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MATHEMATICAL AND S-MODELS OF CARGO OSCILLATIONS DURING MOVEMENT OF BRIDGE CRANE

The effectiveness of research on the basis of mathematical models (linear, nonlinear) describing the dynamics of bridge cranes and cargo oscillations during transitional modes of movement, increases significantly with the use of numerical methods and simulation models created by visual programming tools.

Purpose. To develop and evaluate proposed simulation models of bridge crane dynamics.

Methodology. On the basis of well-known mathematical models, simulation models of the “bridge crane (trolley) – cargo on a flexible suspension” system are developed. The simulation models are created using the visual programming tools of the SIMULINK application running on the MATLAB system. Simulink libraries and DSP System Toolbox components are used in the simulation.

Findings. S-models of cargo oscillations during the bridge crane movement have been developed and adjusted. A comparative analysis of the proposed models has been performed.

Originality. With the help of SIMULINK visual programming tools for the first time we received a set of simulation models of cargo oscillations during the transition modes of the bridge crane movement for linear and nonlinear formulation of the task.

Practical value. The proposed s-models allow automating and visualizing studies of dynamics of bridge crane movement in order to determine their rational kinematic and dynamic characteristics. The models are provided with examples of calculation of dynamic motion modes.

Keywords: *bridge crane dynamic, cargo oscillations, mathematical model, simulation model*

Introduction. The works [1, 2] are devoted to the study of the dynamic modes of movement of the “crane (trolley) – cargo” system. The works [3, 4] consider the issues of optimal control of the crane trolleys movement. Interaction of the crane trolley wheels with rails was investigated in works [5, 6]. The oscillation of the trolley on the rope is described in the work [7]. In them the dynamics of the crane motion is usually described by linear models that may be integrated directly with further dynamic analysis. Non-consideration of nonlinearities leads to simplified results that do not always reflect satisfactorily the real processes. Models are also known which take into account the various nonlinearities that are characteristic of the mechanical system and the excitatory forces [8, 9]. Mathematical models of movement are considered with different variants of assumptions in the calculation schemes, but the issues of automating and increasing the effectiveness of the study of cargo oscillations using models based on numerical methods are given insufficient attention. Modern approaches to the study of oscillatory processes in mechanical systems involve the use of visual modeling methods based on numerical methods for solving problems.

This work reflects the compilation of simulation models of cargo oscillations during the bridge crane (crane trolley) movement in the linear and nonlinear formulation of the problem.

The objective and task statement. The purpose of the work is to develop simulation models of the dynamic “bridge crane (trolley) – cargo” system during the transition modes. In accordance with the purpose there are the following tasks: 1) to carry out an overview of existing calculation schemes and mathematical models of cargo oscillations during the bridge crane movement; 2) to develop and customize the linear and nonlinear simulation models of cargo oscillations; 3) to carry out an assessment of the quality of the developed simulation models of cargo oscillations during the bridge crane (trolley) movement by numerical analysis.

The task execution methods are based on the fundamental research of the bridge crane dynamics. The Simulink tool, which is an extension to the interactive MATLAB system, was adopted by the simulation tool.

Calculation schemes of cargo oscillations during the bridge crane movement. The most common means of mechanization of lifting and transport operations at industrial enterprises are bridge type cranes (single girder, double girder, gantry), common fact for which is that the trolley carrying the cargo on the flexible suspension moves along the span structure (bridge).

During the crane (trolley) movement there are loads that are caused by the interaction of the crane movement mechanism drive, elements of the metal structure, crane track and cargo. Such loads depend on both the design parameters of the machine and the crane track and their deviations from the design values, as well as on some exploitation indicators (control regime, mass and position of the cargo, position of the trolley in the crane span).

During the transitional modes of a crane (trolley) movement there are observed cargo oscillations, which cause uneven movement and, accordingly, additional loads on the structure elements, create inconvenience in the operation of machines, in particular, in the positioning of the cargo. Such influences must be taken into account by specifying the calculations of load-lifting machines and their drives.

In the most general case, the model of oscillatory processes describes the dynamics of nonlinear systems with lumped parameters, which are characterized by stochastic phenomena.

The idealized calculation scheme of a double girder four-wheeled bridge crane with a separate drive takes into account the parameters of the crane and the physical factors that have the most significant effect on its load level, such as: flexibility of the movement mechanism transmission; stiffness of the main and final girders of the bridge; distribution of the main girders masses along the span length; flexibility of the cargo suspension (rope); damping of elastic oscillations in the transmission; transverse displacement of crane wheels within gaps between wheel flanges and rails; change of the resistance forces of the crane movement as a result of the change of wheel flanges pressure on rails; structural damping of elastic vibrations of the main girders.

The crane system in this case is characterized by the some parameters (Fig. 1): m_{red} – mass of rotating parts of the movement mechanism, reduced to the crane displacement (in the direction of the axis y); m_k – reduced mass of the girder and the end truck; m_t – trolley mass; m_c – cargo mass; μ_1 – mass of a length unit of one main girder; C_n – reduced rigidity ratio of transmission; EJ_1 – stiffness on the bend of the main girder; EJ_k – stiffness on bending of the final girder; c_c – analogue of the rigidity of the suspension system of the cargo on the ropes; D_n – damping ratio of transmission; β_1 – coefficient of internal friction of the main girder.

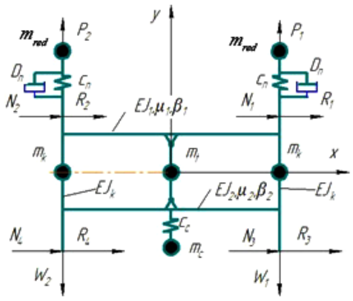

Fig. 1. Calculation scheme of double girder bridge crane

The following external forces act on the crane during its start-up and braking: P_1 and P_2 – driving or braking forces on the corresponding end truck; W_1, W_2 – the resistance forces of movement of the corresponding end truck, including the friction forces between wheel flanges and rails; R_i ($i = 1, 2, 3, 4$) – transverse reactions from the rails acting on the wheels on the rolling lane, which may be either forces of elastic slipping, or forces of slip friction; N_i – the forces acting on the wheel flanges from the rails. All external forces, except the constant components of the resistance forces of crane movement, are not known in advance and are determined as a result of the solution of the equations of the crane movement.

We consider two typical cases of location of a trolley with a cargo: in the middle of the span and near the final girder.

We simplify the calculation scheme of the bridge crane. The two main girders are replaced by one equivalent girder, the mass and stiffness when bending equal the mass and stiffness of the two main girders. This replacement is only needed to determine the bending moments in the main girders, and the bending moments in the final girders are calculated according to the scheme of the complete frame.

In accordance with this idealization, the calculation scheme of the bridge crane for the middle position of the trolley with the cargo during start and stop of the end trucks (Fig. 2) has the following parameters: $EJ = 2EJ_1$; $\mu = 2\mu_1$; $b = 2\beta_1$.

This calculation scheme is suitable and convenient for practical use. In order to further simplify it, we take into account the correlation between the crane eigenfrequencies.

For bridge cranes, the frequency of the pendulum oscillations of the cargo is significantly lower than the frequency of oscillations of the crane structure and the end trucks. Even with a small length of the suspension,

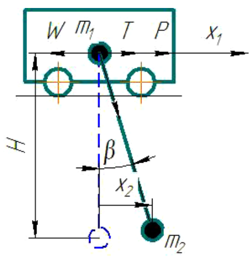

Fig. 2. Simplified crane calculation scheme

the frequency of the pendulum oscillations of the cargo does not exceed 2–3 s^{-1}, while the eigenfrequencies of the crane are an order of magnitude higher [10].

Consequently, we can assume that the pendulum oscillations of the cargo do not depend on the oscillations of the crane structure, and when the cargo oscillations are calculated, the crane structure and the end trucks can be taken absolutely rigid. In calculation the dynamic loads affecting the crane structure and end trucks, the law of the variation of the horizontal component of the ropes tension, which arises as a result of pendulum oscillations of cargo, can be set in the form of a known function of time, determined by the scheme of the absolutely rigid crane. This approach allows us to reduce the order of equations in the mathematical model of the crane as a dynamic system by two units.

The calculation of the pendulum oscillations of the cargo on the ropes is performed according to the simplest scheme of the two-mass system [4] (Fig. 2). In Fig. 2: m_1 – reduced mass of the crane or the trolley; $G = m_2 g$ – cargo weight; P – total traction or braking effort of the driving wheels of the crane (trolley); W – resistance force of the crane (trolley) movement; x_1 and x_2 – generalized coordinates of masses m_1 and m_2; S – total tension of ropes; φ – angle of deviation of ropes from the vertical; T – horizontal component of the ropes tension; H – length of the cargo suspension.

The works [4, 8] propose a refined dynamic model of the movement of trolley with a cargo on a flexible suspension. The calculation scheme of the crane is adopted as a flat pendulum with a cargo mass m_2, the hinge point of which, along with a trolley weighing m_1, moves along a horizontal straight line. The forces acting on the trolley are the motive force of the drive F and the force of dry friction W. Both forces are functions of the speed of the trolley. This scheme corresponds to the simplified scheme (Fig. 2), but the oscillations of the cargo are considered, taking into account the trigonometric functions of the angle of deviation of the cargo from the vertical

Mathematical models of cargo oscillations during the bridge crane movement. When compiling a mathematical model of cargo oscillations in linear formulation (Fig. 2), the following assumptions are introduced:

- the system is conservative with two degrees of freedom;
- the masses of the cargo and the trolley are lumped;
- the driving forces and resistance forces applied to the trolley are constant;
- the ropes do not stretch;
- the maximum deviation of the ropes from the vertical does not exceed 10–12°, therefore we accept: $\sin\varphi \approx \varphi$, $\cos\varphi \approx 1.0$. Given this assumption, we accept $x_2 = x_1 + H\varphi$, $S = G = m_2 g$, and the horizontal component of the ropes tension

$$T = S\varphi = \frac{m_2 g}{H}\left(x_2 - x_1\right),$$

where S is total tension of ropes; φ is the angle of deviation of ropes from the vertical; g is acceleration of gravity; m_2 is cargo mass; H is the length of the cargo suspension; x_1 and x_2 are generalized coordinates of masses m_1 and m_2.

The equations of the oscillations of a cargo and a crane (trolley) is convenient to make in a direct way, as the sum of inertial, restorative, driving and resistance forces on the generalized coordinates.

The equation of crane movement is

$$m_1\ddot{x}_1 + \frac{m_2 g}{H}\left(x_1 - x_2\right) = P - W, \qquad (1)$$

where m_1 is reduced mass of the crane or the trolley, and the equation of cargo movement in a horizontal direction is

$$m_2\ddot{x}_2 + \frac{m_2 g}{H}\left(x_2 - x_1\right) = 0, \qquad (2)$$

where P is force that accelerates or retards a crane (trolley); W is static resistance force of the crane (trolley) movement).

The value of the force P is determined by the formula

$$P = \frac{M_e i}{R_k}\eta,$$

where M_e is drive torque; i is gear ratio of drive; h is the coefficient of efficiency of the drive; R is the crane (trolley) wheel radius.

The force P becomes zero after acceleration or deceleration.

The static resistance force of the crane (trolley) movement is determined by the formula

$$W_k = \left(m_1 + m_2\right) g \left(\frac{fd + 2k}{D_w}\right) k_{fl},$$

where $k_{fl} = 1.5$ is the coefficient taking into account the friction between wheel flanges and rails; f is the wheel bearing friction coefficient; d is the trunnion diameter; D_w is the crane wheel diameter; k is the coefficient of rolling resistance of the wheel on the rail).

The duration of acceleration or deceleration is

$$t_p = 2\pi n \sqrt{\frac{H_{\min}}{g}\left(\frac{m_1}{m_1 + m_2}\right)}.$$

The differential equations (1) and (2) form a system that describes the oscillations of the cargo and the crane (trolley) as a conservative mechanical system with two masses [6]

$$\begin{cases} m_1\ddot{x}_1 + c\left(x_1 - x_2\right) = P - W \\ m_2\ddot{x}_2 + c\left(x_2 - x_1\right) = 0 \end{cases}. \qquad (3)$$

In this equations $c = \dfrac{m_2 g}{H}$ is cargo suspension rigidity.

During several periods the amplitude of oscillations is damped due to the presence of so-called "constructive damping" in the system. We take this phenomenon into account by introducing into the system (3) a linear resistance force proportional to velocity

$$\begin{cases} m_1\ddot{x}_1 + \beta\left(\dot{x}_1 - \dot{x}_2\right) + c\left(x_1 - x_2\right) = P - W \\ m_2\ddot{x}_2 + \beta\left(\dot{x}_2 - \dot{x}_1\right) + c\left(x_2 - x_1\right) = 0 \end{cases}, \quad (4)$$

where b is the coefficient of viscous friction in the system.

A more precise mathematical model of oscillations of a crane with a cargo is obtained with less idealization of the oscillatory system [4]

$$\begin{cases} \left(m_1 + m_2\right)\ddot{x} + m_2 l\left(\ddot{\varphi}\cos\varphi - \dot{\varphi}^2\sin\varphi\right) = \\ = P\left(\dot{x}\right) - W\,\mathrm{sign}(\dot{x}) \\ m_2 l\dot{x}\dot{\varphi}\left(-\sin\varphi\right) + m_2 gl\left(-\sin\varphi\right) - \\ - m_2 l^2\ddot{\varphi} - m_2 l\left(\ddot{x}\cos\varphi - \dot{x}\sin\varphi\dot{\varphi}\right) = 0 \end{cases},$$

or after the transformations

$$\begin{cases} \left(m_1 + m_2\right)\ddot{x} + m_2 l\left(\ddot{\varphi}\cos\varphi - \dot{\varphi}^2\sin\varphi\right) = \\ = P\left(\dot{x}\right) - W\,\mathrm{sign}(\dot{x}) \\ l\ddot{\varphi} + g\sin\varphi + \ddot{x}\cos\varphi = 0 \end{cases}. \quad (5)$$

In the system

$$P\left(\dot{x}\right) = \frac{2M_e\dfrac{i\eta}{R}}{\left(\dfrac{1 - \dfrac{\dot{x}i}{\dot{\varphi}_0 R}}{s_{kp}} + \dfrac{s_{kp}}{1 - \dfrac{\dot{x}i}{\dot{\varphi}_0 R}}\right)}, \quad (6)$$

where $M_e = M_{\max}$ is the maximum value of drive torque; s_{kp} is critical slip of the engine (we accept $s_{kp} = 1$); is synchronous angular speed of the engine).

Simulation models of cargo oscillations during the bridge crane movement. Simulation model (*S*-model) is a formal (that is, executed in some formal language) description of the logic of the functioning of the investigated system and the interaction of its individual elements in time, taking into account the most significant causative relationships inherent in the system; it provides statistical experiments.

In studying the behavior of the system it is necessary to note two important circumstances:

1) the relationship between the individual elements described in the model, as well as between some of the parameters can be represented in the form of analytical dependencies;

2) the model is implemented and has a practical value only if it reflects only those properties of the real system that affect the value of the selected efficiency indicator.

The results of simulation modeling, as with any numerical method, always have an individual character. To obtain substantiated general conclusions, it is necessary to conduct a series of model calculations (experiments), and the processing of results requires the use of special statistical procedures.

In most cases, the ultimate goal of the simulation is to optimize certain parameters of the system. However, the potential of simulation modeling is substantially wider. Depending on the stage and purpose of the research, one of the three most common types of simulation experiments is used:

1) study of the relative influence of various factors on the value of the output system characteristics;

2) finding an analytical dependence between output characteristics and factors;

3) search for optimal or rational values of system parameters.

To perform simulation experiments, the MATLAB system, which contains the Simulink visual simulation application, is efficient and convenient. In this work using Simulink tools we create the simulation models of cargo oscillations for transitional modes of the bridge crane (trolley) movement

Linear model. The linear simulation model (Fig. 3) describing the oscillations of the cargo and the trolley as a conservative mechanical system with two masses, is developed on the basis of system (3). For the convenience of visual programming, the system has been reduced to the form

$$\begin{cases} \ddot{x}_1 = \dfrac{P - W - c\left(x_1 - x_2\right)}{m_1} \\ \ddot{x}_2 = \dfrac{c\left(x_1 - x_2\right)}{m_2} \end{cases}. \quad (7)$$

In the simulation we used the following input parameters:

- cargo mass m_2 = 20 400 kg;
- reduced trolley mass m_1 = 22 400 kg;
- total driving (or braking) force P = 75 kN;
- length of the cargo suspension H = 14 m.

The simulation model (Fig. 3) contains four blocks-integrators (Integrator – Integrator3). The Integrator unit receives the data of the right-hand side of the first equation of the system (7), which are formed by mathematical blocks. After using Integrator, we get the crane speed and after using the Integrator1 unit, we get the value of crane (trolley) moving x_1. Similarly, the Integrator2 unit receives data on the right-hand side of the second equation of system (7) formed by the second group of mathematical blocks. After using the Integra-

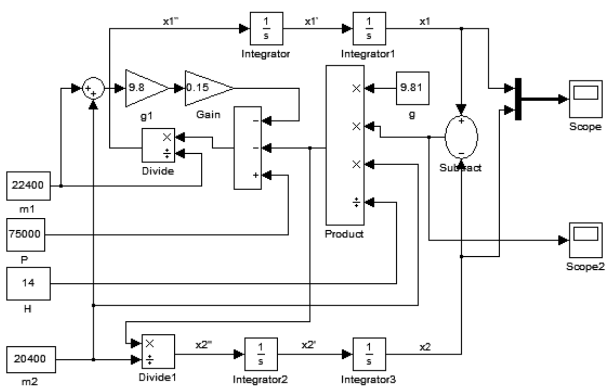

Fig. 3. Simulation model of oscillations of a cargo and a trolley during acceleration (deceleration)

tor2 unit, we get the cargo speed and after using the Integrator3 unit, we get a cargo deviation x_2. The following blocks are used to form the data of the right-hand sides of the system equations (7):

constant P – reduced driving force;

constant m_1, m_2, H, g – reduced trolley mass, cargo mass, length of the cargo suspension, acceleration of gravity;

gain, g_1, *sum*, m_1, m_2 form the resistance forces of movement W;

divide, divide1 are the dividing operations;

product are multiplication and division operations;

subtract is subtraction operation;

scope – virtual oscilloscope for registration of cargo movement x_2 and trolley movement x_1;

scope2 – a virtual oscilloscope for registering cargo oscillations relative to the crane (trolley) as a difference $x_1 - x_2$.

In order to increase the immunity of the model from unintentional modification it is expedient to create a disguised subsystem in the model. The subsystem receives data from the blocks of constants, which form the crane parameters, and the initial data are received in the virtual oscilloscopes *scope* i *scope2*. The initial simulation conditions are asked directly in the dialog boxes of the units *Integrator – Integrator3*.

The model run at the interval 0–10 s allowed us to get the value of the movements of the cargo and the trolley (Fig. 4) and the difference between these values.

In the mathematical model of oscillations of the trolley and the cargo (4) during acceleration, we take into account the energy dissipation due to the friction forces in the rope, the bearings of the trolley and other connections.

To develop the s-model we transform system (4)

$$\begin{cases} \ddot{x}_1 = \dfrac{P - W - \beta(\dot{x}_1 - \dot{x}_2) - c(x_1 - x_2)}{m_1} \\ \ddot{x}_2 = \dfrac{\beta(\dot{x}_1 - \dot{x}_2) + c(x_1 - x_2)}{m_2} \end{cases}. \qquad (8)$$

The simulation model on the system (8) has a unit *B*; it takes into account the viscous friction forces (Fig. 5), which are proportional to the oscillation velocity.

This oscillation model also has four data input units (m_1, m_2, P, H) and two output units (*Scope 1* and *Scope2*).

With the consideration of viscous friction in the system, the amplitude of the cargo oscillations is sufficient-

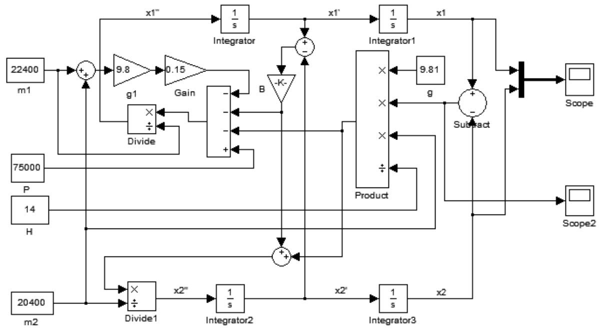

Fig. 5. Simulation model with unit B

ly rapidly damped (Fig. 6). However, there is a constant difference in the movement of the trolley and cargo, which is explained by the assumption of the constant value of the driving force *P* at the simulation interval.

Nonlinear model. The nonlinear simulation model describes the oscillations of the cargo and the trolley. It is developed on the basis of system (5), which is given for ease of simulation to this type

$$\begin{cases} \ddot{x} = \dfrac{P(\dot{x}) - W sign(\dot{x}) - m_2 l(\ddot{\varphi}\cos\varphi - \dot{\varphi}^2 \sin\varphi)}{(m_1 + m_2)} \\ \ddot{\varphi} = \dfrac{-g\sin\varphi - \ddot{x}\cos\varphi}{l} \end{cases}. \qquad (9)$$

Input data for calculating the driving force by formula (6) are the following: $M_e = M_{\max} = 1252$ N · m – maximum value of drive torque; $i = 27.83$ – gear ratio of drive; $h = 0.8$ – the coefficient of efficiency of the drive; $R = 0.275$ m – the crane (trolley) wheel radius; $s_{kp} = 1$ – critical slip of the engine; $= 104.6$ s^{-1} – synchronous angular speed of the engine.

After substituting data in (6), we obtain a simplified formula for determining the driving force of a crane (a trolley)

$$P(\dot{x}) = \frac{202\,724}{1 - 0.9675\dot{x} + \dfrac{1}{1 - 0.9675\dot{x}}}.$$

The simulation model (Fig. 7) implementing the algorithm by the system (9) is much more complicated than the described models in the previous section, but gives us a more objective notion of the course of the cargo oscillatory process. This model allows us to get a schedule for changing the speed of the crane (trolley)

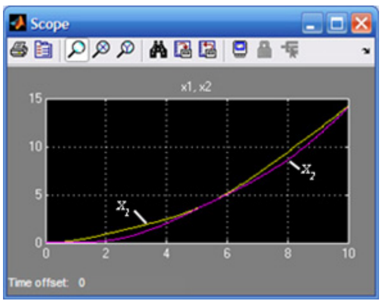

Fig. 4. Trolley movement x_1 and cargo movement x_2

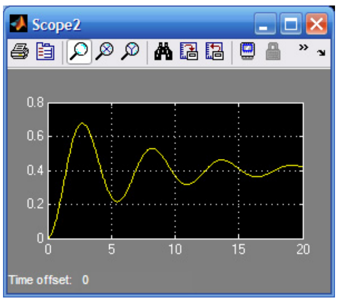

Fig. 6. Cargo oscillations relative to the trolley

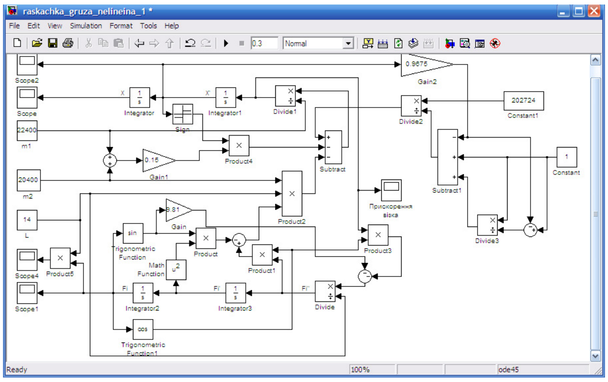

Fig. 7. Nonlinear simulation model describing oscillations of cargo and crane (trolley)

(Fig. 8) from the first second of the start of the movement. The rapid increase in the crane (trolley) speed is due to the insignificant horizontal component of the cargo weight at the initial moment of cargo movement. With the increase in the deviation of the cargo from the vertical, the speed of the crane (trolley) slows down and acquires oscillatory character.

The disguised system and subsystems of this model are presented in Figs. 9–11 and no further explanation is needed.

The simulation results (Fig. 12) indicate that over time the oscillation of cargo speed and cargo movement dampen. This is due to the decrease in the energy of the cargo oscillations. The reason for the “outflow” of energy lies in the damping power of the electric drive: as soon as the cargo deviates in the direction of the trolley,

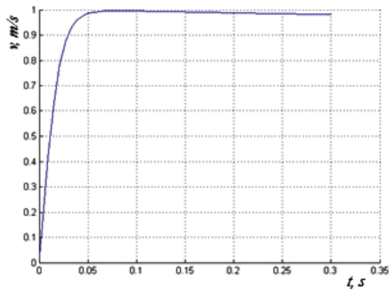

Fig. 8. Chart of the crane (trolley) speed during start-up

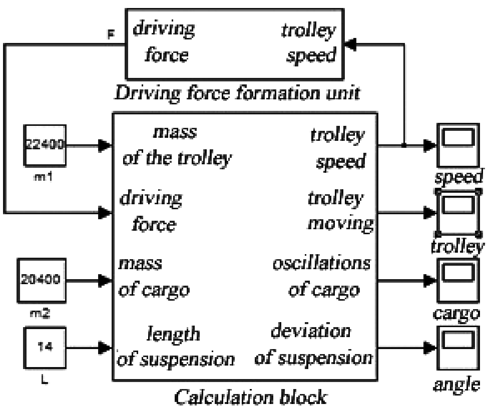

Fig. 9. Disguised nonlinear simulation model

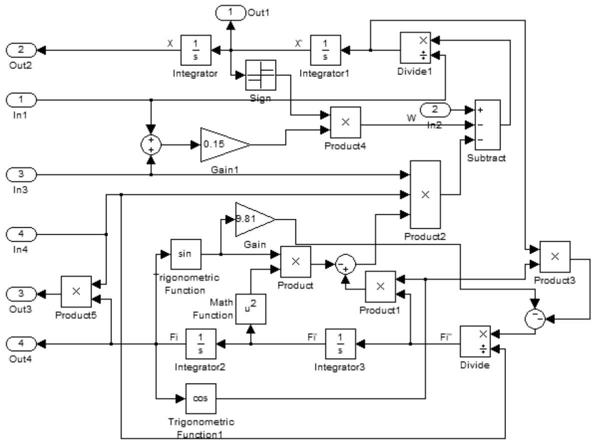

Fig. 10. Main subsystem of disguised nonlinear simulation model

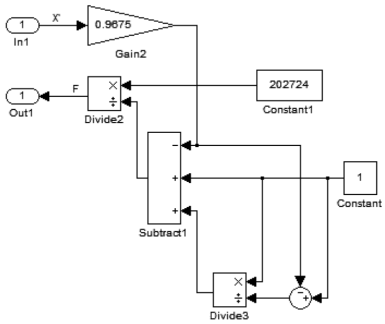

Fig. 11. Subsystem forming the force of crane (trolley) movement

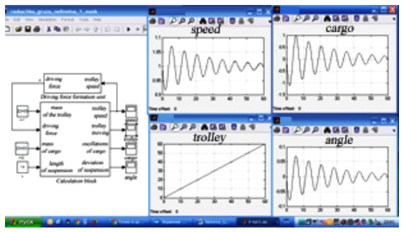

Fig. 12. The windows of the study of oscillations of the “crane (trolley) – cargo” system

the horizontal tension of the ropes compensates for the force of dry friction W (static resistance force of the trolley movement) and accelerates the trolley above the speed corresponding to the speed of the ideal idle travel of the end truck drive. In this case, the electric motor enters the mode of recuperative inhibition with energy return to the electricity grid. This energy is the energy of oscillations.

Main results and conclusions.

1. We performed an analysis of the existing calculation schemes and mathematical models of the pendulum oscillations of cargo during the bridge crane movement.
2. We have developed a linear simulation model that describes the oscillations of the cargo and the trolley as a mechanical conservative system with two masses.
3. We have developed a linear simulation model that describes the oscillations of the cargo and the trolley and

takes into account the viscous friction forces in the system.

4. We have developed a nonlinear simulation model that describes the oscillations of the cargo and the trolley and takes into account the nonlinearity of the driving force and the resistance forces of the crane (trolley) movement.

5. The developed simulation models are proposed for accelerating research on the influence of crane parameters on cargo oscillations during its movement; they can be used at the stages of designing new cranes and modernization of cranes that are already operating at enterprises.

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Математичні та s-моделі коливань вантажу під час руху мостового крана

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Ефективність досліджень на основі математичних моделей (лінійних, нелінійних), що описують динаміку мостових кранів і коливань вантажу під час перехідних режимів руху, суттєво зростає із застосуванням чисельних методів та імітаційних моделей, що створені інструментами візуального програмування.

Мета. Розробка та оцінка запропонованих імітаційних моделей динаміки мостових кранів.

Методика. На основі відомих математичних моделей розроблені імітаційні моделі коливань системи „мостовий кран (візок) – вантаж на гнучкому підвісі“. Імітаційні моделі створені за допомогою інструментів візуального програмування додатка SIMULINK, що працює під управлінням системи MATLAB. При моделюванні використані компоненти бібліотек Simulink і DSP System Toolbox.

Результати. Розроблені та налагоджені s-моделі коливань вантажу під час пересування мостового крана (візка). Виконано порівняльний аналіз запропонованих моделей.

Наукова новизна. Уперше, за допомогою інструментів візуального програмування SIMULINK, отримано набір імітаційних моделей коливань вантажу під час перехідних режимів руху для лінійної та нелінійної постановок задачі.

Практична значимість. Запропоновані s-моделі дозволяють автоматизувати та візуалізувати дослідження динаміки руху мостових кранів з метою визначення їх раціональних кінематичних і динамічних характеристик. Моделі забезпечені контрольними прикладами розрахунку динамічних режимів руху.

Ключові слова: *динаміка мостового крана, коливання вантажу, математична модель, імітаційна модель*

Математические и s-модели колебаний груза при движении мостового крана

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Эффективность исследований на основе математических моделей (линейных, нелинейных), описывающих динамику мостовых кранов и колебания груза во время переходных режимов движения предложено достаточно много. Эффективность исследований на этих моделях существенно возрастает с применением численных методов и имитационных моделей, созданных инструментами визуального программирования.

Цель. Разработка и оценка предложенных имитационных моделей динамики мостовых кранов.

Методика. На основе известных математических моделей разработаны имитационные модели колебаний системы „мостовой крана (тележка) – груз на гибком подвесе“. Имитационные модели созданы с помощью инструментов визуального программирования приложения Simulink, работающего под управлением системы MATLAB. При моделировании использовались компоненты библиотек Simulink и DSP System Toolbox.

Результаты. Разработаны и отлажены s-модели колебаний груза при движении мостового крана. Выполнен сравнительный анализ предложенных моделей.

Научная новизна. Впервые, с помощью инструментов визуального программирования SIMULINK, получен набор имитационных моделей колебаний груза при движении мостового крана для линейной и нелинейной постановок задачи.

Практическая значимость. Предложенные s-модели позволяют автоматизировать и визуализировать исследования динамики движения мостовых кранов с целью определения их рациональных кинематических и динамических характеристик. Модели могут быть использованы при анализе динамики кранов для различных вариантов их модернизации. Все модели снабжены контрольными примерами расчета динамики крана и груза при разгоне.

Ключевые слова: *динамика мостового крана, колебания груза, математическая модель, имитационная модель*

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