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Stabilization of Motion Trajectories of Servo Drive on Varying Parameters of Control Object Conditions

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Introduction

Stability of characteristics of servo drive performing programmed motions in defined working space can be considered as one of most important indices of its performance. In the case when parameters of moved object such as mass or inertia moment are changing, conventional solutions based on multiloop hierarchical structure application can not ensure of sufficient stability and repeatability of motion trajectories Because the sources influencing trajectories deflection or provoking appearance of static error of positioning of servo drive are located in the speed regulation subsystem, necessary actions preventing these shortcomings should be undertaken by selecting structure and parameters of the speed regulation subsystem.

When mentioned above parameters of control object vary relatively slowly, application of adaptive control method based on object parameters (mass or inertia moment) observation and online speed controller parameters updating allow ensuring good stabilization of motion trajectories [1]. In the case of servo drives of handlers or manipulators these parameters may change with each positioning task performance and vary in time with transported object position change, the fast adaptation algorithms should be implemented in the speed regulation subsystem of the drive. The model reference signal adaptive control (MRSAC) method, based on desirable dynamical behavior of speed control subsystem prediction [2] could be applied for this purpose.

The problem arises when, due to speed controller saturation, structure and mathematical model of the speed control subsystems changes. Application of multiple model adaptive control approach [3] in this case does not provide positive effect, because the correcting action of signal adaptive contour becomes blocked. The goal of the paper is to propose and examine an approach based on MRSAC method available for servo drive dynamical features stabilization on nonlinear structure and varying parameters of control object conditions.

Discussion of structure of servo drive with signal adaptive speed control subsystem

Functional diagram of servo drive designed under multiloop hierarchical structure is presented in Fig 1. The speed regulation module of the drive may be considered as control object of the position control contour. In turn, speed regulation module consists of internal torque control subsystem *TC*, adjusted under the quantitative optimum

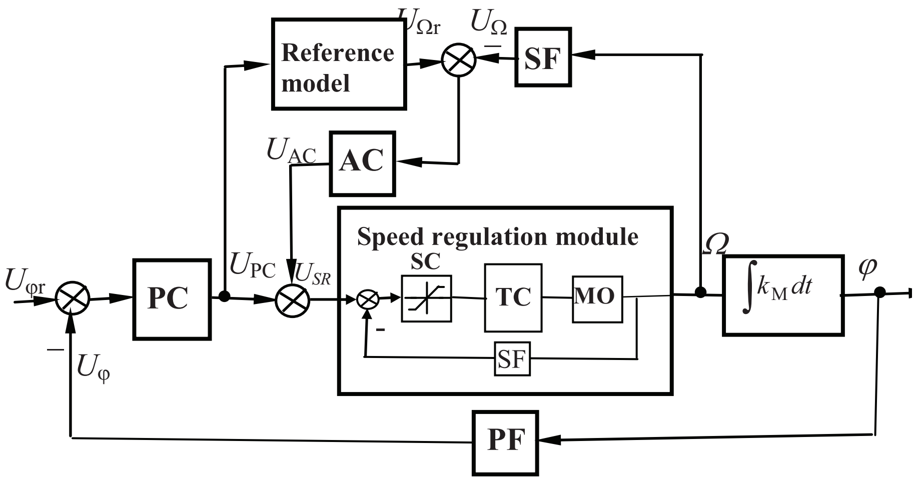

Fig. 1. Functional diagram of multiloop servo drive with MRSAC

conditions, mechanical object MO to be moved, distinguishing by its varying inertia moment J_{var},, and speed controller SC with saturating

Supposing the torque regulation contour *TC* of the drive being adjusted under the quantitative optimum, dynamics of the speed regulation subsystem may be described by following equations:

$$\Omega_m(p) = \frac{1}{pJ_{\boldsymbol{var}}} M_m(p), \tag{1}$$

$$M_m(p) \cong \frac{b_0}{p + a_1} U_{sc}(p) \tag{2}$$

and

$$U_{\boldsymbol{SC}} p(t) = k_{sc}\left(U_{\boldsymbol{SR}}(p) - k_{\boldsymbol{\Omega}} \Omega_m(p)\right), \tag{3}$$

in non-saturated speed controller case, and with

$$u_{\boldsymbol{SC}}(p) = U_{\boldsymbol{SC}\,max} \tag{4}$$

in saturated speed controller case. There – $M_{\text{m}}(p)$ denotes a motor torque; $\Omega_{\text{m}}(p)$ – a motor speed; $U_{\text{SC}}(p)$ – output signal of speed controller; $U_{\text{SR}}(p)$ – input signal of speed regulation module; $U_{\text{SC}\,max}$ - maximum value of output signal of speed controller, $a_1 = 1/2T_{\text{pc}}$; $b_0 = C_{\text{m}}/2T_{\text{pc}} \cdot k_{\text{I}}$; T_{pc} – time constant used power converter; C_{m} – torque constant of the motor; k_{I} – transfer coefficient of the current feedback, k_{Ω} - transfer coefficient of the speed feedback module *SF*.

The main position control contour of servo drive is realised by using position feedback *PF* and position controller *PC* ensuring desired accuracy of positioning and required stability of the whole servo drive. Additional speed correction contour, consisting of reference model, predicting estimated behaviour of speed regulation module, comparator and additional controller AC, serves for compensation of control object mass variation influence on dynamical characteristics of the drive. On this purpose the reference model should correspond as well as possible to estimated model of speed regulation module.

Adjusting and investigation of signal adaptive speed regulation subsystem of the servo drive

Supposing the inertia moment of mechanical part of speed regulation module varying in the range $J_{min} \le J_{var} \le J_{max}$, the certain value J_{var0} on this range is to be selected for speed controller *SC* gain value corresponding to quantitative optimum condition definition

$$k_{\text{SC}0} = \frac{k_{\text{I}}}{4T_{\text{pc}}} \frac{C_{\text{m}}}{J_{var0}}. \tag{5}$$

Transfer function of the speed regulation module in selected operation point gets the form, ensuring optimum response of the output variable $\Omega(p)$ on the applied step mode reference signal $U_{\text{SR}}(p)$

$$H_{\text{SM}}(p) = \frac{\Omega(p)}{U_{\text{SR}}(p)} = \frac{1}{8T_{\text{pc}}^2 p^2 + 4T_{\text{pc}} p + 1}. \tag{6}$$

When inertia moment of transported object deflects from selected value J_{var0}, the dynamical features of the speed control subsystem, defined by its free running frequency $f_{fr} = f_{f0}/\sqrt{\gamma}$ and $\xi_{fr} = \xi_{f0}\sqrt{\gamma}$ changes from its optimum values f_{f0} and ξ_{f0} (there $\gamma = J_{var}/J_{var0}$ - ratio of existing and selected inertia moment values). In order to stabilize dynamical features of the speed module the reference model designed according to (6) is used and additional MRSAC contour, compensating inertia moment value variation by forcing or suppressing processes of the speed regulation subsystem, is formed.

Forcing signal of MRSAC contour being coincident by its sign with position controller output signal U_{PC} may cause saturation of the speed controller *SC*, leading to compensating function of signal adaptive contour blockage. So, in order to avoid such undesirable situation, it is recommended to adjust speed controller for maximum possible inertia moment value. This presumption is confirmed by modeling results presented in Fig. 2.

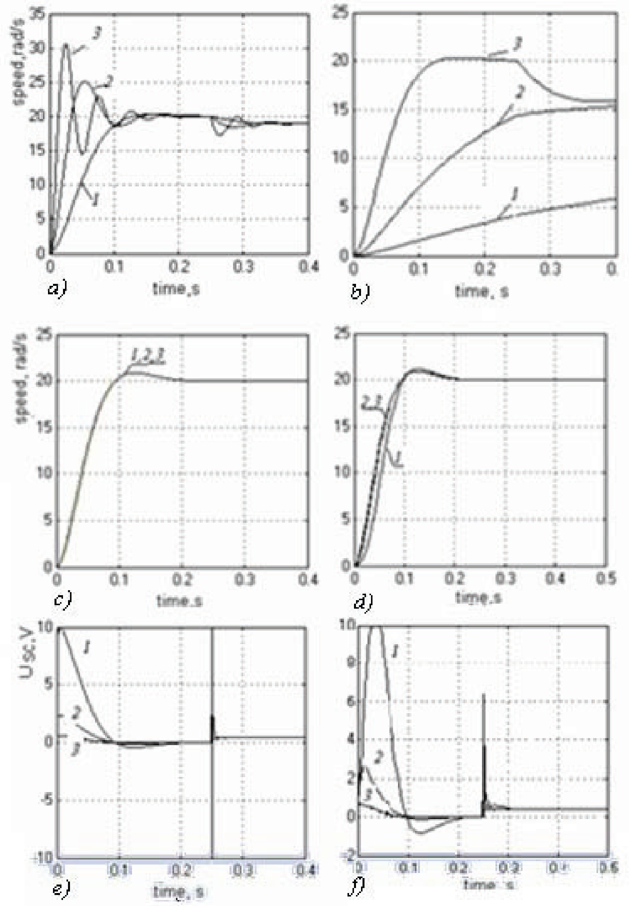

Fig. 2. Modeling results of signal adaptive speed regulation module

Modeling has been carried out using adaptation controller AC, designed under the Liapunow stability condition, realizing following control law

$$U_{AC}(p) = (0.2p + 90)(U_{\Omega r}(p) - U_{\Omega}(p)), \qquad (7)$$

where $U_{\Omega r}(p)$ and $U_{\Omega}(P)$ – model reference signal and measured output signal of speed regulation module correspondingly.. . Output signal of controller was limited on the level of ±10V. System has been modeled by using software MATLAB *Simulink.* The responses of the main speed regulation contour preliminarily adjusted for the maximum inertia moment value $J_{max} = 0.2kgm$, without use of compensating MRSAC contour; are presented in Fig.2a. The curve denoted by number 1 corresponds to response of well adjusted system with $J_{max} = 0.2kgm$, the curve 2 – to the case with medium inertia moment value - $J\,var = 0.05kgm^2$, and the curve 3 – to the case with minimal inertia moment value - $J_{min} = 0.0125kgm^2$. The response curves of the speed regulation contour being adjusted for the minimal inertia moment value $J_{min} = 0.0125kgm^2$ are presented in Fig 2b. Curves denoted by the same numbers 1, 2, 3 correspond to the same inertia moment values as for the above case. Influence of static load, applied to the conventional speed regulation system with proportional speed controller at the time $t = 0{,}25s$ is also shown.

Responses presented in Fig 2c and 2d demonstrate efficiency of MRSAC applied to the speed control subsystem. Curves presented in Fig 2c correspond to the case when speed controller *SC* was preliminarily adjusted under the largest inertia moment value. The responses of the system with MRSAC preliminarily adjusted under the minimal inertia moment value are presented in Fig 2d. In this case, due to saturation of speed controller, MRSAC becomes unable to compensate deflecting action of inertia moment change in the all variation range. Not coinciding response curve 1 corresponds to the case with maximum inertia moment value $J_{max} = 0.2kgm^2$.

The output signal curves of speed controller SC are presented in figures 2e and 2f. It is seen that in the first case (Fig 2e) speed controller signal do not reaches saturation level and MRSAC contour remain active in all the range of inertia moment change. In the case when speed controller has been preliminarily adjusted for the minimum inertia value, forcing signal of MRSAC saturates speed controller and blocks action of adaptation contour.

It is important to point the ability of MRSAC to compensate an influence of external load applied on the system. The response curves presented in the Fig. 2c and 2d demonstrate this property. Static error provoked by load applied at the time $t = 0.25s$ is well compensated by MRSAC contour and there is no necessity to use conventional solution with PI *s*peed controller, leading in the same time to disapproving of dynamical features of speed regulation subsystem and the whole servo drive.

Adjusting and investigation of position control subsystem of the servo drive

When speed control subsystem with MRSAC is functioning properly, dynamical model of the speed regulation subsystem may be considered coinciding with reference model (6). Then gain of position controller *PC is* defined in accordance with quantitative optimum condition

$$k_{PC} = (k_M k_{PF})^{-1} \ . \qquad (7)$$

Modeling results of servo drive with such position controller are presented in Fig. 3.

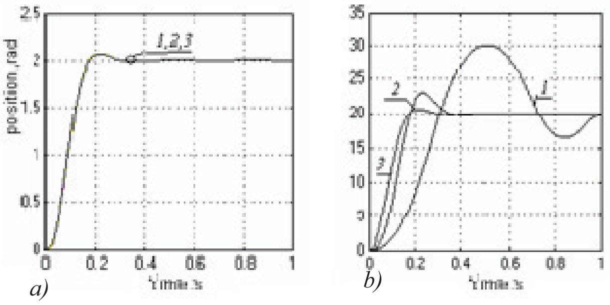

Fig. 3. Response curves of servo drive with proportional position controller

The responses of servo drive to the step mode small size reference signal do not causing speed controller saturation are presented in Fig 3a. In this case influence of inertia moment variation is fully compensated by MRSAC contour of speed control subsystem. However, with increase of position reference signal magnitude, due to saturation of speed controller, compensating action of MRSAC becomes interrupted. The responses of servo drive to ten times larger step mode reference signal are presented in Fig 3b. Number 1 denotes the response, when inertia moment has its maximum value - $J_{max} = 0.2kgm^2$ .The responses 2 and 3 correspond to the inertia moment values equal to 0.05 and 0.0125 kgm^2.

On purpose to prevent the possible saturation of speed controller it is necessary to modify the structure of position controller by means limiting derivative of output signal of position controller according to condition

$$\frac{dU_{PC}}{dt} \le \frac{u_{SC\,max} \cdot C_m}{k_I \cdot J_{max}} , \qquad (7)$$

where J_{max} – maximum probable value of transported object inertia moment. Functional diagram of modified position controller of the servo drive is presented in Fig 4.

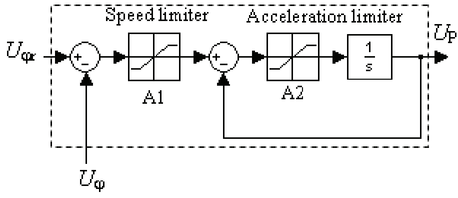

Fig. 4. Functional diagram of modified position controller

Modified position controller of servo drive consists of the proportional position controller $A1$ with k_1=1.1, speed limiter with maximum output signal level equal to ± 3V, and of acceleration limiter ensuring acceleration limitation on the level 1000 rad/s. Modeling results are presented in Fig 5 .

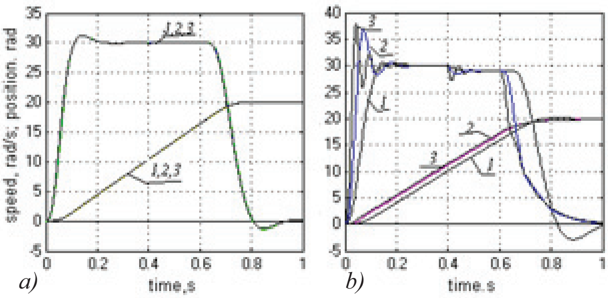

Fig. 5. Transient regime curve of servo drive

The speed and position response curves of the servo drive under different inertia moment values - $J_{var1} = 0.2kgm^2$, $J_{var2} = 0.05kgm^2$ and $J_{var3} = 0.0125kgm^2$ are presented in Fig 5a. Efficiency of proposed approach is well proved by coincidence of obtained trajectories of servo drive. The response curves of the same drive obtained without MRSAC contour use are presented in Fig. 5b. Variation of inertia moment makes the speed and position response curves visibly different. Influence of external load applied to the drive at the time $t = 0.4s$ is also clearly seen in presented speed response curves.

Conclusions

1. An availability of MRSAC method to stabilize the programmed trajectories of servo drive on varying parameters of controlled object (moving object mass or inertia moment) conditions is investigated in this paper.
2. Saturation of speed controller of servo drive limits the range of possible change of parameters. Due to enlarge this range it is recommended to adjust the speed controller for the one of marginal values of the parameter requiring maximum gain of the controller
3. It is demonstrated that application of MRSAC contour in the speed control subsystem together with limitation of derivative of output signal of position controller allows stabilizing of programmed trajectories of servo drive on the large range of parameter variation conditions.

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Practical approach designated for programmed trajectories of servo drive operating on varying parameters of transported object conditions stabilization is proposed and investigated in the paper. It is proposed in combination with MRSAC method, introduced in to speed control subsystem, to use means limiting derivative of position controller output signal. It is shown that in order to enlarge the permissible range of inertia moment variation the speed controller of speed regulation module should be adjusted under the maximum supposed inertia moment value The modelling results of the system are given. Ill. 5, bibl. 3 (in English; abstracts in English and Lithuanian).

V. A. Geleževičius. Vykdymo sistemos trajektorijų stabilizavimas kintant valdymo objekto parametrams // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 3(109). – P. 81–84.

Straipsnyje pateiktas ir išnagrinėtas metodas, įgalinantis stabilizuoti elekromechaninės vykdymo sistemos trajektorijas, kintant transportuojamo objekto parametrams. Pasiūlyta šio tikslo siekti kombinuotai, taikant signalinės adaptacijos metodą greičio reguliavimo posistemėje ir ribojant padėties reguliatoriaus išėjimo signalo išvestinę. Parodyta, kad, norint išplėsti leistiną inercijos momento kitimo diapazoną, greičio reguliavimo posistemės greičio reguliatorių reikia derinti esant didžiausiai prognozuojamai inercijos momento vertei. Pateikti sistemos modeliavimo rezultatai. Il. 5, bibl. 3 (anglų kalba; santraukos anglų ir lietuvių k.).