Robust Crane Control

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Abstract: The paper presents robust crane design by asynchronnous motor with frequency convertor at ensuring system robustness against load weight and rope length variation. Exact position control and elimination of swinging in the final position are required too. Firstly were assemblied mathematical models of main crane components: crab, bridge and uplift by real model of double beamed bridge experimental crane. Was designed robust control for defined interval variation of weight and rope length for real crane. Load weight and swinging are determined by estimators. Finally measured results gained on a laboratory crane are introduced.

Keywords: robust control, crane crab and bridge, uplift, poles region assignment method, observer, estimator, swinging model

1 Introduction

Control of main system drives control has to ensure the most effective and exact motion for crane crab, bridge motion and uplift. This control of crane crab and bridge includes two the most important conditions of exact motion trajectory and forbidden swinging in the final position. Crane systems using today keep precisious positioning but not elimination of the load swinging. Conditions have to be realized for different load weights and lengths of hanging rope. System robustness against change of load weight was designed by Ackermann's by finding suitable feedbacks from robust areas which provides desired properties of the whole system. Rope length belongs to variable parameters what undertakes checking of control design for stability. Switching robust structure feedbacks (areas) for covering total tonnage and all rope lenghts was done by robust subareas which provide robustness against load weight and rope length variaton. Load swinging observer in crane crab and bridge direction were designed for reason of elimination electromechanical load swinging measurement for zero deviation control. Next, load weight observer identified real load weight on the crane hook which can vary between minimum (hook with tackle) and maximum crane

tonnage. All positive solutions of crane drives design are applied for real experimental bridge crane located at experimental laboratory Department of Construction, Transport and logistics at Technical University in Kosice. Load weight estimator was established for identification of real load for robust control. Our tendency was approaching results from swinging model with measurement parameters what demostrates application of subsystem models in connection with real objects.

2   Poles Region Assignment Method

Poles region assignment method has ambition to get values of robust controllers (finding of load weight location in relation to rope lengths) where load swinging will be damped. Control design is procedure for finding feedback vector so that poles of characteristical polynom should be located in Γ - plane at parameters variation (load weight and rope length) (Figure 1). After matrix multiplying in formula (1) and comparison with right side will be expressed pair of robust controllers r_1, r_2, while α is generalized frequency. Graphical draw of $r_1 = f(r_2)$ at load weight changing helps to choose correct controllers parameters from areas of figures 3 and 5 [1, 2].
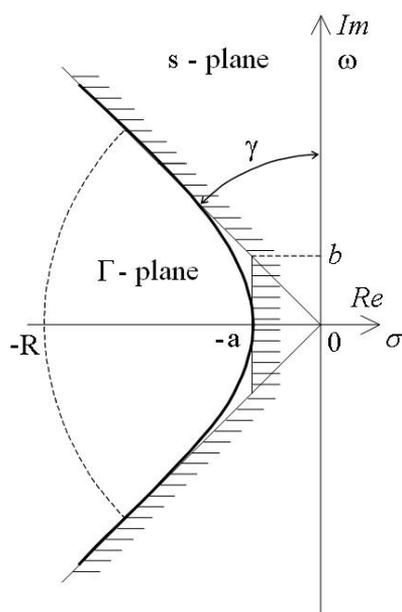
Figure 1
Location of Γ - plane

Ackermann's condition:

$$\begin{bmatrix} 1 & 2\alpha & 3\alpha^2 - \dfrac{b^2}{a^2}\alpha^2 + b^2\alpha^3 & -\dfrac{4b^2}{a^2}\alpha^3 + 4b^2\alpha & ... & d_{n-1} \\ 0 & 1 & 2\alpha & 3\alpha^2 - \dfrac{b^2}{a^2}\alpha^2 + b^2\alpha^3 & ... & d_{n-2} \end{bmatrix} \mathbf{a}(\mathbf{r_1}, \mathbf{r_2}) = \begin{bmatrix} 0 \\ 0 \end{bmatrix}. \tag{1}$$
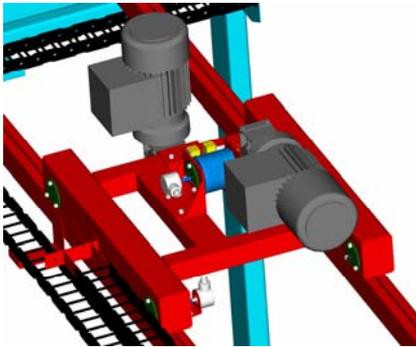
Figure 2
Crane crab
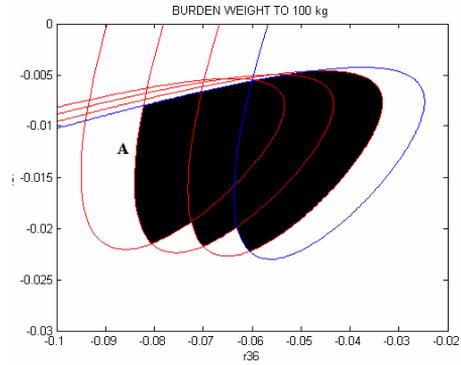
Figure 3
Robust controllers design for crab
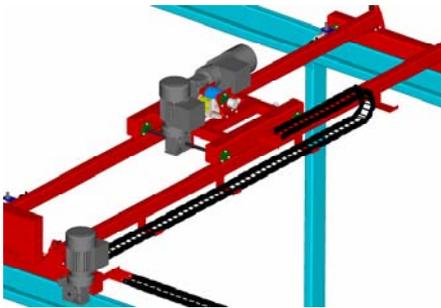
Figure 4
Crane bridge
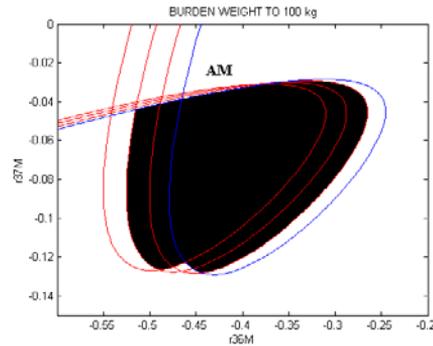
Figure 5
Robust controllers design for bridge
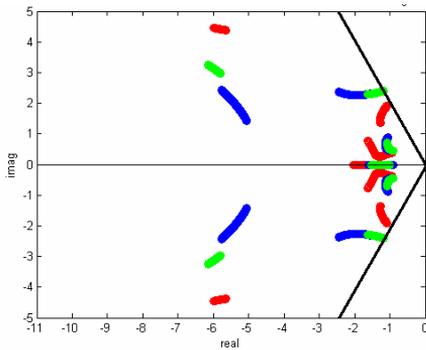
Figure 6
Poles motion at weight change

Robust crab controllers (r_{36}, r_{37}) and bridge (index M) ensure load swinging control and its speed at all crane tonnage. Figure 6 represents keeping poles trajectory of characteristical polynom in allowed area of stability and damping at load weight variation (0,100) kg. It is same for poles trajectory at rope length change (0,5;2,5) m [3].

3 Crane Crab and Bridge Model

Crane crab and bridge serve for load transport (separately or all at once) with weight m_G from initial position x_{K1} to the final position x_{K2} [3].
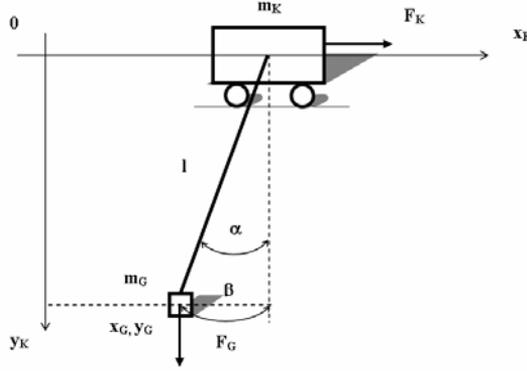
Figure 7
Crane rab and bridge model

Differential and algebra formulas for description of mechanical crane crab and bridge part: $m_K \, \ddot{x}_K = F_K + F_G \sin \alpha$, $m_G \, \ddot{x}_G = -F_G \sin \alpha$, (2)

$$m_G \, \ddot{y}_G = m_G g - F_G \cos \alpha, \tag{3}$$

$$x_G = x_K + l \sin \alpha, \ y_G = l \cos \alpha. \tag{4}$$

$$\ddot{x}_K = \frac{3p}{2} \frac{L_h}{1+\sigma_2} \frac{j}{m_K r} \frac{1}{\left(\dfrac{J_m}{p} \dfrac{j^2}{r^2} \dfrac{1}{m_K} + 1 \right)} i_{2m} i_{1y} + \frac{m_G}{m_K} \frac{g}{l} \frac{1}{\left(\dfrac{J_m}{p} \dfrac{j^2}{r^2} \dfrac{1}{m_K} + 1 \right)} \beta \, ;$$

$$\ddot{\beta} = -\frac{3p}{2} \frac{L_h}{1+\sigma_2} \frac{j}{m_K r} i_{2m} i_{1y} + \frac{J_m}{p} \frac{j^2}{r^2 m_K} \ddot{x}_K - \frac{\left(1 + \dfrac{m_G}{m_K} \right)}{\dfrac{l}{g}} \beta. \tag{5, 6}$$

Formulas 5 and 6 describe crab (bridge) acceleration $\ddot{x}_K$ and swinging acceleration $\ddot{\beta}$ in its direction where r is transmission radius. α is angle of swinging and β is transmitted angle to the meters.
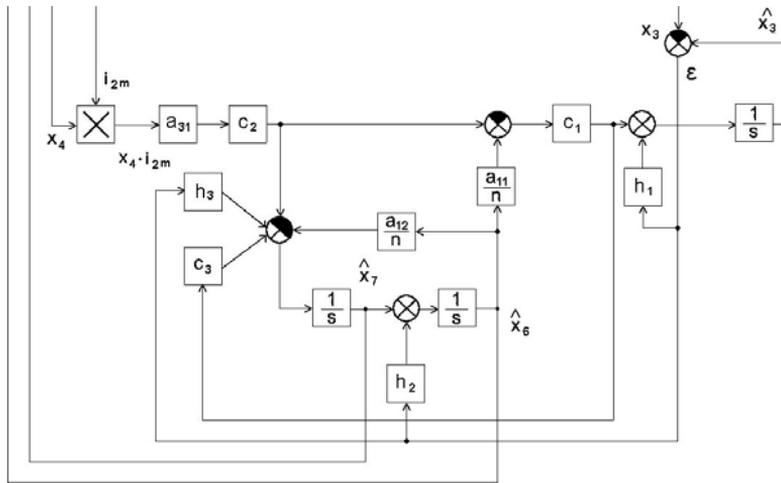
Figure 8

Load swinging observer with output $\hat{x}_6$ and its speed $\hat{x}_7$

Simulations in MATLAB Simulink on figure 9 and 10 are time respond of observer load swinging in crane crab and bridge direction. There was accepted maximum overswing in the final position 0.5 cm from practical reason by low toughness of hanging rope.
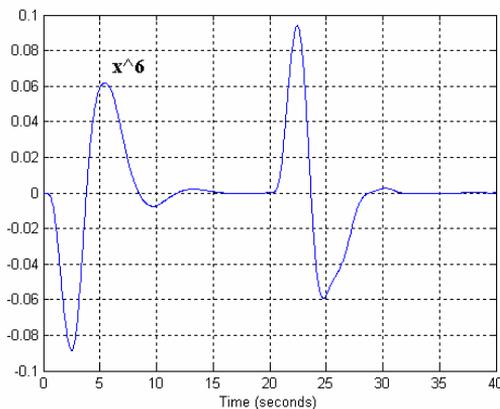
Figure 9

Load swinging in crab direction
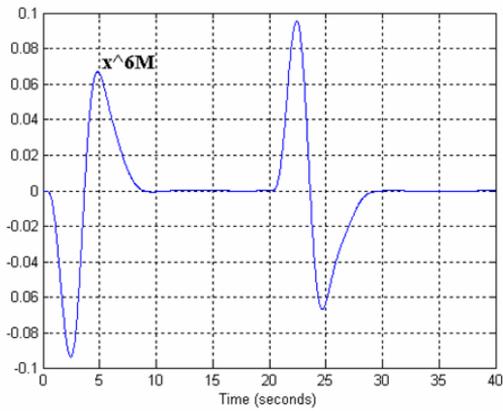
Figure 10
Load swinging in bridge direction

Load swinging control in simulation model is ensured by feedback from load swinging $\hat{x}_6$ ($\hat{x}_{6M}$) [m] and its speed $\hat{x}_7$ ($\hat{x}_{7M}$) [ms^{-1}]. On Figure 10 is observed zero swinging at the end of transport.

4   Crane Uplift Model
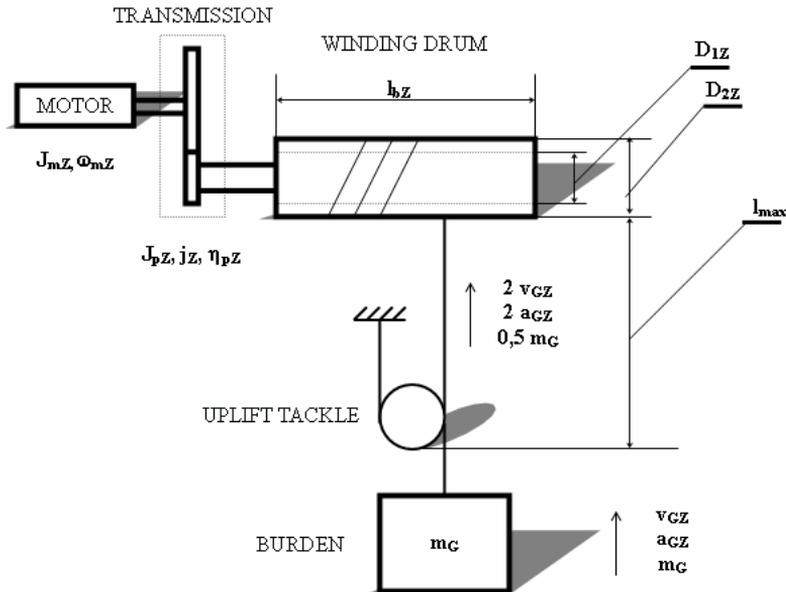
Figure 11
Crane uplift model

Torque formula and total moment of inertia for crane uplift:

$$M_{mZ} - M_{GZ} = J_{CZ} \frac{d\omega_{mZ}}{dt} ,$$ (7)

where M_{mZ} - motor moment, M_{GZ} - load moment, J_{CZ} - total moment inertia, J_{mZ} - motor moment inertia, J_{CbZ} - drum moment inertia, J_{CGZ} - load moment inertia.

Simulation of weight observer output provides real weight on the hook and this information is needed for robust controllers switching by defined subarea.
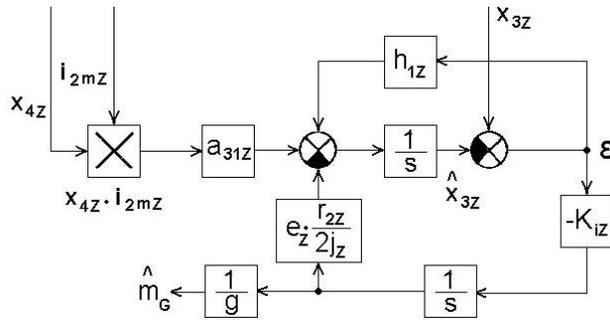
Figure 12

Weight observer with load weight output

On the Figure 13 is shown simulation crane bridge motion x_{5M} [m] after sellecting robust controllers according to identified load weight $\hat{m}_G$ [kg]. Real rope length is gained from uplift model for next setting robust controllers.
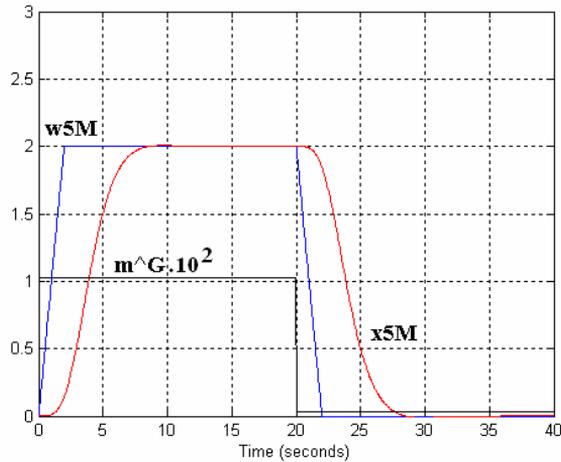
Figure 13

Crane bridge trajectory and identified weight

5 Measured Processes at Experimental Bridge Crane

Bridge crane was experimentaly indentified by ARX model and was acquired linearized transfer functions of crab, bridge and uplift. Swinging in crab and bridge direction was identified by OE model. Robustness of real experimental crane model was ensured by switching structure of robust controllers for covering load weight and rope length variations.

Figure 14
Experimental bridge crane

Swinging sensor design consists of two each other perpendiculary rotary rheostats which measure deviation in crane crab and bridge direction.
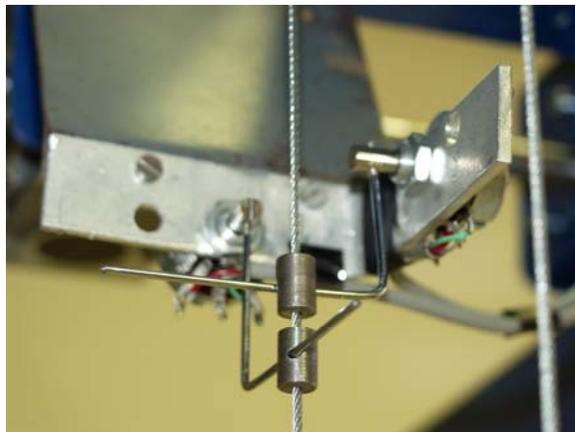
Figure 15
Swinging sensor

On the Figure 16 is shown identification of load weight m_{rG} [kg] by estimator based on load uplift current. Figure 17 represents matching of real load swinging in crane crab direction x_{6r} [m] with swinging model x_{6m} [m] which realized actuating signal to the control. Rope length is l = 1.1 m. Measured time responses on the Figure 18 is time response of contemporary crab x_{5r} and bridge x_{5rM} motion at rope length l = 2.3 m. Load swinging is plotted on the Figure 19 at condition of zero swinging in the final position.
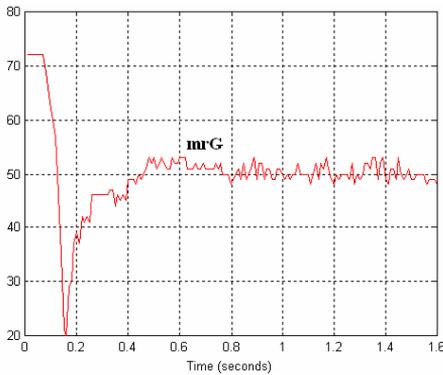
Figure 16
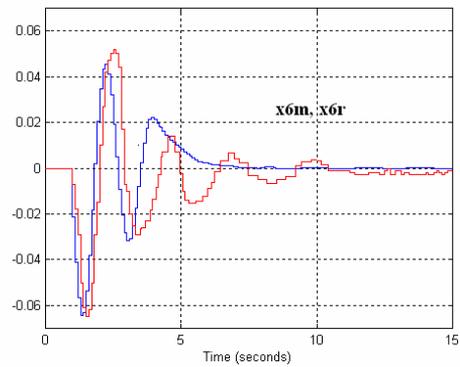
Figure 17
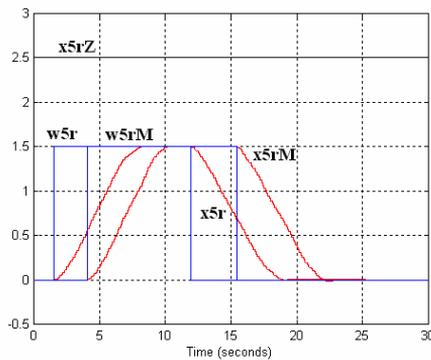
Figure 18
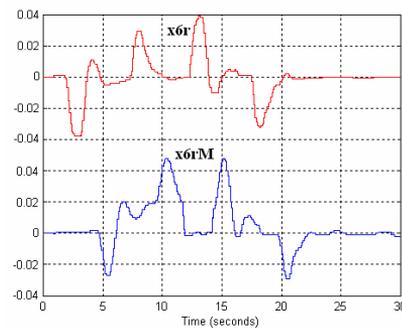
Figure 19

Project Experimental bridge crane was solved in cooperation with Department of Construction, Transport and Logistics and Department of Cybernetics and Artificial Intelligence.

Conclusions

Robust crane control as system with variable parameters was designed by Ackermann method of poles region assignment where by defined algorithm were obtain robust controllers for ensuring stability and damping at load weight and rope length variation in user range. Correct robust design was confirmed by measurement with included weight and model load swinging estimator at disallowed load swinging in the final reference position in crane crab and bridge direction.

Referencies

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