Kassymbek A. OZHIKENOV

(Kazakh National Technical University after K. I. Satpayev, Almaty, Republic of Kazakhstan)

DYNAMIC CONTROL STABILIZING IN MANIPULATOR DRIVES' SYSTEM

Annotation. The article covers the research about the effectiveness of parametric controller's application in a system of manipulator's servo drives. Parametric control is carried out with a help of servo drive regulator's transfer coefficient's direct change, which causes a simplification of the system with parametric controller and its technical realization. The modeling of this system has been conducted in MATLAB medium (Simulink). The comparative results' assessment of modeling of servo drives system with parametric controller and traditionally used technique of coordinate control is carried out. It is shown that servo drives system with parametric controller provides desirable characteristics of the manipulator.

Keywords: servo drive, amplification factor, parametric control, coordinate control, transient process.

Тірек сөздер: қадағалаушы жетек, еселеу коэффициенті, параметрлік реттеу, координаталық реттеу.

Ключевые слова: следящий привод, коэффициент усиления, параметрическое регулирование, коорди-натное регулирование.

Industrial robot consists of multilink systems, stipulating mutual influence between its movability degrees. The motion of one link determines the others' motion. In the process of carrying out techno-logical operations the inertia moments of manipulator have been changing, which causes dynamic errors.

For instance, for flat manipulator working in a polar coordinate system (Figure 1), servo drives' dynamic interaction of movability degrees is reviled in load inertia of servo drive of manipulator's angular movement φ is a variable quantity and depends on linear arm moving-out r.

$$I_н(r) = I_1 + I_{2c} + m_2(l/2 - r)^2, \qquad (1)$$

where I_1 – inertia moment of the first link of manipulator pertaining to rotation axis (I_1 = const); I_{2c} – inertia moment of the second link pertaining to central axis parallel to the rotation axis.

The variability of drive's inertial load in angular position due to changes in linear position of manipulator causes deterioration of its controlling process quality. For instance, this well-known problem can be solved by stabilizing manipulator dynamic in a certain way.

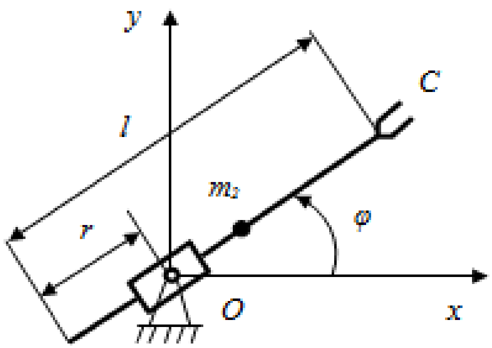


Figure 1 – Kinematic schematic of manipulator:

m_2 – mass of the second link; l – arm length; r – linear arm movement, φ – angular arm movement

In work [1] it is proposed to use along with coordinate control of manipulator of optimal parametric controller (PC) in order to improve the controlling process quality by decreasing the interaction of manipulator drives. The implementation of parametric controller is carried out by means of separate block, which depends on manipulator's configurations. It automatically computes the value of corrective parametric signal in accordance with the expressions for the value of amplification factor in the primary feedback circuit of servo drive. The parametric signal maintains optimal indicated value of amplification factor, and simultaneously stabilizes amplification factor of servomechanism.

Present paper is devoted to the improvement of the parametric control method and its effectiveness research through quality improvement of dynamic processes behavior in manipulator's servomechanism described above in work [1]. One of the improvements is the implementation of parametric control not in the feedback circuit according to the provision (with simultaneous amplification factor stabilizing in a system), but through the changes in controller transfer factor of servo drive, which causes a simplification of the system with its parametric controller and technical feasibility.

Then, in accordance with the methodology [1], and taking into account the expression (1) optimal values of alternating amplification factor in forward circuit of servo drive of angular arm movement (Figure-1) depending on the linear moving-out r, it is determined by the following expression

$$k_{\varphi_i}^{opt}(r) = \left[C\left(A + B(l/2 - r)^2\right)^{3/2} + D\left(A + B(l/2 - r)^2\right)^{-1/2}\right]^2, \qquad (2)$$

where

$$A = I_{dv} + I_r + (I_1 + I_{2c})/(z^2\eta), \qquad B = m_2/(z^2\eta),$$

$$C = (2\alpha_1 / c_e\alpha_2)\times\left(R^3_{armt} z / c^3_{м} k_{pa}\right)^{1/2}, \qquad D = (c_e/2)\times\left(c_{м} z / R_{armt} k_{pa}\right)^{1/2}.$$

Here I_{dv} – inertia moment of slave motor rotor (SM), $I_r = (0{,}05 \div 0{,}25)\times I_{dv}$ – inertia moment of reducer, given to the engine shaft; z - gear ratio of reducer; η - efficiency of reducer; R_{armt} - resistance of slave motor armature winding, (SM); c_e - counter electromotive force factor of engine (EMF); $c_{м}$ - factor of slave motor moment; k_{pa} - gear power amplifier factor of drive (PA); α_1, α_2 - normalizing factors.

To simplify the technical feasibility of the algorithm of the parametric controller it is also advisable to carry out a linearization of the nonlinear expression (2) by the method of least squares:

$$k_\varphi(r) = ar + b, \tag{3}$$

And in this expression the regular linearization a and b are determined for various i^{th} linear positions of arm r_i using the following formulas

$$a=a(r_i,\ k^{opt}_{\varphi_i}),\ \ b=b(r_i,\ k^{opt}_{\varphi_i}) \tag{4}$$

where $k^{opt}_{\varphi_i}$ - amplification factor value for the value of r_i, determined by the nonlinear expression (2); N - number of different value r_i.

Referring back to the research done on controlling process quality of manipulator the mathematical models of manipulator drives have been considered in the form of structural schemes of automatic control systems (ACS), where simplified gear functions of drives' slave motor are aperiodic links of automatic control systems (ACS). Because a direct current motor of separate excitation is used instead of slave motor. Under such conditions direct current motor's dynamic of separate excitation of manipulator' servo drive with angular movement having variable moment of inertia load can be represented by gear functions of aperiodic link with time-variant response factor

$$\Omega_{dv}(p)/u_{armt}(p) = \left(k_{dv} / T_{м}(r)p + 1\right), \tag{5}$$

where $u_{armt}(p)$, $\Omega_{dv}(p)$ - operating images of a voltage on slave motor's armature winding and on a shaft velocity of slave motor; k_{dv} - amplification factor of slave motor; $T_{м}(r)$ - electromechanical time constant of direct current motor of separate excitation, and of drive of manipulator's angular movement, which depends on moment of drive inertia load $I_g(r)$ given to slave motor shaft, in this case it is a function of linear arm position r

$$T_{м}(r) = I_g(r) R_{armt} / c_e c_{м} = \left(\left(I_{dv} + I_p + I_{м}(r)/(z^2\eta)\right)R_{armt}\right) / c_e c_{м}\Big). \tag{6}$$

We get a general view of the expression taking into consideration the expressions in (1), which characterize dynamic influence of servo drive of linear movement on servo drive of manipulator's angular movement:

$$T_{м}(r) = \alpha r^2 + br + \gamma, \tag{7}$$

where

$$\alpha = m_2 R_{Я} / \left(z^2 \eta c_e c_м\right), \quad \beta = -2 r m_2 R_{Я} / \left(z^2 \eta c_e c_м\right),$$
$$\gamma = \left(\left(I_{dv} + I_p + I_1 + I_{2c}\right) / \left(z^2 \eta\right)\right) R_{armt} / \left(c_e c_м\right)$$

Structural schematic of manipulator servo drives' system with their dynamic influence and parametric controlling, where amplifying and transforming composition of drives are described as inertialess links, slave motor - as aperiodic link of automatic control system, and mechanical transfers are considered as absolutely hard, it is clearly represented in Figure 2.

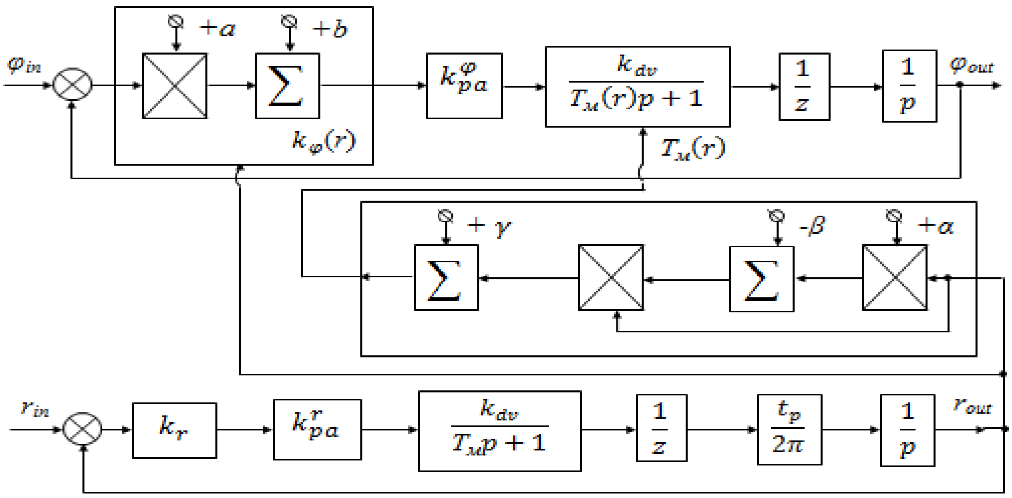


Figure 2 – Structural schematic of servo drives' system with parametric control. In figure φ_{in} – input (controlling) influence, corresponding with required angular position of manipulator; φ_{out} – controlled value, corresponding with angular position

of manipulator; r_{in} – input influence, corresponding with required linear position of arm; r_{out} – controlled value,

corresponding with linear position of manipulator; t_p – a pitch in locking kinematic transfer, for example, rack gear

The following are the computed main characteristics of structural schematic of manipulator drives which have been under research for chosen slave motor types СЛ-569К, СЛ-661(Russia):

k_r=1[v/rad], $k_\varphi(r)$=ar+b,

where

a=0,205[v/m*rad], b=0,44[v/rad], $k_{pa}{}^{r}=k_{pa}{}^{\varphi}=10$, $k_{dv}{}^{r}$=2,29[rad/v*c], $k_{dv}{}^{\varphi}$=1,09[rad/v*c],

z_φ=240, z_r=60, $t_p/(2\pi)$=0,1[м], $T_м$=0,03[c], α=0,0412[c/м^2], β=-0,0412[c/м^2], γ=0,0311[c].

Looking at the modeling schematic in Simulink according to structural schematic of servo drive system of observable manipulator that is shown in Figure 2, where a model of servo drive system of manipulator with parametric controller was examined in comparison with traditional system of coordinate controller (CC) for manipulator (Figure 1) with mutual influence of movability degrees. Structural schematic made in MATLAB medium (Simulink) represented in Figure 3.

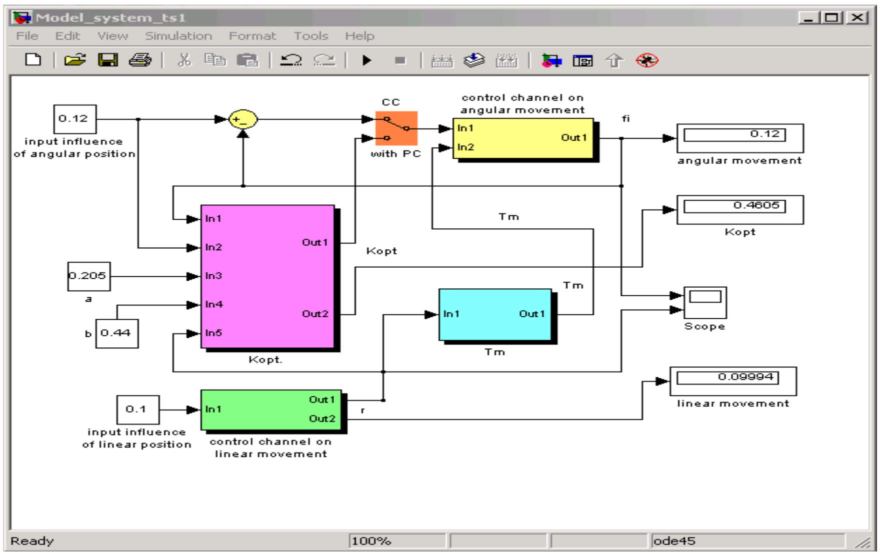


Figure 3 – Simulation model of servo drive system of observable manipulator

Complex functional dependencies were combined into separate subsystems to increase the model illustrativeness: subsystem of control channel on angular movement of manipulator (Figure 4); subsystem of control channel on linear movement of manipulator (Figure 5); subsystem, characterizing dynamic influence of servo drive of linear movement on servo drive of manipulator angular movement (Figure 6); parametric controlling subsystem of amplification factor value of servo drive's main feedback of mani-pulator's angular movement (Figure 7).

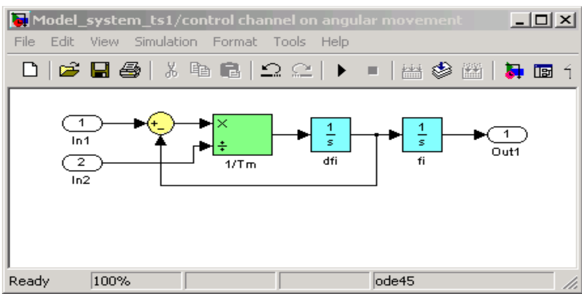


Figure 4 – Subsystem of control channel on angular movement of manipulator of servo drive system

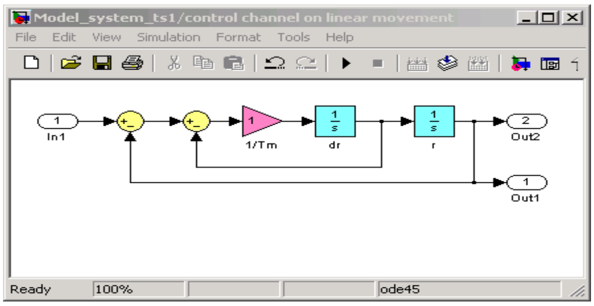


Figure 5 – Subsystem of control channel on linear movement of manipulator of servo drive system

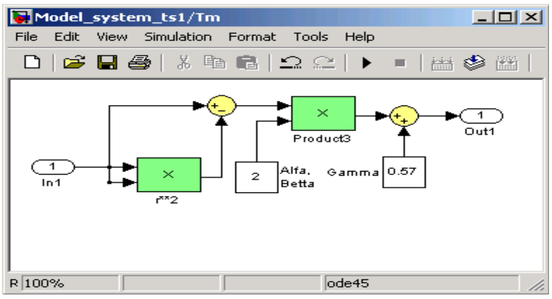


Figure 6 – Subsystem, characterizing dynamic influence of servo drive of linear movement

on servo drive of manipulator's angular movement

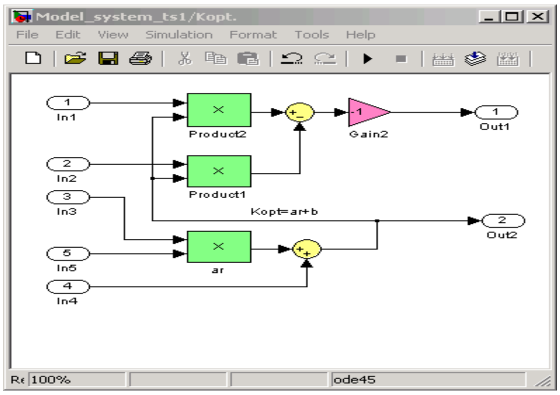


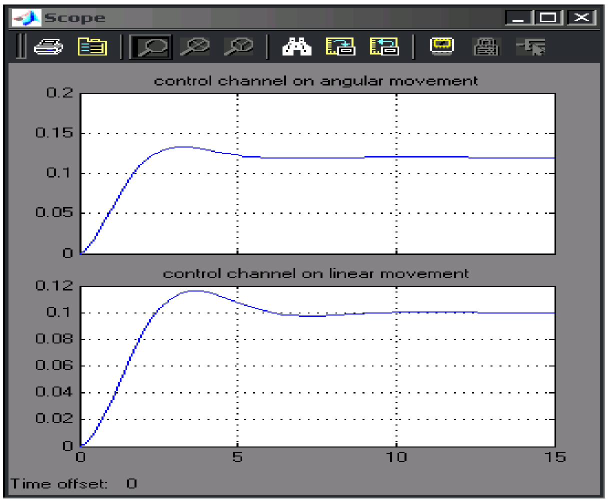
Figure 7 – Subsystem of parametric controlling of amplification factor value of servo drive's main feedback

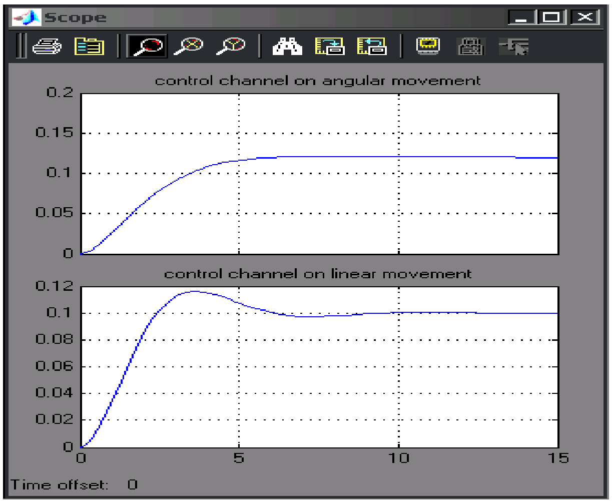
of manipulator's angular movement

The research showed a comparison between model of servo drive system of manipulator with para-metric controller (Figure 3, the provision of coordinate parametric control) and the model of traditional system of coordinate control for manipulator (Figure 3, the provision of coordinate control) with mutual influence movability degrees. There are 2 signals in output of controlling system: transient process of angular movement $\varphi(t)$; transient process of linear movement $r(t)$.

The virtual scope was used for representation of output signal graphs. Oscillograms of transient pro-cesses are received during the development of servo drives' systems with and without parametric regulator in the valley of characteristic points of manipulator's working plane, corresponding to the maximum, average and minimum arm r extensions. The criteria for assessing the impact of parametric regulator on the dynamic properties of the system adopted value of recontrolling and transient process time t_{tp}.

Oscillograms of transient processes for cases with parametric controller and coordinate control are shown as an example in Figure 8. During the movements of manipulator in the valley of characteristic points (Figure 1) corresponding to the maximum and minimum arm extensions r_{max} and r_{min} , where the moment of drive inertia load of manipulator angular position has maximum value $I_{нmax}(r_{max}, r_{min})$ processes recontrolling values in drive's angular movement without parametric regulator are the largest: the average value σ_{avg}=30% . And during manipulator gripper movement in the valley of characteristic point, corresponding to the average arm extension r_{avg}, and minimum value of moment of drive's inertia load in manipulator's angular position $I_{нmin}(r_{avg})$, recontrolling value and transient processes time in angular movement drive without parametric controller – $\sigma=12\%$, when in the system with parametric controller it is - $\sigma=0$, and transient process time has equal values for both cases-due to permanent characteristics of transient processes in servo drive of linear arm movement.





a) *b)*

Figure 8 – Oscillograms of transient processes: *a*) – for case with coordinate control; *b*) – for case with parametric control

Thus, the use of linear parametric controller to maintain the optimal values of amplification factor in a system according to manipulator configurations provides improvement of dynamic processes in servo drive with variable inertia load, and therefore qualitative indicators of manipulation process. Such approach in construction of manipulated robots' servo drive system can be applied to most types of serial produced industrial robots.

REFERENCES

1 Slutsky L.I., Safoncev E.A., Vityukova G.A. Methodology of dynamic synthesis of remote manipulator based on experimental study of control process. Analysis and synthesis of the mechanisms. Collection of scientific works. Alma-Ata. Kazakh State University, pp. 31-37, (1983).

2 Tuleshov A.K., Ozhikenov K.A. Stabilization of dynamical peculiarities in tracking drive system // Materials of Inter-national scientific-technical conference on «Automatic control and automation of industrial processes». BSTU, 2012. P. 372-373.

Резюме

Қ. Ә. Өжікенов

(Қ. И. Сәтбаев атындағы Қазақ ұлттық техникалық университеті, Алматы, Қазақстан Республикасы)

МАНИПУЛЯТОРДЫҢ ЖЕТЕК ЖҮЙЕСІНДЕГІ БАСҚАРУ ДИНАМИКАСЫН ТҰРАҚТАНДЫРУ

Жұмыс қадағалайтын жетек жүйесіне манипулятор қолының инерция моменті мен қадағалайтын жетек-тің кері байланыс тізбегінің күшейткіш коэффициентінің арасын байланыстыратын параметрлік реттегішті енгізу жолдарын зерттеуге арналады. Қадағалайтын жетек жүйесіндегі динамикалық үрдістердің ағымын өтпелі үрдістерді салу негізінде сандық бағалау жүргізіледі. Манипулятордың қадағалайтын жетек жүйесінің динамикасын MATLAB (Simulink) ортасында модельдеудің қорытындыларынан әдеттегі қолданыстағы координатты реттелетін жүйемен салыстырғанда өтпелі үрдістердің ағым сипатының жақсарғаны және олардың берілген көрсеткіштерінің қамтамасыздандырылатындығы көрінеді.

Тірек сөздер: қадағалаушы жетек, еселеу коэффициенті, параметрлік реттеу, координаталық реттеу.

Резюме

К. А. Ожикенов

(Казахский национальный технический университет им. К. И. Сатпаева, Алматы, Республика Казахстан)

СТАБИЛИЗАЦИЯ ДИНАМИКИ УПРАВЛЕНИЯ В СИСТЕМЕ ПРИВОДОВ МАНИПУЛЯТОРА

В работе произведено исследование на эффективность применения параметрического регулятора в систе-ме следящих приводов манипулятора. Осуществлено параметрическое регулирование путем непосредствен-ного изменения коэффициента передачи регулятора следящего привода, что вызывает упрощение системы с параметрическим регулятором и ее технической реализации. Проведено моделирование данной системы в среде MATLAB (Simulink). Произведена сравнительная оценка результатов моделирования систем следящих приводов с ПР и с традиционно используемой методикой координатного регулирования. Показано, что сис-тема следящих приводов с ПР обеспечивает желаемые динамические характеристики манипулятора.

Ключевые слова: следящий привод, коэффициент усиления, параметрическое регулирование, коорди-натное регулирование.

Поступила 04.06.2013 г.