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# ADAPTIVE STATOR CURRENT REGULATION FOR IDENTIFICATION OF INDUCTION MOTOR PARAMETER

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This paper develops and experimentally substantiates a new algorithm to identify unknown parameters of induction motors during self commissioning procedure. To guarantee asymptotic identification, we design adaptive stator current controller based on stator flux observer. Allowed current references guarantee local exponential identification of three induction motor parameters as well as estimation of the stator fluxes in both motionless and rotating rotor operation. Performed experiments demonstrate that the proposed scheme provides identification and estimation accuracy with fast asymptotic convergence of errors to zero. Our procedure compliments the existing industrial control schemes, and, consistent with vector controls including sensorless algorithms.

**Key words**: induction motor, identification, estimation.

# АДАПТИВНЕ РЕГУЛЮВАННЯ СТРУМУ СТАТОРА ДЛЯ ІДЕНТИФІКАЦІЇ ПАРАМЕТРІВ АСИНХРОННОГО ДВИГУНА

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Синтезовано та експериментально протестовано новий алгоритм ідентифікації невідомих параметрів асинхронного двигуна для процедур самоналаштування асинхронних електроприводів. З метою забезпечення асимптотичної ідентифікації розроблено адаптивний регулятор струму статора, який базується на спостерігачі потокозчеплення статора. Спеціально сформовані задані траєкторії струмів статора гарантують локальну експоненціальну ідентифікацію трьох параметрів асинхронного двигуна разом з оцінюванням невимірюваного потокозчеплення статора як при нерухомому, так і при вільно обертовому роторі. Надані результати експериментальних досліджень показують, що розроблений алгоритм гарантує високу точність ідентифікації параметрів і швидкість сходимості похибок у нуль, які не поступаються існуючим у серійних виробах, і є придатним для реалізації процедур самоналаштування систем векторного керування.

**Ключові слова**: асинхронний двигун, ідентифікація, оцінювання.

PPOBLEM STATEMENT. The accurate values of the motor parameters are required to implement the standard and advanced field-oriented vector controls of induction motors (IM). There are six unknown varying parameters of nonlinear lamped-parameter IM models, e.g., the stator and rotor resistances, stator and rotor inductances, magnetizing inductance, and moment of inertia. The influence of parameter uncertainties and variations are studied in many publications, see [1–3] and references therein. It is well known that standard indirect field-oriented control with speed sensors is robustly stabile with respect to variations of the rotor resistance [4]. The rotor resistance is the most critical parameter in closed-loop IM systems. To achieve high dynamic performance during speed and torque tracking, and, ensure energy conversion efficiency, rotor resistance and magnetizing inductance should be precisely known. Sensorless vector control algorithms are more sensitive to parameters accuracy and one needs all electrical parameters including stator resistance [2].

Practical approach to define the IM electric parameters is based on locked rotor and no-load tests [5]. These procedures do not provide required accuracy and have some limitations. Different parameter identification techniques have been proposed since 1980s, see an overview paper [6] and references in [7]. Two classes of identification schemes are [6]: *on-line* – with parameter identification during normal operating conditions, and, *off-line* which may require special testing conditions.

The *off-line* methods are focused on self-commissioning of the controller during drive initialization. They use different approaches [6]: parameter calculation from motor catalog data; parameter estimation based on steady-state motor models; frequency-domain parameter estimation; time-domain parameter estimation. In general self-commissioning procedure requires special testing conditions with free rotating rotor or standstill. The former one presents the recent trend, especially for sensorless controls.

The time-domain approaches are based on MRAS technique, see [7–9] and references [80–100] in overview paper [6]. In [8], the standard hyperstability approach is applied under condition of known motor torque constant. An elegant solution [7], based on parallel adaptive observer with non-minimum state-space presentation, provides asymptotic estimation of motor parameters and fluxes under standstill condition. Intensive simulation and experimental investigations demonstrate effectiveness of this observer. In general, application of MRAS technique leads to development of different modifications of adaptive full-order observers [9]. The evolution of IM variables is formed by applied stator voltages.

The *on-line* techniques lead to the use of adaptive control schemes, allowing real-time controller reconfiguration. However, the identification problem if not all states are measured is a very complex task which remains an open theoretical problem. It is well known that correct value of rotor resistance defines accuracy of field-orientation in majority of vector control systems. The knowledge of stator resistance is required to identify rotor resistance [10] as well as to implement sensorless algorithms. An algorithm for real-time identification of stator and rotor resistances was proposed in [11], where the nine-order adaptive observer was synthesized. Different modifications of the least-square method to identify electric parameters were presented in [12], [13]. In [12], to obtain a linearly-parameterized estimation model, it is assumed that the angular speed varies slowly. The identification despite varying angular velocity was performed in [13], where nonlinear least-square approach is used. Computationally, both solutions are quite complex, and, require significant processing capabilities for real-time implementation. A limited number of theoretically and experimentally proven adaptive controllers with identification of a few parameters are available [14]. The complexity reduction, design of adaptive controllers, performance improvements and practical implementation are very important issues.

The aim of this paper is to develop a new algorithm for IM parameters identification which operates in both standstill and free rotation conditions. In contrast to existing solutions, we propose a new approach which is based on adaptive stator current regulation. Such system structure with inner current loops is utilized in majority of vector controlled induction motor drives. A solution proposed, under suitable excitation, provides asymptotic stator fluxes and three IM parameters estimation (rotor resistance, stator/rotor and magnetizing inductances).

EXPERIMENTAL PART AND RESULTS OBTAINED. Assuming a linear magnetic system, the mathematic model of symmetric IM in the stationary reference frame is [1]

$$\begin{aligned}
&\dot{\omega} = \frac{1}{J}\left(\frac{3}{2}\left(\psi_a i_b - \psi_b i_a\right) - T_L\right);\\
&\begin{pmatrix}\dot{\psi}_a\\ \dot{\psi}_b\end{pmatrix} = -R_1\begin{pmatrix}i_a\\ i_b\end{pmatrix} + \begin{pmatrix}u_a\\ u_b\end{pmatrix};\\
&\begin{pmatrix}\dot{i}_a\\ \dot{i}_b\end{pmatrix} = -\begin{bmatrix}\left(R_1/\sigma+\rho\right) & \omega\\ -\omega & \left(R_1/\sigma+\rho\right)\end{bmatrix}\begin{pmatrix}i_a\\ i_b\end{pmatrix} +\\
&+\begin{bmatrix}\alpha/\sigma & \omega/\sigma\\ -\omega/\sigma & \alpha/\sigma\end{bmatrix}\begin{pmatrix}\psi_a\\ \psi_b\end{pmatrix} + \frac{1}{\sigma}\begin{pmatrix}u_a\\ u_b\end{pmatrix},
\end{aligned} \tag{1}$$

where $\mathbf{i} = \left(i_a, i_b\right)^T$, $\boldsymbol{\psi} = \left(\psi_a, \psi_b\right)^T$ and $\mathbf{u} = \left(u_a, u_b\right)^T$ denote stator current, flux linkage and stator voltage vectors; $\omega$ is the angular velocity; $R_1$ is the stator resistance; $J$ is the moment of inertia; $T_L$ is the load torque. A one pole pair model is used without loss of generality.

In (1), three positive constants $\sigma$, $\alpha$, and $\rho$ are defined using the motor parameters as

$$\sigma = L_1\left(1 - L_m^{\ 2}/L_1 L_2\right);\ \alpha = R_2/L_2;\ \rho = \alpha L_m \beta + \alpha, \tag{2}$$

where $\beta = L_m/\sigma L_2$; $R_2$ is the rotor resistance; $L_1$ and $L_2$ are the stator and rotor inductances; $L_m$ is the magnetizing inductance.

Mathematically, induction motor dynamics is described by five nonlinear differential equations (1). Let assume, that stator currents and rotor angular velocity are measured while flux linkages are not available for measurement. The identification problem can be consistently simplified by applying the following practical and accurate postulates: (1) The numeric values of stator and rotor inductances are practically equal, $L_1 = L_2$; (2) Unknown parameters during identification are constant; (3) Stator resistance can be determined using the Ohm law when the dc voltages are applied to stator windings, e.g., if $u_a = const$ and $u_b = 0$, one has

$$\lim_{t\to\infty} i_a = u_a/R_1;\ \lim_{t\to\infty} i_b = 0. \tag{3}$$

The parameters identification is performed using four electromagnetic equations of motions without the *torsional-mechanical* differential equation. We assume that applied stator currents ensure bounded motion of IM states, and, persistency of excitation conditions is met.

One needs to identify three constants (2), which yield the resulting $R_2$, $L_1$, $L_2$ and $L_m$.

Denoting the flux linkages estimates as $\hat{\boldsymbol{\psi}} = \left(\hat{\psi}_a, \hat{\psi}_b\right)^T$, the identification and estimations errors are

$$\tilde{\alpha} = \alpha - \hat{\alpha};\ \tilde{\sigma} = \sigma - \hat{\sigma};\ \tilde{\rho} = \rho - \hat{\rho}; \tag{4}$$

$$\tilde{\psi} = \psi - \hat{\psi} = \left(\tilde{\psi}_a, \tilde{\psi}_b\right)^{\mathrm{T}}, \tag{5}$$

where $\hat{\alpha}$, $\hat{\sigma}$ and $\hat{\rho}$ are the estimates of $\alpha$, $\sigma$ and $\rho$.

Let the bounded vector of current references $\mathbf{i}^* = \left(i_a^*, i_b^*\right)^T$ has the bounded first and second time derivatives. It is necessary to synthesize an adaptive current controller which guarantees:

1. Asymptotic current tracking, such that

$$\lim_{t\to\infty}\left(\tilde{\mathbf{i}}\right) = 0;\ \tilde{\mathbf{i}} = \mathbf{i} - \mathbf{i}^*. \tag{6}$$

2. Asymptotic stator flux linkages estimation, such that

$$\lim_{t\to\infty}\left(\tilde{\boldsymbol{\psi}}\right) = 0. \tag{7}$$

3. Asymptotic identification of the unknown parameters $\alpha$, $\sigma$, $\rho$, such that

$$\lim_{t\to\infty}\left(\tilde{\alpha}, \tilde{\sigma}, \tilde{\rho}\right) = 0. \tag{8}$$

*Adaptive controller design.* We design an adaptive current controller using stator flux observer in the following form

$$\begin{aligned} \dot{\hat{\psi}}_a &= -R_1 i_a + u_a - v_a; \\ \dot{\hat{\psi}}_b &= -R_1 i_b + u_b - v_b; \\ u_a &= R_1 i_a^* - \hat{\alpha}\hat{\psi}_a - \omega\hat{\psi}_b + \\ &\quad + \hat{\sigma}\left(\hat{\rho} i_a^* + \omega i_b + \dot{i}_a^* - k_i \tilde{i}_a\right); \\ u_b &= R_1 i_b^* - \hat{\alpha}\hat{\psi}_b + \omega\hat{\psi}_a + \\ &\quad + \hat{\sigma}\left(\hat{\rho} i_b^* - \omega i_a + \dot{i}_b^* - k_i \tilde{i}_b\right), \end{aligned} \tag{9}$$

where $k_i > 0$ is the tuning coefficient, $v_a$ and $v_b$ should be defined later.

From (1) and (9), the current tracking and flux estimation error dynamics is

$$\begin{aligned} \begin{pmatrix} \dot{\tilde{i}}_a \\ \dot{\tilde{i}}_b \end{pmatrix} &= -\begin{pmatrix} \left(\frac{R_1}{\sigma} + \rho + k_i\right) & 0 \\ 0 & \left(\frac{R_1}{\sigma} + \rho + k_i\right) \end{pmatrix} \begin{pmatrix} \tilde{i}_a \\ \tilde{i}_b \end{pmatrix} + \\ &+ \begin{bmatrix} \frac{\alpha}{\sigma} & \frac{\omega}{\sigma} & \frac{\hat{\psi}_a}{\sigma} & -\frac{\phi_a}{\sigma} & -i_a^* \\ -\frac{\omega}{\sigma} & \frac{\alpha}{\sigma} & \frac{\hat{\psi}_b}{\sigma} & -\frac{\phi_b}{\sigma} & -i_b^* \end{bmatrix} \tilde{\boldsymbol{\varphi}} \triangleq \\ &\triangleq \mathbf{A}\tilde{\mathbf{i}} + \mathbf{W}(t)\mathbf{D}^{-1}\tilde{\boldsymbol{\varphi}}, \\ \dot{\tilde{\psi}}_a &= v_a, \\ \dot{\tilde{\psi}}_b &= v_b, \end{aligned} \tag{10}$$

where $\tilde{\boldsymbol{\varphi}} = \left(\tilde{\psi}_a, \tilde{\psi}_b, \tilde{\alpha}, \tilde{\sigma}, \tilde{\rho}\right)^T$; $\mathbf{D} = diag\left[\sigma, \sigma, \sigma, \sigma, 1\right] > 0$,

$\mathbf{D} \in |^{5x5}$, $\mathbf{W}(t) = \begin{bmatrix} \alpha & \omega & \hat{\psi}_a & -\phi_a & -i_a^* \\ -\omega & \alpha & \hat{\psi}_b & -\phi_b & -i_b^* \end{bmatrix}$;

$$\mathbf{A} = \begin{bmatrix} -\left(\frac{R_1}{\sigma} + \rho + k_i\right) & 0 \\ 0 & -\left(\frac{R_1}{\sigma} + \rho + k_i\right) \end{bmatrix}.$$

To design our identification algorithm, consider the following positive-definite function

$$\begin{aligned} V &= \frac{1}{2}\left[(\tilde{i}_a^2 + \tilde{i}_b^2) + \gamma_1^{-1}\frac{1}{\sigma}(\tilde{\psi}_a^2 + \tilde{\psi}_b^2)\right] + \\ &+ \frac{1}{2}\left[\gamma_\alpha^{-1}\frac{1}{\sigma}\tilde{\alpha}^2 + \gamma_\sigma^{-1}\frac{1}{\sigma}\tilde{\sigma}^2 + \gamma_\rho^{-1}\tilde{\rho}^2\right]. \end{aligned} \tag{11}$$

Its time derivative along the solutions of (10) is given by

$$\begin{aligned} \dot{V} &= -(\frac{R_1}{\sigma} + \rho + k_i)\tilde{i}_a^2 + \frac{\alpha}{\sigma}\tilde{\psi}_a\tilde{i}_a + \frac{\omega}{\sigma}\tilde{\psi}_b\tilde{i}_a - \tilde{\rho} i_a^* \tilde{i}_a + \\ &+ \frac{\tilde{\alpha}}{\sigma}\hat{\psi}_a\tilde{i}_a - \frac{\tilde{\sigma}}{\sigma}\phi_a\tilde{i}_a - (\frac{R_1}{\sigma} + \rho + k_i)\tilde{i}_b^2 + \frac{\alpha}{\sigma}\tilde{\psi}_b\tilde{i}_b - \\ &- \frac{\omega}{\sigma}\tilde{\psi}_a\tilde{i}_b - \tilde{\rho} i_b^* \tilde{i}_b + \frac{\tilde{\alpha}}{\sigma}\hat{\psi}_b\tilde{i}_b - \frac{\tilde{\sigma}}{\sigma}\phi_b\tilde{i}_b + \gamma_1^{-1}\frac{1}{\sigma}\tilde{\psi}_a v_a + \\ &+ \gamma_1^{-1}\frac{1}{\sigma}\tilde{\psi}_b v_b + \gamma_\alpha^{-1}\frac{1}{\sigma}\tilde{\alpha}\dot{\tilde{\alpha}} + \gamma_\sigma^{-1}\frac{1}{\sigma}\tilde{\sigma}\dot{\tilde{\sigma}} + \gamma_\rho^{-1}\tilde{\rho}\dot{\tilde{\rho}}. \end{aligned} \tag{12}$$

Designing

$$\begin{aligned} \dot{\hat{\alpha}} &= -\dot{\tilde{\alpha}} = \gamma_\alpha\left(\hat{\psi}_a\tilde{i}_a + \hat{\psi}_b\tilde{i}_b\right); \\ \dot{\hat{\sigma}} &= -\dot{\tilde{\sigma}} = -\gamma_\sigma\left(\phi_a\tilde{i}_a + \phi_b\tilde{i}_b\right); \\ \dot{\hat{\rho}} &= -\dot{\tilde{\rho}} = -\gamma_\rho\left(\tilde{i}_a i_a^* + \tilde{i}_b i_b^*\right); \\ v_a &= -\gamma_1\alpha\tilde{i}_a + \gamma_1\omega\tilde{i}_b; \\ v_b &= -\gamma_1\alpha\tilde{i}_b - \gamma_1\omega\tilde{i}_a, \end{aligned} \tag{13}$$

the total derivative of $V$ is found to be negative-definite. In particular, we have

$$\dot{V} = -(\frac{R_1}{\sigma} + \rho + k_i)(\tilde{i}_a^2 + \tilde{i}_b^2). \tag{14}$$

Hence, the positive-definite $V$, given by (11), is a Lyapunov function.

From (11) and (14), it follows that $\tilde{\mathbf{i}}$ and $\tilde{\boldsymbol{\varphi}}$ are bounded. Therefore for bounded $\mathbf{u}$, $\mathbf{i}$, $\boldsymbol{\psi}$ and $\omega$, estimates $\hat{\mathbf{i}}$, $\hat{\boldsymbol{\psi}}$, $\hat{\alpha}$, $\hat{\sigma}$, $\hat{\rho}$ are also bounded because the conditions imposed on a Lyapunov pair is satisfied. Furthermore, $\mathbf{W}(t)$ in (10), and, the total derivative $\dot{\tilde{\mathbf{i}}}$, are also bounded.

Due to $\int_0^t \dot{V} d\tau = -\frac{\left[V(t) - V(0)\right]}{R_1/\sigma + \rho + k_i} \leq \frac{V(0)}{R_1/\sigma + \rho + k_i}$, a square-integrable $\tilde{\mathbf{i}}(t)$ is bounded, with the bounded total derivative. Applying the Barbalat's Lemma [15], we have $\lim_{t\to\infty}\tilde{\mathbf{i}} = 0$.

From (10) and (13), the errors evolution is described as

$$\begin{aligned} \dot{\tilde{i}} &= A\tilde{i} + W(t)D^{-1}\tilde{j}; \\ \dot{\tilde{j}} &= -GW(t)^T\tilde{i}, \end{aligned} \tag{15}$$

where $\boldsymbol{\Gamma} = diag\left(\gamma_1, \gamma_1, \gamma_\alpha, \gamma_\sigma, \gamma_\rho\right) > 0$.

If persistency of excitation conditions are satisfying, for a mapping $\mathbf{W}$ we have

$$\int_t^{t+T} \mathbf{W}(\tau)\mathbf{W}^T(\tau)d\tau > 0;\ T > 0;\ \forall t \geq 0. \tag{16}$$

As $\dot{\mathbf{W}}(t)$ is bounded, an equilibrium $\left(\tilde{\mathbf{i}}, \tilde{\boldsymbol{\varphi}}\right) = 0$ of (15) is globally exponentially stable [15]. Therefore, objectives (6)–(8) are guaranteed. Correspondingly, asymptotic estimation and identification were achieved.

Implementation of the correction terms $v_a$ and $v_b$, given by (13), requires that parameter $\alpha$ is known. To overcome this problem we use implementable

$$\begin{aligned} v_a &= -\gamma_1\hat{\alpha}\tilde{i}_a + \gamma_1\omega\tilde{i}_b; \\ v_b &= -\gamma_1\hat{\alpha}\tilde{i}_b - \gamma_1\omega\tilde{i}_a, \end{aligned} \tag{17}$$

such that flux estimation error dynamics is given by

$$\begin{aligned} \dot{\tilde{\psi}}_a &= -\gamma_1\alpha\tilde{i}_a + \gamma_1\tilde{\alpha}\tilde{i}_a + \gamma_1\omega\tilde{i}_b; \\ \dot{\tilde{\psi}}_b &= -\gamma_1\alpha\tilde{i}_b + \gamma_1\tilde{\alpha}\tilde{i}_b - \gamma_1\omega\tilde{i}_a. \end{aligned} \tag{18}$$

For linearized equation (18), i.e. with $\left(\tilde{\alpha}\tilde{i}_a, \tilde{\alpha}\tilde{i}_b\right) = 0$, previous stability analysis is valid and one concludes that original system with $\left(\tilde{\alpha}\tilde{i}_a, \tilde{\alpha}\tilde{i}_b\right) \neq 0$ is locally exponentially stable.

A set of equations (9) and (13) with $v_a$ and $v_b$, given by (17), provides the resulting equations for adaptive controller and observer. Our scheme guarantees asymptotic identification of unknown motor parameters $\alpha$, $\sigma$, $\rho$ and adaptive estimation of the stator fluxes.

From the estimated values $\hat{\alpha}$, $\hat{\sigma}$, $\hat{\rho}$, derived with the predetermined $R_1$, the parameters $L = L_1 = L_2$, $L_m$ and $R_2$ are given as

$$\hat{L} = \frac{\hat{\rho}\hat{\sigma}}{\hat{\alpha}}; \; \hat{L}_m = \sqrt{\hat{L}\left(\hat{L} - \hat{\sigma}\right)}; \; \hat{R}_2 = \hat{\alpha}\hat{L}.$$

*Experimental studies.* The experiments are carried out using the Rapid Prototyping Station (RPS) at the National Technical University of Ukraine. As shown in Fig. 1, the RPS includes: (1) Induction motor with rated power 0.75 kW (two-pole, 380 V, 2.2 A, 314 rad/sec, 2.5 Nm, 50 Hz) and a loading DC-motor; (2) 20 A and 380 V three-phase PWM controlled inverter, operated at 10 kHz switching frequency; (3) DSP TMS320C32 controller which performs data acquisition, implements control algorithms with programmable tracing of selected variables; (4) Personal computer for processing, programming, interactive oscilloscope, data acquisition, etc. The motor speed is measured by a 1000 pulse/revolution optical encoder. The sampling time is 200 μsec.

To verify the identification algorithm (9), (13), (17) we set the zero initial conditions for the estimates of unknown parameters. This represents the most challenging case. For the adaptive controller we assign $k_i = 100$, $\gamma_1 = 1$, $\gamma_\alpha = 300$, $\gamma_\sigma = 0.001$ and $\gamma_\rho = 200$.

The experimental evolutions of the referenced currents $i_a^*(t)$, $i_b^*(t)$, stator voltages, flux estimates as well as current tracking and parameter identification errors are reported in Fig. 2. During $t\in$[0 1.1] sec, the induction motor operates as a motionless single-phase machine with $i_b^* = 0$ and $u_b = 0$. At $t$=1.1 sec, we apply $i_b^*$, and, motor rotates. The identification is performed for motionless and rotating motor. As it follows from Fig. 2, precise convergence and accurate identification is accomplished within ~3 sec.

The experimental studies are compared with the simulation results. Fig. 3 provides the errors evolution for the current, estimated flux and *characterizing* motor parameters. We analyze experimental results, given in Fig. 2, and, numeric studies as reported in Fig. 3. The documented findings illustrate precise correspondence, accuracy and matching. The reported results justify and substantiate our fundamental findings, analytic results, numerical studies and experimentally-justified practical identification technology.

*Sensorless control with identifyed parameters.* To validate our results, we test sensorless vector control of IM [16] using parameters given by identification algorithm. Fig. 4 documents the evolution of the angular velocity errors, as well as the torque component of the stator current $i_q$ during speed reference tracking with final speed values of 50 rad/sec (16 % of rated speed). The speed reference is applied at t=0.6 sec. At t$\in$[1 1.5] sec, the motor is loaded with the rated load torque 2.5 Nm. Very good dynamic and steady state performances as well as excellent capabilities are guaranteed in an expanded operating envelope, e.g., low angular velocity and up to rated loads. An overall effectiveness and practicality of the proposed identification algorithm in sensorless vector control scheme are substantiated.

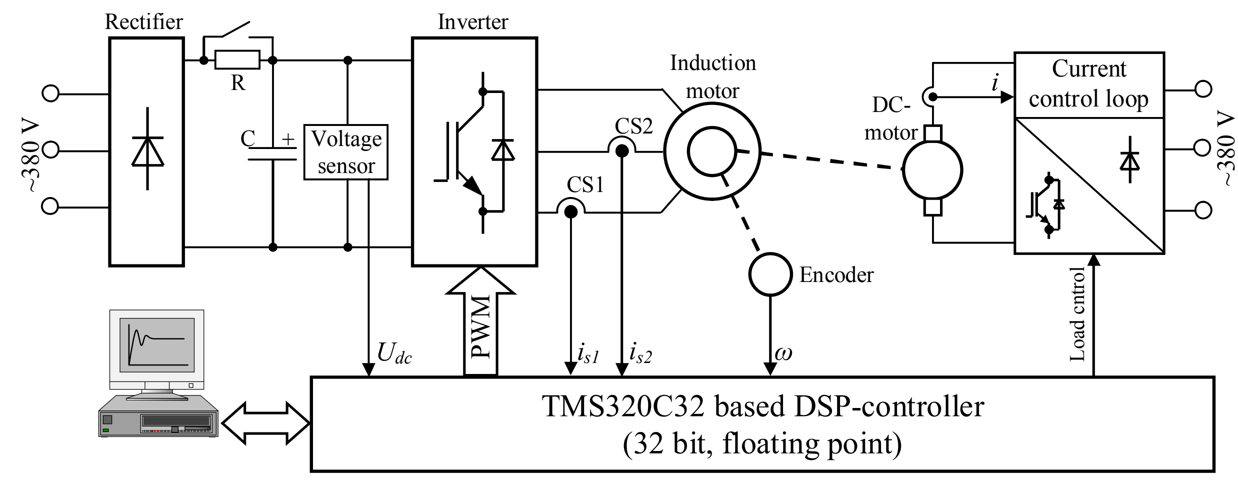


Figure 1 – Experimental setup of electromechanical system with induction motor

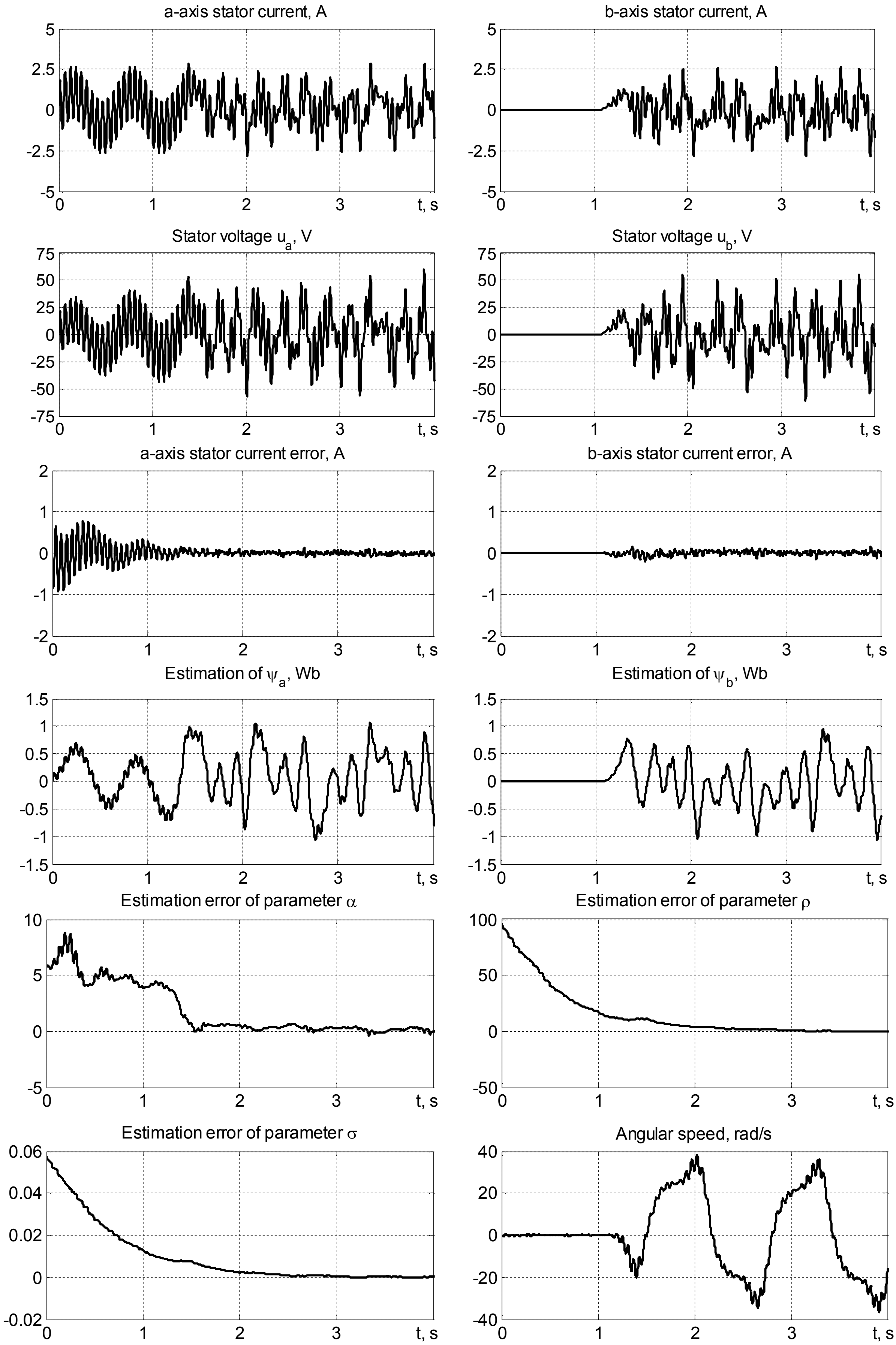


Figure 2 – Experimental results: evolutions of estimates

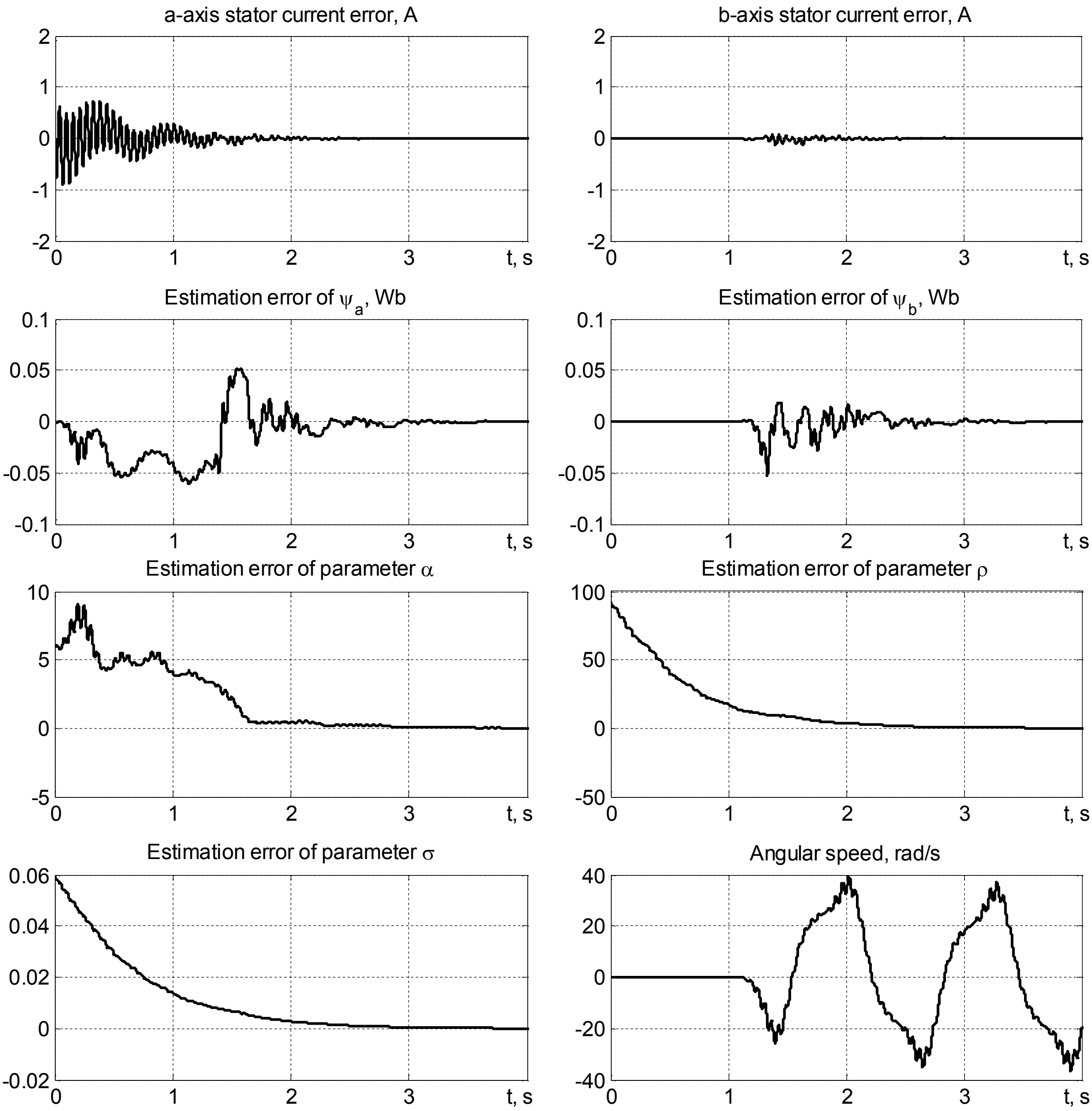


Figure 3 – Simulation results: errors evolution for the characterizing parameters and angular speed during the identification process

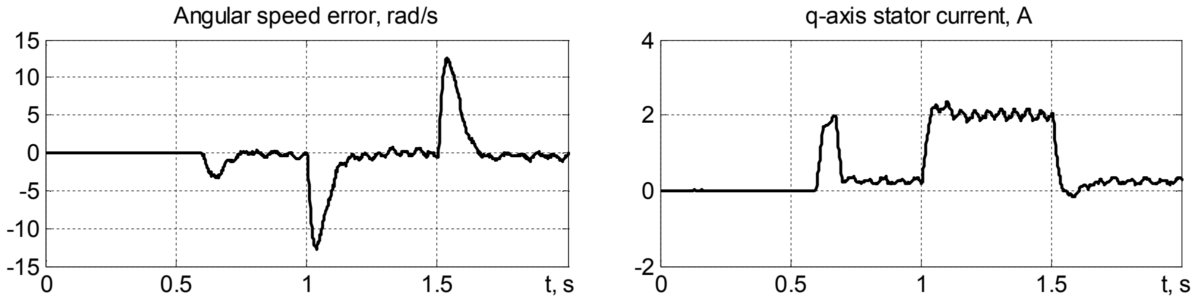


Figure 4 – Experimental transients in the closed-loop system with a sensorless vector control law

CONCLUSIONS. We synthesized and analyzed robust identification algorithms with estimation of not measured states to identify IM parameters. The fifth - order adaptive current tracking control algorithm is designed, which under suitable current references guarantee local exponential identification of three induction motor parameters, as well as estimation of the stator fluxes for motionless and free rotation motor operations conditions.

The experimental results in identification of motor parameters substantiated the proposed identification technology. The use of identified parameters in sensorless vector control experimentally proved the accuracy of identified parameters. Our findings are of a particular interest for high-performance systems, including sensorless vector control. Robust, near-real-time and fast convergence of unknown varying parameters to the actual values leads to design of superior systems which ensure optimal performance and capabilities.

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## АДАПТИВНОЕ РЕГУЛИРОВАНИЕ ТОКА СТАТОРА ДЛЯ ИДЕНТИФИКАЦИИ ПАРАМЕТРОВ АСИНХРОННОГО ДВИГАТЕЛЯ

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Синтезирован и экспериментально проверен новый алгоритм идентификации неизвестных параметров асинхронного двигателя для процедур самонастройки асинхронных электроприводов. С целью обеспечения асимптотической идентификации разработан адаптивный регулятор тока статора, который базируется на наблюдателе потокосцепления статора. Специально сформированные заданные траектории токов статора гарантируют локальную экспоненциальную идентификацию трех параметров асинхронного двигателя вместе с оценкой неизмеряемого потокосцепления статора как при неподвижном, так и при свободно вращающемся роторе. Представленные результаты экспериментальных исследований показывают, что разработанный алгоритм гарантирует высокую точность идентификации параметров и скорость сходимости ошибок в ноль, которые не уступают существующим в серийных изделиях, и может использоваться для реализации процедур самонастройки систем векторного управления.

**Ключевые слова**: асинхронный двигатель, идентификация, оценивание.

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