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COORDINATED CONTROL OF ELECTRIC DRIVES SIMULTANEOUS OPERATION OF THE CRANE MECHANISMS

Abstract. *The method of damping swinging on a rope cargo has been proposed. This method is effective in combining works of trolley (in one or two coordinates) and hoist. It is based on the formation of the angle of deviation from the vertical rope for harmonic function and controlling the speed of the suspension point. The method is invariant to the ratio of the mass and speed lifting. This allows automation of cranes, including positioning cargo at predetermined points. It can be used in the design of container cranes in automated terminals.*

Keywords: *container cranes, load transfer mechanism, the optimal control law, vibrations suppression, electric drive pull-up cables, generator control signals, the observer mechanism of movement*

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СОГЛАСОВАННОЕ УПРАВЛЕНИЕ ЭЛЕКТРОПРИВОДАМИ КРАНОВ ПРИ ОДНОВРЕМЕННОЙ РАБОТЕ МЕХАНИЗМОВ

Аннотация. *Предложен метод демпфирования колебаний подвешенного на канате груза при совмещении операций горизонтального перемещения по одной или двум координатам и подъема/спуска груза, инвариантный к соотношению масс и скорости подъема. Метод основан на формировании угла отклонения каната от вертикали по гармоническому закону и управлении скоростью точки подвеса. Это предоставляет возможность автоматизации кранов, в том числе – позиционирования груза в заданных точках, что может быть использовано при проектировании контейнерных перегружателей в составе автоматизированных терминалов.*

Ключевые слова: *контейнерный перегружатель, механизм перемещения груза, оптимальный закон управления, гашение колебаний, электропривод подтягивающих тросов, формирователь управляющих сигналов, наблюдатель механизма передвижения*

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УЗГОДЖЕНЕ УПРАВЛІННЯ ЕЛЕКТРОПРИВОДАМИ КРАНІВ ПРИ ОДНОЧАСНІЙ РОБОТІ МЕХАНІЗМІВ

Анотація. *Запропоновано метод демпфування коливань підвішеного на канаті вантажу при суміщенні операцій горизонтального переміщення по одній або двох координатах і підйому/спуску вантажу, інваріантний до співвідношення мас і швидкості підйому. Метод заснований на формуванні кута відхилення каната від вертикалі по гармонічному закону та керуванні швидкістю точки підвісу. Це надає можливість автоматизації кранів, в тому числі – позиціонування вантажу в заданих точках, що може бути використано при проектуванні контейнерних перевантажувачів у складі автоматизованих терміналів.*

Ключові слова: *контейнерний перевантажувач, механізм горизонтального переміщення вантажу, оптимальний закон управління, гасіння коливань, електропривод підтягуючих тросів, формувач керуючих сигналів, спостерігач механізму пересування*

Introduction. A move operation took most of the time in the container cranes when a regulated cycle of loading/unloading is about 2...2,5 min. It determines the productivity of cranes [1]. When the length of the suspension is 20...50 m then horizontal displacement mechanisms are characterized by long transition process (20…30 s) due to oscillations of the load suspended on a rope. This problem does the damping oscillation of the load very important [2 – 3].

One possible way of solving it is to apply the Pontryagin maximum principle [4]. It allows taking into account limits on actions supplied to the controlled object, and is the most effective in the synthesis of an optimal systems. But it turns out solutions with 3- and 5-fold switching forces between the maximum and minimum [5 – 8] requires accurate measurement of the mass ratio of the load and the mechanism, the length of the rope and its persistence in the transition process. In an industrial environment it imposes additional requirements not only hardware, but also restricts the freedom of action of the operator. Therefore, for the successful solution of the problem requires applying of such damping control laws that allow simultaneous operation of multiple mechanisms (horizontal movement and hoisting) and less susceptible to errors of measurement parameters of the cargo and to the effects of random disturbances.

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The aim of this work is to develop the law of coordinated anti-sway control for mechanisms of horizontal movement and hoisting, providing effective suppression of oscillations.

Research materials. One of the invariant law to mass ratio of the moving part of the crane and the load is controlling the speed of the point of suspension of cargo [9].

Choose that law of control, when the angle α is defined by the continuous periodic function, is characterized by zero initial and boundary conditions, including the first derivative. So the following conditions are satisfied by the harmonic function:

$$\alpha = \alpha_m \left(1 - \cos\left(\frac{t}{T_G}\right)\right), \quad (1)$$

where α_m – the half-angle of maximum deflection of the rope from the vertical, and T_G – the time constant inverse given angular frequency of oscillations.

Then for small angles of deflection $(\sin\alpha \approx \alpha, \cos\alpha \approx 1)$ speed of cargo from the initial value V_0 to the final value V_E will change according to the law:

$$V_2 = V_0 + \alpha_m g t - \alpha_m g T_G \sin\left(\frac{t}{T_G}\right), \quad (2)$$

where $\alpha_m g = a$ – the average acceleration of the cargo and trolley during the one period of oscillation.

The speed of the point of suspension, in general, must satisfy the condition:

$$V_1 = V_2 + \frac{d(\alpha L)}{dt}. \quad (3)$$

After a time $t = 2\pi T_G$, $\alpha = 0$, $\frac{d\alpha}{dt} = 0$, $V_1 = V_2 = V_E$, acceleration is defined as:

$$a = \frac{V_E - V_0}{2\pi T_G}. \quad (4)$$

But if the value $2a$ exceeds the limit acceleration, then it should be noted, that at the time $t = \pi T_G$ the angle reaches the maximum $\alpha = 2\alpha_m$ and the acceleration of the load is the greatest and equal care $2\alpha_m g$. If at this time change the acceleration of the trolley to acceleration of cargo, then deflection angle α will remain constant. Get the control law for movement of mechanism of three stages [2].

The duration of the transient process is the smallest at the minimum duration of the first and the third stages as the average acceleration mechanism with load during those periods is in two times less than in the second stage. Based on the maximum force of movement drive $F_{\max}$, we obtain the condition of choice T_G:

$$T_G \ge \sqrt{\frac{L m_1}{2g(m_1 + m_2)}}, \quad (5)$$

and duration of the second stage

$$t_2 = \frac{V_E - V_0}{2a} - \pi T_G, \quad (6)$$

where $a = \frac{F_{\max}}{2(m_1 + m_2)}$ is the linear component of the acceleration in the first and the third stages; m_1, m_2 – nominal weight of mechanism and cargo; L – the length of the rope.

With simultaneous horizontal movement and raising or lowering the load at a speed v_L from (3) and (2) we obtain the law of the suspension point speed at each stage:

$$V_1 = \begin{cases} V_0 + at - \left(aT_G - \dfrac{aL}{gT_G}\right)\sin\left(\dfrac{t}{T_G}\right) + \\ +v_L \dfrac{a}{g}\left(1 - \cos\left(\dfrac{t}{T_G}\right)\right) \forall\ 0 \le t \le \pi T_G, \\ V_0 - a\pi T_G + 2at + 2v_L \dfrac{a}{g} \forall\ \pi T_G < t \le \pi T_G + t_2, \\ V_0 + a(t + t_2) - \left(aT_G - \dfrac{aL}{gT_G}\right)\sin\left(\dfrac{t - t_2}{T_G}\right) + \\ +v_L \dfrac{a}{g}\left(1 - \cos\left(\dfrac{t - t_2}{T_G}\right)\right) \forall\ \pi T_G + t_2 < t \le 2\pi T_G + t_2. \end{cases} \quad (7)$$

Thus, it obtained a law of control the speed of the suspension point, which has a wonderful opportunity to combine the operations of the horizontal movement and hoisting. Also, this method does not require precise measurements of the full cargo and crane masses. They can be selected on the basis of some limit values. Deviation of the mass ratio from the calculated results only on a change of forces due the transition process. Theoretically load oscillations at the end of the acceleration mechanism are absent, the real speed of the suspension point and load are coinciding with the settlement.

Fig. 1 shows an example of transition process in two coordinates (longitudinal and transverse horizontal movement with different accelerations and intervals) with simultaneous rise of cargo. Residual oscillations shown on an enlarged scale are a result of the accumulation of errors in the consequent differences $\sin\alpha \ne \alpha, \cos\alpha \ne 1$, but they are less than 0,2...0,5 % the maximum deflection during the transient process.

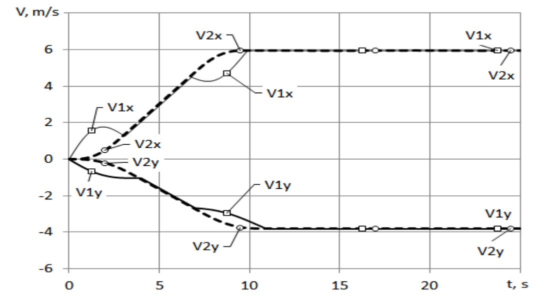
The predicted movement of the cargo allows automatic control of the crane, carrying positioning at predetermined points.

The path traversed by the mechanism during transient start-up and braking (Fig. 2) is calculated as follows:

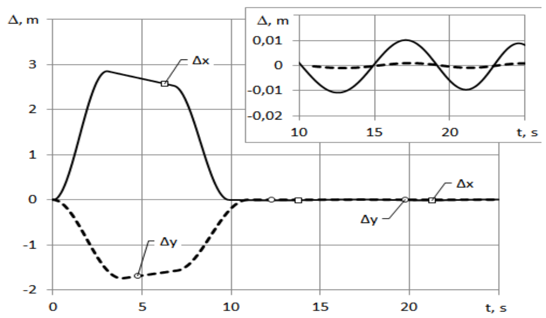
$$s = \begin{cases} V_E(2\pi T_G + t_3) = 2\pi T_G a(2\pi T_G + t_3) \forall\ t_2 = 0 \\ V_E\left(\dfrac{V_E}{2a} + \pi T_G + t_3\right) \forall\ t_2 > 0, \end{cases} \quad (8)$$

where t_3 – duration of the movement with speed V_E.

Fig. 3 shows an example of positioning the load while driving on the coordinates x, y and the descent of cargo (on coordinate x start-up and braking takes place over three stages and on coordinate y – when $t_2 = 0$).



a



b

Fig. 1. The method of anti-sway control with combining of crane operations:
a – speed of crane and load; b – sway angle

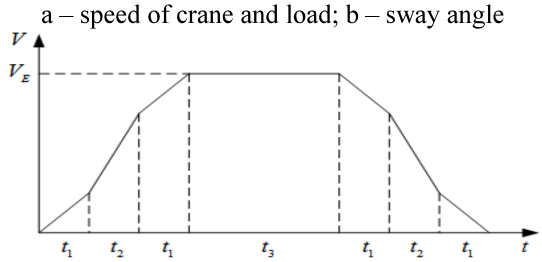
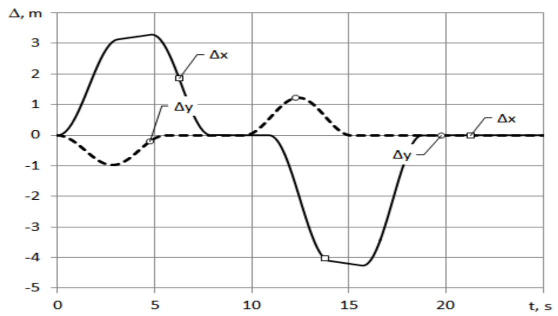
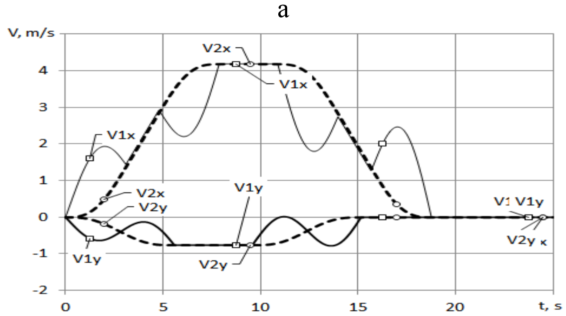


Fig. 2. Diagram of linear component of speed in positioning process



a



b

Fig. 3. Positioning process:
a – sway angle; b – speed of crane and load

Conclusions. The method of anti-sway control is developed. It is invariant to the ratio of the masses of the mechanism and the cargo, to the combining operations of the horizontal displacement on the two coordinates and lifting/lowering the load. On base of generated speed diagram at start-up and braking can be implemented automated crane control and positioning of cargo in given points. This can be applied, for example, in the design of container cranes for automated terminals.

If the observer of mechanism of movement with the drives of pull-up ropes [10] (described for one coordinate in [2]) is implement to the control system the effective suppression of oscillations caused by disturbing factors and errors in determining the parameters of the mechanism will be achieved. A detailed description of the observer for the simultaneous movement on the coordinates x, y will be presented in the following works.

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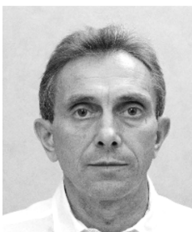

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