# A Robust Nonlinear Luenberger Observer for the Sensorless Control of SM-PMSM: Rotor Position and Magnets Flux Estimation

Nicolas Henwood[1,2], Jérémy Malaizé[1], and Laurent Praly[2]

[1]Control, Signal and System Department, IFP New Energy, FRANCE
[2]Systems and Control Centre, MINES ParisTech, FRANCE

***Abstract*—For a Surface-Mounted Permanent Magnet Synchronous Motor (SM-PMSM) with currents and voltages as only measurements, we propose a robust nonlinear Luenberger observer estimating both the rotor position and the magnets flux. The robustness of the observer to the mechanical load connected to the machine shaft comes from an appropriate choice of coordinates, while its robustness to the physical parameters of the machine is studied and reveals satisfactory results. We prove that observers may be designed, i.e. the system is said to be observable, under the only assumption that the rotor speed is non-zero. Experimental results assess its validity.**

## I. Introduction

Designing high-level control algorithms of SM-PMSM drives requires an accurate knowledge of the rotor position to control the torque delivered by the machine. This knowledge could of course be obtained through a position sensor. However, cost and volume reduction, wires removal and an increased reliability are all arguments in favor of position sensorless control of SM-PMSM drives, using an estimation of the rotor position.

This estimation is in general obtained through observers, with voltages and stator currents as only available measurements. However, other parameters, namely the physical parameters of the machine (stator resistance, inductance, magnets flux) and those related to the mechanical load connected to its shaft (inertia, friction, load torque), are also involved in the observer equations. Therefore, the challenge related to the rotor position estimation may come from its robustness to these data, which are often changing dynamically or are unknown. For instance, the stator windings resistance and the flux created by the rotor magnets are temperature dependant parameters and undergo changes due to the motor heating.

A lot of publications deal with the position estimation for sensorless control of PMSM. Among them, a few are also interested in the impact of such parameter variations on the estimated position, and most of them design estimators robust to stator resistance uncertainties. For example, [1] augments its reduced-order position observer for motion-sensorless salient PMSM drives with a stator resistance adaptive law to improve the robustness at low speed, while [2] develops an online identification method of the resistance to make the control of the PMSM robust to resistance uncertainties. The sensorless control algorithms, based on a back-EMF space-vector estimation in [3] and on an Extended Kalman Filter in [4], are also quite robust to the resistance variations. If [1] and [3] show good robustness to inductance variations too, magnets flux uncertainties cause relatively important position errors in [1], while this magnets flux is assumed to be constant in [3]. Concerning [4] and the phase-locked-loop observer proposed in [5], they also show good robustness to two parameters (resistance and flux for [4], inductance and flux for [5]), but do not consider the robustness to the third physical parameter of the machine. As for [6], not only focusing on the robustness to the physical parameters of the machine, it formulates a linear model-based observer, independant from the parameters related to the mechanical load, robust both to the mechanical parameters and, *via* an adaptive velocity correction, to magnets flux uncertainties.

In this paper, we propose an observer for estimating both the rotor position and the magnets flux of a SM-PMSM in a robust way, with currents and voltages as only measurements. On the one hand, the robustness to the mechanical load, i.e. to inertia, friction and load torque, is obtained *via* the use of a specific two-dimensional subsystem of the motor modeling [7], completely decoupled from the mechanical behavior of the motor. On the other hand, the robustness to the physical parameters of the machine, and more precisely the impact of inductance and stator resistance biases on the estimations, is studied and shows very little dependency. As for the robustness to the magnets flux variations, it is ensured by the combined position and flux estimation. Note that the magnets flux estimation has a double interest: if we are in this paper interested in its ability to make the position estimation robust to the flux uncertainties, it can also be used to estimate the rotor temperature variations, the flux created by the magnets varying linearly with the temperature variations of these magnets.

The structure of this paper is as follows. Section II first presents the two-dimensional subsystem of the SM-PMSM, that we build a nonlinear Luenberger observer on in section IV, after having established the observability of the model in section III. Experimental and also some simulation results are then given in section V to assess the relevancy of the proposed observation scheme.

978-1-4673-2421-2/12/$31.00 ©2012 IEEE 

## II. SM-PMSM MODELING

In this section, we introduce the two-dimensional subsystem of the SM-PMSM model, that is used to design our nonlinear Luenberger observer. This subsystem has been proposed in [7]. An observer has been proposed and studied theoretically in [8], experimentally in [9] and more recently in [10] to design an observer of the rotor position with currents and voltages as only measurements. This two-dimensional subsystem has the advantage of being completely decoupled from the mechanical behavior of the motor, and thus to make possible the position estimation without necessary knowledge about inertia, friction or load torque.

In the following, the modeling of SM-PMSM in the stationnary frame is considered. By making use of the Faraday's and Ohm's Laws, this modeling may be expressed as:

$$v = Ri + \dot{\Psi} \,, \tag{1}$$

where $\Psi$ is the total flux encompassed by the windings, $i$ and $v$ are respectively the currents within these windings and the voltages at the SM-PMSM terminals, and $R$ is the stator windings resistance. In the $\alpha\beta$-frame, the quantities $\Psi$, $i$ and $v$ are two dimensional vectors, and the total flux is given by

$$\Psi = Li + \Phi \begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix} , \tag{2}$$

where $\theta$ is the rotor electrical phase, $\Phi$ is the flux created by the rotor magnets and $L$ is the inductance. Let's also introduce $\omega$ the electrical pulsation, which is the derivative of $\theta$. Note that the total flux $\Psi$ is constrained to evolve on a circle with radius $\Phi$ and time-varying center $Li$, since it satisfies the relation:

$$|\Psi - Li|^2 - \Phi^2 = 0 \tag{3}$$

It is further assumed that the currents $i$ are measured, while the control inputs $v$ are known. This paper is devoted to the construction of an observer for the flux due to the magnets $\Phi$ and the electrical phase $\theta$, from the only knowledge of $i$ and $v$, and under a coarse knowledge of the resistance $R$ and the inductance $L$. The proposed scheme consists in first estimating the total flux $\Psi$, and then extracting the flux created by the magnets and the electrical phase from it. Furthermore, the impact of the coarse knowledge of $R$ and $L$ on the observation is studied and quantified.

## III. INSTANTANEOUS OBSERVABILITY

Before building an observer based on the previously derived model, it is necessary to determine if it is possible to observe the quantities, collected in a state $\chi$, that we want to estimate. This is done through an observability study. Note that, since the system is nonlinear, we have to use here another method than the one consisting in studying the rank of the observability matrix.

Let us remind that a system is said to be observable if two different states can be distinguished by looking at the output during a finite time interval. The instantaneous observability is a stronger property, thus implying the observability, which expresses the fact that this time interval can be as small as we want.

In this section, we study the instantaneous observability of the state $\chi = \begin{pmatrix}\Psi^T & \Phi\end{pmatrix}^T$, satisfying the following dynamic, notably given by (1):

$$\begin{aligned} \dot{\Psi} &= v - Ri \\ \dot{\Phi} &= 0 \,, \end{aligned} \tag{4}$$

knowing the inputs $(i, v)$, approximate values of the physical parameters $R$ and $L$, and the measured output:

$$y = |\Psi - Li|^2 - \Phi^2 \,. \tag{5}$$

Thus, according to the constraint (3), $y$ is identically zero.

Note that, in (4), we assume that the temperature dependant flux $\Phi$ varies slowly with time, which is realistic since the thermal time constant is very large compared to the electric one. We will also use the fact that this flux $\Phi$ is strictly positive.

We choose to prove the instantaneous observability of the system (4,5) by showing it is differentially observable, a stronger property describing the possibility to express the state as a function of the output and a finite number of its derivatives. To that extent, let the vector $H_k(\chi, t)$ be made of $y$ and its successive derivatives, along the system solution, up to order $k-1$. Then, according to [11, Definition 4.2], the system is said to be differentially observable of order $k$ if $H_k$ is an injective mapping, that is to say that we can determine the state in a unique way from y and its derivatives. Let us now prove this differential observability.

**Proposition 1.** *The state* $\chi = \begin{pmatrix}\Psi^T & \Phi\end{pmatrix}^T$*, where* $\Phi > 0$*, satisfying the dynamic (4), knowing the inputs* $(i, v, R, L)$ *and the output (5), is differentially observable of order 3 if and only if* $\omega \neq 0$.

*Proof:* We aim at showing that the function $(\chi \mapsto H_3(\chi, t))$ is injective. Let us start by determining the derivative components of $H_3 = \begin{pmatrix}y & \dot{y} & \ddot{y}\end{pmatrix}^T$:

$$\begin{aligned} y &= |\Psi|^2 - 2L\Psi^T i - \Phi^2 + g_1 \\ \dot{y} &= 2\Psi^T \left( -Ri + v - L\dot{\widehat{i}} \right) + g_2 \\ \ddot{y} &= 2\Psi^T \left( -R\dot{\widehat{i}} + \dot{v} - L\ddot{\widehat{i}} \right) + g_3 \end{aligned}$$

where $(g_1, g_2, g_3)$ are functions of time, not depending on $\chi$, and whose expressions are of no use in the observability study. Let us now prove the injectivity of $H_3$ by contradiction. For this purpose, let us assume that two different states $\chi = \begin{pmatrix}\Psi^T & \Phi\end{pmatrix}^T$ and $\bar{\chi} = \begin{pmatrix}\bar{\Psi}^T & \bar{\Phi}\end{pmatrix}^T$ have generated the same output and derivatives. Then we have $H_3(\bar{\chi}, t) - H_3(\chi, t) = 0$ and thus:

$$\begin{pmatrix} \frac{\bar{\Psi}+\Psi}{2} - Li & v - Ri - L\dot{\widehat{i_\alpha}} & \dot{v} - R\dot{\widehat{i}} - L\ddot{\widehat{i}} \\ -\frac{1}{2} & 0 & 0 \end{pmatrix}^T \delta = 0 \,,$$

where $\delta^T = \left( (\bar{\Psi} - \Psi)^T \quad \bar{\Phi}^2 - \Phi^2 \right)$. Then, using (1) and (2), we get:

$$\begin{pmatrix} \frac{(\bar{\Psi}-\Psi)^T}{2} + \Phi a_1 & -\frac{1}{2} \\ \omega a_2 & 0 \\ \omega^2 a_1 - \dot{\omega} a_2 & 0 \end{pmatrix} \delta = 0 \,,$$

with $a_1 = (\cos\theta \quad \sin\theta)$ and $a_2 = (-\sin\theta \quad \cos\theta)$, which is equivalent to

$$\begin{pmatrix} \cos\theta & \sin\theta & -\frac{1}{2} \\ -\omega\sin\theta & \omega\cos\theta & 0 \\ \dot{\omega}\sin\theta & -\dot{\omega}\cos\theta & \frac{\omega^2}{2} \end{pmatrix} \delta' = \begin{pmatrix} -\frac{1}{2\Phi} \\ 0 \\ \frac{\omega^2}{2\Phi} \end{pmatrix} , \tag{6}$$

with:

$$\delta' = \frac{\delta}{\left|\bar{\Psi} - \Psi\right|^2} \,,$$

where the denominator is non zero since $\bar{\chi} \neq \chi$. Moreover, $\Phi$ being strictly positive, the numerators are also non zero.

If the electrical pulsation $\omega$ is zero, the system (6) has an infinite number of solution. On the other hand, if $\omega \neq 0$, it is easy to verify that the system (6) has no solution, even if $\dot{\omega} = 0$.

Thus, if $\omega \neq 0$, the system $H_3(\bar{\chi}, t) = H_3(\chi, t)$ has no solution if $\bar{\chi} \neq \chi$. This does mean that $H_3(\bar{\chi}, t) = H_3(\chi, t) \Rightarrow \bar{\chi} = \chi$. Therefore, the function $(\chi \mapsto H_3(\chi, t))$ is injective and the state $\chi$ is differentially observable of order 3 if $\omega \neq 0$. On the contrary, if $\omega = 0$, the state is not differentially observable of order 3. Note that if $\omega$ is zero but one of its derivatives is non zero, the system may still be differentially observable but with a higher order.

■

## IV. Nonlinear Luenberger observer

Since, under the conditions explained in Proposition 1, the state $\chi = \begin{pmatrix}\Psi^T & \Phi\end{pmatrix}^T$ is observable instantaneously, it is possible to build an observer on it. Due to the nonlinearity of the model, this observer must be nonlinear. Therefore, in this section, we propose to implement a nonlinear Luenberger observer for $\chi$.

### A. Observer principle

According to [12], this observer takes the following form:

$$\begin{aligned} \dot{z}_j &= \mu_j (z_j - y) + \eta_j, \quad 1 \leq j \leq m \\ \widehat{\chi} &= T^\star (z_1, \ldots, z_m, t) \,, \end{aligned} \tag{7}$$

with $m$ complex numbers with negative real parts $\mu_j$ and state components $z_j$ in $\mathbb{C}$, with $\eta_j$ signals to be defined depending on currents and voltages, and with $T^\star$ a function to determine.

The goal is thus to estimate the state from the components $z_j$. To that extent, we need to express, in a first place, the components $z_j$ in terms of the state, i.e. to determine the functions $T_j$ so that $z_j = T_j(\chi)$. If these functions, solutions of partial differential equations, may in the general case be difficult to determine, they have in our case a quite simple polynomial form. In a second place, since we look for $T^\star$, which conversely expresses the state in terms of the $z_j$ components, we need to solve in $\chi$ the equations $z_j = T_j(\chi)$. However, due to unmodelled effects and/or noise, these equations may not have a solution. Therefore, we transform the problem into a minimization problem, so as to find, from several equations, the state that best matches.

### B. Observer design

The design of the observer consists in choosing the eigenvalues $\mu_j$, the number $m$ of these eignenvalues and the function $T^\star$. Concerning the choice of $m$, $2m$ must be larger than or equal to the size of $\chi$, that is to say 3, if the $\mu_j$ have non zero imaginary parts. If the $\mu_j$ are real, we must have $m \geq 3$. As for the choice of the observer eigenvalues $\mu_j$, it depends on the system requirements, which are essentially rapid response and stable estimation. There is indeed a compromise to make between the speed of convergence and the damping of the estimated signal: the more negative the real parts of the eigenvalues, the faster the estimation convergence, but the noisier the estimation in return. Lastly, the determination of the function $T^\star$ represents the main challenge of the design. As previously mentionned, this determination is done in two steps: determination of the functions $T_j$ verifying $z_j = T_j(\chi)$ and resolution of these equations in $\chi$, using a minimization problem.

#### 1) First step - Determination of $T_j$:

The implementation of the theory developped in [12] and applied in a similar case in [7] leads to the following polynomial form of the functions $T_j$:

$$T_j = |\Psi|^2 - \Phi^2 + c_j^T \Psi \,, \tag{8}$$

the two dimensional vector $c_j$ being defined by (10).

#### 2) Second step - Resolution of the minimization problem:

We have to solve the following minimization problem:

$$\widehat{\chi} = \arg\min_{\chi} \sum_{j=1}^{m} |T_j(\chi) - z_j|^2 \tag{9}$$

However, this cost of dimension 3 is not easy to minimize, since $T_j(\chi) - z_j$ is nonlinear in the three components of the state. Fortunately, we may simplify this with a change of variables to get a linear expression of dimension 2 instead, in which only the two components of $\Psi$ appear (12), the estimated magnets flux $\widehat{\Phi}$ being obtained from $\widehat{\Psi}$ (17). This modified minimization is thus easily performed online by inverting a 2x2 matrix (16). Moreover, we also get an estimate of the position from $\widehat{\Psi}$ (18).

### C. Implementation

Concretely, the coefficients of the vector $c_j$, appearing in the expression of $T_j$ (8), are extra state components of the observer with dynamics:

$$\dot{c}_j = \mu_j c_j + 2i(\mu_j L + R) - 2v \,, \tag{10}$$

and the expressions of the $\eta_j$, appearing in the differential equations verified by the $z_j$ (7), are given by:

$$\eta_j = c_j^T(v - Ri) + \mu_j L^2 |i|^2 . \qquad (11)$$

Concerning the simplification of the minimization problem, the change of variables leads to the following problem:

$$\widehat{\Psi} = \arg\min_{\Psi} \sum_{j=1}^{m} \left|\check{c}_j^T \Psi - \check{z}_j\right|^2 , \qquad (12)$$

with:

$$\begin{aligned} \check{c}_j &= c_j - \frac{1}{m}\sum_{l=1}^{m} \mathrm{Re}(c_l) \\ \check{z}_j &= z_j - \frac{1}{m}\sum_{l=1}^{m} \mathrm{Re}(z_l) . \end{aligned} \qquad (13)$$

In the case where the $\mu_j$ are real, we notice that the solution of this problem can be obtained by solving a linear Least Squares problem:

$$\widehat{\Psi} = \arg\min_{\Psi} |A\Psi - B|^2 = (A^T A)^{-1} A^T B , \qquad (14)$$

with:

$$A = \begin{pmatrix} \check{c}_1^T \\ \vdots \\ \check{c}_m^T \end{pmatrix} \quad \text{and} \quad B = \begin{pmatrix} \check{z}_1 \\ \vdots \\ \check{z}_m \end{pmatrix} . \qquad (15)$$

Besides, if the imaginary parts of the $\mu_j$ are non zero, the solution becomes:

$$\widehat{\Psi} = (A^T \bar{A} + \bar{A}^T A)^{-1} (A^T \bar{B} + \bar{A}^T B) \qquad (16)$$

where $\bar{A}$ stands for the conjugate of $A$. Thus, in both cases, we have to invert a 2x2 matrix, which can easily be done online.

From this estimation of the total flux, we finally deduce those of the magnets flux and of the position thanks to (2):

$$\widehat{\Phi} = \left|\widehat{\Psi} - Li\right| \qquad (17)$$

$$\begin{pmatrix} \cos\widehat{\theta} \\ \sin\widehat{\theta} \end{pmatrix} = \frac{\widehat{\Psi} - Li}{\left|\widehat{\Psi} - Li\right|} . \qquad (18)$$

Figure 1 summarizes the implementation procedure:

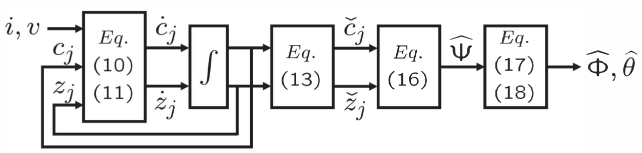



Fig. 1. Luenberger observer implementation

## V. Results

### A. Experimental setup

The performances of the previously designed nonlinear Luenberger observer are experimentally validated on a testbed made up of two PMSM, connected through a shaft. This setup is illustrated in Figure 2. These two drives have respective rated power of 1.7kW and 2.2kW, and similar rated speed of 6000rpm. The former is intended to deliver a desired torque, while the latter is intended to control the rotation speed of the shaft. Table I presents the values of the first motor parameters, which will be used as benchmarks in this section. Also note that this machine is equipped with a fine position sensor used to compare the relevancy of the estimated position to its actual value.

Fig. 2. Experimental setup

TABLE I
ELECTRIC MOTOR PARAMETERS

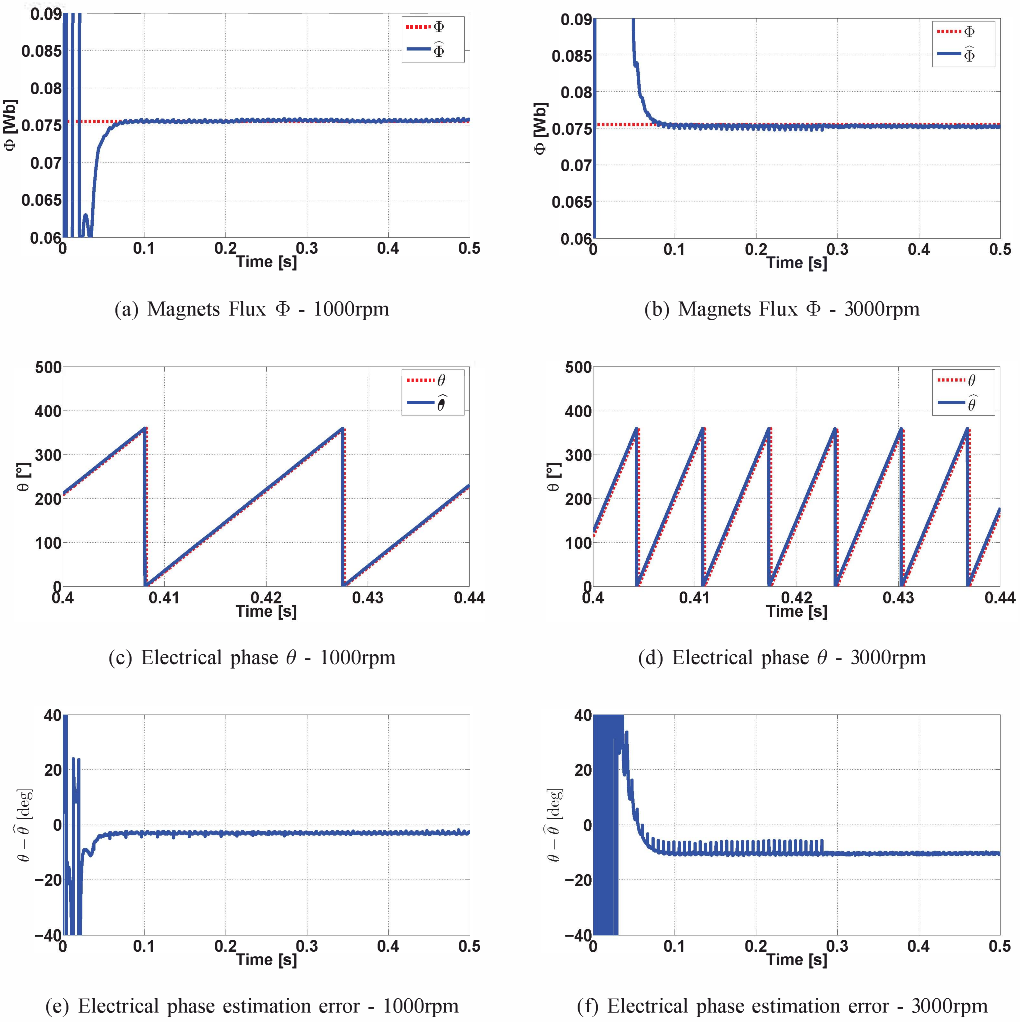
| | |
|---|---|
| stator resistance $R$ | 0.25 Ω |
| magnets flux $\Phi$ | 0.0755 Wb |
| inductance $L$ | 0.77 mH |
| number of poles pairs $p$ | 3 |

### B. Experimental results

The experimental results of the implementation of the nonlinear Luenberger observer on the previously mentioned SM-PMSM are given in Figure 3. Note that the chosen values of the resistance $R$ and inductance $L$, which are inputs of the observer, are those of Table I.

Figures 3(a), 3(c) and 3(e) present the results when the motor is operated at 1000rpm, while Figures 3(b), 3(d) and 3(f) present the results at 3000rpm. In Figures 3(a) to 3(d), the estimated magnets flux $\widehat{\Phi}$ and electrical phase $\widehat{\theta}$ (blue solid lines) are respectively compared to the reference value of $\Phi$ (cf. Table I) and to the electrical phase, acquired with the fine position sensor, that we assume to be the exact phase (red dotted lines).

We notice that the estimation of the magnet flux is satisfactory, since it converges towards the reference values, regardless of the motor speed. The estimation of the phase, almost fitting with the exact phase, is also pretty satisfactory. However, we remark the existence of a slight error between the estimated and exact phases, which is plotted in Figures 3(e) and 3(f).




(a) Magnets Flux Φ - 1000rpm

(b) Magnets Flux Φ - 3000rpm

(c) Electrical phase $\theta$ - 1000rpm

(d) Electrical phase $\theta$ - 3000rpm

(e) Electrical phase estimation error - 1000rpm

(f) Electrical phase estimation error - 3000rpm

Fig. 3. Experimental results of the proposed Luenberger observer

If this phase estimation error remains almost constant with time at a given speed, it increases with the speed (about 3 degrees at 1000rpm and 10.5 degrees at 3000rpm). In future work, we may make the hypothesis that this error comes from a phase difference due the presence of bad known filters in the data measurement process. The phase difference of a low pass filter, for instance, indeed increases with the speed. See [13] for more information about the impact of a such phase difference.

### *C. Robustness to resistance and inductance uncertainties*

As previously mentionned, the stator resistance $R$ and the inductance $L$ are fed to our nonlinear Luenberger observer. However, we may not have a very good knowledge of these physical parameters. For instance, the resistance value is temperature dependant and varies thus with the motor heating. Therefore, in this part, we study the impact of a wrong knowledge of $R$ and $L$ on the magnets flux $\Phi$ and electrical position $\theta$ estimates.

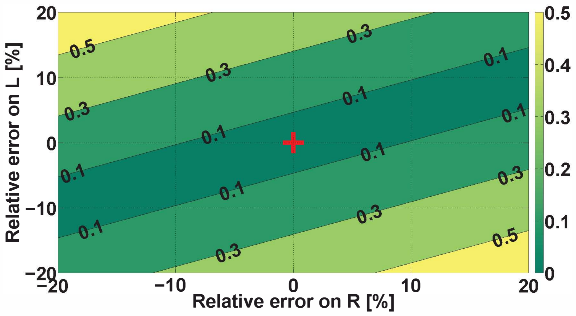
The study is carried out in simulation under MATLAB/SIMULINK. To perform it, a model of the PMSM, whose physical parameters are those of the Table I, is built. The observer is then applied to the currents and voltages signals generated by this model and to biased values of $R$ and $L$, and we look at the steady-state values of the estimated position and magnets flux.

Table II presents the impact of 1% errors on the resistance or the inductance on the estimated magnets flux and position at an electrical speed of 9000rpm (i.e. a mechanical speed of 3000rpm) and a torque of 1Nm, while Figure 4 shows the combined impact of the wrong knowledge of both parameters, at these same speed and torque. We notice that the relative errors on $\widehat{\Phi}$ and $\widehat{\theta}$ seem linear in the relative errors on $R$ and $L$, which is approximately true near the values of $R$ and $L$ of our motor, but is not in the general case. Besides, the impact of the biases depends on the speed and torque. The impact of an error on $R$ on the estimation of $\Phi$ and $\theta$ decreases indeed proportionately with the motor speed, while the impacts of an error on $R$ on the estimation of $\Phi$ and of an error on $L$ on the estimation of $\theta$ increases with the torque. As an example, Table III presents the same impacts than Table II, but at another operating point (mechanical speed of 5000rpm, torque of 0.5Nm).

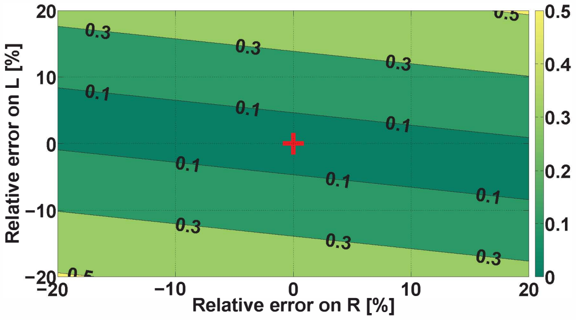
TABLE II

IMPACT OF A WRONG KNOWLEDGE OF $R$ AND $L$ ON $\widehat{\Phi}$ AND $\widehat{\theta}$ 9000$rpm$ (ELEC. SPEED) - 1$Nm$

| | Relative error on $\widehat{\Phi}$ | Relative error on $\widehat{\theta}$ |
|---|---|---|
| 1% error on $R$ | 0.013% | 0.0040° |
| 1% error on $L$ | 0.021% | 0.022° |




(a) Relative error on the estimated magnets flux $\widehat{\Phi}$ (%)




(b) Relative error on the estimated position $\widehat{\theta}$ (°)

Fig. 4. Impact of a wrong knowledge of $R$ and $L$ on $\widehat{\Phi}$ and $\widehat{\theta}$

TABLE III

IMPACT OF A WRONG KNOWLEDGE OF $R$ AND $L$ ON $\widehat{\Phi}$ AND $\widehat{\theta}$ 15000$rpm$ (ELEC. SPEED) - 0.5$Nm$

| | Relative error on $\widehat{\Phi}$ | Relative error on $\widehat{\theta}$ |
|---|---|---|
| 1% error on $R$ | 0.0040% | 0.0024° |
| 1% error on $L$ | 0.021% | 0.011° |

All these results show that, whatever the conditions are, our observer is very robust to a wrong knowledge of the physical parameters $R$ and $L$, as long as we consider realistic errors on them, the errors on $R$ and $L$ having very little impacts on the estimation of $\Phi$ and $\theta$. For instance, a 50% error on the resistance, at 1Nm and a mechanical speed of 3000rpm, leads to relative errors of about 0.2 degree on the estimated electrical position and about 0.65% on the estimated flux. Therefore, a coarse knowledge of the resistance and inductance is sufficient to feed the observer.

## VI. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed a nonlinear Luenberger observer to estimate the position and the flux of SM-PMSM from the only knowledge of the currents and voltages and under a coarse knowledge of the inductance and stator resistance. The observer is indeed robust to a wrong knowledge of these two parameters, and also of the magnets flux, the third parameter of the motor, since we estimate it. The implementation of this observer on the testbed provides good results, except for a slight error, constant with time at a given speed, between the estimated and exact positions. Therefore, future work will consist in improving the position estimation computed by the observer by adding a velocity estimator to it. In fact, the phase difference being function of the velocity, a velocity estimation would allow us to estimate the phase difference and then the position with no phase difference.

## REFERENCES


[1] M. Hinkkanen, T. Tuovinen, L. Harnefors, and J. Luomi, “A combined position and stator-resistance observer for salient pmsm drives: design and stability analysis,” *Power Electronics, IEEE Transactions on*, no. 99, pp. 1–1, 2012.

[2] B. Nahid-Mobarakeh, F. Meibody-Tabar, and F. Sargos, “Mechanical sensorless control of pmsm with online estimation of stator resistance,” *Industry Applications, IEEE Transactions on*, vol. 40, no. 2, pp. 457–471, 2004.

[3] F. Genduso, R. Miceli, C. Rando, and G. Galluzzo, “Back emf sensorless-control algorithm for high-dynamic performance pmsm,” *Industrial Electronics, IEEE Transactions on*, vol. 57, no. 6, pp. 2092–2100, 2010.

[4] Z. Zhang and J. Feng, “Sensorless control of salient pmsm with ekf of speed and rotor position,” in *Electrical Machines and Systems, 2008. ICEMS 2008. International Conference on*. IEEE, 2008, pp. 1625–1628.

[5] M. Preindl and E. Schaltz, “Sensorless model predictive direct current control using novel second-order pll observer for pmsm drive systems,” *Industrial Electronics, IEEE Transactions on*, vol. 58, no. 9, pp. 4087–4095, 2011.

[6] T. Batzel and K. Lee, “Electric propulsion with the sensorless permanent magnet synchronous motor: model and approach,” *Energy Conversion, IEEE Transactions on*, vol. 20, no. 4, pp. 818–825, 2005.

[7] F. Poulain, L. Praly, and R. Ortega, “An observer for permanent magnet synchronous motors with currents and voltages as only measurements,” in *Decision and Control, 2008. CDC 2008. 47th IEEE Conference on*. IEEE, 2008, pp. 5390–5395.

[8] R. Ortega, L. Praly, A. Astolfi, J. Lee, and K. Nam, “Estimation of rotor position and speed of permanent magnet synchronous motors with guaranteed stability,” *Control Systems Technology, IEEE Transactions on*, no. 99, pp. 1–13, 2010.

[9] J. Lee, J. Hong, K. Nam, R. Ortega, L. Praly, and A. Astolfi, “Sensorless control of surface-mount permanent-magnet synchronous motors based on a nonlinear observer,” *Power Electronics, IEEE Transactions on*, vol. 25, no. 2, pp. 290–297, 2010.

[10] J. Malaize and L. Praly, “Globally Convergent Nonlinear Observer for the Sensorless Control of Surface-Mount Permanent Magnet Synchronous Machines,” in *Decision and Control, 2012. CDC 2012. 51th IEEE Conference on (submitted)*.

[11] J. Gauthier and I. Kupka, *Deterministic observation theory and applications*. Cambridge Univ Pr, 2001.

[12] V. Andrieu and L. Praly, “On the existence of a kazantzis-kravaris/luenberger observer,” *Arxiv preprint arXiv:0903.0297*, 2009.

[13] N. Henwood, J. Malaize, and L. Praly, “Pmsm identification for automotive applications: Cancellation of position sensor errors,” in *IECON 2011-37th Annual Conference on IEEE Industrial Electronics Society*. IEEE, 2011, pp. 687–692.