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MASHEK et al.

(54) **MILLING MACHINE HAVING A TIP OVER WARNING SYSTEM**

(71) Applicant: **CATERPILLAR PAVING PRODUCTS INC.**, Brooklyn Park, MN (US)

(72) Inventors: **Nathan L. MASHEK**, Albertville, MN (US); **Dario SANSONE**, Bologna (IT); **Nathaniel S. DOY**, Maple Grove, MN (US)

(73) Assignee: **CATERPILLAR PAVING PRODUCTS INC.**, Brooklyn Park, MN (US)

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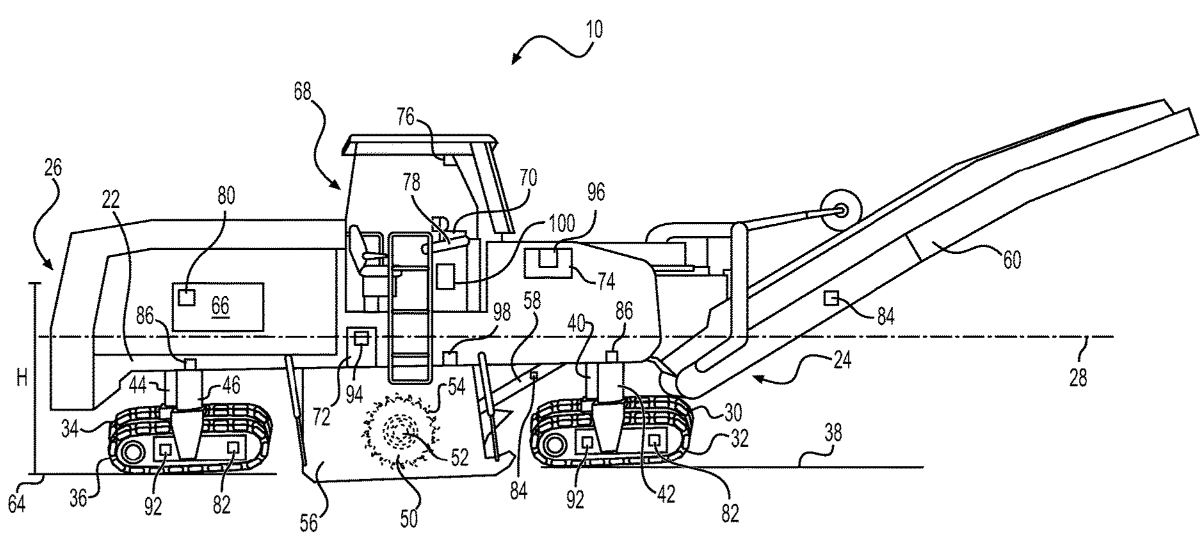
(57) **ABSTRACT**

A milling machine may have a frame extending along a longitudinal axis and a milling drum attached to the frame. The milling machine may have ground engaging tracks that support the frame, and height-adjustable leg columns connecting the frame to the tracks. The milling machine may also have an engine for rotating the milling drum and propelling the ground engaging tracks. The milling machine may have a slope sensor to measure a roll angle of the frame, a speed sensor to measure a ground speed, and a configuration sensor to measure a machine configuration parameter. The milling machine may also have an alarm device and a controller. The controller may determine a threshold roll angle based on the machine configuration parameter, compare the roll angle with the threshold roll angle, and activate the alarm device when the roll angle is greater than or equal to the threshold roll angle.



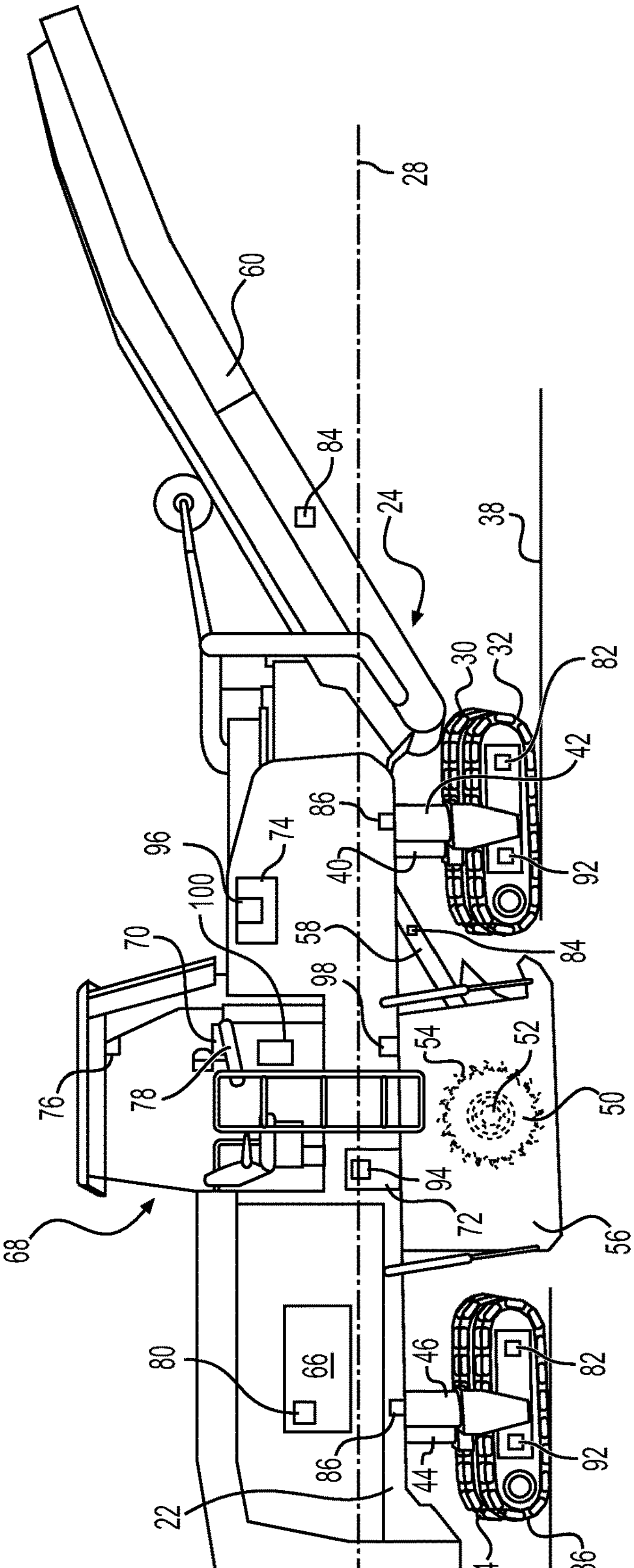

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FIG. 1

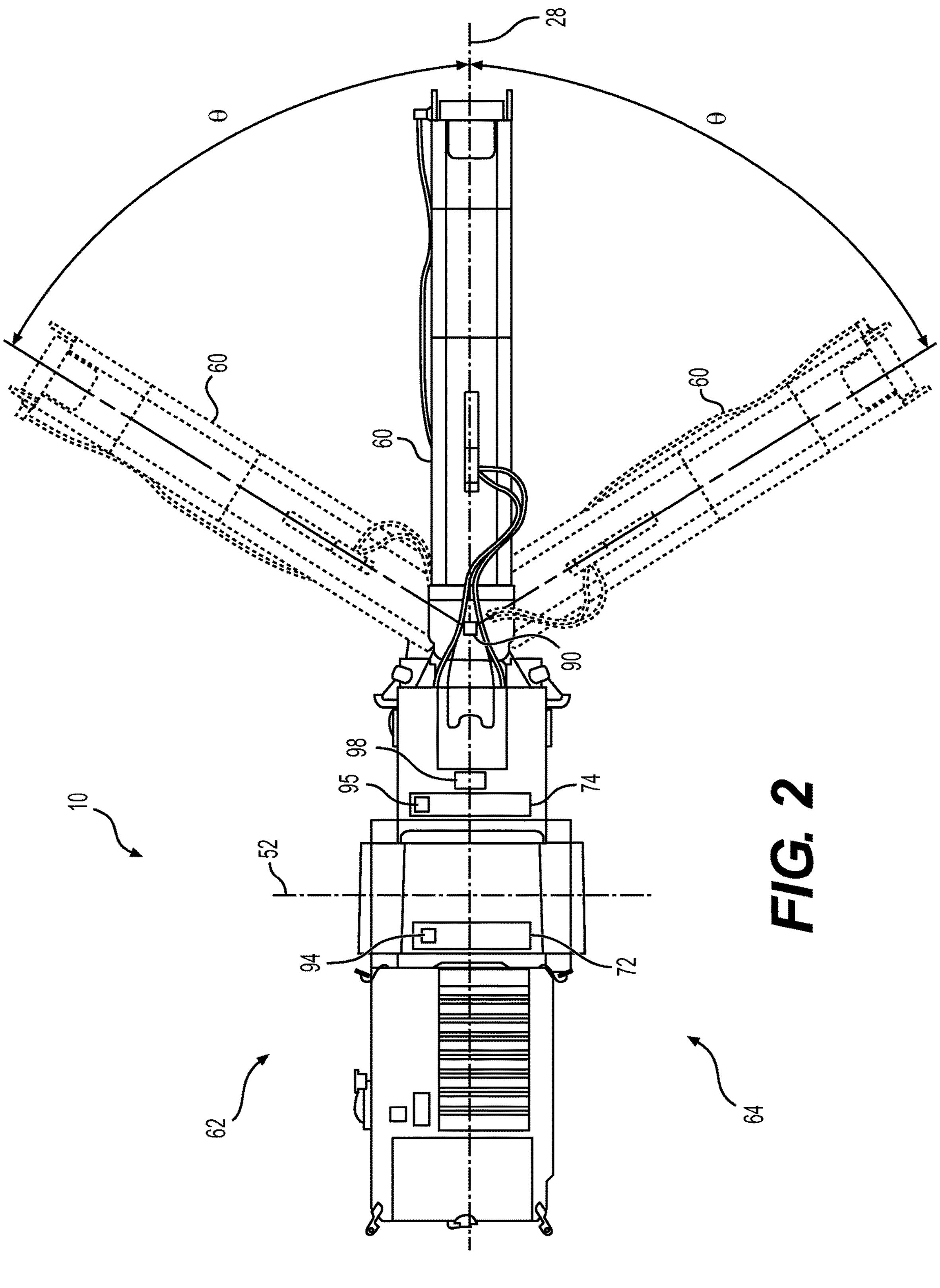

FIG. 2

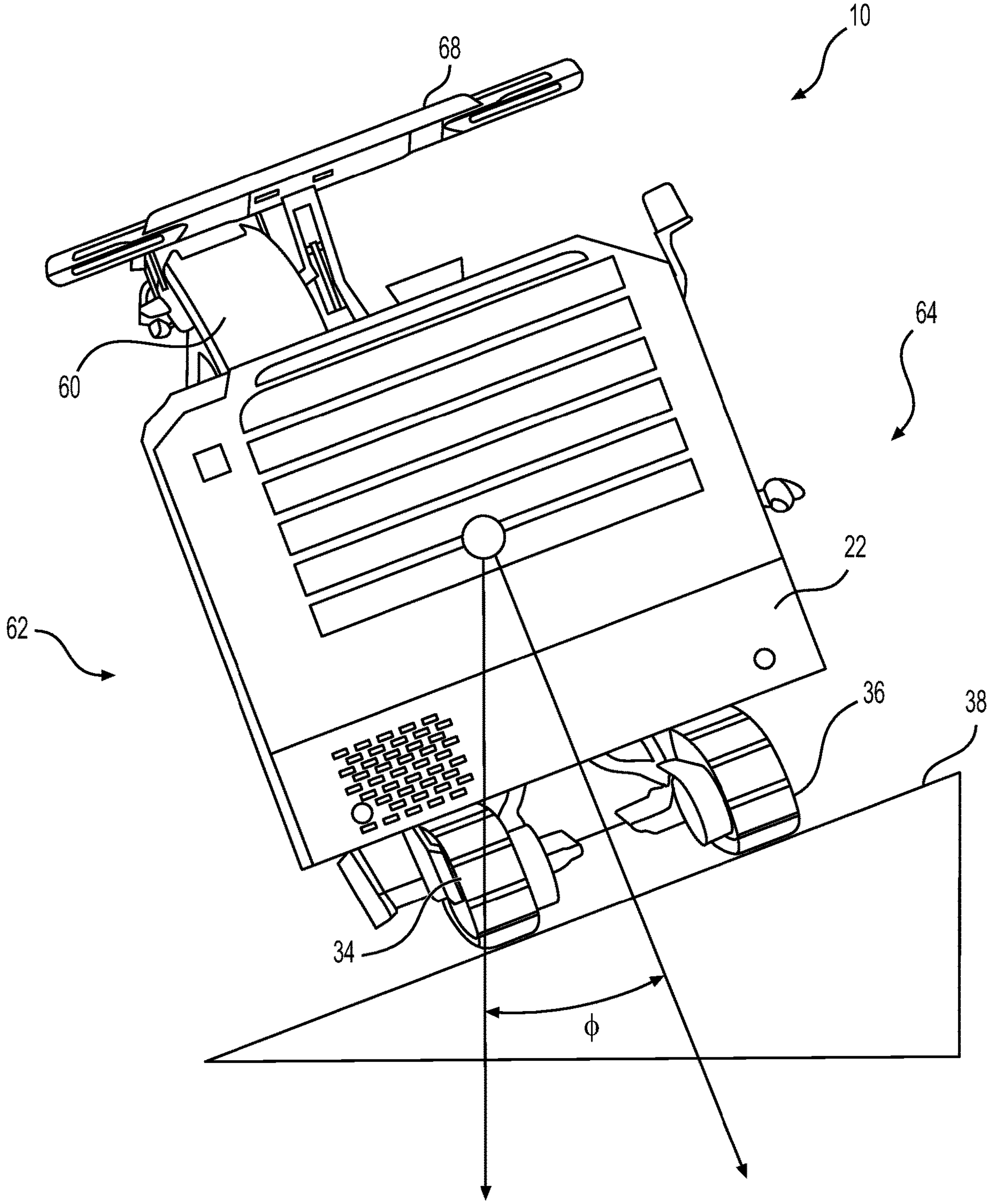

FIG. 3

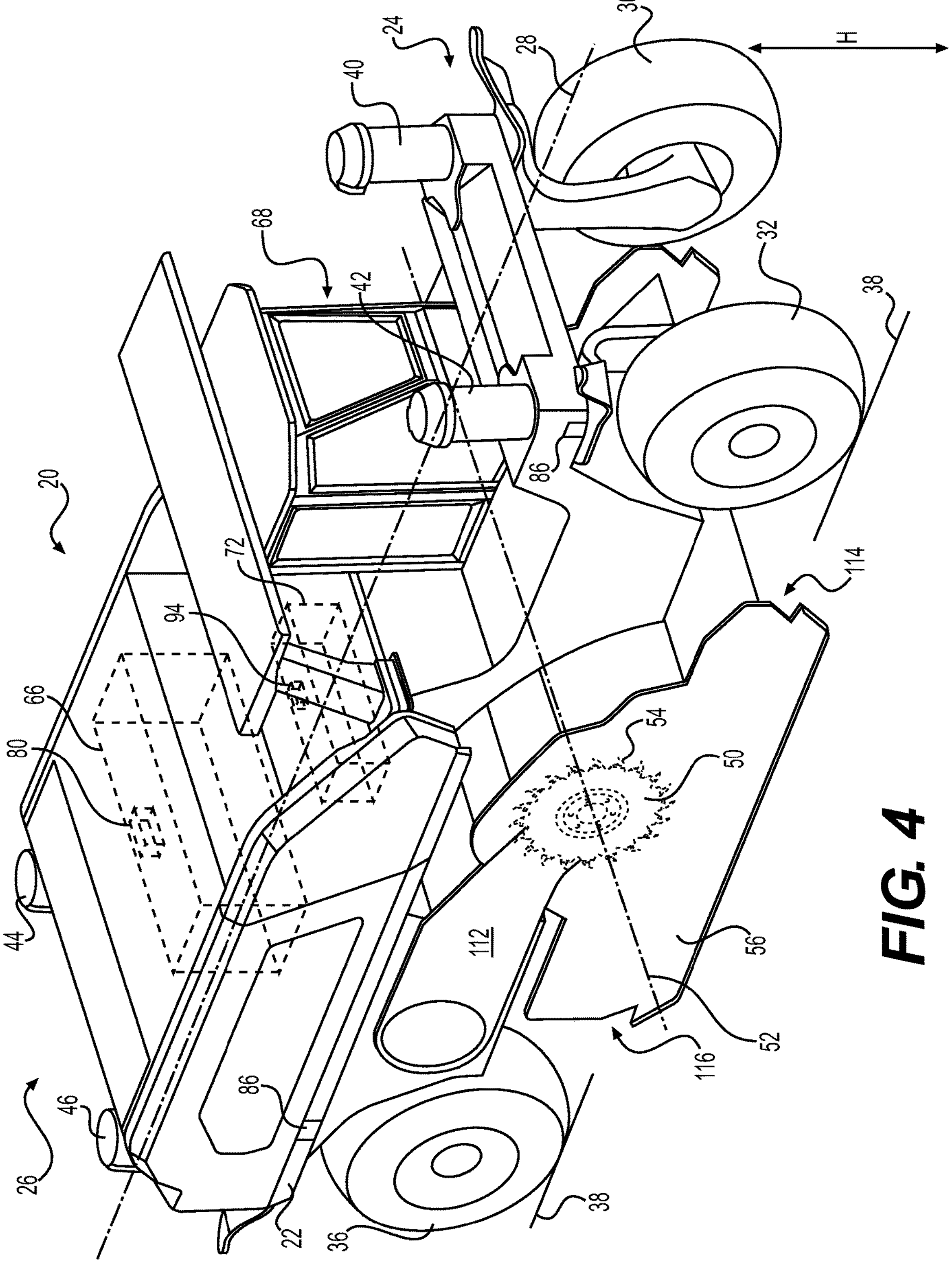
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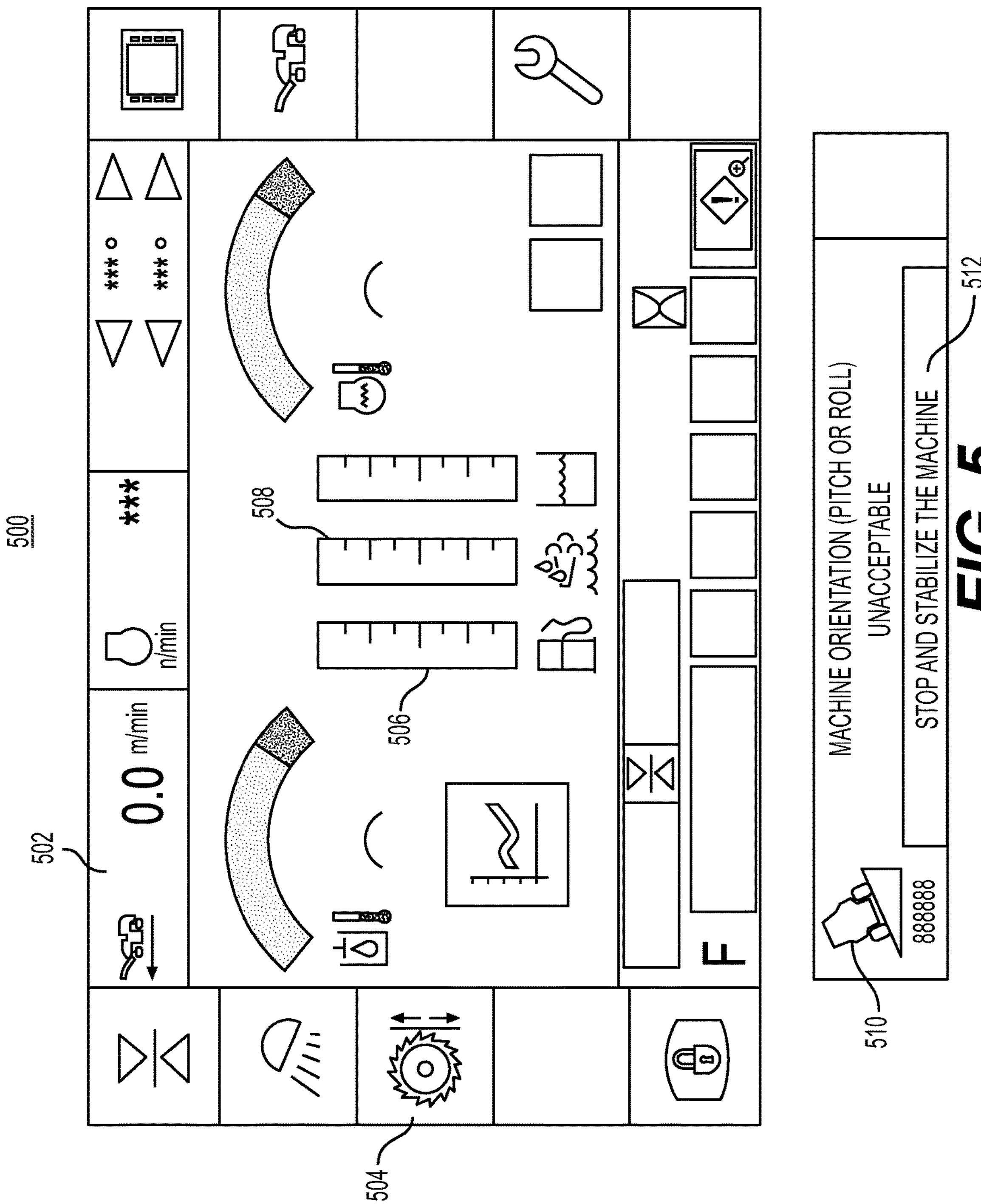
FIG. 4


500
502
504
506
508
510
512
0.0 m/min
n/min
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F
888888
MACHINE ORIENTATION (PITCH OR ROLL)
UNACCEPTABLE
STOP AND STABILIZE THE MACHINE

FIG. 5

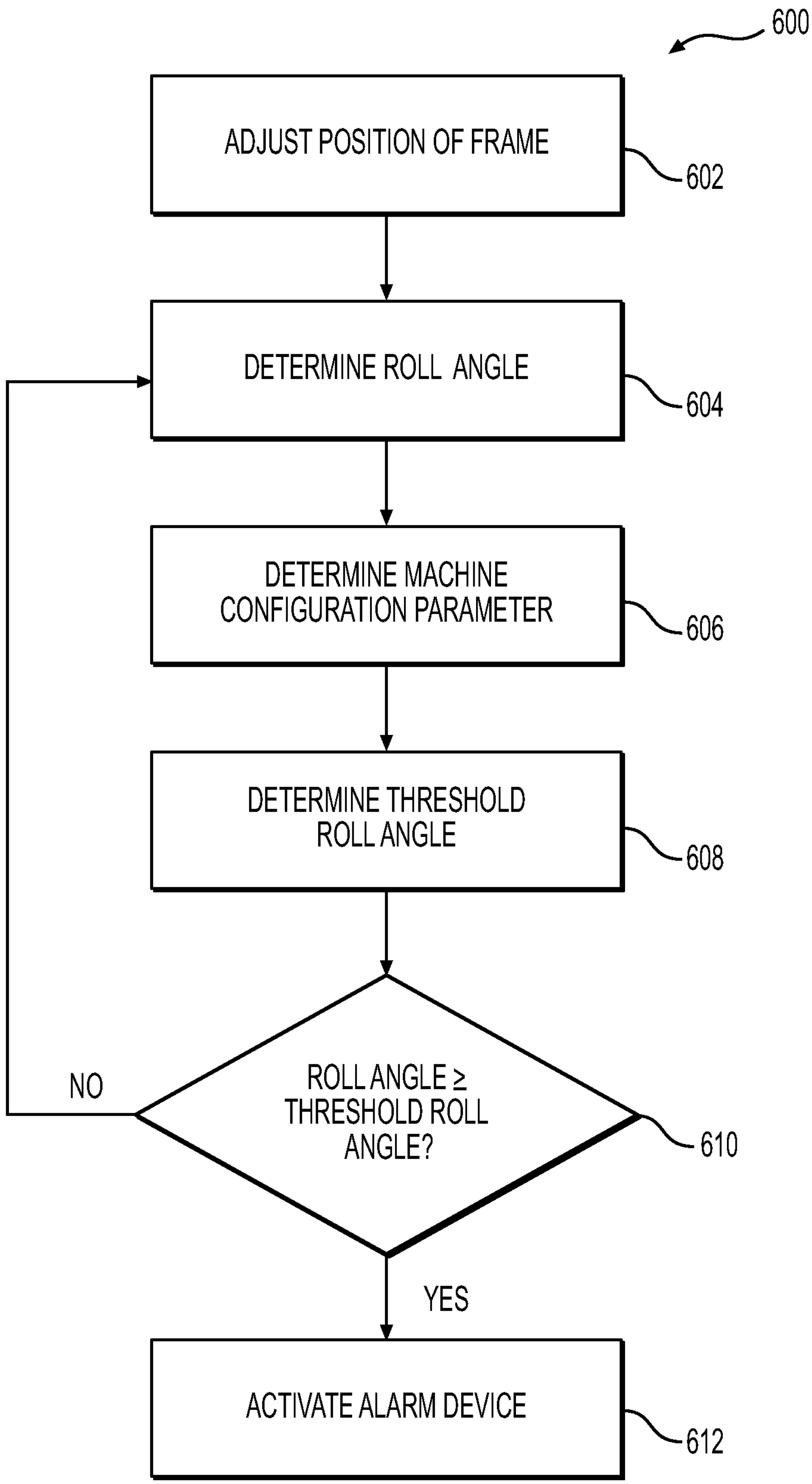
600
ADJUST POSITION OF FRAME
602
DETERMINE ROLL ANGLE
604
DETERMINE MACHINE CONFIGURATION PARAMETER
606
DETERMINE THRESHOLD ROLL ANGLE
608
ROLL ANGLE ≥ THRESHOLD ROLL ANGLE?
610
NO
YES
ACTIVATE ALARM DEVICE
612

FIG. 6

MILLING MACHINE HAVING A TIP OVER WARNING SYSTEM

TECHNICAL FIELD

[0001] The present disclosure relates generally to a milling machine and, more particularly, to a milling machine having a tip over warning system.

BACKGROUND

[0002] Road surfaces typically include an uppermost layer of asphalt or concrete on which vehicles travel. Over time, a road surface may wear out or may be damaged, for example, due to the formation of potholes or development of cracks and ruts. The damaged road surface may in turn cause damage to vehicles travelling on the road surface. The damaged road surface can be repaired locally by filling up the potholes, cracks, and/or ruts. However, it is often desirable to replace the worn or damaged road surface with an entirely new road surface. This is usually accomplished by removing a layer of the asphalt or concrete from the roadway and repaving the roadway by laying down a new layer of asphalt or concrete.

[0003] A milling machine is often used to remove the layer of asphalt or concrete on the roadway surface. A typical milling machine includes a frame supported on wheels or tracks and includes a milling drum attached to the frame. As the milling machine is driven over the existing roadway surface, teeth or cutting tools on the rotating milling drum come into contact with the roadway surface and tear up a layer of the roadway. A milling drum chamber typically encloses the milling drum to contain the milled material. The milled material is typically transported using a conveyor system to an adjacent vehicle, which removes the material from the worksite. Following the milling process, a new layer of asphalt or concrete may be applied on the milled road surface to create a new roadway surface.

[0004] In another application, it is sometimes desirable to stabilize or reconstitute the upper layer of a roadway or a worksite. This is usually accomplished by removing the upper layer, mixing it with stabilizing components such as cement, ash, lime, etc., and depositing the mixture back on top of the roadway or worksite. A milling machine, such as a stabilizer or reclaimer is often used for this purpose. Such milling machines also include a frame supported by tracks or wheels and include a milling drum attached to the frame. The milling drum is enclosed in a drum chamber. The cutting tools or teeth on the milling drum tear up the ground and push the removed material toward a rear of the drum chamber. Stabilizing ingredients and/or water are mixed with the milled material, which is then deposited back on to the ground towards the rear of the drum chamber.

[0005] Both types of milling machines discussed above often work on ground surfaces that may have a significant amount of cross-slope or lateral inclination. Further, in both types of milling machines discussed above, the frame is typically located several feet above the ground. As a result these machines may have a relatively high center of gravity. Moreover, some of the milling machines may have a conveyor slewed to one side or the other of the milling machine to direct the material removed from the ground surface to a truck traveling alongside the machine. The cross-slope, high center of gravity, and slewing of the conveyor may lead to unexpected tipping over of the milling machine, which may damage the machine, the ground surface, and/or objects around the machine. It is, therefore, desirable to provide a tip over warning system that may alert an operator of the milling machine to the possibility of a tip over condition, allowing the operator to take corrective measures to prevent such tip over.

[0006] U.S. Pat. No. 8,275,516 of Murphy, issued on Sep. 25, 2012 ("the '516 patent") and discloses a rollover risk assessment system for estimating rollover risk associated with maneuvering an agricultural tractor on varying terrain. The rollover risk assessment system of the '516 patent identifies a stability baseline as a trapezoidal area defined by the positions where the wheels of the tractor touch the ground surface. The system determines a center of gravity for the tractor based on the type of tractor, attached implements and accessories, and/or tire pressure. The system also determines angle θ between a vertical direction and the tractor z-axis using the tractor's roll angle sensors. Further, the system of the '516 patent determines a position of the center of gravity relative to the stability baseline based on angle θ. The system of the '516 patent causes visual or audible alerts to be issued based on the location of the center of gravity relative to the stability baseline. The system of the '516 patent also discloses a display that shows the determined angle θ relative to warning lines (or angles) that indicate limits of safe operation. The '516 patent discloses that the warning lines may move depending on tractor speed and that high angles θ may be tolerable at low speed.

[0007] Although the rollover risk assessment system of the '516 patent discloses a warning system to alert an operator of a tractor when the tractor is likely to roll over, it may still be less than optimal. For example, although the system of the '516 patent may adjust the warning lines based on tractor speed, the disclosed system still does not account for changes in the machine configuration that may occur during operation of the machine. For example, the disclosed system of the '516 patent does not adjust the threshold angles or stability baseline based on changes in the configuration of the tractor caused by, for example, position of various implements, weights associated with those implements, etc. Furthermore, the disclosed system of the '516 patent does not adjust the threshold angles or stability baseline based on changes to the tractor configuration or changes in weight distribution that may occur during operation of the tractor.

[0008] The milling machines and/or the tip over warning system of the present disclosure solve one or more of the problems set forth above and/or other problems of the prior art.

SUMMARY

[0009] In one aspect, the present disclosure is directed to a milling machine. The milling machine may include a frame having a longitudinal axis. The milling machine may also include a milling drum attached to the frame and extending along a transverse axis of the frame. Further, the milling machine may include a plurality of ground engaging tracks configured to support the frame, and a plurality of height-adjustable leg columns connecting the frame to the tracks. The milling machine may also include an engine configured to rotate the milling drum and propel the ground engaging tracks. The milling machine may include a slope sensor configured to measure a roll angle of the frame, a speed sensor configured to measure a ground speed of the milling machine, and a configuration sensor configured to measure a machine configuration parameter. The milling machine may also include an alarm device and a controller. The controller may be configured to determine a threshold roll angle based on the machine configuration parameter. The controller may also be configured to compare the roll angle with the threshold roll angle. In addition, the controller may be configured to activate the alarm device when the roll angle is greater than or equal to the threshold roll angle.

[0010] In another aspect, the present disclosure is directed to a method of operating a milling machine. The milling machine may include a frame having a longitudinal axis and supported by a plurality of ground engaging tracks connected to the frame by a plurality of height adjustable leg columns, a milling drum attached to the frame, a speed sensor, a slope sensor, a configuration sensor, and a controller. The method may include operating one or more of the leg columns to adjust a position of the frame relative to a ground surface. The method may also include determining a roll angle of the frame based on a signal from the slope sensor. Further, the method may include determining a machine configuration parameter based on a signal from the configuration sensor. The method may also include determining, using the controller, a threshold roll angle based on the machine configuration parameter. The method may include comparing, using the controller, the determined roll angle of the frame with the threshold roll angle. In addition, the method may include activating an alarm device when the determined roll angle is greater than or equal to the threshold roll angle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is an illustration of an exemplary milling machine;

[0012] FIG. **2** is a top view illustration of the exemplary milling machine of FIG. **1**;

[0013] FIG. **3** is a back end view illustration of the exemplary milling machine of FIG. **1** on an inclined ground surface;

[0014] FIG. **4** is an illustration of another exemplary milling machine;

[0015] FIG. **5** is an illustration of an exemplary graphical display for the milling machines of FIGS. **1** and **4**; and

[0016] FIG. **6** is an exemplary method of operating the machines of FIGS. **1** and **4**.

DETAILED DESCRIPTION

[0017] FIGS. **1** and **2** illustrate exemplary milling machines **10** and **20**, respectively. In one exemplary embodiment as illustrated in FIG. **1**, milling machine **10** may be a cold planer, which may also be referred to as a cold milling machine, a scarifier, a profiler, etc. Milling machine **10** may include frame **22**, which may extend from first end **24** to second end **26** disposed opposite first end **24**. In some exemplary embodiments, first end **24** may be a front end and second end **26** may be a rear end of frame **22**. Frame **22** may have any shape (e.g. rectangular, triangular, square, etc.) Frame **22** may have a longitudinal axis **28** extending in a generally forward-rearward travel direction of milling machine **10**.

[0018] Frame **22** may be supported on one or more propulsion devices. For example, as illustrated in FIG. **1**, frame **22** may be supported on propulsion devices **30**, **32**, **34**, **36**. Propulsion devices **30**, **32**, **34**, **36** may be equipped with electric or hydraulic motors which may impart motion to propulsion devices **30**, **32**, **34**, **36** to help propel milling machine **10** in a forward or rearward direction. In one exemplary embodiment as illustrated in FIG. **1**, propulsion devices **30**, **32**, **34**, **36** may take the form of tracks, which may include, for example, sprocket wheels, idler wheels, and/or one or more rollers that may support a continuous track. However, it is contemplated that propulsion devices **30**, **32**, **34**, **36** of milling machine **10** may take the form of wheels (see e.g., FIG. **4**.). It is also contemplated that propulsion devices **30**, **32**, **34**, **36**, when in the form of wheels may also include one or more tires. In the present disclosure, the terms track and wheel will be used interchangeably and will include the other of the two terms.

[0019] Tracks **30**, **32** may be located adjacent first end **24** of frame **22** and tracks **34**, **36** may be located adjacent second end **26** of frame **22**. Track **30** may be spaced apart from track **32** along a width direction of frame **22**. Likewise, track **34** may be spaced apart from track **36** along a width direction of frame **22**. In one exemplary embodiment as illustrated in FIG. **1**, track **30** may be a left front track, track **32** may be a right front track, track **34** may be a left rear track, and track **36** may be a right rear track. Some or all of propulsion devices **30**, **32**, **34**, **36** may also be steerable, allowing milling machine **10** to be turned towards the right or left during a forward or rearward motion on ground surface **38**. Although milling machine **10** in FIG. **1** has been illustrated as including four tracks **30**, **32**, **34**, **36**, it is contemplated that in some exemplary embodiments, milling machine **10** may have only one rear track **34** or **36**, which may be located generally centered along a width of frame **22**.

[0020] Frame **22** may be connected to tracks **30**, **32**, **34**, **36** by one or more leg columns **40**, **42**, **44**, **46**. For example, as illustrated in FIG. **1**, frame **22** may be connected to left front track **30** via leg column **40** and to right front track **32** via leg column **42**. Likewise, frame **22** may be connected to left rear track **34** via leg column **44** and to right rear track **36** via leg column **46**. One or more of leg columns **40**, **42**, **44**, **46** may be height adjustable such that a height of frame **22** relative to one or more of tracks **30**, **32**, **34**, **36** may be increased or decreased by adjusting a length of one or more of leg columns **40**, **42**, **44**, **46**, respectively. It will be understood that adjusting a height of frame **22** relative to one or more of tracks **30**, **32**, **34**, **36** would also adjust a height of frame **22** relative to ground surface **38** on which tracks **30**, **32**, **34**, **36** may be supported.

[0021] Milling machine **10** may include milling drum **50**, which may be attached to frame **22** between front end **24** and rear end **26**. Milling drum **50** may extend along transverse axis **52** (see also e.g., FIG. **2**) of frame **22**. Milling drum **50** may include cutting tools **54** (or teeth **54**) that may be configured to cut into and tear up a predetermined thickness of a roadway or the ground. A height of milling drum **50** relative to the ground surface **38** may be adjusted by adjusting a height of one or more leg columns **40**, **42**, **44**, **46**. As milling drum **50** rotates, teeth **54** of milling drum **50** may come into contact with the ground or roadway surface **38**, thereby tearing up or cutting the ground or roadway surface **38**. Milling drum **50** may be enclosed within drum chamber **56** which may help contain the material removed by teeth **54** from the ground or roadway surface **38**. Milling machine **10** may include one or more conveyors **58**, **60**, which may help transport the material removed by milling drum **50** to an adjacent vehicle such as a dump truck.

[0022] As illustrated in FIG. **2**, at least conveyor **60** may be rotated or slewed towards left side **62** or right side **64** of milling machine **10**. It is to be understood that left side **62** and right side **64** may be determined relative to a forward movement direction of milling machine **10**. As illustrated in FIG. **2**, conveyor **60** may be slewed by slew angle θ relative to longitudinal axis **28** on either side (e.g., left side **62** or right side **64**) of longitudinal axis **28**. Slewing conveyor **60** in this manner may allow material removed by milling drum **50** from ground surface **38** to be directed to a dump truck that may travel alongside milling machine **10** on either left side **62** or right side **64** of milling machine **10**.

[0023] Returning to FIG. **1**, milling machine **10** may include engine **66**, which may be attached to frame **22**. Engine **66** may be any suitable type of internal combustion engine, such as a gasoline, diesel, natural gas, or hybrid-powers engine. It is contemplated, however, that in some exemplary embodiments, engine **66** may be driven by electrical power. Engine **66** may be configured to deliver rotational power output to one or more hydraulic motors associated with propulsion devices **30**, **32**, **34**, **36**, to milling drum **50**, and to the one or more conveyors **58**, **60**. Engine **66** may also be configured to deliver power to operate one or more other components or accessory devices (e.g. pumps, fans, motors, generators, belt drives, transmission devices, etc.) associated with milling machine **10**.

[0024] Milling machine **10** may include operator platform **68**, which may be attached to frame **22**. In some exemplary embodiments, operator platform **68** may be in the form of an open-air platform that may or may not include a canopy. In other exemplary embodiments, operator platform **68** may be in the form of a partially or fully enclosed cabin. As illustrated in FIG. **1**, operator platform **68** may be located at a height "H" above ground surface **38**. In some exemplary embodiments, height H may range between about 2 ft to 10 ft above ground surface **38**. Operator platform **68** may include operator console **70**. Operator console **70** may include one or more controls or input devices, which may be used by an operator to operate and/or control milling machine **10**. The one or more input devices may take the form of buttons, switches, sliders, levers, wheels, touch screens, or other input/output or interface devices.

[0025] Milling machine **10** may also include fuel tank **72** and water tank **74**. In one exemplary embodiment as illustrated in FIG. **1**, fuel tank **72** may be located under operator platform **68** and water tank **74** may be located in front of operator platform **68**. It is to be understood, however, that fuel tank **72** and water tank **74** may be located anywhere else on milling machine **10**.

[0026] Milling machine **10** may also include alarm device **76** that may be located in operator platform **68**. In one exemplary embodiment alarm device **76** may be an audible alarm or a speaker configured to generate an audible alarm or audible message. Additionally or alternatively, alarm device **76** may include one or more visual indicators (e.g., lights or displays) included on operator console **70** in operator platform **68**. It is further contemplated that in some embodiments, alarm device **76** may additionally or alternatively include display device **78** on operator console **70**. Display device **78** may include one or more of a cathode ray tube, a liquid crystal display, a light emitting diode display, a touch-screen display or any other type of display device configured to display one or more symbols, or textual or graphical displays to an operator of milling machine **10**.

[0027] Milling machine **10** may be equipped with numerous sensors, some of which may be configured to determine operational parameters (e.g., engine speed, ground speed, milling drum speed, conveyor speed, acceleration, temperature, pressure, etc.) of milling machine **10**. For example, milling machine **10** may be equipped with engine speed sensor **80**, ground speed sensor **82**, and conveyor speed sensor **84**. Engine speed sensor **80** may be configured to measure, for example, a rotational speed of engine **66** (e.g., in revolutions per minute or rpm). Ground speed sensor **82** may be configured measure a speed of milling machine **10** in the forward or rearward directions relative to ground surface **38** (e.g., in m/s, Km/h, or mph). In one exemplary embodiment, each of propulsion devices **30**, **32**, **34**, **36** may be equipped with one or more ground speed sensors **82** configured to determine a speed of each of propulsion devices **30**, **32**, **34**, **36** relative to ground surface **38**. It is contemplated, however, that ground speed of milling machine **10** or **20** may be determined in other ways, for example, using GPS sensors, inertial sensors, flow rate or pressure of hydraulic fluid in hydraulic motors associated with propulsion devices **30**, **32**, **34**, **36**, etc.

[0028] Each of conveyors **58**, **60** may be equipped with conveyor speed sensor **84**, which may be configured to determine a linear speed of conveyors **58**, **60** (in m/s or ft/s). It is also contemplated that in some embodiments, conveyor speed sensor **84** may be a rotational speed sensor associated with one or more rollers configured to move conveyors **58**, **60**, and the linear speed of conveyors **58**, **60** may be determined from the measured rotational speed of the rollers. Sensors **80**, **82**, **84**, etc. may be operational sensors configured to measure operational parameters associated with operation of engine **66**, propulsion devices **30**, **32**, **34**, **36**, conveyors **58**, **60**, etc. It is contemplated that milling machine **10** may include many additional operational sensors, for example, milling drum speed sensors, temperature sensors to measure a temperature of an engine coolant, temperature sensors to measure temperatures of cutting teeth **54**, and/or other sensors to measure flow rate, pressure, and/or temperature of hydraulic fluid being supplied to various implements of milling machine **10**, etc.

[0029] Milling machine **10** may also include one or more configuration sensors that may be configured to measure configuration parameters associated with milling machine **10**. Configuration parameters may provide information regarding a position or configuration of one or more components of milling machine **10**. For example, configuration parameters may include height of one or more of leg columns **40**, **42**, **44**, **46**, slew angle of conveyor **60** relative to axis **28**, steering angle of one or more of propulsion devices **30**, **32**, **34**, **36**, level of fuel in fuel tank **72**, level of water in water tank **74**, position of one or more optionally attached implements (e.g., additional water tanks, pumps, generators, external sensors, structural beams, etc.). As illustrated in FIGS. **1** and **2**, for example, milling machine **10** may include one or more height sensors **86**, slew angle sensor **90** (see FIG. **2**), one or more steering angle sensors **92**, fuel level sensor **94**, and water level sensor **96**. It is contemplated that milling machine **10** may include other configuration sensors (e.g., distance sensors, weight sensors, etc.)

[0030] Height sensor **86** may be configured to determine a height of frame **22** relative to ground surface **38** adjacent leg column **40**, **42**, **44**, and/or **46**. Height sensor **86** may include one or more of laser sensors, ultrasonic sensors, capacitive, or inductive sensors capable of measuring a length of one or more of leg columns **40**, **42**, **44**, and/or **46**. A height of frame **22** may be determined based on the measured lengths of the one or more leg columns **40**, **42**, **44**, and/or **46** and geometric information regarding frame **22** and/or one or more of propulsion devices **30**, **32**, **34**, and/or **36**. It is also contemplated that in some embodiments, height sensors **86** may include one or more ultrasonic sensors configured to directly measure a height of frame **22** relative to ground surface **38**. In other exemplary embodiments, height sensors **86** may include one or more of GPS sensors, inertial sensors, or other position sensors configured to determine a height of frame **22** relative to ground surface **38**.

[0031] Slew angle sensor **90** may be configured to measure slew angle θ of conveyor **60** relative to longitudinal axis **28**. In one embodiment, slew angle sensor **90** may include a rotational sensor disposed at or adjacent to a pivotable connection between conveyor **60** and frame **22**. Slew angle sensor **90** may be configured to measure an amount of rotation of conveyor **60** in a leftward or rightward transverse direction (e.g., transverse to longitudinal axis **28**). One or more of propulsion devices **30**, **32**, **34**, **36** may include steering angle sensors **92**. Steering angle sensors **92** may be configured to measure an angle of rotation of propulsion devices **30**, **32**, **34**, or **36**, in a transverse direction relative to longitudinal axis **28**.

[0032] Fuel level sensor **94** may be configured to measure a height of fuel relative to a base of fuel tank **72**. It is also contemplated that fuel level sensor **94** may be configured to measure an inclination of a free surface of the fuel in fuel tank **72** relative to the base of fuel tank **72**. In some embodiments, fuel level sensor **94** may be configured to determine a volume of fuel in fuel tank **72** and a height of the fuel relative to the base of fuel tank **72** may be determined based on the measured volume of fuel and geometrical characteristics of fuel tank **72**. Water level sensor **96** may be configured to measure a height of water in water tank **74** relative to a base of water tank **74**. In some embodiments, water level sensor **96** may be configured to determine a volume of water in water tank **74** and a height of the water relative to the base of water tank **74** may be determined based on the measured volume of water and geometrical characteristics of water tank **74**. It is also contemplated that water level sensor **96** may be configured to measure an inclination of a free surface of the water in water tank **74** relative to the base of fuel tank **72**.

[0033] Milling machine **10** may also be equipped with slope sensor **98** that may be configured to determine a cross-slope of frame **22** (e.g., slope in a transverse or left-right direction) along transverse axis **52** of milling machine **10**. In one exemplary embodiment, slope sensor **98** may be configured to determine roll angle ϕ (e.g., inclination or cross-slope) of frame **22** in the left-right or transverse direction, relative to a gravity direction. FIG. **3** illustrates an exemplary position of milling machine **10** on an inclined ground surface **38**. As illustrated in FIG. **3**, frame **22** of milling machine **10** may be inclined in a transverse direction (e.g., left-right direction) by an angle ϕ relative to the gravity direction. In one exemplary embodiment, slope sensor **98** may be configured to measure angle ϕ. It is also contemplated that in some embodiments, slope sensor **98** may be configured to determine a pitch angle (e.g. inclination of frame **22** in a forward-rearward direction relative to longitudinal axis **28**). It is further contemplated that slope sensor **98** may include an inertial measurement unit (IMU) and/or a global positioning system (GPS) sensor. It is also contemplated that additionally or alternatively, pitch angle of frame **22** may be determined based on heights of frame **22** relative to ground surface **38** measured by one or more height sensors **86** and based on geometrical parameters of milling machine **10**.

[0034] Milling machine **10** may include controller **100**, which may be configured to receive inputs, data, and/or signals from the one or more input devices, sensors **80**, **82**, **84**, **86**, **90**, **92**, **94**, **96**, **98**, etc., and/or other sensors associated with milling machine **10**. Controller **100** may include or be associated with one or more processors, memory devices, and/or communication devices. Controller **100** may embody a single microprocessor or multiple microprocessors, digital signal processors (DSPs), application-specific integrated circuit devices (ASICs), etc. Numerous commercially available microprocessors may be configured to perform the functions of controller **100**. Various other known circuits may be associated with controller **100**, including power supply circuits, signal-conditioning circuits, and communication circuits, etc.

[0035] The one or more memory devices associated with controller **100** may store, for example, data and/or one or more control routines, instructions, mathematical models, algorithms, machine learning models, etc. The one or more memory devices may embody non-transitory computer-readable media, for example, Random Access Memory (RAM) devices, NOR or NAND flash memory devices, and Read Only Memory (ROM) devices, CD-ROMs, hard disks, floppy drives, optical media, solid state storage media, etc. Controller **100** may execute one or more routines, instructions, mathematical models, algorithms, and/or machine learning models stored in one or more memory devices to generate and deliver one or more command signals to one or more of propulsion devices **30**, **32**, **34**, **36**, engine **66**, milling drum **50**, conveyors **58**, **60**, and/or other implements and components of milling machine **10**.

[0036] FIG. **4** illustrates another exemplary embodiment of a milling machine **20**. In one exemplary embodiment as illustrated in FIG. **4**, milling machine **20** may be a reclaimer, which may also be called soil stabilizer, reclaiming machine, road reclaimer, etc. Like milling machine **10**, milling machine **20** may include frame **22**, propulsion devices in the form of wheels **30**, **32**, **34** (not visible in FIG. **2**), **36**, and leg columns **40**, **42**, **44**, **46**. In some exemplary embodiments, one or more leg columns **40**, **42**, **44**, **46** may be height adjustable such that a height of frame **22** relative to one or more of wheels **30**, **32**, **34**, **36** may be increased or decreased by adjusting a length of one or more leg columns **40**, **42**, **44**, **46**, respectively. As illustrated in FIG. **2**, leg column **40** may connect frame **22** to the left front wheel **30**, leg column **42** may connect frame **22** to a right front wheel **32**, leg column **44** may connect frame **22** to left rear wheel **34** (not visible in FIG. **2**), and leg column **46** may connect frame **22** to right rear wheel **36**. Although, milling machine **20** has been illustrated in FIG. **2** as including wheels **30**, **32**, **34**, **36**, it is contemplated that milling machine **20** may instead include tracks **30**, **32**, **34**, **36**. One or more of wheels **30**, **32**, **34**, **36**

may be steerable, allowing milling machine **20** to be turned towards the right or left during a forward or rearward motion on ground surface **38**.

[0037] Milling drum **50** of milling machine **20** may be located between first end **24** and second end **26**. Milling drum **50** may extend along transverse axis **52**. In one exemplary embodiment as illustrated in FIG. **4**, milling drum **50** of milling machine **20** may not be directly attached to frame **22**. Instead, as illustrated in FIG. **4** milling drum **50** of milling machine **20** may be attached to frame **22** via arms **112**. Arms **112** may include a pair of arms (only one of which is visible in FIG. **2**) disposed on either side of milling machine **20**. Arms **112** may be pivotably attached to frame **22** and may be configured to be rotatable relative to frame **22** about an axis generally parallel to transverse axis **52**. One or more actuators may be connected between frame **22** and arms **112** and may be configured to move arms **112** relative to frame **22**. Thus, unlike milling machine **10**, milling drum **50** of milling machine **20** may be movable relative to frame **22**. It is contemplated, however, that in other exemplary embodiments, milling drum **50** may be directly attached to frame **22** of milling machine **20** in a manner similar to that described above for milling machine **10**.

[0038] Milling drum **50** of milling machine **20** may include cutting tools **54** (or teeth **54**). A height of milling drum **50** above the ground surface may be adjusted by rotating arms **112** relative to frame **22** and/or by adjusting one or more of leg columns **40**, **42**, **44**, **46**. As milling drum **50** rotates, teeth **54** may come into contact with and tear or cut the ground or roadway surface **38**. Milling drum **50** may be enclosed within drum chamber **56** which may help contain the material removed by teeth **54** from the ground or roadway surface. Rotation of milling drum **50** may cause the removed material to be transferred from adjacent front end **114** of drum chamber **56** towards rear end **116** of drum chamber **56**. Stabilizing components such as ash, lime, cement, water, etc. may be mixed with the removed material and the reconstituted mixture of the milled material and the stabilizing components may be deposited on ground surface **38** adjacent rear end **116** of drum chamber **56**.

[0039] Like milling machine **10**, milling machine **20** may also include engine **66**, operator platform **68**, operator console **70** with one or more control or input devices, fuel tank **72**, water tank **74**, alarm device **76**, controller **100**, and one or more sensors **84**, **92**, **94**, **96**, **98**, all of which may have characteristics similar to those discussed above with respect to milling machine **10**. However, unlike milling machine **10**, milling machine **20** may not include conveyors **58**, **60**, and sensors **86** and **90**. Additionally, it will be understood that as used in this disclosure the terms front and rear are relative terms, which may be determined based on a direction of travel of milling machine **10** or **20**. Likewise, it will be understood that as used in this disclosure, the terms left and right are relative terms, which may be determined based on facing the direction of travel of milling machine **10** or **20**.

[0040] As discussed above, controller **100** may receive one or more input signals from the one or more input devices associated with operator console **70** and/or one or more of sensors **82**, **84**, **86**, **90**, **92**, **94**, **96**, **98**, etc. Controller **100** may be configured to determine a threshold roll angle ϕ_A. Threshold roll angle ϕ_A may be variable and may depend on one or more machine configuration parameters. The threshold roll angle ϕ_A may represent an angle at which milling machine **10** or **20** may be more than 50% likely to tip over when milling machine **10** or **20** is inclined at a roll angle $\phi \geq$ threshold roll angle ϕ_A. Controller **100** may be configured to determine the threshold roll angle ϕ_A based on one or more of various configuration parameters, such as, fuel level in fuel tank **72**, water level in water tank **74**, steering angle of one or more of propulsion devices **30**, **32**, **34**, **36**, slew angle θ of conveyor **60** relative to longitudinal axis **28**, pitch angle of frame **22** relative to ground surface **38**, and/or heights of one or more of leg columns **40**, **42**, **44**, **46**.

[0041] In one exemplary embodiment, controller **100** may be configured to determine threshold roll angle ϕ_A by determining a center of gravity of fuel remaining in fuel tank **82** based on measurements received from fuel level sensor **94**. Additionally or alternatively, controller **100** may be configured to determine threshold roll angle ϕ_A by determining a center of gravity of water remaining in water tank **74** based on measurements received from water level sensor **96**. It is also contemplated that controller **100** may additionally or alternatively determine a center of gravity of milling machine **10** or **20** based on slew angle θ of conveyor **60** based on measurements received from slew angle sensor **90**, steering angles of one or more propulsion devices **30**, **32**, **34**, **36** based on measurements from one or more steering angle sensor **92**, and/or heights of frame **22** based on measurements received from one or more height sensors **86**. Controller **100** may use one or more of look-up tables, correlations, mathematical models, algorithms, etc., to determine threshold roll angle ϕ_A based on measurements from one or more of configuration sensors **86**, **90**, **92**, **94**, **96**, **98**, etc.

[0042] In one exemplary embodiment, controller **100** may be configured to determine a plurality of threshold angles ϕ_i (i=1, 2, 3, . . . m) corresponding to one or more of the configuration parameters associated with milling machine **10** or **20**. For example, controller **100** may determine threshold angle ϕ_1 based on an angle of frame **22** relative to ground surface **38** based on measurements from one or more height sensors **86** or based on measurements from slope sensor **98**. Controller **100** may also determine, for example, threshold angle ϕ_2 based on fuel level in fuel tank **72**, threshold angle ϕ_3 based on water level in water tank **74**, threshold angle ϕ_4 based on slew angle of conveyor **60**, threshold angle ϕ_5 based on steering angles of one or more propulsion devices **30**, **32**, **34**, **36**, threshold angle ϕ_6 based on a pitch angle of frame **22**, etc. Controller **100** may be configured to determine threshold roll angle ϕ_A based on one or more of threshold angles ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5, ϕ_6, etc. It is contemplated that controller **100** may uses one or more of look-up tables, correlations, mathematical expressions, statistical methods, etc. to determine threshold roll angle ϕ_A based on one or more of threshold roll angles ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5, or ϕ_6. It is contemplated that in one exemplary embodiment, controller **100** may determine threshold roll angle ϕ_A as a minimum of threshold angles ϕ_i (i=1, 2, 3, . . . m) (e.g., minimum of ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5, ϕ_6, etc.).

[0043] It is also contemplated that in some exemplary embodiments, controller **100** may execute one or more machine learning models to determine threshold roll angle ϕ_A. For example, controller **100** may be provided with training data, including one or more of the various configuration parameters discussed above and/or their combinations together with the corresponding values of threshold roll angle ϕ_A. Controller **100** may train the machine learning model using the training data. During operation of milling machine **10** or **20**, controller **100** may determine various configuration parameters based on one or more of the configuration sensors discussed above. Further controller **100** may execute the trained machine learning model to determine threshold roll angle ϕ_A based on the one or more measured configuration parameters.

[0044] Controller **100** may be configured to compare the roll angle ϕ(e.g., cross-slope angle or inclination) of milling machine **10** or **20** determined by slope sensor **98** with threshold roll angle ϕ_A. When roll angle ϕ of milling machine **10** or **20** equals or exceeds threshold roll angle ϕ_A ($\phi \geq \phi_A$), controller **100** may be configured to activate alarm device **76**. For example, in one exemplary embodiment, controller **100** may be configured to cause alarm device **76** to generate an audible alarm or warning message, indicating that milling machine **10** or **20** is likely to tip over. Additionally or alternatively, controller **100** may be configured to activate one or more visual indicators (e.g., lights) on operator console **70** in operator platform **68** to alert the operator, regarding likelihood that milling machine **10** or **20** will tip over. It is also contemplated that controller **100** may be configured to activate alarm device **76** by displaying one or more symbols or graphical displays to alert the operator to a potential tip over condition on one or more display devices **78** associated with operator console **70**.

[0045] FIG. **5** illustrates an exemplary graphical display **500** that may be generated by controller **100** for display on display device **78**. Display **500** may include element **502** that may display a ground speed of milling machine **10** or **20**, element **504** that may display a milling depth, element **506** that may display a fuel level of the fuel in fuel tank **72**, element **508** that may display a water level of the water in water tank **74**, and element **510** that may display a current inclination of milling machine **10** or **20** relative to ground surface **38**. Display **500** may be configured to display other parameters (e.g., sensor readings, calculated values, etc.) associated with milling machines **10** or **20**. When roll angle ϕ of milling machine **10** or **20** equals or exceeds threshold roll angle ϕ_A, controller **100** may display the warning message **512** (e.g., STOP AND STABILIZE THE MACHINE) to an operator of milling machine **10** or **20**. Additionally or alternatively, controller **100** may change a color of element **510** or display element **510** in different colors or in a flashing manner to attract the operator's attention. It should be understood that display **500** is exemplary and it is contemplated that many other types of graphical displays may be used to display one or more operational parameters, one or more configuration parameters and/or one or more visual alerts on display device **78** to an operator of milling machine **10** or **20**. It is to be understood that the text of the warning message discussed above and illustrated in the figures is exemplary and non-limiting, and many other types of warning messages may be displayed on graphical display **500**.

[0046] In some embodiments, controller **100** may be configured to additionally or alternatively compare roll angle ϕ of milling machine **10** or **20** determined by slope sensor **98** with threshold roll angle ϕ_B that may be different from threshold roll angle ϕ_A. Threshold roll angle ϕ_B may be a fixed angle that may not depend on a current measurement of one or more of the configuration parameters of milling machine **10** or **20**. Threshold roll angle ϕ_B may be greater than threshold roll angle ϕ_A. Threshold roll angle ϕ_B may represent an angle of inclination at which there is a high likelihood (e.g., greater than 90%, greater than 95%, etc.) that milling machine **10** or **20** may tip over. In some exemplary embodiments, threshold roll angle ϕ_B may be determined by performing tilt table testing on milling machines **10** or **20**. When roll angle ϕ of milling machine **10** or **20** exceeds threshold roll angle ϕ_B, controller **100** may be configured to activate alarm device **76**. It is contemplated that alarm device **76** may generate audible and/or visual alerts that may be the same as or different from the condition discussed above, where milling machine **10** or **20** had a roll angle ϕ greater than or equal to threshold roll angle ϕ_A but smaller than threshold roll angle ϕ_B. In some exemplary embodiments, when milling machine **10** or **20** has roll angle ϕ that is equal to or greater than threshold roll angle ϕ_B, controller **100** may also be configured to stop engine **66** to minimize damage to the engine and/or other components of milling machine **10** or **20** that may be caused as a result of milling machine **10** or **20** tipping over. It is to be understood that it may be possible to manually restart engine **66** on a tipped over milling machine **10** or **20** to allow engine **66** to provide power to one or more components that may help to restore milling machine **10** or **20** to an upright position from a tipped over position.

[0047] In some embodiments, controller **100** may be configured to additionally or alternatively compare roll angle ϕ of milling machine **10** or **20** determined by slope sensor **98** with threshold roll angle ϕ_C that may be different from threshold roll angles ϕ_A and ϕ_B. Threshold roll angle ϕ_C may be smaller than threshold roll angle ϕ_A and may represent a safety threshold. For example, a ratio of threshold roll angle ϕ_C and threshold roll angle ϕ_A may be a predetermined value (e.g., 0.75, 0.85, 0.90, etc.). That is, controller **100** may determine threshold roll angle ϕ_C as a predetermined percentage (less than 100) of threshold roll angle ϕ_A. When controller **100** determines that roll angle ϕ of milling machine **10** or **20** is greater than or equal to threshold roll angle ϕ_C, but less than threshold roll angle ϕ_A, controller **100** may be configured to adjust maximum and/or minimum limits for particular configuration parameters. In one exemplary embodiment, controller **100** may reduce the upper limit θ_{max} of slew angle θ. For example, if θ_{max} is ±45° for milling machine **10** on a level ground surface **38**, controller **100** may reduce θ_{max} to ±15°, when roll angle ϕ of milling machine **10** is greater than or equal to threshold roll angle ϕ_C. Thus, controller **100** may prevent an operator from rotating conveyor **60** in the transverse direction by more than the modified angle θ_{max}, reducing the likelihood the milling machine **10** may tip over. As another example, controller **100** may limit a maximum allowable steering angle. Doing so may prevent an operator from excessively turning one or more of propulsion devices **30**, **32**, **34**, **36**, reducing the likelihood of making sharp turns of milling machine **10** or **20** on an inclined ground surface **38**, which in turn may reduce the likelihood of tipping over for milling machine **10** or **20**. As another example, controller may limit a maximum allowable pitch angle for frame **22**. Doing so may prevent an operator from excessively inclining machine frame **22** relative to ground surface **38**, thereby reducing the likelihood of tipping over for milling machine **10** or **20**. It is contemplated that controller **100** may determine the modified limits of the one or more configuration parameters (e.g., θ_{max}) using look-up tables, correlations, mathematical models, algorithms, etc., based on measured values of various configuration parameters. Controller **100** may be configured repeatedly monitor the one or more sensors, determine and update the threshold roll angles ϕ_A and/or ϕ_C, and compare the roll angle ϕ of milling machine **10** or **20** with the threshold roll angles ϕ_A, ϕ_B, and/or ϕ_C during operation of milling machine **10**.

[0048] A method of operating the disclosed milling machine **10** or **20** is described in more detail with respect to FIG. **6** below.

INDUSTRIAL APPLICABILITY

[0049] The tip over warning system of the present disclosure may be used to continuously monitor a cross-slope ϕ of milling machine **10** or **20** to reduce the likelihood that milling machine **10** or **20** may tip over when operating on an inclined ground surface **38**. In particular, controller **100** of milling machine **10** or **20** may compare the cross-slope ϕ of milling machine **10** or **20** with one or more threshold roll angles ϕ_A, ϕ_B, or ϕ_C and take various actions to either reduce a likelihood of a tip over of milling machine **10** or **20**, or reduce damage to one or more machine components caused by a tip over of milling machine **10** or **20**. An exemplary method of operation of the disclosed milling machines **10** or **20** having the disclosed tip over warning system will be discussed below.

[0050] FIG. **6** illustrates an exemplary method **600** of operating milling machine **10** or **20** having the disclosed tip over warning system. The order and arrangement of steps of method **600** is provided for purposes of illustration. As will be appreciated from this disclosure, modifications may be made to method **600** by, for example, adding, combining, removing, and/or rearranging the steps of method **600**. Method **600** may be executed by controller **100** by, for example, executing one or more instructions stored in a memory device associated with controller **100**.

[0051] Method **600** may include a step of adjusting a position of frame **22** (Step **602**). An operator may perform such an operation, for example, before beginning the milling operation using milling machine **10** or **20**. The operator may do so to set, for example, a cutting depth for the milling drum. In one exemplary embodiment, the operator may initially lower one or more of leg columns **40**, **42**, **44**, **46** until teeth **54** of milling drum **50** barely touch ground surface **38**. At this point, operator may zero out all the depth and slope sensors associated with determining a milling depth of milling machine **10** or **20**. It is to be understood that zeroing out the slope sensor before beginning a milling operation, however, does not zero out the roll angle signal corresponding to angle ϕ, which indicates the inclination of frame **22** of milling machine **10** or **20** relative to a gravity direction. Next, the operator may lower one or more of leg columns **40**, **42**, **44**, **46** so that teeth **54** begin cutting into ground surface **38** at a desired depth of cut.

[0052] Method **600** may include a step of determining a roll angle ϕ of milling machine **10** or **20** (Step **604**). As discussed above, slope sensor **98** of milling machine **10** or **20** may continuously monitor a roll angle ϕ of milling machine **10** or **20** relative to a direction of gravity (see e.g., FIG. **3**). Slope sensor **98** may send one or more signals, representative of roll angle ϕ, to controller **100**. Controller **100** may be configured to determine roll angle ϕ of milling machine **10** or **20** based on the signals received from slope sensor **98**.

[0053] Method **600** may include a step of determining one or more machine configuration parameters (Step **606**). As discussed above, the one or more configuration sensors **86**, **90**, **92**, **94**, **96**, etc. may generate one or more signals representative of a configuration parameter associated with milling machine **10** or **20**. For example, one or more height sensors **86** may generate signals representative of a height of frame **22** relative to ground surface **38**. Controller **100** may be configured to determine a height and/or pitch of frame **22** relative to ground surface **38** based on signals from the one or more height sensors **86**. Slew angle sensor **90** may generate signals representative of a slew angle of conveyor **60** relative to longitudinal axis **28**. Controller **100** may be configured to determine a rotation angle of conveyor **60** relative to longitudinal axis **28** and/or a center of gravity of conveyor **60** based on signals from slew angle sensor **90**. One or more steering angle sensors **92** may generate signals representative of a steering angle of one or more propulsion devices **30**, **32**, **34**, **36**. Controller **100** may be configured to determine a rotation angle of one or more of propulsion devices **30**, **32**, **34**, **36** relative to longitudinal axis **28** based on signals from steering angle sensors **92**.

[0054] Similarly, fuel level sensor **94** and water level sensor **96** may generate signals representative of a fuel level in fuel tank **72** and a water level in water tank **74**, respectively. Controller **100** may be configured to determine the fuel level and water level based on signals from fuel level sensor **94** and water level sensor **96**, respectively. In some embodiments, controller **100** may also be configured to determine a center of gravity of the remaining fuel in fuel tank **72** and/or a center of gravity of the remaining water in water tank **74** based on signals from fuel level sensor **94** and water level sensor **96**, respectively.

[0055] Method **600** may include a step of determining a threshold roll angle (Step **608**). As discussed above, controller **100** may be configured to determine one or more of threshold roll angles ϕ_A and/or ϕ_C based on signals received from one or more of configuration sensors **86**, **90**, **92**, **94**, and/or **96**. Controller **100** may use one or more of look-up tables, correlations, geometric models, algorithms, etc., and/or one or more of the techniques discussed above to determine one or more of threshold roll angles ϕ_A and/or ϕ_C.

[0056] Method **600** may include a step of determining whether roll angle ϕ of milling machine **10** or **20** is greater than or equal to a threshold roll angle, for example, ϕ_A (Step **610**). When controller **100** determines that roll angle ϕ of milling machine **10** or **20** is greater than or equal to threshold roll angle ϕ_A (Step **610**: YES), method **600** may proceed to step **612**. When controller **100** determines that roll angle ϕ of milling machine **10** or **20** is less than threshold roll angle ϕ_A (Step **610**: NO), method **600** may return to step **604**.

[0057] In step **612**, method **600** may include a step of activating an alarm device **76** (Step **612**). For example, in one exemplary embodiment, controller **100** may be configured to cause alarm device **76** to generate an audible alarm or warning message. Additionally or alternatively, controller **100** may be configured to activate one or more visual indicators (e.g., lights) on operator console **70** in operator platform **68**. It is also contemplated that controller **100** may be configured to activate alarm device **76** by displaying one or more symbols or graphical displays on one or more display devices **78** associated with operator console **70**. It is contemplated that controller **100** may repeatedly execute steps **604**-**612** to continuously update the threshold roll angles ϕ_A and/or ϕ_C during operation of milling machine **10** or **20**.

[0058] It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed milling machine and tip over warning system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed milling machine and tip over warning system. 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.

1. A milling machine, comprising:

a frame having a longitudinal axis;

a milling drum attached to the frame and extending along a transverse axis of the frame;

a plurality of ground engaging tracks configured to support the frame;

a plurality of height-adjustable leg columns connecting the frame to the tracks;

an engine configured to rotate the milling drum and propel the ground engaging tracks;

a slope sensor configured to measure a roll angle of the frame;

a speed sensor configured to measure a ground speed of the milling machine;

a configuration sensor configured to measure a machine configuration parameter;

an alarm device; and

a controller configured to:

determine a threshold roll angle based on the machine configuration parameter, wherein the threshold roll angle corresponds to a predetermined probability of tipping over of the milling machine;

compare the roll angle with the threshold roll angle; and

activate the alarm device when the roll angle is greater than or equal to the threshold roll angle.

2. The milling machine of claim **1**, further including a conveyor extending from the frame and configured to be rotatable transverse to the longitudinal axis.

3. The milling machine of claim **2**, wherein the configuration sensor includes at least one of

a fuel level sensor configured to measure a fuel level in a fuel tank of the milling machine,

a water level sensor configured to measure a water level in a water tank of the milling machine,

a steering angle sensor configured to measure a steering angle of at least one of the ground engaging tracks relative to the longitudinal axis, or

a slew angle sensor configured to measure a slew angle of the conveyor relative to the longitudinal axis.

4. The milling machine of claim **3**, wherein the controller is configured to determine the threshold roll angle based on at least one of the fuel level, the water level, the steering angle, or the slew angle.

5. The milling machine of claim **3**, wherein the controller is configured to:

determine a plurality of threshold angles based on respective ones of the fuel level, the water level, the steering angle, and the slew angle; and

determine the threshold roll angle based on at least one of the plurality of threshold angles.

6. The milling machine of claim **5**, wherein the controller is configured to determine the threshold roll angle as a minimum of the plurality of threshold angles.

7. The milling machine of claim **1**, wherein the controller is further configured to:

determine a pitch angle of the frame; and

determine the threshold roll angle based on the pitch angle.

8. The milling machine of claim **1**, wherein the controller is configured to activate the alarm device by at least one of

causing the alarm device to emit an audible alert, or

causing the alarm device to display a visual alert on an operator console of the milling machine.

9. The milling machine of claim **8**, wherein the visual alert includes at least one of

a warning light on the operator console of the milling machine, or

a warning symbol or message displayed on a display device included in the operator console.

10. The milling machine of claim **1**, wherein the machine configuration parameter includes at least one of:

a center of gravity of the milling machine,

a center of gravity of an amount of water in a water tank of the milling machine,

a center of gravity of an amount of fuel in a fuel tank of the milling machine, or

a center of gravity of at least one implement attached to the milling machine.

11. The milling machine of claim **1**, wherein

the threshold roll angle is a first threshold roll angle, and

the controller is further configured to:

compare the roll angle with a second threshold roll angle greater than the first threshold roll angle, and

when the roll angle is greater than or equal to the second threshold roll angle:

activate the alarm device, and

stop the engine.

12. The milling machine of claim **11**, wherein the first threshold roll angle is variable and the second threshold roll angle is fixed.

13. The milling machine of claim **1**, wherein

the threshold roll angle is a first threshold roll angle, and

the controller is configured to adjust a limit of the machine configuration parameter when the roll angle is greater than or equal to a second threshold roll angle less than the first threshold roll angle.

14. The milling machine of claim **13**, wherein

the machine configuration parameter is one of a slew angle of a conveyor extending from the frame or a steering angle of at least one of the ground engaging tracks, and

the controller is configured to adjust a respective one of a maximum slew angle of the conveyor or a maximum steering angle.

15. A method of operating a milling machine including a frame having a longitudinal axis and supported by a plurality of ground engaging tracks connected to the frame by a plurality of height adjustable leg columns, a milling drum attached to the frame, an engine, a speed sensor, a slope sensor, a configuration sensor, and a controller, the method comprising:

operating one or more of the leg columns to adjust a position of the frame relative to a ground surface;

determining a roll angle of the frame based on a signal from the slope sensor;

determining a machine configuration parameter based on a signal from the configuration sensor;

determining, using the controller, a threshold roll angle based on the machine configuration parameter, wherein the threshold roll angle corresponds to a predetermined probability of tipping over of the milling machine;

comparing, using the controller, the determined roll angle of the frame with the threshold roll angle; and

activating an alarm device when the determined roll angle exceeds the threshold roll angle.

16. The method of claim **15**, wherein determining the machine configuration parameter includes determining at least one of

a fuel level in a fuel tank of the milling machine,

a water level in a water tank of the milling machine,

a steering angle of at least one of the ground engaging tracks relative to the longitudinal axis, or

a slew angle of a conveyor relative to the longitudinal axis.

17. The method of claim **16**, further including:

determining, using the controller, a plurality of threshold angles based on respective ones of the fuel level, the water level, the steering angle, and the slew angle; and

determining the threshold roll angle based on the plurality of threshold angles.

18. The method of claim **17**, further including determining the threshold roll angle as a minimum of the plurality of threshold angles.

19. The method of claim **16**, wherein the threshold roll angle is a first threshold roll angle, and the method further includes,

comparing, using the controller, the roll angle with a second threshold roll angle greater than the first threshold roll angle,

when the roll angle is greater than the first threshold roll angle and less than the second threshold roll angle, activating the alarm device, and

when the roll angle is greater than or equal to the second threshold roll angle

activating the alarm device, and

stopping the engine.

20. The method of claim **16**, wherein the threshold roll angle is a first threshold roll angle, and the method further includes adjusting at least one of a maximum slew angle or a maximum steering angle when the roll angle is greater than or equal to a second threshold roll angle less than the first threshold roll angle.

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