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Adaptive Tracking for DC-Derivate Motor Based on Matrix Forgetting

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Abstract

This paper presents the new results concerning the adaptive controller design for a direct current derivate motor. The mathematical model of this DC - derivate motor, which we are dealing with, is a MIMO linear system, containing unknown time varying parameters. To estimate them, we apply the new identification procedure based on Adaptive Matrix Forgetting Factor (AMFF) involved into Instrumental Variables (IV) numerical scheme. Using these estimates, we construct an adaptive controller, realizing one - step minimal variance (locally optimal) control law, to obtain a good tracking for a nominal vector process of pulse and impulse functions type. Simulation results are included.

Keywords:
Derivate Motor. Estimation Algorithm, Adaptive Control, Matrix Forgetting.

I Introduction

In the past three decades, the feedback control problem of DC - derivate motors has received considerable attention. Many authors have treated this problem and there exist a lot of publications proposing more or less suitable solutions for the tracking problem as well as for regulation (to see: Mariano et al., (1993a), Leonhard, (1996) and the references therein). According with Taylor (1994), the existing techniques for nonlinear control of DC electric motors can be classifying into three groups:

a) Exact linearization and passitivity based * (PBA) approach studied by Sastry (1989) and Ortega (1996b);

b) Back stepping method treated by Krzeminski (1987) and Wit (1996);

c) Manifold - like control (Isidori (1991), Ortega (1997a)).

Several advantages and disadvantages of PBA over the other approaches are discussing by Taylor (1994). The experiment results were carried out on a two - poles squirrel - cage current-fed derivate motor of *1.2 kw* and a microcomputer - based control system developed for industrial application by Milent (1992). For a similar experiment, by Ortega (1997a), the readily available standard low - cost hardware (e.g., Motorola 68 000 microprocessor) in practical applications was using. Different (PBC) controllers presented by Ortega (1996b) were studying theoretically as well as experimentally. The best results were obtaining by the exact linearization observer-based in adaptive controller (OBAC).

* In Taylor (1994), these techniques are referred to as "energy shaping" and Ortega (1997a) makes reference to this as " passitivity-based" for the following reasons. First, energy shaping is just one step in the design, which also requires damping injection. Second, passivity is the fundamental systems property that is exploiting in these schemes.

Due to the understanding that the nonlinear observers are quite rudimentary (see, for example, Kim, (1996), many authors use the input - output linearizing technique to obtain any workable model. So, by Rachid (1997) the Field - Orient Control (FOC) was investigated and simplified by the input - output linearization which were obtained without any use of the Lie derivatives. In Mariano (1993b) the authors use the adaptive output feedback control for a class of current-fed derivate motors. All the ideas discussed above show a good perspective of the implementation of control laws using adaptation in current-fed output feedback.

By the other hand, Niedzwiecki (1989) analyzed the problem of identification of a non-stationary stochastic system by estimating the trajectory parameters of the Functional Series Models (FSM). It was shown that the parameter - matching properties of such estimators can be described in terms of the appropriately defined (time varying) impulse and frequency responses. The presented results were verifying via computer simulations. They show that the "averaged" frequency characteristics associated with FSM estimators can gain useful information about their parameter - matching abilities. The control law of derivate motor, studied by Kuo (1996), is linear, but the derivate control law did not contain any perturbations.

In this paper, a new control law (to see: Kel'mans, 1981b) for DC - derivate motor based on current estimates of time varying parameters is presenting. To identify the unknown time varying parameters, the recurrent algorithm presented in Poznyak and Medel (1999a) and Poznyak and Medel (1999b) is applied. It is basing on the Instrumental Variable Method (IVM) with the Adaptive Matrix Forgetting Factor (AMFF). It is assuming that the DC derivate is stable and the output signals are observable completely (to see: Ludyk, (1985)). As for the non - stationary parameters involved in the model description, we assume that they are subjected to slowly and bounded variations.

This paper is organizing as follows. *First*, the model descriptions of DC - derivate motor in continuous and in discrete time, respectively, are presenting. *Second*, the adaptive control law using the current estimates of un-known time varying parameters of the considered model is presented. *Third*, the simulation results for different input signals are analyzing, and finally, the resulting remarks concerning the presented study conclude this paper.

II Derivate Motor an Tracking Problem

DC - derivate machines are using in the power-output stage of a large class of electromechanical servomechanisms. They are preferred over AC - machines in high-power applications because of the ease control of the speed and the direction of rotation of large DC - motors (see Gibson and Tuteur (1958)). A widely used arrangement of DC - motor is giving in Fig. 1.

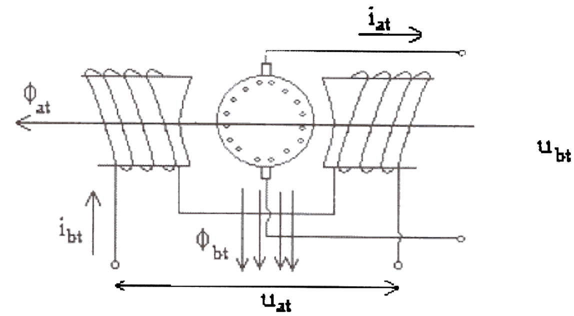

Fig. Motor Block Scheme

The field of the motor is separately exciting by a constant - voltage source (in low - power servos, the motor field may be established by a permanent magnet as well).

Following Rachid (1997), we will consider the next dynamic non-stationary model for DC - derivate motor:

$$dx_t = \left[A(\omega)x_t + Bu_t\right]dt + Dd\xi_t \qquad (1)$$

where

$$x_t = \left[i_{a_t} \quad i_{b_t} \quad \varphi_{a_t} \quad \varphi_{b_t}\right]^T \in R^4$$

are the state space vector containing the currents i_{a_t} i_{b_t} (amp) and fluxes φ_{a_t} φ_{b_t} (Weber) of the stator and the rotor, respectively; and

$$u_t = \left[u_{a_t} \quad u_{b_t}\right]^T \in R^2$$

is the stator voltages (v); ξ_t is the remainder flow will be describing by a Standard Brownian Motion Process. The matrices A(ω), B an the vector D are defined as follows:

$$A(\omega) = \begin{vmatrix} -\gamma & 0 & \dfrac{K}{T_r} & p\omega K \\ 0 & -\gamma & -p\omega K & \dfrac{K}{T_r} \\ \dfrac{M}{T_r} & 0 & T_r & -p\omega \\ 0 & \dfrac{M}{T_r} & p\omega & T_r \end{vmatrix}$$

$$B=\begin{pmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{pmatrix} \quad D=\begin{pmatrix} 0.000573 \\ 0.000457 \\ 0 \\ 0 \end{pmatrix}$$

Here ω is a mathematical speed (s^{-1}) which is assuming to be varying according to the following dynamics:

$$\omega_t = \frac{pM}{JL_r}\left(\varphi_{a_t} i_{b_t} - \varphi_{b_t} i_{a_t}\right) - \frac{T_l}{J}, \qquad (2)$$

$\omega_0 = 0.01 s^{-1}$

Defining all parameters participating in description of the dynamic model (1) as: $R_r = 0.1\Omega$, $R_s = 0.2\Omega$, are resistances (rotor and stator, respectively); $L_r = 0.29 henry$, $L_s = 0.3 henry$, are inductances (rotor and stator, respectively); $M00.25 henry$ is a mutual inductance; $T_r = \frac{L_r}{R_r} = 2.9s$ is the rotor time constant; $T_s = \frac{L_s}{R_s} = 1.5s$ is the stator time constant; $T_l = 300x10^{-3} Nm$ is the torque load; $J = 27.9x10^{-4} Nm^2$ is the inertia rotor moment; $p = 0.2hp$ is the number of poles power; K, γ, σ are expressed by:

$$K = \frac{M}{\sigma L_s L_r},\ \gamma = \frac{R_s}{\sigma L_s} + \frac{R_r M^2}{\sigma L_s L_r^2},\ \sigma = 1 - \frac{M^2}{L_s L_r^2}.$$

Selecting the time sequence $t_\tau(\tau = 1,2,\ldots)$, defined by:

$t_{\tau+1} = t_\tau + \Delta_\tau, (\Delta_\tau = 0.003s)$

and using the following considerations:

$x_{t_\tau} = x_\tau, \omega_{t_\tau} = \omega_\tau, u_{t_\tau} = u_\tau$

We can rewrite in discrete time the dynamical model of DC-derivate motor expressed in (1), and the speed dynamical model expressed in (2):,

$$x_{\tau+1} = [I + A(\omega)\Delta_\tau]x_\tau + B\Delta_\tau u_\tau + D\tilde{\xi}_\tau \qquad (3)$$

$$\omega_{\tau+1} = \omega_\tau + \left(\frac{pM\Psi_\tau}{JL_r} - \frac{T_l}{J}\right)\Delta_\tau; \qquad (4)$$

Where Ψ_τ is defined by:

$\Psi_\tau = \varphi_{a_\tau} i_{b_\tau} - \varphi_{b_\tau} i_{a_\tau}$,

and the random variable $\tilde{\xi}_\tau$, defined by

$$\tilde{\xi}_\tau = \xi_{\tau+1} - \xi_\tau; \qquad (5)$$

and is i.i.d., of Gaussian sequence with a zero mean an covariance $\sigma_\xi^2 = \Delta$. Hereafter, we assume that all coordinates of the state space vector x_τ are measurable without any noise perturbations. As for the mechanical speed ω_τ, we cannot measure its values and as result, the matrix $A(\omega_\tau)$ should be considering as a collection of unknown time-varying parameters.

Since the points of view about the definitions accepted above, the tracking problem for the considered DC - derivate motor can be formulated as follows: for a given nominal trajectory $\{x^*_\tau\}$ derive the control law $\{u^*_\tau\}$ which guarantees "a good enough" tracking error in the presence of an unknown parametric uncertainty given by $A(\omega_\tau)$.

In this situation, there is only one-way to construct any tracking controller: estimate on - line the unknown sequence matrix $\{A(\omega_\tau)\}$ and use these estimates in the applied feedback control law. Hence, we have to derive an adaptive controller based only on available current state space measurements.

III Adaptive Controller

Let us first, assume that we know the functional matrix $A(\omega_\tau)$ and that the current values of the mechanical frequency ω_τ are available at each time τ=1,2,..., .Based on "the locally optimal (variance minimal) control approach" (to see: Kel'mans and Poznyak ,(1977ä)), for a given nominal trajectory $\{x^*_\tau\}$ we define the control action u^*_τ in such a way to fulfill the following relation:

$$x^*_{\tau+1} = [I + A(\omega_\tau)\Delta_\tau]x_\tau + B\Delta_\tau u_\tau \qquad (6)$$

In equivalent form:

$$u_\tau = B^+\left(\frac{x^*_\tau - x_\tau}{\Delta} - A(\omega_\tau)x_\tau\right) \qquad (7)$$

Following Kel'mans and Poznyak (1981b), "the adaptive locally optimal control" can be obtained from (7) if we change the unknown matrices $A(\omega_\tau)$ and B to their current estimates $\hat{A}(\omega_\tau)$ and B and introduce the regularizing i.i.d. random sequence $\{\nu_n\}$ for the identification aims. Rewriting the dynamic model equation (3) in the standard form:

$$y_\tau = A(\omega_\tau)z_\tau + D\xi_\tau; \qquad (8)$$

where

$$y_\tau = x_{\tau+1}, A_\tau = [I + A(\omega_\tau)\Delta_\tau \vdots B\Delta_\tau],$$

$$z_\tau = (x_\tau, u_\tau)^T,$$

Applying the IV method with Adaptive Matrix Forgetting Factor suggested by Poznyak and Medel (199a), we obtain the current estimates $\hat{A}_\tau$ of the matrix A_τ according to the following procedure:

$$\hat{A}_\tau = \hat{A}_{\tau-1} + [y_\tau - \hat{A}_{\tau-1}z_\tau]\vartheta^T{}_\tau\Gamma_\tau \qquad (9)$$

where the matrix gain Γ_τ satisfies

$$\Gamma_\tau = R^{-1}{}_\tau\Gamma_{\tau-1} \quad \frac{R^{-1}{}_\tau\Gamma_{\tau-1}z_\tau\vartheta^T{}_\tau R^{-1}{}_\tau\Gamma_{\tau-1}}{1+\vartheta^T{}_\tau R^{-1}{}_\tau\Gamma_{\tau-1}z_\tau}, \qquad (10)$$

and $\vartheta_\tau = z_{\tau-1}$ is the instrumental variable (IV). Here

$$\tau \geq \tau_0 = \inf\left\{t \ \det\left[\sum_{s=1}^{t} z_s\vartheta^T{}_s\right] \neq 0\right\}.$$

And R_τ is the Matrix Forgetting Factor, adapted in time according to the following procedure:

$$r_\tau = \pi_{D_{\varepsilon_\tau}}\left\{r_\tau - \gamma_\tau(\det\Theta)^{-16}\Theta_\tau^{-\frac{1}{2}}\kappa_\tau q_\tau\right\}, \qquad (11)$$

where

$$q_\tau := \left\|y_\tau - \hat{y}_\tau\left(col^{-1}\left(r_\tau + \Theta^{\frac{1}{2}}{}_\tau\kappa_\tau\right)\right)\right\|^2$$

$$:= col(R_\tau),$$

γ_τ is a positive deterministic time-varying gain step, $\Theta_\tau = \Theta_\tau^T \in R^{16x16}$ is a positive time- varying matrix, and $\kappa_\tau \in R^{16}$ is a Independent Gaussian Random Vector with Standard Distribution $N(0,I)$. In (11) the operator $\pi_{D_{\varepsilon_\tau}}$ indicate the projection operator acting from R^{16} to the set

$$D_{\varepsilon_\tau} := \begin{Bmatrix} r \in R^{4x4} : col^{-1}(r) \in R_{\varepsilon_\tau} = \\ \{R : \|R\| \leq 1-\varepsilon, \varepsilon \in [0,1)\} \end{Bmatrix} \qquad (12)$$

In this algorithm the vector:

$$\hat{y}_\tau\left(col^{-1}\left(r_\tau + \Theta_\tau^{-\frac{1}{2}}\kappa_\tau\right)\right)$$

in accordance to

$$\hat{y}_\tau(R) = \hat{A}_\tau z_\tau . \qquad (13)$$

The parameters , and, are selected by the optimal way following Poznyak and Medel (1999b) as follows:

$$\gamma_\tau := \frac{\gamma_0}{\tau^{1/4}},\ \varepsilon_\tau := \frac{\varepsilon_0}{\tau^{1/2}}$$

$$\Theta_\tau := \theta_\tau I,\ \theta_\tau := \frac{\theta_0}{\quad}$$

With $\gamma_0 = 0.002, \varepsilon_0 = 0.035, \theta_0 = 0.058$. We can treat the sequence $\{\hat{y}_\tau\}$ as the output of the model or our given ARMA process (8).

Notice that $\hat{y}_\tau(R_\tau)$ is a function of R_τ because the matrix estimates $\hat{A}_\tau$ are the functions of R_τ. The convergence and rate convergence analysis of this procedure can also be found in Poznyak and Medel (1999a).

Introducing into adaptive control a small regularizing i.i.d random sequence $\{\nu_n\}$ satisfying:

$$E\{\nu_n\} = 0,\ E\{\nu_n\nu_n^T\} = \sigma_{\nu_n}I > 0, \sigma_{\nu_n} = 0.1.$$

Finally, we suggest a new adaptive control law in the following form:

$$u_\tau^* = B_\tau^+\Big[\qquad \Big] \qquad (15)$$

The simulation results are presenting in the next section. Two experiments are included; the first corresponds to the step function input, and the second to the pulse input.

IV Simulation Results

The Adaptive Matrix Forgetting Factor (AMFF) with Instrumental Variable (IV) discussed above; was tested to estimate the 4th dimensional matrix C_τ defined in (3) as $C_\tau := I + A(\omega_\tau)\Delta_\tau$. It has four time varying elements $C_{1,4}(\omega_\tau), C_{2,3}(\omega_\tau), C_{3,4}(\omega_\tau), C_{4,3}(\omega_\tau)$, respectively

The examples presented below correspond with two different control inputs, which were applying to the DC-derivate motor under consideration: one of it is with the step function input, and the other one to the pulse input. All simulation results, presented below (to see: Fig. 3 – Fig. 14) have been carrying out with help of Mat lab. Ver.5 Software with Simulink. Ver. 4.2 (1992) as a toolbox.
A block scheme of corresponding simulation process is presenting in Fig. 2.

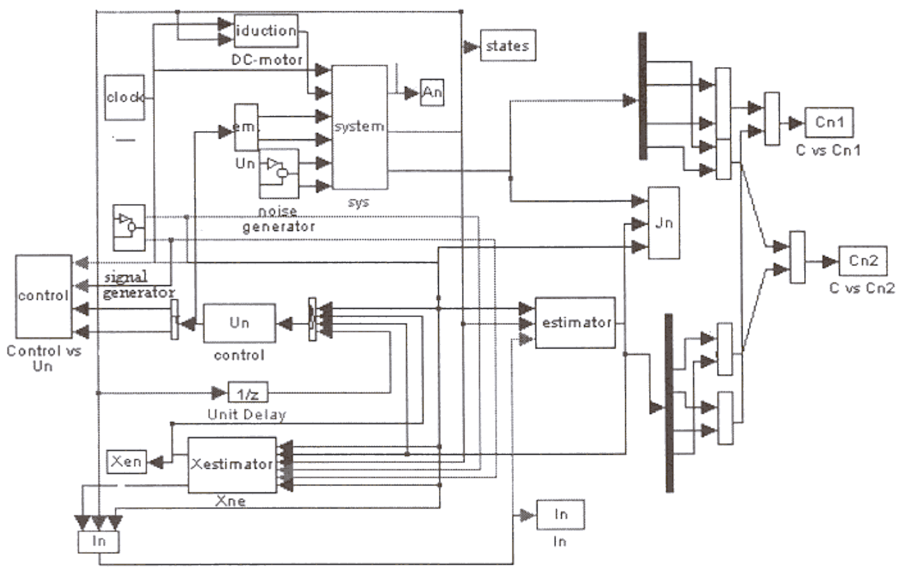

Fig. 2. Block Scheme

Experiment 1

The behavior of DC- derivate motor subjected to the step control input has been exposing in Fig. 3 – Fig. 8. Hence, Fig.3 shows the correspondence of the obtained estimated to the real ones. We can see that the adaptive identifier does job well.

The time evaluation of the corresponding performance index J_n given by:

$$J_n = \frac{1}{n}\sum_{t=1}^{n} tr\{(\hat{C}_t - C_t)(\hat{C}_t - C_t)^T\} \qquad (16)$$

Is depicted in Fig.4:

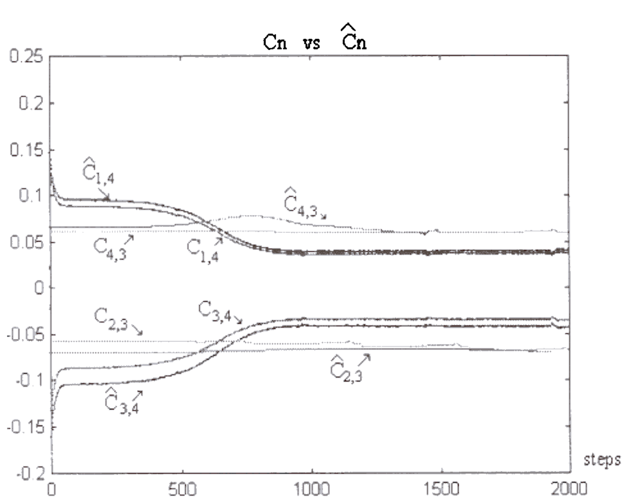

Fig. 3. Parameters $C_{i,j}(\omega)$ and their estimates

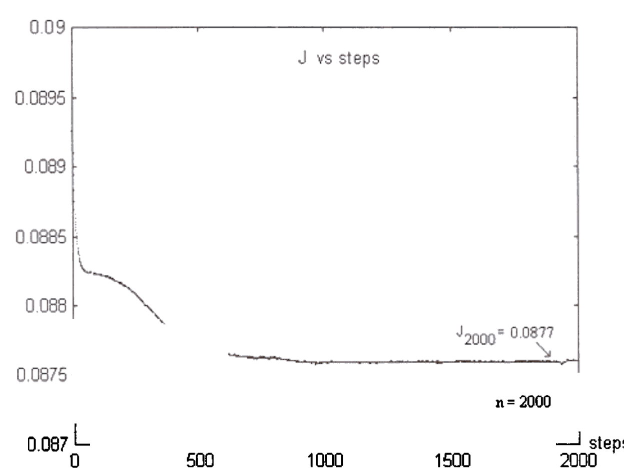

Fig. 4. Time evaluation of the performance index J

The characteristic of two step control inputs are presented in Fig.

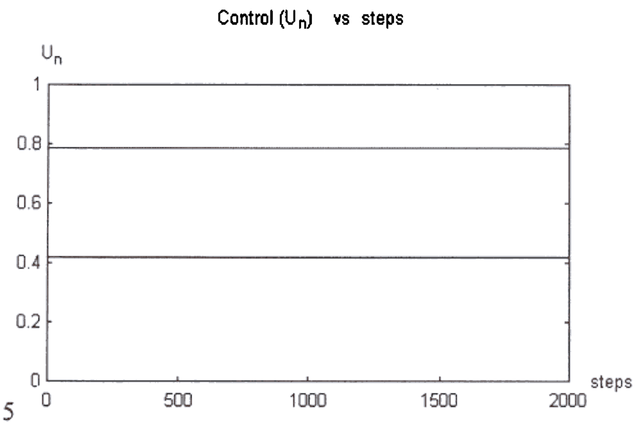

Fig. 5. Step control inputs

The states x_t of the model (1) and their estimates obtained by the suggested technique are presenting in Fig. 6 and Fig. 7:

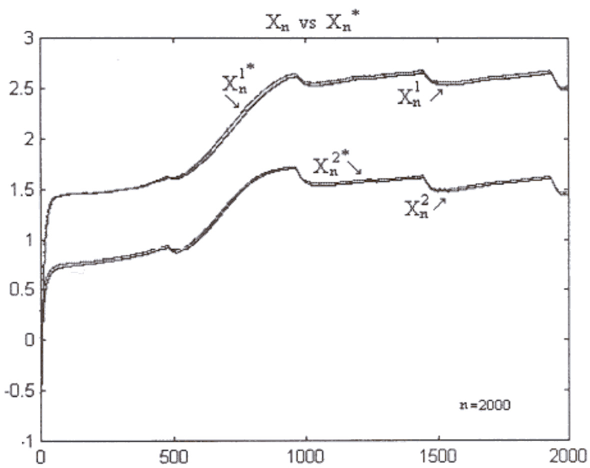

Fig. 6. Tracking for X^1 and X^2 states.

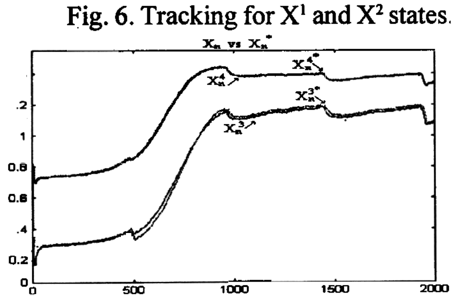

Fig. 7. Tracking for X^3 and X^4 states.

The tracking performance index I_n given by:

$$I_n = \frac{1}{n}\sum_{t=1}^{n}\left\|\hat{x}_t - x_t\right\|^2, \tag{17}$$

Is exposed in Fig. 8:

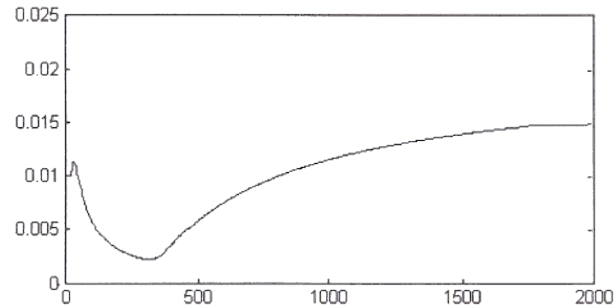

Fig. 8. Tracking performance index I

Experiment 2

The analogous illustrations corresponding to the pulse input control signal are showing in the Fig. 9 – Fig. 14. Hence, Fig.9 shows the correspondence of the obtained estimated to the real ones.

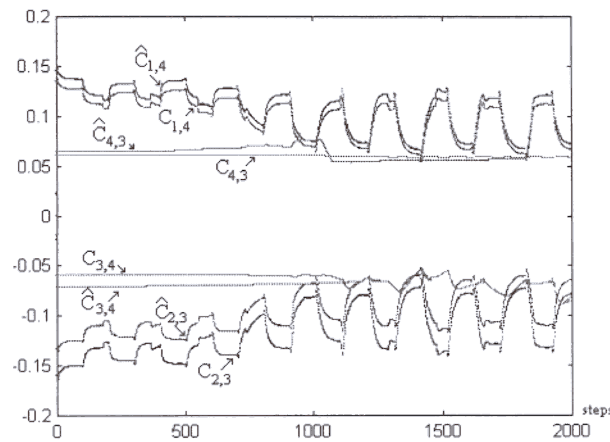

Fig. 9. Parameters $C_{i,j}(\omega)$ and their estimates

The time evaluation of the corresponding performance index J_n given in (16), is the depicted in the Fig. 10:

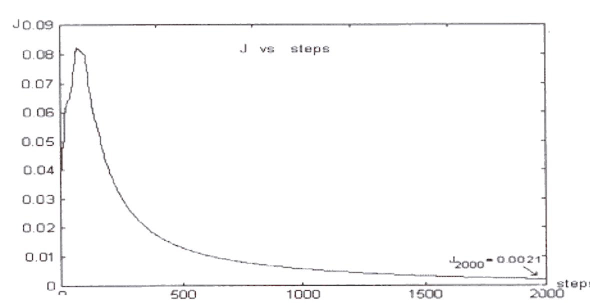

Fig. 10. Time evaluation of the performance index J

The characteristic of two impulse control inputs are presented in Fig. 11:

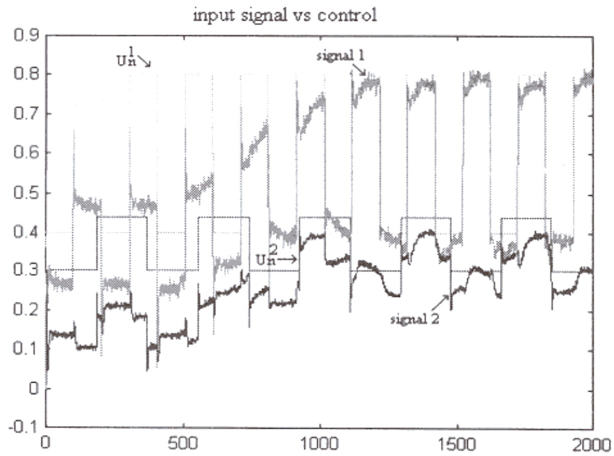

Fig. 11. Pulse control inputs

The states x_t of the model (1) and their estimates obtained by the suggested technique are presenting in Fig. 12 and Fig. 13:

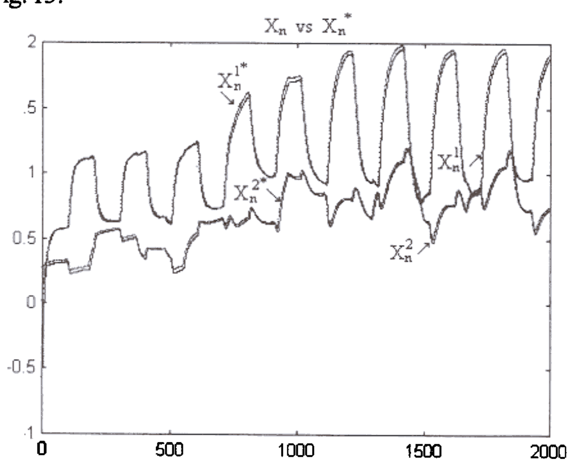

Fig. 12. Tracking for X^1 and X^2 states

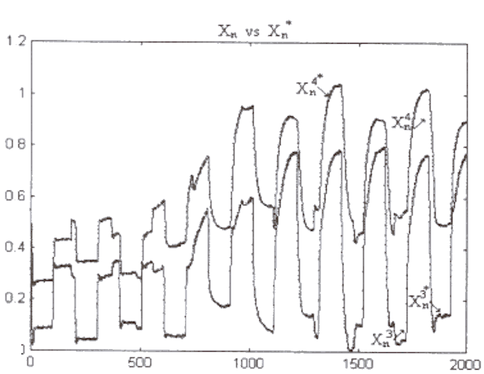

Fig. 13. Tracking for $X^3$and X^4 states

The tracking performance index I_n given in (17), is exposed in Fig. 14:

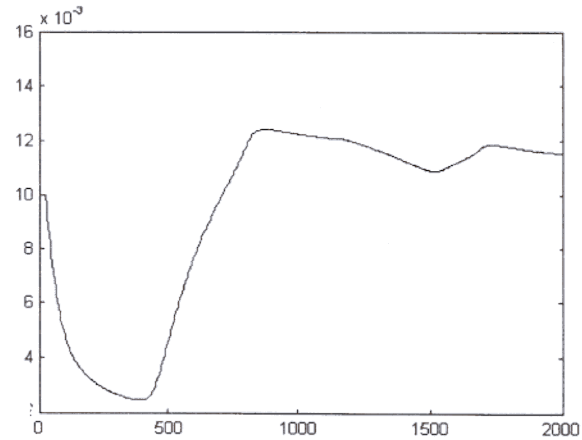

Fig. 14. Tracking performance index I

As follows from these simulation results, the designed identifiers as well as the suggested adaptive controller turn out to be workable in the presence of essential non-stationary parameters, involved in to description of the corresponding enigmatical model of a given DC-derivate motor.

V Conclusions

In this study we have considered the identification problem of non-stationary characteristics of a DC - derivate motor as well as the adaptive tracking problem which was solved by means of a locally optimal technique based on current estimates supplied by the AMFF algorithm suggested in Poznyak and Medel (1998b). We suggested a new adaptive control law. The simulation results, performed under two different input signals illustrated the applicability and the good behavior of this adaptive procedure.

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