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ANTI-SWAY CONTROL METHOD AND BRIDGE CRANE.

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The present invention provides an anti-sway control method and a bridge crane. The anti-sway control method includes: starting a crane or a trolley, and determining a starting acceleration pulse A_0 and an anti-driving-sway acceleration pulse A_1 ; calculating a theoretical driving sway angle θ_1 ; measuring a first actual sway angle θ_2 , calculating a disturbance sway angle θ_3 and determining whether it is greater than the minimum disturbance sway angle, if not, controlling the crane or the trolley in operation based on the anti-driving-sway acceleration pulse A_1 , if yes, controlling the crane or the trolley in operation based on the anti-driving-sway acceleration pulse A_1 , calculating a first anti-disturbance-sway acceleration pulse A_2 and controlling the crane or the trolley in operation based on the first anti-disturbance-sway acceleration pulse A_2 ; in a uniform-velocity phase, measuring a second actual sway angle θ_3 and determining whether it is greater than the minimum disturbance sway angle, if yes, calculating a second anti-disturbance-sway acceleration pulse A_3 and controlling the crane or the trolley in operation based on the second anti-disturbance-sway acceleration pulse A_3 ; and repeating the steps in the uniform-velocity phase. This anti-sway control method enables closed-loop control over sway of the lifting hook with high accuracy and allows efficient operation of the bridge crane.

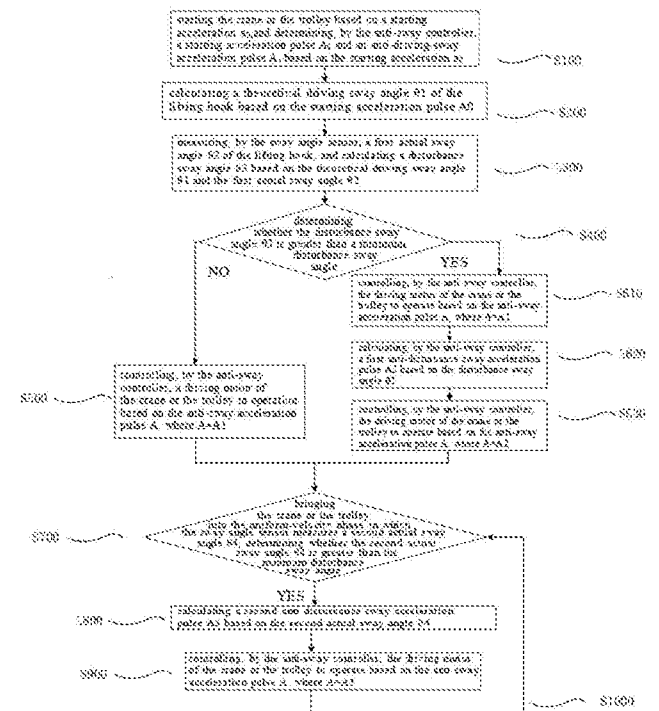


Fig. 1

ANTI-SWAY CONTROL METHOD AND BRIDGE CRANE

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FIELD OF THE INVENTION

The present invention relates to the technical field of bridge crane control, more particularly, to an anti-sway control method and a bridge crane.

DESCRIPTION OF THE RELATED ART

Bridge cranes are important logistics transportation equipment. Currently, during manual operation of a lifter, such as a clamshell lifter or an electromagnetic lifter, of the bridge crane for material handling, the lifted weight always sways, which causes decreased operation efficiency and presents certain safety hazards.

Currently, the anti-sway technique commonly used on the market is the electronic open-loop anti-sway technique that focuses on an optimized design of the control algorithm of the driving inverter on the crane or the trolley in the bridge crane, in which the control elements, such as the actual sway length, the actual sway angle, are mostly determined by indirect calculation or defined through input. However, deflection of the bridge crane in practical engineering is caused by combined factors, including both its own sway during weight lifting and sway due to external interferences. Therefore, determination of the numeric values of the anti-sway control elements through indirect calculation or open-loop definition cannot be easily controlled specifically depending on actual operating conditions, thereby causing low control accuracy and low operating efficiency of anti-sway control.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an anti-sway control method and a bridge crane, to solve the problems of low control accuracy and low operating efficiency of the anti-sway method based on open-loop control during operation of the bridge crane.

In view of this object, the present invention adopts the following technical solutions.

An anti-sway control method is provided for controlling sway of a lifting hook in a bridge crane during an acceleration phase and a uniform-velocity phase, the bridge crane including an anti-sway controller, a crane and a trolley in transmission connection with the crane, the lifting hook being in transmission connection with the trolley, the crane and the trolley both being provided with a sway angle sensor, the anti-sway controller is used for applying an anti-sway acceleration pulse A to the crane or the trolley. The method includes the following steps.

S100: starting the crane or the trolley based on the starting acceleration a_0 , and determining, by the anti-sway controller, the starting acceleration pulse A_0 and the anti-driving-sway acceleration pulse A_1 based on the starting acceleration a_0 .

S200: calculating the theoretical driving sway angle θ_1 of the lifting hook based on the starting acceleration pulse A_0 .

S300: measuring, by the sway angle sensor, the first actual sway angle θ_2 of the lifting hook, and calculating the disturbance sway angle θ_3 based on the theoretical driving sway angle θ_1 and the first actual sway angle θ_2 .

S400: determining whether the disturbance sway angle θ_3 is greater than the minimum disturbance sway angle, and if so, proceeding to S500, otherwise proceeding in sequence to S610, S620 and S630.

S500: controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse A , where $A=A_1$.

S610: controlling, by the anti-sway controller, the driving motor of the crane or the trolley to operate based on the anti-sway acceleration pulse A , where $A=A_1$.

S620: calculating, by the anti-sway controller, a first anti-disturbance-sway acceleration pulse A_2 based on the disturbance sway angle θ_3 .

S630: controlling, by the anti-sway controller, the driving motor of the crane or the trolley to operate based on the anti-sway acceleration pulse A , where $A=A_2$.

S700: bringing the crane or the trolley into the uniform-velocity phase, in which the sway angle sensor measures the second actual sway angle θ_4 , determining whether the second actual sway angle θ_4 is greater than the minimum disturbance sway angle, and if so, proceeding to S800.

S800: calculating the second anti-disturbance-sway acceleration pulse A_3 based on the second actual sway angle θ_4 .

S900: controlling, by the anti-sway controller, the driving motor of the crane or the trolley to operate based on the anti-sway acceleration pulse A , where $A=A_3$.

S1000: repeating S700 to S900.

Preferably, a reel is provided on the trolley. The lifting hook and the reel are in transmission connection with each other by a lifting rope. The reel is provided with a sensor for detecting the measured rope length l_1 of the lifting rope. The first sway period T_1 of the lifting hook during the acceleration phase is calculated according to $T_1 = 2\pi\sqrt{l_1/g}$, where T_1 is the first sway period in s; l_1 is the measured rope length in m, and g is the acceleration of gravity in N/Kg.

Preferably, the anti-driving-sway acceleration pulse A_1 is calculated according to LU502155

$$A_1 = \exp \left(-\frac{\zeta_1 \omega_1 \left(kT_1 + \frac{T_1}{2} \right)}{\sqrt{1 - \zeta_1^2}} \right) * A_0$$

. The starting acceleration pulse A_0 and the anti-driving-sway acceleration pulse A_1 are applied with a difference in timing of $KT_1 + T_1/2$, where T_1 is the first sway period in s; ζ_1 is the first damping coefficient valued in the range of 0 to 1; ω_1 is the first frequency in rad/s; and K is a positive integer equal to or greater than zero.

Preferably, the step S620 includes specifically the following steps:

S621: calculating the first disturbance acceleration a_1 according to $a_1 = l_1 \theta_3'' + g \theta_3$; and

S622: determining the first disturbance acceleration pulse A_4 and the first anti-disturbance-sway acceleration pulse A_2 based on the first disturbance acceleration a_1 , where l_1 is the measured rope length in m; θ_3 is the first disturbance sway angle; g is the acceleration of gravity in N/Kg and θ_3'' is the second derivative of the first disturbance sway angle.

Preferably, the first anti-disturbance-sway acceleration pulse A_2 is calculated according to

$$A_4 = \exp \left(-\frac{\zeta_1 \omega_1 \left(kT_1 + \frac{T_1}{2} \right)}{\sqrt{1 - \zeta_1^2}} \right) * A_2$$

and the first disturbance acceleration pulse A_4 and the first anti-disturbance-sway acceleration pulse A_2 are applied with a difference in timing of $KT_1 + T_1/2$, where T_1 is the first sway period in s; ζ_1 is the first damping coefficient valued in the range of 0 to 1; ω_1 is the first frequency in rad/s; and K is a positive integer equal to or greater than zero.

Preferably, the step S800 includes specifically:

S810: determining the second sway period T_2 of the lifting hook based on the second actual sway angle θ_4 ;

S820: calculating the actual rope length l_2 according to $T_2 = 2\pi\sqrt{l_2/g}$;

S830: calculating the second disturbance acceleration a_2 based on the actual rope length l_2 ; and

S840: determining the second disturbance acceleration pulse A_5 and the second anti-disturbance-sway acceleration pulse A_3 based on the second disturbance acceleration a_2 , where T_2 is the second sway period in s; l_2 is the actual rope length in m; and g is the acceleration of gravity in N/Kg.

Preferably, the second anti-disturbance-sway acceleration pulse A_3 is calculated according to

$$A_5 = \exp \left(-\frac{\zeta_2 \omega_2 \left(kT_2 + \frac{T_2}{2} \right)}{\sqrt{1 - \zeta_2^2}} \right) * A_3$$

, and the second disturbance acceleration pulse A_5 and the second anti-disturbance-sway acceleration pulse A_3 are applied with a difference in timing of $NT_2 + T_2/2$, where T_2 is the second sway period in s; ζ_2 is the second damping coefficient valued in the range of 0 to 1; ω_2 is the second frequency in rad/s; and N is a positive integer equal to or greater than zero.

Preferably, the second disturbance acceleration a_2 is calculated according to $a_2 = l_2 \theta_4'' + g \theta_4$, where l_2 is the actual rope length in m; θ_4 is the second actual sway angle; g is the acceleration of gravity in N/Kg; and θ_4'' is the second derivative of the second actual sway angle.

Preferably, the step S500 includes specifically the following step: converting, by the anti-sway controller, the anti-driving-sway acceleration pulse A_1 into an electrical signal and transmitting it to the inverter on the crane or the trolley that controls the driving motor of the crane or the trolley in operation.

The invention also provides a bridge crane adopting the anti-sway control method described above.

As compared with the prior art, the present invention has the following beneficial effects.

It is an object of the present invention to provide an anti-sway control method and a bridge crane for controlling sway of a lifting hook in the bridge crane during an acceleration phase and a uniform-velocity phase. The bridge crane includes an anti-sway controller, a crane and a trolley in transmission connection with the crane. The lifting hook is in transmission connection with the trolley, and the crane and the trolley both are provided with a sway angle sensor. The anti-sway controller is used for applying an anti-sway acceleration pulse A to the crane or the trolley. The method includes the following steps: starting the crane or the trolley based on the starting acceleration a_0 , and determining the starting acceleration pulse A_0 based on the starting acceleration a_0 and determining the anti-driving-sway acceleration pulse A_1 based on A_0 , by the anti-sway controller; calculating the theoretical driving sway angle θ_1 of the lifting hook based on the starting acceleration pulse A_0 ; measuring, by the sway angle sensor, the first actual sway angle θ_2 of the lifting hook, and calculating the disturbance sway angle θ_3 based on the theoretical driving sway angle θ_1 and the first actual sway angle θ_2 ; determining whether the disturbance sway angle θ_3 is greater than the minimum disturbance sway angle, and if not, controlling, by the anti-sway controller, the driving motor of the crane or the trolley in

operation based on the anti-sway acceleration pulse $A=A_1$; and if yes, controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse $A=A_1$, calculating the first disturbance acceleration pulse A_4 based on the disturbance sway angle θ_3 and determining the first anti-disturbance-sway acceleration pulse A_2 based on the first disturbance acceleration pulse A_4 , by the anti-sway controller, controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse $A=A_2$; bringing the crane or the trolley into the uniform-velocity phase, in which the sway angle sensor measures the second actual sway angle θ_3 , determining whether the second actual sway angle θ_3 is greater than the minimum disturbance sway angle; if yes, calculating the second disturbance acceleration pulse A_5 based on the second actual sway angle θ_3 and determining the second anti-disturbance-sway acceleration pulse A_3 based on the second disturbance acceleration pulse A_5 ; controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse $A=A_3$; and repeating the operation steps in the uniform-velocity phase. In contrast to the open-loop control from prior art, in this anti-sway control method, when the crane or the trolley starts to operate, the crane or the trolley enters the acceleration phase. The sway angle sensor detects the sway angle of the lifting hook in real time during the operation. It is determined whether there is any external disturbance during the acceleration phase based on the angle value detected by the sway angle sensor, so that the anti-sway controller accurately controls the driving motor of the crane or the trolley in operation based on the angle value of the inherent sway and the external disturbance to reduce the sway of the lifting hook to the allowable range. After entering the uniform-velocity phase, the external environment interferes with the normal operation of the bridge crane at uncertain time points. The sway angle sensor detects the sway angle of the lifting hook in real time to determine whether there is any external disturbance. The anti-sway controller controls the driving motor of the crane or the trolley in operation in real time based on the angle value detected by the sway angle sensor to reduce the sway of the lifting hook due to external disturbance to the allowable range. Operation steps in the uniform-velocity phase are repeated to enable closed-loop control over sway of the bucket with high control accuracy, thereby ensuring stable operation of the lifting hook, increasing operation efficiency of the crane or the trolley and improving use security of the bridge crane.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow diagram of an anti-sway control method according to an embodiment of the present invention; LU502155

Fig. 2 is a first partial flow diagram of an anti-sway control method according to an embodiment of the present invention;

Fig. 3 is a second partial flow diagram of an anti-sway control method according to an embodiment of the present invention;

Fig. 4 is a first simulation pulse diagram of an anti-sway control method according to an embodiment of the present invention;

Fig. 5 is a second simulation pulse diagram of an anti-sway control method according to an embodiment of the present invention; and

Fig. 6 is a third simulation pulse diagram of an anti-sway control method according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described hereinafter in further detail with reference to the drawings and embodiments. It is appreciated that the particular embodiments described here are merely intended to explain the present invention and not to limit it. In addition, for convenience of description, only part of the structure related to the present invention is shown in the drawings, but not all of it.

In the description of the present invention, unless otherwise explicitly specified and defined, the terms "jointed", "connected" and "fixed" should be broadly understood, for example, as being fixedly connected, detachably connected or integrated; mechanically connected or electrically connected; directly connected or indirectly connected through an intermediate medium, or the internal communication of two elements or the interaction between two elements. For those of ordinary skills in the field, the specific meanings of the above terms in the present invention can be understood depending on specific contexts.

In the present invention, unless otherwise specified and defined, the expression the first feature being "above" or "below" the second feature may include direct contact between the first and second features, or contact between the first and second features through another feature therebetween them. Furthermore, the expression first feature being "on" or "above" the second feature means the first feature is directly above or obliquely above the second feature, or simply indicates that the horizontal height of the first feature is greater than that of the second feature. The expression the first feature being "under" or "below" the second feature means that the first feature is directly below or obliquely below the second feature, or simply indicates that

the horizontal height of the first feature is lower than that of the second feature.

In the description of this embodiment, the terms "up", "down", "right", etc. represent an orientation or positional relationship as shown in the drawings, which is intended only for convenience of description and simplification of operation, but not for indicating or implying that the indicated device or element must have a specific orientation or be constructed and operated in a specific orientation, and therefore cannot be understood as a limitation of the present invention. In addition, the terms "first" and "second" are merely intended for distinguishment in description and have no special meaning.

The present invention provides an anti-sway control method and a bridge crane. This anti-sway control method is used to control sway of a lifting hook in a bridge crane during an acceleration phase and a uniform-velocity phase. Compared with the open-loop control from prior art, in this anti-sway control method, the crane or the trolley enters the acceleration phase when they start to operate. The sway angle sensor detects the sway angle of the lifting hook in real time during the operation. It is determined whether there is any external disturbance during the acceleration phase based on the angle detected by the sway angle sensor, so that the anti-sway controller accurately controls the driving motor of the crane or the trolley in operation based on the angle of the inherent sway and the external disturbance, to reduce the sway of the lifting hook to the allowable range. After entering the uniform-velocity phase, the external environment interferes with the normal operation of the bridge crane at uncertain time points. The sway angle sensor detects the sway angle of the lifting hook in real time to determine whether there is any external disturbance. The anti-sway controller controls the driving motor of the crane or the trolley in operation in real time based on the detected angle value to reduce the sway of the lifting hook due to external disturbance to the allowable range. Operation steps in the uniform-velocity phase are repeated to enable closed-loop control over sway of the bucket with high control accuracy, thereby ensuring stable operation of the lifting hook, increasing operation efficiency of the crane or the trolley and improving use security of the bridge crane.

The bridge crane includes an anti-sway controller, a crane and a trolley in transmission connection with the crane. A lifting hook is in transmission connection with the trolley. The crane and the trolley are both provided with a sway angle sensor. An anti-sway controller applies an anti-sway acceleration pulse A to the crane or the trolley. As shown in Figs. 1-3, this anti-sway control method includes the following steps.

S100: starting the crane or the trolley based on the starting acceleration a_0 , and determining, by the anti-sway controller, the starting acceleration pulse A_0 and the anti-driving-sway

acceleration pulse A_1 based on the starting acceleration a_0 .

Specifically, the crane or the trolley starts and enters the acceleration phase. The starting acceleration pulse A_0 is derived from the starting acceleration a_0 . The specific calculation process belongs to prior art and is not to be described in detail here.

S200: calculating the theoretical driving sway angle θ_1 of the lifting hook based on the starting acceleration pulse A_0 .

S300: measuring, by the sway angle sensor, the first actual sway angle θ_2 of the lifting hook, and calculating the disturbance sway angle θ_3 based on the theoretical driving sway angle θ_1 and the first actual sway angle θ_2 .

Specifically, the disturbance sway angle θ_3 is calculated by $\theta_2 = \theta_1 + \theta_3$. It is appreciated that the driving sway angle is a sway angle generated by the lifting hook itself when lifting the weight. The disturbance sway angle is a sway angle generated by external interference. The driving sway angle and the disturbance sway angle are respectively calculated to facilitate determination of whether there is any external disturbance to the bridge crane as well as determination of the degree of influence of the external disturbance to the bridge crane, thereby facilitating improvement in operation environment of the bridge crane.

S400: determining whether the disturbance sway angle θ_3 is greater than the minimum disturbance sway angle, and if not, proceeding to S500, if yes, proceeding to S610, S620 and S630 in sequence.

Specifically, if the disturbance sway angle θ_3 is less than the minimum disturbance sway angle, that is, the value of the disturbance sway angle θ_3 is in the allowable range, then only the sway generated by the lifting hook itself when lifting the weight needs to be ameliorated. Therefore, proceed to S500.

S500: Controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse $A = A_1$. The anti-sway controller converts the anti-driving-sway acceleration pulse A_1 into an electrical signal and transmits the electrical signal to the inverter on the crane or the trolley. The inverter controls the driving motor of the crane or the trolley in operation, so that the motor of the crane or trolley outputs corresponding torque for operation to reduce sway of the lifting hook. It is appreciated that the sway generated by the lifting hook itself when lifting the weight can be improved by the steps described above, so that the value of the driving sway angle of the lifting hook when lifting the weight can be controlled to the allowable range.

A reel is provided on the trolley. The lifting hook and the reel are in transmission connection with each other by a lifting rope. The reel is provided with a sensor for detecting the measured

rope length l_1 of the lifting rope. The first sway period T_1 of the lifting hook during the acceleration phase is calculated according to $T_1 = 2\pi\sqrt{l_1/g}$, where T_1 is the first sway period in s; l_1 is the measured rope length in m, and g is the acceleration of gravity in N/Kg.

The anti-driving-sway acceleration pulse A_1 is calculated according to

$$A_1 = \exp\left(-\frac{\zeta_1\omega_1\left(kT_1 + \frac{T_1}{2}\right)}{\sqrt{1-\zeta_1^2}}\right) * A_0$$

, where T_1 is the first sway period in s; ζ_1 is the first damping coefficient valued in the range of 0 to 1; and ω_1 is the first frequency in rad/s. The value of the first damping coefficient ζ_1 is set depending on the specific operation conditions

during the acceleration phase and $\omega_1 = 1/T_1$.

Preferably, as shown in Fig.4, an anti-driving-sway acceleration pulse A_1 is applied with a difference in timing of $KT_1 + T_1/2$. That is, the anti-driving-sway acceleration pulse A_1 is applied at a time point where the lifting hook has the maximum sway amplitude, which is the best time point for application of the anti-driving-sway acceleration pulse A_1 . It is appreciated that, the anti-sway controller applies a pulse of an equal magnitude and in an opposite direction to the lifting hook. Therefore, the sway of the lifting hook is ameliorated in a fastest and most effective way. t_0 is any instant during the acceleration phase in s.

If the disturbance sway angle θ_3 is greater than the minimum disturbance sway angle, that is, the value of the disturbance sway angle θ_3 exceeds the allowable range, then both the sway generated by the lifting hook itself when lifting the weight and the sway of the lifting hook caused by external disturbance need to be ameliorated. Therefore, proceed to S610, S620 and S630.

S610: controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse $A=A_1$. The anti-sway controller converts the anti-sway acceleration pulse $A=A_1$ into an electrical signal and transmits the electrical signal to the inverter on the crane or the trolley. The inverter controls the driving motor of the crane or the trolley in operation, so that the motor of the crane or the trolley outputs corresponding torque for operation, to reduce sway of the lifting hook.

The starting acceleration pulse A_0 and the anti-driving-sway acceleration pulse A_1 are applied with a difference in timing of $KT_1 + T_1/2$, where K is a positive integer equal to or greater than zero.

S620: calculating, by the anti-sway controller, the first anti-disturbance-sway acceleration pulse A_2 based on the disturbance sway angle θ_3 . LU502155

As shown in Figs. 2, 4 and 5, t_1 is a certain instant later than t_0 during the acceleration phase, in s. S620 includes specifically the following calculation steps.

S621: calculating the first disturbance acceleration a_1 according to $a_1 = l_1 \theta_3'' + g \theta_3$.

S622: determining the first disturbance acceleration pulse A_4 and the first anti-disturbance-sway acceleration pulse A_2 based on the first disturbance acceleration a_1 . The first disturbance acceleration pulse A_4 is derived from the first disturbance acceleration a_1 . The specific calculation process belongs to prior art and shall not be described in detail here. l_1 is the measured rope length in m; θ_3 is the first disturbance sway angle; g is the acceleration of gravity in N/Kg and θ_3'' is the second derivative of the first disturbance sway angle.

The first anti-disturbance-sway acceleration pulse A_2 is calculated according to

$$A_4 = \exp \left(-\frac{\zeta_1 \omega_1 \left(kT_1 + \frac{T_1}{2} \right)}{\sqrt{1 - \zeta_1^2}} \right) * A_2, \text{ where } T_1 \text{ is the first sway period in s; } \zeta_1 \text{ is the first}$$

damping coefficient valued in the range of 0 to 1; and ω_1 is the first frequency in rad/s. The value of the first damping coefficient ζ_1 is set depending on the specific operation conditions

during the acceleration phase and $\omega_1 = 1/T_1$.

S630: controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse $A=A_2$. The anti-sway controller converts the anti-sway acceleration pulse $A=A_2$ into an electrical signal and transmits the electrical signal to the inverter on the crane or the trolley. The inverter controls the driving motor of the crane or the trolley in operation, so that the motor of the crane or the trolley outputs corresponding torque for operation to reduce sway of the lifting hook.

Preferably, the first disturbance acceleration pulse A_4 and the first anti-disturbance-sway acceleration pulse A_2 are applied with a difference in timing of $KT_1 + T_1/2$, where K is a positive integer equal to or greater than zero. It is appreciated that the anti-driving-sway acceleration pulse A_1 is applied later in timing than the driving sway produced upon the start of the crane or the trolley by $KT_1 + T_1/2$, and the first anti-disturbance-sway acceleration pulse A_2 is applied in timing later than the external disturbance by $KT_1 + T_1/2$.

A first anti-disturbance-sway acceleration pulse A_2 is applied with a difference in timing of

$KT_1 + T_1/2$. That is, the first anti-disturbance-sway acceleration pulse A_2 is applied at a time point where the lifting hook has the maximum sway amplitude, which is the best time point for application of the first anti-disturbance-sway acceleration pulse A_2 . Therefore, the sway of the lifting hook caused by external disturbance is ameliorated in a fastest and most effective way. It is appreciated that both the sway generated by the lifting hook itself when lifting the weight and the sway of the lifting hook caused by external interference can be ameliorated by the steps described above, so that the value of the driving sway angle of the lifting hook when lifting the weight can be controlled in the allowable range. Meanwhile, the anti-driving-sway acceleration pulse A_1 and the first anti-disturbance-sway acceleration pulse A_2 are calculated respectively, so that the inherent sway and the sway due to external disturbance can be respectively controlled accurately, thereby improving the control accuracy, ensuring the use security of the bridge crane, facilitating determination of the degree of influence of the external disturbance to the bridge crane, and consequently facilitating improvement in operation environment of the bridge crane. LU502155

At this time, the anti-sway controller accomplishes control over sway caused by the driving sway angle θ_1 and the disturbance sway angle θ_3 during the acceleration phase, so that the crane or the trolley enters the uniform-velocity operation phase in which the lifting hook is in stable operation. However, the external environment interferes with the normal operation of the bridge crane at uncertain time points and causes sway of the lifting hook. The sway angle sensor detects the sway angle of the lifting hook in real time and the following steps are performed.

S700: bringing the crane or the trolley into the uniform-velocity phase, in which the sway angle sensor measures the second actual sway angle θ_4 , determining whether the second actual sway angle θ_4 is greater than the minimum disturbance sway angle, and if yes, proceeding to S800.

Specifically, the anti-sway controller determines whether the second actual sway angle θ_4 is greater than the minimum disturbance sway angle. If the second actual sway angle θ_4 is less than the limit value of the minimum sway angle, then the bridge crane operates stably. If the second actual sway angle θ_4 is greater than the limit value of the minimum sway angle, then the sway of the lifting hook caused by external disturbance needs to be ameliorated. Then proceed to S800.

S800: calculating the second anti-disturbance-sway acceleration pulse A_3 based on the second actual sway angle θ_4 .

As shown in Figs 3 and 6, where t_2 is any instant in the uniform-velocity phase in s, S800 includes specifically the following steps.

S810: determining the second sway period T_2 of the lifting hook based on the second actual

sway angle θ_4 .

S820: calculating the actual rope length l_2 according to $T_2 = 2\pi\sqrt{l_2/g}$.

S830: calculating the second disturbance acceleration a_2 based on the actual rope length l_2 .

Specifically, the second disturbance acceleration a_2 is calculated according to $a_2 = l_2\theta_4'' + g\theta_4$, where l_2 is the actual rope length in m; θ_4 is the second actual sway angle; g is the acceleration of gravity in N/Kg; and θ_4'' is the second derivative of the second actual sway angle.

S840: determining the second disturbance acceleration pulse A_5 and the second anti-disturbance-sway acceleration pulse A_3 based on the second disturbance acceleration a_2 , where T_2 is the second sway period in s; l_2 is the actual rope length in m; and g is the acceleration of gravity in N/Kg.

The second disturbance acceleration pulse A_5 is derived from the second disturbance acceleration a_2 . The specific calculation process belongs to prior art and shall not be described in detail here.

The second anti-disturbance-sway acceleration pulse A_3 is calculated according to

$$A_5 = \exp\left(-\frac{\zeta_2\omega_2\left(kT_2 + \frac{T_2}{2}\right)}{\sqrt{1-\zeta_2^2}}\right) * A_3, \text{ where } T_2 \text{ is the second sway period in s; } \zeta_2 \text{ is the second}$$

damping coefficient valued in the range of 0 to 1; and ω_2 is the second frequency in rad/s. The value of the second damping coefficient ζ_2 is determined depending on the specific operation

condition during the uniform-velocity phase, and $\omega_2 = 1/T_2$.

S900: controlling, by the anti-sway controller, the driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse A , where $A=A_3$. The anti-sway controller converts the second anti-disturbance-sway acceleration pulse A_3 into an electrical signal and transmits the electrical signal to the inverter on the crane or the trolley. The inverter controls the driving motor of the crane or the trolley in operation, so that the motor of the crane or the trolley outputs corresponding torque for operation to reduce sway of the lifting hook.

Preferably, the second disturbance acceleration pulse A_5 and the second anti-disturbance-sway acceleration pulse A_3 are applied with a difference in timing of $NT_2+T_2/2$, N is a positive integer equal to or greater than zero. It is appreciated that the second anti-disturbance-sway acceleration pulse A_3 is applied later in timing than the external disturbance by $NT_2+T_2/2$.

A second anti-disturbance-sway acceleration pulse A_3 is applied at the instant $NT_2+T_2/2$. That

is, the second anti-disturbance-sway acceleration pulse A_3 is applied at a time point where the lifting hook has the maximum sway amplitude, which is the best time point for application of the second anti-disturbance-sway acceleration pulse A_3 . Therefore, the sway of the lifting hook is ameliorated in a fastest and most effective way. As such, during the uniform-velocity phase, control over the sway of the lifting hook caused by external environment is accomplished for once.

S1000: S700 to S900 are repeated. Through repetition of S700 to S900, it is ensured that in the case where the external environment interferes with normal operation of the bridge crane at uncertain time points, the anti-sway controller controls the driving motor of the crane or the trolley in operation in real time based on the second actual sway angle θ_4 to reduce the sway of the lifting hook due to external disturbance to the allowable range, so as to enable closed-loop control over sway of the bucket with high control accuracy, thereby ensuring stable operation of the lifting hook, increasing operation efficiency of the crane or the trolley and improving use security of the bridge crane.

In this embodiment, the anti-sway control method further includes the deceleration phase and the stop of the crane subsequent to the uniform-velocity phase, and the control method for entrance into the deceleration phase and the stop of the crane is the same as the control method for the start and entrance into the acceleration phase and shall not be described in detail here.

In a bridge crane adopting the anti-sway control method described above, the anti-sway controller can control sway of the lifting hook in real time based on the measurement data detected by the sway angle sensor and control disturbance to the bridge crane during operation caused by the external environment at uncertain time points, so as to enable closed-loop control over sway of the lifting hook during operation of the bridge crane, thereby ensuring stable operation of the lifting hook, increasing operation efficiency of the crane or the trolley and improving use security of the bridge crane.

Obviously, the above-mentioned embodiments of the present invention are merely examples intended for clear illustration of the present invention and not limitation on the implementations of the present invention. It is obvious to those skilled in the art that various changes, readjustments and substitutions can be made without departing from the scope of protection of the present invention. It is unnecessary and impossible to exhaust all the implementations here. Any modification, equivalent substitution and improvement within the spirit and principle of the present invention should be included within the scope of protection of the claims of the present invention.

WHAT IS CLAIMED IS:

1. An anti-sway control method for controlling sway of a lifting hook in a bridge crane during an acceleration phase and a uniform-velocity phase, the bridge crane including an anti-sway controller, a crane and a trolley in transmission connection with the crane, the lifting hook being in transmission connection with the trolley, the crane and the trolley both being provided with a sway angle sensor, the anti-sway controller being used for applying an anti-sway acceleration pulse A to the crane or the trolley, wherein the method comprises steps of:

S100: starting the crane or the trolley based on a starting acceleration a_0 , and determining, by the anti-sway controller, a starting acceleration pulse A_0 and an anti-driving-sway acceleration pulse A_1 based on the starting acceleration a_0 ;

S200: calculating a theoretical driving sway angle θ_1 of the lifting hook based on the starting acceleration pulse A_0 ;

S300: measuring, by the sway angle sensor, a first actual sway angle θ_2 of the lifting hook, and calculating a disturbance sway angle θ_3 based on the theoretical driving sway angle θ_1 and the first actual sway angle θ_2 ;

S400: determining whether the disturbance sway angle θ_3 is greater than a minimum disturbance sway angle, and if so, proceeding to S500, otherwise proceeding in sequence to S610, S620 and S630;

S500: controlling, by the anti-sway controller, a driving motor of the crane or the trolley in operation based on the anti-sway acceleration pulse A , where $A=A_1$;

S610: controlling, by the anti-sway controller, the driving motor of the crane or the trolley to operate based on the anti-sway acceleration pulse A , where $A=A_1$;

S620: calculating, by the anti-sway controller, a first anti-disturbance-sway acceleration pulse A_2 based on the disturbance sway angle θ_3 ;

S630: controlling, by the anti-sway controller, the driving motor of the crane or the trolley to operate based on the anti-sway acceleration pulse A , where $A=A_2$;

S700: bringing the crane or the trolley into the uniform-velocity phase, in which the sway angle sensor measures a second actual sway angle θ_4 , determining whether the second actual sway angle θ_4 is greater than the minimum disturbance sway angle, and if so, proceeding to S800;

S800: calculating a second anti-disturbance-sway acceleration pulse A_3 based on the second actual sway angle θ_4 ;

S900: controlling, by the anti-sway controller, the driving motor of the crane or the trolley to operate based on the anti-sway acceleration pulse A , where $A=A_3$; and

S1000: repeating S700 to S900.

2. The anti-sway control method of claim 1, wherein a reel is provided on the trolley, the lifting hook and the reel are in transmission connection with each other by a lifting rope, the reel is provided with a sensor for detecting the measured rope length l_1 of the lifting rope, and the first sway period T_1 of the lifting hook during the acceleration phase is calculated according to $T_1 = 2\pi\sqrt{l_1/g}$, where T_1 is the first sway period in s; l_1 is the measured rope length in m, and g is the acceleration of gravity in N/Kg.

3. The anti-sway control method of claim 2, wherein the anti-driving-sway acceleration pulse

$$A_1 = \exp\left(-\frac{\zeta_1\omega_1\left(kT_1 + \frac{T_1}{2}\right)}{\sqrt{1-\zeta_1^2}}\right) * A_0$$

A_1 is calculated according to , the starting acceleration pulse A_0 and the anti-driving-sway acceleration pulse A_1 are applied with a difference in timing of $KT_1 + T_1/2$, where T_1 is the first sway period in s; ζ_1 is the first damping coefficient in the range of 0 to 1; ω_1 is the first frequency in rad/s; and K is a positive integer equal to or greater than zero.

4. The anti-sway control method of claim 2, wherein the step S620 comprises steps of:

S621: calculating a first disturbance acceleration a_1 according to $a_1 = l_1\theta_3'' + g\theta_3$; and

S622: determining a first disturbance acceleration pulse A_4 and the first anti-disturbance-sway acceleration pulse A_2 based on the first disturbance acceleration a_1 , where l_1 is the measured rope length in m; θ_3 is the first disturbance sway angle; g is the acceleration of gravity in N/Kg and θ_3'' is the second derivative of the first disturbance sway angle.

5. The anti-sway control method of claim 4, wherein the first anti-disturbance-sway

$$A_4 = \exp\left(-\frac{\zeta_1\omega_1\left(kT_1 + \frac{T_1}{2}\right)}{\sqrt{1-\zeta_1^2}}\right) * A_2$$

acceleration pulse A_2 is calculated according to and the first disturbance acceleration pulse A_4 and the first anti-disturbance-sway acceleration pulse A_2 are applied with a difference in timing of $KT_1 + T_1/2$, where T_1 is the first sway period in s; ζ_1 is the first damping coefficient valued in the range of 0 to 1; ω_1 is the first frequency in rad/s; and K is a positive integer equal to or greater than zero.

6. The anti-sway control method of claim 1, wherein the step S800 comprises:

S810: determining a second sway period T_2 of the lifting hook based on the second actual sway angle θ_4 ; LU502155

S820: calculating an actual rope length l_2 based on $T_2 = 2\pi\sqrt{l_2/g}$;

S830: calculating a second disturbance acceleration a_2 based on the actual rope length l_2 ; and

S840: determining a second disturbance acceleration pulse A_5 and the second anti-disturbance-sway acceleration pulse A_3 based on the second disturbance acceleration a_2 , where T_2 is the second sway period in s; l_2 is the actual rope length in m; and g is the acceleration of gravity in N/Kg.

7. The anti-sway control method of claim 6, wherein the second anti-disturbance-sway

$$A_5 = \exp\left(-\frac{\zeta_2\omega_2\left(kT_2 + \frac{T_2}{2}\right)}{\sqrt{1-\zeta_2^2}}\right) * A_3$$

acceleration pulse A_3 is calculated according to , and the second disturbance acceleration pulse A_5 and the second anti-disturbance-sway acceleration pulse A_3 are applied with a difference in timing of $NT_2 + T_2/2$, where T_2 is the second sway period in s; ζ_2 is the second damping coefficient valued in the range of 0 to 1; ω_2 is the second frequency in rad/s; and N is a positive integer equal to or greater than zero.

8. The anti-sway control method of claim 6, wherein the second disturbance acceleration a_2 is calculated according to $a_2 = l_2\theta_4'' + g\theta_4$, where l_2 is the actual rope length in m; θ_4 is the second actual sway angle; g is the acceleration of gravity in N/Kg; and θ_4'' is the second derivative of the second actual sway angle.

9. The anti-sway control method of claim 1, wherein the step S500 comprises step of:

converting, by the anti-sway controller, the anti-driving-sway acceleration pulse A_1 into an electrical signal and transmitting it to an inverter on the crane or the trolley that controls the driving motor of the crane or the trolley in operation.

10. A bridge crane adopting the anti-sway control method of any of claims 1-9.

1. Procédé de contrôle anti-balancement pour contrôler le balancement d'un crochet de levage dans un pont roulant pendant une phase d'accélération et une phase de vitesse uniforme, le pont roulant comprenant un contrôleur anti-balancement, un système de levage et un chariot en liaison de transmission avec le système de levage, le crochet de levage étant en liaison de transmission avec le chariot, le système de levage et le chariot étant tous deux équipés d'un capteur d'angle de balancement, le contrôleur anti-balancement étant utilisé pour appliquer une impulsion d'accélération anti-balancement au système de levage ou au chariot, dans lequel le procédé comprend les étapes consistant à :

S100 : démarrage du système de levage ou du chariot sur la base d'une accélération de démarrage a_0 , et détermination, par le contrôleur anti-balancement, d'une impulsion d'accélération de démarrage A_0 et d'une impulsion d'accélération anti-balancement d'entraînement A_1 sur la base de l'accélération de démarrage a_0 ;

S200 : calcul d'un angle de balancement d'entraînement théorique θ_1 du crochet de levage sur la base de l'impulsion d'accélération de démarrage A_0 ;

S300 : mesure, par le capteur d'angle de balancement, d'un premier angle de balancement réel θ_2 du crochet de levage, et calcul d'un angle de balancement de perturbation θ_3 sur la base de l'angle de balancement d'entraînement théorique θ_1 et du premier angle de balancement réel θ_2 ;

S400 : déterminer si l'angle de balancement de perturbation θ_3 est supérieur à un angle de balancement de perturbation minimum, et si tel est le cas, passer à S500, sinon passer de manière séquentielle à S610, S620 et S630 ;

S500 : commande, par le contrôleur anti-balancement, d'un moteur d'entraînement du système de levage ou du chariot en fonctionnement sur la base de l'impulsion d'accélération anti-balancement A , où $A = A_1$;

S610 : commande, par le contrôleur anti-balancement, du moteur d'entraînement du système de levage ou du chariot pour fonctionner sur la base de l'impulsion d'accélération anti-balancement A , où $A = A_1$;

S620 : calcul, par le contrôleur anti-balancement, d'une première impulsion d'accélération anti-balancement de perturbation A_2 sur la base de l'angle de balancement de perturbation θ_3 ;

S630 : commande, par le contrôleur anti-balancement, du moteur d'entraînement du système de levage ou du chariot pour fonctionner sur la base de l'impulsion d'accélération anti-balancement A , où $A = A_2$;

S700 : amener le système de levage ou le chariot dans la phase de vitesse uniforme, dans laquelle le capteur d'angle de balancement mesure un deuxième angle de balancement réel

θ_4 , déterminer si le deuxième angle de balancement réel θ_4 est supérieur à l'angle de balancement perturbateur minimum, et si tel est le cas, passer à S800 ; LU502155

S800 : calcul d'une deuxième impulsion d'accélération anti-balancement de perturbation A_3 sur la base du deuxième angle de balancement réel θ_4 ;

S900 : commander, par le contrôleur anti-balancement, le moteur d'entraînement du système de levage ou du chariot pour qu'il fonctionne sur la base de l'impulsion d'accélération anti-balancement A , où $A=A_3$; et

S1000 : répétition de S700 à S900.

2. Le procédé de contrôle anti-balancement selon la revendication 1, dans lequel un enrouleur est prévu sur le chariot, le crochet de levage et l'enrouleur sont en liaison de transmission l'un avec l'autre par un câble de levage, l'enrouleur est pourvu d'un capteur pour détecter la mesure la longueur de câble l_1 du câble de levage, et la première période de balancement T_1 du crochet de levage pendant la phase d'accélération est calculée selon $T_1 = 2\pi\sqrt{l_1/g}$, où T_1 est la première période de balancement en s ; l_1 est la longueur de corde mesurée en m, et g est l'accélération de la pesanteur en N/Kg.

3. Le procédé de contrôle anti-balancement selon la revendication 2, dans lequel l'impulsion d'accélération anti-balancement d'entraînement A_1 est calculée selon

$$A_1 = \exp\left(-\frac{\zeta_1 \omega_1 \left(KT_1 + T_1/2\right)}{\sqrt{1-\zeta_1^2}}\right) * A_0$$

l'impulsion d'accélération de démarrage A_0 et l'impulsion d'accélération d'anti-balancement d'entraînement A_1 sont appliquées avec une différence de synchronisation de $KT_1 + T_1/2$, où T_1 est la première période de balancement en s ; ζ_1 est le premier coefficient d'amortissement dans la plage de 0 à 1 ; ω_1 est la première fréquence en rad/s ; et K est un entier positif égal ou supérieur à zéro.

4. Le procédé de contrôle anti-balancement selon la revendication 2, dans lequel l'étape S620 comprend les étapes :

S621 : calcul d'une première accélération de perturbation a_1 selon $a_1 = l_1 \theta_3'' + g\theta_3$; et

S622 : détermination d'une première impulsion d'accélération de perturbation A_4 et de la première impulsion d'accélération anti-balancement de perturbation A_2 sur la base de la première accélération de perturbation a_1 , où l_1 est la longueur de câble mesurée en m ; θ_3 est le premier angle de balancement de perturbation ; g est l'accélération de la pesanteur en N/Kg et θ_3'' est la dérivée seconde du premier angle de balancement de perturbation.

5. Le procédé de commande anti-balancement selon la revendication 4, dans lequel la première impulsion d'accélération anti-balancement de perturbation A_2 est calculée selon

$$A_4 = \exp \left(- \frac{\zeta_1 \omega_1 \left(kT_1 + \frac{T_1}{2} \right)}{\sqrt{1 - \zeta_1^2}} \right) * A_2$$

et la première impulsion d'accélération de perturbation A_4 et la première impulsion d'accélération anti-balancement de perturbation A_2 sont appliquées avec une différence en synchronisation de $KT_1 + T_1/2$, où T_1 est la première période de balancement en s ; ζ_1 est le premier coefficient d'amortissement dans la plage de 0 à 1 ; ω_1 est la première fréquence en rad/s ; et K est un entier positif égal ou supérieur à zéro.

6. Le procédé de contrôle anti-balancement selon la revendication 1, dans lequel l'étape S800 comprend :

S810 : détermination d'une deuxième période de balancement T_2 du crochet de levage sur la base du deuxième angle de balancement réel θ_4 ;

S820 : calcul d'une longueur de câble réelle l_2 basée sur $T_1 = 2\pi\sqrt{l_2/g}$;

S830 : calcul d'une seconde accélération de perturbation a_2 sur la base de la longueur de câble réelle l_2 ; et

S840 : détermination d'une seconde impulsion d'accélération de perturbation A_5 et de la seconde impulsion d'accélération anti-balancement de perturbation A_3 sur la base de la seconde accélération de perturbation a_2 , où T_2 est la seconde période de balancement en s ; l_2 est la longueur réelle du câble en m ; et g est l'accélération de la pesanteur en N/Kg.

7. Le procédé de contrôle anti-balancement selon la revendication 6, dans lequel la seconde impulsion d'accélération anti-balancement de perturbation A_3 est calculée selon

$$A_3 = \exp \left(- \frac{\zeta_2 \omega_2 \left(NT_2 + \frac{T_2}{2} \right)}{\sqrt{1 - \zeta_2^2}} \right) * A_2$$

et la seconde impulsion d'accélération de perturbation A_5 et la seconde impulsion d'accélération anti-balancement de perturbation A_3 sont appliquées avec un différence de synchronisation de $NT_2 + T_2/2$, où T_2 est la deuxième période de balancement en s ; est ζ_2 le deuxième coefficient d'amortissement dans la plage de 0 à 1 ; ω_2 est la deuxième fréquence en rad/s ; et N est un nombre entier positif égal ou supérieur à zéro.

8. Le procédé de contrôle anti-balancement selon la revendication 6, dans lequel la seconde LU502155 accélération de perturbation a_2 est calculée selon $a_2 = l_2 \ddot{\theta}_4 + g \theta_4$, où l_2 est la longueur réelle de câble en m; θ_4 est le deuxième angle de balancement réel ; g est l'accélération de la gravité en N/Kg ; et $\ddot{\theta}_4$ est la seconde dérivée du second angle de balancement réel.
9. Le procédé de commande anti-balancement selon la revendication 1, dans lequel l'étape S500 comprend l'étape consistant à :
convertir, par le contrôleur anti-balancement, l'impulsion d'accélération anti-balancement d'entraînement A_1 en un signal électrique et la transmettre à un onduleur sur le système de levage ou le chariot qui commande le moteur d'entraînement du système de levage ou du chariot en fonctionnement.
10. Un pont roulant adoptant le procédé de contrôle anti-balancement selon l'une quelconque des revendications 1 à 9.

DRAWINGS

LU502155

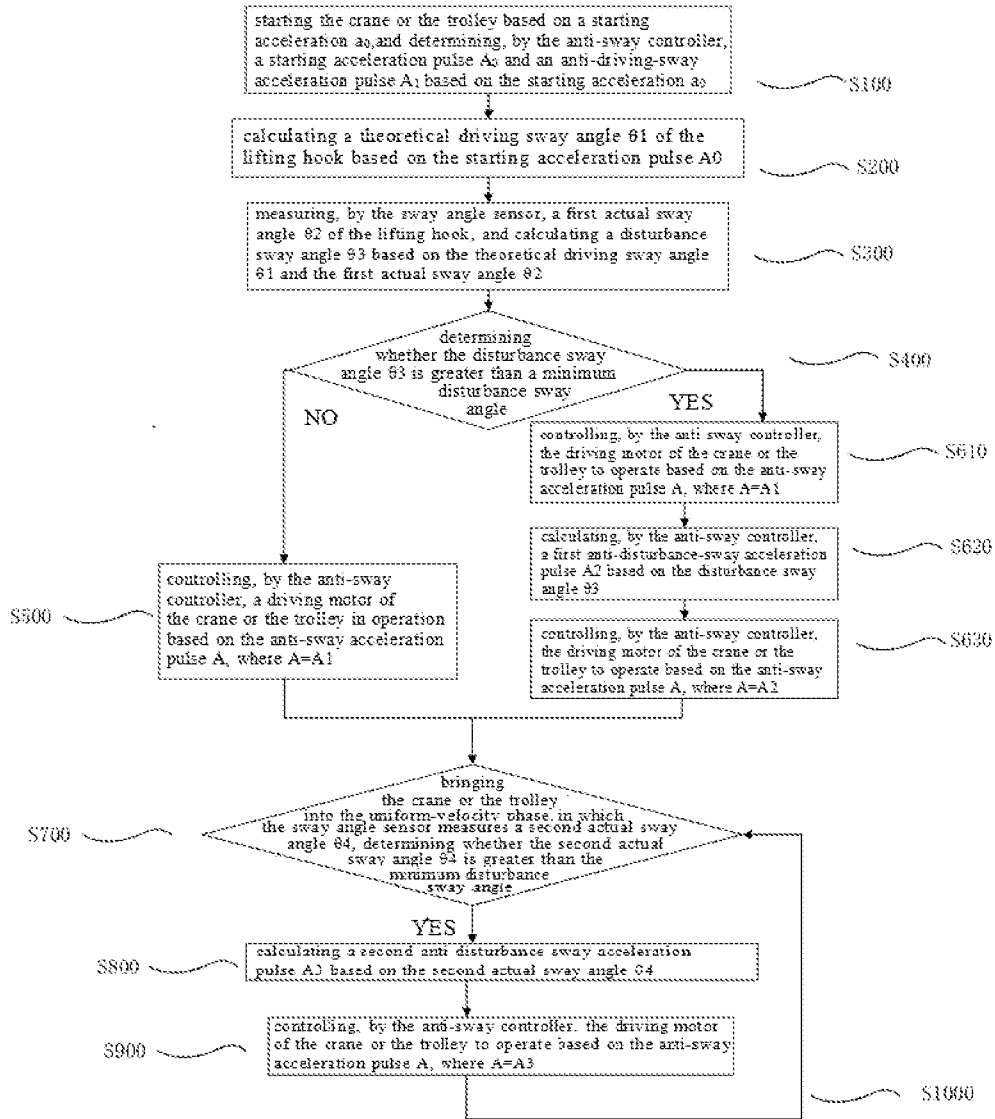


Fig. 1

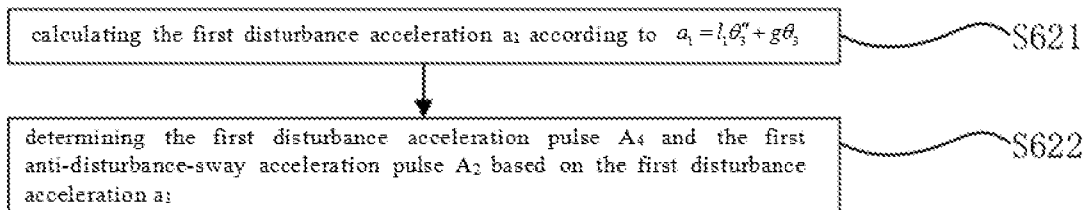


Fig. 2

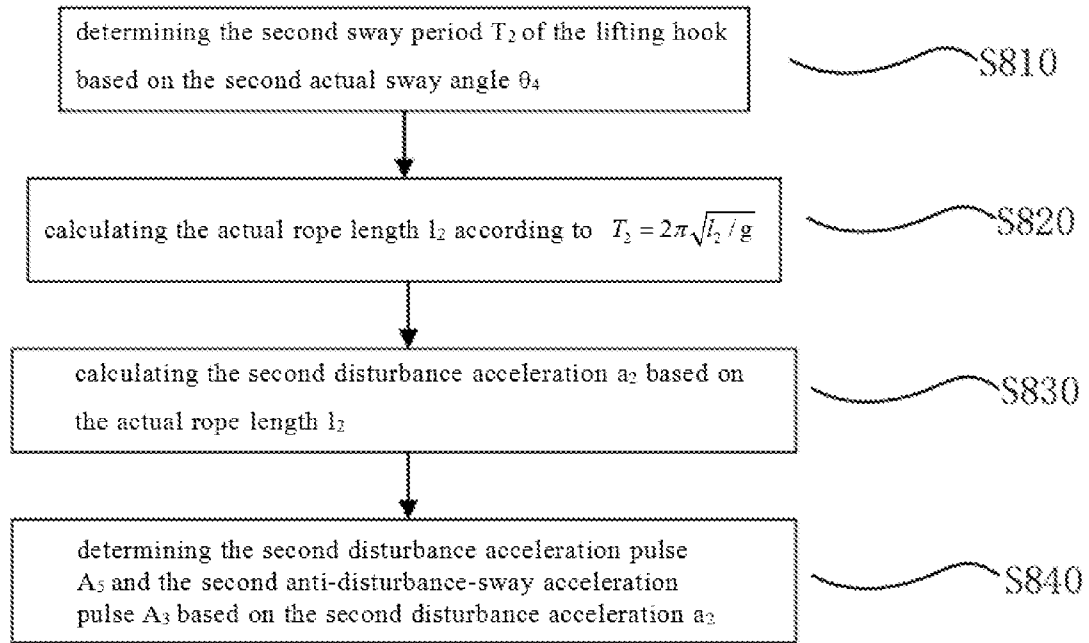


Fig. 3

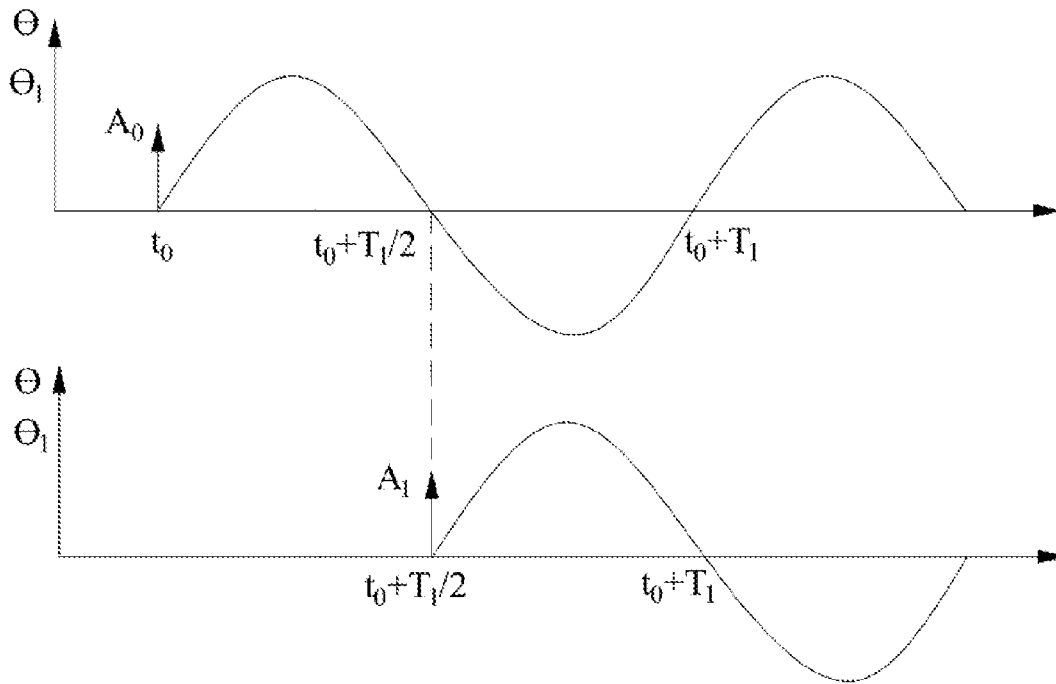


Fig. 4

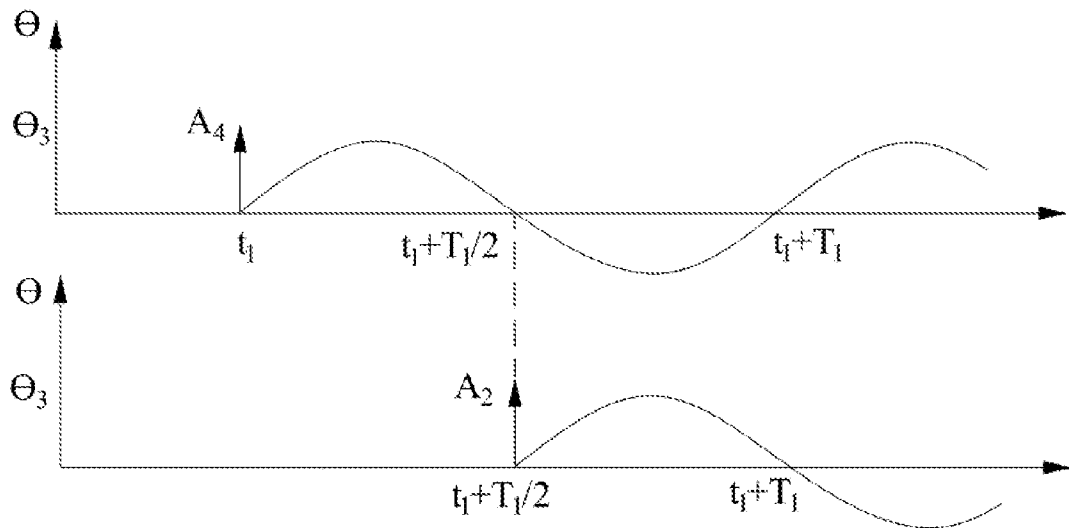


Fig. 5

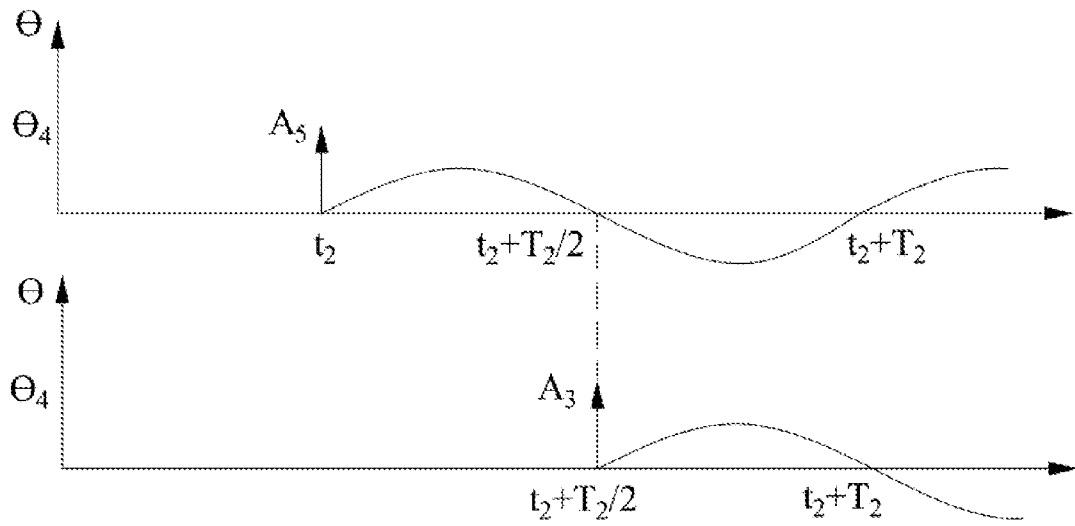


Fig. 6