compacted material that can be easy or difficult for the machine to process. As the machines traverse a site that has changing terrain and/or varying ground surface conditions, the magnitude of resistance applied to the implements by the material also varies, and higher amounts of resistance can lead to machine slip. Generally, slip represents the error between driven speed and actual machine travel speed. In order to ensure that a maximum productivity of the machine is attained without damaging the machine (i.e. a maximum amount of power is transmitted to the material with minimal slip), the operator of the machine must continuously alter settings of the machine and implements to accommodate the changing terrain and ground surface conditions. This continuous altering can be tiring for even a skilled operator and difficult, if not impossible, for a novice operator to achieve optimally.

United States Patent 5,950,141 ("'141 Patent"), entitled "Dozing System for Bulldozer", addresses automatically shifting a bulldozing operation from digging to carrying. The '141 Patent describes calculating a load factor based on horizontal and vertical reaction forces on a blade of a bulldozer and, based on the calculated load factor, automatically controlling the blade backward to hold earth. However, the design of the '141 Patent may still result in constant manual altering of a ripper depth and machine acceleration or torque.

Summary

In one aspect of this disclosure, a method of controlling a ripping operation, the method includes lowering a ripper of a machine to a depth under a work surface, determining when a drawbar pull of the machine is at a drawbar pull target for the machine, and when the drawbar pull is greater than the drawbar pull target, reducing power source torque of the machine from a first power source torque to a second power source torque is disclosed.

In another aspect of this disclosure, a system for controlling a ripping operation, the system including a power source configured to provide power to a machine; an actuator configured to move a ripper of the machine; a plurality of sensors configured to sense a position of the ripper; a controller in communication with the power source, the actuator, and the plurality of sensors, the controller being configured to: lower a ripper of a machine to a depth under a work surface, determine when a drawbar pull of the machine is at a drawbar pull target for the machine, and when the drawbar pull is greater than the drawbar pull target, reduce power source torque of the machine from a first power source torque to a second power source torque is disclosed.

In yet another aspect of this disclosure, a system for controlling a ripping operation, the system including a plurality of sensors configured to sense a position of a material engaging implement; a controller in communication with the plurality of sensors, the controller being configured to: lower a ripper of a machine to a depth under a work surface, determine when a drawbar pull of the machine is at a drawbar pull target for the machine, and when the drawbar pull is greater than the drawbar pull target, reduce power source torque of the machine from a first power source torque to a second power source torque is disclosed.

Brief Description of the Drawings

FIG. 1 is a diagrammatic illustration of an exemplary disclosed excavation machine, according to one aspect of this disclosure.

FIG. 2 is a diagrammatic and schematic illustration of an exemplary disclosed control system for use with the machine of FIG. 1, according to one aspect of this disclosure.

FIG. 3 is a flowchart showing operation of the system, according to one aspect of this disclosure.

FIG. 4 is a flowchart showing operation of the system, according to another aspect of this disclosure.

Detailed Description

FIG. 1 illustrates an exemplary machine 10. The machine 10 may include any mobile machine that performs some type of operation associated with an industry, such as, mining, construction, farming, or any other industry known in the art. For example, the machine 10 may be an earth moving machine such as a dozer, a loader, a backhoe, an excavator, a motor grader, or any other earth moving machine. The machine 10 may traverse a work site to manipulate material beneath a work surface 12, e.g. transport, cultivate, dig, rip, and/or perform any other operation known in the art. The machine 10 may include a power source 14 configured to produce mechanical power, a traction device 16, at least one material engaging element, such as a ripper 18, and an operator station 20 to house operator controls. The machine 10 may additionally include a frame 22 configured to support one or more components of the machine 10.

The power source 14 may be any type of internal combustion engine such as, a diesel engine, a gasoline engine, or a gaseous fuel-powered engine. Further, the power source 14 may be a non-engine type of power producing device such as, a fuel cell, a battery, a motor, or another type of power source known in the art. The power source 14 may produce a variable power output directed to the ripper 18 and the traction device 16 in response to one or more inputs.

The traction device 16 may include tracks located on each side of the machine 10 (only one side shown) and operatively driven by one or more sprockets 24. The sprockets 24 may be operatively connected to the power source 14 to receive power therefrom and drive the traction device 16. Movement of the traction device 16 may propel the machine 10 with respect to the work surface 12. The traction device 16 may additionally or alternately include wheels, belts, or other traction devices, which may or may not be steerable. The traction device 16 may be hydraulically actuated, mechanically actuated, electronically actuated, or actuated in any other suitable manner.

The ripper 18 may be configured to lift, lower, and tilt relative to the frame 22. For example, the ripper 18 may include a shank 26 held in place by

a mounting member 27. The shank 26 may penetrate the work surface 12 to disturb or disrupt (i.e. rip) the material below the work surface 12, and may move relative to the mounting member 27. More specifically, the shank 26 may have several configurations relative to the mounting member 27. For example, the shank 26 may be moved higher, lower, away from, and toward the frame 22. The mounting member 27 may be connected to the frame 22 via a linkage system with at least one implement actuator forming a member in the linkage system, and/or in any other suitable manner. For example, a first hydraulic actuator 28 may be connected to lift and lower the ripper 18, and a second hydraulic actuator 30 may be connected to tilt the ripper 18. The ripper 18 may alternatively include a plow, a tine, a cultivator, and/or any other task-performing device known in the art.

The movement of the ripper 18 may correspond to a plurality of predetermined locations and/or orientations (i.e. angle settings of the shank 26). For example, the shank 26 may have a discrete penetration angle and a discrete dig angle that can change based on a material composition of the work surface 12, a size or capacity of the machine 10, and/or the configuration of the shank 26 relative to the mounting member 27. In one example, the penetration angle of the shank 26 may be substantially vertical relative to the work surface 12 for efficient penetration of the work surface 12. In order to maintain this vertical angle for each of the available shank configurations, the implement actuators of the mounting member 27 may need to be adjusted based on the current shank configuration. Further, the dig angle of the shank 26 may correspond to a forward tilt of the shank 26 to facilitate efficient digging, while keeping the shank 26 from digging under the machine 10 and forcing material against an underbelly of the machine 10. In order to maintain the shank 26 at the correct digging position relative to the underbelly of the machine 10, the implement actuators of the mounting member 27 may again need to be adjusted based on the current shank configuration.

The machine 10 may have a drawbar 25 associated with it. The drawbar 25 may have a drawbar pull, or alternatively a load factor, attribute associated with it. Drawbar pull may be defined as the amount of horizontal force available to a machine at a drawbar when pulling a load. Thus, when the ripper 18 is below the work surface 12 and the machine 10 is propelled forward

by the power source 14, the drawbar 25 experiences a certain amount of drawbar pull. Drawbar pull may be calculated in conventional manners known to those of ordinary skill in the art. Alternatively, drawbar pull may be expressed as a load factor. The load factor may be expressed as a percentage. For example, a desired load factor for the machine 10 while ripping may be between 80% and 105%. A lookup table or a mapping may provide a relationship between the drawbar pull and the load factor.

When the machine 10 is experiencing a current drawbar pull value that is greater than the desired drawbar pull or load factor, the operator may take steps to reduce the current drawbar pull. Currently, the operator may raise the ripper 18 to reduce the current drawbar pull. However, this action may have undesirable results. For example, while raising the ripper 18 may reduce the current drawbar pull, it may also be difficult to penetrate the work surface 12 again. Thus, a system and method to reduce the current drawbar pull without raising the ripper 18 would be beneficial.

In an exemplary digging operation, an operator of the machine 10 may set the configuration of the shank 26. For example, the operator may manually loosen bolts fastening the shank 26 to the mounting member 27 in a first configuration, move the shank 26 to a discrete location on the mounting member 27, and tighten the bolts to retain the shank 26 in place. In another example, the shank 26 may be moveable by a motor, pulley system, or a hydraulic actuator to mechanically slide from the first configuration to the second configuration. This sliding mechanism may be controlled electrically or mechanically by the operator and/or a controller. That is, the operator may set the configuration of the shank 26 by manipulating a switch, a joystick, a button, or any other interface known in the art.

The operator may then control the implement actuators of the mounting member 27 to set the shank 26 to a predetermined penetration angle associated with the current configuration of the shank 26. That is, the operator may control the implement actuators of the mounting member 27 to orient the shank 26 at a vertical angle relative to the work surface 12 prior to penetration. The operator may then control the implement actuators to lower the shank 26 and penetrate the work surface 12. Once the shank 26 has penetrated the work surface 12, the operator may control the implement actuators of the

mounting member 27 to set the shank 26 to a predetermined dig angle for the current configuration of the shank 26. That is, the operator may again control the implement actuators to set the shank 26 to a dig angle that does not place the shank 26 under the machine 10, yet facilitates efficient digging. All or some of the above-described digging process may be managed automatically, as will be described further below.

On some terrains, the penetration of the shank 26 into the work surface 12 may cause the machine 10 to slip. Slip may be exemplified by a difference between an actual ground speed of the machine 10 and a speed of the traction device 16. That is, slip is determined to be occurring when the actual ground speed of the machine 10 is less than the speed of the traction device 16. The magnitude of slip may be influenced by characteristics of the material below the work surface 12, the cut depth or angle of the shank 26, and a speed or torque of the traction device 16. For example, when the machine 10 is engaged in a ripping operation, the material below the work surface 12 may resist the movement of the shank 26 through it, thus resisting the forward movement of the machine 10. The amount of resistance applied by the material may increase with an increasing cut depth or angle of the shank 26, and an increasing speed of the traction device 16. As resistance to shank movement increases, a torque of the traction device 16 may also increase. Eventually, the torque imparted by the traction device 16 may exceed a capacity of the work surface 12 to resist the torque, and slip may occur.

The magnitude of slip may be represented by a value. For example, a unitless expression of slip error (Se) may be calculated by relating a speed of traction device 16 (St) with respect to machine 10 and the speed of machine 10 (Sm) with respect to work surface 12, according to the mathematical formula: $Se=1-(Sm/St)$. Thus, zero slip (e.g. $St=Sm$) may correspond to a slip error value of 0, and complete slip (e.g. $Sm=0$ when $St>0$) may correspond to a slip error value of 1. The expression of slip error may alternatively be represented as a fraction of machine or driven speed, a percentage, and/or any other value, if desired. Zero slip may or may not be desirable and that it may be beneficial to monitor and allow slip within a predetermined range.

Hydraulic actuators 28, 30 may each include a piston-cylinder arrangement, a hydraulic motor, and/or another known hydraulic device having

one or more fluid chambers therein. In a piston-cylinder arrangement, pressurized fluid may be selectively supplied to and drained from one or more chambers thereof to affect linear movement of the actuator, as is known in the art. In a hydraulic motor arrangement, pressurized fluid may be selectively supplied to and drained from chambers on either side of an impeller to affect rotary motion of the hydraulic actuators 28, 30. The movement of the hydraulic actuator 28 may assist in moving the ripper 18 with respect to the frame 22 and the work surface 12, particularly down toward and up away from the work surface 12. An extension of the hydraulic actuator 28 may correlate to a position of the ripper 18 with respect to the work surface 12. Similarly, the movement of the hydraulic actuator 30 may assist in orienting the ripper 18 with respect to the frame 22 and the work surface 12, particularly decreasing or increasing the angle of the ripper 18 relative to the work surface 12. An extension of the hydraulic actuator 30 may correlate to an orientation of the ripper 18 with respect to the work surface 12.

The operator station 20 may provide a control interface for an operator of the machine 10. For example, the operator station 20 may include a deceleration pedal 32, a ripper control 34, and an automatic digging switch 36. Although not shown, the operator station 20 may additionally include other controls such as a machine direction control, an acceleration pedal, or any other control device known in the art.

The deceleration pedal 32 may determine, at least in part, the amount of mechanical power delivered to the traction device 16. That is, the machine 10 may be operable in a "high idle" mode, during which a maximum amount of mechanical power is delivered to move the traction device 16. This amount of mechanical power may be decreased from the maximum by manipulation of the deceleration pedal 32. That is, the deceleration pedal 32 may be operatively connected to the power source 14 to affect the operation of the power source 14 by reducing an amount of fuel delivered to the power source 14, changing a timing of fuel injections into the power source 14, and/or reducing an amount of air delivered to the power source 14.

The deceleration pedal 32 may be continuously moveable between a first position and a second position such that an operator may depress the deceleration pedal 32 from the first position to the second position. The

degree of movement of the deceleration pedal 32 toward the second position may proportionally decrease the amount of power delivered to drive the traction device 16. For example, the maximum amount of power may be delivered to drive the traction device 16 when the deceleration pedal 32 is in the first position (i.e. fully extended), a minimum amount of power may be delivered to drive the traction device 16 when the deceleration pedal 32 is in the second position (i.e. fully depressed), and approximately 50% of the maximum amount of power may be delivered to drive the traction device 16 when the deceleration pedal 32 is in a position substantially halfway between the first and second positions. The machine 10 may alternatively be operable in a "low idle" mode, with acceleration being controlled by the acceleration pedal of the operator station 20, or in any other mode known in the art.

The ripper control 34 may allow an operator of the machine 10 to manipulate the ripper 18. More specifically, the ripper control 34 may control an amount or a pressure of fluid supplied to and drained from the hydraulic actuators 28, 30. Thus, the ripper control 34 may allow the operator to set a height of the shank 26 above or below work surface and an angle of the shank 26 relative to the work surface 12. The ripper control 34 may allow the operator to move the shank 26 from a position above the work surface 12 down to penetrate the work surface 12, and to set a depth of cut below the work surface 12 so that the shank 26 may disturb or disrupt the material below the work surface 12 during a ripping operation. The ripper control 34 may also allow the operator to change the angle of the shank 26 relative to the work surface 12 while the shank 26 is above or below the work surface 12. For example, the operator may manipulate the ripper control 34 to set the shank 26 to an optimal penetration angle before lowering the shank 26 to penetrate the work surface 12. The operator may further manipulate the ripper control 34 to set the shank 26 to an optimal dig angle once the shank 26 has penetrated the work surface 12 to a desired depth. The ripper control 34 may embody, for example, a joystick. The ripper control 34 may embody any other appropriate control apparatus known in the art, and that the ripper control 34 may alternatively embody separate control apparatuses for determining the height and angle of the shank 26, respectively.

A minimum amount of slip may contribute to a maximum digging productivity of the machine 10. For example, digging productivity of the machine 10 may be represented by a ratio of an amount of material disturbed by the shank 26 to the amount of time taken to disturb the material. Thus, a maximum digging productivity may correspond to a maximum amount of material disturbed in a minimum amount of time. More specifically, digging productivity may be maximized by maximizing the depth of the shank 26 below the work surface 12, maximizing a ground speed of the machine 10, and minimizing slip of the machine 10. It may be difficult for an operator to achieve optimal productivity. Therefore, an autonomous dig function may be provided for control of the ripper 18.

The automatic digging switch 36 may allow the operator of the machine 10 to signal a desired beginning and end of the autonomous dig function. For example, the operator may move the automatic digging switch 36 to an on position to signal that an automatic digging operation should begin, and to an off position to signal that the automatic digging operation should end. The automatic digging switch 36 may be communicatively coupled with a control system 38 (shown in FIG. 2) that controls the automatic digging operation. Thus, the automatic digging switch 36 may deliver a signal to the control system 38 to indicate the beginning or end of an automatic digging operation. The control system 38 may alternatively check the position of the automatic digging switch 36 to determine whether an automatic digging operation should start or stop. The automatic digging switch 36 may alternatively embody an on/off button, wherein each press of the button toggles an automatic digging operation on and off. The operator may additionally or alternatively signal the end of an automatic digging operation by manually manipulating the deceleration pedal 32 or the ripper control 34, if desired.

FIG. 2 illustrates the control system 38 as having components that cooperate to move the ripper 18 during an automatic digging operation. For example, the control system 38 may include a user interface 39, a first sensor 40 to measure true ground speed, a second sensor 42 to measure the speed of traction device 16, a third sensor 44 to monitor the position of the ripper 18, and a controller 46. The user interface 39 may allow an operator to input values relevant to an automatic digging operation, such as, an operation of the shank 26,

an upper threshold for machine slip, a lower threshold for machine slip, a desired penetration angle of the shank 26, a desired dig angle of the shank 26, and a desired depth of the shank 26. These input values may be delivered to the control system 38 when the operator signals the beginning of an automatic digging operation, before the operator signals the beginning of the automatic digging operation, or substantially immediately after the operator signals the beginning of the automatic digging operation. Optimal penetration and dig angle values may be predetermined or calculated automatically by the controller 46 based on, for example, the configuration of the shank 26 relative to the mounting member 27.

The sensors 40, 42, 44 may each include conventional hardware to establish a signal as a function of a sensed physical parameter. The sensor 40 may be located to sense the speed of the machine 10 with respect to the work surface 12. For example, the sensor 40 may be disposed adjacent the work surface 12, and may generate a signal indicative of a speed of the machine 10 relative to the work surface 12. The sensor 40 may embody any type of motion or speed sensing sensor such as, a global positioning sensor, an infrared sensor, or a radar sensor. For example, the sensor 40 may transmit a radio signal with a given wavelength and frequency toward the work surface 12. The radio signal may bounce off of the work surface 12 back to the sensor 40 with a changed wavelength and/or frequency according to the Doppler effect. Sensor 40 may then use the difference between the original wavelength and frequency and the changed wavelength and frequency to calculate the speed of the machine 10. The sensor 40 may selectively include a plurality of sensors establishing a plurality of signals, and that the plurality of signals may be combinable into a common signal, if desired.

The sensor 42 may sense the speed of the traction device 16 with respect to the machine 10. For example, the sensor 42 may be disposed adjacent a driven component associated with the traction device 16, e.g. the sprockets 24. The sensor 42 may operate similarly to the sensor 40. That is, the sensor 42 may generate a signal indicative of a speed of the driven component, and may embody any type of motion or speed sensing sensor such as, a hall sensor, or a rotation sensor. For example, the sensor 42 may be sensitive to variations in a given magnetic field generated by the sensor 42 or by another component near

the sensor 42. As the sprockets 24 rotate to drive the traction device 16, magnetic elements embedded within the sprockets 24 may cause a variation in a magnetic field. The sensor 42 may then use the frequency of the variations to calculate the speed of the driven component. The sensor 42 may selectively include a plurality of sensors establishing a plurality of signals, and that the plurality of signals may be combinable into a common signal, if desired.

The sensor 44 may sense a position of the ripper 18 with respect to the frame 22 and/or the work surface 12. As indicated in FIG. 2, the sensor 44 may embody two individual sensors 44*a*, 44*b*. The sensor 44*a* may be disposed on or within the ripper 18 to generate a signal indicative of an angle of the ripper 18 with respect to gravity. The sensor 44*a* may embody any type of sensor known in the art, such as, a position sensor, a rotary potentiometer, a linear displacement sensor, and a position sensing cylinder. The sensor the 44*a* may selectively include a plurality of sensors each establishing a plurality of signals, and that the plurality of signals may be combinable into a common signal.

The sensor 44*b* may operate similarly to the sensor 44*a*. More specifically, the sensor 44*b* may be disposed on or within the frame 22 to generate a signal indicative of an angle of the frame 22 with respect to gravity. The sensor 44*b* may embody any type of sensor known in the art, such as, a position sensor. The sensor 44*b* may selectively include a plurality of sensors each establishing a plurality of signals, and that the plurality of signals may be combinable into a common signal. The controller 46 may use the two angle measurements generated by the sensors 44*a*, 44*b* to calculate an angle of the ripper 18 with respect to the frame 22.

The controller 46 may receive the signals generated by the sensors 40, 42, 44 to assist in controlling operation of the machine 10 during an automatic digging operation. That is, the controller 46 may be communicatively coupled with the sensors 40, 42, 44, the automatic digging switch 36, the deceleration pedal 32, the ripper control 34, the hydraulic actuators 28, 30, the user interface 39, and any other component of the machine 10 that may be used in controlling operation of the machine 10 during an automatic digging operation. For example, the controller 46 may use the signals received from the sensors 44*a*, 44*b* to calculate a position of the ripper 18. For example, the

controller 46 may perform arithmetic operations using the angle information generated by the sensors 44*a*, 44*b* to calculate the position of the ripper 18 with respect to the frame 22. By calculating the position of the ripper 18, the controller 46 may reposition the ripper 18 to, for example, reduce the current drawbar pull, as described herein.

The controller 46 may embody a single microprocessor or multiple microprocessors that include a means for controlling the machine 10 during an automatic digging operation. For example, the controller 46 may include a memory, a secondary storage device, and a processor, such as a central processing unit or any other means for controlling the machine 10 during an automatic digging operation. Numerous commercially available microprocessors can be configured to perform the functions of the controller 46. It should be appreciated that the controller 46 could readily embody a general power source microprocessor capable of controlling numerous power source functions. Various other known circuits may be associated with the controller 46, including power supply circuitry, signal-conditioning circuitry, solenoid driver circuitry, communication circuitry, and other appropriate circuitry. It should also be appreciated that the controller 46 may include one or more of an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a computer system, and a logic circuit, configured to allow the controller 46 to function in accordance with the present disclosure. Thus, the memory of the controller 46 may embody, for example, the flash memory of an ASIC, flip-flops in an FPGA, the random access memory of a computer system, or a memory circuit contained in a logic circuit. The controller 46 may be further communicatively coupled with an external computer system, instead of or in addition to including a computer system.

The controller 46 may control the movement of the ripper 18 during an automatic digging operation. To that end, the controller 46 may receive input signals from an operator of the machine 10, monitor signals generated by the sensors 40, 42, 44, perform one or more algorithms to determine appropriate output signals, and deliver the output signals to one or more components of the machine 10 to control the angle and penetration depth of the ripper 18. The controller 46 may move the shank 26 to an angle corresponding to a configuration of the shank 26, as discussed above,

and/or to an operation of the shank 26, such as penetrating or digging. For example, the controller 46 may store a plurality of values representing the possible angle settings of shank 26 in its memory, each angle being mapped to corresponding configurations and/or operations of the shank 26. The controller 46 may cause the shank 26 to move to one of those angles based on the current configuration and/or operation of the shank 26.

The controller 46 may also control the deceleration of the traction device 16. That is, the controller 46 may be communicatively connected to the power source 14 to affect the operation of the power source 14 by reducing an amount of fuel delivered to the power source 14, changing a timing of fuel injections into the power source 14, and/or reducing an amount of air delivered to the power source 14. The controller 46 may alternatively control the deceleration of traction device by directly manipulating the position of the deceleration pedal 32, if desired.

The controller 46 may control the movement of the shank 26 and deceleration of the traction device 16 in response to a calculation of machine slip. That is, the controller 46 may monitor the signals generated by the sensors 40, 42, and use them to calculate a value representative of actual machine slippage. For example, in accordance with the formula disclosed above, the controller 46 may calculate the actual machine slippage (i.e. slip error) $Se=1-(Sm/St)$, where Sm represents the true ground speed of the machine 10, as indicated by the signal from the sensor 40, and St represents the speed of the traction device 16, as indicated by the signal from the sensor 42. The controller 46 may compare actual machine slippage to an upper slip threshold input by an operator of the machine10 and stored in its memory. More specifically, the controller 46 may compare actual machine slippage to an acceptable slip value (i.e. the upper slip threshold input by the operator) to determine whether the actual machine slippage exceeds the acceptable slip value by a predetermined amount. The predetermined amount may be stored in the memory of the controller 46. The predetermined value may be 0, if desired. The controller 46 may then raise or lower the shank 26, and/or affect deceleration of the machine 10 until the actual slip of the machine 10 is within an acceptable range of a desired slip value (i.e. Se is within an acceptable amount of a desired

slip error). An exemplary operation of the controller 46 will be discussed below with reference to the flowchart of FIGs. 3 and 4.

Industrial Applicability

The disclosed method and apparatus may be applicable to controlling the position and/or movement of a ripper, as well as the speed and/or torque of an associated machine, to maximize productivity. The disclosed system may maximize productivity by targeting a desired drawbar pull value through control of ripper depth and machine deceleration. An exemplary disclosed operation of the control system 38, with reference to the ripper 18 and the traction device 16, is provided below.

Referring to FIG. 1, the shank 26 may be positioned by an operator to an angle and depth of cut below the work surface 12, and the traction device 16 may be operated to propel the machine 10 and thus "pull" the shank 26 through the material below the work surface 12. The material may have varying characteristics that can affect productivity of the machine 10. For example, the shank 26 may transition from relatively soft or loose material to hard material and/or encounter rocks or other obstacles. As discussed above, the changing terrain may cause the shank 26 to apply an increasing resistance on the movement of the machine 10 that leads to machine slip. It may be difficult for the operator to adjust the acceleration of the machine 10 and the position and/or angle of the shank 26 to productively complete the ripping operation over the changing terrain without inducing excessive slip. FIGs. 3 and 4 illustrate an exemplary automatic digging operation to automate the adjustments of the acceleration of the machine 10 and position and/or angle of the shank 26.

FIG. 3 is a flowchart showing a method of operation of this system, according to one aspect of this disclosure. At block 304, the machine 10 lowers the ripper 18 into the work surface 12. A target ripping depth may be set by an operator of the machine 10 before operating the machine 10. Alternatively, the target ripping depth may be pre-programmed. The pre-programmed target ripping depths may be programmed during manufacture or they may be set depending on the type of material the machine 10 is ripping. For example, the target ripping depth with respect to the machine chassis may be configured by an operator of the machine 10. For example, the operator may set

the target depth so that the ripper lift arm is parallel to the traction device 16. Alternatively, or additionally, an operator of the machine 10 may set the target ripping depth based on a location of the machine 10 within a work site. For example, the operator may set a target ripping depth based on Global Positioning System (GPS) coordinates. Alternatively, the controller 46 may set and adjust the target ripping depth based on GPS coordinates without operator intervention. For example, the operator may set two ripping depth values. The first ripping depth value may represent a minimum ripping depth. The second ripping depth value may represent a maximum ripping depth. For example, there may be an ore vein or a leach pad liner located below the work surface 12. The operator may wish not to disturb or rip the ore vein or leach pad liner. Accordingly, the operator may set the second ripping depth value such that the ripper 18 will not penetrate so deep as to rip the ore vein or leach pad liner. Once the ripper 18 has been lowered below the work surface 12, the method proceeds to block 306.

At block 306, the controller 46 determines when the ripper 18 has reached the target ripping depth. The controller 46 may use the values represented by the signals generated by the sensors 44*a*, 44*b* to calculate the position of the ripper 18 below the work surface 12. For example, the controller 46 may calculate the position of the ripper 18 using arithmetic operations using the angle information generated by the sensors 44*a*, 44*b* to calculate the position of the ripper 18 with respect to the frame 22. When the ripper 18 is higher than the target ripping depth, the method proceeds to block 308. When the ripper 18 is at or below the target ripping depth, then the method proceeds to block 314.

At block 308, the controller 46 determines when the drawbar pull target of the ripper 18 has been met. The drawbar pull target, also known as a load factor, may be received as an input from an operator. Alternatively the drawbar pull target or load factor may be pre-programmed into the machine 10, for example, at manufacture. For example, a load factor, which may be expressed as a percentage, may be set to 95%. The controller 46 would calculate a drawbar pull target using the load factor using, for example, a lookup table. The controller 46 may calculate the current drawbar pull using conventional methods known to those of ordinary skill in the art. When the current drawbar pull is less than the drawbar pull target, the method continues to block 310. If the drawbar pull target has been met, then the method continues to block 312.

At block 310, the controller 46 lowers the ripper 18. The controller 46 lowers the ripper 18 because, for example, a drawbar pull lower than the target may signify that the ripper 18 may continue to rip at a depth lower than the current ripper depth.

At block 312, the controller 46 may adjust the ripper height to maintain drawbar pull. For example, the controller 46 may adjust the position of the ripper 18 higher or lower. If the drawbar pull begins to exceed the drawbar pull target, then the controller 46 may raise the ripper 18 to lower the drawbar pull to the drawbar pull target. Alternatively, if the drawbar pull begins to become lower than the drawbar pull target, then the controller 46 may lower the ripper 18 to increase the drawbar pull so that the drawbar pull meets the drawbar pull target.

At block 314, which is reached when the ripper target depth is reached, the controller 46 determines when the drawbar pull is less than the drawbar pull target. If the controller 46 determines that the drawbar pull is less than the drawbar pull target, then the method proceeds to block 316. If the controller 46 determines that the drawbar pull is not less than the drawbar pull target, then the method proceeds to block 318.

At block 316, which is reached when the controller 46 determines that the drawbar pull is less than the drawbar pull target, the controller 46 holds the position of the ripper 18 steady. In other words, the controller 46 does not lower or raise the ripper 18.

At block 318, which is reached when the controller 46 determines that the drawbar pull is less than the drawbar pull target, the controller 46 determines when the drawbar pull is greater than the drawbar pull target. When controller 46 determines that the drawbar pull is not greater than the drawbar pull target, then the method proceeds to block 316. When the controller 46 determines that the drawbar pull is greater than the drawbar pull target, then the method proceeds to block 320.

At block 320, the controller 46 reduces the power source torque. The controller 46 decelerates the power source 14 from a first power source torque to a second power source torque. For example, the controller 46 may cause the decelerator 32 to become depressed. Alternatively, the controller 46 may decelerate or reduce the torque of the power source 14 by other methods,

such as reducing an amount of fuel delivered to the power source 14, changing a timing of fuel injections into power source 14, and/or reducing an amount of air delivered to the power source 14. By decelerating the power source 14, the controller 46 may reduce the machine torque. The controller 46 may decelerate or reduce the torque of the power source 14 for a certain amount of time, for example, two seconds. While the power source 14 is decelerated, or the torque of the power source 14 is reduced, the controller 46 holds the position of the ripper 18 constant. The position of the ripper 18 is not raised. Thus, by decelerating or reducing the torque of the power source 14 while keeping the depth of the ripper 18 constant, the controller 46 allows the ripper 18 to attempt to rip the harder area without slipping. Once the engine torque has been reduced, the method proceeds to block 322.

At block 322, the controller 46 determines when the drawbar pull is greater than the drawbar pull target. When the controller 46 determines that the drawbar pull is greater than the drawbar pull target, the method proceeds to block 316, which holds the position of the ripper 18 steady. When the controller 46 determines that the drawbar pull is greater than the drawbar pull target, the method proceeds to block 324.

At block 324, the controller 46 raises the power source torque and the position of the ripper 18. The controller 46 raises the power source 14 to high idle. By raising the power source 14 to high idle, the controller 46 raises the power source torque to a power source torque greater than the second power source torque.

The controller 46 may continuously execute method as described in FIG. 3 while the machine 10 is operating.

FIG. 4 is a flowchart showing a method 400 of operating the ARC, according to one aspect of this disclosure. The controller 46 may receive from an operator of the machine 10 various inputs indicating a control of the ARC system. The following description describes actions an operator of the machine 10 may take. It should be noted, however, that any of the actions taken by the operator is received by the controller 46. The method 400 may be executed continuously while the ARC system is being executed. While FIG. 4 shows that the method 400 is executed in parallel, it may also be executed serially.

At block 404, the operator activates ARC. The operator may activate ARC, for example, in two ways. One way the operator may activate ARC is by pressing and holding the automatic digging switch 36. When the operator does this, then ARC may store the current depth of the ripper 18 as the target depth. Alternatively, the operator may activate ARC by pressing, but not holding, the automatic digging switch 36. This way may begin ARC and lower or raise the depth of the ripper 18 according to a previously input target depth. After ARC is activated, the method 400 proceeds to block 406, which executes ARC. While ARC is executing at block 406, the controller 46 may monitor operating conditions of the machine 10 and ARC. Thus, the controller 46 is periodically monitoring for any of the events described in blocks 408, 412, 416, 420, and 424.

At block 408, the operator presses the automatic digging switch 36. When the operator does that, the method 400 proceeds to block 410 and ARC may be turned off. However, when the operator does not press the automatic digging switch 36, the method 400 returns to block 406.

At block 412, the operator presses and holds the automatic digging switch 36. When the operator does that, the method 400 proceeds to block 414. At block 414, the controller 46 sets the current depth of the ripper 18 as the target depth. However, when the operator does not press and holder the Automatic Ripper Control button 34, the method 400 returns to block 406.

At block 416, the operator manually changes the ripper 18 depth. When the operator does that, then the method 400 proceeds to block 418. At block 418, the controller 46 temporarily overrides the current target depth with the manually adjusted depth of the ripper 18. The operator may revert to the overridden target depth by, for example, turning ARC off and then on. However, when the operator does not manually change the ripper 18 depth, the method 400 returns to block 406.

At block 420, the controller 46 monitors the position of the ripper 18. When the controller 46 determines that the ripper 18 is at a depth lower than the target depth, the method 400 proceeds to block 422. At block 422, the controller 46 generates commands to inhibit ARC from lowering the ripper 18 further. However, when the ripper 18 is not at a depth lower than the target depth, the method 400 returns to block 406.

At block 424, the operator activates a feature to stow the ripper 18. When the operator does that, the method proceeds to block 426. At block 426, the controller 46 turns off ARC. Additionally, the controller 46 may also stow the ripper 18. However, when the operator does not activate a feature to stow the ripper 18, the method 400 returns to block 406.

The disclosed control system and method may improve machine efficiency and productivity, while reducing the effects of operator inexperience by fully automating a ripping process. In particular, because the disclosed control system and method consider and modify the depth and angles of a ripping tool, as well as the speed of the machine, productivity of the machine may be optimized over a changing terrain. In addition, because the disclosed control system and method may be fully automated, the level of experience of a machine operator may have little or no impact on the productivity of the ripping process. Thus, productivity of the machine may be optimized regardless of the operator.

Further, because the disclosed control system and method may be fully automated, it may be applicable to any ripper configuration. That is, by storing preset ripper positions and/or orientations for each configuration of the ripper, the control system may allow a ripper to optimally penetrate and dig below a work surface, regardless of its configuration.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed system for controlling implement position and machine speed. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed method and apparatus. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

Claims

1. A method of controlling a ripping operation, the method comprising:

lowering a ripper (18) of a machine (10) to a depth under a work surface (12);

determining when a drawbar pull of the machine (10) is at a drawbar pull target for the machine (10); and

when the drawbar pull is greater than the drawbar pull target, reducing power source torque of the machine from a first power source torque to a second power source torque.

2. The method of claim 1, further comprising:

when the second power source torque lowers the drawbar pull to less than or equal to the drawbar pull target, raising the power source torque to a torque greater than the second power source torque.

3. The method of claim 1, further comprising:

when the drawbar pull is greater than the drawbar pull target after reducing the power source torque of the machine (10) to the second power source torque, raising the ripper (18) and the power source torque of the machine to a torque greater than the second power source torque.

4. The method of claim 1, wherein:

the lowering of the ripper (18) to a depth under the work surface (12) is based at least on a target depth.

5. The method of claim 1, further comprising:

when the ripper (18) is shallower than a target depth under the work surface (12) and the drawbar pull is at the drawbar pull target, adjusting a depth of the ripper (18) to maintain the drawbar pull.

6. A system for controlling a ripping operation, the system comprising:

a power source (14) configured to provide power to a machine (10);

an actuator (28, 30) configured to move a ripper (18) of the machine (10);

a plurality of sensors (44) configured to sense a position of the ripper (18);

a controller (46) in communication with the power source (14), the actuator (28, 30), and the plurality of sensors (44), the controller (46) being configured to:

lower a ripper (18) of a machine (10) to a depth under a work surface (12);

determine when a drawbar pull of the machine (10) is at a drawbar pull target for the machine (10); and

when the drawbar pull is greater than the drawbar pull target, reduce power source torque of the machine from a first power source torque to a second power source torque.

7. The system of claim 6, wherein the controller is further configured to:

when the second power source torque lowers the current drawbar pull to less than or equal to the drawbar pull target, raise the power source torque to a torque greater than the second power source torque.

8. The system of claim 6, wherein the controller is further configured to:

when the drawbar pull is greater than the drawbar pull target after reducing the power source torque of the machine to the second power source torque, raise the ripper (18) and the power source torque of the machine to a torque greater than the second power source torque.

9. The system of claim 6, wherein the controller is further configured to:

lower the ripper (18) to a depth calculated using the plurality of sensors (44) configured to sense the position of the ripper (18) under a work surface based on at least a target depth.

10. The system of claim 6, wherein the controller is further configured to:

when the ripper (18) is shallower than a target depth under the work surface (12) and the drawbar pull is at the drawbar pull target, adjust a depth of the ripper (18) to maintain the drawbar pull.

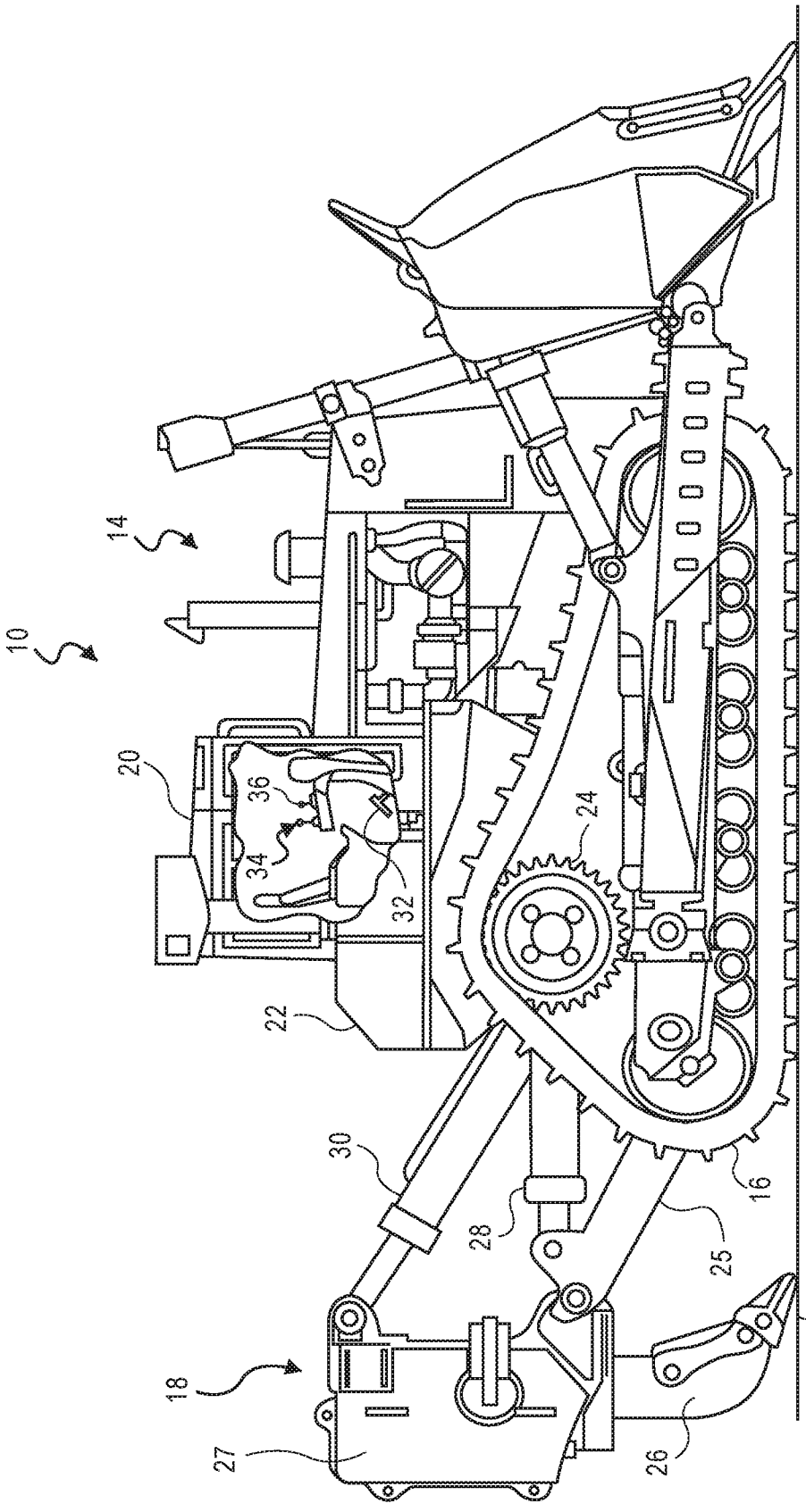


FIG. 1

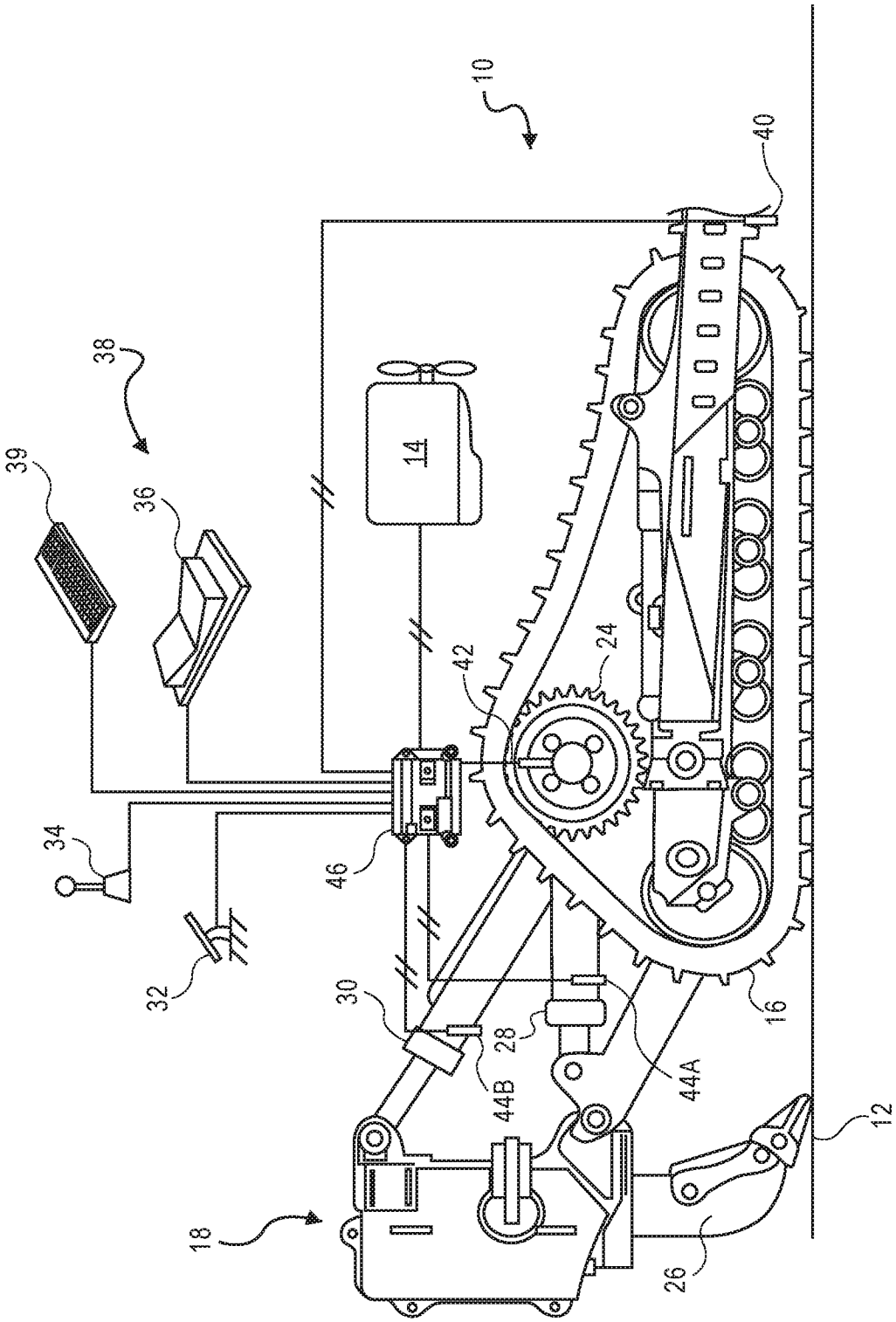


FIG. 2

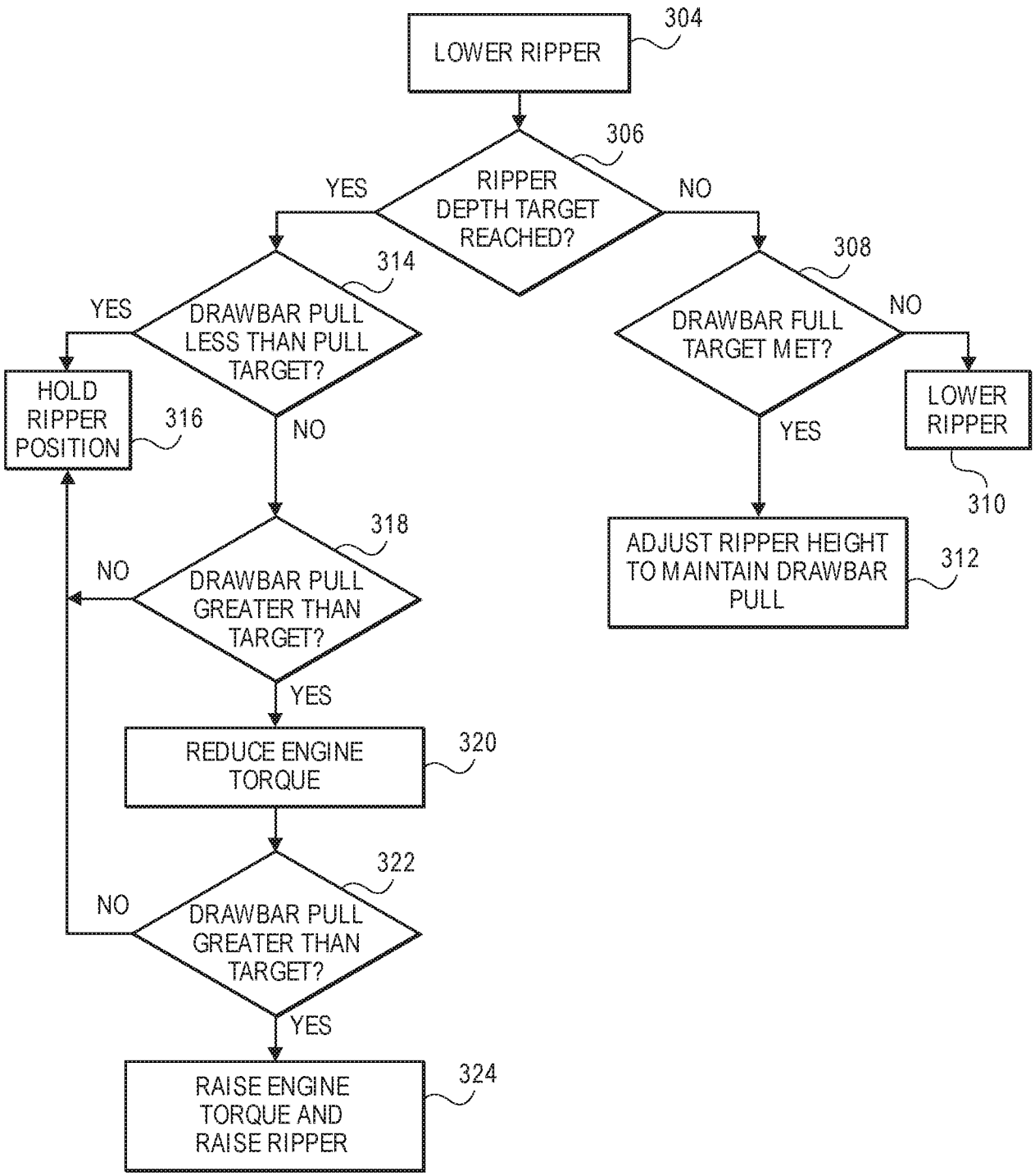

LOWER RIPPER
304
RIPPER DEPTH TARGET REACHED?
306
YES
NO
DRAWBAR PULL LESS THAN PULL TARGET?
314
YES
NO
HOLD RIPPER POSITION
316
DRAWBAR FULL TARGET MET?
308
NO
YES
LOWER RIPPER
310
ADJUST RIPPER HEIGHT TO MAINTAIN DRAWBAR PULL
312
DRAWBAR PULL GREATER THAN TARGET?
318
NO
YES
REDUCE ENGINE TORQUE
320
DRAWBAR PULL GREATER THAN TARGET?
322
NO
YES
RAISE ENGINE TORQUE AND RAISE RIPPER
324

FIG. 3

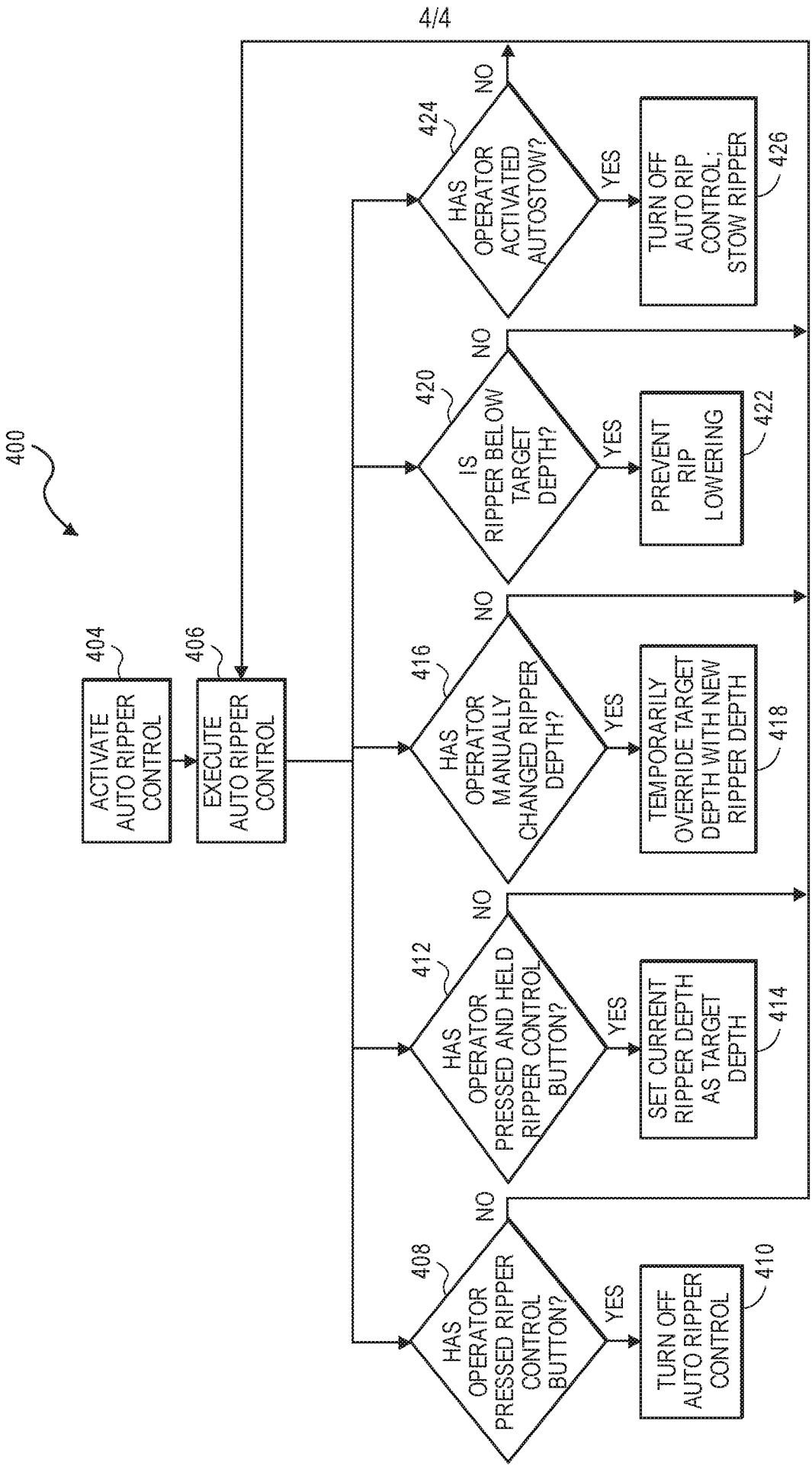

400
ACTIVATE AUTO RIPPER CONTROL
404
EXECUTE AUTO RIPPER CONTROL
406
HAS OPERATOR PRESSED RIPPER CONTROL BUTTON?
408
YES
TURN OFF AUTO RIPPER CONTROL
410
NO
HAS OPERATOR PRESSED AND HELD RIPPER CONTROL BUTTON?
412
YES
SET CURRENT RIPPER DEPTH AS TARGET DEPTH
414
NO
HAS OPERATOR MANUALLY CHANGED RIPPER DEPTH?
416
YES
TEMPORARILY OVERRIDE TARGET DEPTH WITH NEW RIPPER DEPTH
418
NO
IS RIPPER BELOW TARGET DEPTH?
420
YES
PREVENT RIP LOWERING
422
NO
HAS OPERATOR ACTIVATED AUTOSTOW?
424
YES
TURN OFF AUTO RIP CONTROL; STOW RIPPER
426
NO

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/013861

A. CLASSIFICATION OF SUBJECT MATTER

E02F 9/20(2006.01)i, E02F 5/32(2006.01)i, E02F 3/80(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E02F 9/20; G06F 19/00; B60W 10/04; E02F 3/84; G05D 1/00; G06F 7/00; E02F 5/32; E02F 3/80

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: ripper, depth, drawbar pull, power source torque, lower, and sensor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014-0336881 A1 (CATERPILLAR INC.) 13 November 2014 See paragraphs [0022], [0027]-[0029], [0031], [0038]-[0039], [0046], [0049], [0059], [0066]-[0069] and figure 2.	1-10
A	US 2008-0243345 A1 (KNIGHT, ROBERT PAUL) 02 October 2008 See paragraphs [0040]-[0050] and figure 3.	1-10
A	US 2012-0136508 A1 (TAYLOR et al.) 31 May 2012 See paragraphs [0017]-[0018] and figure 2.	1-10
A	US 2012-0199371 A1 (SAKAI et al.) 09 August 2012 See paragraph [0089] and figure 2.	1-10
A	US 2013-0255977 A1 (BRAUNSTEIN et al.) 03 October 2013 See paragraph [0033] and figure 1.	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
21 April 2017 (21.04.2017)	**01 May 2017 (01.05.2017)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/013861

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