

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
07.02.2024 Bulletin 2024/06

(51) International Patent Classification (IPC):
B66C 13/06^(2006.01) **B66C 13/22**^(2006.01)

(21) Application number: **21935165.7**

(22) Date of filing: **03.12.2021**

(86) International application number:
PCT/JP2021/044415

(87) International publication number:
WO 2022/209012 (06.10.2022 Gazette 2022/40)

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
 GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
 PL PT RO RS SE SI SK SM TR**
 Designated Extension States:
BA ME
 Designated Validation States:
KH MA MD TN

- **WATANABE, Michiharu**
Tokyo 101-0021 (JP)
- **IESHIGE, Koji**
Tokyo 101-0021 (JP)
- **OIKAWA, Yugo**
Tokyo 101-0021 (JP)
- **TAGAMI, Tatsuya**
Tokyo 101-0021 (JP)

(30) Priority: **29.03.2021 JP 2021055350**

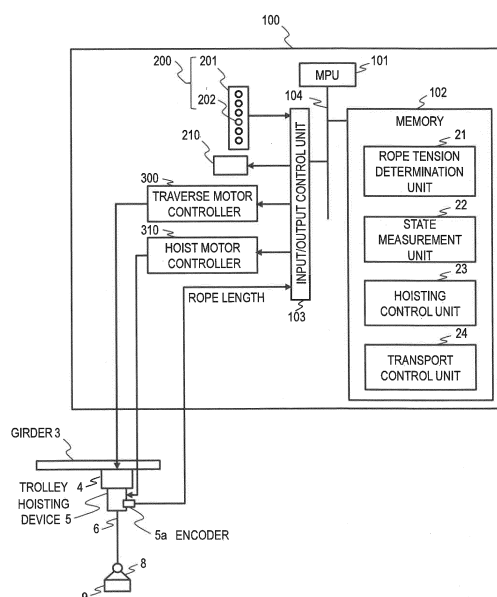
(71) Applicant: **Hitachi Industrial Equipment Systems
Co., Ltd.**
Tokyo 101-0021 (JP)

(74) Representative: **MERH-IP Matias Erny Reichl
Hoffmann
Patentanwälte PartG mbB
Paul-Heyse-Strasse 29
80336 München (DE)**

(72) Inventors:
• **MOMOI, Yasuyuki**
Tokyo 101-0021 (JP)

(54) CRANE, AND CONTROL METHOD FOR CRANE

(57) A crane includes a horizontal transport device horizontally movable with a motor, a hoisting device mounted on the horizontal transport device, the hoisting device being capable of winding a rope with a hoist motor, a hook attached on the rope to hang a payload and a control unit including a processor and a memory, the control unit being configured to control the horizontal transport device and the hoisting device. The control unit includes a rope tension determination unit configured to determine whether the rope is in a taut state without a slack; a state measurement unit configured to measure at least one state value of the crane when the rope has been wound up into a taut state by the hoisting device being driven and a transport control unit configured to move the horizontal transport device.



Description

Incorporation by Reference

- 5 **[0001]** The present application claims priority from Japanese patent application JP 2021-55350 filed on March 29, 2021, the content of which is hereby incorporated by reference into this application.

Technical Field

- 10 **[0002]** This invention relates to a crane for hanging and transporting a payload and a method of controlling the crane.

Background Art

- 15 **[0003]** In recent years, aging of skilled crane operators and increasing installation of cranes have caused labor shortage; inexperienced and unskilled workers more often operate cranes. Unskilled workers are especially not good at steadying operation to suppress sway of the payload (payload sway). Payload sway generates high risks of accidents such as collision with and press by the payload. Furthermore, it takes a long time to be stopped, which increases the working time. Accordingly, a technique for automatically suppressing the payload sway is demanded to increase the safeness and work efficiency.

- 20 **[0004]** In hoisting a grounded payload, if the horizontal transport device (trolley) carrying the payload with a rope has a horizontal positional deviation from the payload, the payload may start pendular movement at the moment when the payload leaves the ground, causing payload sway (initial sway).

- 25 **[0005]** To reduce this initial sway, a technique is disclosed in Patent Document 1. The existing technique according to Patent Document 1 winds up the rope into a taut and slackless state before hoisting the payload, measures the length of the rope in the taut state, slightly moves the trolley in the direction to reduce the rope length, and repeats the foregoing operation until the trolley is positioned directly above the payload where the rope length is minimized and the positional deviation is eliminated. According to Patent Document 1, the condition to determine that the rope length is minimized is that the variation in rope length caused by move of the trolley has decreased to a predetermined small value or the variation in rope length changes from decreasing to increasing.

30

CITATION LIST

PATENT DOCUMENT

- 35 **[0006]**

Patent Document 1: JP 2019-119583 A

Patent Document 2: WO 2018/211739 A

- 40 SUMMARY

PROBLEMS TO BE SOLVED BY THE INVENTION

- 45 **[0007]** Patent Document 1 determines whether the rope length is minimized with its variation. However, the variation in rope length becomes smaller as the positional deviation of the trolley from the payload becomes smaller and accordingly, the precision in detecting the position where the rope length is minimized has a limit, generating a limit in reducing the positional deviation.

- 50 **[0008]** Furthermore, Patent Document 1 repeats straining the rope by winding up, measuring the rope length, and slightly moving the trolley and therefore, if the positional deviation is large, the operation has to be repeated for a large number of times. It takes a long time (operation time) to move the trolley to directly above the payload.

[0009] This invention is accomplished in view of these problems and aims to provide a crane and a method of controlling the crane that can hoist a grounded payload sooner by attaining a smaller horizontal positional deviation of the trolley from the payload in a shorter operating time of the trolley before the hoisting operation.

- 55 Solution to Problem

[0010] One aspect of the present invention is a crane includes a horizontal transport device horizontally movable with a motor, a hoisting device mounted on the horizontal transport device, the hoisting device being capable of winding a

rope with a hoist motor, a hook attached on the rope to hang a payload and a control unit including a processor and a memory, the control unit being configured to control the horizontal transport device and the hoisting device. The control unit includes a rope tension determination unit configured to determine whether the rope is in a taut state without a slack; a state measurement unit configured to measure at least one state value of the crane when the rope has been wound up into a taut state by the hoisting device being driven and a transport control unit configured to move the horizontal transport device. The state measurement unit is configured to identify a payload location x_p of a grounded payload, using a position x of the horizontal transport device and the at least one state value measured when the rope is in a taut state, and the transport control unit is configured to move the horizontal transport device to the identified payload location x_p to position the rope directly above the payload.

EFFECTS OF THE INVENTION

[0011] This invention enables a crane to hoist a grounded payload sooner by attaining a smaller horizontal positional deviation of a trolley from the payload in a shorter operating time of the trolley before the hoisting operation.

[0012] The details of at least one embodiment of a subject matter disclosed herein are set forth in the accompanying drawings and the following description. Other features, aspects, and effects of the disclosed subject matter become apparent from the following disclosure, drawings, and claims.

Brief Description of Drawings

[0013]

FIG. 1 illustrates a general configuration of an overhead crane in a first embodiment of this invention.

FIG. 2 illustrates a configuration of the control device of the crane in the first embodiment of this invention.

FIG. 3A illustrates the movement of the crane in hoisting a grounded payload in the first embodiment of this invention.

FIG. 3B illustrates the movement of the crane in hoisting a grounded payload in the first embodiment of this invention.

FIG. 4 is a flowchart of an example of the control in accordance with an existing art.

FIG. 5 illustrates the movement of the crane in accordance with the existing art.

FIG. 6 illustrates the relation among the positions of the trolley and the payload and the rope length in the first embodiment of this invention.

FIG. 7 is a graph representing the relation between the positional deviation D and the rope length L obtained from Expression in the first embodiment of this invention.

FIG. 8 is a graph representing the relation between the rope length L and the trolley position x for illustrating the principle of the first embodiment of this invention.

FIG. 9 is a diagram illustrating the movement of the crane in the first embodiment of this invention.

FIG. 10 is a flowchart of an example of processing to be performed in the control device 100 of the first embodiment of this invention.

FIG. 11 is a flowchart of the details of identifying the payload location in the first embodiment of this invention.

FIG. 12 illustrates the movement of the crane in a third embodiment of this invention.

FIG. 13 illustrates the movement of the crane in a fourth embodiment of this invention.

FIG. 14 illustrates a configuration of the control device of the crane in the third and fourth embodiment of this invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0014] Hereinafter, embodiments of this invention will be specifically described with reference to the drawings. However, this invention is not limited to the embodiments and the scope of this invention includes various modifications and applications within its technical concept.

EMBODIMENT 1

Configuration and Operation of Crane

[0015] The configuration and operation of a crane 1 in Embodiment 1 of this invention are described. Throughout the drawings, the same apparatuses (devices and components) are denoted by the same reference signs and description about already described apparatuses may be skipped in the subsequent description.

[0016] FIG. 1 illustrates a general configuration of an overhead crane. The crane 1 includes runways 2 provided along the walls on opposite sides of a building such as a factory (not shown), a girder 3 that moves on the top sides of the runways 2, and a trolley 4 that moves along the underside of the girder 3.

[0017] The girder 3 and the trolley 4 have wheels (not shown) to be driven by electric motors (not shown); the girder 3 and the trolley 4 can move with these wheels. The girder 3 travels along the runways 2 and the trolley 4 moves along the underside of the girder 3 transversely (horizontally: leftward and rightward in FIG. 1) between the runways 2.

[0018] The trolley 4 is provided with a hoisting device (hoist) 5. The hoisting device 5 includes a drum (not shown) to be driven by an electric motor; this drum is rotated to wind or unwind a rope 6, so that a hook 7 at the end of the rope 6 is raised or lowered.

[0019] A payload 9 is hooked on the hook 7 directly or through wires 8; the payload 9 is raised and lowered with up and down of the hook 7. The crane 1 can move the payload 9 horizontally by horizontal movement (traveling) of the girder 3 and horizontal movement (traversing) of the trolley 4 and can move the payload 9 vertically (up and down) with the hoisting device 5.

[0020] The sling member for hanging the payload 9 from the hook 7 is not limited to the wires 8; other kinds of slings such as chain and rope can be employed.

[0021] In FIG. 1, the trolley 4 and the girder 3 correspond to horizontal transport devices. However, at least either one of the trolley 4 and the girder 3 can be referred to as horizontal transport device; otherwise, the trolley 4 that moves along the girder 3 can be referred to as a first horizontal transport device and the girder 3 that moves along the runways 2 can be referred to as a second horizontal transport device.

[0022] The hoisting device 5 includes an encoder 5a (see FIG. 2) for detecting the rotation angle of the drum to measure the length of the rope 6 (rope length) paid out from the drum.

Control Device

[0023] FIG. 2 illustrates a configuration of the control device of the crane 1 in this embodiment. For simplicity of description, FIG. 2 illustrates traverse control for the trolley 4 and up and down control for the hoisting device 5 and excludes travel control for the girder 3.

[0024] FIG. 2 also does not include driving members such as electric motors. The control device 100 of the crane 1 includes an arithmetic and control unit, a traverse motor controller 300 for controlling the electric motor (traverse motor) of the trolley 4, a hoist motor controller 310 for controlling the electric motor (hoist motor) of the hoisting device 5, an operation input device 200, and a display device 210. Although not shown in FIG. 2, the control device 100 includes a travel motor controller for controlling the electric motor (travel motor) to drive the girder 3 along the runways 2.

[0025] The control device 100 calculates and outputs speed command values for the trolley 4 and the hoisting device 5 and outputs information to the display device 210, based on the operation command input through the operation input device 200 and information acquired from sensors including the encoder 5a (first sensor).

[0026] The arithmetic and control unit in the control device 100 is commonly a general-purpose computer; it includes a micro-processing unit (MPU) 101 for performing control and arithmetic operation using installed programs and data, a memory 102 for storing the programs and data, and an input/output control unit 103 for inputting data and signals from the external and outputting signals arithmetically processed by the MPU 101 to the external. The MPU 101, the memory 102, and the input/output control unit 103 are connected by a bus line 104 for transmitting signals and data.

[0027] The operation input device 200 is connected to an operation terminal 201 to be operated by the operator of the crane 1. The operation terminal 201 has operation buttons 202 associated with transport directions of the payload: forward, backward, rightward, leftward, upward, and downward.

[0028] The display device 210 displays information such as the state of the crane 1. The operation terminal 201 can be connected to the control device 100 with wire or wirelessly. The display device 210 can be mounted on the same housing as the operation terminal 201.

[0029] The traverse motor controller 300 and the hoist motor controller 310 control the electric motors of the trolley 4 and the hoisting device 5 in accordance with the speed command values output from the control device 100. Although FIG. 2 does not illustrate specific configurations of the traverse motor controller 300 and the hoist motor controller 310, they can be configured with general-use computers like the control device 100 or inverter circuits. The traverse motor controller 300 and the hoist motor controller 310 can be mounted on the same housing as the control device 100.

[0030] Although not shown in FIG. 2, the control device 100 further outputs a speed command value for the girder 3, in addition to the speed command values for the trolley 4 and hoisting device 5. As for the girder 3, a not-shown electric motor (travel motor) controller controls an electric motor in accordance with this speed command value.

[0031] The memory 102 includes a rope tension determination unit 21, a state measurement unit 22, a hoisting control unit 23, and a transport control unit 24, which are programs loaded and executed by the MPU 101.

[0032] The MPU 101 performs processing in accordance with the programs of function units to work as the function units for providing predetermined functions. For example, the MPU 101 performs processing in accordance with the rope tension determination program to function as the rope tension determination unit 21. The same applies to the other programs. Furthermore, the MPU 101 works as function units for providing functions of a plurality of processes executed by a program. A computer and a computer system are an apparatus and a system including these function units.

[0033] The rope tension determination unit 21 determines whether the rope 6 is in a taut and slackless state based on the current value of the electric motor of the hoisting device 5. The state measurement unit 22 measures the state values such as the rope length and the positions of the trolley 4 and the girder 3 after winding up the rope 6 connected to a grounded payload into a taut state, infers the location of the payload from the state values, and positions the crane 1 by moving the trolley 4 and the girder 3 so that the rope 6 is positioned directly above the payload 9.

[0034] The transport control unit 24 receives command values from the operation terminal 201 and the payload location from the state measurement unit 22 and drives the trolley 4 and the girder 3 with the traverse motor controller 300 and a not-shown travel motor controller, respectively, to horizontally move the trolley 4 and the girder 3.

[0035] The hoisting control unit 23 outputs command values to the hoist motor controller 310 in accordance with the command values from the operation terminal 201 and the state measurement unit 22.

Hoisting Grounded payload

[0036] In hoisting a grounded payload 9, payload sway (initial sway) may occur when the payload 9 leaves the ground (or the floor). FIGS. 3A and 3B illustrate the movement of the crane 1 in hoisting a grounded payload 9. If the trolley 4 has a positional deviation D from the grounded payload 9 in a horizontal direction as illustrated in FIG. 3A, the payload 9 starts pendular movement with an amplitude D (positional deviation D) and an angular frequency $(g/L)^{1/2}$ (L : the distance from the trolley 4 to the payload 9, g : the acceleration of gravity) when the rope 6 is wound and the payload 9 leaves the ground as illustrated in FIG. 3B. This is the initial sway.

Existing Art and Issues

[0037] To reduce this initial sway, the horizontal positional deviation of the trolley 4 from the payload 9 when the payload 9 leaves the ground should be reduced and accordingly, the trolley 4 should be moved to directly above the payload 9 before hoisting the payload 9. To satisfy this condition, there exists an art disclosed in the aforementioned Patent Document 1.

[0038] This existing art winds up the rope into a taut and slackless state before hoisting the payload, measures the length of the rope in the taut state, slightly moves the trolley in the direction to reduce the rope length, and repeats the foregoing operation until the trolley is positioned directly above the payload where the rope length is minimized and the positional deviation is eliminated.

[0039] According to Patent Document 1, the condition to determine that the rope length is minimized is that the variation in rope length caused by the movement of the trolley has decreased to a predetermined small value or the variation in rope length changes from decreasing to increasing.

[0040] FIG. 4 is a flowchart of an example of the control in accordance with an existing art. The details are as follows. Described here is an example of the control such that the control device controls the trolley and the hoisting device to transport a payload.

[0041] The control device first prohibits a hoisting operation (S101). Next, the control device instructs the hoisting device to wind up the rope into a taut and slackless state (S102). The control device detects the rope length as a state value ψ with an encoder attached on the hoisting device (S103).

[0042] At Step S104, the control device performs termination determination based on the state value ψ . The termination condition is that the variation in rope length is smaller than a predetermined value or that the rope length changes from decreasing to increasing. If the termination condition is not satisfied, the control device proceeds to Step S105 and if satisfied, proceeds to Step S107.

[0043] At Step S105, the control device determines the direction to move the trolley. It determines the direction to decrease the rope length to be the direction to move (transversally) the trolley. At Step S106, the control device moves the trolley in the direction determined by the control device at the foregoing Step S105 by a predetermined distance. After the trolley has moved, the control device returns to Step S102 and repeats the above-described processing.

[0044] At Step S107, the control device determines whether the termination condition is satisfied and the trolley has moved to directly above the payload and permits a hoisting operation to the operator.

[0045] FIG. 5 illustrates the movement of the crane 1 in accordance with the existing art. The existing art moves the trolley 4 asymptotically to directly above the payload 9 by repeating straining the rope 6 by winding up, measuring the rope length, and slightly moving the trolley 4.

[0046] This existing art has raised two issues. One of them is the limit of reducing the positional deviation because of the precision in detection of the rope length. FIG. 6 illustrates the relation among the positions of the trolley 4 and the payload 9 and the rope length. Letting D be the positional deviation of the trolley 4 from the payload 9 in a horizontal direction and H be the height from the payload 9 to the trolley 4, the distance from the trolley 4 to the payload 9 or the length L of the rope 6 including the length of the wires 8 can be expressed by the following Expression (1):

[Expression 1]

$$L = \sqrt{H^2 + D^2} \quad \dots (1)$$

[0047] FIG. 7 is a graph representing the relation between the positional deviation D and the rope length L obtained from Expression 1. FIG. 7 indicates that the variation of the rope length L becomes smaller and the travel distance of the trolley 4 required to detect variation of the rope length L becomes longer as the positional deviation D becomes smaller. The rope length L can be detected by the encoder 5a and let ΔL be the detection resolution of the encoder 5a for the rope length L. The minimum value Dmin for the positional deviation D can be expressed by the following Expression (2):

[Expression 2]

$$D_{min} = \sqrt{2H\Delta L + \Delta L^2} \quad \dots (2)$$

[0048] As understood from the above description, the minimum value Dmin for the positional deviation D depends on the detection resolution of the encoder 5a and reducing the positional deviation D has a limit.

[0049] Another issue is that the operating time to move the trolley 4 to directly above the payload 9 is long when the positional deviation D is large. As illustrated in FIG. 4, the existing art repeats straining the rope by winding up, measuring the rope length, and slightly moving the trolley 4. For this reason, when the positional deviation D is large, more repeats are required, increasing the operating time.

Overview and Principle of This Invention

[0050] This invention addresses the above-described issues as follows. FIG. 8 is a graph representing the relation between the rope length L and the trolley position x for illustrating the principle of this invention. FIG. 9 is a diagram illustrating the movement of the crane 1 in this invention. The trolley position x(i) in the traversing direction of the trolley 4 and the distance L(i) between the trolley 4 at the position x(i) and the payload 9 (the length of the taut rope including the length of the wires 8) have the relation expressed by the following Expression (3):

[Expression 3]

$$L(i) = \sqrt{H^2 + (x(i) - xp)^2} \quad \dots (3)$$

where i is a natural number representing the ordinal number of the measurement of the rope length L.

[0051] In FIG. 8, the payload location xp is the position of the trolley 4 where the rope length L takes a minimum value when the trolley 4 is moved transversely (along the girder 3) and is the location (payload location) xp of the payload 9 in the transverse direction. The following Expression (4) can be obtained by squaring the both members of the Expression (3):

[Expression 4]

$$x(i)^2 - 2xp \times x(i) - L(i)^2 + xp^2 + H^2 = 0 \quad \dots (4)$$

[0052] Letting p1 and p2 be the parameters including the height H from the payload 9 to the trolley 4 (or the hoisting device 5) and the payload location xp, the foregoing Expression (4) can be expressed by the following Expression (5):

[Expression 5]

$$x(i)^2 - L(i)^2 + p1 \times x(i) + p2 = 0 \quad \dots (5)$$

[0053] As expressed by Expression (5), the squared value of the rope length L(i) can be expressed by a quadratic function of the trolley position x(i). Hence, the control device 100 in this embodiment moves the trolley 4 transversely and measures at least two different trolley positions x(i) and the rope lengths L(i) of the taut rope there as state values and fits the acquired trolley positions x(i) and rope lengths L(i) to the foregoing Expression (5) by a well-known or publicly

known method such as the method of least squares to calculate the parameters p_1 and p_2 . The fitting in this embodiment obtains the best curve (the foregoing expression (5)) that fits the measured data by curve fitting or curve regression.

[0054] The control device 100 can calculate the payload location x_p of the payload 9 in the transverse direction, using the following Expression (6) with the calculated parameters p_1 and p_2 :

[Expression 6]

$$x_p = \frac{-p_1}{2} \dots (6)$$

[0055] In similar, the control device 100 measures at least two different girder positions $y(i)$ in its traveling direction and the rope length $L(i)$ there to calculate the payload location y_p of the payload 9 in the traveling direction where the rope length L from the trolley 4 takes the minimum value in the traveling direction of the girder 3, like the payload location x_p .

[0056] The control device 100 can reduce the horizontal positional deviation D of the trolley 4 from the payload 9 by moving the trolley 4 in the transverse direction and the traveling direction to the calculated payload location (x_p, y_p) and as a result, the initial sway is reduced.

[0057] As described above, the method of this invention fits the rope lengths $L(i)$ and the trolley positions $x(i)$ to the quadratic curve expressed by the foregoing Expression (5). This method can determine the position directly above the payload 9 more precisely than the existing art that depends on the detection resolution of the encoder, achieving a smaller positional deviation D .

[0058] Furthermore, the method of this invention requires at least two times of operation of straining the rope 6 by winding up, measuring the rope length L , and moving the trolley 4 in each of the transverse direction and the traveling direction. The number of repeats is smaller than the existing art, achieving a shorter operating time.

Control in This Invention

[0059] FIG. 10 is a flowchart of an example of processing to be performed in the control device 100 of this invention. This processing starts based on the operator's instruction. The details are as follows.

[0060] At Step S201, the control device 100 changes the operation mode to an initial positioning mode in this invention to move the trolley before hoisting a grounded payload. For example, the operation input device 200 can have an operation mode selection switch and the operator operates the switch to change the operation mode.

[0061] The control device 100 may display the operation mode with the display device 210 or the crane 1 can have a lamp for indicating the operation mode so that the surroundings can know the selected operation mode.

[0062] At Step S202, the control device 100 moves the trolley 4 to identify the payload location x_p in the transverse direction. The details of this control will be described later. At Step S203, the control device 100 moves the girder 3 along the runways 2 to identify the payload location y_p in the traveling direction of the girder 3.

[0063] At Step S204, the control device 100 moves the trolley and the girder 3 to the identified payload location (x_p, y_p) . As a result, the rope 6 drooping from the trolley 4 is positioned directly above the payload 9.

[0064] At Step S205, the control device 100 changes the operation mode to a normal operation mode in which the crane 1 transports the payload 9 in the direction corresponding to the pressed operation button 202 of the operation terminal 201. This mode change can be performed not only in response to an explicit operation such as operating the operation mode selection switch of the operation terminal 201 but also automatically as soon as the trolley 4 reaches the payload location (x_p, y_p) .

[0065] To ensure the safeness, the trolley 4 can be configured to move only when an operation button 202 of the operation terminal 201 is being pressed in the above-described Steps S202, S203, and S204.

[0066] FIG. 11 is a flowchart of the details of identifying the payload location x_p at Step S202 in FIG. 10. The details are as follows. The details of Step S203 are the same as those of Step S202 in which the transverse direction in the following description is replaced by the traveling direction.

[0067] At Step S301, the control device 100 winds up the rope 6 until it becomes taut at the initial position $x(1)$ of the trolley 4 and measures the rope length $L(1)$ when the rope 6 is taut from the detection value of the encoder 5a.

[0068] Whether the rope 6 is taut can be determined by a well-known or publicly-known technique, for example, by determining whether the current value of the hoist motor is higher than a threshold value or by determining whether the tension of the rope 6 is higher than a threshold value with a tension sensor attached to the rope 6.

[0069] At Step S302, the control device 100 moves the trolley 4 to a trolley position $x(2)$ that is distant from the trolley position $x(1)$ by a predetermined distance dx , winds up the rope 6 at the position $x(2)$ until the rope becomes taut, and measures the rope length $L(2)$ with the encoder 5a. The horizontal position of the trolley 4 can be calculated from the moving time of the trolley 4 or measured with a laser distance sensor attached on the trolley 4.

[0070] The control device 100 performs the foregoing Steps S301 and S302 with respect to the traveling direction of

the girder 3 in the same way; specifically, the control device 100 moves the girder 3 to a girder position $y(2)$ that is distant from the initial girder position $y(1)$ by a predetermined distance dy , winds up the rope 6 at the position $y(2)$ until the rope 6 becomes taut, and measures the rope length $L(2)$ with the encoder 5a.

[0071] At Step S303, the control device 100 fits the trolley positions and rope lengths $(x(1), L(1))$ and $(x(2), L(2))$ measured at the foregoing Steps S301 and S302 to the aforementioned Expression (5) by a well-known or publicly-known method such as the method of least squares to identify the parameters $p1$ and $p2$ in the traversing direction of the trolley 4.

[0072] The control device 100 further identifies the parameters $p1$ and $p2$ in the traveling direction of the girder 3 by the same method as described above, or by fitting the girder positions and rope lengths $(y(1), L(1))$ and $(y(2), L(2))$ to the aforementioned Expression (5) by a well-known or publicly-known method such as the method of least squares.

[0073] At Step S304, the control device 100 determines the payload location x_p in the transverse direction where the rope length L (state value) takes a minimum value using the aforementioned Expression (6) with the parameter in the traversing direction of the trolley 4 denoted by $p1x$ in FIG. 11. Further, the control device 100 determines the payload location y_p in the traveling direction where the rope length L takes a minimum value using the aforementioned Expression (6) with the parameter in the traveling direction of the girder 3 denoted by ply in FIG. 11.

[0074] At the aforementioned Step S302, if the trolley 4 is moved in the state where the rope 6 is taut, the payload 9 may be dragged. Accordingly, the rope 6 should be paid out before moving the trolley 4. The same applies to moving the girder 3 in the traveling direction.

[0075] Although this example moves the trolley transversally to measure the rope length at two positions, the positions to measure the rope length can be increased for higher accuracy in detecting the payload location x_p .

[0076] As described above, the location of the payload 9 can be determined more precisely by fitting the trolley positions $x(1)$ and $x(2)$ and the lengths $L(1)$ and $L(2)$ of the taut rope to the quadratic curve in FIG. 8, so that a smaller positional deviation is attained.

[0077] This embodiment requires straining the rope 6 by the hoisting device 5 winding up, measuring the rope length L , and moving the trolley 4 (or the girder 3) for at least two times in each of the transverse direction and the traveling direction, achieving a smaller number of repeats. Accordingly, the operating time of the trolley 4 before hoisting the grounded payload can be reduced, enabling the hoisting operation to start sooner.

Modified Example 1

[0078] Focusing on the constant terms of the foregoing Expressions (4) and (5), the height H can be calculated by the following Expression (7):

[Expression 7]

$$H = \sqrt{p2 - xp^2} \quad \dots (7)$$

[0079] Subtracting the rope length $L_r (x = x_p)$ of the taut rope 6 from the trolley 4 positioned directly above the payload 9 to the hook 7 from this height H provides the length L_w of the wires 8 from the hook 7 to the payload 9 as expressed in the following Expression (8):

[Expression 8]

$$L_w = H - L_r (x = x_p) \quad \dots (8)$$

[0080] The above expression enables automatic acquisition of the length L_w of the wires 8 (hereinafter wire length). This wire length L_w enables automatic acquisition of the distance L from the trolley 4 to the payload 9 by being added to the length L_r of the rope 6 from the trolley 4 to the hook 7 detected with the encoder 5a. This distance L is the same as the aforementioned rope length L from the trolley 4 to the payload 9.

[0081] This distance L is a parameter necessary for the control to suppress the payload sway occurring in transporting a suspended payload 9. The payload sway in transportation is generated by an inertia force caused by acceleration or deceleration of the trolley 4 and acting on the suspended payload 9. The inertia force exerts sway at an angular frequency ω expressed as follows:

[Expression 9]

$$\omega r = \sqrt{\frac{g}{L}}$$

[0082] This payload sway can be suppressed by payload sway suppression control to remove the frequency component of angular frequency ωr from the speed command value for the trolley 4, as provided in WO 2018/211739 A (hereinafter, the known art), for example.

[0083] However, this known art predetermines the wire length L_w or reads out a recorded value; it does not disclose a method of automatically acquiring the wire length L_w depending on the wires 8 in use. The foregoing calculation enables automatic acquisition of the wire length L_w , improving the performance to suppress the payload sway in transporting a payload.

Effect of Modified Example 1

[0084] The foregoing calculation also enables automatic acquisition of the height H from the payload 9 to the trolley 4. Hence, the limit in unwinding (paying out) the rope 6 can be automatically determined; the payload can prevent inadvertent impact onto the ground or unhook from slack wires caused by excessive unwinding, increasing the safeness of the crane 1.

EMBODIMENT 2

[0085] Described next is a crane 1 in Embodiment 2 of this invention. The repetitive description of the points in common with the foregoing embodiment is omitted here. The configurations of the crane 1 and the control device 100 are the same as those in Embodiment 1.

[0086] The crane 1 in Embodiment 1 identifies the payload location using the distance between the trolley 4 and the payload 9 (the length of the rope 6 including the length of the wires 8) as a state value. In this regard, a hook 7 is attached at the end of the rope 6 drooping from the trolley 4 to hang the payload 9 with the wires 8, as illustrated in FIG. 1.

[0087] Although the distance from the trolley 4 to the hook 7 or the length of the rope 6 can be detected with the encoder attached on the hoisting device 5, the crane 1 does not usually equip a device for directly detecting the distance from the hook 7 to the payload 9 or the length of the wires 8. Accordingly, this embodiment regards the length of the wires 8 as an unknown to identify the payload location x_p (y_p).

[0088] Letting $L_r(i)$ be the rope length, L_w be the wire length, $x(i)$ be the position of the trolley 4, x_p be the payload location, and H be the height from the payload 9 to the trolley 4, these have a relation as expressed by the following Expression (9):
[Expression 10]

$$L_r(i) + L_w = \sqrt{H^2 + (x(i) - x_p)^2} \quad \dots (9)$$

[0089] The following Expression (10) can be obtained by squaring the both members of Expression (9):
[Expression 11]

$$x(i)^2 - 2x_p \times x(i) + x_p^2 - L_r(i)^2 - 2L_r(i) \times L_w - L_w^2 + H^2 = 0 \quad \dots (10)$$

[0090] Letting p_1 , p_2 , and p_3 be the parameters including the wire length L_w , the height H , and the payload location x_p , the following Expression (11) is obtained:
[Expression 12]

$$x(i)^2 - L_r(i)^2 + p_1 \times x(i) + p_2 \times L_r(i) + p_3 = 0 \quad \dots (11)$$

[0091] The control device 100 transversely moves the trolley 4 and measures at least three different trolley positions $x(i)$ and the rope lengths $Lr(i)$ of the taut rope 6 there and fits the acquired trolley positions $x(i)$ and rope lengths $Lr(i)$ to the foregoing Expression (11) by the method of least squares to calculate the parameters $p1$, $p2$, and $p3$. Then, the payload location x_p of the payload 9 in the transverse direction can be calculated by the following Expression (12) with the calculated parameters:
[Expression 13]

$$x_p = \frac{-p_1}{2} \quad \dots (12)$$

[0092] In similar, the control device 100 measures at least three different girder positions $y(i)$ in the traveling direction and the rope lengths $Lr(i)$ there. Then, the control device 100 can calculate the payload location y_p of the payload 9 in the traveling direction where the rope length Lr takes a minimum value when the girder 3 is moved in the traveling direction.

[0093] The control device 100 can eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9 by moving the trolley 4 and the girder 3 to the calculated payload location (x_p, y_p) and as a result, the initial sway is reduced.

[0094] The above-described method enables the location of the payload 9 to be identified, even if the distance from the hook 7 to the payload 9 or the wire length Lw is unknown.

Modified Example 2

[0095] Focusing on the coefficients of the rope length $Lr(i)$ in the foregoing Expressions (10) and (11), the wire length Lw can be calculated by the following Expression (13):
[Expression 14]

$$Lw = \frac{-p_2}{2} \quad \dots (13)$$

[0096] Focusing on the constant terms of the Expressions (10) and (11), the height H can be calculated by the following Expression (14):
[Expression 15]

$$H = \sqrt{p_3 - x_p^2 + Lw^2} \quad \dots (14)$$

[0097] The wire length Lw can also be calculated by the aforementioned Expression (8) with the calculated height H and the rope length Lr ($x = x_p$) of the taut rope 6 from the trolley 4 positioned directly above the payload 9 to the hook 7.

[0098] The above-described method enables automatic acquisition of the wire length Lw , which improves the payload sway suppression control in transporting a payload. Further, automatic acquisition of the height H is also available; the safeness of the crane 1 can be increased by automatically determining the limit in unwinding the rope 6.

EMBODIMENT 3

[0099] Described next is a crane 1 in Embodiment 3 of this invention. The repetitive description of the points in common with the foregoing embodiments is omitted here.

[0100] FIG. 14 illustrates a configuration of the control device of the crane 1 in Embodiment 3. The configurations same as those in the foregoing Embodiment 1 are assigned same reference signs and repetitive description thereof is omitted here. FIG. 14 includes a force sensor 4a (fourth sensor) on the trolley 4 to detect the force transversely acting on the trolley 4, a tension sensor 5b (third sensor) on the hoisting device 5 to detect the tension of the rope 6, and a sway angle sensor 7a (second sensor) on the hook 7 to detect the angle of the rope 6, in addition to the configuration in the foregoing Embodiment 1. Furthermore, the control device 100 additionally includes a horizontal force detector 301 (another implementation means of the fourth sensor) for detecting the transversal force applied to the trolley 4 and a tension detector 311 (another implementation means of the third sensor) for measuring the tension of the rope 6.

[0101] FIG. 12 illustrates the movement of the crane 1 in Embodiment 3. The crane 1 in this Embodiment 3 detects the angle (rope sway angle) of the rope 6 in a taut state with respect to the vertical direction of the trolley 4 with the sway

angle sensor 7a and uses the rope sway angle as a state value to identify the payload location.

[0102] The rope sway angle can be detected with the encoder by detecting the angle of a weight hanging from the hook 7 as described in the aforementioned Patent Document 1 or with a gyrosensor attached on the hook 7.

[0103] Letting $\theta(i)$ be the rope sway angle, $x(i)$ be the position of the trolley 4, x_p (or y_p) be the location of the payload 9, and H be the height from the payload 9 to the trolley 4, these have a relation expressed by the following Expression (15):
[Expression 16]

$$x(i) - x_p = H \times \tan\theta(i) \quad \dots (15)$$

[0104] Letting p_1 and p_2 be the parameters including the height H and the payload location x_p , the following Expression (16) is obtained:

[Expression 17]

$$x(i) + p_1 \times \tan\theta(i) + p_2 = 0 \quad \dots (16)$$

[0105] The control device 100 transversely moves the trolley 4 and measures at least two different trolley positions $x(i)$ and the rope sway angles $\theta(i)$ there and fits the acquired trolley positions $x(i)$ and rope sway angles $\theta(i)$ to the foregoing Expression (16) by the method of least squares to calculate the parameters p_1 and p_2 .

[0106] The control device 100 can calculate the trolley position where the rope sway angle takes a minimum value or the location of the payload 9 in the transverse direction, using the following Expression (17) with the calculated parameters p_1 and p_2 :

[Expression 18]

$$x_p = -p_2 \quad \dots (17)$$

[0107] In similar, the control device 100 measures at least two different girder positions $y(i)$ in the traveling direction of the girder 3 and the rope sway angles $\theta(i)$ there. Then, the control device 100 can calculate the payload location y_p of the payload 9 in the traveling direction where the rope sway angle takes a minimum value when the girder 3 is moved in the traveling direction.

[0108] The acquired location (x_p, y_p) is the location of the payload; the control device 100 can eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9 by moving the trolley 4 and the girder 3 to this calculated payload location, and as a result, the initial sway is reduced.

[0109] The above-described method enables the location of the payload 9 to be identified, using the sway angle θ of a taut rope 6 as a state value.

Modified Example 3

[0110] Focusing on the coefficient of $\tan\theta$ in the foregoing Expressions (15) and (16), the height H can be calculated by the following Expression (18):

[Expression 19]

$$H = -p_1 \quad \dots (18)$$

[0111] The control device 100 can calculate the wire length L_w by the aforementioned Expression (8) with the calculated height H and the rope length L_r ($x = x_p$) of the taut rope 6 from the trolley 4 positioned directly above the payload 9 to the hook 7.

[0112] The above-described method enables automatic acquisition of the wire length L_w , which improves the payload sway suppression control in transporting a payload. Further, automatic acquisition of the height H is also available; the safeness of the crane 1 can be increased by automatically determining the limit in unwinding the rope 6.

EMBODIMENT 4

[0113] Described next is a crane 1 in Embodiment 4 of this invention. The repetitive description of the points in common with the foregoing embodiments is omitted here. The configurations of the crane 1 and the control device 100 are the same as those in Embodiment 3 illustrated in FIG. 14.

[0114] FIG. 13 illustrates the movement of the crane 1 in Embodiment 4. The crane 1 in this embodiment uses the tension of the taut rope 6 and the force horizontally acting on the trolley 4 as state values to identify the payload location.

[0115] The tension of the rope 6 can be detected by the tension sensor 5b attached on the hoisting device 5 or the tension detector 311 that calculates the tension of the rope 6 from the current value of the hoist motor acquired from the hoist motor controller 310.

[0116] The force horizontally acting on the trolley 4 can be detected by the force sensor 4a or the horizontal force detector 301 that detects the motor current when the trolley 4 keeps a horizontal position in a transverse direction.

[0117] Letting $T(i)$ be the tension of the rope 6, $F(i)$ be the force horizontally acting on the trolley 4, $x(i)$ be the position of the trolley, x_p (or y_p) be the location of the payload 9, and H be the height from the payload 9 to the trolley 4, these have relations expressed by the following Expressions (19) and (20):

[Expression 20]

$$\theta(i) = \arcsin\left(\frac{F(i)}{T(i)}\right) \quad \dots (19)$$

$$x(i) - x_p = H \times \tan\theta(i) \quad \dots (20)$$

[0118] Letting p_1 and p_2 be the parameters including the height H and the payload location x_p , the following Expression (21) is obtained:

[Expression 21]

$$x(i) + p_1 \times \tan\theta(i) + p_2 = 0 \quad \dots (21)$$

[0119] The control device 100 transversely moves the trolley 4 and measures at least two different trolley positions $x(i)$ and the tensions $T(i)$ of the rope 6 and the forces $F(i)$ horizontally acting on the trolley 4 there and fits the acquired trolley positions $x(i)$, tensions $T(i)$, and forces $F(i)$ to the foregoing Expression (21) by the method of least squares to calculate the parameters p_1 and p_2 .

[0120] Then, the control device 100 can calculate the position x_p of the trolley 4 where the rope sway angle $\theta(i)$ takes a minimum value or the location x_p of the payload 9 in the transverse direction, using the following Expression (22) with the calculated parameters p_1 and p_2 :

[Expression 22]

$$x_p = -p_2 \quad \dots (22)$$

[0121] In similar, the control device 100 measures at least two different girder positions $y(i)$ in the traveling direction of the girder 3 and the tensions $T(i)$ of the rope 6 and the forces $F(i)$ horizontally acting on the trolley 4 there to calculate the payload location y_p of the payload 9 in the traveling direction where the rope sway angle $\theta(i)$ takes a minimum value when the girder 3 is moved in the traveling direction.

[0122] The control device 100 can eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9 by moving the trolley 4 and the girder 3 to the calculated payload location (x_p , y_p), and as a result, the initial sway is reduced.

[0123] The above-described method enables the location of the payload 9 to be identified, using the tension of the rope 6 and the force horizontally acting on the trolley 4 as state values.

Modified Example 4

[0124] The crane 1 in this Modified Example 4 can also identify the wire length L_w and the height H in the same way as the crane 1 in Modified Example 3. Automatic acquisition of the wire length L_w enables improvement in payload sway suppression control in transporting a payload and automatic acquisition of the height H enables increase in safeness of the crane 1 because automatic determination of the limit in unwinding the rope 6 is available.

EMBODIMENT 5

[0125] Described next is a crane 1 in Embodiment 5 of this invention. The repetitive description of the points in common with the foregoing embodiments is omitted here. The configurations of the crane 1 and the control device 100 are the same as those in Embodiment 3 illustrated in FIG. 14.

[0126] The crane 1 in Embodiment 5 pays out the rope 6 before moving the trolley 4 to prevent the payload 9 from being lifted or dragged, in the case where the payload 9 is grounded. The control device 100 uses the time taken to wind up the rope 6 from the paid-out state to a taut state as a state value to identify the payload location.

[0127] Letting $L_f(i)$ be the paid-out length of the rope 6, $T_f(i)$ be the time taken to wind up the rope 6 into a taut state, V be the winding speed, L_0 be the rope length when the rope 6 is first wound up to a taut state, $x(i)$ be the position of the trolley 4, and x_p be the location of the payload 9, these have relations expressed by Expressions (23) and (24) below. The winding speed V can be calculated by the control device 100 from the time T_f taken to wind up the rope 6 into a taut state and the variation of the rope length L_0 when the rope 6 is wound up to the taut state. The time T_f taken to wind up the rope 6 into a taut state can be measured with a timer included in the control device 100. The rope length L_0 can be measured with the encoder 5a, like in the above-described Embodiment 1.

[Expression 23]

$$dL(i) = L_f(i) - V \times T_f(i) \quad \dots (23)$$

$$L_0 + dL(i) = \sqrt{H^2 + (x(i) - x_p)^2} \quad \dots (24)$$

[0128] The following Expression (25) can be obtained by squaring the both members of Expression (24):
[Expression 24]

$$x(i)^2 - 2x_p \times x(i) + x_p^2 - L_0^2 - 2L_0 \times dL(i) - dL(i)^2 + H^2 = 0 \quad \dots (25)$$

[0129] Letting p_1 , p_2 , and p_3 be the parameters including the rope length L_0 , the height H , and the payload location x_p , the following Expression (26) is obtained:
[Expression 25]

$$x(i)^2 - dL(i)^2 + p_1 \times x(i) + p_2 \times dL(i) + p_3 = 0 \quad \dots (26)$$

[0130] The control device 100 transversely moves the trolley 4 and measures at least three different trolley positions $x(i)$ and the lengths $L_f(i)$ of the rope 6 paid out before moving the trolley 4 and the times $T_f(i)$ taken to wind up the rope into a taut state there and fits the acquired trolley positions $x(i)$, paid-out lengths $L_f(i)$, and winding times $T_f(i)$ to the foregoing Expression (25) by the method of least squares to calculate the parameters p_1 , p_2 , and p_3 . Then, the control device 100 can calculate the trolley position where dL takes a maximum value or the location of the payload 9 in the transverse direction, using the following Expression (27) with the calculated parameters:
[Expression 26]

$$x_p = \frac{-p_1}{2} \quad \dots (27)$$

[0131] In similar, the control device 100 measures at least three different girder positions $y(i)$ in the traveling direction of the girder 3 and the lengths $Lf(i)$ of the rope 6 paid out before moving the girder 3 and the times $Tf(i)$ taken to wind up the rope into a taut state there to calculate the payload location yp of the payload 9 in the traveling direction where dL takes a maximum value when the girder 3 is moved in the traveling direction.

[0132] The control device 100 can eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9 by moving the trolley 4 and the girder 3 to the calculated payload location (xp, yp) , and as a result, the initial sway is reduced.

[0133] The above-described method enables the location of the payload 9 to be identified, using the length of the rope 6 paid out before moving the trolley 4 and the time taken to wind up the rope 6 into a taut state as state values.

Modified Example 5

[0134] Focusing on the coefficient of the $dL(i)$ and the constant terms in the foregoing Expressions (24) and (25), the height H can be calculated by the following Expressions (28) and (29):

[Expression 27]

$$L0 = \frac{-p^2}{2} \quad \dots (28)$$

$$H = \sqrt{p^3 - xp^2 + L0^2} = \sqrt{p^3 - xp^2 + \left(\frac{p^2}{2}\right)^2} \quad \dots (29)$$

[0135] The control device 100 can calculate the wire length Lw by the aforementioned Expression (8) with the calculated height H and the rope length Lr ($x = xp$) of the taut rope 6 from the trolley 4 positioned directly above the payload 9 to the hook 7.

[0136] The above-described method enables automatic acquisition of the wire length Lw , which improves the payload sway suppression control in transporting a payload. Further, automatic acquisition of the height H is also available; the safeness of the crane 1 can be increased by automatically determining the limit in unwinding the rope 6.

[0137] As described in the foregoing Embodiments 1 to 5, this invention is generally effective for cranes 1 capable of horizontally transporting a payload 9 and is applicable to not only a crane 1 (such as an overhead crane) for transporting a payload in the transverse direction and the traveling direction with a trolley 4 and a girder 3 but also a crane (such as an unloader) for transporting a load only in either the transverse direction or the traveling direction. That is to say, the term "crane" referred to in the subsequent description includes any kinds of cranes capable of horizontally transporting a payload 9.

[0138] The payload (hooked payload) to be transported by the crane 1 is hung by a rope 6 or a chain in transportation. The hanging member (or sling member) used in this invention is not limited to a specific one, even in terms of its material or shape, as far as it can be used to hang a payload.

[0139] Accordingly, the term "rope" is used as a generic term for referring to a hanging member (sling member) for hanging a payload, as already stated. That is to say, the term "rope" includes not only a so-called rope but also chain, belt, wire, cable, band, cord, and the like.

CLOSING

[0140] As set forth above, claims based on the above-described embodiments can be configured as follows.

[0141]

(1) A crane comprising a horizontal transport device (trolley 4) horizontally movable with a motor, a hoisting device (5) mounted on the horizontal transport device (4) and being capable of winding a rope (6) with a hoist motor, a hook (7) attached on the rope (6) to hang a payload (9), and a control unit (control device 100) including a processor (MPU 101) and a memory (102) and being configured to control the horizontal transport device (4) and the hoisting device (5), wherein the control unit (100) includes a rope tension determination unit (21) configured to determine whether the rope (6) is in a taut state without a slack, a state measurement unit (22) configured to measure at least one state value of the crane when the rope (6) has been wound up into a taut state by the hoisting device (5) being driven, and a transport control unit (24) configured to move the horizontal transport device (4); the state measurement unit (22) is configured to identify a payload (9) location of a grounded payload (9), using a position of the horizontal

transport device (4) and the at least one state value measured when the rope (6) is in a taut state; and the transport control unit (24) is configured to move the horizontal transport device (4) to the identified payload (9) location to position the rope (6) directly above the payload (9).

The above-described configuration enables the control device 100 to determine the location of the payload 9 more precisely by fitting the trolley positions $x(1)$ and $x(2)$ and the lengths $L(1)$ and $L(2)$ of the taut rope to the quadratic curve in FIG. 8, attaining a smaller positional deviation.

(2) The crane according to the foregoing (1), wherein the at least one state value is a distance L from the horizontal transport device (4) to the payload (9) when the rope (6) has been wound up into a taut state; and the state measurement unit is configured to measure the position x of the horizontal transport device (4) and the distance L from the horizontal transport device (4) to the payload (9) with a first sensor (encoder 5a) attached on the horizontal transport device (4) at least two points in a moving direction, calculate parameters $p1$ and $p2$ in $x^2 - L^2 + p1 \times x + p2 = 0$ with results of the measurement, and calculate a position x of the horizontal transport device (4) at which the distance L takes a minimum value as the payload (9) location x_p , using the calculated parameters $p1$ and $p2$.

The above-described configuration enables the control device 100 in Embodiment 1 to require straining the rope 6 by the hoisting device 5 winding up, measuring the rope length L , and moving the trolley 4 (or the girder 3) for at least two times in each of the transverse direction and the traveling direction, achieving a smaller number of repeats. Accordingly, the operating time of the trolley 4 before hoisting the grounded payload can be reduced, enabling the hoisting operation to start sooner.

(3) The crane according to the foregoing (1), wherein the rope (6) is connected to the hook (7) at an end and the hook (7) is connected to a sling member to hang the payload (9); the at least one state value is a rope (6) length when the rope (6) has been wound up into a taut state; and the state measurement unit (22) is configured to measure the position x of the horizontal transport device (4) and the rope (6) length L_r with a first sensor (5a) attached on the horizontal transport device (4) at least three points in a moving direction, calculate parameters $p1$, $p2$, and $p3$ in $x^2 - L_r^2 + p1 \times x + p2 \times L_r + p3 = 0$ with results of the measurement, and calculate a position x of the horizontal transport device (4) at which the rope (6) length L_r takes a minimum value as the payload (9) location x_p , using the calculated parameters $p1$, $p2$, and $p3$.

The above-described configuration enables the control device 100 to automatically acquire the wire length L_w , so that the control device 100 can identify the location of the payload 9 even if the distance from the hook 7 to the payload 9 or the distance including the wire length L_w is unknown.

(4) The crane according to the foregoing (1), wherein the at least one state value is a sway angle (θ) of the rope (6) with respect to the horizontal transport device (4) when the rope (6) has been wound up into a taut state; and the state measurement unit (22) is configured to measure the position x of the horizontal transport device (4) and the sway angle θ of the rope (6) with a second sensor (sway angle sensor 7a) attached on the horizontal transport device (4) at least two points in a moving direction, calculate parameters $p1$ and $p2$ in $x + p1 \times \tan\theta + p2 = 0$ with results of the measurement, and calculate a position x of the horizontal transport device (4) at which the sway angle θ takes a minimum value as the payload (9) location x_p , using the calculated parameters $p1$ and $p2$.

The above-described configuration enables the control device 100 to identify the location of the payload 9 using the sway angle θ of the rope 6 in a taut state as a state value and eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9 by moving the trolley 4 and the girder 3 to the calculated payload location, so that the initial sway is reduced.

(5) The crane according to the foregoing (1), wherein the at least one state value comprises a tension T of the rope (6) and a force F horizontally acting on the horizontal transport device (4) when the rope (6) has been wound up into a taut state; and the state measurement unit (22) is configured to measure the position x of the horizontal transport device (4) and the tension T of the rope (6) with a third sensor (tension sensor 5b) attached on the hoisting device (5) and the horizontally acting force F with a fourth sensor (horizontal force detector 301) attached on the horizontal transport device (4) at least two points in a moving direction, calculate a sway angle θ of the rope (6) and parameters $p1$ and $p2$ in $x + p1 \times \tan\theta + p2 = 0$ using $\theta = \arcsin(F/T)$ and results of the measurement, and calculate a position x of the horizontal transport device (4) at which the sway angle θ takes a minimum value as the payload (9) location x_p , using the calculated parameters $p1$ and $p2$.

The above-described configuration enables the control device 100 to identify the location of the payload 9 using the tension of the rope 6 and the force horizontally acting on the trolley 4 as state values and eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9, so that the initial sway is reduced.

(6) The crane according to the foregoing (1), wherein the at least one state value comprises a length L_f of the rope (6) paid out before moving the horizontal transport device (4) and a time T_f taken to wind up the rope (6) into a taut state; and the state measurement unit (22) is configured to measure the position x of the horizontal transport device (4), the paid-out length L_f of the rope (6), and the time T_f taken to wind up the rope (6) into a taut state at least three points in a moving direction, calculate a rope (6) winding speed V from variations t in the paid-out length L_f of the rope (6) and the times T_f taken to wind up the rope into a taut state, calculate parameters $p1$, $p2$, and $p3$ in $x^2 - dL^2$

+ $p_1 \times x + p_2 \times dL + p_3 = 0$ using $dL = L_f - V \times T_f$ and results of the measurement, and calculate a position x of the horizontal transport device (4) at which dL takes a minimum value as the payload (9) location x_p , using the calculated parameters p_1 , p_2 , and p_3 .

The above-described configuration enables the control device 100 to identify the location of the payload 9 using the length of the rope 6 paid out before moving the trolley 4 and the time taken to wind up the rope 6 into a taut state as state values and eliminate the horizontal positional deviations of the trolley 4 and the girder 3 from the payload 9 by moving the trolley 4 and the girder 3 to the calculated payload location (x_p , y_p), so that the initial sway is reduced. (7) The crane according to any one of the foregoing (1) to (6), wherein the state measurement unit (22) is configured to identify a height H from the payload (9) to the horizontal transport device (4) based on the at least one state value and the position x of the horizontal transport device (4).

The above-described configuration enables the control device 100 to automatically acquire the height H from the payload 9 to the trolley 4. Hence, the limit in unwinding the rope 6 can be automatically determined; the payload can prevent inadvertent impact onto the ground or unhook from slack wires caused by excessive unwinding, increasing the safeness of the crane 1.

(8) The crane according to the foregoing (7), wherein the state measurement unit (22) is configured to identify the height H from the payload (9) to the horizontal transport device (4) based on the at least one state value and the position x of the horizontal transport device (4) and identify a length L_w of a sling member from a length L_r of the rope (6) and the height H .

The above-described configuration enables the control device 100 to automatically acquire the wire length L_w , improving the payload sway suppression control in transporting a payload. Further, automatic acquisition of the height H is also available.

(9) The crane according to the foregoing (3), wherein the state measurement unit (22) is configured to identify a length L_w of the sling member based on the at least one state value and the position x of the horizontal transport device (4).

[0142] The above-described configuration enables the control device 100 to automatically acquire the wire length L_w , improving the payload sway suppression control in transporting a payload.

[0143] This invention is not limited to the embodiments described above, and encompasses various modification examples. For instance, the embodiments are described in detail for easier understanding of this invention, and this invention is not limited to modes that have all of the described components. Some components of one embodiment can be replaced with components of another embodiment, and components of one embodiment may be added to components of another embodiment. In each embodiment, other components may be added to, deleted from, or replace some components of the embodiment, and the addition, deletion, and the replacement may be applied alone or in combination.

[0144] Some of all of the components, functions, processing units, and processing means described above may be implemented by hardware by, for example, designing the components, the functions, and the like as an integrated circuit. The components, functions, and the like described above may also be implemented by software by a processor interpreting and executing programs that implement their respective functions. Programs, tables, files, and other types of information for implementing the functions can be put in a memory, in a storage apparatus such as a hard disk, or a solid state drive (SSD), or on a recording medium such as an IC card, an SD card, or a DVD.

[0145] The control lines and information lines described are lines that are deemed necessary for the description of this invention, and not all of control lines and information lines of a product are mentioned. In actuality, it can be considered that almost all components are coupled to one another.

Claims

1. A crane comprising:

a horizontal transport device horizontally movable with a motor;
a hoisting device mounted on the horizontal transport device, the hoisting device being capable of winding a rope with a hoist motor;
a hook attached on the rope to hang a payload; and
a control unit including a processor and a memory, the control unit being configured to control the horizontal transport device and the hoisting device,
wherein the control unit includes:

a rope tension determination unit configured to determine whether the rope is in a taut state without a slack;
a state measurement unit configured to measure at least one state value of the crane when the rope has

been wound up into a taut state by the hoisting device being driven; and
a transport control unit configured to move the horizontal transport device,

wherein the state measurement unit is configured to identify a payload location x_p of a grounded payload, using
a position x of the horizontal transport device and the at least one state value measured when the rope is in a
taut state, and

wherein the transport control unit is configured to move the horizontal transport device to the identified payload
location x_p to position the rope directly above the payload.

2. The crane according to claim 1,

wherein the at least one state value is a distance L from the horizontal transport device to the payload when
the rope has been wound up into a taut state, and
wherein the state measurement unit is configured to:

measure the position x of the horizontal transport device and the distance L from the horizontal transport
device to the payload with a first sensor attached on the horizontal transport device at least two points in
a moving direction; and

calculate parameters p_1 and p_2 in $x^2 - L^2 + p_1 \times x + p_2 = 0$ with results of the measurement and calculate
a position x of the horizontal transport device at which the distance L takes a minimum value as the payload
location x_p , using the calculated parameters p_1 and p_2 .

3. The crane according to claim 1,

wherein the rope is connected to the hook at an end and the hook is connected to a sling member to hang the
payload,

wherein the at least one state value is a rope length L_r when the rope has been wound up into a taut state, and
wherein the state measurement unit is configured to:

measure the position x of the horizontal transport device and the rope length L_r with a first sensor attached
on the horizontal transport device at least three points in a moving direction; and

calculate parameters p_1 , p_2 , and p_3 in $x^2 - L_r^2 + p_1 \times x + p_2 \times L_r + p_3 = 0$ with results of the measurement
and calculate a position x of the horizontal transport device at which the rope length L_r takes a minimum
value as the payload location x_p , using the calculated parameters p_1 , p_2 , and p_3 .

4. The crane according to claim 1,

wherein the at least one state value is a sway angle θ of the rope with respect to the horizontal transport device
when the rope has been wound up into a taut state, and

wherein the state measurement unit is configured to:

measure the position x of the horizontal transport device and the sway angle θ of the rope with a second
sensor attached on the horizontal transport device at least two points in a moving direction; and

calculate parameters p_1 and p_2 in $x + p_1 \times \tan\theta + p_2 = 0$ with results of the measurement and calculate
a position x of the horizontal transport device at which the sway angle θ takes a minimum value as the
payload location x_p , using the calculated parameters p_1 and p_2 .

5. The crane according to claim 1,

wherein the at least one state value comprises a tension T of the rope and a force F horizontally acting on the
horizontal transport device when the rope has been wound up into a taut state, and

wherein the state measurement unit is configured to:

measure the position x of the horizontal transport device and the tension T of the rope with a third sensor
attached on the horizontal transport device and the horizontally acting force F with a fourth sensor attached
on the horizontal transport device at least two points in a moving direction; and

calculate sway angles θ of the rope and parameters p_1 and p_2 in $x + p_1 \times \tan\theta + p_2 = 0$ using $\theta = \arcsin(F/T)$
and results of the measurement and calculate a position x of the horizontal transport device at which the

sway angle θ takes a minimum value as the payload location x_p , using the calculated parameters p_1 and p_2 .

6. The crane according to claim 1,

wherein the at least one state value comprises a length L_f of the rope paid out before moving the horizontal transport device and a time T_f taken to wind up the rope into a taut state, and wherein the state measurement unit is configured to:

measure the position x of the horizontal transport device, the paid-out length L_f of the rope, and the time T_f taken to wind up the rope into a taut state at least three points in a moving direction and calculate a rope winding speed V from variations t in the paid-out length L_f of the rope and the times T_f taken to wind up the rope into a taut state; and

calculate parameters p_1 , p_2 , and p_3 in $x^2 - dL^2 + p_1 \times x + p_2 \times dL + p_3 = 0$ using $dL = L_f - V \times T_f$ and results of the measurement and calculate a position x of the horizontal transport device at which dL takes a minimum value as the payload location x_p , using the calculated parameters p_1 , p_2 , and p_3 .

7. The crane according to any one of claims 1 to 6, wherein the state measurement unit is configured to identify a height H from the payload to the horizontal transport device based on the at least one state value and the position x of the horizontal transport device.

8. The crane according to claim 7, wherein the state measurement unit is configured to identify the height H from the payload to the horizontal transport device based on the at least one state value and the position x of the horizontal transport device and identify a length L_w of a sling member from a rope length L_r and the height H .

9. The crane according to claim 3, wherein the state measurement unit is configured to identify a length L_w of the sling member based on the at least one state value and the position x of the horizontal transport device.

10. A method of controlling a crane including a horizontal transport device horizontally movable with a motor, a hoisting device mounted on the horizontal transport device and being capable of winding a rope with a hoist motor, a hook attached on the rope to hang a payload, and a control unit including a processor and a memory and configured to control the horizontal transport device and the hoisting device,

the method comprising:

a rope tension determination step of determining, by the control unit, whether the rope is in a taut state without a slack;
a state measurement step of measuring, by the control unit, at least one state value of the crane when the rope has been wound up into a taut state by the hoisting device being driven; and
a transport control step of moving, by the control unit, the horizontal transport device,

wherein the state measurement step includes identifying a payload location x_p of a grounded payload using a position x of the horizontal transport device and the at least one state value measured when the rope is in a taut state, and

wherein the transport control step includes moving the horizontal transport device to the identified payload location x_p to position the rope directly above the payload.

11. The method of controlling the crane according to claim 10,

wherein the at least one state value is a distance L from the horizontal transport device to the payload when the rope has been wound up into a taut state, and wherein the state measurement step includes:

measuring the position x of the horizontal transport device and the distance L from the horizontal transport device to the payload with a first sensor attached on the horizontal transport device at least two points in a moving direction; and

calculating parameters p_1 and p_2 in $x^2 - L^2 + p_1 \times x + p_2 = 0$ with results of the measurement and calculating a position x of the horizontal transport device at which the distance L takes a minimum value as the payload location x_p , using the calculated parameters p_1 and p_2 .

12. The method of controlling the crane according to claim 10,

wherein the rope is connected to the hook at an end and the hook is connected to a sling member to hang the payload,

wherein the at least one state value is a rope length L_r when the rope has been wound up into a taut state, and wherein the state measurement step includes:

measuring the position x of the horizontal transport device and the rope length L_r with a first sensor attached on the horizontal transport device at least three points in a moving direction; and calculating parameters p_1 , p_2 , and p_3 in $x^2 - L_r^2 + p_1 \times x + p_2 \times L_r + p_3 = 0$ with results of the measurement and calculating a position x of the horizontal transport device at which the rope length L_r takes a minimum value as the payload location x_p , using the calculated parameters p_1 , p_2 , and p_3 .

13. The method of controlling the crane according to claim 10,

wherein the at least one state value is a sway angle θ of the rope with respect to the horizontal transport device when the rope has been wound up into a taut state, and wherein the state measurement step includes:

measuring the position x of the horizontal transport device and the sway angle θ of the rope with a second sensor attached on the horizontal transport device at least two points in a moving direction; and calculating parameters p_1 and p_2 in $x + p_1 \times \tan\theta + p_2 = 0$ with results of the measurement and calculating a position x of the horizontal transport device at which the sway angle θ takes a minimum value as the payload location x_p , using the calculated parameters p_1 and p_2 .

14. The method of controlling the crane according to claim 10,

wherein the at least one state value comprises a tension T of the rope and a force F horizontally acting on the horizontal transport device when the rope has been wound up into a taut state, and

wherein the state measurement step includes:

measuring the position x of the horizontal transport device and the tension T of the rope with a third sensor attached on the horizontal transport device and the horizontally acting force F with a fourth sensor attached on the horizontal transport device at least two points in a moving direction; and calculating a sway angle θ of the rope and parameters p_1 and p_2 in $x + p_1 \times \tan\theta + p_2 = 0$ using $\theta = \arcsin(F/T)$ and results of the measurement, and calculating a position x of the horizontal transport device at which the sway angle θ takes a minimum value as the payload location x_p , using the calculated parameters p_1 and p_2 .

15. The method of controlling the crane according to claim 10,

wherein the at least one state value comprises a length L_f of the rope paid out before moving the horizontal transport device and a time T_f taken to wind up the rope into a taut state, and

wherein the state measurement step includes:

measuring the position x of the horizontal transport device, the paid-out length L_f of the rope, and the time T_f taken to wind up the rope into a taut state at least three points in a moving direction and calculating a rope winding speed V from variations t in the paid-out length L_f of the rope and the times T_f taken to wind up the rope into a taut state; and calculating parameters p_1 , p_2 , and p_3 in $x^2 - dL^2 + p_1 \times x + p_2 \times dL + p_3 = 0$ using $dL = L_f - V \times T_f$ and results of the measurement and calculating a position x of the horizontal transport device at which dL takes a minimum value as the payload location x_p , using the calculated parameters p_1 , p_2 , and p_3 .

16. The method of controlling the crane according to any one of claims 10 to 15, wherein the state measurement step includes identifying a height H from the payload to the horizontal transport device based on the at least one state value and the position x of the horizontal transport device.

17. The method of controlling the crane according to claim 16, wherein the state measurement step includes:

identifying the height H from the payload to the horizontal transport device based on the at least one state value and the position x of the horizontal transport device and identifying a length L_w of a sling member from a rope length L_r and the height H .

- 5 **18.** The method of controlling the crane according to claim 12, wherein the state measurement step includes:
identifying a length L_w of the sling member based on the at least one state value and the position x of the horizontal
transport device.

10

15

20

25

30

35

40

45

50

55

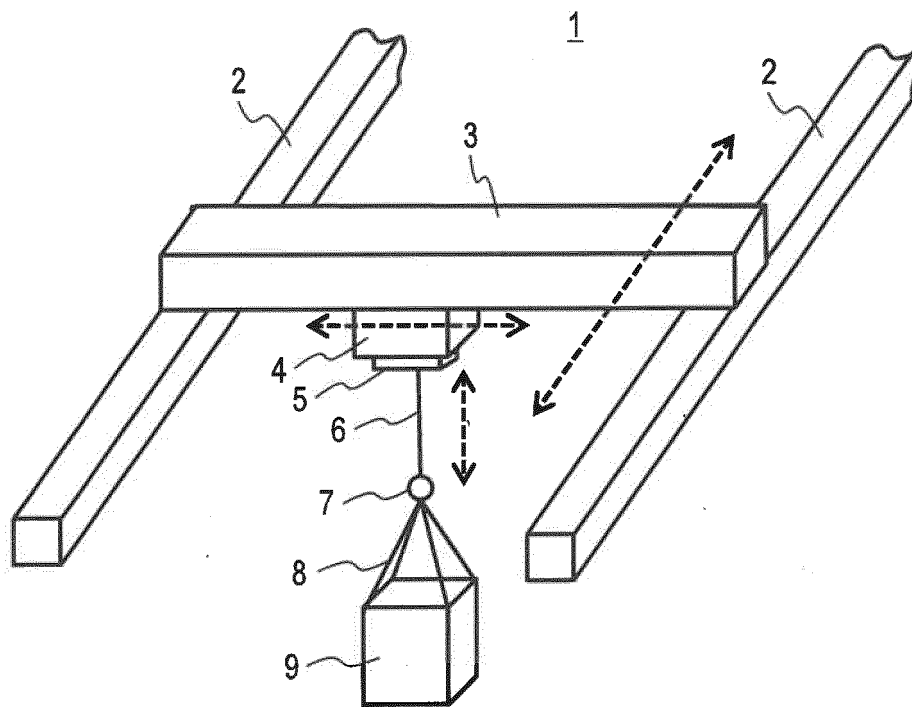


FIG.1

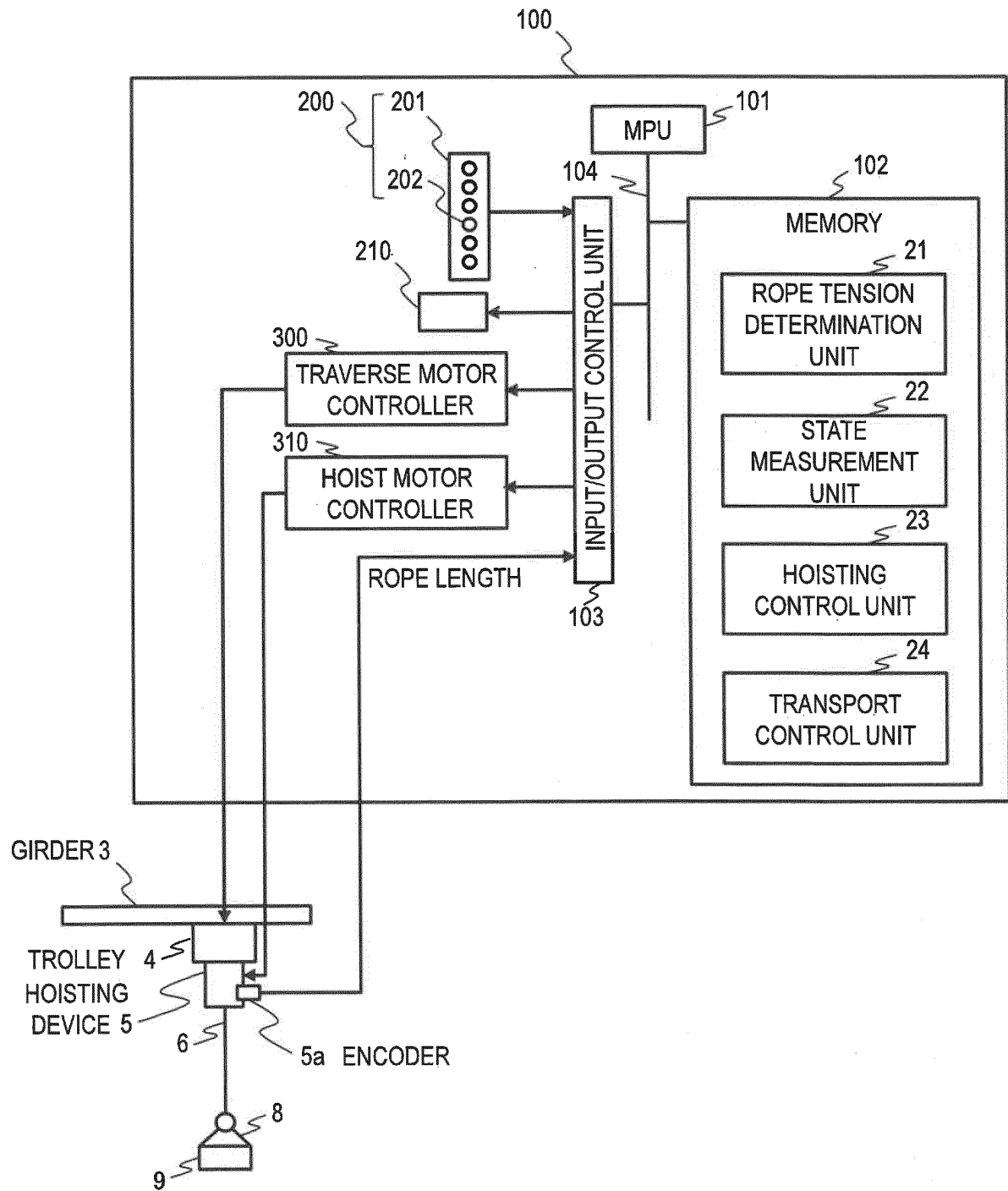
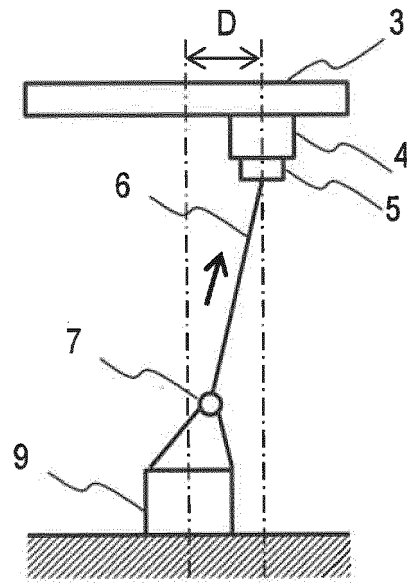
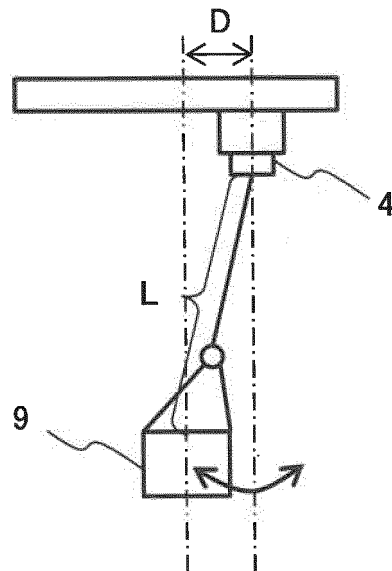


FIG.2



(a)

FIG. 3A



(b)

FIG. 3B

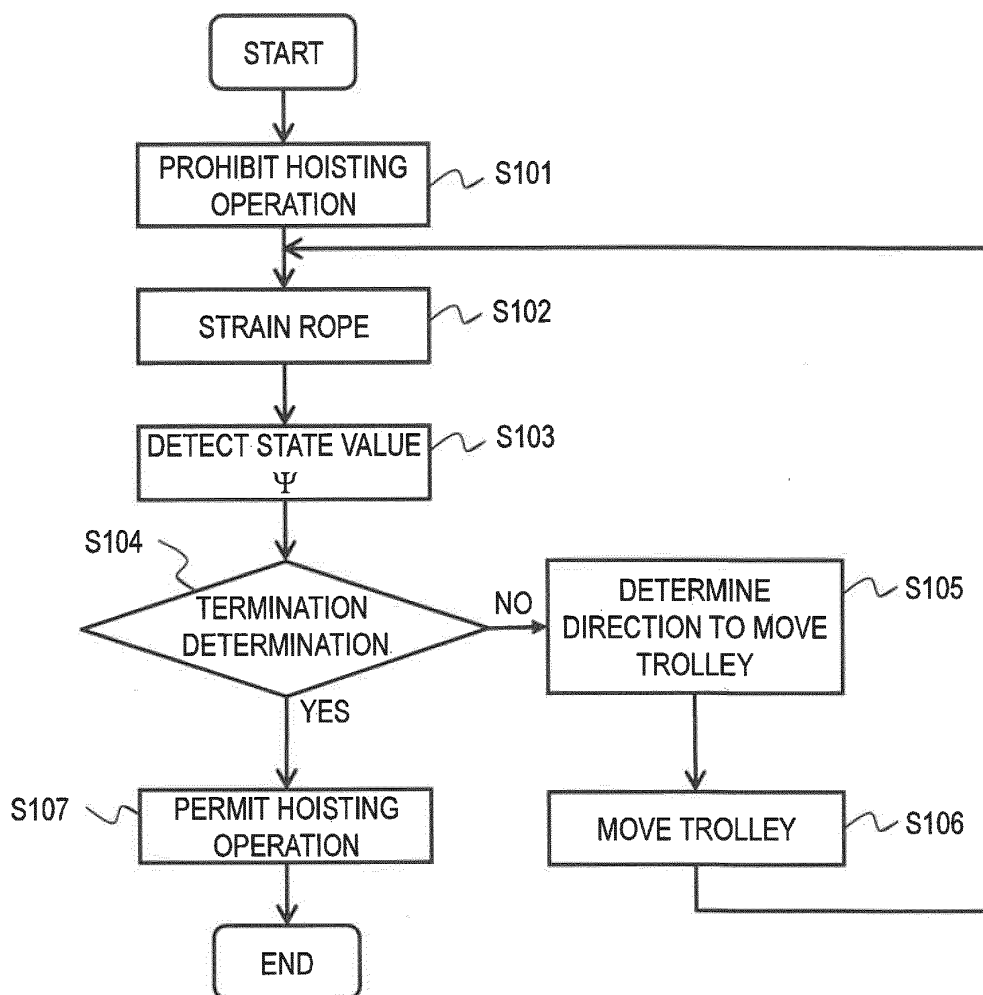


FIG.4

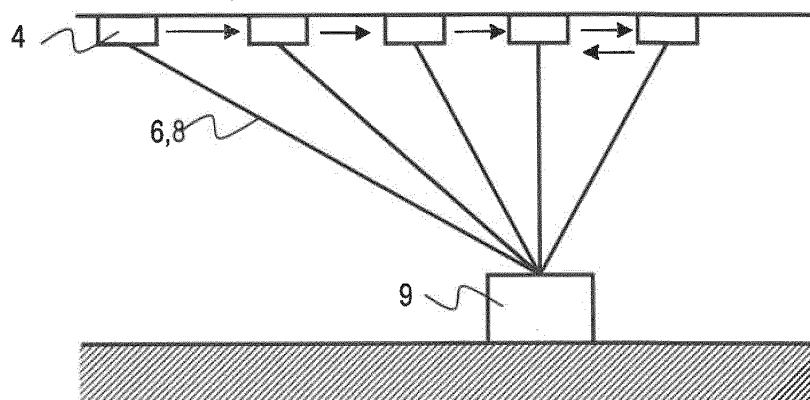


FIG.5

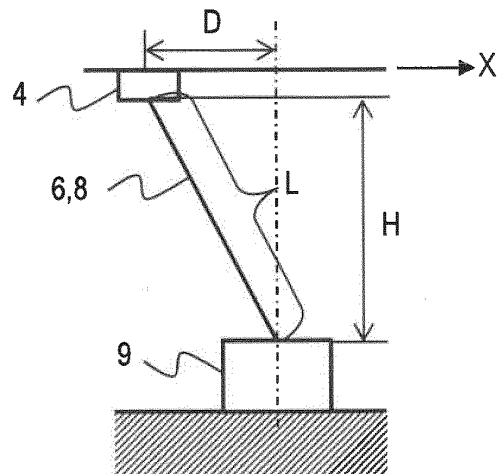


FIG.6

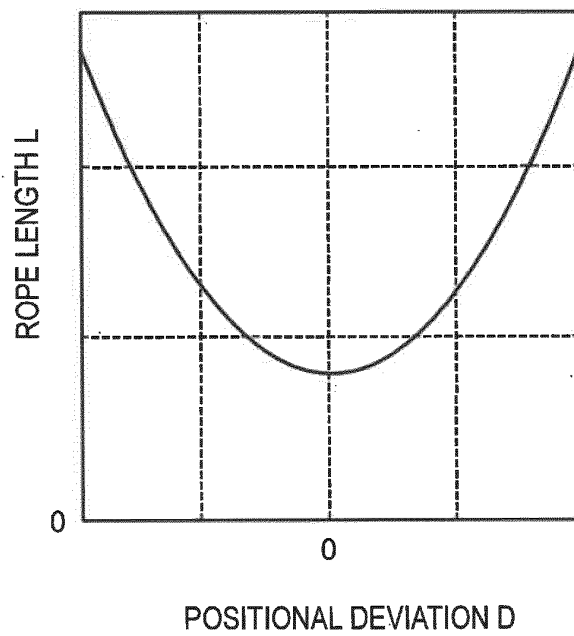


FIG.7

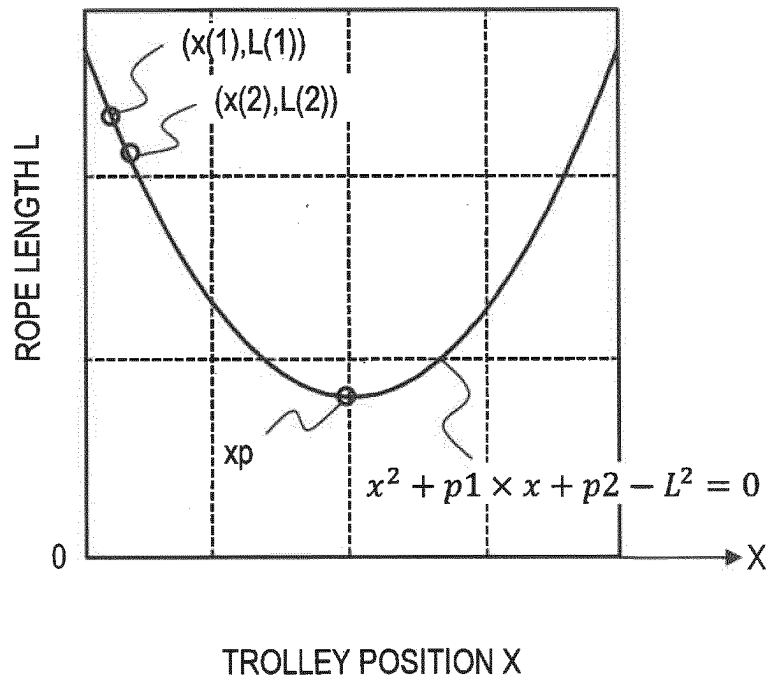


FIG.8

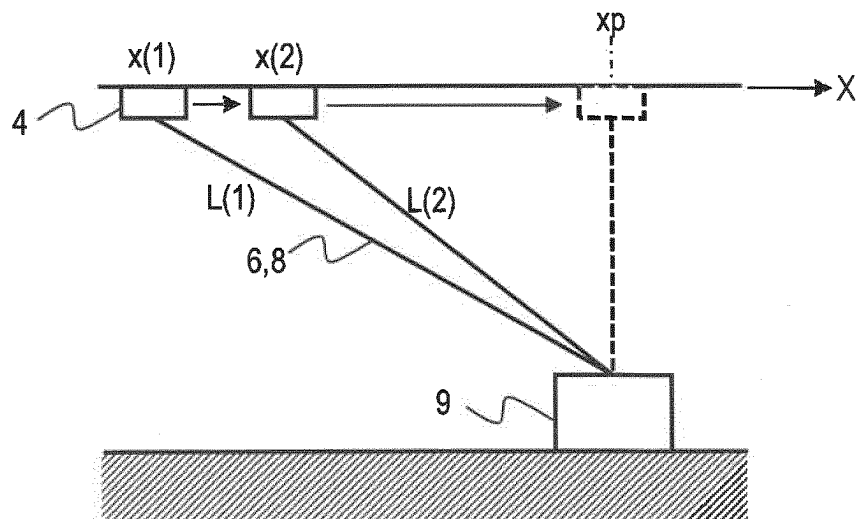


FIG.9

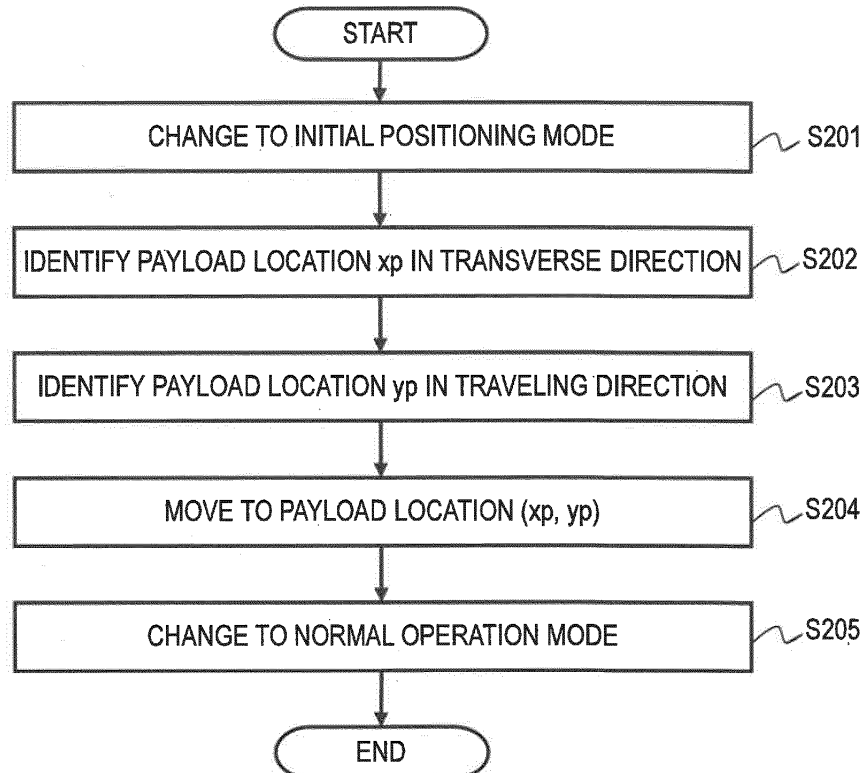


FIG. 10

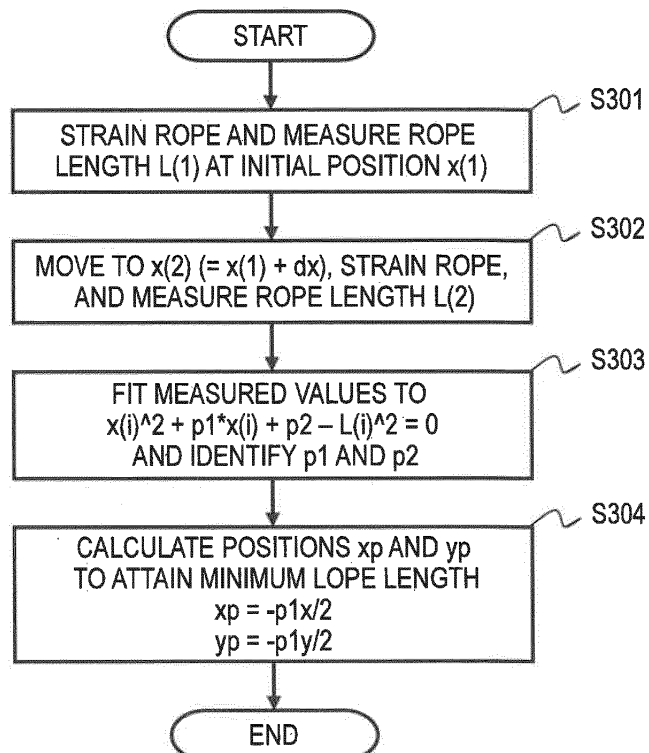


FIG. 11

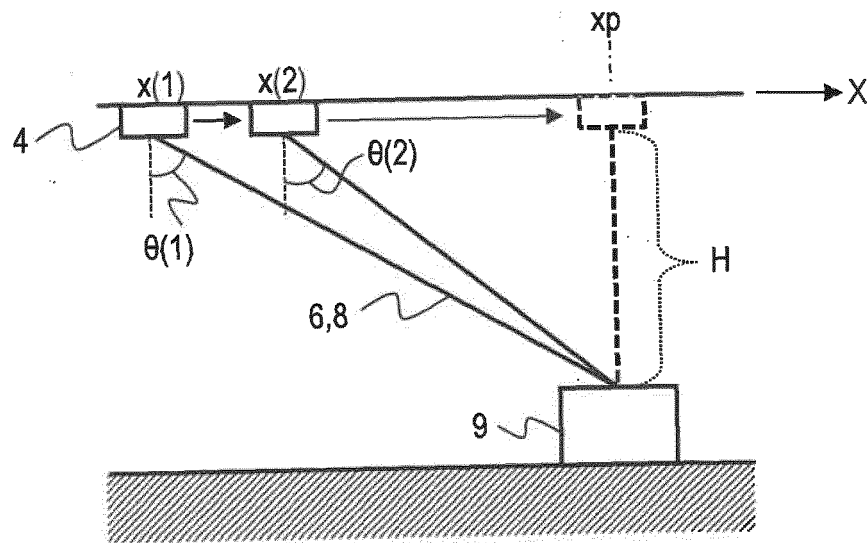


FIG. 12

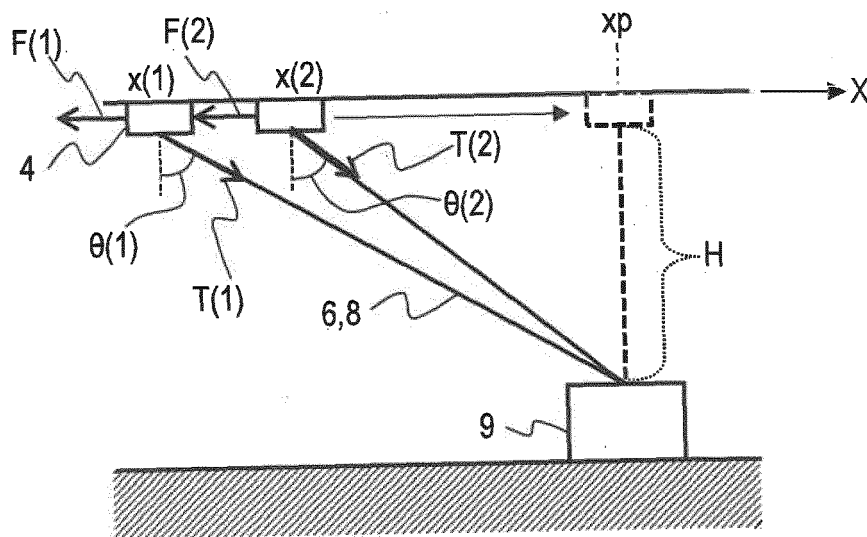


FIG. 13

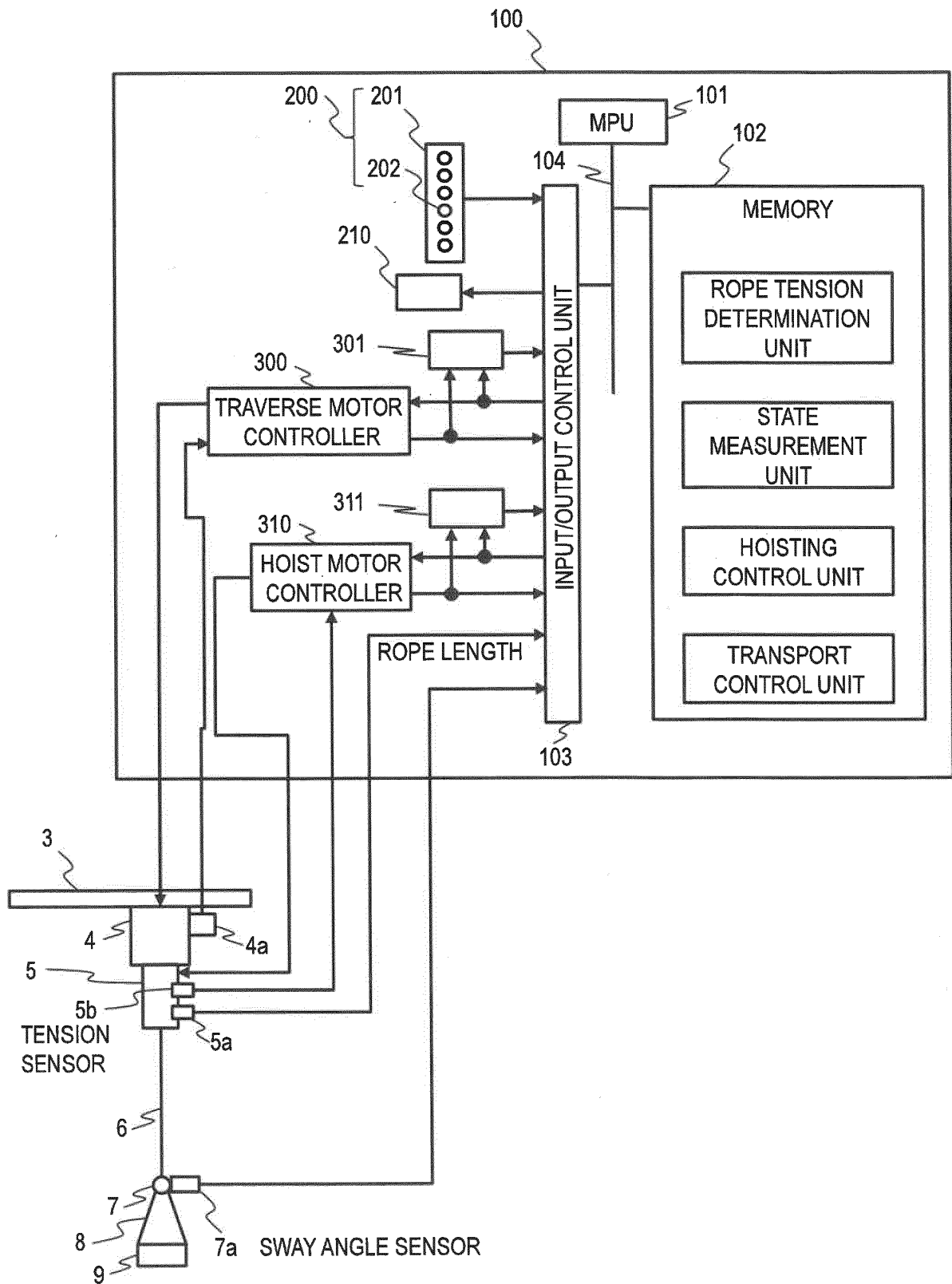


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/044415

A. CLASSIFICATION OF SUBJECT MATTER <i>B66C 13/06</i> (2006.01)i; <i>B66C 13/22</i> (2006.01)i FI: B66C13/06 M; B66C13/22 U 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) B66C13/00-15/06; B66C19/00-23/94 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2022 Registered utility model specifications of Japan 1996-2022 Published registered utility model applications of Japan 1994-2022 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)	
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2019-119583 A (HITACHI INDUSTRIAL EQUIPMENT SYSTEMS CO., LTD.) 22 July 2019 (2019-07-22) paragraphs [0022]-[0057], fig. 1-5	1, 10 2-9, 11-18
Y A	JP 2010-235249 A (TADANO LTD.) 21 October 2010 (2010-10-21) paragraphs [0025], [0038], [0040], [0049], [0052], [0060]	1, 10 2-9, 11-18
A	JP 2010-149943 A (HITACHI INDUSTRIAL EQUIPMENT SYSTEMS CO., LTD.) 08 July 2010 (2010-07-08)	1-18
A	JP 2018-34904 A (RYOEI KOKI CO., LTD.) 08 March 2018 (2018-03-08)	1-18
A	US 2014/0224755 A1 (KONECRANES PLC) 14 August 2014 (2014-08-14)	1-18
A	JP 2004-244151 A (ISHIKAWAJIMA TRANSPORT MACHINERY CO., LTD.) 02 September 2004 (2004-09-02)	1-18
☐ 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 15 February 2022	Date of mailing of the international search report 22 February 2022	
Name and mailing address of the ISA/JP Japan Patent Office (ISA/JP) 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915 Japan	Authorized officer Telephone No.	

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2021/044415

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2019-119583 A	22 July 2019	CN 111465572 A	
JP 2010-235249 A	21 October 2010	(Family: none)	
JP 2010-149943 A	08 July 2010	(Family: none)	
JP 2018-34904 A	08 March 2018	(Family: none)	
US 2014/0224755 A1	14 August 2014	FI 20125975 A	
		CN 103998367 A	
		RU 2014114125 A	
JP 2004-244151 A	02 September 2004	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2021055350 A [0001]
- JP 2019119583 A [0006]
- WO 2018211739 A [0006] [0082]