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Robust Positional Control System for Induction Actuator Using a Simplified Indirect Field Oriented Control

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Abstract: This study presents a robust positional control system for small power induction actuators. A simple control algorithm is obtained by performing field orientation through an estimated linearizing state feedback, avoiding any measurement or estimation of the rotor flux. The good performance of the system has been validated by digital simulation.

Key words: Induction actuator . Disturbance observer . Field oriented control . Position control

INTRODUCTION

If DC actuators are still very popular for motion control in industrial applications (machine tools, flexible production systems, robots), they are more frequently replaced by AC actuators in order to avoid the drawbacks associated to the mechanical commutation. On the other hand, AC actuators need much more complex control strategies if one requires high static and dynamic performances [1-4].

Field orientation allows to bring the dynamics of an induction motor almost similar to that of a DC machine. Consequently, some of the robust positional control strategies developed for DC actuators can also be used for induction actuators [5].

In this paper, a robust positional control system using an induction actuator is investigated. It consists of a position controller associated with an estimated decoupling state feedback which ensures field orientation in open loop. With this control strategy, the control algorithm is very simple and needs only a sensor of the actuator rotor position.

The good performance of the proposed control system is validated by digital simulation.

EQUATIONS OF THE INDUCTION ACTUATOR

In a generalized two axes (d,q) reference frame selected in such a way that the rotor flux along the q axis is equal to zero, the equation of an induction actuator are (with the stator currents, the rotor flux along the d axis and the speed of the reference frame as electrical state variables):

$$U_d = R_s i_{sd} + \sigma L_s \frac{di_{sd}}{dt} + \frac{M}{L_r}\frac{d\psi_{rd}}{dt} - \omega\sigma L_s i_{sq}$$

$$U_q = R_s i_{sq} + \sigma L_s \frac{di_{sq}}{dt} + \omega \frac{M}{L_r}\psi_{rd} + \omega\sigma L_s i_{sd}$$

$$M i_{sd} = \psi_{rd} + \frac{L_r}{R_r}\frac{d\psi_{rd}}{dt} \qquad (1)$$

$$\omega = \omega_m + \frac{M R_r}{L_r}\frac{i_{sq}}{\psi_{rd}}$$

$$T_{em} = \frac{M}{L_r}\psi_{rd} i_{sq}$$

In these equations

- R_s and R_r are respectively the resistances of the stator and the rotor d and q equivalent windings;
- L_s and L_r are respectively the inductances of the stator and the rotor d, q windings;
- M is the mutual inductance between the stator and the rotor d, q windings;
- s is the dispersion coefficient of the machine
- $[s=1-M^2/(L_sL_r)]$;
- ω is the angular speed of the d, q reference frame with respect to the actuator stator and θ its position;
- ω_m is the rotor angular speed and θ_m the angular position of the rotor with respect to the stator;
- ψ_{rd} is the rotor flux along the d axis, $\psi_{rd}=Mi_{sd}+L_r i_{rd}$
- T_{em} is the electromagnetic torque.

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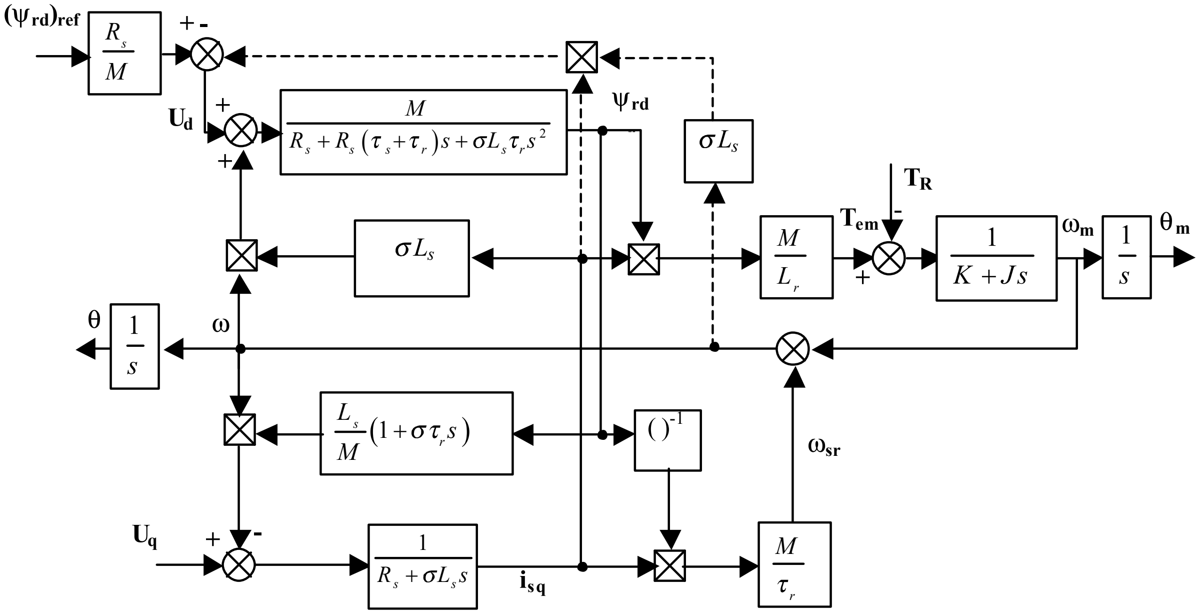

Fig. 1: Induction actuator block diagram

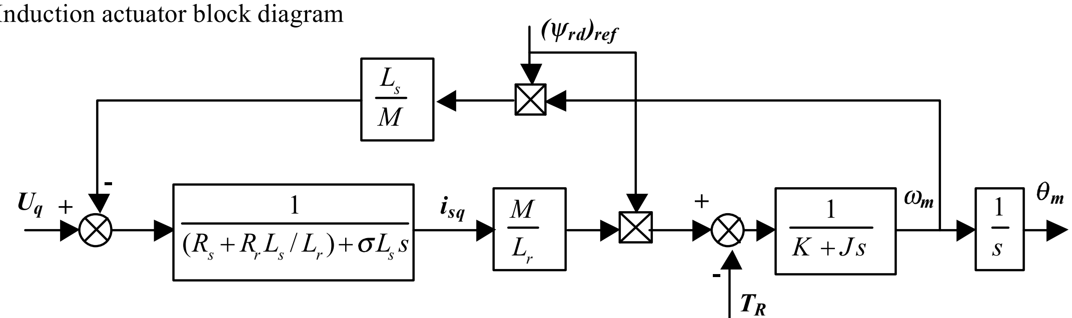

Fig. 2: Block diagram of the q axis after decoupling

The corresponding block diagram is shown in full line in Fig. 1. In this diagram T_R is the load torque, J is the inertia of the actuator rotor and of the mechanical load, K is the viscous torque coefficient, $t_s = L_s/R_s$ and $t_r = L_r/R_r$ are the stator and rotor electrical time constant and s is the Laplace operator.

CONTROL STRATEGY

It can be seen from Fig. 1 that, if the rotor flux along the d axis ψ_{rd} is kept constant, block diagram of the induction actuator becomes similar to that of a DC machine as far as concern the position control (Fig. 2).

It can also be seen from Fig. 1 that by introducing on the axis control input an appropriate state feed back (shown in broken line in the figure) which ensure the decoupling of the d axis from the q axis, it is theoretically possible to keep the flux ψ_{rd} constant, after a transient associated to its rise time, simply by considering [6]:

$$U_d = \frac{R_s}{M}(\psi_{rd})_{ref} - \omega\sigma L_s i_{sq} \tag{2}$$

with

$$\omega = \omega_m + \frac{MR_r}{L_r}\frac{i_{sq}}{(\psi_{rd})_{ref}} \tag{3}$$

Where, $(\psi_{rd})_{ref}$ is the constant reference value for the flux and $-\omega\sigma L_s i_{sq}$ the decoupling feed back.

In the proposed control algorithm, the computation of U_d is performed by using an estimated value of i_{sq}. this value is deduced from the rotor speed and from the value of the control voltage U_q by neglecting the electrical time constant associated to the q axis $[sL_s/(R_s+(L_s/L_r)R_r)]$:

$$i_{sq} = \frac{U_q - \omega_m \frac{L_s}{M}(\psi_{rd})_{ref}}{R_s + \frac{L_s}{L_r}R_r} \tag{4}$$

Owing to the uncertainties on the parameters, to the approximation made in the estimation of i_{sq} and to the discretisation inherent to every digital controller, some variation of the flux ψ_{rd} will appear.

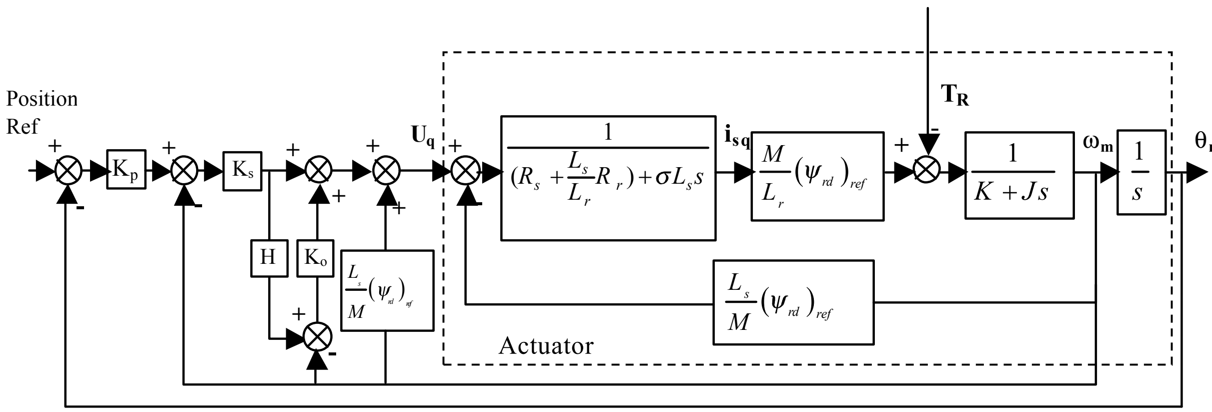

Fig. 3: Block diagram of the position control

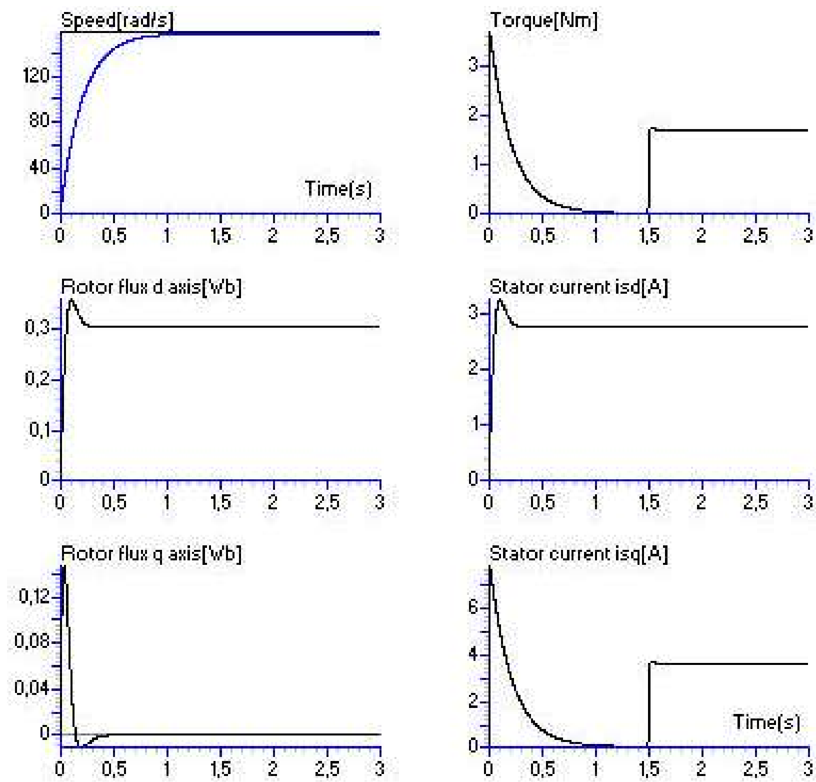

Fig. 4: Simulation of the dynamic behavior of the system

Nevertheless these variations can be considered as perturbation acting on the system shown in Fig. 2, so that their influence on the position control will be negligible if the position controller is robust [7].

The actuator rotor position is controlled through the q axis voltage U_q by using a regulator comprising a subordinate speed loop with a disturbance observer. As the block diagram of the actuator reduces to the linear SISO system shown in Fig. 3 (inside the frame in dotted line). When the rotor flux is constant, the synthesis of this controller is straightforward [8, 9]. The model *H* of the disturbance observer is deduced from the SISO equivalent system after compensating the emf $(\psi_{rd})_{ref}\,\omega_m L_s/M$ and by neglecting the viscous torque coefficient and the electrical time constant:

$$H = \frac{M(\psi_{rd})_{ref}}{(R_s L_r + R_r L_s)Js} \qquad (5)$$

As an integral action exists in the disturbance observer, the position and speed controllers may be simply proportional regulators. More details about the disturbance observer used are given in [6].

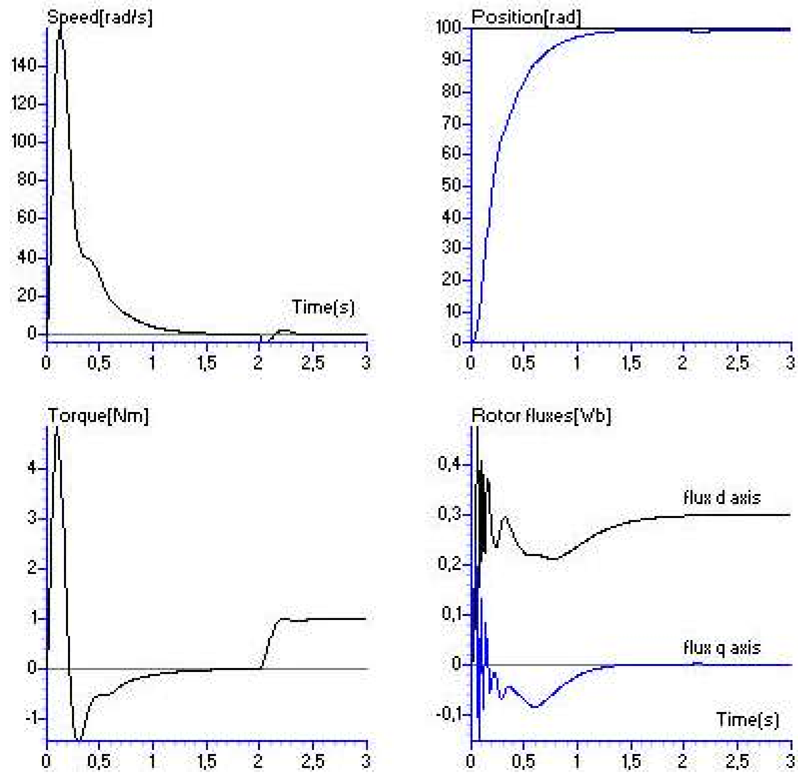

Fig. 5: Simulation of the dynamic behavior of the system when there is an error of 20% on R_r

Table 1: Induction machine data

Components	Rating values
Voltage	V = 110V
Power	P = 0.25 Kw
Speed	N_m =1500 r/min
Moment of inertia	J = 0.012 kg m^2
Coefficient of viscous friction	K = 0.0011Nms
Stator resistance	R_s =1.923 Ω
Rotor resistance	R_r =1.739 Ω
Stator inductance	L_s=0.1157 H
Rotor inductance	L_r=0.1154 H
Mutual inductance	M=0.1126 H

SIMULATED RESULTS AND DISCUSSIONS

The parameters of the used machine model are given in Table 1. Figure 4 shows the response of the actuator to a step in the speed reference and to the application of a positive step of torque (equal to the nominal torque) at *t=1.5s*. The interesting effect of the disturbance observer appears in figure, where the system is insensitive to the load variation.

Figure 5 show the response of the system to a step in the reference position and to the sudden application of a load torque equal to the rated torque at *t=2s*.

An error of *20%* on the rotor resistance has been introduced in the simulations. This simulations show the flux error when the speed decreases.

CONCLUSION

In this study, a robust positional control system for an induction actuator is presented. Owing to the chosen approach for the decoupling problem and the open loop control of the flux, the control algorithm is very simple and the good performance of the system has been confirmed by digital simulation.

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