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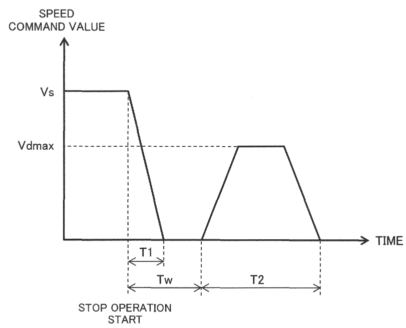
(54) CRANE AND CRANE CONTROL METHOD

(57) A crane is provided in which a stopping distance is reduced to improve safety while a payload sway occurring when the crane is stopped is suppressed. The crane includes: a velocity command generation section that generates a movement velocity command for a horizontal movement device; and a crane control section that moves the horizontal movement device according to the velocity command. And, the velocity command generation section generates: a deceleration pattern v1 in which deceleration is performed from the moment a stop operation start signal is received; and an acceleration and deceleration pattern v2 in which acceleration and deceleration are performed to cancel out a payload sway x01 resulting from superposition of a payload sway x0 at the time of the stop operation start and a payload sway x1 occurring when the horizontal movement device is driven according to the deceleration pattern v1. The horizontal movement device is driven according to the deceleration pattern v1 from the time of the stop operation start, and then the horizontal movement device is driven according to the acceleration and deceleration pattern v2 such that a time at which the amount of payload sway of the payload sway x01 reaches a maximum and a center time of the acceleration and deceleration pattern v2 coincide with each other.

FIG. 3



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Description

Technical Field

[0001] The present invention relates to techniques for controlling the operation of cranes that suspend and carry suspended payloads. In particular, the present invention relates to a crane, a crane controller, a crane control method, and a program for controlling the crane.

Background Art

[0002] In recent years, the number of situations where an unskilled operator not having much experience runs (operates) a crane is increasing in association with the aging of well-experienced operators of cranes and a shortage of operators due to an increase in the number of installed cranes. In the crane operation by the unskilled operator, there are risks such as misjudgment of the position and height of an obstruction, overlooking of surrounding obstructions, unskillfulness to predict crane behavior such as a payload sway and the like, misoperation due to unfamiliarity with crane operation, and the like. On this account, accidents such as a collision of the payload with an obstruction, an accident that an operator is caught in a payload and an obstruction, and the like may occur more often in the crane operation by an unskilled operator than in the crane operation by a well-experienced operator.

[0003] PTL 1 discloses a technique as one of countermeasures to prevent such accidents. PTL 1 discloses the control method to stop a crane with suppressing apayload sway, in which, at the time of the start of a stop operation for the crane, a notch or mechanical braking is applied once, and then a reverse notch or mechanical braking is applied once or more than once at the time after one half period of thesway, or alternatively, a reverse notch application or mechanical braking is applied once or more than once at the time after one quarter period of the sway.

Citation List

Patent Literature

[0004] PTL 1: Japanese Patent Application Laid-Open No. Hei 8-324960

Summary of Invention

Technical Problem

[0005] In the method disclosed in PTL 1, after deceleration by the notch or mechanical braking, the notch is applied one or more times (triangle wave velocity pattern) in order to suppress a payload sway, but the sway can’t be completely suppressed by only one operation. As a result, a reduction in stopping distance is not expected. However, it is to be desired that the crane is stopped at once with safety, that is, the stopping distance is shorter with suppressing a payload sway even if an immediate change such as a stop occurs.

[0006] Here, when the crane velocity is changed, there is a trade-off between a amplitude of a payload sway and a moving distance, the time to reach a target velocity or the time until velocity variation is within a certain range. Specifically, as a rate of change of crane velocity is increased, the above time or moving distance is shorter, but the payload sway is larger. In particular, the problem is made conspicuous by an abrupt change of velocity. For example, as an example of the velocity change, if the crane is stopped, the stopping distance over which a trolley moves until the crane comes to stop is shorter, but a large payload sway occurs. For mitigating the payload sway, the velocity change time (e.g., deceleration time) may be longer or the control to suppress the payload sway may be added. In this case, there is a problem that, although suppression of the payload sway can be achieved, the stopping distance is longer.

[0007] The present invention has been made in view of such problems and it is an object of the present invention to provide a technique to control crane operation with higher safety in which a distance and/or time required for control can be reduced with suppressing a payload sway.

Solution to Problem

[0008] To solve the above problems, in the present invention, a second velocity pattern is generated to cancel out an "overlap payload sway" resulting from superposition of a payload sway occurring when control on a crane is started and a payload sway occurring by a first velocity pattern for the crane control ("control" means control in which a target velocity or a velocity change falls within a certain range), and the acceleration and deceleration pattern is used to control the operation of the crane. By way of example, a crane includes: a horizontal movement device that moves, in a horizontal direction, a suspended payload which is suspended by a rope; a velocity command generation section that generates a velocity command for controlling the horizontal movement device; and a crane control section that controls a velocity of the horizontal movement device according to the velocity command. In the crane, as the velocity command, the velocity command generation section generates a first velocity pattern in which a velocity at a velocity change start of the horizontal movement is changed to a predetermined velocity, and generates a second velocity pattern in which acceleration and deceleration are performed to cancel out a third payload sway resulting from superposition of a first payload sway at the velocity change start and a second payload sway occurring in driving according to the first velocity pattern. The crane control section controls the horizontal movement device according to the first velocity pattern and the second velocity pattern that are thus generated.

[0009] The present invention also provides a method of controlling the crane and a program for executing the control method to control the crane.

[0010] It is noted that, as used herein, the term "rope" is defined as representing tools in general capable of being used to suspend a burden, such as chains, cords, bonds, bands, cables and the like as well as the ropes. Advantageous Effects of Invention

[0011] According to the present invention, the payload sway produced by a velocity change can be cancelled or mitigated by a smaller number of operations of acceleration and deceleration. This enables a reduction in distance to a target velocity with suppressing the payload sway. In turn, a higher level of safety of the crane is offered.

Brief Description of Drawings

[0012]

Figure 1 is a diagram illustrating a mechanism of an example crane to which the present invention is directed.
Figure 2 is a diagram illustrating a configuration of a crane according to Example 1 of the present invention.
Figure 3 is a chart illustrating velocity patterns generated in Example 1.
Figure 4 is a diagram illustrating a processing flow in a velocity command generation section of the crane according to Example 1.
Figure 5 shows charts for explaining an example operation according to Example 1.
Figure 6 is a diagram illustrating a configuration of a crane according to Example 2 of the present invention.
Figure 7 is a diagram illustrating a configuration of a crane according to Example 3 of the present invention.

Description of Embodiments

[0013] Several examples of embodiments of a crane according to the present invention will now be described with reference to the accompanying drawings.

[0014] Here, the present invention covers all types of cranes capable of moving a suspended payload in the horizontal direction. Specifically, the techniques can be applied to cranes moving a trolley in traverse and travel for a suspended payload (e.g., ceiling crane), as well as cranes performing only one of traverse and travel (e.g., unloader) and so-called crane vehicles. As used herein, the term "crane" includes all types of cranes capable of moving a suspended payload in the horizontal direction. It is noted that the word "horizontal/horizontally" includes curvilinear movement made by an arm of a crane vehicle and/or the like. Stated another way, any movement is included if the movement can cause a payload sway.

[0015] Also, a burden (suspended payload) to be carried by a crane is suspended with a chain, a rope, and/or the like to be carried. In the present invention, as long as a tool can be used to suspend a burden, any tool can be used irrespective of materials, shape, and the like. Therefore, as just mentioned, the term "rope" as used herein is referred as a general term for tools used to suspend a burden.

[0016] Specifically, a "rope" includes not only so-called ropes but also chains, bands, wires, cables, cords, bonds, and the like.

<Example 1>

[0017] A crane according to Example 1 in the present invention will now be described with reference to Figure 1 to Figure 5. It is noted that, in each figure, like reference signs are used to indicate like equipment (devices/apparatuses) and the explanation about previously discussed equipment may be omitted in the description of subsequent figures.

[0018] Figure 1 is a schematic diagram illustrating the mechanism of a ceiling crane. It should be noted that the present invention is not limited to a ceiling crane as described above.

[0019] In Figure 1, a crane 1 includes: runways 2 installed along both side walls of a building (not shown); a girder 3 moving on the tops of the runways 2; and a trolley 4 moving along the underside of the girder 3. A winch (hoist) which is not shown is mounted in a lower portion of the trolley 4 and is used to wind or unwind a rope 5 in order to lift or lower a hook 6 attached at the distal end of the rope 5. A suspended payload 8 is suspended directly or via a wire 7 from the hook 6, so that the suspended payload 8 is lifted and lowered as the hook 6 is lifted and lowered. Specifically, the crane 1 is capable of moving the suspended payload 8 in the horizontal direction by means of horizontal movement of the girder 3 (hereinafter referred to simply as "travel") and horizontal movement of the trolley 4 (hereinafter referred to simply as "traverse"), and the crane 1 is capable of lifting and lowering the suspended payload 8 vertically (in the up and down direction) by use of the winch.

[0020] In this example, the horizontal movement is performed by the traverse of the trolley 4 and the travel of the girder 3. In Figure 1, the trolley 4 and the girder 3 corresponds to a horizontal movement device. Since the present invention is pertinent to the operation of moving the suspended payload horizontally, the following description for Example 1 according to the present invention focuses mainly on the operation of horizontal movement by means of the traverse and the travel. Therefore, in the description in the following examples, the movement of the suspended payload refers to any one or both of the movement by driving the trolley 4 (traverse) and the movement by driving the girder 3 (travel).

[0021] Figure 2 is a diagram illustrating the configuration of the crane according to Example 1 of the present invention. Figure 2 illustrates the crane 1 operating the trolley 4 for traverse for the purpose of clear and simple description, in which travel of the girder 3 is omitted. A drive portion such as a motor/motors and/or the like used to move the trolley 4 and the girder 3 is also omitted.

[0022] In Figure 2, reference sign 10 denotes a velocity command generation section that generates velocity patterns and the like for use of controlling the horizontal movement device (the girder 3 and the trolley 4) in order to move the suspended payload 8 to a desired position, and Figure 2 shows an example of using a general-purpose computing machine. Reference sign 101 denotes an MPU (Microprocessing Unit) that performs arithmetic processing using programs, data and/or the like contained therein for generation of velocity patterns and/or the like. Reference sign 102 denotes memory to store the programs, the data and/or the like. Reference sign 103 denotes an input/output control section for input of data and signals from the outside and output of signals obtained through the arithmetic processing by MPU and/or the like to the outside. Reference sign 104 denotes a bus for communication of signals and data among components in the velocity command generation section 10. Reference sign 12 denotes a crane control section that receives the velocity patterns output from the velocity command generation section 10 and controls the velocity of horizontal movement (traverse) of the trolley 4. The crane control section 12 outputs, to the trolley 4, a control signal according to the received velocity pattern. Alternatively, the crane control section 12 may provide the function to the velocity command generation section 10 so that the control signal may be output from the velocity command generation section 10.

[0023] Although not shown in Figure 2, in addition to the trolley 4, the velocity command generation section 10 outputs velocity patterns for velocity control of horizontal movement (travel) of the girder 3 in the travel control. On the girder 3 side, the velocity of horizontal movement (travel) of the suspended payload is controlled based on the velocity pattern. The velocity command generation section 10 also receives a rope length L0 which is output from a rope length detector not shown, and a velocity Vs at the time of the stop operation start from a velocity detector also not shown. It is noted that when there is no change in the rope length L0 and the velocity Vs, the data on them may be stored in the memory 102. Note that reference sign 9 denotes an obstruction. The obstruction 9 is not always present on the carry route for a suspended load, but the possible presence is assumed in Figure 2.

[0024] It is noted that, in the specification, a description of the deceleration and stop of the crane is provided by way of example, but each example is also applicable to control performed to reach a target velocity in acceleration, deceleration up to a velocity which is slow but not stop, an/or the like. In this case, a velocity when control is initiated is used for a velocity at the time of the deceleration start. The time of the deceleration start may be input from the velocity detector or may be a predicted value based on control.

[0025] Details of the crane control in Figure 2 will now be described. In Figure 2, when an operator uses an operation input device 100 to instruct a direction of moving the suspended payload, the velocity command generation section 10 generates a velocity command to move the girder 3 and the trolley 4 in a direction corresponding to the instructed moving direction. The crane control section drives the girder 3 and the trolley 4 according to the velocity command generated, to move (in this case, cause traverse of) the suspended payload 8 horizontally.

[0026] For stopping the horizontal movement (traverse, travel), the operator uses the operation input device 100 to instruct the velocity command generation section 10 for a stop operation start signal 11. For example, push buttons corresponding to the moving directions are disposed on the operation input device 100. Hence, one of the buttons corresponding to a desired moving direction is pressed for start of the movement, and then the button is released for stop of the movement. In this operation, the velocity command generation section 10 receives the stop operation start signal 11 serving as a trigger for the stop operation start when the push button is released. Alternatively, the stop operation start signal 11 may be configured to be input by use of a separately disposed stop button or form external equipment.

[0027] Figure 3 is a chart illustrating velocity patterns generated by the velocity command generation section 10 when the stop operation start signal 11 is received. Upon reception of the stop operation start signal 11, initially, a drive is provided in a first velocity pattern v1 in which a velocity of the girder/trolley is reduced over a time duration T1 from Vs at the time of the stop operation start.

[0028] Then, the drive is provided in a second velocity pattern v2 in which acceleration and deceleration are performed with a maximum velocity Vdmax over a time duration T2 after a lapse of Tw from the stop operation start in such a manner as to cancel out the payload sway occurring at the start of the stop operation and the payload sway produced by the drive in v1. The above velocity patterns are obtained the following relational expressions. It is noted that the velocity patterns may be a pattern showing changes in velocity.

[0029] Initially, a transfer function P(s) from a crane velocity command to the amount of payload sway is given by the following equation.

$$P(s) = -s/(s^2 + wr^2) \qquad \text{(Eq. 1)}$$

where wr is an angular frequency of a payload sway, which is obtained from a payload sway period Tc of the suspended payload by wr = 2*π/Tc. Alternatively, this is obtained from a distance L from the rotation center of the rope to the center of gravity of the suspended payload by wr = sqrt(g/L) (g: acceleration of gravity). It is noted that L is obtained by adding, to the rope length L0, a distance ΔL from the hook position to the center of gravity of the suspened payload by the wire. ΔL changes depending on a suspended payload and/or a wire used, and ΔL is measured by a distance sensor mounted to the trolley and/or the like, alternatively, ΔL is input by the operator and prestored in the memory 102.

[0030] A payload sway x0(t) at the time of the stop operation start is given as the following equation.

$$x0(t) = A0*\sin(wr*t + \theta 0) \qquad \text{(Eq. 2)}$$

where when the amount of payload sway at the time of the stop operation start is x0(0) and the payload sway velocity is v0(0), A0 and θ0 are as follows.

$$A0 = \mathrm{sqrt}(x0(0)^2 + (v0(0)/wr)^2) \qquad \text{(Eq. 3)}$$

$$\theta 0 = \mathrm{atan}((v0(0)/wr)/x0(0)) \qquad \text{(Eq. 4)}$$

[0031] If the first velocity pattern v1 is given by a function v1(t) with respect to time t, the payload sway x1(t) occurring when the trolley is driven in v1(t) can be obtained by performing a laplace transform on v1(t) to determine V1(s), then by performing an inverse laplace transform on X1(s) = P(s)*V1(s), and it is given as follows.

$$x1(t) = A1*\sin(wr*t + \theta 1) \qquad \text{(Eq. 5)}$$

where if v1(t) decelerates at a constant deceleration, A1 and θ1 are as follows.

$$A1 = 2*Vs*\sin(T1*wr/2)/(T1*wr^2) \qquad \text{(Eq. 6)}$$

$$\theta 1 = -T1*wr/2 \qquad \text{(Eq. 7)}$$

where Vs is a velocity of the trolley at the time of the stop operation start, and T1 is deceleration time.

[0032] If the second velocity pattern v2 is given by a function v2(t) with respect to time t, the payload sway x2(t) occurring when the trolley is driven in v2(t) can be obtained by performing a laplace transform on v2(t) to determine v2(s), then by performing an inverse laplace transform on X2(s) = P(s)*V2(s), and it is given as follows.

$$x2(t) = A2*\sin(wr*t + \theta 2) \qquad \text{(Eq. 8)}$$

where when v2(t) has a trapezoidal wave, A2 and θ2 are as follows:

$$A2 = -4*Vdmax*(\cos(r*T2*wr/2) - \cos(T2*wr/2))/((1 - r)*T2*wr^2) \quad \text{(Eq. 9)}$$

$$\theta 2 = \pi/2 - Tw*wr - T2*wr/2 \quad \text{(Eq. 10)}$$

where r is upper side/lower side of the trapezoidal wave.

[0033] For suppressing the payload sway after stopping, the payload sway x01(t) resulting from superposition of x0(t) and x1(t) may be canceled by x2(t).

[0034] The following equation gives x01(t).

$$x01(t) = A01*\sin(wr*t + \theta 01) \quad \text{(Eq. 11)}$$

where A01 and θ01 used in Equation 11 are as follows.

$$A01 = \mathrm{sqrt}(2*Vs^2 + A0^2*T1^2*wr^4 - 2*Vs^2*\cos(T1*wr) - 2*A0*T1*Vs*wr^2*\sin(\theta 0) + 2*A0*T1*Vs*wr^2*\sin(\theta 0 + T1*wr))/(T1*wr^2) \quad \text{(Eq. 12)}$$

$$\theta 01 = \mathrm{atan}((-Vs + Vs*\cos(T1*wr) + A0*T1*wr^2*\sin(\theta 0))/(A0*T1*wr^2*\cos(\theta 0) + Vs*\sin(T1*wr))) \quad \text{(Eq. 13)}$$

[0035] For canceling x01(t) with x2(t), x01(t) and x2(t) may be made identical in phase to cancel out each other's amplitudes. Therefore, θ01 = θ2, A01 = -A2 may be established.

[0036] The following equation is obtained from θ01 = θ2.

$$Tw + T2/2 = (\pi/2 - \theta 01)/wr \quad \text{(Eq. 14)}$$

[0037] From this, x01(t) at the center time (t = Tw + T2/2) of V2(t) is as follows.

$$x01(Tw + T2/2) = A01*\sin(\pi/2) \quad \text{(Eq. 15)}$$

[0038] This states that the time at which x01(t) reaches a maximum and the center time of V2(t) may coincide with each other.

[0039] The following equation is obtained from A01 = -A2.

$$Vdmax = 1/4*A01*(1 - r)*T2*wr^2/(\cos(r*T2*wr/2) - \cos(T2*wr/2)) \quad \text{(Eq. 16)}$$

From the equation, T2, Vdmax, r can be obtained as follows.

[0040] Initially, if a set time T for T2 and a set velocity V for Vdmax are given, r is determined as follows. Assuming that T2*wr/2 is minute, Vdmax can be approximated as expressed in the following equation.

$$Vdmax = 2*A01/(1 + r)/T2 \quad \text{(Eq. 17)}$$

From this, r is determined as expressed in the following equation.

$$r = 2*A01/T/(k*V) \quad \text{(Eq. 18)}$$

where k is a correction factor taking the influence of the approximation into account. From the determined r, an exact solution of Vdmax is calculated by Equation 16.

[0041] Also, if a set velocity V for Vdmax and a set acceleration α for a trapezoidal acceleration are given, T2 and r may be determined as follows. Assuming that T2*wr/2 is minute, an acceleration can be obtained as expressed in the following equation.

$$\alpha = Vdmax/((1 - r)*T2/2) = 4*A01/(1 - r\hat{}2)/T2\hat{}2 \quad \text{(Eq. 19)}$$

From this, T2 and r are determined as expressed in the following equation.

$$T2 = A01/(k*V) + (k*V)/\alpha \quad \text{(Eq. 20)}$$

$$r = 2*\alpha*A01/(\alpha*A01 + (k*V)\hat{}2) - 1 \quad \text{(Eq. 21)}$$

From the determined T2 and r, an exact solution of Vdmax is calculated by Equation 16.

[0042] Further, when r is zero, i.e., a triangular waveform, if a set velocity V for Vdmax is given, T2 is determined as follows. If r = 0, Vdmax is as expressed in the following equation.

$$Vdmax = 1/8*A01*T2*wr\hat{}2/sin(T2*wr/4)\hat{}2 \quad \text{(Eq. 22)}$$

Assuming that T2*wr/4 is minute, Vdmax can be approximated as expressed in the following equation.

$$Vdmax = 2*A01/T2 \quad \text{(Eq. 23)}$$

From this, T2 is determined as expressed in the following equation.

$$T2 = 2*A01/(k*V) \quad \text{(Eq. 24)}$$

where k is a correction factor taking the influence of the approximation into account. From the determined T2, an exact solution of Vdmax is calculated by Equation 22.

[0043] Also, if r = 0, and a set acceleration α for a trapezoidal acceleration is given, T2 and Vdmax may be determined as follows. An acceleration can be obtained as expressed in the following equation.

$$\alpha = Vdamx/(T2/2) = 1/4*A01*wr\hat{}2/sin(T2*wr/4)\hat{}2 \quad \text{(Eq. 25)}$$

From this, T2 is determined as expressed in the following equation.

$$T2 = 4/wr*asin(1/2*sqrt(A01*wr\hat{}2/\alpha)) \quad \text{(Eq. 26)}$$

From the determined T2, Vdmax is calculated by Equation 22.

[0044] A start time Tw of v2(t) is obtained by the following equation.

$$Tw = (\pi/2 - \theta 01)/wr - T2/2 \quad \text{(Eq. 27)}$$

If Tw < 0 in this equation, since the drive by v2(t) must be started before the stop operation start, this cannot be realized. In this case, since x01(t) is a periodic function of an angular period 2π, the time at which the amount of payload sway reaches a maximum after one period and the center time of v2(t) may coincide with each other. Therefore, Tw is determined by the following equation.

$$Tw = ((2*n + 1/2)*\pi - \theta 01)/wr - T2/2 \quad \text{(Eq. 28)}$$

where n is zero or one.

[0045] Thus, the start time Tw and the time duration T2 of the second velocity pattern v2, the maximum velocity Vdmax, and the upper side/lower side r of the trapezoidal wave are determined.

[0046] It is noted that when the velocity Vs at the time of the stop operation start is very slow, T1 becomes approximate zero. In this case, the payload sway x01(t) resulting from superposition of the payload sway x0(t) at the time of the stop operation start and the payload sway x1(t) by the first velocity pattern becomes only x0(t). From this, the amplitude A01 and the phase θ01 of x01(t) may be assumed as the amplitude A0 and the phase θ0 of x0 (t).

[0047] For reducing the stopping distance, it is desired to reduce the time duration T1 of the first velocity pattern v1(t) and the time duration T2 of the second velocity pattern v2(t). To this end, based on the performance of the girder/trolley, a deceleration of v1(t), a set value V for the maximum velocity of v2(t), and a set value α for an acceleration are desirably taken as high as possible.

[0048] Figure 4 is a diagram illustrating a processing flow in the velocity command generation section 10. Details of the processing will be described below.

[0049] At S01, from the amount of payload sway x0(0) and a payload sway velocity v0(0) at the time of the stop operation start, an amplitude A0 and a phase θ0 of the payload sway x0(t) at the time of the stop operation start are estimated by Equations 3 and 4. It is noted that if the velocity of the girder/trolley Vs at the time of the stop operation start is very slow and A0 is below an allowable value of the amount of payload sway, a stop may be reached without subsequent calculations.

[0050] At S02, from A0, θ0, Vs, a time duration T1 of the first velocity pattern v1 and an angular frequency wr of a payload sway, amplitudes A01, θ01 of the payload sway x01 resulting from superposition of x0 and the payload sway x1 produced by the drive by v1 are obtained by Equations 12 and 13. At this stage, if Vs is a very slow velocity, without the drive by v1 (T1 = 0), A01 = A0 and θ01 = θ0 are determined.

[0051] At S03, from a set value V for the maximum velocity in the second velocity pattern v2 in which A01, wr, and the upper side/lower side r of the trapezoidal waveform are zero, i.e., a triangular wave, a time duration T2 of v2 and a maximum velocity Vdmax are obtained by Equations 24 and 22.

[0052] At S04, T2 obtained in S03 is compared with a threshold T2s = $2*((\pi/2 - \theta 01)/wr - T1)$. If T2 > T2s, a reduction of T2 is made possible by setting r>0. Because of this, a parameter calculation is made to specify a maximum velocity and a time duration.

[0053] At S05, taking Vdmax as V and T2 as T2s, Vdmax and r are obtained by Equations 17, 18. If a trapezoidal acceleration thus obtained is equal to or less than a maximum acceleration, it is determined that a trapezoidal wave to be driven is determined, and the flow goes to S10.

[0054] At S06, it is determined whether the acceleration exceeds a maximum acceleration αmax. If it exceeds, a parameter calculation is performed to specify the acceleration such that the acceleration becomes equal to or less than αmax.

[0055] At S07, taking a set value for the acceleration as αmax, T2 and Vdmax are obtained by Equations 26 and 22.

[0056] At S08, it is determined whether a triangular acceleration is equal to or less than an allowable value (minimum allowable acceleration αmin). If it is equal to or less than the allowable value, a reduction of T2 is made possible by setting r>0. Because of this, a parameter calculation is performed to specify a maximum velocity and an acceleration.

[0057] At S09, taking Vdmax as V and an acceleration as αmin, T2, r, and Vdmax are obtained by Equations 20, 21, and 16.

[0058] At S10, Equation 28 is used to calculate start time Tw. First, a calculation is made as n=0, and when Tw<0, a recalculation is made as n=1.

[0059] Parameters of the velocity patterns are calculated as described above. If the triangular wave causes the time duration to increase, using the trapezoidal wave reduces the time duration. This enables a reduction in stopping distance and in time until the payload sway is suppressed and a stop is reached.

[0060] Figure 5 shows charts for explaining the operation in Example 1, which illustrates temporal changes of the trolley velocity and the amount of payload sway from above. As seen from Figure 5, deceleration is started according to the first velocity pattern from the time of the stop operation start at which a stop operation start signal 11 is input. Then, because of drive by the trapezoidal velocity command which is the second velocity pattern, the payload sway produced at the time of the stop operation start and by the deceleration is canceled out by the trapezoidal velocity command, so that the trolley is stopped and subsequent payload sway can be suppressed. Also, a stop is enabled by a single application of trapezoidal wave. This enables a shorter stopping distance than that in a method of performing the operation over several times.

[0061] As described above, according to Example 1, the payload sway produced by deceleration can be canceled out by a single application of the acceleration and deceleration, which in turn enables a reduction in stopping distance with suppressing the payload sway, thereby improving the safety of the crane.

[0062] It will be understood that although the case of stopping the crane has been described in the above example, the payload sway can be suppressed similarly even if the velocity is changed to any given velocity. Also, the first velocity pattern and the second velocity pattern may be superposed on each other, i.e., Tw may be smaller than T1.

<Example 2>

[0063] A crane according to Example 2 of the present invention will now be described. It is noted that repetition in the description of commonalities with the above example is avoided. Figure 6 is a diagram illustrating the configuration of the crane according to Example 2. In Example 2, a significant difference from Example 1 illustrated in Figure 2 is to have a payload sway amount acquisition device that acquires the amount of payload sway and a payload sway velocity in Figure 6. In the velocity command generation in the previous examples, an amplitude A0 and a phase θ0 of the payload sway x0 at the time of the stop operation start are used, and they can be obtained by Equations 3 and 4 from the amount of payload sway x0(0) and the payload sway velocity v0(0) at the time of the start of stop which are acquired by the payload sway amount acquisition device.

[0064] The payload sway amount acquisition device is a device for obtaining the amount of payload sway and the payload sway velocity. The payload sway amount acquisition device in the example includes a payload sway amount detector 13 that measures the amount of payload sway, and a payload sway velocity arithmetic device that computes the payload sway velocity from the measured amount of payload sway. The payload sway amount detector 13 is implemented by use of, for example, a camera or a 3D laser distance sensor which is mounted in a downward direction to the trolley, to observe (measure) sway of the hook 6 or the suspended payload 8. Also, a payload sway velocity acquisition device performs, for example, a differentiation operation or a pseudo differentiation operation on the measured amount of payload sway. In the example, the payload sway velocity acquisition device is configured as a function of the velocity command generation section 10, rather than being separately installed.

[0065] Also, a payload sway amount estimation device may be provided to estimate the amount of payload sway and a payload sway velocity, and the payload sway amount acquisition device may also obtain by estimating the amount of payload sway and a payload sway velocity from the angular frequency wr of a payload sway and a velocity command for the girder/trolley. Therefore, the payload sway amount acquisition device may not detect the amount of payload sway directly from the payload sway amount detector 13. The angular frequency wr may be estimated from the rope length L0. The function of the payload sway amount estimation device may be configured to perform computations in the velocity command generation section 10.

[0066] For the estimation of the amount of payload sway and a payload sway velocity, when the girder trolley velocity command is vt(t) and the amount of payload sway is x(t), VT(s) and X(s) resulting from performing a laplace transform on vt(t) and x(t) are calculated from the following equation.

$$X(s) = P(s)*VT(s) \qquad \text{(Eq. 29)}$$

[0067] Therefore, the payload sway amount estimation device may estimate the amount of payload sway by performing a filtering operation in which a transfer function is given by P(s) for vt(t), and may estimate a payload sway velocity by differentiating the obtained amount of payload sway.

[0068] As described above, according to Example 2, the payload sway produced by deceleration can be canceled out by a single application of the acceleration and deceleration, which in turn enables a reduction in stopping distance with suppressing the payload sway, thereby improving the safety of the crane.

<Example 3>

[0069] A crane according to Example 3 of the present invention will now be described. It is noted that repetition in the description of commonalities with the above examples is avoided.

[0070] Figure 7 is a diagram illustrating the configuration of the crane according to Example 3 of the present invention. In the example, an obstruction detector 14 is included to detect an obstruction 9 located around the suspended load 8, the trolley 4, and the girder 3. Also, a collision determination device 15 is included, which receives a detection signal from the obstruction detector 14, and determines whether a risk of a collision between the obstruction 9 and any of the suspended payload 8, the trolley 4, and the girder 3 is present or absent. If it is determined that the risk of the collision is present, the collision determination device 15 outputs a stop operation start signal 11 to the velocity command generation section 10.

[0071] The obstruction detector 14 observes surroundings of the suspended payload 8 by use of, for example, a camera or a 3D laser distance sensor which is mounted in a downward direction to the trolley 4, in order to detect an obstruction around the suspended payload. If a collision between the detected obstruction and the suspended payload is estimated, the collision determination device 15 immediately outputs a stop operation start signal 11. Upon receiving the stop operation start signal 11, the velocity command generation section 10 generates velocity patterns similarly to those in the above examples. Specifically, the velocity command generation section 10 generates a first velocity pattern for deceleration from the velocity at the time of the deceleration start to a first deceleration end velocity, and a second velocity pattern for acceleration and deceleration to cancel out a payload sway occurring when the horizontal movement device is driven in first velocity pattern. And, the generated velocity patterns are output to the crane control section 12, so that the crane control section 12 controls the velocitys of the girder 3 and/or the trolley 4 to stop the crane. Such control operation enables the avoidance of a collision between a suspended load and an obstruction and an accident that an operator is caught in a payload and an obstruction.

[0072] Also, a collision of the crane with a wall, a stopper or another crane running on the same rail may be estimated by use of, for example, a length measurement sensor mounted to the trolley 4 and/or the girder 3 to measure a distance to the wall, the stopper or the other crane. If, upon the estimation, the stop operation start signal is immediately output to stop the crane, the avoidance of a collision between the crane and the wall, the stopper and/or the other crane and a caught accident is enabled.

[0073] With the crane according to Example 3 of the present invention as described above, a payload sway produced by deceleration can be canceled out by a single application of acceleration and deceleration, which in turn enables a reduction in stopping distance with suppressing the payload sway, thereby improving the safety of the crane. Furthermore, the avoidance of a collision and a caught accident is enabled to provide a further improvement in safety of the crane.

[0074] Also, according to each of the examples using the stop control as an example, a payload sway produced by deceleration can be canceled out or mitigated by a single application of acceleration and deceleration, and therefore a reduction in stopping distance while suppressing the payload sway is enabled to provide improved safety of the crane.

[0075] It will be understood that the present invention is not limited to the above some examples, and is intended to embrace various modifications. The above examples have been described in detail for the purpose of explaining the present invention clearly, and the present invention is not necessarily limited to including all the components and configurations described above. Further, a portion of the configuration in one example may be substituted for configuration in another example, and configuration in one example may be added to configuration in another example. Further, for the configuration in each example, addition, deletion, and substitution of another configuration may be made. In particular, the control on the crane is not limited to the stop control, and the application to deceleration and acceleration to any given velocity (target velocity) is enabled. In this case, maintaining the target velocity constantly within a redetermined range is involved. Also, the stopping distance means a moving distance to the target velocity.

Reference Signs List

[0076]

1 crane,
2 runway,
3 girder,
4 trolley,
5 rope,
6 hook,
7 wire,
8 suspended payload,
9 obstruction,

10 velocity command generation section,
11 stop operation start signal,
12 crane control section,
13 payload sway amount detector,
14 obstruction detector,
15 collision determination device

Claims

1. A crane comprising:

a horizontal movement device that produces, in a horizontal direction, horizontal movement of a suspended payload which is suspended by a rope;
a velocity command generation section that generates a velocity command for controlling the horizontal movement device; and
a crane control section that controls a velocity of the horizontal movement device according to the velocity command,
wherein as the velocity command, the velocity command generation section generates a first velocity pattern in which a velocity at a velocity change start of the horizontal movement is changed to a predetermined velocity, and generates a second velocity pattern in which acceleration and deceleration are performed to cancel out a third payload sway resulting from superposition of a first payload sway at the velocity change start and a second payload sway occurring in driving according to the first velocity pattern, and
the crane control section controls the horizontal movement device according to the first velocity pattern and the second velocity pattern that are thus generated.

2. The crane according to claim 1,
wherein the velocity command generation section uses a deceleration pattern to decelerate and stop the horizontal movement of the crane, as the first velocity pattern.

3. The crane according to claim 1 or 2,
wherein the crane control section controls the horizontal movement device according to the first velocity pattern from the velocity change start, and controls the horizontal movement device to achieve coincidence between a time at which an amount of payload sway of the third payload sway reaches a maximum and a center time of the second velocity pattern.

4. The crane according to any one of claims 1 to 3,
wherein the velocity command generation section generates the first velocity pattern by calculating a control start time, a time duration, and a maximum velocity in the second velocity pattern, based on an angular frequency according to a length of the rope, an amplitude and a phase of the third payload sway, a crane velocity at the velocity change start, and time to change a velocity of the first velocity pattern.

5. The crane according to claim 4,
wherein the velocity command generation section:

calculates an amplitude and a phase of the first payload sway based on an amount of payload sway, a payload sway velocity, and an angular frequency in the first payload sway; and
calculates an amplitude and a phase of the third payload sway based on the calculated amplitude, calculated phase, and calculated angular frequency of the first payload sway and deceleration time of a deceleration pattern which is the first velocity pattern.

6. The crane according to claim 4 or 5,
wherein as the second velocity pattern, the velocity command generation section generates a second velocity pattern showing a trapezoidal wave.

7. The crane according to claim 6,

wherein as the first velocity pattern, the velocity command generation section generates a first velocity pattern in which a velocity change of the horizontal movement indicates acceleration or deceleration at a certain rate, and the trapezoidal wave satisfies the following

$$\theta 01 = (2*n + 1/2)*\pi - Tw*wr - T2*wr/2$$

$$A01 = -4*Vdmax*(\cos(r*T2*wr/2) - \cos(T2*wr/2))/((1 - r)*T2*wr^2),$$

where a start time is Tw, a time duration is T2, a maximum velocity is Vdmax, an upper side/lower side of the trapezoidal wave is r, the angular frequency is wr, an amplitude of the third payload sway is A01, and the phase is θ01 (n is 0 or 1).

8. The crane according to any one of claims 1 to 7, further comprising a payload sway acquisition section that acquires an amount of payload sway and a payload sway velocity,
wherein the velocity command generation section uses the amount of payload sway and the payload sway velocity to generate the velocity command.

9. The crane according to claim 8,
wherein the payload sway acquisition section estimates the amount of payload sway and the payload sway velocity from either an angular frequency of the payload sway or the angular frequency obtained from a length of the rope, and the velocity command for the crane.

10. The crane according to any one of claims 1 to 9, further comprising:

an obstruction detector that detects an obstruction to the suspended load and the crane; and
a collision determination section that determines whether a risk of a collision between the obstruction detected by the obstruction detector and at least one of the suspended payload and the crane is present or absent, and, if the risk of the collision is present, outputs a stop operation start signal for starting a stop operation to the velocity command generation section.

11. A crane control method of controlling a crane having: a horizontal movement device that produces, in a horizontal direction, horizontal movement of a suspended payload which is suspended by a rope; and a velocity command generation section that generates a velocity command for controlling the horizontal movement device; and a crane control section that controls a velocity of the horizontal movement device according to the velocity command,
the method comprising:

generating, by the velocity command generation section, as the velocity command, a first velocity pattern in which a velocity at a velocity change start of the horizontal movement is changed to a predetermined velocity;
generating, by the velocity command generation section, as the velocity command, a second velocity pattern in which acceleration and deceleration are performed to cancel out a third payload sway resulting from superposition of a first payload sway at the velocity change start and a second payload sway occurring in driving according to the first velocity pattern; and
controlling, by the crane control section, the horizontal movement device according to the first velocity pattern and the second velocity pattern which are thus generated.

12. The crane control method according to claim 11, wherein the method comprises using, by the velocity command generation section, a deceleration pattern to decelerate and stop the horizontal movement of the crane, as the first velocity pattern.

13. The crane control method according to claim 11 or 12, wherein the method comprises controlling, by the crane control section, the horizontal movement device according to the first velocity pattern from the velocity change start, and controlling the horizontal movement device to achieve coincidence between a time at which an amount of payload sway of the third payload sway reaches a maximum and a center time of the second velocity pattern.

14. The crane control method according to any one of claims 11 to 13, wherein the method comprises generating, by the velocity command generation section, the first velocity pattern by calculating a control start time, a time duration, and a maximum velocity in the second velocity pattern, based on an angular frequency according to a length of the rope, an amplitude and a phase of the third payload sway, a crane velocity at the velocity change start, and time to change a velocity of the first velocity pattern.

15. The crane control method according to claim 14, the method comprises, by the velocity command generation section,

calculating an amplitude and a phase of the first payload sway based on an amount of payload sway, a payload sway velocity, and an angular frequency in the first payload sway, and
calculating an amplitude and a phase of the third payload sway based on the calculated amplitude, calculated phase, and calculated angular frequency of the first payload sway and deceleration time of a deceleration pattern which is the first velocity pattern.

16. The crane control method according to claim 14 or 15, wherein the method comprises, as the second velocity pattern, by the velocity command generation section, generating a second velocity pattern showing a trapezoidal wave.

17. The crane control method according to claim 16, wherein the method comprises, as the first velocity pattern, by the velocity command generation section, generating a first velocity pattern in which a velocity change of the horizontal movement indicates acceleration or deceleration at a certain rate,
wherein the trapezoidal wave satisfies the following equations:

$$\theta01 = (2*n + 1/2)*\pi - Tw*wr - T2*wr/2$$

$$A01 = -4*Vdmax*(\cos(r*T2*wr/2) - \cos(T2*wr/2))/((1 - r)*T2*wr^2),$$

where a start time is Tw, a time duration is T2, a maximum velocity is Vdmax, an upper side/lower side of the trapezoidal wave is r, the angular frequency is wr, an amplitude of the third payload sway is A01, and the phase is θ01 (n is 0 or 1).

18. The crane control method according to any one of claims 11 to 17,

wherein a payload sway acquisition section is further included to acquire an amount of payload sway and a payload sway velocity, and
the velocity command generation section uses the amount of payload sway and the payload sway velocity to generate the velocity command.

19. The crane control section according to claim 18, wherein the method comprises estimating, by the payload sway acquisition section, the amount of payload sway and the payload sway velocity from either an angular frequency of the payload sway or the angular frequency obtained from a length of the rope, and the velocity command for the crane.

20. The crane control method according to any one of claims 11 to 19,

wherein the crane further includes an obstruction detector and a collision determination section, and
the method comprises:

by the obstruction detector, detecting an obstruction to the suspended payload and the crane; and
by the collision determination section, determining whether a risk of a collision between the obstruction detected by the obstruction detector and at least one of the suspended load and the crane is present or absent, and, if the risk of the collision is present, outputting a stop operation start signal for starting a stop operation to the velocity command generation section.

FIG. 1

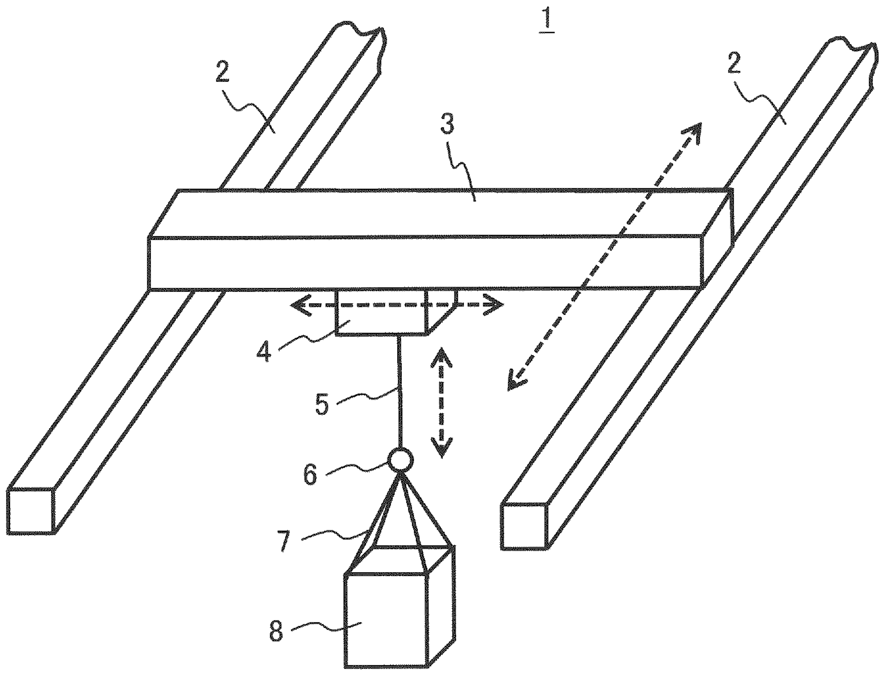


FIG. 2

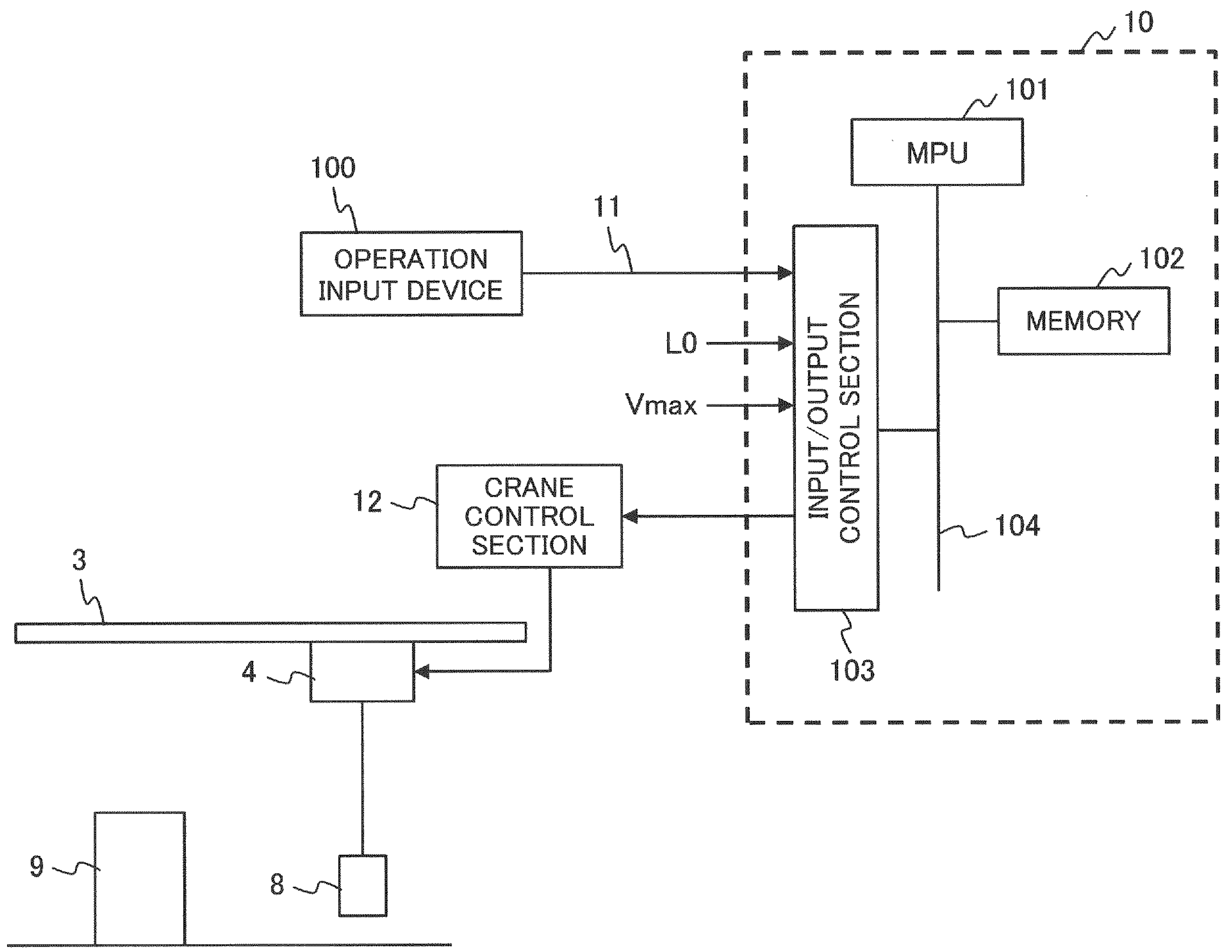

10
101
MPU
100
11
102
OPERATION
INPUT DEVICE
MEMORY
L0
Vmax
INPUT/OUTPUT
CONTROL SECTION
CRANE
CONTROL
SECTION
12
104
3
4
103
9
8

FIG. 3

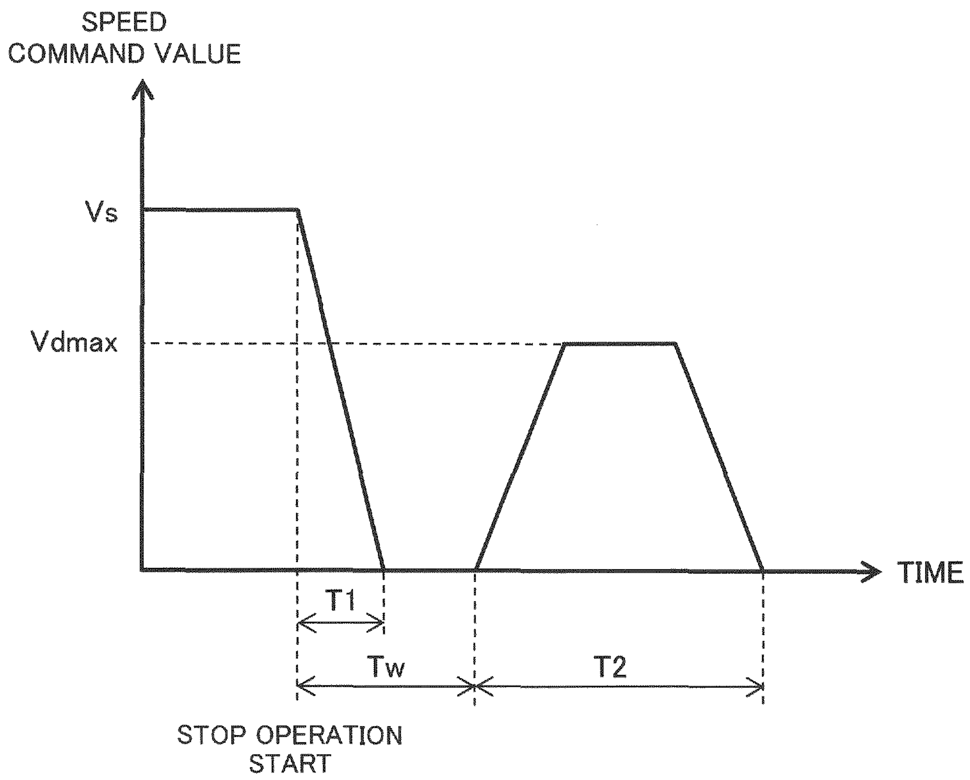

SPEED
COMMAND VALUE
Vs
Vdmax
TIME
T1
Tw
T2
STOP OPERATION
START

FIG. 4

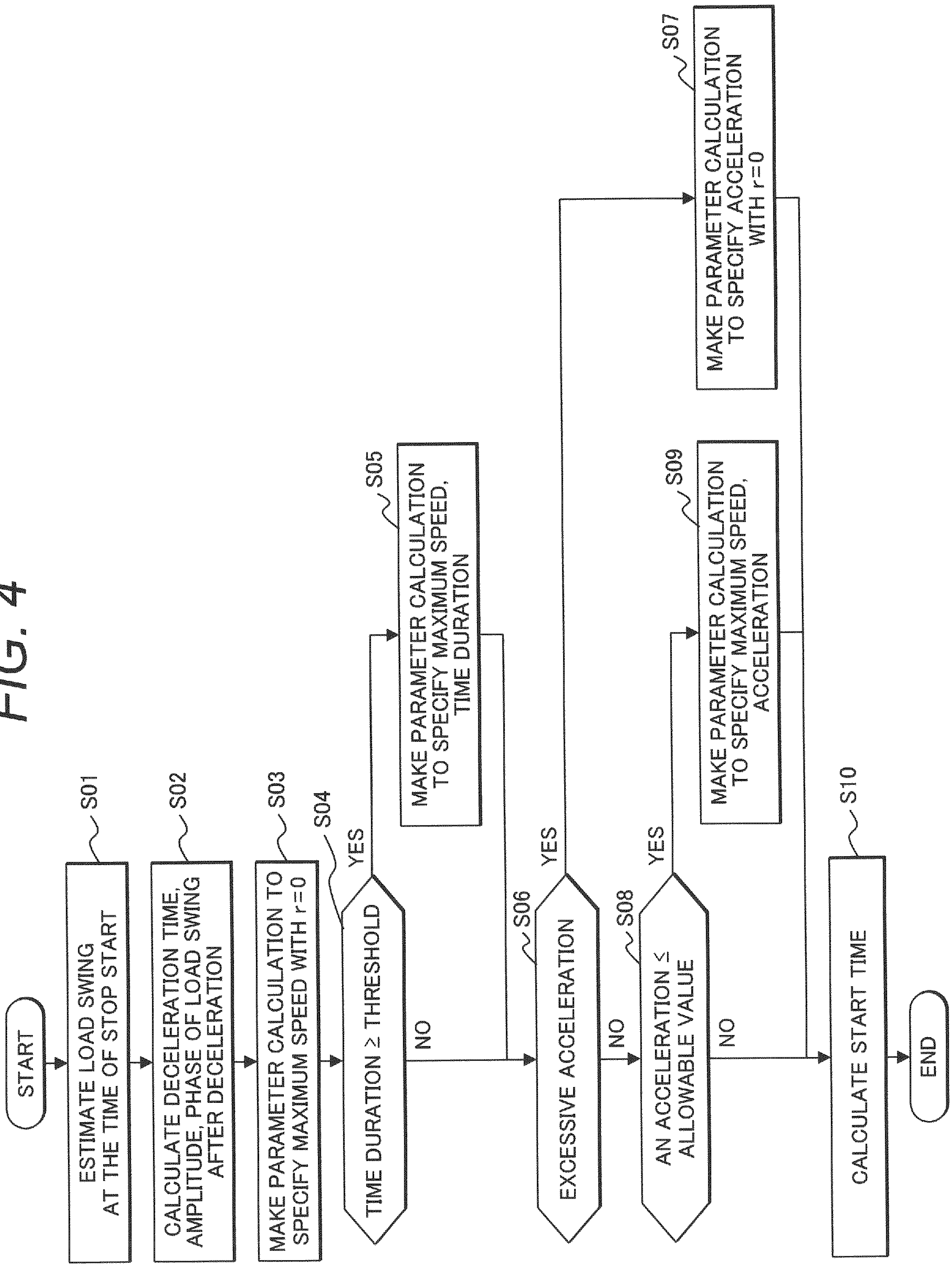

START
ESTIMATE LOAD SWING AT THE TIME OF STOP START
S01
CALCULATE DECELERATION TIME, AMPLITUDE, PHASE OF LOAD SWING AFTER DECELERATION
S02
MAKE PARAMETER CALCULATION TO SPECIFY MAXIMUM SPEED WITH r=0
S03
TIME DURATION ≥ THRESHOLD
S04
YES
NO
MAKE PARAMETER CALCULATION TO SPECIFY MAXIMUM SPEED, TIME DURATION
S05
EXCESSIVE ACCELERATION
S06
YES
NO
MAKE PARAMETER CALCULATION TO SPECIFY ACCELERATION WITH r=0
S07
AN ACCELERATION ≤ ALLOWABLE VALUE
S08
YES
NO
MAKE PARAMETER CALCULATION TO SPECIFY MAXIMUM SPEED, ACCELERATION
S09
CALCULATE START TIME
S10
END

FIG. 5

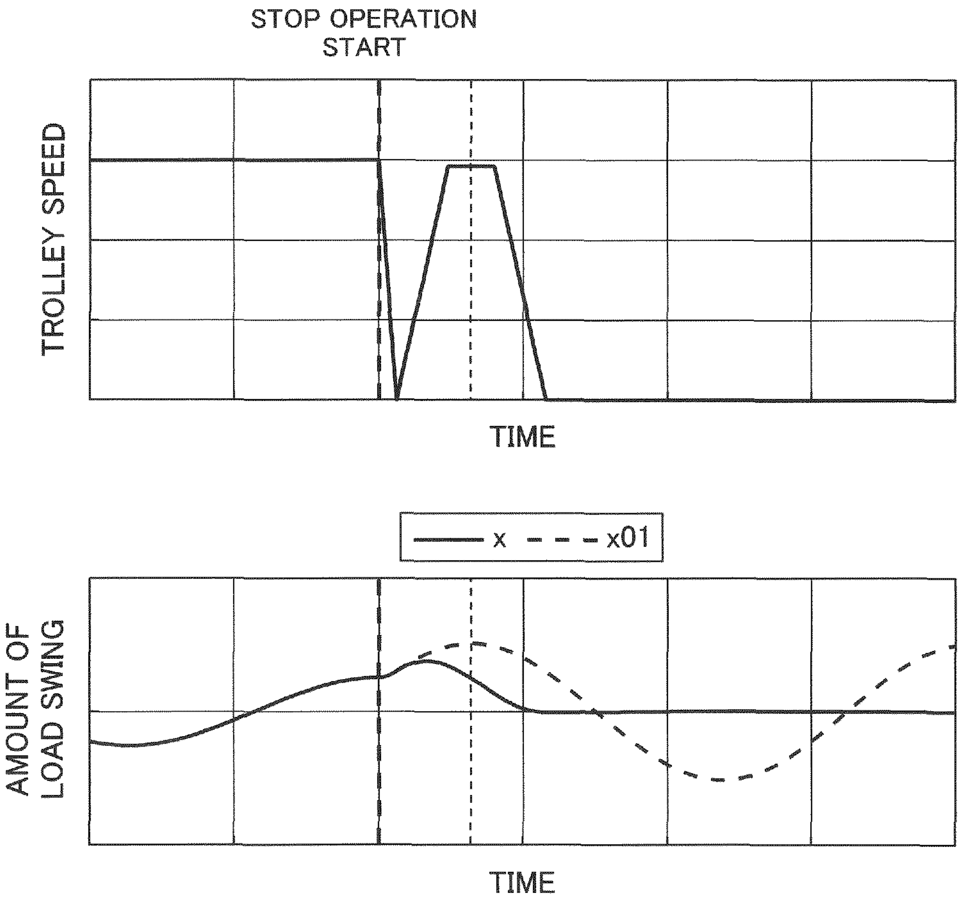

STOP OPERATION
START
TROLLEY SPEED
TIME
x
x01
AMOUNT OF
LOAD SWING
TIME

FIG. 6

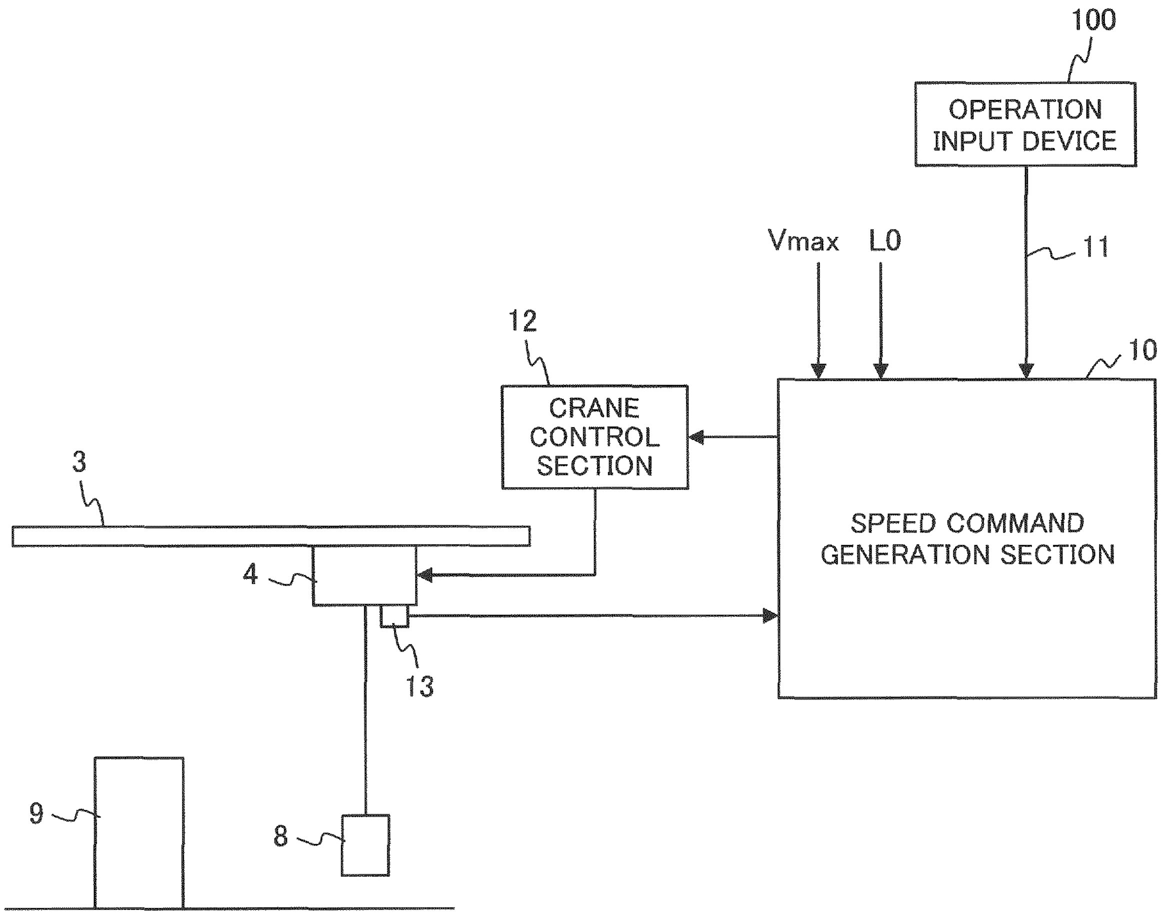
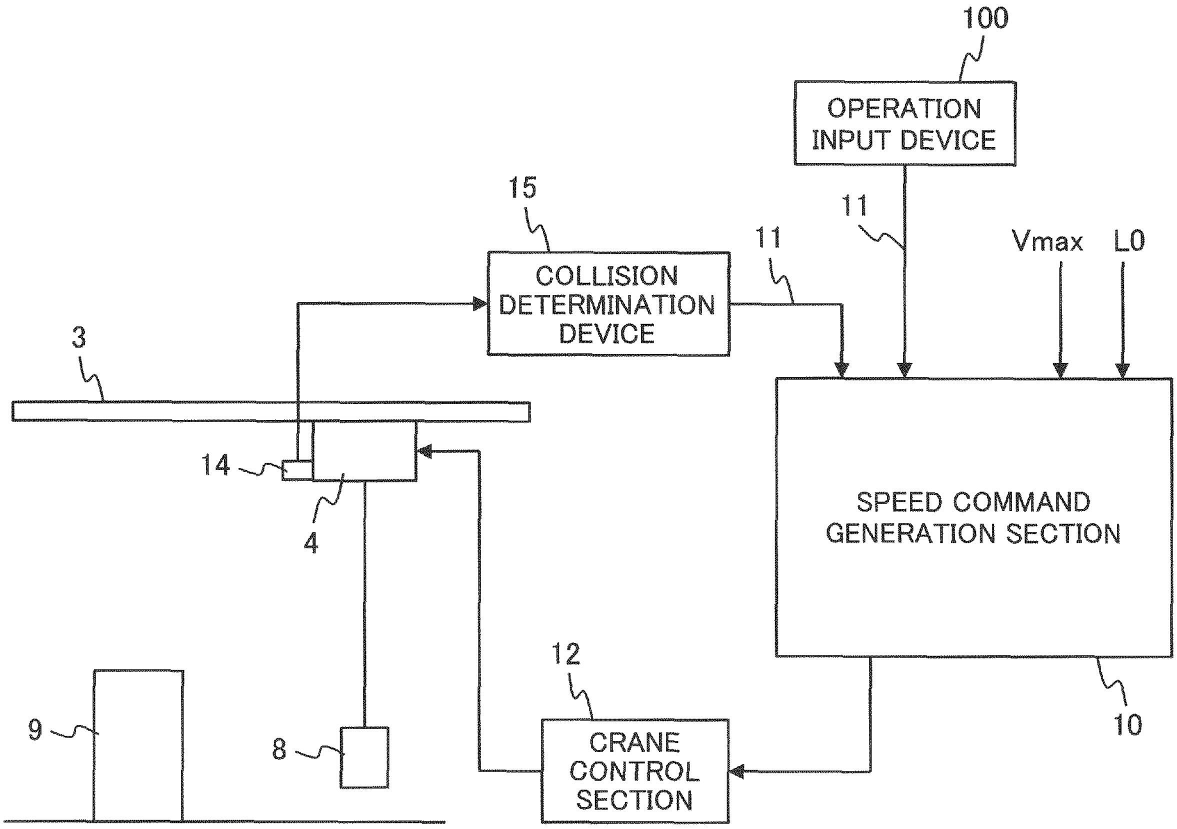

100
OPERATION INPUT DEVICE
Vmax
L0
11
12
10
CRANE CONTROL SECTION
3
SPEED COMMAND GENERATION SECTION
4
13
9
8

FIG. 7


100
OPERATION INPUT DEVICE
15
COLLISION DETERMINATION DEVICE
11
11
Vmax
L0
3
14
4
SPEED COMMAND GENERATION SECTION
12
10
9
8
CRANE CONTROL SECTION

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/026086

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. B66C13/22(2006.01)i
FI: B66C13/22 M

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)
Int. Cl. B66C13/22, B66C15/00

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	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

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.
X Y A	JP 56-149986 A (MITSUBISHI ELECTRIC CORP.) 20 November 1981, column 1, line 18 to column 18, line 14, fig. 1-3, 4, 10	1-2, 4, 11-12, 14 10, 20 3, 5-9, 13, 15-19
Y	JP 60-153392 A (TOSHIBA CORP.) 12 August 1985, page 2, upper left column, line 20 to upper right column, line 6, page 2, lower right column, lines 12-17, page 3, upper left column, lines 16-20, page 3, upper right column, lines 10-13, fig. 2	10, 20
A	JP 55-123882 A (MITSUBISHI ELECTRIC CORP.) 24 September 1980, column 10, line 20 to column 12, line 1, fig. 6, 7	1-20

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07.09.2020	29.09.2020

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/026086

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 6-80387 A (HITACHI KIDEN KOGYO LTD.) 22 March 1994, paragraphs [0013]-[0018], fig. 9-11	1-20

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/026086

Patent Documents referred to in the Report	Publication Date	Patent Family	Publication Date
JP 56-149986 A	20.11.1981	(Family: none)	
JP 60-153392 A	12.08.1985	(Family: none)	
JP 55-123882 A	24.09.1980	(Family: none)	
JP 6-80387 A	22.03.1994	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP HEI8324960 A **[0004]**