Identifying dynamic model parameters of a servo drive

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Abstract: - An off-line identification method based on the least-squares approximation technique is applied for identifying of electromechanical parameters of a servo drive model. The proposed identification method solves a problem of experimental data automatic obtaining with angular velocity limitation and angle limitation. The developed algorithm can be automatically adjusted during its work to achieve high accuracy of the estimated parameters. The paper provides an example of algorithm work with a servo drive of a tracking telescope. The developed algorithm is of interest for developers of electromechanical systems with limitation of motion.

Key-Words: - Identification; Servo Drive; Automatization; Tracking Telescope; Least-Squares Approximation; Motion Limitation.

1 Introduction

Problem of identification occurs frequently in engineering practice [1-6]. Sometimes identifiable system is quite complex and the design of some of its parameters (viscous friction, moment of inertia, cogging torque) are not calculated. Periodically the parameters of the finished product do not match design parameters, and it is needed to quickly determine their values and to realize reconfiguration of control system regulators. Occasionally task is to control a system that was created by another team of developers with whom contact is lost along with documentation on the system. In all these cases it is necessary to determine the values of the system parameters on the results of the experiments as accurately as possible, i.e., perform identification.

Commissioning of precision servo drives for optomechanical systems particularly for positioning and tracking systems, usually takes a relatively long time and requires special teams of qualified commissioning personnel [7-8]. Often the problem of parameter identification for these servo drives is complicated by velocity limitation, angle limitation and acceleration limitation. Experimental data are obtained by iteration with a gradual increase in the input signal due to the lack of information about the

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This work was financially supported by Government of Russian Federation, Grant 074-U01.

parameters of the servo drive. As a result this process takes an essential quantity of qualified personnel working hours, which could be spent on the solution of more difficult and more important tasks.

There are a large number of methods aimed at solving various problems of identification, including methods targeted to identification of electromechanical systems [1-6, 9-11]. The simultaneous estimation of drive parameters and states are presented in [12-14]. The use of linear techniques based on the dynamic model is proposed in [15].

Generally, parameter identification methods can be classified into five different categories, depending on what data is available, and what the data is used for:

- Parameter calculation from motor construction data. This method requires a detailed knowledge of the machine's construction, such as geometry and material parameters. It is the most accurate procedure, since it is closely related to the physical reality and the most costly one since it is based on field calculation methods, such as the finite element method [16-18].
- Parameter estimation based on steady-state motor models. The methods use iterative solutions based on motor steady-state network equations [19-20]. This is the most common type of parameter estimation for system studies since the data needed for it is usually available.
- Frequency-domain parameter estimation. The stand-still frequency response method is based on measurements that are performed at standstill. The motor parameters are estimated from the resulting transfer function. In fact, stand-still tests are not common industry practice. Control signal computation in the absence of a priori knowledge of the frequencies of mechanical resonances can lead to equipment damage during the experiment.
- Time-domain parameter estimation. The time-domain motor measurements are performed and model parameters are adjusted to match the measurements. Since not all parameters can be observed using measurable quantities, the motor models need to be simplified [21]. The method is costly, and the required data is usually not available.
- Real-time parameter estimation. This type of parameter estimation is used to tune the controllers of electric drive systems. This requires real-time parameter estimation techniques, using simplified drive models [22-23]. Such systems are not used in high-precision electric drives, as do not allow to achieve high accuracy of electric drive control.

The use of artificial neural networks [24-26] or neuro-fuzzy controllers to drive parameter identification [27] can lead to equipment damage during the experiment as frequency-domain parameter estimation. Generally a whole lot of attention is paid to the identification algorithms in these papers, but it is not mentioned how the input signal must be selected for an experiment. Most often, the parameters are identified by step response, but no information is given how the algorithm chooses step amplitude [2, 6, 25, 26]. Obviously the high step amplitude not only provides a high accuracy of parameter estimation in the presence of external disturbances but also increases the probability of equipment damage.

This paper examines the problem of automating the process of identifying servo drive parameters with drive motion limitation. The developed algorithm not only ensures high accuracy of parameter estimation, but also prevents damage to equipment. The paper presents how the estimation accuracy depends on the parameters of the experiment and how the algorithm uses this data to produce high accuracy of identification limiting the motion of servo drive to prevent equipment damage.

2 Problem Formulation

Limitation of servo drive movement is often caused by design of entire object, which motion it provides. For example, large values of acceleration in the optomechanical systems may lead to a shift of optical elements, or even to its destruction. The presence of power and data cables connecting the equipment on the movable part of the system with the equipment on the stationary part requires angle limitation. Precision optical encoders, such as incremental encoders from Renishaw, can work in a limited range of angular velocities. Motors for servo drive are calculated with margin, so often they are able to operate at angular velocity and acceleration over the limit values.

Overspeed protection and protection from exceeding acceleration, as well as protection against servo drive rotation outside permissible angular range is provided. However, the system is stopped and does not allow to obtain necessary amount of data for parameter identification when the protection is activated. Thus, it is necessary to develop a simple control system which is not configured on the basis of the known parameters of servo drive, and based on requirements for limitation of movement.

We will consider object model type [28-30]

$$\begin{cases} i = \frac{1}{T_T s+1} u \\ \omega = \frac{K}{s}(i+f) \\ \alpha = \frac{1}{s}\omega \end{cases} \qquad (1)$$

where $\alpha(t)$ is angle, $\omega(t)$ is angular velocity, $i(t)$ is current, T_T is time constant of current loop tuned to the linear optimum [31-32], $u(t)$ is input signal of the current loop, $s = \frac{d}{dt}$ is Laplace operator, K is unknown parameter equal to the ratio of electromechanical torque constant to the total moment of inertia. In this case the disturbance $f(t)$ can be interpreted as a resistance torque divided by a value of torque constant. So the identification of the parameter K becomes an important engineering problem, as often exact moment of inertia of complex multi-unit load is unknown [30]. Resistance torque has two components: active (from the cable resistance forces, telescope axis imbalance torque, etc.) and reactive (from the forces of Coulomb friction and viscous friction).

Mathematical model of friction is:

$$\tau_F = K_C sign(\omega) + K_V \omega \qquad (2)$$

where $\omega = \frac{dy}{dt}$ is angular velocity; K_C и K_V are coefficients of Coulomb friction and of viscous friction, respectively; and the function $sign(\omega)$ is determined as follows:

$$sign(\omega) = \begin{cases} 1, & if\ \omega > 0 \\ 0, & if\ \omega = 0 \\ -1, & if\ \omega < 0 \end{cases}$$

This model is simple and does not take into account features of friction at low values of angular velocity. But the use of such model greatly simplifies the identification. Then, we can carry out the identification of servo drive parameters with angular velocity values for which the model is correct. In this case the experimental data sample with angular velocity values of constant sign should be used to identify the static gain K of the control object. Design of algorithm that allows to maintain constant sign angular velocity values also facilitate solving of the problem of rotation limitation.

3 Problem Solution

3.1 Algorithm of angular velocity limitation and angle limitation

First we consider technique for obtaining the experimental data because not any technique can limit angular velocity, acceleration and rotation. As a solution a system with relay control with angular velocity loop and angle loop is provided (Fig. 1).

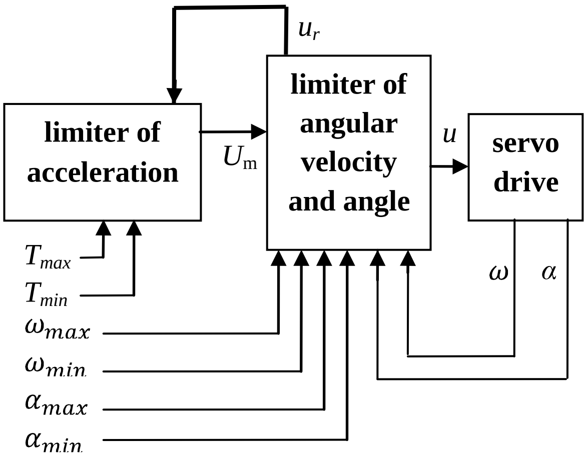

Fig 1: Functional diagram of the control system, which allows to obtain experimental data required for identification.

The limiter of angular velocity and angle (Fig. 2) performs the appropriate function of motion limitation by changing sign of the control signal U_m. The signal u_ω changes sign of control signal U_m at marginal velocity values (Fig. 3b). The signal u_α changes direction of motion by changing the sign of the velocity limits when electric drive rotates out of the angular limits (Fig. 3a). Obviously, the following conditions are necessary to control the direction of electric drive motion: $\omega_{max} > 0$ and $\omega_{min} > 0$.

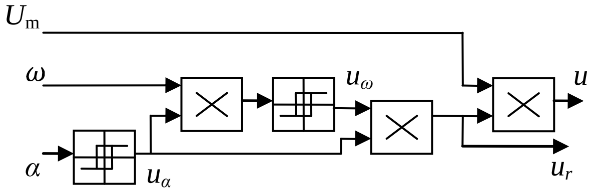

Fig. 2: Functional diagram of the limiter of angular velocity and angle.

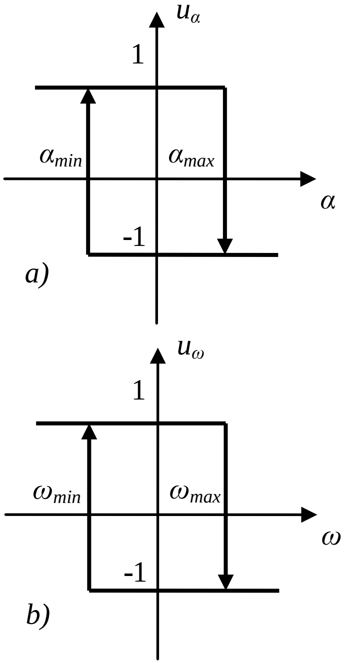

Fig. 3: Graphics of angle limiter relay switching (*a*) and angular velocity limiter relay switching (b).

The limiter of acceleration provides control signal U_m which has the form of a piecewise constant function. This block measures the time between relay switching (signal u_r). If the time exceeds the specified interval T_{max}, then the signal U_m is increased by a certain value ΔU. If the time is less than the specified interval T_{min}, the signal U_m is decreased by a certain value ΔU. Values T_{max} and T_{min} allow to keep the acceleration within the prescribed limits with fixed values ω_{max} and ω_{min}. The signal U_m increases linearly at start of algorithm operation as long as the electric drive does not start to move. This speeds up the experiment.

3.2 Estimation of the control object static gain.

So, all the experimental data consists of consecutive acceleration and deceleration of the electric drive caused by piecewise constant control signal $u(t)$. Acceleration and deceleration intervals with a period corresponding to values between T_{max} and T_{min} are selected as the samples used for estimation of the parameter *K*. The system (1) can be converted for these intervals as follows:

$$\begin{cases} i = u \\ \omega = \frac{K}{s}(i + f) \\ \alpha = \frac{1}{s}\omega \end{cases} \qquad (3)$$

where

$f = -f_a - f_c sign(\omega) - f_v \omega$,

f_a is disturbance caused by active resistance forces (cable resistance force, telescope axis imbalance torque, etc.);

f_c is disturbance corresponding to the Coulomb friction;

f_v is disturbance corresponding to the viscous friction.

Analyzed data correspond to samples with constant sign angular velocity, so the value of Coulomb friction is constant on these intervals. In this case it is possible to combine for each interval:

$f_{ac} = f_a + f_c sign(\omega)$

and this value is also constant in these intervals.

Then the expression for the angular velocity can be rewritten as:

$$\omega(t) = K\int_{t_0}^{t_k}(u - f_{ac} - f_v\omega(t))dt \qquad (4)$$

where t_0 is start time of the interval, t_k is end time of the interval.

To simplify the calculations, we assume that the angular velocity varies linearly on the sampling intervals. Then:

$$\omega(t_k) = \omega(t_0) + K\Big(u \cdot (t_k - t_0) - f_{ac} \times (t_k - t_0) - \sum_{i=1}^{k} f_v \left(\frac{\omega(t_{i-1}) + \omega(t_i)}{2}\right) T_d\Big) \qquad (5)$$

where T_d is sampling interval of digital system.

We suppose that

$\Omega = [\omega(t_1) - \omega(t_0) \ldots \ \omega(t_k) - \omega(t_0)]^T$

$H =$

$$\begin{bmatrix} u\cdot(t_1-t_0) & (t_1-t_0) & \sum_{i=1}^{1}\left(\frac{\omega(t_{i-1})+\omega(t_i)}{2F_d}\right) \\ \vdots & \vdots & \vdots \\ u\cdot(t_k-t_0) & (t_k-t_0) & \sum_{i=1}^{k}\left(\frac{\omega(t_{i-1})+\omega(t_i)}{2F_d}\right) \end{bmatrix}$$

$X = [K \;\; K\cdot f_{\mathrm{ac}} \;\; K\cdot f_v\,]^T$

where $F_d = {T_d}^{-1}$.

Then the expression (5) can be rewritten as:

$$\Omega = H\cdot X \qquad (6)$$

The estimation vector of unknown parameters $\hat{X}$ can be found by least squares technique [33]:

$$\hat{X} = (H^T H)^{-1}\cdot H^T\Omega \qquad (7)$$

The physical meaning of the parameters f_{ac} and f_v is how much current is required to compensate for the influence of resistance forces. In fact, disturbances are more complex, so parameter $T_{\min}$ can be increased to improve the accuracy of parameter K estimating. System evaluates the deviation of obtained values $\widehat{K}$ and decides to make new experiment with higher value $T_{\min}$.

3.3 Experimental results

Figure 4 shows photographs of rotary support for tracking telescope "Sazhen" (3) and the control unit (1) of its optical axes servo drives, which include electric drive information subsystem and electric drive energy subsystem and personal computer (2). Three-phase synchronous motor with permanent magnets (SMPM) and incremental optical encoders from Renishaw are mounted on the azimuthal axis of the telescope. According to the passport data SMPM has the following parameters: back-EMF constructive constant $C_e = 2\,V\cdot s/rad$, phase resistance $R = 13{,}5\,\Omega$, electromagnetic time constant of electromagnetic $T_e = 1\,ms$, number of pole pairs $p = 16$. Digital control system sampling frequency F_d is 1 kHz. Current loop is configured to linear optimum with time constant $T_T = 3\,ms$. Estimation of azimuthal axis moment of inertia is required to adjust servo drive control system.

Fig. 4: Laboratory bench of control system prototyping for tracking telescope servo drives.

Figure 5 shows the control signal graph, the angular velocity graph and angle graph necessary for identification of the parameter *K*. The absolute value of the angular velocity does not exceeds 10 degrees per sec. The range of angle variation is [0, 50] degrees. Electric drive changes motion direction when the angle reaches the boundary values. Control signal changes its sign when the angular velocity reaches the boundary values. Figure 5 shows the variation of control signal necessary to achieve the desired oscillation period.

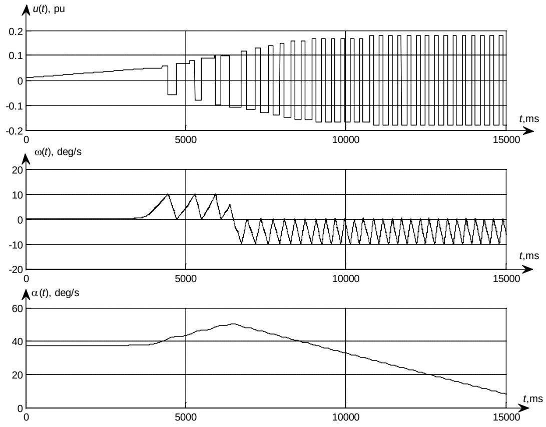

Fig. 5: Experimental data obtained from tracking telescope "Sazhen".

Estimated values of the parameter *K* are shown in Table 1. Experimental data were obtained for various values of $T_{\min.}$ Table 1 shows the mean values of K and its deviation. The standard deviation σ of data vector x is defined as:

$$\sigma = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}(x_i - \bar{x})^2}$$

where $\bar{x}$ is the mean value of the elements in vector x.

Table 1.

$T_{\text{min, ms}}$	$\bar{K}$	σ
200	374.08	39.92
400	419.92	26.68
600	428.85	26.07
800	432.55	29.03

The system uses a first set of data satisfying requirements of estimation parameter accuracy. If this data is missing, it uses the data with the highest estimation parameter accuracy. Figure 6 shows results of angular velocity estimation. The term “estimated velocity” refers to electric drive angular velocity obtained from the simulation using the estimated parameter *K*. Matching of the simulated and experimental data is good enough to justify the applicability of the proposed identification method.

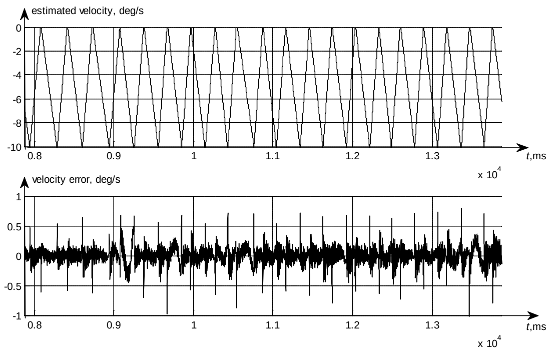

Fig. 6: The results of velocity estimation.

4 Conclusion

Designed offline identification algorithm allows to estimate the electromechanical parameters of the electric drive. The experimental data are obtained with speed limitation, acceleration limitation and angle limitation that is important for systems with limitation of motion, for example, for precision servo drives for optomechanical systems [7-8]. Identification algorithm is fully automated and does not require qualified personnel. This system is not operator time consuming because it diagnoses itself and protects itself against damage. The applicability of this system was validated by experiments on rotary support of tracking telescope "Sazhen."

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