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Short Manuals for Distance Laboratories of PEMCWebLab

(English version)

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Short Manuals for Distance Laboratories of PEMCWebLab

(English version)

Edited by: Pavol Bauer, Viliam Fedak, Ondrej Vitek

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effect by turning on *Enb_ct* and *Enb_H_comp* (so that the buttons are light green). Do following:

a) Explore the influence of high and low values of position gain *Kp_ct* and velocity gain *Kv_ct*. Comment following aspects: position error, stability.
b) Find controller's parameters that give the lowest position error. Use trial and error procedure.
c) Disable compensation of the spring torque, gravitation and friction by turning off *Enb_H*. In this case only inertia influence is compensated. Observe the efficiency of this partial computed torque control method and compare the results with the results obtained for complete computed torque controller. Comment the discrepancy.
d) Compare the efficiency of the full and partial computed torque controller (*Enb_H* is turned off) with the efficiency of other two controllers by comparing position error for best cases. Best case for each controller is when the chosen parameters resulted in the lowest position errors. Comment the results.

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Vienna University of Technology

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Module 4.3

High Dynamic Drives – Motion Control

Vienna University of Technology

Authors: Thomas M. Wolbank
Peter Macheiner
Markus Vogelsberger

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Introduction

The Laboratory of Module 4.3 described in the following is intended to teach students the interactions of power converter, AC machine and mechanical system.
he central hardware used is a two axes positioning system consisting of two linear axes one mounted on top of the other each driven by an AC synchronous machine.
In order to concentrate on the fundamental structure of field oriented control, permanent magnet synchronous machines are used. The control of the system consists of a cascaded structure with an inner current control loop, and outer speed and position control loops.
All control structures are predefined in the system to avoid time-consuming and frustrating debugging of mathematical calculations by the students.
The task of the students is thus to identify the system stepwise by performing the experiments and to tune the different control loops for good overall performance.

Objectives of the experiment

The educational goals of the module are as follows:

- Understanding of high dynamic operation of AC drives
- Identify parasitic influence of inverter dead time
- Practical application of field oriented control
- Realization of cascaded control structure
- Implementation of 2-dimensional motion control

Each student is assumed to have some basic knowledge in the field of power electronics and drives. The required knowledge to perform all tasks is as follows:

- Pulse width modulation of three phase inverters
- Permanent magnet synchronous machines
- Space phasor calculation
- Field oriented control

This knowledge can be obtained from the corresponding lectures held at the partner Universities of the EDIPE project, as well as from the different textbooks listed in the references.
As a result, after working through the whole module, the students should have increased their knowledge in:

- PMSM:
  - used as part of a high dynamic drive
  - what are d/q- components,...
- Resolver - position estimation
  - Possibilities of Calibration
  - Interaction of number of possible resolver offsets -machine pole pair number
- Field oriented control
  - advantages
  - necessary basic conditions
- Cascaded control structures and controller design strategies
  - correct tuning sequence of the different control loops (inner → outer loop)

  - design strategy - optimum magnitude method – control parameter estimation
  - design strategy - symmetrical optimum method – control parameter estimation
- PWM
  - Influence of the inverter dead time to the controller parameter, current signals
  - Influence of the PWM frequency to the current signals
- Calculation and measurement results
  - Calculated controller parameters – and the corresponding system reaction
  - Control parameter optimization – comparison of manually tuned, calculated values
- Influence of the non-ideal system behaviour
  - Friction
  - Mechanical slip/stick
  - Parasitic influences like sensor and measurement noise, non-linearity of inverter/power electronics

Description of the system – Hardware

Mechanical system

During the laboratory course "high dynamic drives - motion control" students will have the possibility to perform tests and experiments in the topics field oriented control, inverter fed operation, and cascaded control. The mechanical system operated is a two axes positioning system fed by PM synchronous machines. The whole arrangement of the mechanical system can be seen in Fig. 1. It consists of two linear axes (6,7) each equipped with a lead screw that is driven by a permanent magnet synchronous machine (PMSM) (4,5). The second axis (7) is mounted on top of the first (6). Each of the PMSM is fed by individual inverter and control electronics (1, 2, 3) thus allowing separated movement of the two carriages. On the carriage of the second axis (7) a lifting magnet is fixed (8) allowing a third axis movement (pen up/down). The maximum working range of the two axes is 300mm.

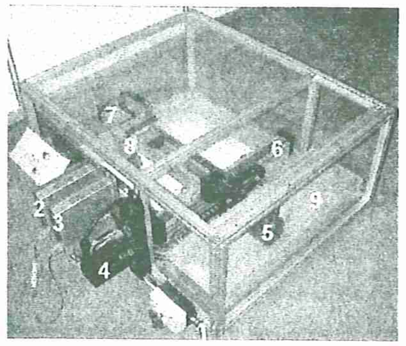

Fig. 1: Mechanical arrangement of the two axes positioning system

Control electronics

The control electronics is realized on an industrial system using high level programming language (LabView). To avoid time consuming debugging and repetitive compiling, all software loops necessary for carrying out the experiment are predefined. The student can thus focus on the control structure the identification of the system parameters and on the performance of different control loops.

Electric machines

Each machine driving an axis is a synchronous machine with permanent magnets (Fig2.) The data is as follows:

Nominal Voltage:	$U_{N,eff} = 560V$
Nominal Current:	$I_{N,eff} = 2{,}4A$
Nominal torque:	$M_N = 1{,}72Nm$
Nominal speed:	$n_N = 7200min^{-1}$
Number of pole pairs:	$p = 3$

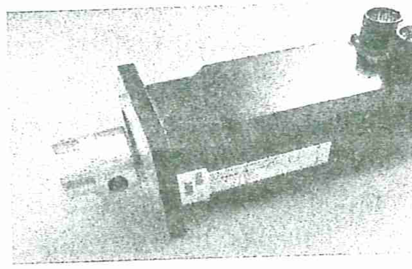

Fig. 2: Photo of the PMSM

Position measurement and field oriented control

The rotor position of each machine is measured using a built-in resolver. The working principle of a resolver is shown in Fig. 3. It consists of an arrangement of three coils. The first one is mounted on the rotor and fed by a sinusoidal voltage with some kHz frequency. The other two coils are fixed to the stator each oriented 90° apart. The rotating coil induced a sinusoidal voltage in the two stator fixed coils each with a phase shift correlated to the angular position of the coils. Evaluating the phase correlation between the coils it is thus possible to determine the rotor position.

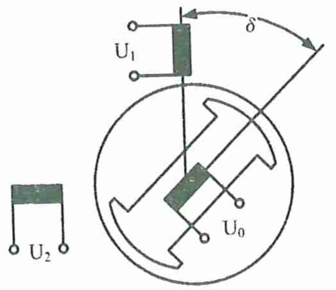

Fig. 3. Schematic of resolver

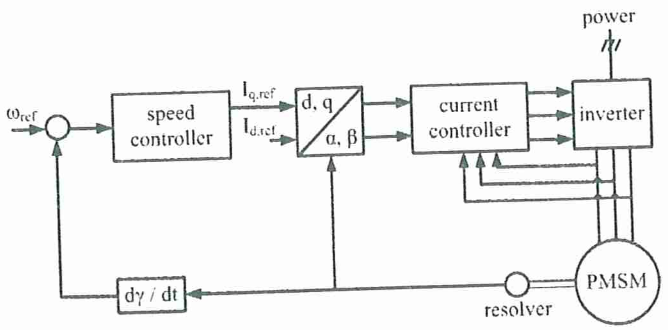

Fig. 4: Schematic of the field oriented control

Field oriented control

Resulting from field oriented control strategy AC machines acquire the advantage of DC machine control and without the drawback of the mechanical commutation. Furthermore, this control structure, by achieving a very accurate steady state and transient control, leads to high dynamic performance.

The basic idea behind the field oriented control (FOC) is to separate the interrelationship of the flux and the torque, what results in a separation of the corresponding current components to get two orthogonal and thus independent values. A schematic of field oriented control structure can be seen in Fig 4.

System identification, parameter tuning (Description of the experiments)

In the following the experiments are named to stepwise identify the necessary system parameters.

Identification of the machine parameter

Goal of the experiment:

Identification and knowledge of the machine parameters, like the stator resistance, stator inductance and the stator time constant, is absolutely necessary for any executable drive operation.

Solution:

The time constant is identified by establishing a simple voltage step to the machine and exploiting the current response. The time duration, the current needs to rise from zero to 63.2% (5/8) of its final steady state value will be identified and labelled as stator time constant. The stator resistance can be identified and calculated by using the current values and voltage values from two different established voltage phasor. The inductance follows from the knowledge of stator resistance and the stator time constant.

For details about the experiment see the online description on the web page as well as the full version of the manual (experiment description).

Calibration of the resolver

Goal of the experiment:

As mentioned the rotor position is determined using a resolver. Though the resolver delivers an absolute position signal it has to be calibrated with respect to the axis of the magnets (d-axis) as the mounting of the resolver on the rotor shaft is unknown.

Solution:

The angle information about the three d-directions, each 120° (mechanical) apart, is identified by establishing a simple current space phasor to the machine, that produce a torque that is higher than the friction torque. As a result the rotor of the PMSM will rotate towards the direction of the current phasor and the d-axis will be aligned **with the axis of the current phasor.**

For details about the experiment see the online description on the web page as well as the full version of the manual (experiment description).

Current control loop design

Goal of the experiment:

Identification of the system parameters necessary to tune the current control loop. As the machine is driven by a voltage source inverter, the output of the current controller is a voltage. In order to calculate the optimum voltage to accurately adjust the reference current the correlation between voltage and current has to be identified.

Solution:

The current control is the innermost control loop. The control structure for both axes of the system is the same with different parameters and will be realized in the rotor fixed d,q-reference frame. A proportional-integral PI-controller will be realized as current controller, by using the optimum magnitude method as design strategy.

For details about the experiment see the online description on the web page as well as the full version of the manual (experiment description).

Speed control loop design

Goal of the experiment:

Identification of the system parameters necessary to establish high dynamic speed control of the drive. The main system parameter is the moment of inertia. Based on the results obtained in the previous experiments as well as on the tuned current control loop this parameter can be identified.

Solution:

The next control loop that lies above the innermost current controller is the speed control loop. As design strategy for the speed controller (realized as a PI-controller) the symmetrical optimum method was selected. Therefore the moment of inertia must determined by a simple experiment.

For details about the experiment see the online description on the web page as well as the full version of the manual (experiment description).

Position control loop design

Goal of the experiment:

Tune the position control loop based on experimental results. Evaluate performance using different reference functions (rectangular, triangular, sinusoidal). Identify influence of slip-stick during zero crossing of speed. Identify influence of inner control loops when reference values for current or speed saturate. Tune first for minimum settling time and then for minimum overshoot.

Solution:

The outermost part of the cascaded control scheme is the position control loop.

In the implemented structure the position controller should be realised with a proportional gain only. The way of parameter identification (for the necessary proportional controller parameter) is done by carrying out empirically experiments.

For details about the experiment see the online description on the web page as well as the full version of the manual (experiment description).

Two axes position control

If all the previous experiments have been successfully carried out for both axes of the system the student can test a two axes position control implemented on the two dimensional plane of the system. For that purpose predefined tracks will be executed with the parameters determined in the previous experiments.

For details about the experiment see the online description on the web page as well as the full version of the manual (experiment description).

After the time-slot of the laboratory has ended the system will be automatically disabled, the internet connection terminated and the reports send by em