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NUMERICAL TESTS ON THE FLC SYSTEM OF A CRANE MODEL'S SLEWING MOVEMENT

Summary. In this paper, selected results from numerical tests on the influence of FLC settings upon the accuracy and quality of controlling, as well as the settling times, of a crane model's slewing movement are presented.
Keywords: mobile crane; numerical investigations; payload positioning; FLC controller

1. INTRODUCTION

Typically, the swinging of payloads carried by cranes represents an essential impediment in their work. Moreover, this phenomenon may also have a direct influence on the safety of operators, as well as pose a risk to objects in the surroundings of the service area a particular crane. A proper strategy for controlling a crane's work movements can lead to an essential reduction in the amplitude of payload swinging during the performance of versatile movements [2, 8] and/or after their termination (Fig. 1).

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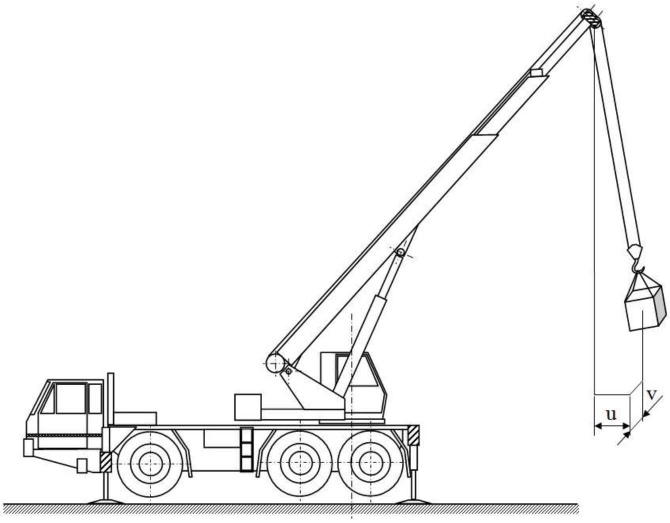

Fig. 1. Scheme of a mobile crane in the course of moving a payload

The application of a control system upon working motions also allows for an increase in the precision of payload positioning in the target point of motion, as well as a reduction in the sensitivity towards distortions. The general principle is that a properly chosen controller has an essential role to play in control systems. For standard controllers, establishing their settings also depends on the dynamics of the considered object. It seems that an application involving controllers, which are based upon fuzzy logic, could be very beneficial; however, in this particular case, one should properly chose the structure and the settings of the controller. In the present paper, we describe investigations in which the settings of the chosen types of controllers based on a fuzzy logic were analysed, along with their influence on the precision and quality of controlling as well as on the time when working motion was performed. The numerical investigations were performed using the prepared mathematical model of a crane, which was mounted on a vehicle chassis together with its driving system. The investigations were restricted to controlling the slewing motion of the rotational bodywork of the crane, thereby allowing for payload displacement by a chosen (set) slewing angle [1, 3, 7].

2. MATHEMATIC MODEL OF THE MOBILE CRANE

Within the simulation investigations, the mathematical model of the crane described in paper [2] was utilized. It was derived by taking into account the following assumptions:

- The bodies of the chassis and the bodywork of the determined masses and inertial moments were rigid, with six degrees of freedom; moreover, mutual slewing of the bodywork in relation to the chassis possible.
- The support system was replaced by a system of springs; masses of springs were neglected.
- Slewing of the bodywork was conducted by means of a hydraulic drive system driven via a mechanical gear of determined stiffness; moreover, the stiffness of the jib was also taken into account (in the direction that was compliant with its slewing around the vertical axis), while masses and moments of inertia concerning the elements of mechanical gear were neglected.

- The jib was considered as a stiff rod of constant length, known mass and moment of inertia.
- The payload was hung from/attached to a non-extensible, weightless and (flabby) flexible rope, that was wound on the drum of a hoisting winch placed on the end of the jib; the hanging payload was considered to be mathematical pendulum.
- Backlashes and friction, which occurred in the support system, jib and mechanical gear, were neglected
- Damping in the system was taken into account.
- The characteristics of elastic connections and damping elements, found within the assumed intervals in the deflection of elements, were assumed as linear.
- The supports were assumed as unilateral, as well as having the capacity to lose contact with the ground.

The crane model, together with the model of the driving system, was considered as a controlling object, which was connected to the controller model of controller equipped with fuzzy logic in order to create the model of the control system. It is presented as a block diagram in Fig. 2.

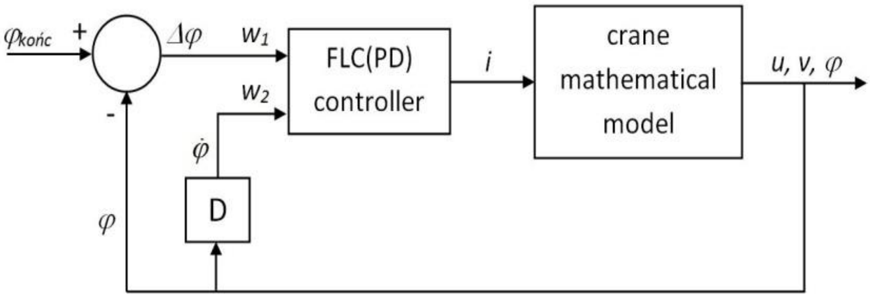

Fig. 2. Functional scheme of the control system of the mobile crane

In the system under consideration, we applied a first version proportional-differential (PD) controller, where the input signals were $\Delta\varphi$, i.e., the difference between the value of the set slewing (rotational) angle of a jib and the value of the current rotational angle $\Delta\varphi = \varphi_{zad} - \varphi$, as well as being a derivative of rotational angle $\dot{\varphi}$. The controller was assumed to be of the Mamdani type, equipped with the assumed base of rules and the base of triangular membership functions [3]. The investigations were performed in relation to different values in the amplification of input and output signals of the controller. Some chosen results of the performed simulation investigations are also presented in papers [4, 5, 6].

3. NUMERICAL INVESTIGATIONS OF THE CONTROL SYSTEM EQUIPPED WITH FLC CONTROLLER

The numerical investigations were performed using specially prepared software, based on MATLAB. In the written program, it was possible to change the amplification of input and output signals of the controller. The courses of the chosen variables in the model – for the chosen variant for the values of amplification coefficients w_1 and w_2, as well as for the assumed slewing angle of a jib – are shown in the figures below. In Fig. 3, the course of the slewing motion angle and the controlling signal (generated by a controller) are presented. In Fig. 4, the trajectory of the payload motion in relation to the motion of the jib ending is presented.

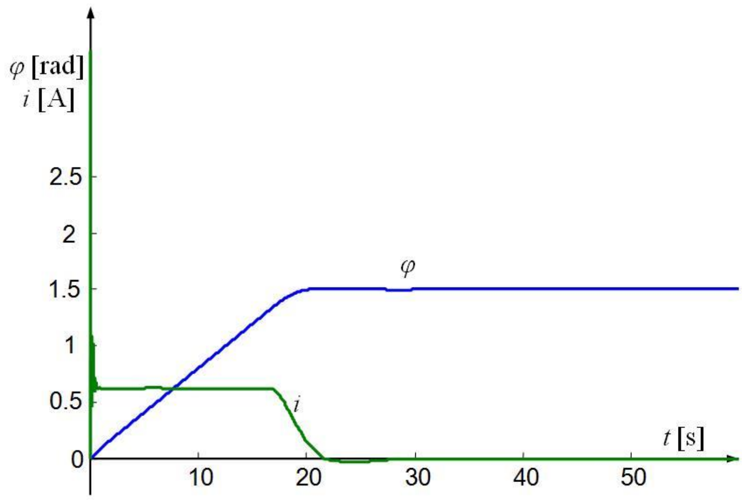

Fig. 3. The angle of rotation φ and control signal i

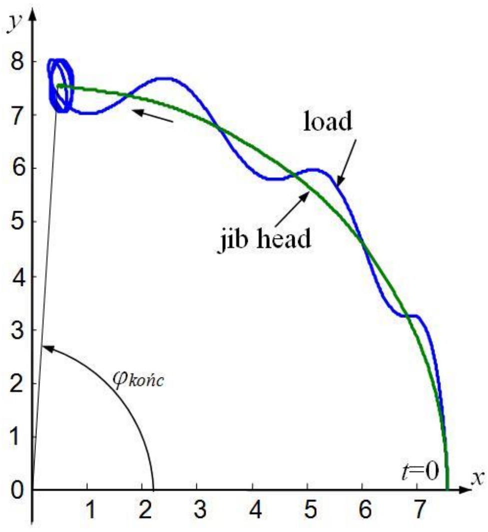

Fig. 4. Trajectories of the jib head and the payload for control system simulation

These characteristics were used to determine the time stabilization of motion (achieving an accuracy of less than 5% of the set value) and the amplitude of payload swinging that remains after the slewing motion has ended. The relationships for both quantities in relation to the values of coefficients w_1 and w_2 are presented in Fig. 5 and Fig. 6 in the form of spatial charts. We can see that, for some combinations of w_1 and w_2, the times of the stabilization of responses or the amplitude of payload swings, which remain after motion has terminated, can be sufficiently high that the utilization of these amplifications would be improper from technical point of view.

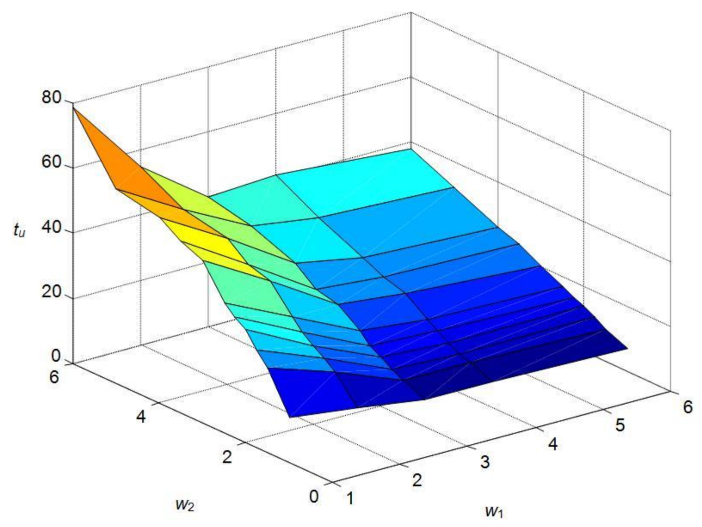

Fig. 5. Diagrams: time regulation t_u *vs*. amplification coefficients of the controller input w_1, w_2

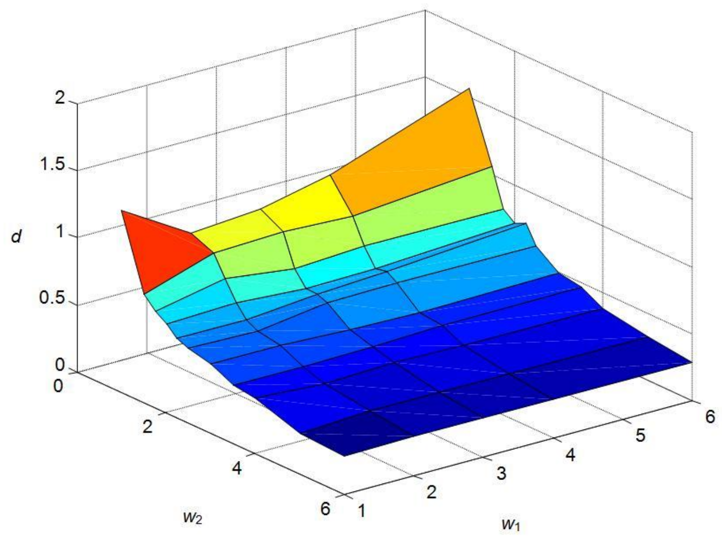

Fig. 6. Diagrams: maximum amplitude of the payload swings remain after the rotating movement ends *vs*. amplification coefficients of the controller input w_1, w_2

The performed investigations also considered the behaviour of the considered model in the following cases:

a) When operator determines the value of the slewing motion of the jib (target rotational angle), i.e., $\varphi_{ko\acute{n}c}$; then, after a particular time from the beginning of the motion, the operator changes the decision to increase the target rotational angle (the trajectory of payload movement for this case is shown in Fig. 7).

b) When the activity is similar to that described above, but an operator reduces the target rotational angle due to changing the decision (Fig. 8).
c) When the activity is similar to that described above, but the decision about whether to change the rotational angle is taken by the operator after the set value of the rotational angle is overcrossed (Fig. 9).
d) When the activity is similar to that described above, but the operator changes the decision about the target rotational angle on two occasions (Fig. 10).

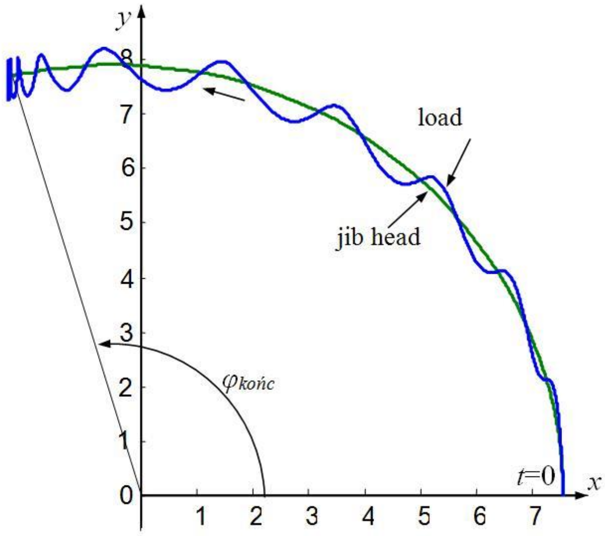

Fig. 7. Trajectories of the jib head and the payload for control system simulation: at time t=20s, $\varphi_{końc}$ changes from 1.5rad to 1.8rad

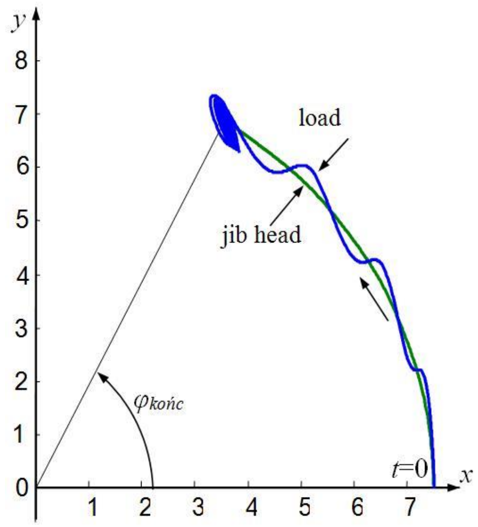

Fig. 8. Trajectories of the jib head and the payload for control system simulation: at time t=20s, $\varphi_{końc}$ changed from 1.5rad to 1rad

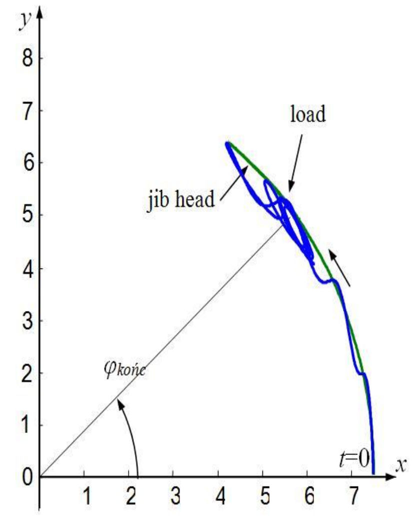

Fig. 9. Trajectories of the jib head and the payload for control system simulation: at time t=20s, $\varphi_{końc}$ changes from 1rad to 0.8rad

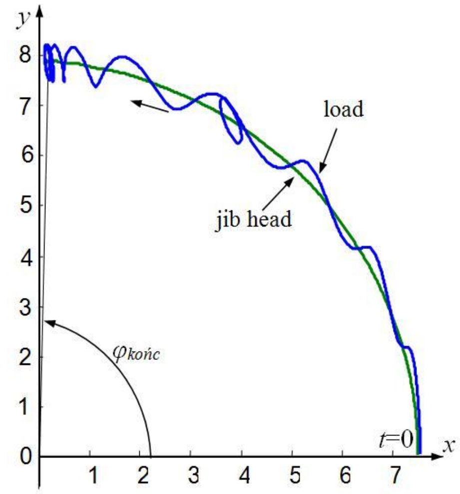

Fig. 10. Trajectories of the jib head and the payload for control system simulation: at time t=20s, $\varphi_{końc}$ changes from 1.5rad to 1rad; at time t=25s, it returns to 1.5rad

4. CONCLUSIONS

Control systems, in which fuzzy logic-based controllers are applied, offer several advantages:

- The choice of a controller and the establishment of its setting can be done without a complete identification of the object of control.
- Even a proximate choice of a membership function and a base of rules usually offers satisfactory quality of control (at least for properly chosen amplifiers of input and output signals of the controller).
- A complicated imposing function, which controls the system, does not need to be set on an input of the system.

A disadvantage of the discussed approach is the lack of possibility in achieving a total reduction in payload swinging after the termination of movement. It is caused by particular properties of the object that were applied in the simulation investigations, as well as the static character of the controller. The model of the mobile crane is an object with a relatively low level of stability, due to neglecting the effect of damping and movement resistance, which together result in controlling that is complicated and/or difficult. The performed simulation investigations have proved that an application of a different type of FLC controller (e.g., P-type) does not reduce errors in the positioning of the payload in the end point of the planned movement.

References

1. Cho S.K., H.H. Lee. 2002. "A fuzzy-logic antiswing controller for three-dimensional overhead cranes." *ISA Transactions* 41: 235-243.
2. Kłosiński J. 2005. "Swing-free stop control of the slewing motion of the mobile crane". *Control Engineering Practice* 13: 451-460.
3. Kłosiński J. 2011. "Fuzzy logic-based control of a mobile crane slewing motion". *Mechanics and Mechanical Engineering* 15(4): 73-80.
4. Kłosiński J., J. Janusz, R. Nycz. 2014. „The impact of an FLC controller's settings on the precision of the positioning of a payload transferred by a mobile crane". *Acta Mechanica et Automatica* 8(4): 181-184.
5. Kłosiński J., J. Janusz. 2015. „Wpływ typu i nastaw regulatora w układzie regulacji ruchu obrotowego żurawia na dokładność pozycjonowania ładunku". *TTS Technika Transportu Szynowego* 12: 787-791. [In Polish: "Influence of the type and parameters of the controller in the control system of a slewing crane motion on the accuracy of payload positioning". *Railway Transport Technology* 12: 787-791].
6. Kłosiński J., J. Janusz. 2016. „Badania numeryczne układów regulacji ruchu obrotowego modelu żurawia samochodowego". [In Polish: "Numerical investigations into the control systems of the rotation model of a mobile crane"]. In *29th Conference on Development Problems for Working Machines*. Institute of Mechanized Construction and Rock Mining, Warsaw, Poland. 25-27 June 2016, Zakopane, Poland. ISBN: 978-83-86040-23-0.
7. Smoczek J. 2014. "Fuzzy crane control with sensorless payload deflection feedback for vibration reduction." *Mechanical Systems and Signal Processing* 46: 70-81.
8. Terashima K., Y. Shen, K. Yano. 2007. "Modeling and optimal control of a rotary crane using the straight transfer transformation method". *Control Engineering Practice* 15: 1179-1192.

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