THE ROBUST CONTROL OF THE CRANE'S CRAB

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SUMMARY

This paper deals with application of the pole region assignment method for position control of a crane's crab. The same form of the track arc at uncertain burden weight and rope length is required. To avoiding swinging of the burden in the final position is also supposed. Crab's drive is realized by asynchronous motor fed from a frequency converter. Simulation results have shown that this control design may be successful for a certain interval of system parameter variations. Robust control method are derived by two different approaches:

- *methods based on stability condition of the characteristic polynomial or the state equation by means Lyapunov criterion. Some of them consider the reference damping (exponential stability),*
- *methods shifting poles of the characteristic polynomial into the Γ- region situated in the left part of the complex plain.*

Crab of the crane may be loaded by certain burden weight and also the rope length may vary within an interval. Then robust control with constant controller parameters is advantageously applied ensuring the same arc. We applied for the reduced system the method from ***Ackermann of system robustness****. After specification the conditions for improving of the control system, which lead to stabilizing and damping the vibrations, is eliminated such stage, which could cause the instability of a system. We get the area after longwinded mathematical modification of potential selection for position of the controllers and by feedback control we ensured the certain interval of the burden weights at the rope length.*

Keywords*: classical state design, robustness design, rope, swinging of the burden, method of poles region assignment*

1. INTRODUCTION

A crane control has to ensure the following drive properties: the reference position should be reached with the defined exactness, swinging in the final position is not allowed, a drive with induction motor fed from a converter is assumed and insensitivity to the load mass and the rope length is required.

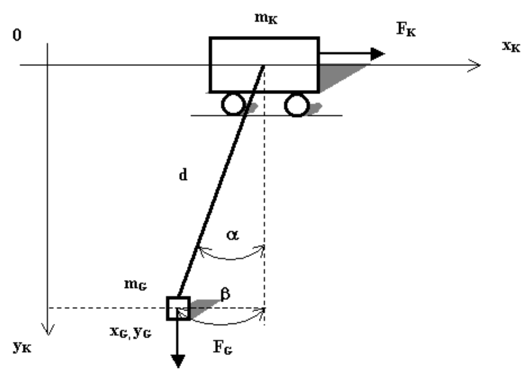

Fig.1. Mechanical part of the crane's crab

Pole region assignment method [1] enables calculation of two feedback parameters. Further of them have to be given. Modified singular perturbation method [4] enables to reduce control of each loop in cascade structure to the third order, so that the only one controller parameter has to be chosen. This approach enables to solve the above formulated task. Simulation results determine the accessible interval of system parameter variations.

2. SYSTEM EQUATIONS

The mechanical part of the crab is shown in Figure 1. Crane and burden variables are denoted by indices K and G respectively. Motor drives the crab's load m_K by force F_K. The mechanical system is described by following differential equations [5]:

$$m_K \ddot{x}_K - m_G \, g \frac{\beta}{d} = F_K \,, \tag{1}$$

$$m_K \ddot{\beta} + \left(m_K + m_G\right) g \frac{\beta}{d} = -F_K \,. \tag{2}$$

Differential equations may be linearized by assuming small quantity of α and this angle is substituted by corresponding arc β:

$$\sin\alpha = \alpha; \;\; \cos\alpha = 1; \;\; \alpha^2 = 0; \;\; \dot{\alpha}^2 = 0 \,. \tag{3}$$

Force F_G in rope may be excluded. Load of the motor m_z is expressed by means of the gear ratio j and drive wheel radius r, so that motor dynamical equation of an induction motor equals [2]:

$$\frac{J}{p}\frac{d\omega}{dt} = \frac{3p}{2}\frac{L_h}{1+\sigma_2} i_{2m} i_{1y} - m_z \,, \tag{4}$$

where i_{2m} and i_{1y} are flux and torque creating current components. Resulting equations of the crab's acceleration $\ddot{x}_K$ and angular acceleration $\ddot{\beta}$ are as follows:

$$\ddot{x}_K = a_{31}c_2c_1 i_{2m} i_{1y} + \frac{a_{11}}{z} c_1 \beta , \tag{5}$$

$$\ddot{\beta} = -a_{31}c_2 i_{2m} i_{1y} + c_3 \ddot{x}_K - \frac{a_{12}}{z}\beta , \tag{6}$$

where following expressions were introduced:

$$c_1 = \frac{1}{\frac{J}{p}\frac{j^2}{r^2}\frac{1}{m_K}+1}, \qquad c_2 = \frac{j}{m_K r},$$

$$c_3 = \frac{J}{p}\frac{j^2}{r^2 m_K}, \qquad a_{11} = \frac{m_G}{m_K},$$

$$a_{12} = 1 + a_{11},$$

$$z = \frac{d}{g}, \qquad a_{31} = \frac{3p}{2}\frac{L_h}{1+\sigma_2}. \tag{7}$$

As state variables were chosen: flux creating current $w_1 = i_{2m}$ [A], crab speed $x_3 = \dot{x}_K = \omega$ [rads^{-1}], torque creating current $x_4 = i_{1y}$ [A], crab position $x_5 = x_K$ [m], arc circumscribed by the burden $x_6 = \beta$ [m] and speed of the burden in the arc $x_7 = \dot{\beta}$ [ms^{-1}].

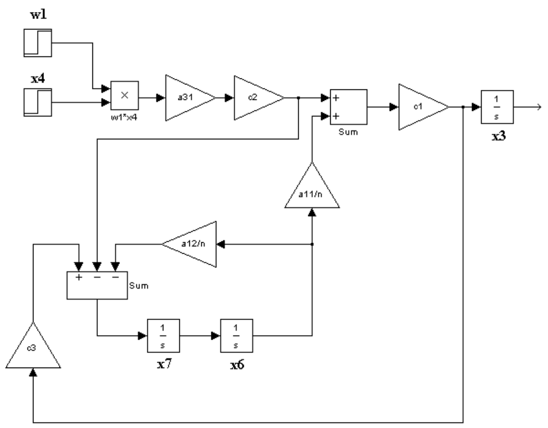

Fig.2 Block scheme of the crab's structure

3. CONTROL METHOD

A system with uncertain parameters may be described by the following state equations:

$$\dot{\mathbf{x}} = \mathbf{A}(\mathbf{p})\mathbf{x} + \mathbf{b}(\mathbf{p})u + \mathbf{e}(\mathbf{p})z ,$$
$$y = \mathbf{c}^T \mathbf{x}. \tag{8}$$

Pole region assignment method [1] enables to determine the feedback control:

$$u = -\mathbf{r}^T \mathbf{x}, \tag{9}$$

such that all varying poles of closed loop remain in Γ-region (Fig.3) for all admissible parameters **p**.

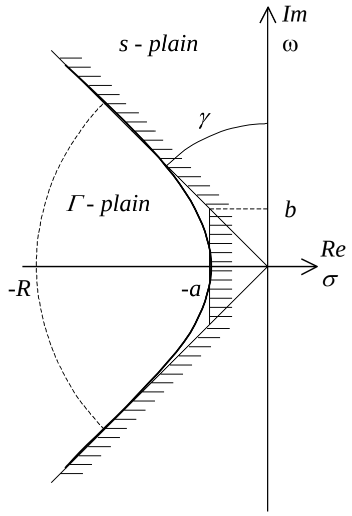

Fig.3. Γ-region definition

However, by the above mentioned method only two feedback parameters may be calculated, further of them should be given. This can be considered as disadvantage, because state controllers need more parameters. Fortunately, order of control circuit in cascade structure may be reduced by means of modified singular perturbation method to the third order [6]. Thus only one controller parameter (usually gain of integrator) must be chosen for nominal or medium system parameters, two remaining parameters are calculated by pole region assignment method.

Γ-region is projected into R-plane (Fig.4). Two curves corresponding to the limit parameters of the considered interval are drawn. The operating point A in the common area determines two feedback parameters of the controller (r_{56} = -165; r_{57} = 85).

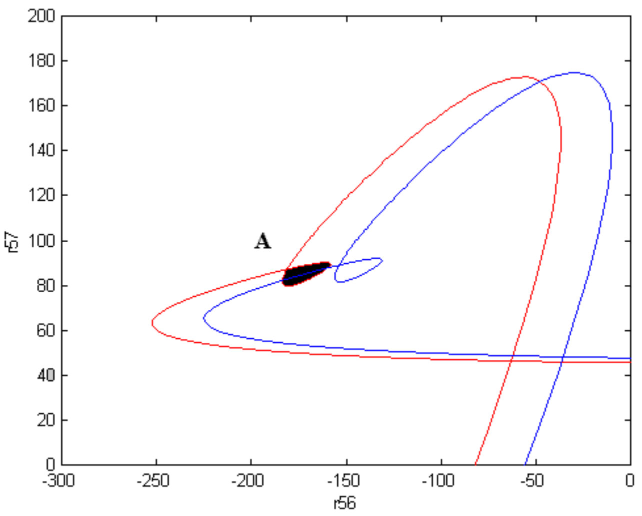

Fig.4 Determination of feedback parameters at change weight of the burden from 100 kg to 500 kg

4. SIMULATION RESULTS

Robust position controller was designed for the rope length equals 3 m and varying load burden within the interval <100kg; 500kg> (Fig.8). A higher load would decrease the desired damping ratio.

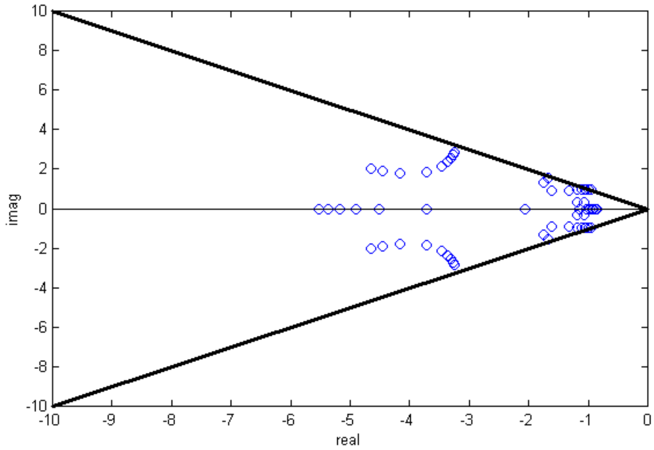

Fig.5 Pole placement at the load burden variation from 100 kg to 500 kg

Corresponding position time response is drawn in Figure 6, where forward movement of the crab was simulated with 500 kg of the load burden and backward movement with 100 kg. Arcs for both directions are very similar and do not show any swinging in the final position.

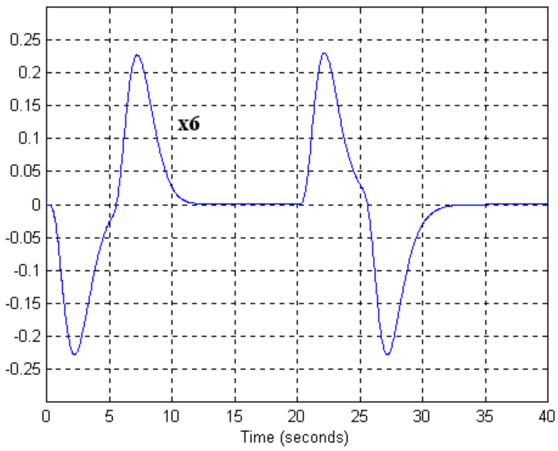

Fig.6 Arc circumscribed by the burden with the rope length 3 m

If the same controller was used for the shorter the rope length equals 1 m then the arc contains oscillatory components (Fig.7).
The shorter rope, the higher frequency of system oscillation may appear. Therefore it is useful to analyse relation between the rope length and burden mass (Fig.9).

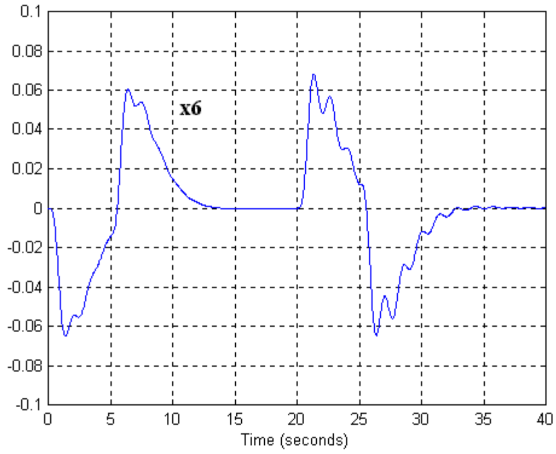

Fig.7 Arc circumscribed by the burden with the rope length 1 m

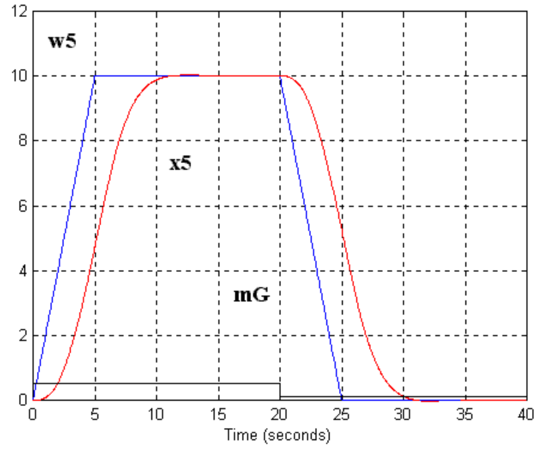

Fig.8 Reference and real crab position, weight of the load burden in time response

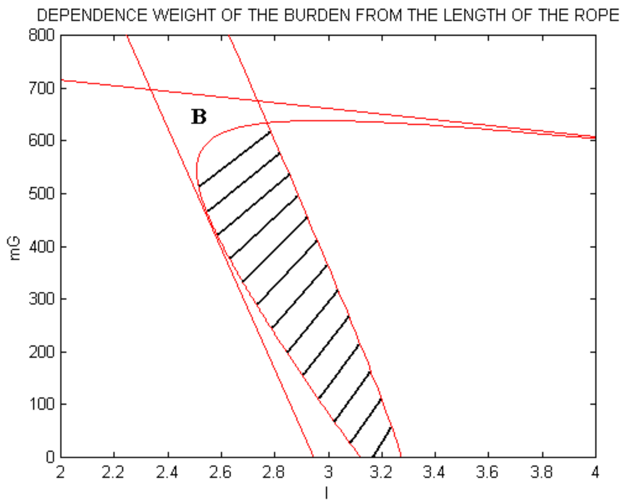

Fig.9 The weight of the load burden as the function of the rope length

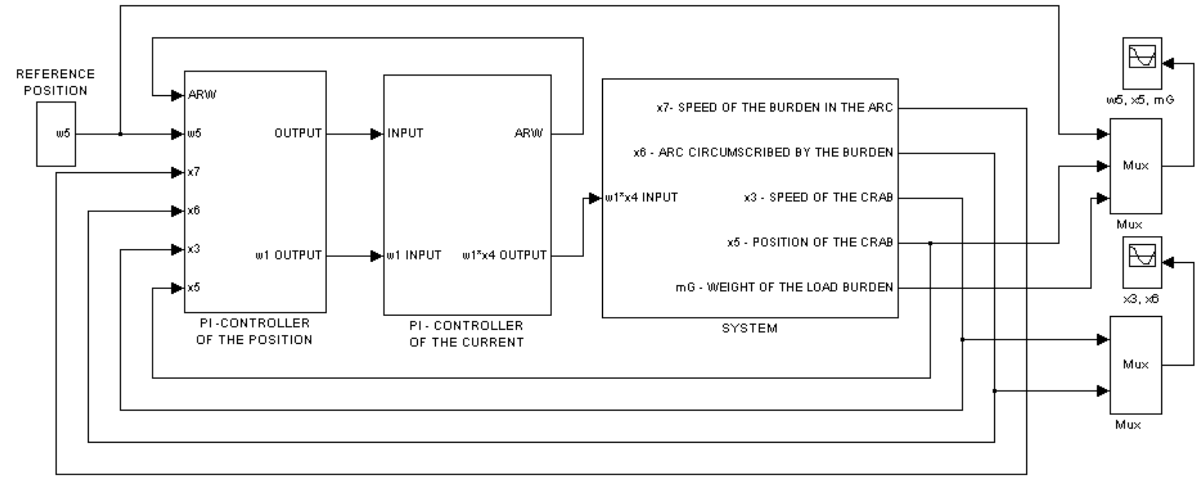

Fig.10 Block scheme of the control system

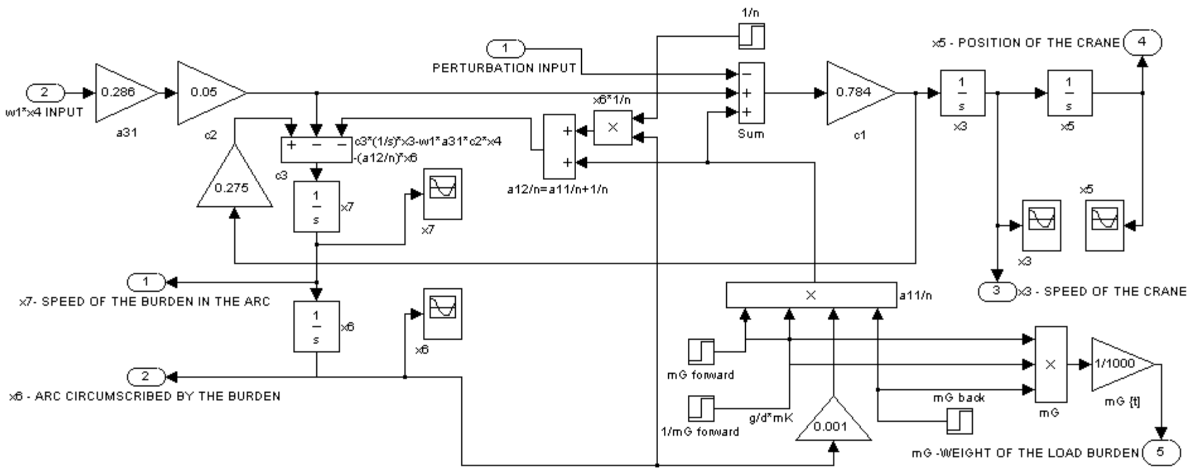

Fig.11 Block scheme of the crab's crane system and measure

Block scheme of the whole control system from MATLAB v5.21 consists of (Fig.10):
1. Reference position: possible to change the speed of movement the crane's crab,
2. PI Controller of the position and current,
3. System and measure: detailed scheme on the Figure 11.

The most important part of control design is detailed subscribed the system of the crane's crab. Usually in practise situation is needed that the crab should move with difference weight of the burden in one way and back. This kind of problem solve blocks marked m_G $forward$ and m_G back. Different rope length is set up in the block $1/n$, where $n = \frac{l}{g}$, l - the rope length, g - constant of gravitation acceleration. Blocks marked a_{31}, c_1, c_2 and c_3 are the results of the linearization mathematical - physical process for model of the crab's crane.

5. CONCLUSIONS

Pole region assignment method completed with system order reduction is feasible for systems with parameters varying in a certain vicinity of their nominal quantities. The border of this interval will be transients. Requirements for parameter variations could be fulfilled to limitation only for which a common area of limiting curves is possible to find (Fig.4). Spreading of the necessary interval could be reached e.g. by means of an observer, which could give approximate quantities of changing parameters. Finally, after conclusions we present table where are results for different rope lengths of the hanging rope.

ALLOWING THE WEIGHT OF THE LOAD BURDEN 100 - 1000 KG (* to 500 KG)						
WITHOUT THE ACTIVITY OF THE EXTERNAL PERTURBATION						
length of the rope [m]		**10**	**6**	**3 ***	**2 ***	**1 ***
delay of the position [s]		5	5	5	5	5
maximum arc circumscribed by the burden [m]	at movement of the crab	0,8	0,5	0,25	0,15	0,07
	at final movement of the crab	0	0	0,02	0	0,005
burden speed in the arc [rads^{-1}]		0,7	0,55	0,2	0,17	0,1

Tab.1 Simulations results

6. REFERENCES

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BIOGRAPHY

Marek HIČÁR (Ing.) graduated at the Faculty of Electrical Engineering and Informatics, TU in Košice in 2000. Since that time he is busy as a part - time PhD student at the Department of Electrical Drives and Mechatronics, FEI TU in Košice. His research activity is focused to the robust control of the cranes.

Ladislav Balara (Ing.) received his Ing. Degree in electrical engineering from the Technical University in Košice in 1998. This time he has finished PhD study at the Department of Electrical Drives and Mechatronics. His research activity is oriented to robust control of asynchronous motors.

Ladislav Zboray (Prof. Ing. CSc.) received the degree of Ing. in electrical engineering from the Slovak Technical University in Bratislava in 1953 and CSc (PhD) from the University in Žilina in 1964. After a short industrial practice he has been with the Technical University in Košice, since 1982 as professor at the Department of Electrical Drives and Mechatronics. His major field of interest is the control of electrical drives, especially by the means of state control.