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Fuzzy Logic – Based Control of a Mobile Crane Slewing Motion

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In the paper, a model of control system controlling the working motions of a mobile crane is described. The control system is equipped in a fuzzy logic controller. The results of simulation investigations of this model obtained for different constructional solutions of the controller layout are presented. The results are shown in the following forms: time histories of selected parameters of the model and charts representing the properties of the applied controller.

Keywords: Mobile crane, load swings, fuzzy logic controller, control system

1. Introduction

Canceling of swings of a payload carried by a crane as well as a mobile crane has an essential influence on: a shortening of a load trans–shipment, an assurance of a precision of positioning of the payload in the selected point in 3D space and a safety of an operating personnel. It has also an influence on prevention of a possible damage of a payload and any other objects in a neighborhood of a working crane (for example the different technological installations, buildings, networks of electrical power supply etc). Performability of the swings canceling procedure allows for a remote control of an operation of a pay–load transfer. The swings extinguishment is performed by means of different control systems equipped in special counter–oscillation systems. One of the methods of canceling of the swings remaining after a finish a work motion is usage of the systems: control of a payload position and/or control of an amplitude of its swings.

In the paper, the working motions control system is presented. This model of the control system of work motions of the mobile crane incorporates a fuzzy–logic controller as well as results of simulation routines executed for different constructional versions of the controller. The obtained results are presented in a form of the time histories of selected variables characteristic for the model and the charts representing properties of the controller.

2. Model of system of control of the working motions of a mobile crane

Analysis of the models presented in the different papers allow for making the assumptions which refer to creating the model of the crane. This model is aimed for investigations of slewing motion of its body. The following assumptions have been made [2, 3, 6]:

- the solids of chassis and body, of known masses and moments of inertia are rigid and have six degrees of freedom; the only possible motion of the body in relation to the chassis is its rotation around the vertical axis;
- the support system was substituted by a set of springs, mass of springs is omitted;
- the crane body is rotated by means of a hydrostatic drive system through a mechanical gear of known rigidity, the mass centre of body lies on the axis of rotation of the body;
- the crane jib is treated as a rigid bar of constant length, of known mass and moment of inertia; it is connected with the body by means of cylindrical joint allowing only for change of jib's inclination angle;
- the payload hangs on an inextensible, weightless, flexible rope; the hanging payload can be treated as a spherical pendulum;
- the drum of the winch is rotated by means of a hydrostatic drive system through a mechanical gear of known rigidity,
- friction and clearances in all elements of the support system, jib and mechanical gear are not taken into consideration;
- damping in the system is taking into consideration;
- characteristics of elastic constraints are assumed as linear,
- three working motions are possible: slewing motion of the crane body, luffing in consequence of change of jib's inclination angle caused by change of the length of hydraulic cylinder as well as hoist or lower of the payload in consequence of reeling or unreeling the rope; simultaneous association of all motions is permitted;
- all supports of the crane are treated as unilateral constraints, the supports can come off the foundation.

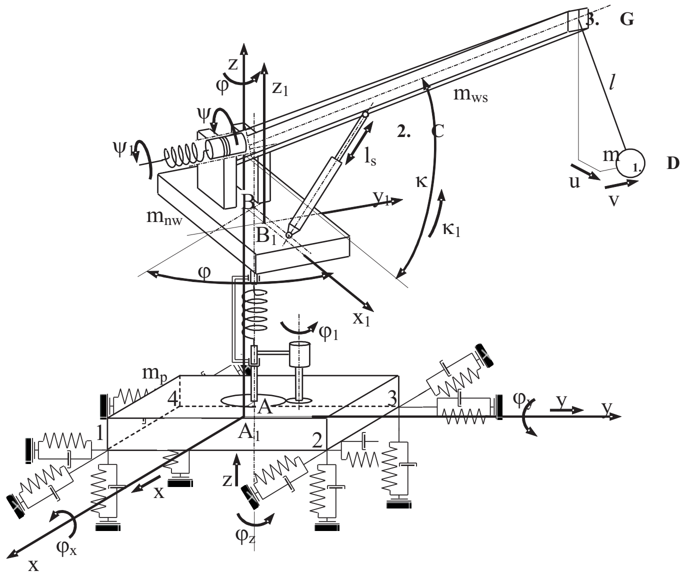


Figure 1 Schematic diagram of the crane model [3]

Schematic diagram of the crane model is presented in Fig. 1. Generalized co–ordinates of the model are put together in the n–element vector **q**. Its co–ordinates are as follows:

$$\mathbf{q} = [x \ \ y \ \ z \ \ u \ \ v \ \ \varphi \ \ \varphi_x \ \ \varphi_y \ \ \varphi_z \ \ \kappa \ \ l]^T \tag{1}$$

where:

x, y, z – linear displacements of the centre of mass of the chassis referred to a fixed reference system,

u, v – projections of payload displacement onto horizontal plane in the radial, and in the tangential direction to the circle described by jib's head, respectively; these components are determined in a movable system rotating with the jib,

φ – angle of rotation of the body and the jib round a vertical axis,

φ_x, φ_y, φ_z – angles of oscillation of the crane in reference to axes connected with the centre of mass of the chassis,

κ – jib inclination angle in reference to the horizontal plane,

l – distance from jib's head to centre of gravity of payload,

Calculating kinetic and potential energies of the system and inserting the obtained formulas into the II order Lagrange's equation, written in the form:

$$\frac{d}{dt}\left(\frac{\partial E_{\mathrm{K}}}{\partial \dot{\mathbf{q}}}\right) - \frac{\partial E_{\mathrm{K}}}{\partial \mathbf{q}} + \frac{\partial E_{\mathrm{P}}}{\partial \mathbf{q}} + \frac{\partial E_{\mathrm{R}}}{\partial \dot{\mathbf{q}}} = 0 \tag{2}$$

one can state the matrix, non–linear, differential equation in the following form [3]:

$$\mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} = \mathbf{P}(\dot{\mathbf{q}}, \mathbf{q}) \tag{3}$$

where:

$\mathbf{M}(\mathbf{q})$ – symmetrical block matrix, which elements are functions of masses, inertial moments of elements of the model and generalized co–ordinates,

$\mathbf{P}(\dot{\mathbf{q}}, \mathbf{q})$ – n–element vector, which components are functions of generalized co–ordinates and their derivatives.

This equation can be transformed to the form:

$$\ddot{\mathbf{q}} = \mathbf{f}(\dot{\mathbf{q}}, \mathbf{q}) + \mathbf{b}(\mathbf{q})\mathbf{q}_{\mathrm{u}} \tag{4}$$

where:

$$\mathbf{q}_{\mathrm{u}} = \left[\begin{array}{ccc} \varphi_1 & \kappa_1 & \psi_1 \end{array}\right]^T$$

φ_1 – rotational angle of the shaft of the hydraulic motor which is used for bringing the crane body with the jib in slewing motion,

κ_1 – inclination angle of jib longitudinal axis related to the horizontal plane; the axis is determined by two points: the point of vertical rotation of the jib and the point of fixing of the luffing cylinder to the jib,

ψ_1 – rotational angle of the motor driven the drum of the winding machine,

$\mathbf{b}(\mathbf{q})$ – vector, which components are functions of generalized co-ordinates and stiffness coefficients of elastic elements.

The formula (4) represents matrix–form motion equation of the crane model describing the slewing motion of its body, changes of jib reach through changes of jib declination as well as hoisting or lowering of the payload through winding or unwinding of rope from the drum. Components of oscillations of the payload as well as angle of rotation of the body can be calculated by means of the following equations:

$$v = \mathbf{c_1}^T\mathbf{q}, \qquad u = \mathbf{c_2}^T\mathbf{q}, \qquad \varphi = \mathbf{c_3}^T\mathbf{q} \tag{5}$$

where:

$\mathbf{c}_1$=[0 0 0 0 1 0 0 0 0 0 0]^T,

$\mathbf{c}_2$=[0 0 0 1 0 0 0 0 0 0 0]^T,

$\mathbf{c}_3$=[0 0 0 0 0 1 0 0 0 0 0]^T

In the similar way, the mathematical models of drive systems used for different work motions have been derived. They have been proposed as hydrostatic systems powered by engines of constant absorbing capacity (or by servo–motor) and proportional valves as the elements which throttle an oil flow [3, 6].

Adding to these models equation (4), formulas modelling the dynamics of fuzzy logic controller and equation of summation point, it has been obtained the equations which were considered as mathematical model of the complete control system. A functional scheme of the control system is presented in Fig. 2 [1, 5]. On the scheme, the character e was used to describe an error signal which is an input to the controller. The character i describes vector of variables which control a work of the hydrostatic systems used for a drive of a crane, usually they are currents of electro–hydraulic transformers – controlling crane hydraulic drive systems.

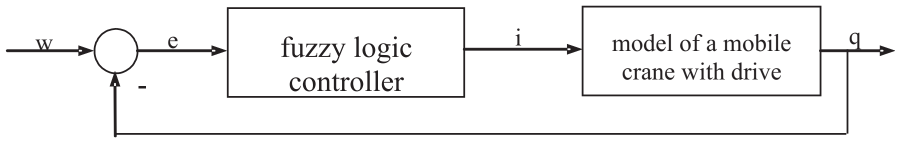


Figure 2 Functional scheme of control system of mobile crane

3. Simulation investigations of the system

Numerical investigations of the model were performed for the fuzzy logic controller of Mamdani's version [4, 7, 8, 9] as the controller in the system. For slewing motion the following main elements of the controller can distinguished:

fuzzyfication block; input signals used in the simulation investigations were as follows:

– tangent co–ordinate of the payload swings v and angle distance of a jib from a target point i.e.: $\Delta\varphi = \varphi_{zad}$-$\varphi$ or

– angle distance of a jib from a target point $\Delta\varphi = \varphi_{zad}$-$\varphi$ and angular velocity;

fuzzyfication was performed using a triangle membership functions;

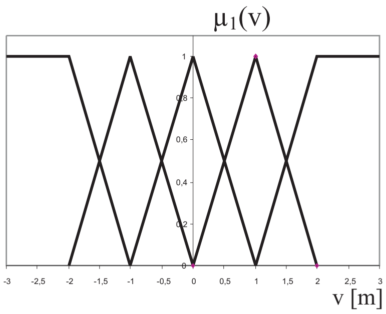
– qualifier block; acting based on the assumed rule data base; the data base consisting of 25 reasoning rules was used in the performed numerical simulations [5, 9],

– defuzzyfication block – based on the method of a center of gravity – COS.

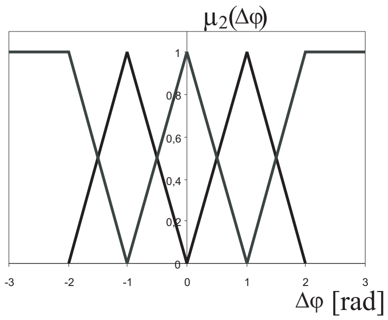
Calculations were performed for the above mentioned combinations of the controller input signals for slewing motion, different levels of density of triangle membership functions and different reasoning rules applied in the qualifier (reasoning) block. The selected results are presented in a form of charts e.g. in Figs 3, 4 and 5.

The above presented simulations were performed for the assumed rule data base of controller characteristics shown in Fig. 3c. Assuming the same membership sets for variables: $\Delta\varphi$ and $\dot{\varphi}$, and additionally entering modification of the FLC controller characteristics it is possible to diminish the coordinates of swings v and u achieving the set slew angle $\varphi_{zad.}$ (Fig. 4).

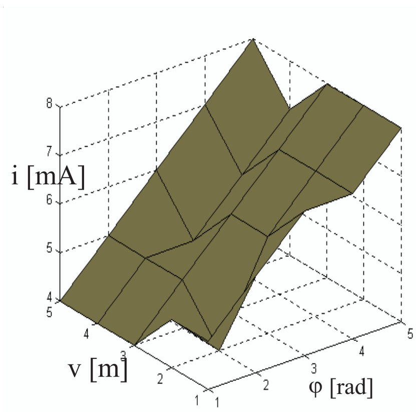
The problem of changing of the set angle of jib rotation was considered during numerical examinations of the slewing motion of the model. The results are shown in the Fig. 5. It was considered a case where the set initial angle was equal φ_{zad0} = 0.785 [rad]. After time equal 10s the operator changed decision and put φ_{zad} = 1.57 [rad].



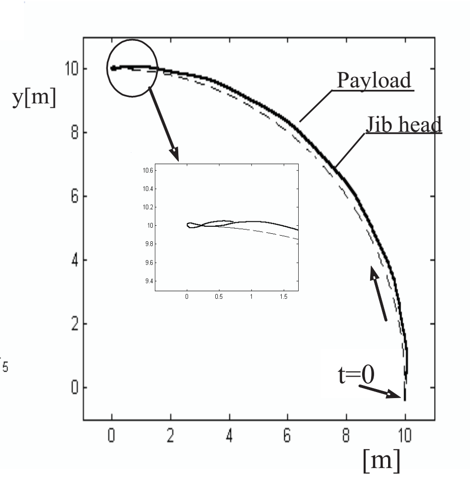
a) membership functions for variable: v



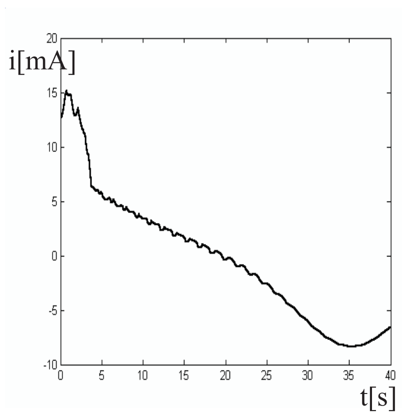
b) mambership functions for variable: $\Delta\varphi=\varphi_{zad}-\varphi$



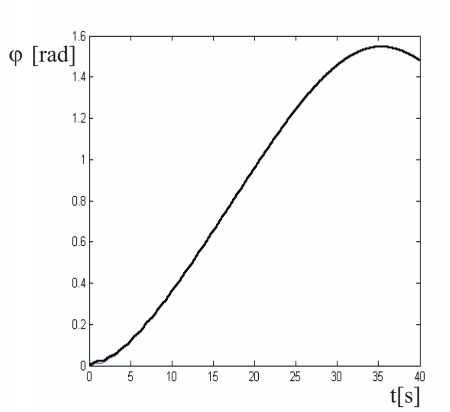
c) characteristic of FLD controller



d) trajectories of the jib head and payload



e) control signal for the crane model i(t)



f) time history of an angleof jib motion φ

Figure 3 Results of simulations of the control system for e = [v, $\Delta\varphi]^T$ (jib slew angle φ_{zad}=1.57 [rad])

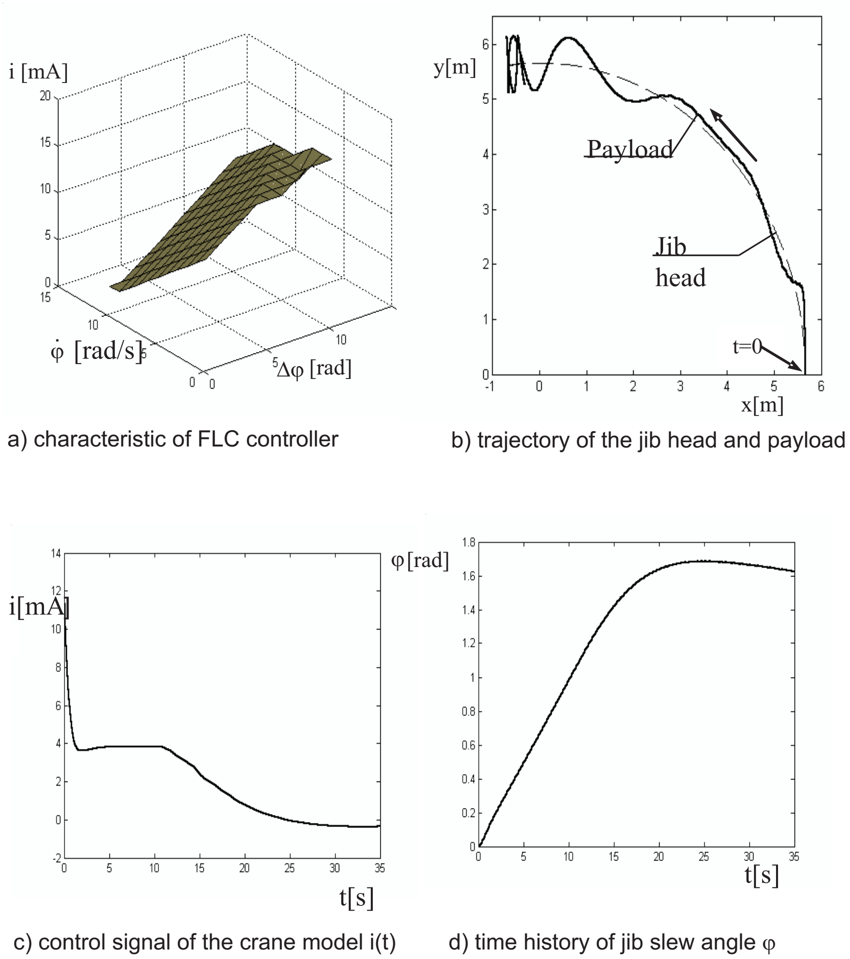
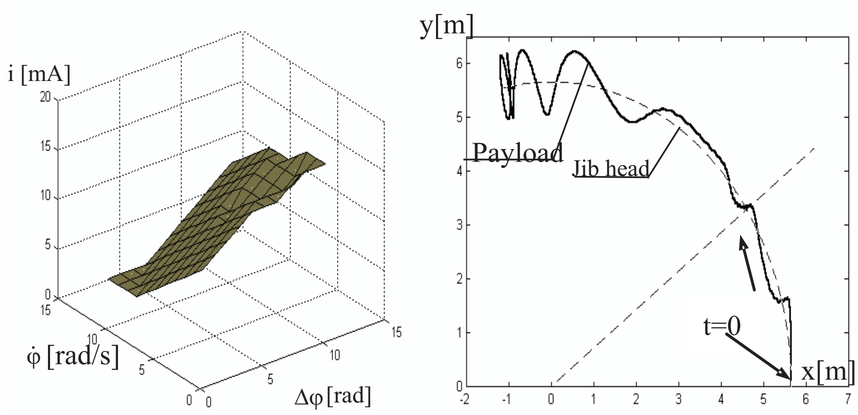


Figure 4 Results of control system simulation for e = [$\dot{\varphi}$, $\Delta\varphi]^T$

4. Conclusions

Some selected presented above results of simulations performed by means on the derived model of the control system show that it is possible to perform a slewing motion of crane body and stopping it in a chosen 3D point assuring simultaneously an extinguishment of the payload oscillations. An effectiveness of the extinguishment of the payload oscillations and a precision of its positioning depend on several factors: a choice of controller input signals, assumed membership functions, methods of defuzzyfication, applied amplifications of control signals as well as a choice of a rule data base and a method of performance of a motion extortion.



a) characteristic of the FLC controller b) trajectory of the jib head and payload

Figure 5 Results of control system simulation for e = $[\dot{\varphi}, \Delta\varphi]^T$ (jib slew angle φ_{zad}=1.57 [rad])

Creation of the rule data base is possible based on a knowledge of an expert – a crane operator or based on numerical simulation investigations. It is also possible to use methods of an adjustment or an auto–adjustment of the controller to achieve the same task.

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