

TITLE OF THE INVENTION

CONTROL DEVICE AND INVERTER DEVICE OF SUSPENSION
CRANE

5 BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a control device of a suspension crane that is used in, for example, harbors, steelworks, and various factories,
10 which causes a trolley to traverse to perform cargo handling work, and an inverter device including the control device; and more specifically, relates to a control technique for transporting a suspended load, which is suspended by a support member such as a
15 rope or wire from a trolley, to a target position while suppressing the swing of the suspended load.

2. Description of the Related Art

[0002] In general, in cargo handling work using
20 suspension cranes, it is desirable to control a suspended load to precisely reach a target position within a short period of time, and at the same time, to perform swing-stop control that makes the swing angle of the suspended load diminish to zero
25 ideally, while the trolley is accelerated, decelerated or stopped. As a conventional technique to perform this type of swing-stop control, in recent years, electric swing-stop control using a computer has been adopted as described below.

30 [0003] The electric swing-stop control includes a first scheme that calculates a speed command (speed pattern) to minimize the swing of a suspended load at the end of acceleration/deceleration of the

trolley, so as to control the trolley; and a second scheme that feeds back the swing angle of the suspended load to the drive system of the trolley so as to control the trolley.

- 5 [0004] As a conventional technique according to the first scheme, for example, a swing-stop control device has been known as described in Patent Document 1. FIG. 11 is a block diagram of this swing-stop control device that includes:
- 10 an input device 101 to take as input the length l of a rope 123 supporting a suspended load 124, the travel distance L of a trolley 122, which will be described later, and the maximum acceleration $\alpha_{\max}$ and the maximum speed $V_{\max}$ are entered as travel
- 15 conditions;
- a speed pattern generator 102 to generate multiple speed patterns 1 to N by using the above travel conditions, predetermined equations of motion, boundary conditions, and constraint
- 20 conditions;
- a swing angle calculator 105 to generate swing angle calculation values 1 to N for the suspended load 124 (rope 123) corresponding to the respective speed pattern 1 to N ;
- 25 an evaluation criteria calculator 106 to evaluate the speed patterns 1 to N so as to select a speed pattern with which the suspended load can reach the target position in the shortest time with a minimum swing angle θ , based on the acceleration, amount of acceleration change, acceleration change
- 30 time, and the like output from the speed pattern generator 102, and a swing angle θ (swing angle calculation values 1 to N) output from the swing

angle calculator 105;

a speed pattern selector 103 to select a predetermined speed pattern according to a selection signal output from the evaluation criteria

5 calculator 106;

a speed command generator 104 to generate a speed command V_d according to the selected speed pattern; and

a speed control device 110 to drive a trolley
10 device 120 according to the speed command V_d .

Here, the speed control device 110 includes a compensator 111, an amplifier 112, an electric motor 113 and a speed detector 114; and the trolley device 120 is constituted with a gear mechanism 121 driven
15 by the electric motor 113, a trolley 122, a rope 123, and a suspended load 124.

[0005] In the swing-stop control device illustrated in FIG. 11, the speed patterns 1 to 4 may include, for example, as illustrated in FIG. 12,
20 a simple speed pattern 1 that includes a constant speed section (t_1 to t_2) between an acceleration section and a deceleration section, and in addition, a speed pattern 2 that provides constant speed sections in an acceleration section and a
25 deceleration section, and speed patterns 3 and 4 that repeat acceleration and deceleration in an acceleration section and in a deceleration section.

[0006] Next, FIG. 13 is a block diagram of a swing-stop control device, which is described in
30 Patent Document 2, and corresponds to the conventional technique based on the second scheme described earlier. In FIG. 13, a lumped derived speed command N_{RF0} output from the linear command

dispatcher 201 is fed into the damping controller 202, added with a speed command correction signal N_{RFDF} , and the added result is output as a final speed command N_{RF2} . The speed controller 203

5 operates to generate a torque command T_{RF} so as to eliminate the deviation between the speed command N_{RF2} and a speed feedback signal N_{MFB} of the electric motor, and the deviation between an electric motor torque T_M via the torque controller 204 and a load

10 torque T_L from a load model 209 is converted into an electric motor speed N_M by a mechanical constant 205 of the electric motor. This electric motor speed N_M is converted into the speed feedback signal N_{MFB} by a speed detection filter 206, and at the same time,

15 fed into the swing angle model 207 to calculate the swing angle θ of the suspended load, and this swing angle θ is fed into the load model 209.

[0007] Further, the swing angle θ is converted into a swing angle signal θ_E by a swing angle

20 detector 208, and fed into the damping controller 202. The damping controller 202 subtracts a calculation result using the swing angle signal θ_E ; the traveling speed V_R of the trolley; the natural angular frequency ω_E ; gravity acceleration g ; and a

25 damping coefficient δ , from the speed command N_{RF0} , to calculate a speed command N_{RF1} . The deviation between this speed command N_{RF1} and the speed feedback signal N_{MFB} is fed into a PI controller that includes a swing-stop control gain G , to obtain the

30 speed command correction signal N_{RFDF} , and by adding the correction signal N_{RFDF} to the speed command N_{RF0} , the speed command N_{RF2} described above is calculated. As a result of the above operations, the speed

command N_{RF2} is damped according to the swing angle θ and the damping coefficient δ , and thereby, it is possible to suppress the swing of the suspended load.

5 [0008] Also, as a conventional technique according to the second scheme, an overhead crane control system has been known as described in Patent Document 3. FIG. 14 is a block diagram illustrating main parts of this control system. In FIG. 14,
10 based on a target speed value of a suspended load and a model speed, a control calculator 301 in a DSP (Digital Signal Processor) 300 calculates a control speed of a trolley and a girder forming a traverse trajectory of the trolley, and outputs the control
15 speed to a model calculator 302 and a real controller 330. Based on the fed control speed, and information detected by a rotary encoder 310 and a line laser device 320, the model calculator 302 simulates motion of a suspended load and the like,
20 and feeds back the model speed of the suspended load as the result of simulation to the control calculator 301. Also, according to the control speed calculated by the control calculator 301, the real controller 330 operates an inverter for driving
25 an electric motor in the trolley drive device. Note that the rotary encoder 310 detects a rotational displacement or the like in a winding device of a wire that supports the suspended load; and the line laser device 320 detects the swing angle and the
30 swing period of the wire (suspended load), the wire length, and the like.

[Related-Art Documents]

[Patent Documents]

[0009]

[Patent Document 1] Japanese Patent Publication No. H2-44757 (line 23 in the right-hand column on page 2 to lines 24 on page 3, FIG. 2, FIG. 3, etc.)

[Patent Document 2] Japanese Laid-Open Patent Application No. H8-2877 ([0039], [0040], FIG. 1, etc.)

[Patent Document 3] Japanese Laid-Open Patent Application No. 2018-2391 ([0021] to [0025], [0042] to [0044], FIGs. 1 to 4, etc.)

[Summary of Invention]

[Problem to be Solved by the Invention]

15 [0010] The conventional techniques illustrated in FIGs. 11 and 12 determine the swing angle θ by so-called feed-forward control, and at the same time, assumes that the conditions of the speed patterns 1 to N depend on the natural frequency (swing period) that varies with the length l of the rope 123, and
20 the initial value of the swing angle is zero. Therefore, in the case where the natural frequency changes while the trolley is traversing, the control performance decreases. Also, in the conventional
25 techniques illustrated in FIGs. 13 and 14, feedback control is performed using the swing angle, swing angular speed, swing period, and the like detected by optical sensors (the swing angle detector 208 and the line laser device 320, which are generally
30 delicate and expensive, and robust against disturbance, but the entire system becomes expensive. In particular, there have been problems that calculation for performing the swing-stop

control is complicated, and hence, an expensive computing device such as a DSP is required.

[0011] Thereupon, the problem to be solved by the present invention is to implement swing-stop control
5 by simulation using a computing device such as a relatively inexpensive PLC (Programmable Logic Controller) or the like, and to provide a control device of a suspension crane and an inverter device including the control device that can be applied to
10 existing simple crane systems.

[Means for Solving Problems]

[0012] In order to solve the above problems, a control device of a suspension crane according to
15 claim 1 that transports a suspended load suspended from a trolley via a support member by driving, as a moving part, the trolley or a girder served as a traverse trajectory of the trolley, includes:

a crane simulator unit configured to
20 calculate a swing angle estimate of the suspended load and a speed estimate of the moving part by simulation using a speed command for the moving part, a length of the support member, a time constant of a speed response, and gravitational
25 acceleration;

a swing-stop controller configured to generate a speed correction signal for suppressing the swing of the suspended load, by using the speed command for the moving part, the swing angle
30 estimate, the speed estimate, a natural angular frequency of the suspended load, and a damping coefficient; and

a correction unit configured to correct and

output the speed command by the speed correction signal,

wherein the control device drives the moving part, based on the corrected speed command output from the correction unit.

[0013] According to claim 2, the crane simulator unit in the control device of the suspension crane as claimed in claim 1 includes:

a first-order lag element configured to generate the speed estimate from the speed command for the moving part,

an oscillation model configured to calculate an amplitude of the suspended load from a distance estimate obtained by integrating the speed estimate, and

a swing angle conversion element configured to convert the amplitude into the swing angle estimate.

[0014] An inverter device according to claim 3 includes:

a simulator device configured to include the crane simulator unit, the swing-stop controller, and the correction unit as claimed in claim 1 or 2;

a speed adjuster configured to generate a torque command based on the speed command output from the correction unit; and

an inverter controller and a main circuit configured to supply electric power to the moving part of the drive device, based on the torque command.

[Effects of the Invention]

[0015] According to the present invention, it is

not necessary to detect the swing angle of a
suspended load by using expensive optical sensors,
and it is possible to implement a control device and
an inverter device that are capable of suppressing
5 the swing of a suspended load, by performing a
simple simulation that uses a speed command for a
moving part, such as a trolley, and the length of a
support member such as a rope, to correct the speed
command.

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[Brief Description of Drawings]

[0016] FIG. 1 is a schematic configuration diagram
of a suspension crane system according to an
embodiment of the present invention;

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FIG. 2 is a diagram illustrating a crane
model that is equivalent to the system in FIG. 1;

FIG. 3 is a block diagram of a simple crane
model corresponding to the model in FIG. 2;

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FIG. 4 is a block diagram of a crane
simulator unit obtained by applying an equivalent
transformation to the simple crane model in FIG. 3;

FIG. 5 is a block diagram of an inverter
device according to an embodiment of the present
invention;

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FIG. 6 is an explanatory diagram of
simulation conditions according to an embodiment of
the present invention;

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FIG. 7 is a waveform diagram illustrating a
simulation result according to an embodiment of the
present invention in the case of setting the rope
length to be constant;

FIG. 8 is a waveform diagram illustrating a
simulation result according to an embodiment of the

present invention in the case of gradually lengthening the rope length;

FIG. 9 is a block diagram of a real crane model that takes friction into account;

5 FIG. 10 is a waveform diagram illustrating a simulation result according to an embodiment of the present invention in the case of ignoring part of friction on the side of a real crane model;

10 FIG. 11 is a block diagram of a swing-stop control device according to Patent Document 1;

FIG. 12 is a diagram illustrating a speed pattern of a trolley according to Patent Document 1;

FIG. 13 is a block diagram of a swing-stop control device according to Patent Document 2; and

15 FIG. 14 is a block diagram illustrating main parts of an overhead crane control system according to Patent Document 3.

[Mode for Carrying Out the Invention]

20 [0017] In the following paragraphs, an embodiment according to the present invention will be described with reference to the drawings. FIG. 1 is a schematic configuration diagram of a suspension crane system to which the present embodiment is applied. In FIG. 1, a trolley 1 can be moved along a traverse trajectory on a girder 2 by a trolley drive device 6, and a suspended load 4 suspended by a support member 3 such as a rope or wire (hereinafter, the support member is assumed to be a rope) from a trolley 1 which can be wound up or down by a hoist drive device 5. Here, both the hoist drive device 5 and the trolley drive device 6 are equipped with electric motors, and these electric

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motors are operated by an inverter device 10. Note that the girder 2 can be moved in a direction orthogonal to the plane of the sheet by another drive device, which is not illustrated.

5 [0018] The crane system in FIG. 1 can be represented by an equivalent crane model as illustrated in FIG. 2. In FIG. 2, M represents the weight of the trolley 1; m represents the weight of the suspended load 4 including a hook and the like; 10 l represents the length of the rope 3; and θ represents the swing angle of the suspended load 4 (rope 3). Also, x represents the travel distance of the trolley 1 relative to point 0 as the reference position; y represents the moved distance of the 15 suspended load 4 relative to the same point 0 as the reference position; and $(y-x)$ represents the relative travel distance of the suspended load 4 with respect to the trolley 1, namely, the amplitude of the suspended load 4. Further, f represents the 20 drive force acting on the trolley 1; and d represents the disturbance force acting in a direction that disturbs the drive force f .

[0019] Assuming that the position of the trolley 1 is not affected by the swing of the suspended load 25 4; the weight M of the trolley 1 and the weight m of the suspended load 4 are ignored; and the speed response to a speed command given to the trolley drive device 6 until the trolley 1 reaches a real speed is approximated as a first-order lag, the 30 crane model in FIG. 2 can be represented by a simple crane model 11 in FIG. 3. In the simple crane model 11 in FIG. 3, n_r represents a speed command given to the trolley drive device 6; 11a designates a

distance calculation model; 11b designates an oscillation model of a simple pendulum; 11c designates a subtractor; 11d designates a swing angle conversion element; T represents a time constant of the speed response; k represents a conversion coefficient from the speed to the distance travelled ; g represents gravitational acceleration; l represents the length of the rope 3 as described earlier; and s represents the Laplace operator. The oscillation model 11b described above can be derived, for example, from [Formula 2] described in the paragraph [0046] of Japanese Laid-Open Patent Application No. 2006-225138. Here, the speed command n_r may be a command of either one of a linear speed for causing the trolley 1 to traverse, or a rotational speed of the electric motor in the trolley drive device 6.

[0020] According to the simple crane model 11 described above, the difference between the output y of the oscillation model 11b and the output x of the distance calculation model 11a, namely, the amplitude (y-x) of the suspended load 4 can be obtained by the subtractor 11c, and this amplitude (y-x) can be converted into the swing angle θ by the swing angle conversion model 11d.

[0021] Further, by applying an equivalent transformation to the simple crane model 11 in FIG. 3 for extracting a speed estimate n_{sim} and a swing angle estimate θ_{sim} , the crane simulator unit 11A in FIG. 4 is obtained. This crane simulator unit 11A has a function of calculating the speed estimate n_{sim} and the swing angle estimate θ_{sim} by simulation that uses the speed command n_r (or a speed command n_r'

after correction) and the length l of the rope 3.

[0022] In other words, the crane simulator unit 11A converts the speed command n_r into the speed estimate n_{sim} by the first-order lag element 11e, and
5 outputs n_{sim} . Also, the speed estimate n_{sim} is fed into an integration element 11f to calculate the distance estimate x_{sim} , and this distance estimate x_{sim} is fed into the oscillation model 11b to calculate the distance estimate y_{sim} . Then, the
10 difference between the distance estimate y_{sim} and the distance estimate x_{sim} , namely, the amplitude estimate $(y_{sim}-x_{sim})$ is calculated by the subtractor 11c, and this amplitude estimate $(y_{sim}-x_{sim})$ is converted into the swing angle estimate θ_{sim} by the
15 swing angle conversion model 11d.

[0023] Next, FIG. 5 is a block diagram of an inverter device 10 equipped with the crane simulator unit 11A. This inverter device 10 includes a simulator device 14 that includes a crane simulator
20 unit 11A and a swing-stop controller 12, which will be described later; a speed adjuster (ASR) 15 to calculate a torque command or the like from a speed command n_r ' output from the simulator device 14; an inverter controller and a main circuit 16 to turn on
25 and off a semiconductor switching element by control pulses generated based on the output of the ASR 15.

[0024] The simulator device 14 is implemented by, for example, hardware such as a PLC and a program installed thereon. The swing angle estimate θ_{sim} and
30 the speed estimated n_{sim} output from the crane simulator unit 11A are fed into the swing-stop controller 12. The swing angle estimate θ_{sim} is fed into a damping calculator 12a (ω : natural angular

frequency= $\sqrt{g/l}$, σ : damping coefficient), and the difference between the speed command n_r from the speed change rate limiter (HLR) 17 and the output of the damping calibrator 12a is calculated by a
5 subtractor 12b. Further, the difference between the output of the subtractor 12b and the speed estimate n_{sim} is calculated by a subtractor 12c, and the result is multiplied by a swing-stop control gain G_1 , to calculate a speed correction signal n_{comp} .
10 This speed correction signal n_{comp} is added with the speed command n_r by an adder 13 to obtain a final speed command n_r' , and based on this speed command n_r' , by controlling the speed adjuster 15, the inverter controller, and the main circuit 16, the
15 trolley 1 of a real machine is driven through the trolley drive device 6.

[0025] As described above, once a speed command n_r (or n_r') and the rope length l are given, by using these with the time constant T of the speed
20 response, the conversion coefficient k , and the gravitational acceleration g in simulation, the crane simulator unit 11A can obtain a swing angle estimate θ_{sim} and a speed estimate n_{sim} . Then, the swing-stop controller 12 can obtain a speed
25 correction signal n_{comp} , by calculation using the above swing angle estimate θ_{sim} , the speed estimate n_{sim} , the damping coefficient σ , the natural angular frequency ω , and the swing-stop control gain G_1 . By driving the trolley 1 according to a speed command
30 n_r' for damping control corrected by the speed correction signal n_{comp} , it is possible to transport the suspended load 4 while suppressing the swing.

[0026] Here, in order to confirm the effects of

the present embodiment, the inventors performed a simulation under the conditions in FIG. 6, wherein the rope length l is set to be constant ($l = 15[m]$). Also, the damping coefficient σ and the swing-stop control gain G_1 were assumed to work ideally without a lag, and set as $\sigma=0.55$ and $G_1=0.55$, and the time constant T of the speed response was assumed to be $T = 50 [ms]$, although T varies in practice depending on the machine and/or the gain of the speed adjuster

10 15.

[0027] Note that the weight M' of the "girder part" among the simulation conditions in FIG. 6 is the weight of the entire moving part including the trolley 1 and the girder 2 in FIG. 1. In other words, in this simulation, although the trolley 1 and the girder 2 are regarded as an integrated "girder part", and this "girder part" is assumed to be driven in a direction orthogonal to the sheet of FIG. 1, the principles of the swing-stop control are

15 20 substantially the same as those used when driving the trolley 1 described earlier, and this corresponds to the case where the output of the inverter device 10 in FIG. 5 is given to the girder part drive device.

[0028] FIG. 7 is a waveform diagram illustrating a simulation result based on the conditions described above, in which the girder part speed (corresponding to n_r and n_r' in FIG. 5), the electric motor torque of the girder part drive device, the swing angle θ of the suspended load 4, and the swing angle estimate θ_{sim} obtained by the crane simulator unit 11A are shown. According to FIG. 7, the swing angle estimate θ_{sim} obtained was almost identical to the

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swing angle θ , and it can be seen that, by operating with the speed command n_r' after making the correction based on this swing angle estimate θ_{sim} , the swing can be stopped.

5 [0029] Next, FIG. 8 illustrates waveforms in the case of lengthening the rope length l from 15 [m] by 0.05 [m/s]. According to FIG. 8, it was confirmed that a residual swing in the swing angle θ was present after approximately 35 [s]. This residual
10 swing was present because, as illustrated in FIG. 9, in the real crane model, static friction 22 and dynamic friction 23 were added to be fed back to the torque (thrust), and thereby, the friction component (mechanical loss) was taken into account. Note that
15 in FIG. 9, 20 designates a friction model; 21 designates a sign function; 30 designates a girder part model including a trolley and a girder; and 40 designates a suspended load model including a rope and a suspended load. Thereupon, the simulation was
20 performed ignoring the friction component on the side of the real crane model, and as a result, waveforms as illustrated in FIG. 10 were obtained. According to FIG. 10, it can be seen that the residual swing present in FIG. 8 almost disappears,
25 and the swing of the suspended load converges to zero.

[0030] Note that as illustrated in FIG. 5, by having the simulator device 14, the speed adjuster
15, the inverter controller, and the main circuit 16
30 built in the inverter device 10, it is possible to configure an inverter device for suspension crane control as a stand-alone device, which makes it easier to introduce the device in a workspace having

constraints in terms of the installation space and/or the installation environment of the device.

[0031] As described above, in the present embodiment, by giving a speed command for a moving
5 part constituted with a trolley and a girder in a suspension crane system; the length of a support member (a rope, wire, or the like) for the suspended load; together with predetermined constants and coefficients, to a simulator device having a
10 relatively simple configuration based on a simple crane model, and by performing simulation, it is possible to obtain a speed estimate of the moving part and a swing angle estimate of the suspended load. Then, by controlling the speed of the moving
15 part by using a speed command corrected based on these estimates, it is possible to implement swing-stop control of the suspended load without requiring a swing angle value detected by expensive optical sensors and the like, and, at the same time, to
20 provide an inexpensive control device, that can be easily applied to existing simple crane systems.

[0032] Further, by putting together the simulator device, the speed adjuster for operating the electric motor for driving the moving part, the
25 inverter controller, and the main circuit, to configure an inverter device as a stand-alone device, it is possible to reduce the size and to lower the cost of the entire device, compared to the case of configuring each of the devices and circuits
30 independently.

WHAT IS CLAIMED IS

1. A control device of a suspension crane
5 that transports a suspended load suspended from a trolley via a support member by driving, as a moving part, the trolley or a girder served as a traverse trajectory of the trolley, the control device comprising:
 - 10 a crane simulator unit configured to calculate a swing angle estimate of the suspended load and a speed estimate of the moving part by simulation using a speed command for the moving part, a length of the support member, a time
15 constant of a speed response, and gravitational acceleration, wherein the swing angle estimate and the length of the support member are not measured values measured during operation of the suspension crane.;
 - 20 a swing-stop controller configured to generate a speed correction signal for suppressing the swing of the suspended load, by using the speed command for the moving part, the swing angle estimate, the speed estimate, a natural angular
25 frequency of the suspended load, and a damping coefficient; and
 - a correction unit configured to correct and output the speed command by the speed correction signal,
 - 30 wherein the control device drives the moving part, based on the corrected speed command output from the correction unit.

2. The control device of the suspension crane as claimed in claim 1, wherein the crane simulator unit includes

5 a first-order lag element configured to generate the speed estimate from the speed command for the moving part,
 an oscillation model configured to calculate an amplitude of the suspended load from a
10 distance estimate obtained by integrating the speed estimate, and
 a swing angle conversion element configured to convert the amplitude into the swing angle estimate.

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3. An inverter device comprising:

 a simulator device configured to include the crane simulator unit, the swing-stop controller,
20 and the correction unit as claimed in claim 1 or 2;
 a speed adjuster configured to generate a torque command based on the speed command output from the correction unit; and
 an inverter controller and a main circuit
25 configured to supply electric power to the moving part of a drive device, based on the torque command.