

SPECIFICATION

METHOD OF BRACING CRANE

TECHNICAL FIELD

The present invention relates to a method of controlling the stoppage of the swing of suspended type cranes having a trolley car and a hoisting winch and container cranes having a rope trolley driven traverse gear and a hoisting winch.

BACKGROUND ART

In general, a suspended type crane has a configuration as shown in Fig. 8, wherein a trolley car 1 travels on wheels 2 along rails 3. The rails 2 are driven for rotation by a travel motor 11 mounted on the trolley car 1 through a reducer 12. An electromagnetic brake 12 and a speed detector 14 for detecting the speed of the travel motor 11 are attached to the rotational axis of the motor 11.

A hoisting winch 4 having a hoisting drum 41 is mounted on the trolley car 1. The hoisting drum 41 is driven for rotation by a hoisting motor 42 through a reducer 43. An electromagnetic brake 44 and a pulse signal generator 45 for detecting the speed of the motor are attached to the rotational axis of the hoisting motor 42. A rope 5 is wound around the hoisting drum 41 for hoisting a load 6 through a hoisting accessory 51.

Control over the traveling speed of the trolley car 1 is effected by controlling the traveling motor 11 using a travel driving controller 20. Fig. 10 is a block diagram of the travel driving controller 20. A speed command signal from a speed commander 21 is input to a linear commander 22 which provides a ramp speed command N_{RF} . The deviation of the ramp speed command N_{RF} from a motor speed feedback signal N_{MFB} , which is detected by the speed detector 14 and generated through a filter 26 as a first-order lag element is input to and amplified by a speed controller 23 with an integrator having a proportional gain A and a time constant τ_i to be output as a torque command signal T_{RF} . The torque command signal T_{RF} is input to a motor torque controller 24 for controlling the torque of the motor with a first-order lag time constant τ_y applied. Thus, the torque T_M of the travel motor 11 is adjusted to control the speed of the travel motor 11. The speed feedback signal N_{MFB} is generated by passing the rotational speed of the motor through the first-order lag element. 25 designates a block representing a mechanical time constant τ_M of the travel motor 11, and N_M designates the speed of the motor (p. u). 27 designates a block representing a dynamic model of the load, and 28 designates a block representing a model of load torque T_L (p.u) of the motor.

In the block 27, θ represents the swing angle (rad) of the rope 5.

When the travel drive controller 20 in Fig. 10 controls the traveling speed of the trolley car 1 in accordance with a ramp acceleration/deceleration speed command N_{RF} obtained by inputting a speed command signal for high or low speed from the speed commander 21 to the linear commander 22, periodic swings of the load occur in response to the acceleration and deceleration of the trolley car 1. The swing angle of the rope 5 increases as the acceleration and deceleration of the trolley car 1 increase.

As a solution to this problem, the operators have manually changed the traveling speed of the trolley car during acceleration or deceleration of the trolley car depending on the swings of the load to stop the periodic swings of the load.

Fig. 11 illustrates the relationship between a speed command, motor speed, the swing angle of the rope, and load torque, and shows that periodic swings of the load continuously occur during the acceleration and deceleration of the trolley car, destabilizing the variable speed characteristics of the trolley car. The swing angle θ of the rope is indicated using the symbol " $^\circ$ ".

With the above-described configuration, in order to stop the periodic swings of the load, the operator of the crane must accelerate and decelerate the trolley car depending on the swings of the load. When the crane is operated remotely or automatically, the acceleration and

deceleration of the trolley car must be very slow. This has significantly reduced the transporting capability of the crane.

DISCLOSURE OF THE INVENTION

It is an object of the present invention to suppress periodic swings of a load caused by acceleration and deceleration of a trolley car, thereby allowing a crane to be operated automatically with the travel of the trolley car maintained at a high speed.

According to the present invention, there is provided a method of stopping swings of a suspended type crane having a travel motor for driving a trolley car for travel, a travel drive controller having a controlling function to control the speed of the motor by calculating a torque command using a speed controller having only a proportional integrator or proportional gain from a signal indicative of the deviation of a travel motor speed feedback signal N_{MFB} detected by a speed detector on the travel motor and from a speed command signal N_{RFO} output by a speed commander of the travel motor, a hoist motor for driving a hoisting winch provided on the trolley car, a hoisting accessory for suspending a load at the end of a rope to be hoisted by the hoisting winch, and a drive controller for the hoist motor, wherein:

a damping factor is generated upon the swings of the load by controlling the speed of the travel motor by

use of the speed controller of the travel motor in accordance with a travel speed command signal N_{RF1} which has been corrected to make the positional error E_{RR1} of the trolley car from the optimum traveling position where the swing of the load is suppressed closer to 0, the correction being performed by adding to the speed command signal N_{RF0} output by the speed commander a speed correction signal N_{RFDp} obtained by amplifying the positional error E_{RR1} with a proportional integral amplifier or proportional amplifier, the positional error E_{RR1} being obtained by making the following calculation from the speed V_{LE} of the load in the direction of its travel detected by a speed detector attached to the hoisting accessory, a set damping coefficient δ , the travel speed command signal N_{RF0} , the motor speed feedback signal N_{MFB} , and a measured value L_E of the length of the rope from the hoisting drum and the load obtained by the hoisting speed detector:

$$E_{RR1} = N_{RF0}/s - N_{MFB}/s - \{2\delta/(V_R\omega_E)\}V_{LE}$$

where $\omega_E = (g/L_E)^{1/2}$; V_R represents the speed of the trolley car corresponding to the rated speed of the travel motor; g represents gravitational acceleration; and s represents a Laplace operator.

A description will now be given of the operation of a controller according to the invention for suppressing periodic swings of a load and the principle behind the suppression of swings of the rope.

Referring to Fig. 9, a wing angle θ (rad) of the rope is obtained from a well known equation of motion given below as Equation 1 where the traveling speed of the trolley car is represented by V_1 (m/sec) and the length of the rope is represented by L (m).

$$\frac{d^2\theta}{dt^2} + \omega^2\theta = \left(\frac{\omega^2}{g}\right) \frac{dV_1}{dt}, \quad \text{where } \omega = \sqrt{\frac{g}{L}} \quad (1)$$

The traveling speed V_1 of the trolley car and the speed N_M of the travel motor are in the relationship defined by the Equation 2 shown below.

$$V_1 = V_R N_M \quad (2)$$

Substitution of Equation (2) in Equation (1) gives Equation 3 as shown below.

$$\frac{d^2\theta}{dt^2} + \omega^2\theta = \left(\frac{\omega^2 V_R}{g}\right) \frac{dN_M}{dt} \quad (3)$$

Equation 3 can be changed as follows using the Laplace operator s .

$$s^2\theta + \omega^2\theta = \left(\frac{\omega^2 V_R}{g}\right) sN_M(s) \quad (4)$$

$\theta(s)$ can be given as Equation 5 shown below from Equation 4.

$$\theta = \left(\frac{\omega^2 s}{s^2 + \omega^2}\right) \left(\frac{V_R}{g}\right) N_M(s) \quad (5)$$

Equation 5 is equivalent to the dynamic model of the swing angle of the rope in block 27 in Fig. 1.

Since $\theta=0$ when $t=0$, $\theta(t)$ at the time of predetermined acceleration α (p.u./sec) of the travel motor can be obtained as Equation 6 shown below from Equation 4.

$$\theta = \left(\frac{V_R \alpha}{g} \right) (1 - \cos \omega t) \quad (6)$$

Equation 6 indicates that the swing angle θ vibrates. The vibration starts as the acceleration of the trolley car starts and lasts for a considerable time after the acceleration stops, as it is only air resistance or the like which applies a force to damp the periodic swing of the load.

Equation 7 is obtained if the traveling position of the load in its traveling direction from the starting point of the travel of the trolley car as the origin is represented by x and the swing angle θ (rad) of the rope is approximated by $\sin \theta \doteq \theta$ because it is small.

$$\theta = \frac{V_R N_M}{Ls} - \frac{x}{L} \quad (7)$$

where L represents the length of the hoisting rope.

Equation 4 is changed into an equation for the position x of the load in the traveling direction thereof (Equation 8 below) after substituting Equation 7 for the θ in Equation 4.

$$s^2x + \omega^2x = \frac{\omega^2 V_R N_M}{s} \quad (8)$$

where $\omega = (g/L)^{1/2}$.

Equation 8 indicates that the position x of the load in the traveling direction thereof is a function which varies periodically.

Damping of such a motion of the load so that its position periodically changes can be performed by controlling the speed of the motor for causing the trolley car to travel, so that the right side of Equation 8 will include a function of $-sx$. Then, the right side of Equation 8 is divided as shown on the right side of Equation 9 shown below.

$$\frac{\omega^2 V_R N_M}{s} = \frac{\omega^2 V_R N_{MO}}{s} - 2\delta\omega sx \quad (9)$$

where δ represents a set value of the damping coefficient for the swinging motion of the load, and N_{MO} represents a component of speed in the motor speed N_M which is proportional to the speed command N_{RFO} output by the speed commander. Equation 9 can be changed into Equation 10 as shown below with N_{MO} replaced by N_{RFO} .

$$\frac{N_{RFO}}{s} - \frac{N_M}{s} - \left(\frac{2\delta}{V_R \omega} \right) sx = 0 \quad (10)$$

sx of the third term on the left side of Equation 10 is a differential signal of the position x of the

load and is equal to the moving speed V_L of the load. Therefore, Equation 11 is obtained as shown below by replacing sx with V_L and by substituting E_{RR} for the left side of Equation 10.

$$E_{RR} = \frac{N_{RFO}}{s} - \frac{N_M}{s} - \left(\frac{2\delta}{V_R\omega} \right) V_L \quad (11)$$

The first term on the right side of Equation 11 indicates the value of a position command because it is the time integration of the speed command signal for the travel motor.

The second term on the right side of Equation 11 indicates the position of the trolley car because it is the time integration of the speed of the travel motor.

The third term on the right side of Equation 11 is a signal proportional to the moving speed of the load.

E_{RR} on the left side of Equation 11 represents a positional error of the trolley car in relation to the optimal positional condition for suppressing the swing of the load indicated by Equation 10.

Equation 11 can be changed into Equation 13 shown below which gives a positional error E_{RR1} of the trolley car in relation to the optimal positional condition for suppressing the swing of the load by replacing N_M of the second term on the right side thereof with the travel motor feedback signal N_{MFB} , replacing V_L of the third term with the moving speed detection signal V_{LE} of the load, and replacing ω of the third term with the angular

velocity ω_B of the swing of the load calculated according to Equation 12 as shown below from the measured length L_E of the hoisting rope and gravitational acceleration g .

$$\omega_E = \sqrt{\frac{g}{L_E}} \quad (12)$$

$$E_{RR1} = \frac{N_{RFO}}{s} - \frac{N_{RFB}}{s} - \left(\frac{2\delta}{V_R \omega_E} \right) V_{LE} \quad (13)$$

A damping factor is generated upon the swinging motion of the load to suppress periodic swings by controlling the speed of the travel motor using a travel speed command signal corrected so that the positional error signal E_{RR1} approaches zero.

As described above, the present invention enables periodic swings of the load generated during acceleration and deceleration of the trolley car to be suppressed, thereby eliminating the need for manual operations to stop the swings. This allows the trolley car to travel at a high speed and enables significant improvement in the transporting capability of the crane through automatic operation.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing a first embodiment of a travel drive controller according to the present invention.

Fig. 2 is a block diagram showing a second embodiment of a travel drive controller according to the present invention.

Fig. 3 is a block diagram showing a third embodiment of a travel drive controller according to the present invention.

Fig. 4 is a block diagram showing a fourth embodiment of a travel drive controller according to the present invention.

Fig. 5 is a block diagram showing a fifth embodiment of a travel drive controller according to the present invention.

Fig. 6 is a block diagram showing a sixth embodiment of a travel drive controller according to the present invention.

Fig. 7 illustrates acceleration and deceleration characteristics of a travel drive controller for a trolley car according to the present invention.

Fig. 8 illustrates a configuration of a suspended type crane on which a trolley car having a hoisting winch mounted thereon travels.

Fig. 9 illustrates the dynamic relationship between a trolley car travel device and the weight of a load.

Fig. 10 is a block diagram showing a conventional travel driving device.

Fig. 11 illustrates acceleration and deceleration characteristics of a conventional travel driving device.

Fig. 12 illustrates a configuration of a rope driven crane having a traverse driving device and a hoist driving device mounted on a fixed side thereof.

BEST MODE FOR CARRYING OUT THE INVENTION

The present invention will now be described with reference to the embodiments thereof as shown in the accompanying drawings.

Fig. 1 is a block diagram of a travel drive controller for a trolley car having a speed controller according to the present invention. The components identical to those in Fig. 10 referred to in the section of the description of the related art are given like names and reference numbers and so will not be described.

A first embodiment of the present invention will now be described with reference to Fig. 1.

A motor speed detection feedback signal N_{RFB} which is a signal from a speed detector 14 attached to the rotational axis of a travel motor 11, is fed back through a filter 26 having a first-order lag element to a signal N_{RF1} , which is obtained by adding a speed command correction signal N_{RFDP} for damping control to an output signal $NRFO$ of a speed commander 21.

The deviation of the speed command N_{RF1} from the motor speed detection signal N_{MFB} is input to a speed controller 23 which in turn outputs a torque command signal T_{RF} , which is obtained by adding a signal

achieved by multiplying the speed deviation signal by a proportional gain A and a signal obtained by integrating the speed deviation signal at a time constant τ_I . If the speed controller 23 has only the proportional gain A , a signal obtained by multiplying the speed deviation signal by A is output to a torque controller 24 as the motor torque command signal T_{RF} .

The torque controller 24 controls the torque of the motor torque T_M using the first-order lag element τ_T in accordance with the torque command signal T_{RF} .

30 designates an angular velocity calculator for calculating the angular frequency ω_B of the swing of a load. The angular frequency ω_B is calculated from a measured value of the length (L_E) of the rope from the hoisting drum and the load obtained by the hoisting speed detector according to Equation 12.

Next, the operation of a damping controller 29 will be described.

In the damping controller 29, a proportional integral amplifier comprising a proportional gain G and an integral time constant τ_{DP} amplifies a positional error E_{RR1} of the trolley car that differs from the optimal position for suppressing the swing thereof obtained according to Equation 13 based on the travel speed command signal N_{RFO} , the motor speed feedback signal N_{MFB} , the angular frequency signal ω_B , a detection signal L_E indicating the speed of the load in the traveling direction thereof detected by a load speed

detector 31 attached to a hoisting accessory 51, and a preset damping coefficient δ . As a result, the damping control speed command correction signal N_{RFDP} for stopping the swing is obtained.

A speed command signal N_{RF1} (p. u) is obtained by adding the damping control speed command correction signal N_{RFDP} to the travel speed command signal N_{RFO} (p. u) output by the speed commander 21, and the deviation thereof from the speed detection signal N_{MFB} (p.u) is input to the speed controller 23. Then, the speed controller 23 controls motor speed N_M so that it follows up the speed command signal N_{RF1} .

Such control allows the swinging motion of a load to be damped at the preset damping coefficient δ , and this suppresses periodic swings of the load.

A second embodiment of the present invention will now be described with reference to Fig. 2.

Instead of the detection signal V_{LE} indicating the speed of a load in the traveling direction thereof as in the first embodiment, acceleration/deceleration α_{VLE} of a load in the traveling direction thereof is detected by an acceleration detector 32. The positional error E_{RR1} from the optimal position of the trolley car for suppressing swing as in the first embodiment is calculated using speed V_{LE1} of the load in the traveling direction thereof obtained by integrating the acceleration/deceleration detection signal α_{LVB} using a

load speed calculator 36. Thus, control is performed in the same manner as in the first embodiment.

A third embodiment of the present invention will now be described with reference to Fig. 3.

Instead of the traveling speed detection signal V_{LE} as in the first embodiment, in this third embodiment, speed V_{LE2} of the load in the traveling direction thereof is used, which is calculated according to Equation 14 shown below based on the motor speed feedback signal N_{MFB} from the travel speed controller, a measured value L_E of the length of the hoisting rope, and a swing angle signal θ_E detected by a rope swing angle detector 38. Using the speed V_{LE2} , the positional error E_{RR1} from the optimal position of the trolley car for suppressing swing as in the first embodiment is calculated to perform control in the same manner as in the first embodiment.

$$V_{LE2} = V_R N_{MFB} - s L_E \theta_E \quad (14)$$

A fourth embodiment of the present invention will now be described with reference to Fig. 4.

In the method of controlling the swing of a crane as described in the first embodiment of the invention, switches SW_1 through SW_n of a damping coefficient switcher 34 are operated according to the state of the operation of the travel motor to select any one of a plurality of damping coefficient preset values δ_1 through δ_n , thereby outputting a damping coefficient preset value signal.

When the damping coefficient preset value signal selected by the damping coefficient switcher 34 is input to a damping coefficient switching adjuster 35, the selected damping coefficient preset value signal is generated through a first-order lag element as a damping coefficient preset value δ .

For example, assume that the output signal of the damping coefficient switcher 34 is switched from δ_1 to δ_2 . Then, although the output signal of the damping coefficient switcher 34 is instantaneously switched from δ_1 to δ_2 , the signal from the output side of the damping coefficient switching adjuster 35 changes slowly. As a result, no direct delay occurs in the calculation of the speed correction signal N_{RFDP} for damping control performed by the damping controller 29. This allows stable control over the stoppage of swings of a crane.

As a fifth and sixth embodiment of the invention, arrangements as shown in Fig. 5 and Fig. 6 may be made wherein the damping coefficient switcher 34 and damping coefficient switching adjuster 35 as described in the fourth embodiment are provided in the configurations according to the second and third embodiments. Thus, switches SW_1 through SW_n of the damping coefficient switcher 34 are operated to select any one of a plurality of damping coefficient preset values δ_1 through δ_n , thereby outputting a damping coefficient preset value signal; the damping coefficient preset value signal selected by the damping coefficient

switcher 34 is input to the damping coefficient switching adjuster 35; and the selected damping coefficient preset value signal is generated through a first-order lag element as a damping coefficient preset value δ .

Although preferred embodiments of the invention have been described with reference to a crane having a travel driving device and a hoist driving device mounted on a trolley car, as shown in Fig. 12, the present invention may be applied as it is to cranes such as container cranes having a traverse trolley car using a rope trolley driving system in which a traverse driving device and hoist driving device are provided on a fixed side thereof. In Fig. 12, 51 designates a traversing device; 56 designates rails; 58 designates a traverse trolley car; 53 designates a hoisting device; 54 designates a container which is a load; 55 designates a controller; 60 designates a traversing rope; 59 designates wheels; 61 designates a drum for driving the rope; 62 designates a reducer; 63 designates a traverse motor; 64 designates an electromagnetic brake; 65 designates a speed detector; 67 and 69 designate guide controllers; 71 designates a hoisting drum; 72 designates a reducer; 73 designates a hoist motor; 74 designates an electromagnetic brake; 75 designates a speed detector; 76 designates a hoisting rope; 77 designates a hoisting portion; 80 designates a hoisting accessory; 81 through 89 designate guide rollers; and 90

designates a winding drum. The description so far applies to the method of controlling the traverse driving device shown in Fig. 12 if the word "travel" is amended to read "traverse". The contents of the disclosure and the appended claims may be read with the word "travel" replaced by "traverse" to apply the present invention to such a method in the same manner as for cranes wherein a travel driving device and a hoist driving device are mounted on a trolley car.

Fig. 7 is a view corresponding to Fig. 11 illustrating the prior art, which shows the operational characteristics of a trolley car obtained using the method of suppressing swing according to the present invention. It is apparent from this view that load swings are sufficiently suppressed and the variable speed characteristics of the trolley car are stable compared to the characteristics shown in Fig. 11 illustrating the prior art.

The present invention may be applied to the field of automatic operations of suspended type cranes having a travel device for driving a trolley car and a hoisting device and container cranes having a traverse device of a rope trolley driving type and a hoisting winch and the like.

CLAIMS

1. A method of stopping swings of a suspended type crane having a travel motor for driving a trolley car for travel, a travel drive controller having a controlling function to control the speed of the motor by calculating a torque command signal T_{RF} using a speed controller having only a proportional integrator or proportional gain from a signal indicative of the deviation of a travel motor speed feedback signal N_{MFB} detected by a speed detector on the travel motor and from a speed command signal N_{RFO} output by a speed commander of the travel motor, a hoist motor for driving a hoisting winch provided on the trolley car, a hoisting accessory for suspending a load at the end of a rope to be hoisted by the hoisting winch, and a drive controller for the hoist motor, wherein:

a damping factor is generated upon the swings of the load by controlling the speed of the travel motor by the speed controller of the travel motor in accordance with a travel speed command signal N_{RF1} which has been corrected to make the positional error E_{RR1} of the trolley car from the optimal traveling position where the swing of the load is suppressed closer to 0, the correction being performed by adding to the speed command signal N_{RFO} output by the speed commander a speed correction signal N_{RFDp} obtained by amplifying the positional error E_{RR1} by a proportional integral amplifier or proportional amplifier, the positional



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error E_{RR1} being obtained by making the following calculation from the speed V_{LE} of the load in the direction of its travel detected by a speed detector attached to the hoisting accessory, a set damping coefficient δ , the travel speed command signal N_{RFO} , the motor speed feedback signal N_{MFB} , and a measured value L_E of the length of the rope from the hoisting drum and the load obtained by the hoisting speed detector:

$$E_{RR1} = N_{RFO}/s - N_{MFB}/s - \{2\delta/(V_R\omega_E)\}V_{LE}$$

where $\omega_E = (g/L_E)^{1/2}$; V_R represents the speed of the trolley car corresponding to the rated speed of the travel motor; g represents gravitational acceleration; and s represents a Laplace operator.

2. The method of stopping swings of a crane according to Claim 1, wherein the positional error E_{RR1} of the trolley car from the optimal traveling position thereof for suppressing the swing of the load is calculated using a speed signal V_{LE1} obtained by performing time integration on a detection signal α_{VL} from a detector for detecting acceleration of the load in the traveling direction thereof attached to the hoisting accessory, instead of the speed signal V_{LE} of the load in the traveling direction thereof detected by the speed detector attached to the hoisting accessory according to Claim 1.

3. The method of stopping swings of a crane according to Claim 1, wherein the positional error E_{RR1} of the trolley car from the optimal traveling position



thereof for suppressing the swing of the load is calculated using a speed signal V_{LE2} obtained by performing a calculation:

$$V_{LE2} = V_R N_{MFB} - S L_E \theta_E$$

based on the motor speed feedback signal N_{MFB} obtained from the travel speed controller, a swing angle signal θ_E detected by a rope swing angle detector, and a measured value L_E of the length of the hoisting rope obtained by the speed detector of the hoist motor, instead of the traveling speed detection signal V_{LE} of the load in the traveling direction thereof detected by the speed detector attached to the hoisting accessory according to Claim 1.

4. The method of stopping swings of a crane according to any one of Claims 1, 2, and 3, wherein a signal arbitrarily selected from among a plurality of damping coefficient preset values according to the state of the operation of the motor is generated through a first-order lag element and wherein the signal is used as the final damping coefficient preset value.

