Overhead Crane Computer Model

To cite this article: S S Enin *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **327** 022028

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Abstract. The paper has a description of a computer model of an overhead crane system. The designed overhead crane system consists of hoisting, trolley and crane mechanisms as well as a payload two-axis system. With the help of the differential equation of specified mechanisms movement derived through Lagrange equation of the II kind, it is possible to build an overhead crane computer model. The computer model was obtained using Matlab software. Transients of coordinate, linear speed and motor torque of trolley and crane mechanism systems were simulated. In addition, transients of payload swaying were obtained with respect to the vertical axis. A trajectory of the trolley mechanism with simultaneous operation with the crane mechanism is represented in the paper as well as a two-axis trajectory of payload. The designed computer model of an overhead crane is a great means for studying positioning control and anti-sway control systems.

1. Introduction

One of the most widespread means of the loading and unloading operation is an overhead crane. It is applicable in civil construction, metallurgical production, on river and sea ports etc. It provides ascent or descent of cargoes and their distance shifting using hoisting and traveling devices. The analysis of a crane mechanism dynamics is always specified with the analysis of each element of a crane with many simplifications.

In this paper the lumped-mass method is used to describe motion of crane mechanisms. This method is based on modeling a hoisting line as a massless cable [1].

There is a description of crane mechanisms movement in [2] but the movement of crane elements is considered as an independent operation. Actually, there is a mutual influence on movement and loads between mechanisms while operation. The algorithm of motion equations obtained through Lagrange equation of the II kind allows one to have dependencies and patterns of the whole bridge crane system. There is an accurate description of a bridge crane operation by the Lagrange equations represented in [3]. A dynamic influence of moving payload has been taken into account but an effect of friction in moving parts of crane mechanisms has not been included. Friction occurring during the movement of crane mechanisms has a significant impact on the system behavior [4, 5]. That is why the definition of friction is an important task to avoid imprecisions during a simulation of a system operation.

The differential equations of crane mechanisms motion used in the paper have allready been derived and will be represented in this work without the derivation process. Mechanical friction and static load calculation for each mechanism have been taken into account [6, 7] while building the mathematical model of an overhead crane.

2. Materials and methods

The mathematical model that was obtained for the overhead crane system in [3] is represented as an equation system for each crane mechanism (hoisting mechanism, trolley and crane mechanisms). This system also has a mathematical description of payload movement originated from the movement of a trolley and (or) crane. Thus there are five equations that make it possible to build a computer model of a mechanical system of a crane. This task was performed with the help of MATLAB software (MathWorks) using Simulink imbedded library [8, 9].

The simulation of dynamical and static loads of crane mechanisms has been accomplished with the stiff/Trapezoidal Solver with the variable step type. The maximum and minimum values of the solver step are set in the auto mode, the relative tolerance is equal to $1e^{-5}$. An adaptive zero-crossing algorithm was used.

Throughout the paper the following parameters and abbreveations will be used:

Table 1. The parameters and abbreviations used in equations and the computer model of an overhead crane mechanical system

Parameter	Description
z_1	payload vertical coordinate (height)
x_t	trolley coordinate
y_b	crane coordinate
α	payload sway angle along a trolley movement axis
β	payload sway angle along a crane movement axis
F_1	hoisting mechanism electrical drive system force
F_2	trolley mechanism electrical drive system force
F_3	crane mechanism electrical drive system force
f_1	hoisting mechanism friction force
f_{0x}	trolley mechanism friction force
f_{0y}	crane mechanism friction force
m_1	payload mass
m_t	trolley mass
m_b	crane (bridge) mass
b_x	damping coefficient (x-axis)
b_y	damping coefficient (y-axis)

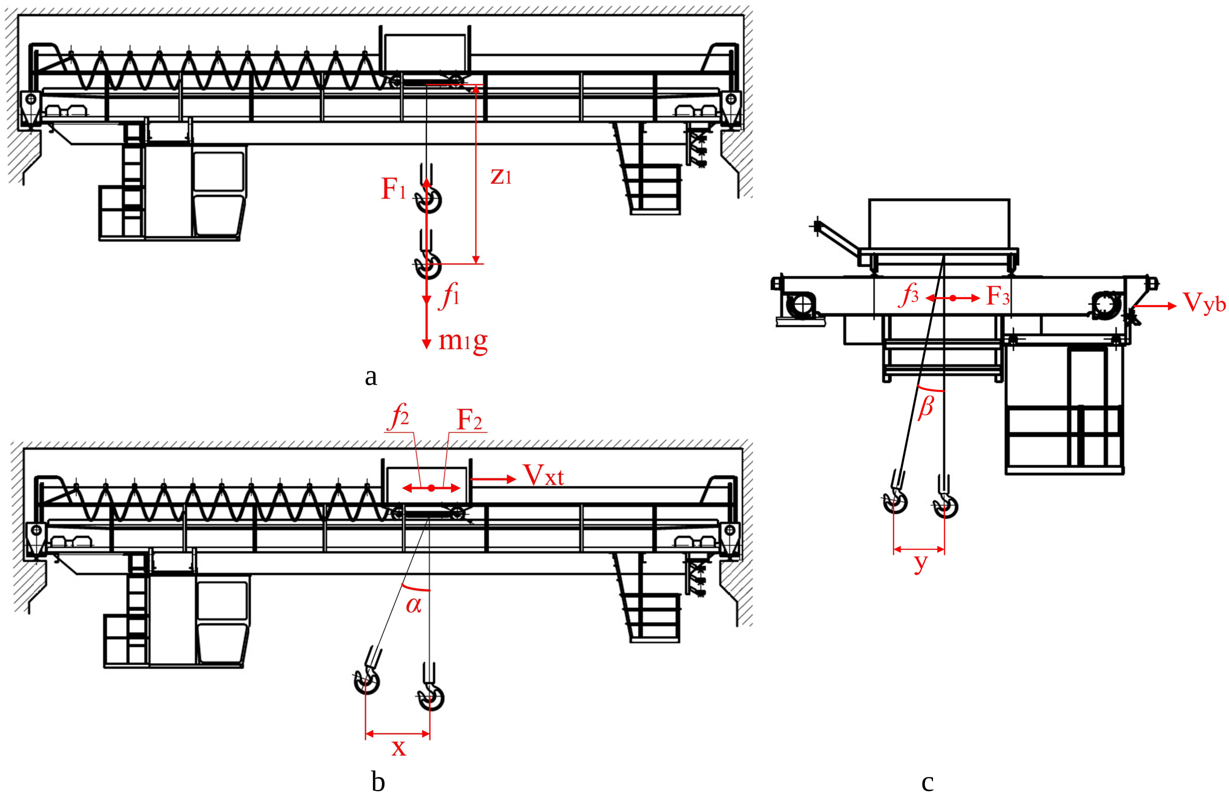


Figure 1. Mechanical schemes of overhead mechanisms: a – hoisting mechanism; b – trolley mechanism; c – crane (bridge) mechanism

The movement of all mechanisms is represented by the formulas in Table 2. It should be noticed that the derivatives of mechanisms coordinates are substituted by symbolic names to simplify and accelerate simulation. For example, the trolley coordinate x_t derivative (trolley speed) is not calculated by the derivative block of Matlab but substituted by symbolic name V_t.

Table 2. Expressions for each mechanism movement

Mechanism	Formula
hoist	$\ddot{z}_1 = \frac{-F_1 + m_1 g + f_1 + m_1\ddot{x}_t\sin\alpha + m_1\ddot{y}_b\sin\beta + m_1 z_1\left(\dot{\alpha}^2 + \dot{\beta}^2\right)}{m_1}$
trolley	$\ddot{x}_t = \frac{F_2 - f_{0x}sign(\dot{x}_t) + m_1\ddot{z}_1\cos\alpha + 2m_1\dot{\alpha}\dot{z}_1\sin\alpha + m_1 z_1(\ddot{\alpha}\sin\alpha - \dot{\alpha}^2\cos\alpha)}{m_1 + m_t}$
crane	$\ddot{y}_b = \frac{F_3 - f_{0y}sign(\dot{y}_b) + m_1\ddot{z}_1\cos\beta + 2m_1\dot{\beta}\dot{z}_1\sin\beta + m_1 z_1\left(\ddot{\beta}\sin\beta - \dot{\beta}^2\cos\beta\right)}{m_1 + m_t + m_b}$
payload (x-axis)	$\ddot{\alpha} = \frac{(2m_1 z_1\dot{\alpha} - b_x\cos\alpha)\dot{z}_1 - \ddot{x}_t m_1 z_1\sin\alpha + m_1 g z_1\sin\alpha - b_x\dot{\alpha}z_1\sin\alpha + b_x\dot{x}_t}{m_1 {z_1}^2}$
payload (y-axis)	$\ddot{\beta} = \frac{\left(2m_1 z_1\dot{\beta} - b_y\cos\beta\right)\dot{z}_1 - \ddot{y}_b m_1 z_1\sin\beta + m_1 g z_1\sin\beta - b_y\dot{\beta}z_1\sin\beta + b_y\dot{y}_b}{m_1 {z_1}^2}$

The equations allow one to build a computer model of each crane mechanism. As an example the trolley mechanism and the payload movement computer model are represented in Figure 2. All the mechanisms as well as the payload movement computer model are built in this way.

IOP Conf. Series: Materials Science and Engineering **327** (2018) 022028 doi:10.1088/1757-899X/327/2/022028

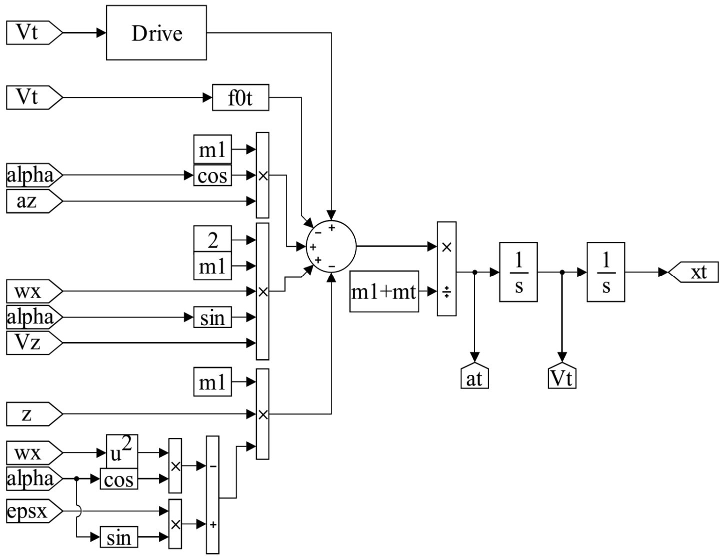
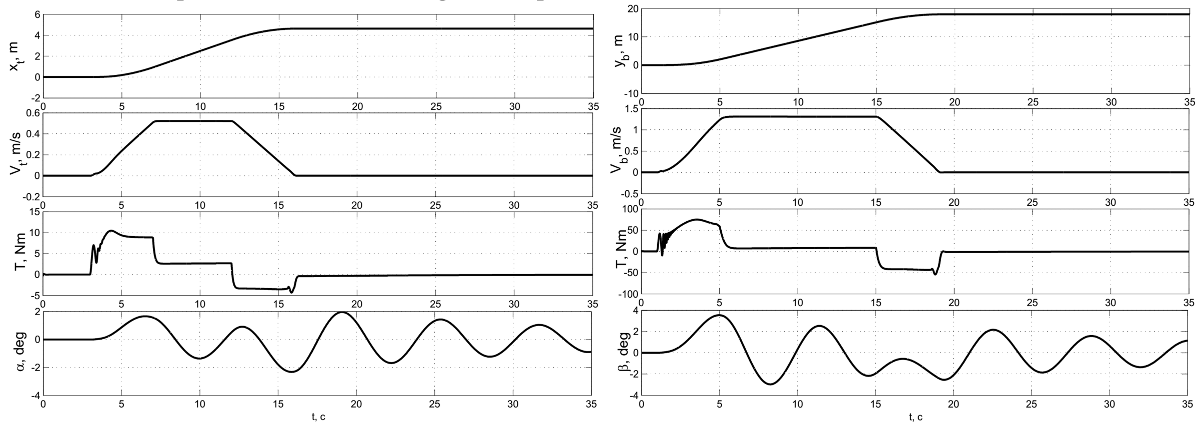


Figure 2. Computer model of crane trolley mechanical system

The result of simulation is shown in Figure 3. It consists of a mechanism coordinate, linear speed, drive motor electromegnetic torque and sway angle of the payload.

In order to simulate operation of an overhead crane, a typical crane that is rated at 10 tons has been used. It has 0.5 m/s linear trolley speed and 1.3 m/s linear crane speed. Mechanisms have different start time and operation time. The length of ropes for the simulation is 10 m.



a b

Figure 3. Transients of crane mechanism variables: a – trolley mechanism; b – crane mechanism

The computer model of an overhead crane system makes it possible to simulate simultaneous operation of separate mechanisms. The task of trajectory simulation is performed in [10], but the used model of a crane is simplified and does not cover the payload movement aspect.

The trajectories of trolley and payload in XY axis (2D) are shown in Figure 4.

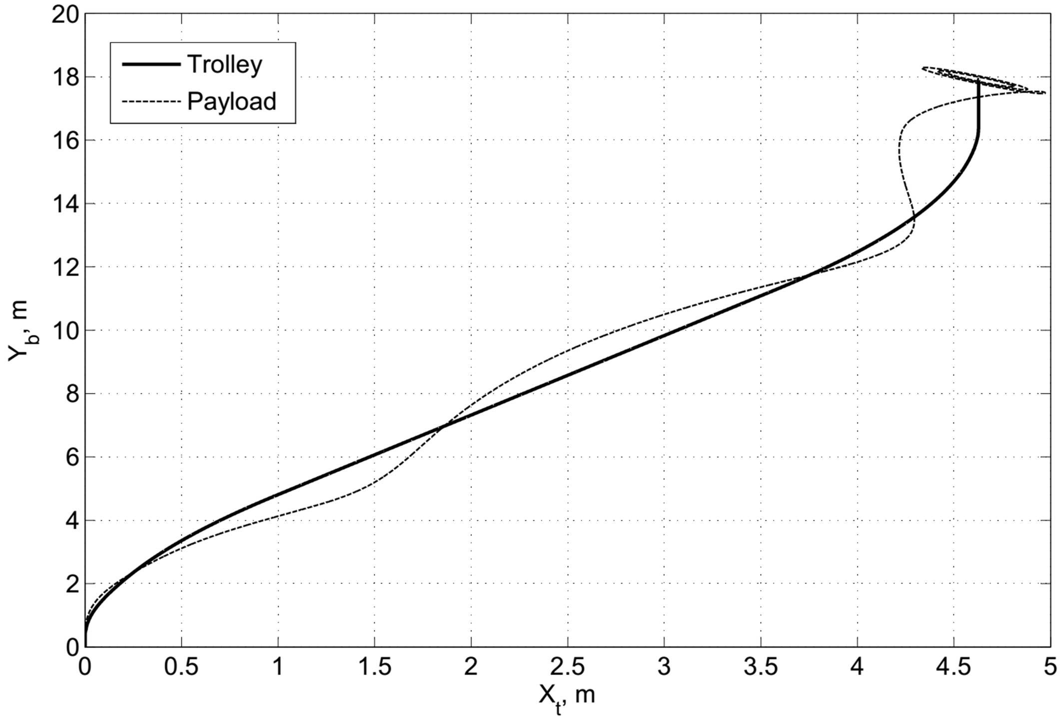


Figure 4. Trolley and payload trajectories

3. Conclusion

The differential equations derived through Lagrange equation of the II kind were used for building an overhead crane computer model. The model consists of five separate mechanism models, but each model has an interconnection with others by means of Matlab software.

The computer model of an overhead crane system allows simulating and studying dynamic and static regimes of crane operation. The transients of the crane mechanisms variables indicate efficiency and appropriateness of the designed computer model. It is especially beneficial for studying electrical drive control systems and anti-sway control systems. The transients of payload movement provide a possibility to research sway processes of cargo for precision positioning.

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