# A STUDY OF LOW SPEED RANGE OBSERVER FOR EMBEDDED VECTOR ORIENTED CONTROL SYSTEMS

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## 1. INTRODUCTION

In the technical literature exist a large number of papers about the use of state observers in speed, position and torque control systems for asynchronous machines. The researches about the influences due to machines parameter changes on drive systems are not so divers.
This study has been performed on a rotor flux oriented control system with a given induction motor, shown in Fig.1.

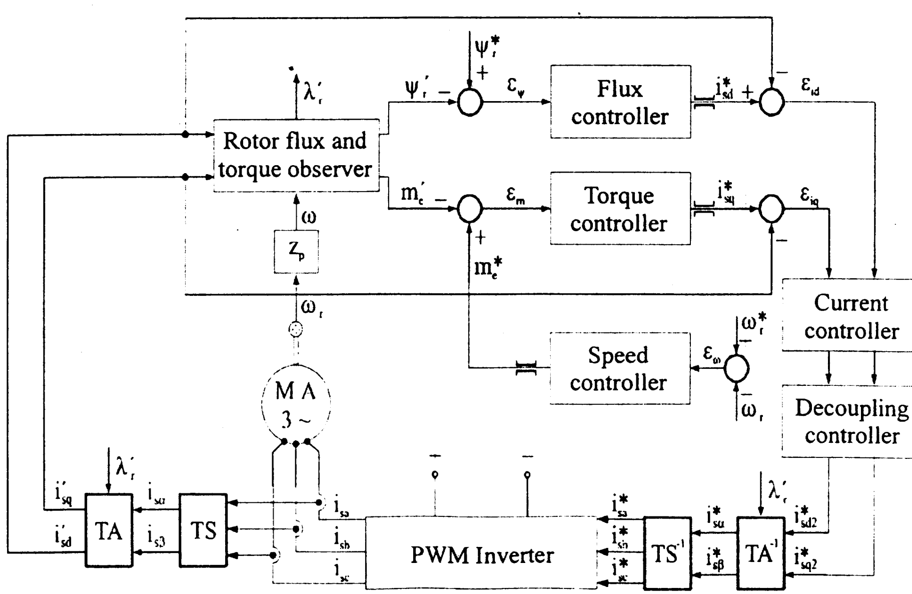


Fig. 1. The rotor flux oriented induction motor drive

The simulated control system uses a machine model, which takes into account the main flux paths saturation and the rotor resistance variation due to the increase of the rotor temperature.

For the rated speed range of the machine, the control system uses the classical type of the flux and torque observer, having as inputs the flux oriented stator current components and the rotor angular velocity, as is showed in Fig. 1.

The use of this type of flux and torque estimation has the disadvantages that the two current components $i'_{sd}$, $i'_{sq}$ can have incorrect values, being estimated themselves by meaning of calculated angular position $\lambda'_r$ of rotor flux phasor. In principle, this disadvantage can be avoided by using as inputs of the observer, the measured values of the stator current components $i_{s\alpha}$, $i_{s\beta}$ in a fixed reference frame and the angular velocity ω of the machine rotor [1]. But, even in this case the work of the observer is influenced by the rotor resistance variations, due to the rotor heating, by means of the rotor time constant $T'_r = L'_r / R'_r$. At least, this disadvantage can be avoided by developing a flux observer that uses more informations as measured values of the stator voltages [1, 2].

## 2. THE FLUX OBSERVER FOR THE LOW SPEED RANGE

It can be deduced an appropriate observer model, which shall run, in principle, towards zero speed of the machine rotor, if the measured values of the stator voltages and of the rotor angular velocity shall be considered as inputs. This new model has been deduced based on observations from [1]. The achievement of this observer is based on the machine equations having the fluxes as state variables. Thus, in a fixed reference frame (α-β), for the squirrel caged motor, the following can be written:

$$\sigma T'_s \frac{d\Psi'_{s\alpha}}{dt} + \Psi'_{s\alpha} = \frac{L'_m}{L'_r} \Psi'_{r\alpha} + \sigma T'_s u_{s\alpha}, \tag{1}$$

$$\sigma T'_s \frac{d\Psi'_{s\beta}}{dt} + \Psi'_{s\beta} = \frac{L'_m}{L'_r} \Psi'_{r\beta} + \sigma T'_s u_{s\beta}, \tag{2}$$

$$\sigma T'_r \frac{d\Psi'_{r\alpha}}{dt} + \Psi'_{r\alpha} = \frac{L'_m}{L'_r} \Psi'_{s\alpha} - \sigma T'_s \omega \Psi'_{r\beta}, \tag{3}$$

$$\sigma T'_r \frac{d\Psi'_{r\beta}}{dt} + \Psi'_{r\beta} = \frac{L'_m}{L'_r} \Psi'_{s\beta} + \sigma T'_s \omega \Psi'_{r\alpha}, \tag{4}$$

where, the following shall be used as notations:

$$\sigma' = 1 - \frac{L'^2_m}{L'_s L'_r}; \; T'_s = \frac{L'_s}{R'_s}; \; T'_r = \frac{L'_r}{R'_r}, \qquad \text{(5 a, b, c)}$$

A possible estimation of the electromagnetic torque shall be made, in this case, by the expression:

$$m'_e = \frac{3}{2} \cdot \frac{z_p L'_m}{\sigma' L'_s L'_r} \cdot \left( \Psi'_{s\beta} \cdot \Psi'_{r\alpha} - \Psi'_{s\alpha} \cdot \Psi'_{r\beta} \right), \quad (6)$$

The results of simulating the above presented observer are given in Fig. 2, assuming that its parameters values coincide with the values of the real parameters corresponding in the machine.

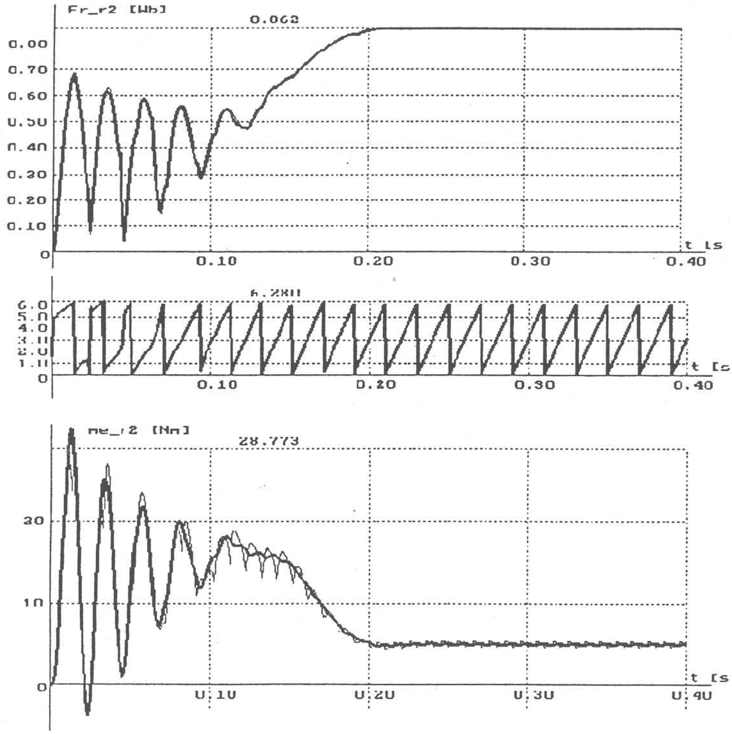


Fig. 2 The estimated amplitude $\Psi'_r$ (a) and angular position $\lambda'_r$ (b) and the estimated torque $m'_e$ (c), for the observer at low speed range.

At this type of observer it is remarkable that the phase error (see eq. (7)) has zero value, namely a correct rotor flux orientation can be obtained even at low speed range.

## 4. STUDY OF THE OBSERVER SENSITIVITY

An evaluation of the observer model shall be made in this paragraph, based on the study of the deviations which occur between the values of the real parameters in the machine and the equivalent parameters present in the observer structure. This aspect was and is still the subject of many researches. Assuming that the input quantities of the observers are correctly measured, without errors, in practice the following issues remains of outmost importance: the errors caused by the slow variations of the stator and rotor resistances, due to the fluctuation of the temperature, as well as the errors caused by the fast variations of the $L_m$ , $L_{\sigma s}$ and $L_{\sigma r}$ inductances, due to the magnetic circuits saturation of the $\Psi_m$ ,$\Psi_{\sigma s}$ , $\Psi_{\sigma r}$ fluxes.
The study of the observer sensitivity to the parameter deviations can be made using some estimation quantities for the deviations which occur between the calculated output quantities and the real ones, equivalent in the machine.
In the case of the rotor flux estimation, the amplitude error $\in\Psi_r$ and the phase error $\in\lambda_r$ shall be used according to:

$$\Delta\Psi_r = \Psi_r - \Psi_r'; \quad \Delta\lambda_r = \lambda_r - \lambda_r' \qquad (7)$$

At the torque estimation the following error quantity shall be used:

$$\Delta m_e = m_e - m_e' \qquad (8)$$

In (7) and (8) the notations with (') refer to estimated quantities.

The simulation results of the above defined error quantities are given in Fig.3 for the observer behavior. The simulations were made for the starting process of the motor given in the Appendix, with a load torque $m_L = 5$ Nm, considering different cases of the incorrect adjustment of the observers parameters. Further the results of this study shall be presented.

The observer used at low speed range is influenced in its behavior by the $R_s'$, $R_r'$, $L_s'$, $L_r'$ parameters.
On left column in Fig.3 the errors caused by rotor resistance variation is shown. Both directions of the incorrect adjustment cause the same behavior, namely: in steady state null average values are obtained for all error quantities. In the right column of Fig.3 the case of the incorrect and simultaneous adjustment of the $L_m'$, $L_{\sigma s}'$ and $L_{\sigma r}'$ parameters is presented. These variations, one way or another, which are actually modifications of $L_s'$, $L_r'$ inductances, cause insignificant stationary errors of flux and torque overestimation with 20%.
At this type of observer it is remarkable that in all the cases of its parameter deviations, the stationary phase error has zero value, namely a correct rotor flux

orientation is obtained. At the same time in the low speed range, the maximum values of the estimation errors are insignificant.

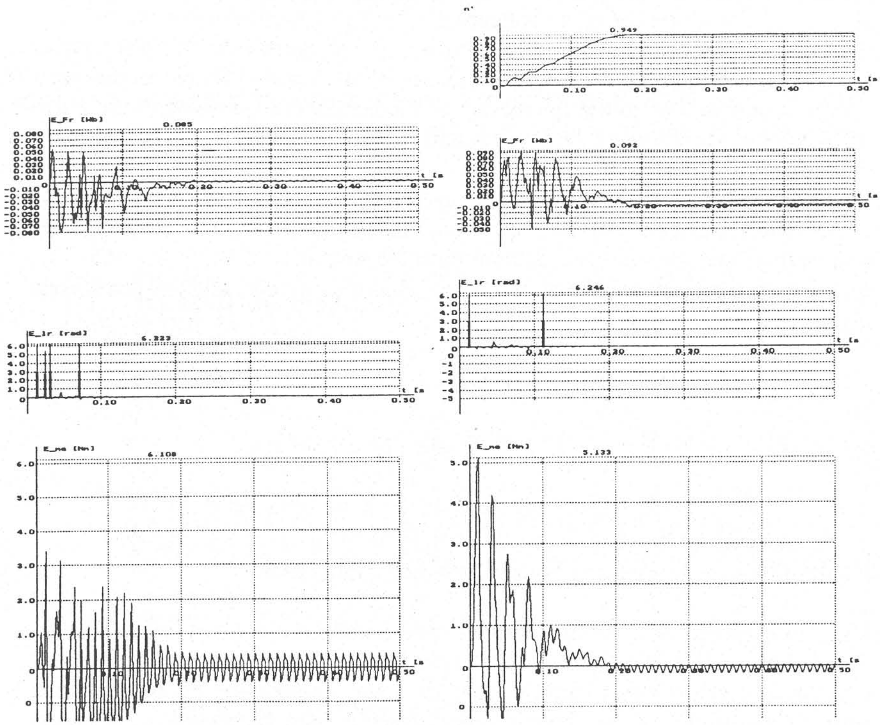

Fig. 3. The $\Delta\Psi_r$, $\Delta\lambda_r$ amplitude and phase errors of the rotor flux and $\Delta m_e$ torque error, in case of the observer at low speed range, at incorrect adjustment of the rotor resistance with $\pm$ 20% (left column) of the $L'_m$, $L'_{\sigma s}$, $L'_{\sigma r}$ inductances with ±10% (right column)

## 4. CONCLUSIONS

This type of observer has a complex structure which leads to a high cost of its achievement. But, at the correct adjustment of the $R'_s$, $R'_r$, $L'_s$, $L'_r$ parameters which influence its diagram, his behavior is remarkable: both in dynamic regime and in stationary regime, the rotor flux and electromagnetic torque estimation errors are practically null.

The present study, where a significant decrease of the maximum values of $\Delta\Psi_r$, $\Delta\lambda_r$, $\Delta m_e$ errors is obtained, points out its main advantage: a very appropriate behavior in low speed range, close to zero. It can be concluded that though its diagram is apparently influenced by the variation of many parameters, the total effect of their deviations leads to a relatively well-balanced behavior.
Finally, we consider that for the small power induction motors the variation of the $R_s$ or $R_r$ parameters values does not significantly influence the observers behavior in the feedback loops of the rotor flux oriented control systems. But the adaptation of the observer at the inductance parameters deviations, due to the magnetic saturation, is very important, providing good dynamic performances of the whole control system.

## 5. REFERENCES


[1] Schröder, D.: Elektische Antriebe (Electrical Drives) Springer Verlag Berlin, vol. I, II, 1994.

[2] Apostoaia, C. M., Scutaru, Gh.: Flux and Speed Control in a Field-oriented System of an Induction Motor, Proceedings of OPTIM'96 Conference, May 15-17, "Transilvania" University of Brasov, 1996, Vol V, pp. 1455-1460

[3] Ungar, R.: Simulation research of systems used in automatic measurement, identification and control – Doctoral thesis, "Transilvania" University of Brasov, 1997


## 6. APPENDIX

The induction motor data:
$P_N = 1.1$ kW; $z_p = 2$; $m_{eN} = 5$ Nm;
$n_0 = 1500$ rot/min; $J = 0.0106$ kg m$^2$;
$R_s = 7.78\ \Omega$; $R_r = 7.10\ \Omega$;
$L_{\sigma s} = 0.037$ H; $L_{\sigma r} = 0.02$ H; $L_m = 0.45$ H.