

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

Romain Delpoux¹, Lubin Kerhuel²

romain.delpoux@insa-lyon.fr, lubin.kerhuel@microchip.com

¹Ampère Lab CNRS UMR 5005, INSA de Lyon

²Microchip Technology Inc.

2020, May 12th



Controlle
Machines

+



Convertisseurs
Electriques



INSA



Plan

Team Expertise

Motor Control and Identification

Experimental Setup Description

Perspectives

Outline

Team Expertise

Motor Control and Identification

Experimental Setup Description

Perspectives

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

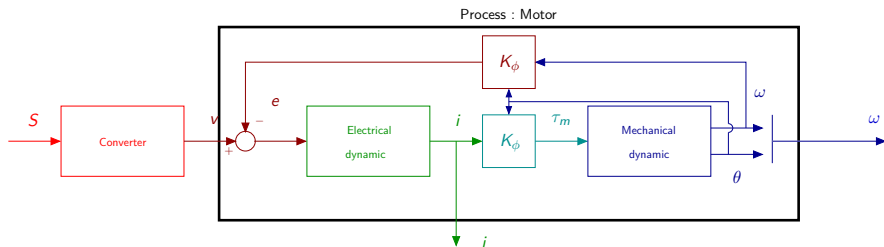
Motor Control and Identification

Experimental Setup Description

Perspectives

Permanent magnet synchronous motor (PMSM)

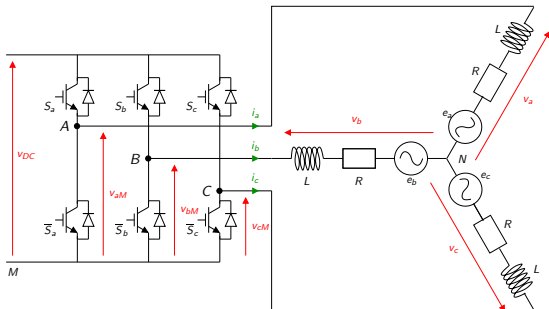
PMSM Scheme



- $S_{abc} \in \{0, 1\}^3$: 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)

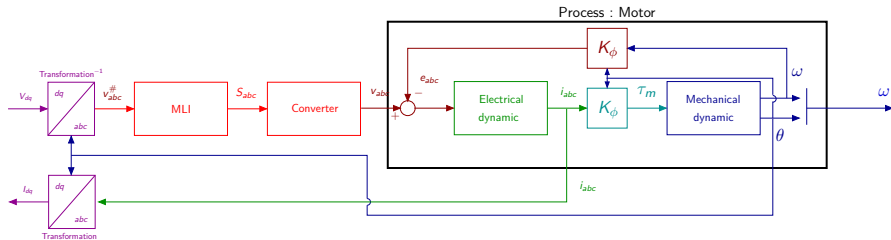
PMSM model

$$\left\{ \begin{array}{l} L \frac{di_a}{dt} = v_a - Ri_a + p\phi_f \Omega \sin(p\theta) \\ L \frac{di_b}{dt} = v_b - Ri_b + p\phi_f \Omega \sin\left(p\theta - \frac{2\pi}{3}\right) \\ L \frac{di_c}{dt} = v_c - Ri_c + p\phi_f \Omega \sin\left(p\theta + \frac{2\pi}{3}\right) \\ J \frac{d\Omega}{dt} = \tau_m - F\Omega - \tau_l \end{array} \right. \quad \left| \quad \begin{array}{l} \bullet p \text{ pole pairs number} \\ \bullet L \text{ (in H) phase inductance} \\ \bullet R \text{ (in } \Omega \text{) phase resistor} \\ \bullet \phi_f \text{ (in Wb) flux constant} \\ \bullet J \text{ (in kg.m}^2\text{) inertia} \\ \bullet F \text{ (in kg.m}^2\text{) viscous friction} \\ \bullet \tau_l \text{ (in Nm) load torque} \end{array} \right.$$

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

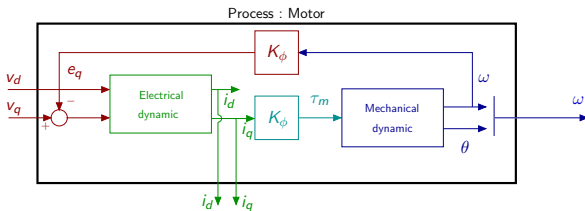
Field oriented control

Transform AC model to DC motor equivalent model



Field oriented control

Transform AC model to DC motor equivalent model



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

$$L \frac{di_q}{dt} = v_q - Ri_q - Lp\Omega i_d \quad (1b)$$

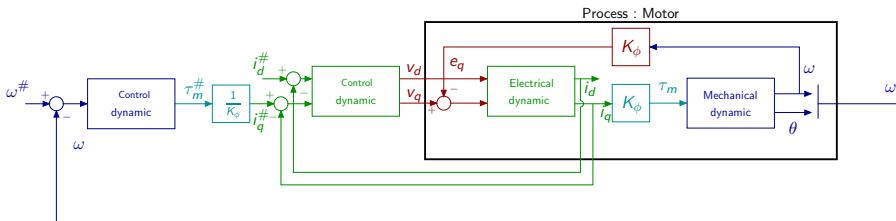
$$J \frac{d\Omega}{dt} = p \frac{3}{2} \phi_f i_q - f\Omega - \tau_l \quad (1c)$$

[illegible]

- 12 / 29

Field oriented control

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].

$$\mathbf{y}[n] = \mathbf{W}^T[n] \mathbf{p}_{nom}, \quad (2)$$

- $\mathbf{y}[n]$ is the output vector,
- n is either an index or the time instant,
- $\mathbf{W}[n]$ 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} :

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

Identification procedure

Electrical parameters

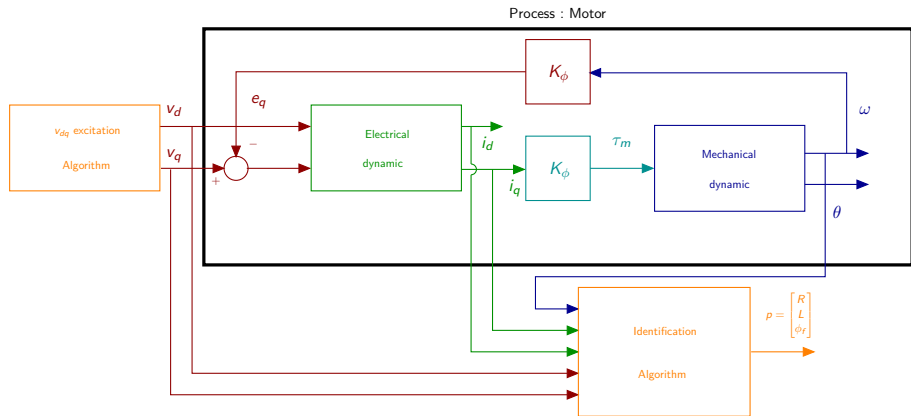
For this identification, consider the model of the motor in the dq frame, at steady state.

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

such that least square parameter identification (3) apply .

Identification procedure

Electrical parameters



Plan

Team Expertise

Motor Control and Identification

Experimental Setup Description

Perspectives

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

Hardware setup

- dsPICDEM™ MCLV-2 Development Board



- 2 PMSM



AC300022 - BLDC with Encoder



N23 Industrial Grade Motor

Experimental Setup

Model based design

MotorIdentification_VT100_v05 - Simulink academic use

Simulink Interface:

- Toolbox:** SIMULINK, DEBUC, MODELING, FORMAT, APPS, C CODE
- File:** Open, Save, Print, Library, Browser
- Log Signals:** Add, Viewed, Signal Table
- Stop Time:** inf
- Step:** Back, Run, Step Forward, Stop
- Analysis:** Data Inspector, Logic Analyzer, Bird's-eye Scope
- REVIEW RESULTS**

Model Identification_VT100_v05

System Functions:

```

P10 P10 = 1;
P11 P11 = 1;
P12 P12 = 1;
P13 P13 = 1;
P14 P14 = 1;
P15 P15 = 1;
P16 P16 = 1;
P17 P17 = 1;
P18 P18 = 1;
P19 P19 = 1;
P20 P20 = 1;
P21 P21 = 1;
P22 P22 = 1;
P23 P23 = 1;
P24 P24 = 1;
P25 P25 = 1;
P26 P26 = 1;
P27 P27 = 1;
P28 P28 = 1;
P29 P29 = 1;
P30 P30 = 1;
P31 P31 = 1;
P32 P32 = 1;
P33 P33 = 1;
P34 P34 = 1;
P35 P35 = 1;
P36 P36 = 1;
P37 P37 = 1;
P38 P38 = 1;
P39 P39 = 1;
P40 P40 = 1;
P41 P41 = 1;
P42 P42 = 1;
P43 P43 = 1;
P44 P44 = 1;
P45 P45 = 1;
P46 P46 = 1;
P47 P47 = 1;
P48 P48 = 1;
P49 P49 = 1;
P50 P50 = 1;
P51 P51 = 1;
P52 P52 = 1;
P53 P53 = 1;
P54 P54 = 1;
P55 P55 = 1;
P56 P56 = 1;
P57 P57 = 1;
P58 P58 = 1;
P59 P59 = 1;
P60 P60 = 1;
P61 P61 = 1;
P62 P62 = 1;
P63 P63 = 1;
P64 P64 = 1;
P65 P65 = 1;
P66 P66 = 1;
P67 P67 = 1;
P68 P68 = 1;
P69 P69 = 1;
P70 P70 = 1;
P71 P71 = 1;
P72 P72 = 1;
P73 P73 = 1;
P74 P74 = 1;
P75 P75 = 1;
P76 P76 = 1;
P77 P77 = 1;
P78 P78 = 1;
P79 P79 = 1;
P80 P80 = 1;
P81 P81 = 1;
P82 P82 = 1;
P83 P83 = 1;
P84 P84 = 1;
P85 P85 = 1;
P86 P86 = 1;
P87 P87 = 1;
P88 P88 = 1;
P89 P89 = 1;
P90 P90 = 1;
P91 P91 = 1;
P92 P92 = 1;
P93 P93 = 1;
P94 P94 = 1;
P95 P95 = 1;
P96 P96 = 1;
P97 P97 = 1;
P98 P98 = 1;
P99 P99 = 1;

```

Motor Parameters:

- Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11, Y12, Y13, Y14, Y15, Y16, Y17, Y18, Y19, Y20, Y21, Y22, Y23, Y24, Y25, Y26, Y27, Y28, Y29, Y30, Y31, Y32, Y33, Y34, Y35, Y36, Y37, Y38, Y39, Y40, Y41, Y42, Y43, Y44, Y45, Y46, Y47, Y48, Y49, Y50, Y51, Y52, Y53, Y54, Y55, Y56, Y57, Y58, Y59, Y60, Y61, Y62, Y63, Y64, Y65, Y66, Y67, Y68, Y69, Y70, Y71, Y72, Y73, Y74, Y75, Y76, Y77, Y78, Y79, Y80, Y81, Y82, Y83, Y84, Y85, Y86, Y87, Y88, Y89, Y90, Y91, Y92, Y93, Y94, Y95, Y96, Y97, Y98, Y99, Y100

Identification Algorithm:

User Interface:

Motor Control:

Timing Legend:

- Discrete: D0, D1, D2, D3, D4, D5, D6, D7, D8, D9
- Other: 3rd Constant, T1 Triggered, Source: D4, T2 Triggered, Source: D6, M, Multirate

Model Data Editor | **Code Mappings** | **C**

Ready | View diagnostics | 86% | FastStepDiscrete

Experimental Setup

Serial interface

```

COM11 - Tera Term VT
Fichier Edition Configuration Contrôle Fenêtre(W) Aide

----- Motor Control Demo -----
Developped by R. DELPOUX & L. KERHUEL
romain.delpoux@insa-lyon.fr, lubin.kerhuel@microchip.com

CPU Load = 20.521313 %
Mode: 0

Supply parameters :
  Vdc = 23.86V          Vmax = 11.93V          Imax = 4A

Encoder parameters :
  p = 5                lines = 250          eleclines = 200

Electrical Parameters :
  R = 0.533599 Ohm     L = 0.000672 H          Phif = 0.008001Wb

Mechanical Parameters :
  J = 0.000191 kg.m^2  F = 0.000104 kg.m^2.s

Electrical Control Gains :
  K1 = 0.213440        K2 = -423.580688

Mechanical Control Gains :
  K1 = 0.011615        K2 = -0.028618          TrMeca = 1.000000

Speed control :
  omref = 0.00 rpm rpm  om = 2.39 rpm

Available commands:
-----
\"ident\" => identify motor parameters.
\"run\" => run motor speed control.
<ESC> Clear | <ENTER> Select | <BACKSPACE> Delete char
  
```

Experimental Setup

Motors Datasheets Parameters



L-L Resistance (R_m) Ohms :	0.57
L-L Inductance (L_m) 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](#)

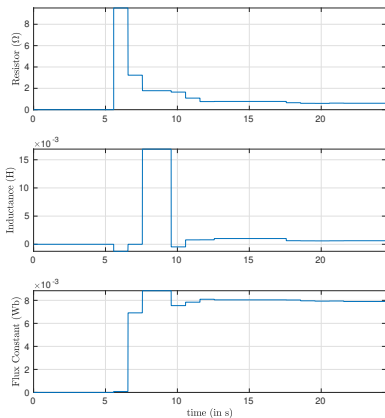


Model	2310
Electrical Interface Option	P/C/Y
Resistance, phase to phase, [Ω]	0.72
Inductance, phase to phase, [mH]	0.40
Electrical Time Constant, [mS]	0.56
Back EMF (K_e), [$V_{peak}/kRPM$]	4.64
Continuous Torque [oz-in] ^{1/2}	39

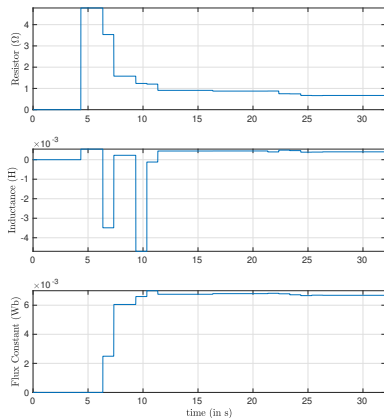
[Click for full datasheet](#)

Experimental results

AC300022 - BLDC with Encoder



N23 Industrial Grade Motor



Experimental Setup

Experimental results

AC300022 - BLDC with Encoder

$R = 0.533 \text{ Ohm}$	$L = 0.574 \text{ mH}$	$\text{Phif} = 0.00789\text{Wb}$
$R = 0.512 \text{ Ohm}$	$L = 0.835 \text{ mH}$	$\text{Phif} = 0.00804\text{Wb}$
$R = 0.557 \text{ Ohm}$	$L = 0.766 \text{ mH}$	$\text{Phif} = 0.00798\text{Wb}$
$R = 0.546 \text{ Ohm}$	$L = 0.791 \text{ mH}$	$\text{Phif} = 0.00799\text{Wb}$
$R = 0.540 \text{ Ohm}$	$L = 0.807 \text{ mH}$	$\text{Phif} = 0.00802\text{Wb}$

N23 Industrial Grade Motor

$R = 0.656 \text{ Ohm}$	$L = 0.438 \text{ mH}$	$\text{Phif} = 0.00658\text{Wb}$
$R = 0.698 \text{ Ohm}$	$L = 0.406 \text{ mH}$	$\text{Phif} = 0.00654\text{Wb}$
$R = 0.667 \text{ Ohm}$	$L = 0.361 \text{ mH}$	$\text{Phif} = 0.00665\text{Wb}$
$R = 0.682 \text{ Ohm}$	$L = 0.337 \text{ mH}$	$\text{Phif} = 0.00659\text{Wb}$
$R = 0.677 \text{ Ohm}$	$L = 0.323 \text{ mH}$	$\text{Phif} = 0.00661\text{Wb}$

Experimental Setup

Experimental results

[Click for Demonstration Video](#)

Plan

Team Expertise

Motor Control and Identification

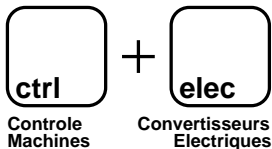
Experimental Setup Description

Perspectives

Perspectives

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




Thank you for your attention



INSA



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.