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*In this article Flag prohrammnыh analysis dydaktycheskyh funds USED IN AGRICULTURAL education. Rassmotrenы aspects kommunykatsyonnoy Information and Preparation traktorystov-mashynystov agricultural production.*

***Andnformatsyonno-kommunykatsyonnыe technology, prohrammyruemыe dydaktycheskye materials, profession, tractor-mashynyst, Teaching program.***

*In analysis of didactic software programs, which are used in agrarian education and information and communication preparation of tractor driver-machinist, is executed in paper.*

***Information and communication technologies, programmable didactic materials, profession, tractor-driver, tutorials.***

UDC 621.50

## AnalogFrom the optimal traffic control cable crane direct variational method

***VS Loveykin, PhD YA Romasevych, Ph.D.***

*In the paper the formulation of the problem of optimal control movement of the crane lifting cargo on a flexible suspension. Showing inability to use variational method for solving the problem. Based on the direct variational method Approximate solution of the problem. The influence of the number of additional boundary conditions on the value of the optimization criterion. A exponent
"Bleezkosti "criterion value to its minimum value.*

***Pryamyy variational method, optimal control, crane, nonlinear regression.***

**Resolutionska problem.** One problem operating cranes with flexible suspension load is a load fluctuations that occur during transient states of the crane.

DFor in order to reduce unwanted vibrations that reduce the productivity of the crane, we require a law change management (since the drive speed of the crane), which would allow to eliminate these fluctuations during transient states of motion. In addition, this law should improve the performance of the tap, for example, reducing dynamic loads in the elements of its design or energy efficiency and more. In order to achieve these requirements necessary to optimization of the crane. Thus, the function of the control valve must be optimal.

**AnaLease** **Latestnih research.** PROBLEMth usuNennius fluctuations

Cargo mounted on a flexible suspension was engaged many researchers [1-10]. These studies were based on the methods of optimal control: the calculus of variations, maximum principle, dynamic programming and the theory of moments. The results are optimal according to certain criteria: power, speed, kinematic, dynamic and more. It should be noted that one of the criteria for optimum laws of the crane is suboptimal for others. For example, the optimum for speed control is suboptimal for energy consumption, dynamic and kinematic indicators. This is because in the course of the crane its speed can change its sign on the opposite, which is achieved by reversing the drive. This consumes a significant amount of electricity. Sign Change electromagnetic torque of the engine in optimal control causes an increase in the coefficient of dynamic drive crane, so this mode of motion is suboptimal in this category.

In addition, there is a large amount of results dedicated to the problem of the fluctuations of cargo on a flexible suspension that can be called rational. To find them unused methods
Optimament control and other techniques such as fuzzy logic [11, 12]. Optimal results with this method has its advantages and disadvantages. Their main advantage - the control is in the form of feedback, the main drawback - a large amplitude oscillations of cargo during the process of eliminating vibrations, which in some cases is unacceptable from technology
reasons.

**Metanddperssurvey findings** - EID-identification functionsth Optimament sound controlmovement of cranes, which would allow cargo to eliminate vibrations on flexible suspension.

DTo achieve this goal it is necessary to solve the following problem:

1. The problem perform optimal motion control crane with a load on a flexible suspension and perform its analysis;

2. RoseKnit problem of optimal control of the motion of the crane by direct variational method;

3. to analyze the solution.

VikoThe problem hire determining the optimal motion control crane lifting a load on flexible suspension mode of inhibition. Surveys taken dvomasovu model of the mechanism of movement of the crane (Fig. 1), which is widely used in the study of the dynamics problems [13-15] and optimum motion control cranes span of the [1-12]. We make observations on the adopted dynamic model (Fig. 1): it reflects only load fluctuations on flexible suspension, it does not take into account fluctuations in the drive mechanism of the crane, and tacosSimilar fluctuations crane metal. These oscillations have frequencies several orders of magnitude greater than the oscillation frequency load on flexible suspension and so the calculations can be assumed that the crane moves on a completely rigid base and a law changing the driving force *F*"Absolyutno just "tap implemented drive (in the calculations neglect the dynamic processes Drivers crane).

Atled by the design model of the crane with a load on flexible suspension (Fig. 1) is described by a system of differential equations:

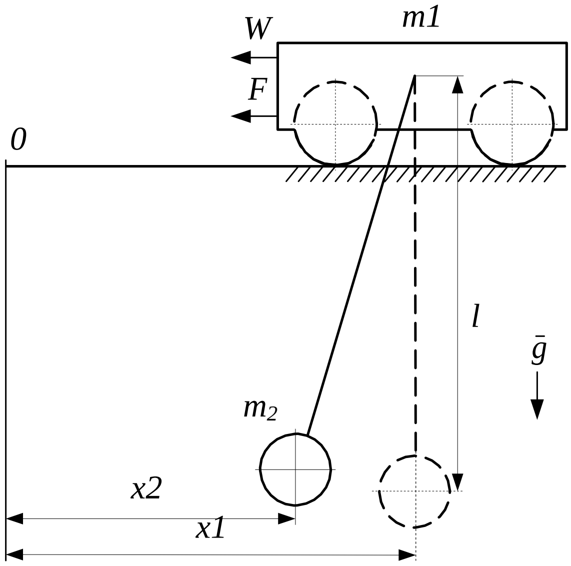
$$\begin{cases} m_1\ddot{x}_1 + m_2\ddot{x}_2 = -F - W sign\dot{x}_1; \\ \ddot{x}_2 + \dfrac{g}{l}(x_2 - x_1) = 0, \end{cases} \qquad (1)$$

where $m_1$- Reduced weight drive mechanism and truck crane; $m_2$- Bulk cargo; $x_1$,$x_2$- Coordinates of the centers of mass under the crane and cargo; *g*- Acceleration of gravity; *l*- The length of the flexible suspension; *F* - suvain pulling or braking force acting on the valve (in this work effort *F*is the brake, so its direction coincides with the direction of the resistance movement resulted crane); *W*- Reduced the resistance movement of the crane.

Willmo ccazhaty, uabout prand replacement countryto againsttion braking it does not change its velocity, ie $sign\dot{x}_1 = 1$. To Fixedfluctuations of load and stop the crane in a given situation must provide the following:

$$\begin{cases} x_1(T) = x_2(T) = s; \\ \dot{x}_1(T) = \dot{x}_2(T) = 0, \end{cases} \qquad (2)$$

where $x_1(T)$ And $x_2(T)$- Coordinates of the centers of mass and punishable under load at time $T$; $\dot{x}_1(T)$ and $\dot{x}_2(T)$ – seamsdkist crane and cargo in accordance at time $T$;$s$- Set the position of the crane at the moment $T$;$T$- The end of braking.




Ric. 1. Design model of "truck load".

Initialtion state of the system is described by the following conditions:

$$\begin{cases} x_{2\,(0)} = x_{1\,(0)} - \Delta x(0) \\ \dot{x}_2(0) = \dot{x}_1(0) - \Delta\dot{x}(0) \\ \ddot{x}_2(0) = \dfrac{g}{l}\Delta x(0) \\ \dddot{x}_2(0) = \dfrac{g}{l}\Delta\dot{x}(0) \end{cases} \tag{3}$$

where $x_{1\,(0)}$ and $\dot{x}_1(0)$ – onprovisions and speed of the crane at the moment $t$=0 respectively.

Optimization criterionth tasksand hurrayinto account from sitem differential equations (1) can be written in the following form:

$$I = T^{-1}\int_0^T [\delta_0 (x_2 - s)^2 + \delta_1 \dot{x}_2^2 + \delta_2 (x_1 - s)^2 + \delta_3 \dot{x}_1^2 + \delta_4 (\frac{-F-W}{m_1})^2] dt =$$

$$= T^{-1}\int_0^T [\delta_0 (x_2 - s)^2 + \delta_1 \dot{x}_2^2 + \delta_2 (x_2 + \ddot{x}_2 \Omega_0^{-2} - s)^2 + \delta_3 (\dot{x}_2 + \dddot{x}_2 \Omega_0^{-2})^2 + \delta \; {}^{IV}$$

February 1 2 2 2 0 3 2 2 0

$$+\frac{\delta_4}{m_1^2}(x_2 m_1\Omega_0^2+\ddot{x}_2(m_1+m_2))^2]dt\rightarrow \min. \qquad (4)$$

where $\delta_0,\delta_1,\delta_2,\delta_3,\delta_4$- Coefficients.

PoyaMRC whyin withamth stilland criterionth edubut. Unitary criteriaand $(x_2-s)^2$reflects the magnitude squared distance from the current given to the condition of the goods, that is the place addressing. Criterion $\dot{x}_2^2$ reflects the grand square velocity of the load, which should be reduced to zero during braking. Two other single criteria reflect the magnitude square of the distance to the place of tap stopsand $(x_1-s)^2$tand the square of the velocity of the crane $\dot{x}_1^2$. Last term shows management costs.

Stillof way criterion (4) prohibits continued "existence" phase point of a dynamical system at a considerable distance from the origin (dynamic system "will try to" get in early position and orientation).

Mnozhnyk to criteria $T^{-1}$showthat is, the dimension criterion coincides with the dimension of its integrand.

Single indicators included in the criterion (5.6) have the same physical meaning, so they need to bring one dimension or dimensionless quantities. Later, we assume that this function is performed coefficients $\delta_{and}$(*and*= 0, 1, 2, 3, 4). This means that coefficientsiyenty $\delta_{and}$(*and*= 0, 1, 2, 3, 4) are represented as the product of two values:

$$\delta_i = k_i \tilde{I}_i, \tag{5}$$

where $k_{and}$ - toASCtion coefficientsiyent, Wormsand mogoodzhaye tountilof the banks to *and*-togabout aboutdynychnoho criterion of expression (6); $\tilde{I}_i$ - A factor that atleads Rosedimension sporadicallyth criterionuw dabout Bezrozmirnoho look.

Expandmo essence ratios criteria: $\tilde{I}_i$ for each unit

$$\begin{cases} \tilde{I}_0 = \tilde{I}_2 = s^{-2}; \\ \tilde{I}_1 = \tilde{I}_3 = v^{-2}; \\ \tilde{I}_4 = \dfrac{m_1}{F_{butm}^2}, \end{cases} \tag{6}$$

where $v$- Rated speed of the crane; $F_{Nom}$ - Nominal driving force of the crane.

DFor solving this problem try to use the method of the calculus of variations [16]. To do this, write the necessary condition for extremum criterion (4) - Euler-Poisson

$$\overset{VIII}{x_2} + C_1\overset{VI}{x_2} + C_2\overset{IV}{x_2} + C_3\ddot{x}_2 + C_4x_2 = C_4s, \tag{7}$$

where $C_1$,$C_2$,$C_3$,$C_4$- Factors which are of the following expressions:

$$\begin{cases} C_1 = \dfrac{2gm_1(m_1+m_2)\delta_4 - l\delta_3}{lm_1^2\delta_4}; \\ C_2 = \dfrac{l^2\delta_2 - 2gl\delta_3 + g^2(m_1+m_2)\delta_4}{l^2 m_1\delta_{\text{April 1}}}; \\ C_3 = \dfrac{g(2l\delta_2 - g(\delta_1+\delta_3))}{l^2 m_2^2\delta_{\text{April 1}}}; \\ C_4 = \dfrac{\Omega_0^2(\delta_1+\delta_2)}{l^2 m^2\delta_{\text{April 1}}}. \end{cases} \tag{8}$$

DTo determine the type of extremum criterion (2) use the Legendre condition that for criterion (2) is written as:

$$\frac{\partial^2 f}{\partial \overset{IV}{x}_2^{\,2}} = \frac{2m_1^2\delta_4}{\Omega_0^2} > 0, \tag{9}$$

where *f*- Integrand criterion (4). We come to the conclusion that solving the differential equation (7), we find the minimum criterion (4).

As is known, the solution of the inhomogeneous differential equation is the sum total solution corresponding homogeneous equation and the particular solution of the inhomogeneous differential equation. First, we write the homogeneous differential equation, which corresponds to equation (7):

$$\overset{VIII}{x}_2 + C_1\overset{VI}{x}_2 + C_2\overset{IV}{x}_2 + C_3\ddot{x}_2 + C_4 x_2 = 0. \tag{10}$$

DFor its solution must pass characteristic equation. We will write:

$$r^8 + C_1 r^6 + C_2 r^4 + C_3 r^2 + C_4 r = 0. \tag{11}$$

Can not find the roots of an algebraic equation of the eighth degree (9) radicals. This means that you can not find the analytical solution of the Euler-Poisson (7). Of the task (1) - (6) try to solve the direct variational method [17].

In theidpovidno the direct variational method need to find a solution to three-point boundary value problem:

$$\begin{cases} \overset{IX}{x}_2 = 0; \\ \begin{cases} x_2(0) = x_1(0) - \Delta x(0); \dot{x}_2(0) = \dot{x}_1(0) - \Delta\dot{x}(0); \ddot{x}_2(0) = \Delta x(0); \dddot{x}_2(0) = \Delta\dot{x}(0) \\ x_2\left(\dfrac{T}{2}\right) = q_1; \\ x_2(0) = \dot{x}_2(0) = \ddot{x}_2(0) = \dddot{x}_2(0) = 0, \end{cases} \end{cases} \tag{12}$$

where $x_{1(0)}$ $\dot{x}_1(0)$ - onprovisions and speed of the crane at the moment tand $t$=0 respectively; $q_1$- The value of the cargo position at time $t = \dfrac{T}{2}$.

Rosebunches of boundary value problem (10) is written in the following form:

$$x_2 = \frac{(t-T)^4}{T^8}(256q_1 t^4 - (2t-T)(\dot{x}_1(0)tT(22t^2+6tT+T^2) - \Delta\dot{x}(0)tT \times$$
$$\times(22t^2+6tT+T^2) + (64t^3+22t^2T+6tT^2+T^3)(x(0)-_1\Delta x(0))) - lt^2 \times \tag{13}$$
$$\times(2t-T)T^2(\Delta\dot{x}(0)tT+3(6t+T)\Delta x(0))).$$

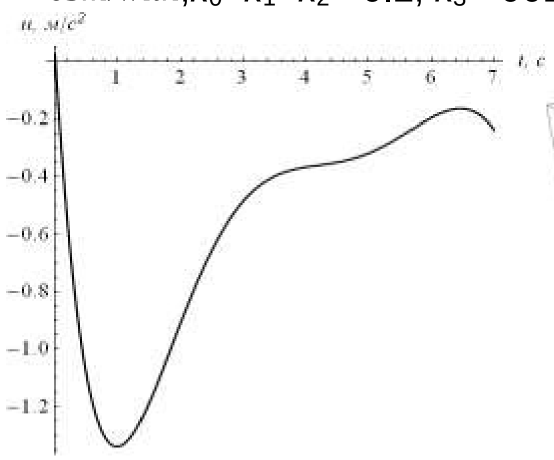
Tepehe can find higher derivatives of (11) and substitute the expressions in the integrand expression test (4). In the future, take definite integral (4). We will not record this expression because it has a significant amount, we note only that in the present setting nomu $q_1$.Dll order to minimize the criterion (4) is necessary to solve the following equation:

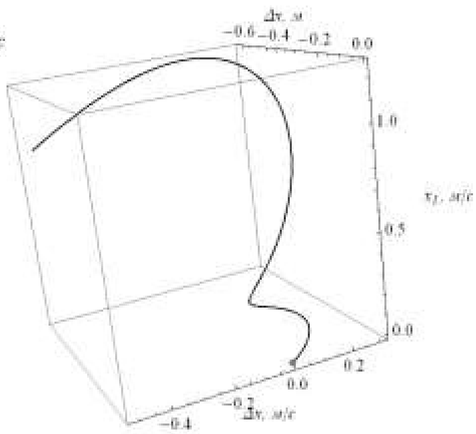
$$\frac{\partial I}{\partial q_1} = 0 \tag{14}$$

relatively Categoriesthknown couplemeter $q_1$.

Phizychtion frombridge optimizatsiyi fieldlies in the fact that such values are in the position of cargo time $t = \frac{T}{2}$ prand which criterion (4) takes at least from-identification. However, this does not mean that the problem is solved exactly.

The resulting solution - it is only an approximation to the exact solution, Wormsand is a solution of the Euler-Poisson (7). Approximate solution for the problem of optimal control of the motion of lifting crane with a load on flexible suspension construct graphs of functions (Fig. 2), illustrating the dynamics of the system. Graphs in Fig. 2 built with the following parameters: $T7$ = c; $m_1$= 10000 forg; kg; $m_2$= 20000 $l$= 10 m; $\dot{x}_{1(0)} = 1m/with$; $\Delta x(0) = -05m$, $\Delta\dot{x}(0) = -05m/with$;$k_0$=$k_1$=$k_2$= 0.2; $k_3$= 001.




and) b)

Ric. 2. Earlics Funktsiy: and) countryto; to) Nonclassical mation pyHom phasetion

Portreet motionin danddynamically sitem in

Koridynatah "angle rope with a load of vertical - speed angleand modhyletion ropein from toandntazhem from VERTICLee - wvydkist of the crane. "

DFor in order to increase the accuracy of problem solution is necessary to obtain a baseline feature that would zadovilnyala more additional boundary conditions. Set as increasing the additional boundary conditions of basis functions reductions in the value of the functional (4). To solve this problem in two, three, four and five additional boundary conditions. For each task we define the criterion value (4). Thus, we have a table of data where the number of additional boundary conditions corresponding to a value functionality.

Try to find an analytical dependence between these variables. To do this, use the method of nonlinear regression [18]. First ask regression model that will display the required dependency:

$$I_k = a + b \cdot e^{c-k}, \tag{13}$$

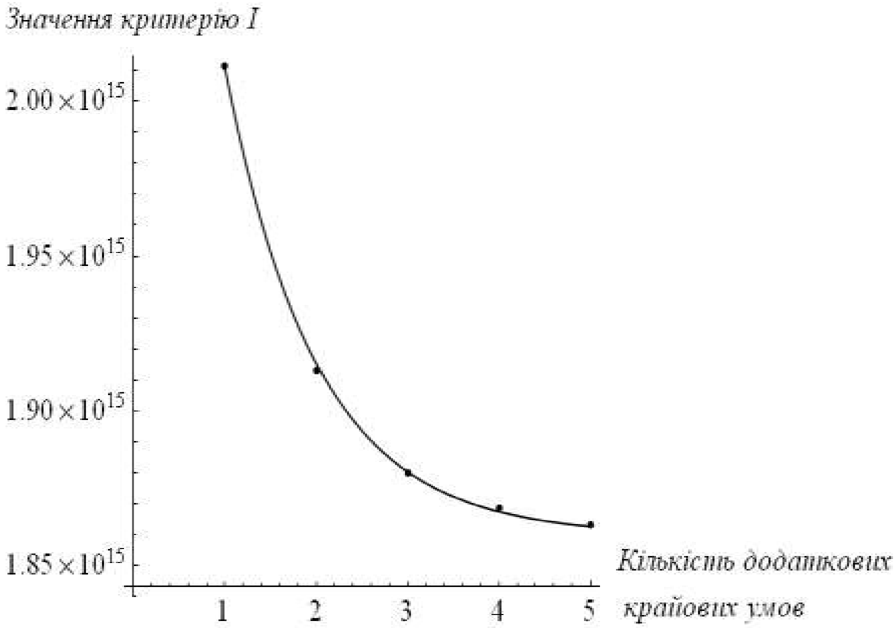
where *and*,*b*,*c*- The parameters of the regression model to be found; *k*- The number of additional boundary conditions; *And*$_k$- Value of which corresponds to the boundary-value problem with *k*forilkistyu additional boundary conditions. Using the method of nonlinear regression find unknown parameters *and*,*b*,*c*. The calculations were performed for the confidence level of 0.99. Table 1 will result statistics of regression function (13).

***1. Statistical indicators regression function (13).***

| Options regression modeli | Value UAAachennya statistical indicators | | |
|---|---|---|---|
| | Value UAAachennya option | Standard error | KRieter Student |
| *and* | 1.86007 · 1015 | 1.12799 · 10-16 | 1.64902 · |
| *b* | 1.0172 · 106 | 1.24853 10-8 | 8, 1472 × |
| *c* | 19.8117 | .0127 | 1559.98 |

DFor the calculations coefficient of determination *R*pivnyy 0.9999995365, indicating a fairly accurate representation model (13)orselnyh data. The critical value of Student's t test for a given number of degrees of freedom is 4.604, which is significantly less than the calculated values for the parameters of the model (13). This means uof all parameters of the model are statistically significant. In addition, the standard error of the model parameters are small: they show the average forvadratychne model parameter deviation from its true value. Thus, the calculated regression function accurately reflects the change in the functional depending on the number of additional boundary conditions (Fig. 3). Explore function (13). To do this, find its border:

$$\lim_{k \to \infty} I = a. \tag{14}$$




Ric. 3. The regression function (13) and the numerical value of the criterion *And*,
asand correspond to the number of additional boundary conditions.

Virwith (14) implies that the approach adopted within the setting *and*rehresional function (13) reflects the exact value of the optimization criterion (4). The above calculations were performed in order to establish "closeness" to the exact approximate solution. One indicator of "proximity" could be:

$$\gamma = \frac{I_k - a}{I_k} \cdot 100\% \qquad (15)$$

Table. 2 shows the value of the index (15) for different number of additional boundary conditions.

***2. From-identification indicatorand (15) to piznoyi forilkosti additional boundary conditions.***

| The number of additional boundary | The value of $\gamma$% |
|---|---|
| 1 | 7.51 |
| 2 | 2.63 |
| 3 | 0.99 |
| 4 | 0.44 |
| 5 | 0.15 |

Andnalizuyuchy data presented in Table. 2, we conclude that when *k*3 = approximate solution of the optimization problem is very "close" to the value of the criterion, which is equal to the parameter *and*Dhresiynoho equation (13), that is the minimum of the functional (4), which is analytically. Further complications task to increase the accuracy of the solution does not fit.

**Conclusion.** Stillof way, in this paper we solve the problem of optimal control movement of the crane lifting cargo on a flexible suspension. The nature of the impact of complexity of the problem (number of additional boundary conditions in basis functions which approximate solution is sought) by the amount of optimization criteria. The results of the model to be used to develop algorithms mechatronic system control movement of cranes. In addition, the results of mathematical calculations using the direct variational method can be used to assess the degree of approximation solution of optimal control problem to an exact solution.

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*In this article Flag formulation of the problem of optimal control movement hruzopodъemnoho crane with cargo at Mount the bending. Showing nevozmozhnost Using varyatsyonnoho method for problem solutions. Based on the direct method varyatsyonnoho Found pryblyzhennoe decision problem. Effect of Quantity of research dopolnytelnыh kraevыh uslovyy the magnitude optymyzatsyonnoho Criteria. Proposals pokazatel Class "Bleezosty "importance Criteria for him The minimum value.*

***Pryamoy varyatsyonnыy method optymalnoe Management, hruzopodъemnыy crane, nonlinear rehressyya.***

*The paper made formulation of problem of crane motion optimal control with load on flexible suspension. Shown the inability to use variational method to solve the problem. On basis of direct variational method approximate solution of problem. The influences of number of additional boundary conditions on value of optimization criterion have been showed. Proposed exponent of "closeness" to value of criterion to its minimum value.*

***Direct variational method, optimal control, load-lifting crane, nonlinear regression.***

UDC 662.767.3

## METODYKA DEFINITION alkalinity biodiesel

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