Gradient identification method of the model parameters for electrohydraulic servo drive of FESTO learning system

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Abstract. Gradient identification method of the model parameters for electrohydraulic servo drive is considered. The method is adapted to be implemented by an experimental complex consists from FESTO hydraulic learning system and Matlab/Simulink. The implementation of the considered identification algorithm in the Matlab/Simulink package is shown.

Introduction

While the electrohydraulic servo drive (EHSD) is working, its parameters may vary. It can be caused by changing mass of the load, oil bulk modulus [1], friction model parameters [2], electrohydraulic amplifier characteristics. One way to obtain the EHSD required control quality is increasing robustness property of controlled hydraulic drive with controller to be synthesized, another way — using adaptive controller, i.e. controller that changes its parameters for adaptation to changing actuator parameters. The works [3–4] were dedicated to a question of using FESTO hydraulic learning system for research static and dynamic EHSD characteristics on the base its physical model. The questions of controller synthesis with required quality criterion was considered in [5–11]. The required control quality can be provided due to the high robustness of the synthesized controller. However, when a real drive is operating, its parameters can change significantly, and in this case, it becomes advisable to identify the changing parameters and adjust the controller parameters directly during the drive operation, i.e. use an adaptive controller. Adaptive control issues, including EHSD, are discussed in [5,6,12–18]. The paper [5] describes a method of synchronous detection that allows identifying parameters by applying a high-frequency search signal to an object under study and determining the sign of change in the configurable parameter by comparing the phase of the search signal and the same-frequency component of the quality criterion signal. The work [13] describes the use of the above method with the disclosure of the analytical dependence that determines the gradient of change in the required quality criterion. The quality criterion used was a mismatch between the states of the model of object and the object whose parameters were identified. In this paper, we consider the application of a gradient identification algorithm to the EHSD using work [13], with the prospective goal of using it as part of indirect adaptive control. Just as in [3,4], the EHSD based on FESTO research system is considered.
Thanks to FESTO electronic status controller unit, it is possible to measure the state vector of the object under study in this work, and it is possible to avoid the need for a full-fledged simulation of the control object with a state vector independent of the object.

**Mathematical formulation of the EHSD as a control object**

Figure 1 shows open loop mathematical model block-diagram of the EHSD that is assembled on FESTO hydraulic research system. The mathematical model have been used to determine the state components feedback coefficients [3].

\[ K_{\text{amp}} \quad W_{\text{HSV}} (s) \quad \frac{1}{T_{\text{HDS}}} \quad \frac{1}{T_{\text{c}}^2 s^2 + 2 \zeta c T_{\text{c}} s + 1} \quad Y_{\text{rod}} \]

\[ K_{\text{pt}} \]

**Fig. 1.** The EHSD open loop mathematical model block-diagram.

- \( K_{\text{amp}} \) — electronic amplifier gain;
- \( W_{\text{HSV}} (s) \) — hydraulic servo valve transfer function;
- \( \zeta_{\text{c}} \) — the hydraulic cylinder damping coefficient;
- \( T_{\text{HDS}} \) — the hydraulic drive time constant;
- \( T_{\text{c}} \) — the time constant of the loaded hydraulic cylinder;
- \( K_{\text{pt}} \) — the potentiometric feedback sensor gain.

The loaded cylinder parameters are defined by the expressions [8]:

\[
T_{\text{c}} = \sqrt{\frac{mV}{2BF_c^2}}; \quad \zeta_{\text{c}} = \frac{T_{dc}}{2T_{\text{c}}}; \quad T_{dc} = \frac{K_{\rho}V}{2B \cdot F_c^2} + \frac{K_{\text{op}}m}{F_c^2}. \tag{1}
\]

To conduct research on the use of a gradient algorithm for identifying parameters of the EHSD mathematical model, we present the mathematical model of the hydraulic drive with state components feedback to the form Fig. 2.

\[ \dot{X} = AX + Bu, \tag{2} \]

**Fig. 2.** The EHSD mathematical model block-diagram.

State space representation of the second order object — object under study (Fig.1) has the form
where

\[
A = \begin{pmatrix}
0 & 1 \\
\frac{1}{T_c^2} & \frac{2\xi}{T_c}
\end{pmatrix},
B = \begin{pmatrix}
0 \\
\frac{K_p}{T_c^2}
\end{pmatrix}
\] (3)

**Gradient descent algorithm for the EHSD parameters identification**

The essence of this method is to configure the desired parameters of the model in the process of system operation, by changing them in the negative direction of gradient of an objective function.

\[\hat{\Theta} = -\Gamma \cdot \nabla_{\Theta_m} q(E)\] (4)

Here:

- \(\Theta_m\) — the defined parameters vector of the object mathematical model;
- \(\Gamma\) — matrix of weight coefficients \(\Gamma = \Gamma^T > 0\);
- \(q(E) = E^T E\) (5)
- \(\Delta E = X_o - X_m\) (6)

- the discrepancy between the state vector of the object under study and the vector \(X_m\) of the mathematical model;
- \(X_o\) — the state vector of the object under study;
- \(X_m\) — the one-step forecast vector of the object under study state based on its mathematical model.

We assume that the difference in the structure of the control object and its model, together with the initial mismatch of the desired parameters and their evaluation, leads to a single extremum of the objective function in the identification process [13].

For numerical calculation of the objective function gradient, we will use high-frequency changes in the configurable parameters with a small amplitude (search signals), which are superimposed on the "slowly" changing (adjusting) parameters of the mathematical model.

In this paper, we consider the application of an identification algorithm to determine the parameter \(c\) of the linearized mathematical model of the hydraulic cylinder, since it changes most strongly when the load mass and volume of the hydraulic cylinder cavities change (1).

To define the objective function changes, the following expressions were entered:

\[
X_{m1} = X_{o,i-1} + F_m(X_{o,i-1}, y_{i-1}, \Theta_{m,i-1}) \cdot dt;
\] (7)

where:

- \(F_m(\ldots)\) — function of the mathematical model right parts;
- \(y\) — the signal according to Fig. 2;
- \(\Theta_m\) and \(\delta\Theta_m\) — the definable parameter and its small change.

The determination of the state vector components of the model and the object under study using the formulas (7) are shown in Fig. 3.
Fig. 3. Illustration of the components definition $X_{oi}, X_{oi-1}, X_{mi1}, X_{mi2}$.

Notation in Fig.3:

- $X_{oi}, X_{oi-1}$ — the current and previous state of the object, respectively;
- $X_{mi1}$ — the current state of the model as a forecast relative to the previous state of the object $X_{oi-1}$ by a known function of the right parts of the model with the previous value of the parameter being determined $\Theta_{mi-1}$;
- $X_{mi2}$ — differs from $X_{mi1}$ in that $\Theta_{mi-1} + \delta\Theta_{mi-1}$ is taken in place of $\Theta_{mi-1}$.

For a linear mathematical model written in the state space, equations (7) take the form:

\[
X_{mi1} = X_{oi-1} + \left[ A_m \left( \Theta_{mi-1} \right) X_{oi-1} + B_m \left( \Theta_{mi-1} \right) y_{i-1} \right] \cdot dt \quad (8)
\]

\[
X_{mi2} = X_{oi-1} + \left[ A_m \left( \Theta_{mi-1} + \delta\Theta_{mi-1} \right) X_{oi-1} + B_m \left( \Theta_{mi-1} + \delta\Theta_{mi-1} \right) y_{i-1} \right] \cdot dt
\]

The discrepancies between the object state vector under study and the state vectors of its mathematical model obtained in accordance with (7) are defined as:

\[
E_2 = X_{oi} - X_{mi2}, \quad E_1 = X_{oi} - X_{mi1}. \quad (9)
\]

The gradient of the objective function will be determined in accordance with the expression:

\[
\frac{\partial q(E)}{\partial \Theta_m} = \frac{E_2^T E_2 - E_1^T E_1}{\delta \Theta_m} \quad (10)
\]

Thus, substituting expressions (8)–(10) in (4), you can get the equation of the defined parameter change:

\[
\Theta_{mi} = f \left( X_{oi}, X_{oi-1}, y_{i-1}, \Theta_{mi}, \delta\Theta_{mi} \right) \quad (11)
\]
Investigation of the identification algorithm for the EHSD mathematical model

To study the gradient algorithm for identifying EHSD parameters described above, a program was developed in Matlab/Simulink, the block diagram of which is shown in Fig. 4.

![Block Diagram](image)

**Fig. 4.** The block diagram that shows the identification algorithm adapted to Matlab/Simulink.

Some numerical simulation results of the block-diagrams in Figure 4 are shown in Figure 5. The drive follows-up some harmonic input. During the simulation, a stepwise change in the time constant $T_c$ is modeled (it can be implemented on FESTO hydraulic learning system by changing load mass and additional volumes connected to the cavities of the hydraulic cylinders). Figure 5 shows the parameter adjustment of the mathematical model during the EHSD simulates.

![Graph](image)

**Fig. 5.** Adjustment of the mathematical model parameter $T_c$ for its various step changes.
Conclusions
In this paper, a modification of the gradient search method for the parameter of the control object under study based on [13] in relation to the EHSD of FESTO research system [3] is performed. The modified method is applied to the linearized mathematical model EHSD, but it is not limited in principle to the linearity of the mathematical model. The study shows good convergence of the method based on the results of numerical modeling in the Matlab/Simulink environment. It is shown that the considered method is suited for implementation on FESTO hydraulic research system, which is provided by the presence of an element base that allows experimentally determining the control object state components: valve position measurement, rod position and its velocity and acceleration determination. The considered algorithm expands the possibilities of using the Festo experimental complex for educational and research purposes.

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