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REALIZATION OF OPTIMUM MODE OF MOVEMENT OF ROLLER FORMING INSTALLATION ON ACCELERATION OF FOURTH ORDER

Loveykin V. S.[1], Pochka K. I.[2]

[1]National University of Life and Environmental Sciences of Ukraine, Ukraine.
[2]Kyiv National University of Construction and Architecture, Ukraine.

Corresponding authors: lovvs@ukr.net.

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Abstract. For the purpose of increase in reliability and durability of roller forming installation the optimum mode of back and forth motion of the forming cart on acceleration of the fourth order is calculated. Kinematic characteristics of the forming cart at the optimum mode of the movement on acceleration of the fourth order are calculated. The design of roller forming installation with the drive from the high-moment step engine which is built in the rolling rollers of the forming cart is offered and provides the optimum mode of back and forth motion of the forming cart on acceleration of the fourth order. Use in installation of the specified driving mechanism leads to improvement of quality of a surface to the processed concrete mix, reduction of dynamic loadings in elements of the driving mechanism, to disappearance of excess destructive loads of a frame design and, respectively, to increase in reliability and durability of installation in general.

Key words: roller forming installation, mode of the movement, step engine, drive.

Introduction

In the existing installations of superficial consolidation of concrete goods the crank ram or hydraulic drive of back and forth motion of the forming cart with the condensing rollers is used [1-3].

Formulation of problem

During the constant starting and brake modes of the movement there are considerable dynamic loadings in elements of the driving mechanism and in elements of the forming cart which can lead to premature getting out of installation of the working condition.

Analysis of recent research results

In the existing theoretical and pilot studies of cars of roller formation of concrete goods it is proved their design data and efficiency [1-3]. At the same time not enough attention is paid to a research to the operating dynamic loadings and the modes of the movement that considerably influences work of installation and quality of finished goods [4-19]. During the constant starting and brake modes of the movement there are considerable dynamic loadings in elements of the driving mechanism and in elements of the forming cart that can lead to premature getting out of installation of the working condition [4-19]. In work [20] optimization of the dynamic mode of a reversal of roller forming installation is carried out. However in such mode acceleration and acceleration of the second order (breakthrough) of the cart are of great importance in his extreme provisions. By optimization of the breakthrough mode of a reversal of installation [21] acceleration of the cart in extreme provisions changes smoothly, however the breakthrough changes sharply and is of rather great importance. Optimization of the mode of a reversal of roller forming installation on acceleration of the third about [22, 23] leads to the fact that in extreme provisions of the cart acceleration and breakthrough change smoothly, however acceleration of the third order at the same time is of rather great importance and changes sharply from zero to the maximum value. Therefore urgent there is a problem of improvement of the driving mechanism of roller forming installation for the purpose of providing such mode of the movement of the forming cart at which dynamic loadings in elements of installation would decrease and its durability increased.

Purpose of research

The purpose of work consists in improvement of a design of the driving mechanism of roller forming installation for increase in her reliability and durability.

Results of research

Coefficients of unevenness of the movement and dynamism can be criteria of the mode of the movement of mechanisms and cars [24]. In this work as criterion of the mode of the movement the criteria action which is integral on time with sub integral function which expresses a measure of the movement or action of system is used. For the optimum mode of the movement on acceleration of the fourth order we will have criterion of an optimality of the movement in a look:

$$I_Z = \int_0^{t_1} Q\,dt \to \min , \qquad (1)$$

where t – time; t_1 – duration of the movement of the cart from one extreme situation in another; Q – energy of accelerations of the fourth order:

$$Q = \frac{1}{2} \cdot m \cdot \overset{V}{x}{}^2 , \qquad (2)$$

where m – mass of the forming cart; $\overset{V}{x}$ – acceleration of the fourth order.

Poisson's equation is a condition of a minimum of criterion (1):

$$\frac{\partial Q}{\partial x} - \frac{d}{dt}\frac{\partial Q}{\partial \dot{x}} + \frac{d^2}{dt^2}\frac{\partial Q}{\partial \ddot{x}} - \frac{d^3}{dt^3}\frac{\partial Q}{\partial \dddot{x}} + \frac{d^4}{dt^4}\frac{\partial Q}{\partial \overset{IV}{x}} - \frac{d^5}{dt^5}\frac{\partial Q}{\partial \overset{V}{x}} = 0, \qquad (3)$$

where x, $\dot{x}$, $\ddot{x}$, $\dddot{x}$, $\overset{IV}{x}$ – movement coordinate, speed, acceleration, acceleration of the second order and acceleration of the third order of the cart respectively.

From expression (3) it is possible to write down:

$$\frac{\partial Q}{\partial x} = \frac{\partial Q}{\partial \dot{x}} = \frac{\partial Q}{\partial \ddot{x}} = \frac{\partial Q}{\partial \dddot{x}} = \frac{\partial Q}{\partial \overset{IV}{x}} = 0;$$

$$\frac{\partial Q}{\partial \overset{V}{x}} = m \cdot \overset{V}{x}; \qquad (4)$$

$$\frac{d^5}{dt^5}\frac{\partial Q}{\partial \overset{V}{x}} = m \cdot \overset{X}{x} = 0.$$

From the last equation (4) we receive the differential equation and its decisions:

$$\overset{X}{x} = 0; \quad \overset{IX}{x} = C_1; \quad \overset{VIII}{x} = C_1 \cdot t + C_2;$$

$$\overset{VII}{x} = \frac{1}{2} \cdot C_1 \cdot t^2 + C_2 \cdot t + C_3;$$

$$\overset{VI}{x} = \frac{1}{6} \cdot C_1 \cdot t^3 + \frac{1}{2} \cdot C_2 \cdot t^2 + C_3 \cdot t + C_4;$$

$$\overset{V}{x} = \frac{1}{24} \cdot C_1 \cdot t^4 + \frac{1}{6} \cdot C_2 \cdot t^3 + \frac{1}{2} \cdot C_3 \cdot t^2 + C_4 \cdot t + C_5;$$

$$\overset{IV}{x} = \frac{1}{120} \cdot C_1 \cdot t^5 + \frac{1}{24} \cdot C_2 \cdot t^4 + \frac{1}{6} \cdot C_3 \cdot t^3 + \frac{1}{2} \cdot C_4 \cdot t^2 + C_5 \cdot t + C_6;$$

$$\dddot{x} = \frac{1}{720} \cdot C_1 \cdot t^6 + \frac{1}{120} \cdot C_2 \cdot t^5 + \frac{1}{24} \cdot C_3 \cdot t^4 + \frac{1}{6} \cdot C_4 \cdot t^3 + \frac{1}{2} \cdot C_5 \cdot t^2 + C_6 \cdot t + C_7;$$

$$\ddot{x} = \frac{1}{5040} \cdot C_1 \cdot t^7 + \frac{1}{720} \cdot C_2 \cdot t^6 + \frac{1}{120} \cdot C_3 \cdot t^5 + \frac{1}{24} C_4 \cdot t^4 + \frac{1}{6} C_5 \cdot t^3 + \frac{1}{2} C_6 \cdot t^2 + C_7 t + C_8;$$

$$\dot{x} = \frac{1}{40320} C_1 \cdot t^8 + \frac{1}{5040} C_2 \cdot t^7 + \frac{1}{720} C_3 \cdot t^6 + \frac{1}{120} C_4 \cdot t^5 + \frac{1}{24} C_5 \cdot t^4 + \frac{1}{6} C_6 \cdot t^3 + \frac{1}{2} \cdot C_7 \cdot t^2 + C_8 \cdot t + C_9;$$

$$x = \frac{1}{362880} \cdot C_1 \cdot t^9 + \frac{1}{40320} \cdot C_2 \cdot t^8 + \frac{1}{5040} \cdot C_3 \cdot t^7 + \frac{1}{720} \cdot C_4 \cdot t^6 + \frac{1}{120} \cdot C_5 \cdot t^5 + \frac{1}{24} C_6 \cdot t^4 + \frac{1}{6} C_7 \cdot t^3 + \frac{1}{2} C_8 \cdot t^2 + C_9 \cdot t + C_{10}, \qquad (5)$$

where C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10} – integration constants which are defined from boundary conditions.

Boundary traffic conditions of the cart from one extreme situation in another the following: entry conditions

$$- \; t = 0, \quad x = x_0, \quad \dot{x} = 0, \quad \ddot{x} = 0, \quad \dddot{x} = 0, \quad \overset{IV}{x} = 0;$$

final conditions

$$- \; t = t_1, \quad x = x_1, \quad \dot{x} = 0, \quad \ddot{x} = 0, \quad \dddot{x} = 0, \quad \overset{IV}{x} = 0.$$

Here x_0 and x_1 – coordinates of extreme provisions of the center of mass of the cart.

Having substituted boundary conditions in the equations (5), we receive:

$$t = 0: \quad C_{10} = x_0; \quad \tilde{N}_9 = 0; \quad \tilde{N}_8 = 0; \quad \tilde{N}_7 = 0; \quad \tilde{N}_6 = 0; \qquad (6)$$

$$t = t_1: \begin{cases} \frac{1}{362880}\cdot C_1\cdot t_1^9 + \frac{1}{40320}\cdot C_2\cdot t_1^8 + \\ + \frac{1}{5040}\cdot C_3\cdot t_1^7 + \frac{1}{720}\cdot C_4\cdot t_1^6 + \\ + \frac{1}{120}\cdot C_5\cdot t_1^5 + x_0 = x_1; \\ \frac{1}{40320}\cdot C_1\cdot t_1^8 + \frac{1}{5040}\cdot C_2\cdot t_1^7 + \\ + \frac{1}{720}\cdot C_3\cdot t_1^6 + \frac{1}{120}\cdot C_4\cdot t_1^5 + \\ + \frac{1}{24}\cdot C_5\cdot t_1^4 = 0; \\ \frac{1}{5040}\cdot C_1\cdot t_1^7 + \frac{1}{720}\cdot C_2\cdot t_1^6 + \\ + \frac{1}{120}\cdot C_3\cdot t_1^5 + \frac{1}{24}\cdot C_4\cdot t_1^4 + \\ + \frac{1}{6}\cdot C_5\cdot t_1^3 = 0; \\ \frac{1}{720}C_1\cdot t_1^6 + \frac{1}{120}C_2\cdot t_1^5 + \frac{1}{24}C_3\cdot t_1^4 + \\ \quad + \frac{1}{6}\cdot C_4\cdot t_1^3 + \frac{1}{2}\cdot C_5\cdot t_1^2 = 0; \\ \frac{1}{120}\cdot C_1\cdot t_1^5 + \frac{1}{24}\cdot C_2\cdot t_1^4 + \frac{1}{6}\cdot C_3\cdot t_1^3 + \\ \quad + \frac{1}{2}\cdot C_4\cdot t_1^2 + C_5\cdot t_1 = 0. \end{cases} \quad (7)$$

Having solved system of the equations (7), we receive integration constants C_1, C_2, C_3, C_4 and C_5:

$$C_1 = 25401600\cdot\frac{(x_1 - x_0)}{t_1^9};$$

$$C_2 = -12700800\cdot\frac{(x_1 - x_0)}{t_1^8};$$

$$C_3 = 2721600\cdot\frac{(x_1 - x_0)}{t_1^7}; \quad (8)$$

$$C_4 = -302400\cdot\frac{(x_1 - x_0)}{t_1^6};$$

$$C_5 = 15120\cdot\frac{(x_1 - x_0)}{t_1^5}.$$

We will accept amplitude of movement of the forming cart $\Delta x = x_1 - x_0$. Having substituted certain constants of integration (6) and (8) in the equations (5) we receive expressions for definition of kinematic characteristics of the forming cart when moving from one extreme situation to another at the optimum mode of back and forth motion on acceleration of the fourth order:

$$x = x_0 + \Delta x\cdot\left(70\cdot\frac{t^4}{t_1^4} - 315\cdot\frac{t^3}{t_1^3} + 540\cdot\frac{t^2}{t_1^2} - 420\cdot\frac{t}{t_1} + 126\right)\cdot\frac{t^5}{t_1^5};$$

$$\dot{x} = 630\cdot\Delta x\cdot\left(\frac{t^4}{t_1^4} - 4\cdot\frac{t^3}{t_1^3} + 6\cdot\frac{t^2}{t_1^2} - 4\cdot\frac{t}{t_1} + 1\right)\cdot\frac{t^4}{t_1^5};$$

$$\ddot{x} = 2520\cdot\Delta x\cdot\left(2\cdot\frac{t^4}{t_1^4} - 7\cdot\frac{t^3}{t_1^3} + 9\cdot\frac{t^2}{t_1^2} - 5\cdot\frac{t}{t_1} + 1\right)\cdot\frac{t^3}{t_1^5};$$

$$\dddot{x} = 2520\cdot\Delta x\cdot\left(14\cdot\frac{t^4}{t_1^4} - 42\cdot\frac{t^3}{t_1^3} + 45\cdot\frac{t^2}{t_1^2} - 20\cdot\frac{t}{t_1} + 3\right)\cdot\frac{t^2}{t_1^5};$$

$$\overset{IV}{x} = 15120\cdot\Delta x\cdot\left(14\cdot\frac{t^4}{t_1^4} - 35\cdot\frac{t^3}{t_1^3} + 30\cdot\frac{t^2}{t_1^2} - 10\cdot\frac{t}{t_1} + 1\right)\cdot\frac{t}{t_1^5};$$

$$\overset{V}{x} = 15120\cdot\Delta x\cdot\left(70\cdot\frac{t^4}{t_1^4} - 140\cdot\frac{t^3}{t_1^3} + 90\cdot\frac{t^2}{t_1^2} - 20\cdot\frac{t}{t_1} + 1\right)\cdot\frac{1}{t_1^5}. \quad (9)$$

Having accepted amplitude of movement of the forming cart $\Delta x = 0{,}4m$ and duration of the movement of the forming cart from one extreme situation to another $t_1 = 3s$, on the equations (9) kinematic characteristics of the forming cart at the optimum mode of back and forth motion on acceleration of the fourth order have been calculated. By results of calculations schedules of the optimum mode on acceleration of the fourth order of change of movement (Fig. 1, a), speeds (Fig. 1, b), accelerations (Fig. 1, c), accelerations of the second order (Fig. 1, d), accelerations of the third order (Fig. 1, e), accelerations of the fourth order are constructed (Fig. 1, f) at the movement of the forming cart of one extreme situation in another. The law of the movement of the cart described by the equations (9) can be carried out by the drive from the high-moment step engine which is built in the rolling rollers of the forming cart of installation. At the same time the law of change of angular speed of the driving step engine is described by the equation:

$$\dot{\varphi} = 630\frac{\Delta x}{R}\cdot\left[\frac{t^4}{t_1^4} - 4\frac{t^3}{t_1^3} + 6\frac{t^2}{t_1^2} - 4\frac{t}{t_1} + 1\right]\cdot\frac{t^4}{t_1^5}, \quad (10)$$

$$0 \le t \le t_1.$$

Similarly the law of change of angular speed of the driving step engine at the movement of the forming cart is defined in the opposite direction:

$$\dot{\varphi} = -630\frac{\Delta x}{R}\cdot\left[\frac{(t-t_1)^4}{t_1^4} - 4\frac{(t-t_1)^3}{t_1^3} + 6\cdot\frac{(t-t_1)^2}{t_1^2} - 4\cdot\frac{(t-t_1)}{t_1} + 1\right]\frac{(t-t_1)^4}{t_1^5}, \quad (11)$$

$$t_1 \le t \le 2t_1;$$

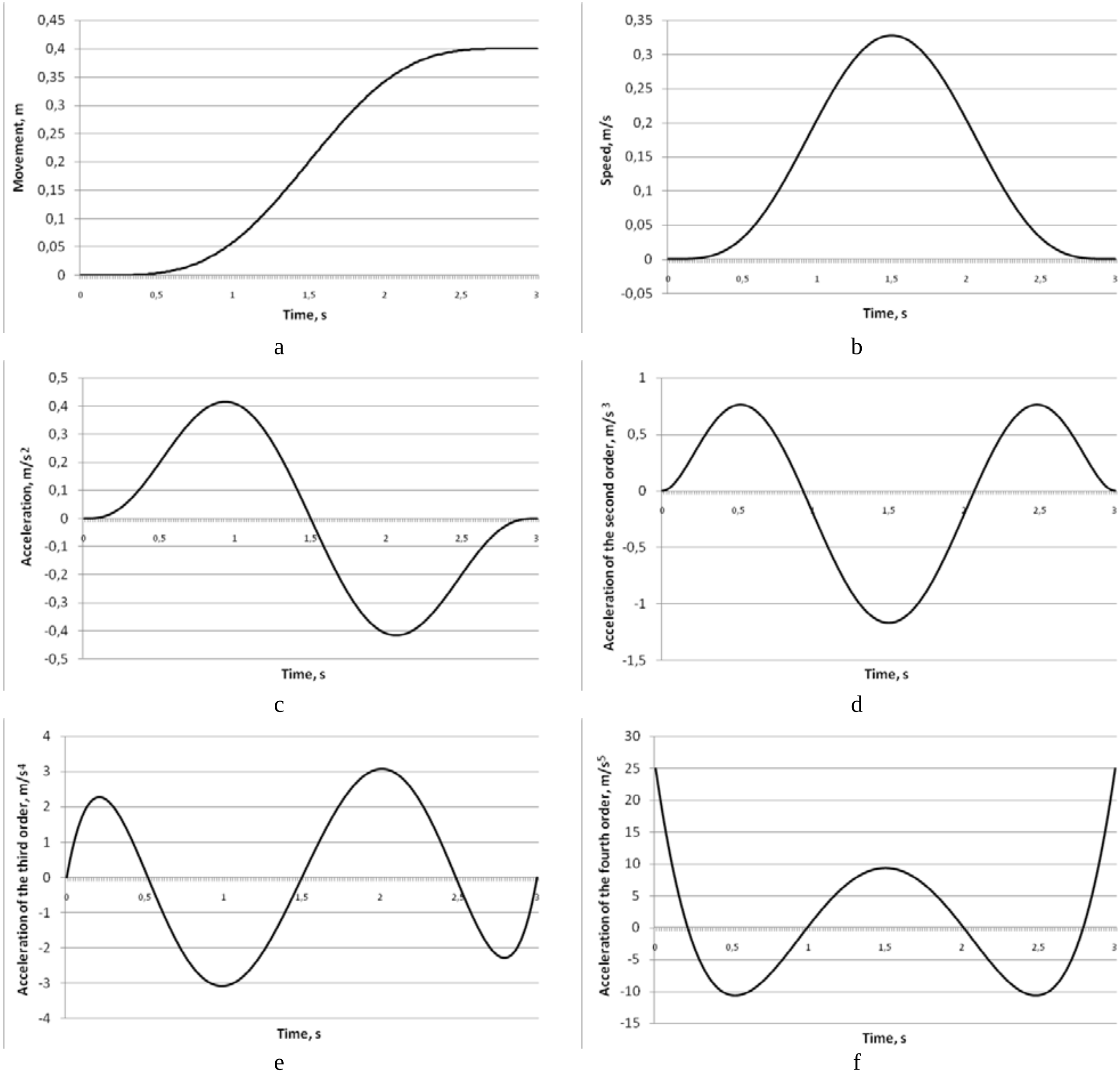

Fig. 1. Schedules of change of movement – a, speed – b, acceleration – c, accelerations of the second order – d, accelerations of the third order – e and accelerations of the fourth order – f at the optimum mode of the movement carts on acceleration of the fourth order.

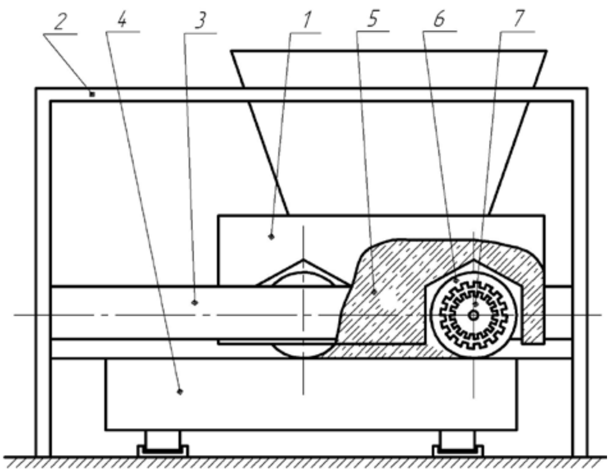

Fig. 2. Roller forming installation with the drive from the step engine.

For the purpose of reduction of dynamic loadings in elements of installation and for increase in her reliability the design of roller forming installation with the drive from the high-moment step engine for ensuring back and forth motion of the forming cart with the optimum break-through mode of a reversal (Fig. 2) is offered. Installation consists from the forming cart 1 which is mounted on the portal 2 and carries out back and forth motion in guides 3 over emptiness of a form 4. The forming cart contains the giving bunker 5 and the rolling rollers 6 on axis 7.

The cart is set in back and forth motion by means of the high-moment step engine which is built in rollers, and the axis of a roller plays a stator role, and a roller – a rotor [25].

Transforming the first expression (9) for a case when the beginning of coordinates is counted from the average provision of his movement, we will receive:

$$x=\frac{\Delta x}{2}\left[2\cdot\left(70\cdot\frac{t^4}{t_1^4}-315\cdot\frac{t^3}{t_1^3}+540\cdot\frac{t^2}{t_1^2}-420\cdot\frac{t}{t_1}+126\right)\cdot\frac{t^5}{t_1^5}-1\right].\qquad(12)$$

The law of the movement of the cart described by the equation (12) can be carried out by the drive with the cam mechanism (Fig. 3) of back and forth motion of the cart.

At the same time the movement of the cart in one direction is carried out due to turn of a cam 1 on a half of a turn (that is $\varphi=\pi$) and in the returnable direction on a half of a turn; a full motion cycle of the cart – for one turn of a cam.

It is necessary for implementation of the described law of the movement of the cart that the increment of radius of a cam corresponded to an increment to movement of the cart.

According to it the variable radius of a cam is defined by dependence:

$$\rho=\frac{b}{2}+\frac{\Delta x}{2}\left[2\cdot\left(70\cdot\frac{t^4}{t_1^4}-315\cdot\frac{t^3}{t_1^3}+540\cdot\frac{t^2}{t_1^2}-420\cdot\frac{t}{t_1}+126\right)\frac{t^5}{t_1^5}-1\right],\qquad(13)$$

where b – distance between pushers 2 (Fig. 3).

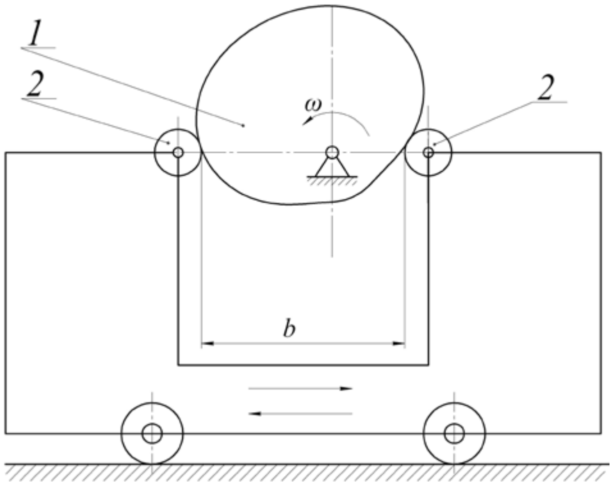

Fig. 3. The scheme of the mechanism with the cam drive of back and forth motion of the cart.

Time t can be excluded from dependence (13) as $t=\varphi/\omega$, and $t_1=\pi/\omega$.

Here φ – angular coordinate of turn of a cam, and ω – angular speed of a cam.

After the corresponding transformations the radius of a cam which describes his profile contacts angular coordinate the following expression:

$$\rho=\frac{b}{2}+\frac{\Delta x}{2}\cdot\left[2\cdot\left(70\cdot\frac{\varphi^4}{\pi^4}-315\cdot\frac{\varphi^3}{\pi^3}+540\cdot\frac{\varphi^2}{\pi^2}-420\cdot\frac{\varphi}{\pi}+126\right)\cdot\frac{\varphi^5}{\pi^5}-1\right],\qquad(14)$$

$$0\le\varphi\le\pi$$

Similarly the cam profile on the site of his turn from π to 2π which is described by the radius changing on dependence is defined:

$$\rho=\frac{b}{2}-\frac{\Delta x}{2}\left[2\left(70\frac{(\varphi-\pi)^4}{\pi^4}-315\frac{(\varphi-\pi)^3}{\pi^3}+540\frac{(\varphi-\pi)^2}{\pi^2}-420\frac{(\varphi-\pi)}{\pi}+126\right)\frac{(\varphi-\pi)^5}{\pi^5}-1\right],\qquad(15)$$

$$\pi\le\varphi\le2\pi$$

For prevention of blows of a cam about pushers at change of the direction of the movement of the cart (14) and (15) profile of a cam (Fig. 4) described by the equations have such appearance that its diameter the d constant and is equal to distance between pushers b ($d=b$) in any situation.

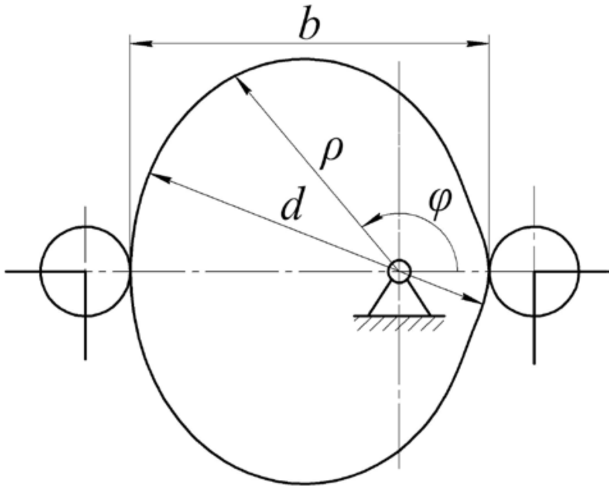

Fig. 4. The cam profile realizing the optimum mode of the movement on acceleration of the fourth order.

For the purpose of reduction of dynamic loadings in elements of installation and for increase in her reliability it is offered an installation design with the driving mechanism for providing the optimum mode of back and forth motion of the forming cart on acceleration of the fourth order (Fig. 5). The driving mechanism is executed in the form of pivotally the cam mechanisms installed on the portal which contact to the pushers which are rigidly attached to the forming cart.

Installation contains 1 forming cart 2 mounted on the motionless portal which contains in itself the giving bunker 3 and the rolling rollers 4 and carries out reciprocating the movement in guides 5 over emptiness of a form 6 [26]. The cart is set in motion by means of two drives 7 attached to the portal 1 in the form of the cam mechanisms rotating with a constant angular speed ($\omega = const$), but different in the direction and contact to two pushers 8 which are rigidly connected to a cart 2 frame. Existence of two pushers 8 from each party of the forming cart 2 allows to create a rigid power chain at her direct and returnable movement.

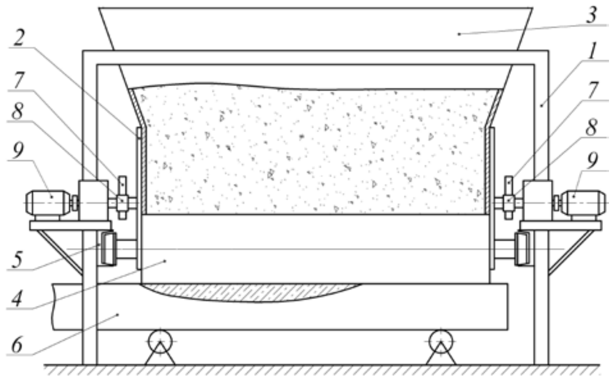

Fig. 5. Roller forming installation with the cam driving mechanism.

When using in installation of the drive from the high-moment step engine which is built in the rolling rollers which law of change of angular speed is described by the equations given above quality of the processed concrete mix increases, dynamic loadings in drive elements decrease, excess destructive loads of a frame design decrease and, respectively, durability of installation in general increases.

When using in installation of the cam driving mechanism from each party of the forming cart the possibility of her axial distortion is prevented, the quality of the processed concrete mix increases, dynamic loadings in drive elements decrease, excess destructive loads of a frame design decrease and, respectively, the durability of installation in general increases.

Conclusions

1. As a result of the conducted researches for the purpose of increase in reliability and durability of roller forming installation the optimum mode of back and forth motion of the forming cart on acceleration of the fourth order is calculated.
2. Kinematic characteristics of the forming cart at the optimum mode of back and forth motion on acceleration of the fourth order are calculated.
3. The design of roller forming installation with the drive from the high-moment step engine which is built in the rolling rollers of the forming cart with a possibility of realization of the optimum mode of back and forth motion on acceleration of the fourth order is offered.
4. The design of the drive of installation in a type of the cam mechanism is offered and the cam profile for providing the optimum mode of back and forth motion of the forming cart on acceleration of the fourth order is constructed.
5. Results of work can be used further for specification and improvement of the existing engineering methods of calculation of driving mechanisms of cars of roller formation both at design/designing stages, and in the modes of real operation. Also results of work can be useful at design or improvement of mechanisms with back and forth motion of executive elements.

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РЕАЛІЗАЦІЯ ОПТИМАЛЬНОГО РЕЖИМУ РУХУ РОЛИКА ФОРМУЮЧОЇ УСТАНОВКИ НА ПРИСКОРЕННЯ ЧЕТВЕРТОГО ПОРЯДКУ

В. С. Ловейкин, К. І. Почка

Анотація. В цілях збільшення надійності і довговічності ролика формуючи встановлення оптимального режиму руху вперед і назад в формуючої візки на розгін четвертого порядку розраховується. Кінематичні характеристики формуючи кошик при оптимальному режимі руху на прискорення четвертого порядку розраховуються. Дизайн роликові формувальні установки з приводом від високого моменту крокового двигуна, який побудований на прокатних роликів, утворюють візок і забезпечує оптимальний режим руху вперед і назад формуючої візки на розгін четвертого порядку. Використання в установці зазначеного приводного механізму призводить до покращення якості оброблюваної поверхні бетонної суміші, зниження динамічних навантажень в елементах приводного механізму, до зникнення зайвого руйнівних навантажень конструкція рами і, відповідно, збільшити надійність і довговічність установки в цілому.

Ключові слова: роликові формувальні установки, режим руху, крок двигуна, привод.

РЕАЛИЗАЦИЯ ОПТИМАЛЬНОГО РЕЖИМА ДВИЖЕНИЯ РОЛИКА ФОРМИРУЮЩЕЙ УСТАНОВКИ НА УСКОРЕНИЕ ЧЕТВЕРТОГО ПОРЯДКА

В. С. Ловейкин, К. И. Почка

Аннотация. В целях увеличения надежности и долговечности ролика формируя установки оптимального режима движения вперед и назад в формующей тележки на разгон четвертого порядка рассчитывается. Кинематические характеристики формируя корзину при оптимальном режиме движения на ускорение четвертого порядка рассчитываются. Дизайн роликовые формовочные установки с приводом от высокого момента шагового двигателя, который построен на прокатных роликов, образующих тележку и обеспечивает оптимальный режим движения вперед и назад формующей тележки на разгон четвертого порядка. Использование в установке указанного приводного механизма приводит к улучшению качества поверхности обрабатываемой бетонной смеси, снижение динамических нагрузок в элементах приводного механизма, к исчезновению лишнего разрушительных нагрузок конструкция рамы и, соответственно, увеличить надежность и долговечность установки в целом.

Ключевые слова: роликовые формовочные установки, режим движения, шаг двигателя, привод.