"All-In-One" motor parameters identification and control embedded in a dsPIC DSCs.

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Plan

Outline

Team Expertise
Automatic Control for Power Electronic (ACPE)

Strength and **originality** in a positioning between :

- **Power Electronic**
- **Control theory**

The objective is to take advantage of a **fine knowledge of power electronics systems** and of an **expertise on some tools of control theory**, identified as relevant for these applications ;

Keywords :

electric machines, power converters
control theory, control allocation, hybrid dynamic modeling and control.

Automatic Control for Power Electronic (ACPE)

Leading applications

- Electric machines
- Power converters

Expertise

- Identification
- Control
- Observation

Focus on experimentation

- Laboratory experience
- Realization of new benches
- Rapid Control Prototyping (dSpace, SpeedGoat)

Plan

Team Expertise

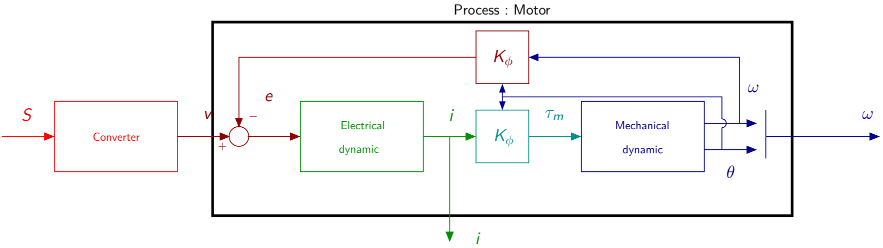
Motor Control and Identification

Experimental Setup Description

Perspectives

Permanent magnet synchronous motor (PMSM)

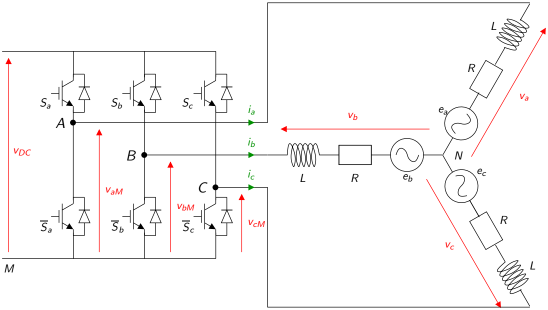
PMSM Scheme



- $S_{abc} \in \{0,1\}^3$: switch : 0 or 1 on each arms
- v_{abc} (in V) : input voltages
- i_{abc} (in A) : phase currents
- τ_m (in Nm) : produced torque
- ω, θ (in rad/s and rad) angular speed and position

Permanent magnet synchronous motor (PMSM)

PMSM Scheme



- Kirchhoff's current law :

$$i_a + i_b + i_c = 0$$

- Balanced motor : $$v_a + v_b + v_c = 0$$

Permanent magnet synchronous motor (PMSM)

PMSM model

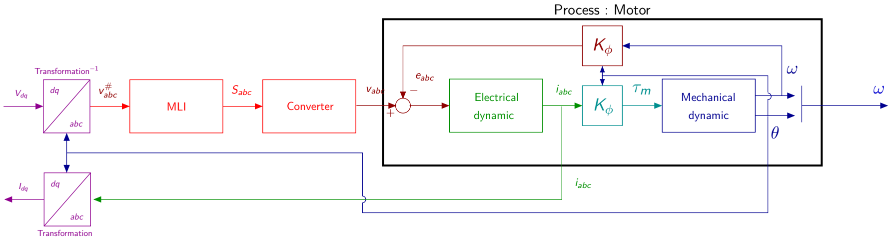
$$
\begin{cases}
L\dfrac{di_a}{dt} & = & v_a - Ri_a + p\phi_f\Omega\sin(p\theta) \\
L\dfrac{di_b}{dt} & = & v_b - Ri_b + p\phi_f\Omega\sin\left(p\theta - \dfrac{2\pi}{3}\right) \\
L\dfrac{di_c}{dt} & = & v_c - Ri_c + p\phi_f\Omega\sin\left(p\theta + \dfrac{2\pi}{3}\right) \\
J\dfrac{d\Omega}{dt} & = & \tau_m - F\Omega - \tau_l
\end{cases}
$$

- p pole pairs number
- L (in H) phase inductance
- R (in Ω) phase resistor
- ϕ_f (in Wb) flux constant
- J (in kg.m^2) inertia
- F (in kg.m^2) viscous friction
- τ_l (in Nm) load torque

$$
\tau_m = -p\phi_f\left[i_a\sin(p\theta) + i_b\sin\left(p\theta - \frac{2\pi}{3}\right) + i_c\sin\left(p\theta + \frac{2\pi}{3}\right)\right]
$$

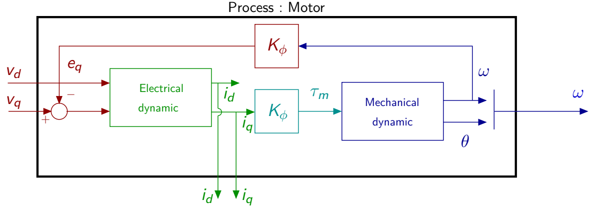
Field oriented control

Transform AC model to DC motor equivalent model



Field oriented control

Transform AC model to DC motor equivalent model



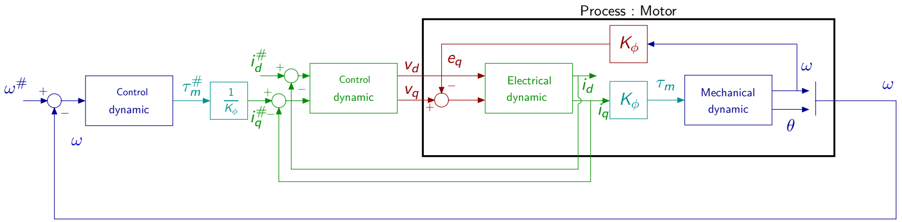
$$L\frac{di_d}{dt} = v_d - Ri_d + Lp\Omega i_q \tag{1a}$$

$$L\frac{di_d}{dt} = v_d - Ri_d + Lp\Omega i_q \tag{1b}$$

$$J\frac{d\Omega}{dt} = p\frac{3}{2}\phi_f i_q - f\Omega - \tau_l \tag{1c}$$

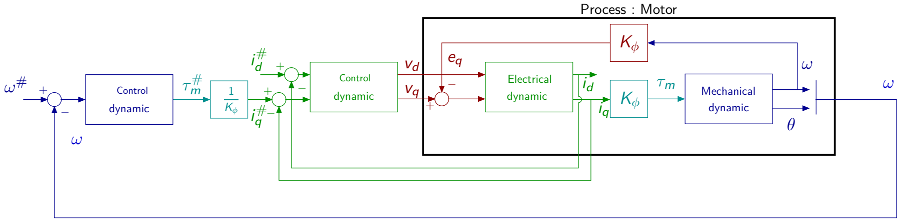
Field oriented control

Control Objective : Speed control



- Current control
  - Compute voltages $v_k, k \in \{d, q\}$ as a function of $i_k^\#$ and i_k
    $$v_k^\# = f(i_k^\# - i_k)$$
- Speed control
  - Compute $\tau_m^\#$ as a function of $\omega^\#$ and ω, $\tau_m^\# = f(\omega^\# - \omega)$
  - $C^\#$ provide to the control loop the current $i_q^\# = \frac{1}{K_\phi} C^\#$
- Transient state : Respect performances indices (T_s, $O_\%$,...)

Control Objective : Speed control



- Required parameters for the control :
  - p pole pairs number
  - L (in H) phase inductance
  - R (in Ω) phase resistor
  - ϕ_f (in Wb) flux constant
  - J (in kg.m^2) inertia
  - F (in kg.m^2) viscous friction

Identification procedure

The core of the identification procedures of this section is the least-squares algorithm : [Blauch et al., 1993], [Delpoux et al., 2012], [Delpoux et al., 2014].

$$\mathbf{y}[n] = \mathbf{W}^{\mathsf{T}}[n]\mathbf{p}_{nom}, \tag{2}$$

- $y[n]$ is the output vector,
- n is either an index or the time instant,
- $W[n]$ is the regressor matrix, and
- $\mathbf{p}_{nom}$ is the nominal (unknown) parameter vector.

Given measurements of $\mathbf{y}$ and $\mathbf{W}$, the objective is to determine $\mathbf{p}$, the estimate of the nominal parameter vector $\mathbf{p}_{nom}$:

$$\mathbf{p} = \left(\sum_{n=N_0}^{N_1} \mathbf{W}[n]\mathbf{W}^{\mathsf{T}}[n]\right)^{-1} \left(\sum_{n=N_0}^{N_1} \mathbf{W}[n]\mathbf{y}[n]\right). \tag{3}$$

Identification procedure

Electrical parameters

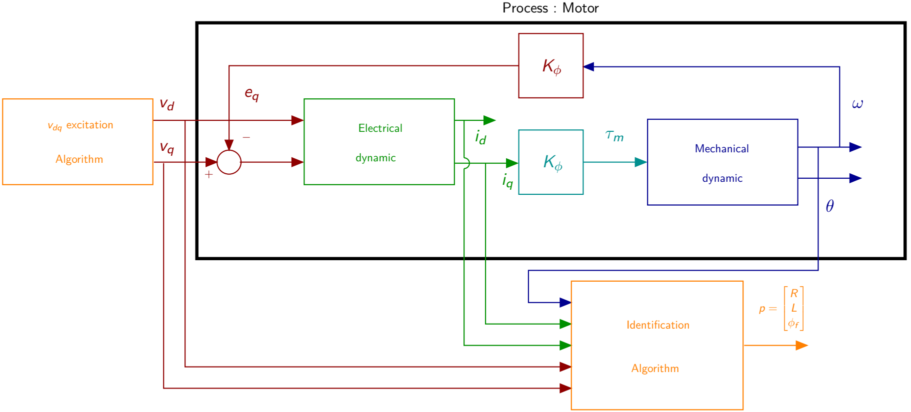
For this identification, consider the model of the motor in the *dq* frame, at steady state.

$$\underbrace{\begin{bmatrix} v_d \\ v_q \end{bmatrix}}_{\mathbf{y}} = \underbrace{\begin{bmatrix} i_d & -p\Omega i_q & 0 \\ i_q & p\Omega i_d & p\Omega \end{bmatrix}}_{\mathbf{W}^{\intercal}} \underbrace{\begin{bmatrix} R \\ L \\ \phi_f \end{bmatrix}}_{\mathbf{p}} \tag{4}$$

such that least square parameter identification (3) apply .

Identification procedure

Electrical parameters



Plan

Experimental Setup

Feature

- Sensored motor speed control
- Electrical parameters Identification
- Modify all parameters from interface
- Modify closed loop control dynamics
- Adapt V_{dc} from measurement

Experimental Setup

Harware setup

- dsPICDEM™ MCLV-2 Development Board

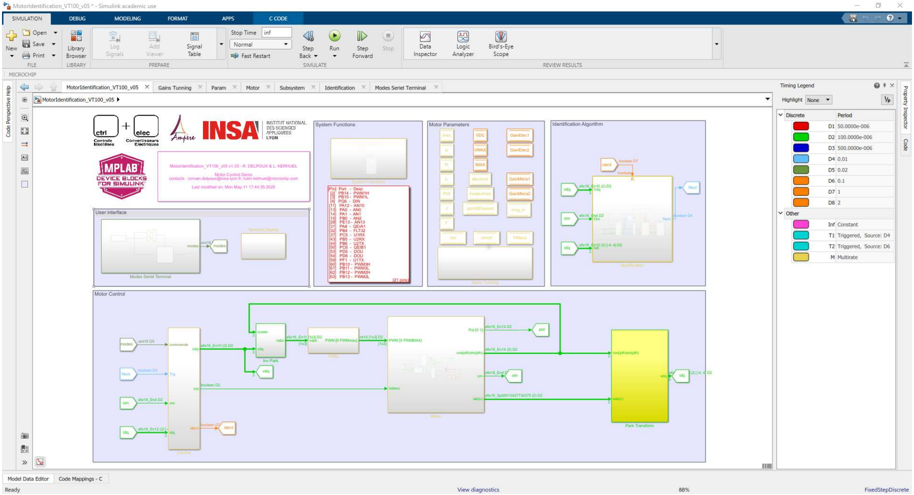
- 2 PMSM

AC300022 - BLDC with Encoder

N23 Industrial Grade Motor

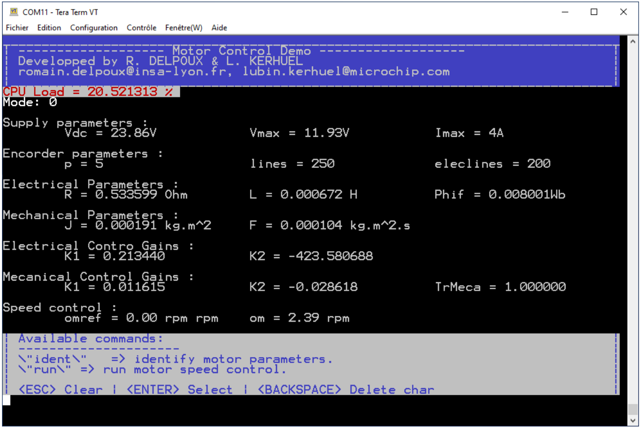
Experimental Setup

Model based design



Experimental Setup

Serial interface



Experimental Setup

Motors Datasheets Parameters

L-L Resistance (R_{tm}) Ohms :	0.57
L-L Inductance (L_{tm}) mH at 1Khz :	0.64
Torque Constant (K_t) oz.in./Amp :	8.38
Voltage Constant (K_e) V_{peak}/K_{RPM} :	6.2
Stack Length:	3.00

Click for full datasheet

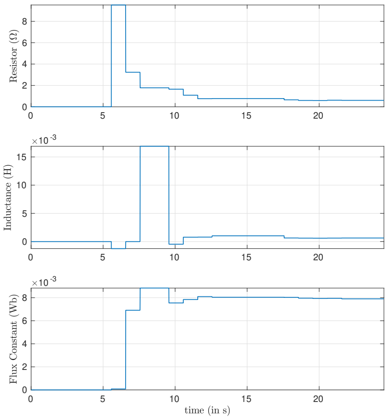
Model	2310
Electrical Interface Option	P/C/Y
Resistance, phase to phase, [Ω]	0.72
Inductance, phase to phase, [mH]	0.40
Electrical Time Constant, [mS]	0.56
Back EMF (Ke), [Vpeak/kRPM]	4.64
Continuous Torque [oz-in][1,2]	39

Click for full datasheet

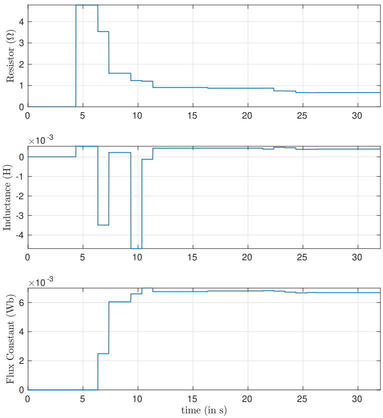
Experimental Setup

Experimental results

AC300022 - BLDC with Encoder



N23 Industrial Grade Motor



Experimental Setup

Experimental results

AC300022 - BLDC with Encoder			N23 Industrial Grade Motor		
R = 0.533 Ohm	L = 0.574 mH	Phif = 0.00789Wb	R = 0.656 Ohm	L = 0.438 mH	Phif = 0.00658Wb
R = 0.512 Ohm	L = 0.835 mH	Phif = 0.00804Wb	R = 0.698 Ohm	L = 0.406 mH	Phif = 0.00654Wb
R = 0.557 Ohm	L = 0.766 mH	Phif = 0.00798Wb	R = 0.667 Ohm	L = 0.361 mH	Phif = 0.00665Wb
R = 0.546 Ohm	L = 0.791 mH	Phif = 0.00799Wb	R = 0.682 Ohm	L = 0.337 mH	Phif = 0.00659Wb
R = 0.540 Ohm	L = 0.807 mH	Phif = 0.00802Wb	R = 0.677 Ohm	L = 0.323 mH	Phif = 0.00661Wb

Experimental Setup

Experimental results

Click for Demonstration Video

Plan

Perspectives

- Encoder resolution
- Mechanical parameters identification
- Sensorless parameters identification
- Sensorless motor control

Thank you for your attention

ctrl + elec

Controle Machines

Convertisseurs Electriques

References

Blauch, A.-J., Bodson, M., and Chiasson, J.-N. (1993).
High-speed parameter estimation of stepper motors.
IEEE Transactions on Control Systems Technology, 1(4) :270–279.

Delpoux, R., Bodson, M., and Floquet, T. (2012).
Joint Identification of Stepper Motor Parameters and of Initial Encoder Offset.
In *16th IFAC Symposium on System Identification*, Brussels, Belgique.

Delpoux, R., Bodson, M., and Floquet, T. (2014).
Parameter estimation of permanent magnet stepper motors without mechanical sensors.
Control Engineering Practice, 26 :178–187.