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VIBRATIONS OF ROBOCRANE IN VERTICAL BASE PLANE CONSIDERING THE VARIABLE LOAD MASS

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1. Introduction

Vibration characteristics of a robocrane are investigated in a vertical base plane with simultaneous linear travelling movement and lifting load movement. The investigation is carried out on the basis of the created two mass dynamic model of the robocrane considering the variable load mass according to a certain time function. The system non-linear differential equations of movement [1] is analyzed in different cases of formation of reactive force with a definite crane control. The computer solutions of the system differential equations represent the vibration crane parameters [2]. The carried out investigation is a basis for defining optimal solutions for crane control in different working modes. A comparison is made with the vibration behaviour of the crane with a constant load mass [3].

2. General concept of the mechanical model

In this paper a principally new approach to a classical construction of a crane like a robocrane is presented. The robocrane is a mechanical system of a crane with the following three components: 1. Mechanical construction; 2. Electrical driving; 3. Computer control. In this sense, the robocrane can be concerned as a typical mechatronic system [3].

We accept a two mass dynamic system for the dynamical model of a crane presented in Fig. 1. A spatial rope handling of the end effector is investigated, modelled by the help of a flexible nondeformated string, considering its weight and elasticity. The

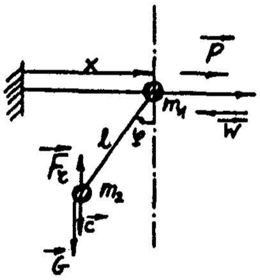

Fig. 1

elasticity of the mechanical construction of the crane as a whole is disregarded. The dynamic model consists of a straight–forward moving mass m_1 – a mass of the crane and bent additional mass from the end effector, and mass m_2 – mass of the load and bent additional mass from the end effector. The crane is activated by driving force $P(t)$ and resistance $W(t)$, where t is the time.

We suppose a variable rule for variation of mass m_2 according to formulas:

$$m_2 = m_0 + \gamma t \tag{1}$$

$$\vec{F}_r = (\vec{u} - \vec{v})\,\frac{dm_2}{dt};\ -\vec{F}_r = \vec{c}\,\frac{dm_2}{dt};\ -\vec{F}_r = \vec{c}\,(-\gamma) \Rightarrow \vec{F}_r = \vec{c}\,\gamma \tag{2}$$

where $\vec{c}$ is the velocity of outflow , if $|\vec{u}| = 0$ then $\vec{v} \equiv \vec{c}$ is the relative velocity of the outflow mass according to material point m_2, and F_r is the reactive force.

Movement along two generalized coordinates is investigated by x and φ. Labour of the external forces we consider with formulae:

$$\begin{aligned} &y = l\cos\varphi;\ \delta y = -l\sin\varphi\,\delta\varphi \\ &\delta A = -F_r\,\delta y = (-c\gamma)\,(-l\sin\varphi\,\delta\varphi) \\ &\delta A = c\gamma l\sin\varphi\,\delta\varphi = Q_\varphi\,\delta\varphi,\ Q_\varphi = c\gamma l\sin\varphi. \end{aligned} \tag{3}$$

After differentiation and replacement in the equation of Lagrange:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_j}\right) - \frac{\partial T}{\partial q_j} = Q_j \tag{4}$$

a system of differential equations (5) of second order is obtained defining movement in vertical base plane:

$$\begin{aligned} &l(m_0+\gamma t)\ddot{\varphi} + \cos\varphi(m_0+\gamma t)\ddot{x} + \gamma l\dot{\varphi} + \cos\varphi\gamma\dot{x} + \sin\varphi g(m_0+\gamma t) = 0 \\ &\cos\varphi l(m_0+\gamma t)\ddot{\varphi} + (m_1+m_0+\gamma t)\ddot{x} + \cos\varphi\gamma l\dot{\varphi} + \gamma\dot{x} - \sin l(m_0+\gamma t)\dot{\varphi}^2 = P - W \end{aligned} \tag{5}$$

3. General concept of the mathematical model

Concerning system (5) the following substitutions are developed:

$$(6)\qquad \begin{aligned} A &= m_0 + \gamma t; \; C = \cos\varphi l(m_0 + \gamma t) \\ B &= \cos\varphi(m_0 + \gamma t); \; D = m_1 + m_0 + \gamma t \\ A_1 &= \gamma l\dot{\varphi} + \cos\varphi\gamma\dot{x} + \sin\varphi g(m_0 + \gamma t) \\ B_1 &= \cos\varphi\gamma l\dot{\varphi} + \gamma\dot{x} - \sin\varphi l(m_0 + \gamma t)\dot{\varphi}^2 - P + W \end{aligned}$$

In this way system (5) can be presented in the form

$$(7)\qquad \begin{aligned} A\ddot{\varphi} + B\ddot{x} + A_1 = 0 \\ C\ddot{\varphi} + D\ddot{x} + B_1 = 0 \end{aligned}$$

From system (7) can be written formulae for $\ddot{x}$ and $\ddot{\varphi}$

$$(8)\qquad \ddot{x} = \frac{A_1\,C - A\,B_1}{A\,D - B\,C}; \quad \ddot{\varphi} = -\frac{B}{A}\,\frac{A_1\,C - A\,B_1}{A\,D - B\,C} - \frac{A_1}{A}$$

Using the method of Runge–Kutta – programme RKGS from the SSP–package a computer solution is developed for the system equations (8).

4. Example

Concrete parameters are used from a real crane construction presented in the next formula

$$(9)\qquad \begin{aligned} &\gamma = 1 \\ &m_1 = 80\ kg \\ &m_2 = 350\ kg \\ &l = 2\ m \\ &c = 0,5\ m/s \end{aligned}$$

The following four private cases are considered:

1. $P = 0,\ W = 0 \Rightarrow\ x = 0,\ \varphi = 0$
2. $P \neq 0,\ W \neq 0 \Rightarrow\ x = \ldots,\ \varphi = \ldots$
3. $P = 0,\ W = 0;\ \dot{x}_0 \neq 0,\ \dot{\varphi}_0 = 0$
4. $P = 0,\ W = 0;\ \dot{x}_0 \neq 0,\ \dot{\varphi}_0 \neq 0$

Private case 1. $P = 0,\ W = 0 \Rightarrow\ x = 0,\ \varphi = 0$. When the external forces are zero the dynamic system remains not activated.

Private case 2. $P \neq 0,\ W \neq 0 \Rightarrow\ x,\ \varphi$ have real qualities. The dynamic system is activated and real movement is observed. The results from the computer solution are presented in Fig. 2.

In private case 3 dynamic system is activated by means of the initial data. As a result the system is activated along generalized coordinate x. Coordinate φ remains not activated. Results from computer experiment are presented in Fig. 3.

In private case 4 the system is activated along the two generalized coordinates x, φ. Results from computer experiments are presented in Fig. 3. It is obvious that there is a great dependence of the dynamic system on the initial data.

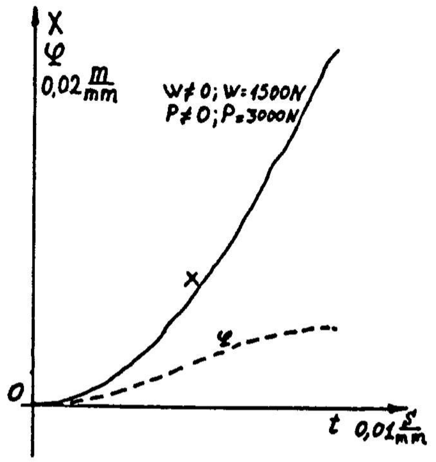

Fig. 2

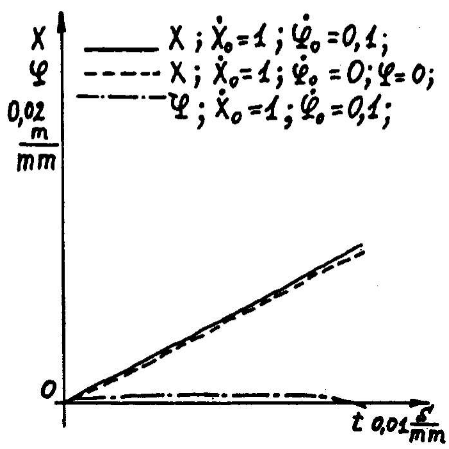

Fig. 3

5. Conclusions

1. A new approach to a crane like a robocrane is presented, concerning the crane with three components: a mechanical construction, electric drive and computer control.

2. Mechanical and mathematical modelling creates a complex non–linear mechanical system dependent on the parameters and initial and boundary data.

3. A variable mass rule and as a result excited reactive force exist in the dynamic system which influence the concrete technological process.

4. The developed methodology can be used in further investigations on optimization and control of dynamic systems concerning robocranes in production.

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