Educational laboratory setup of DC motor cascade control based on dSpace1104 platform

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Introduction

• Nowadays electric drives consume more than 40% of the total electric energy production and more than 60% total industrial consume.

• Motor control algorithms should also be developed having in mind energy efficiency of the electric drive in general.
Introduction

• With an exponential growth of power electronic development during the last few decades a huge number of electric drive control algorithms was developed.

• This paper describes experimental setup for testing DC machine control algorithms combining modern laboratory equipment with model-based design and rapid control prototyping.

• These methods allow quick development of control algorithm strategies, their analysis in sense of control quality, dynamics as well as energy efficiency of the drive.
Content:

• Model Based Design and Rapid Control Prototyping
• dSPACE 1104 platform
• Laboratory experimental setup
• Simulink model of DC motor cascade speed control
• Graphical user interface and Control application - Control Desk
• Estimation of DC motor parameters and synthesis of the current and speed loop – PI regulators tuning
• Simulation and Experimental results
• Conclusion
Model-Based design (MBD) and Rapid Control Prototyping (RCP)

- **Model-Based Design** is a modern trend in developing different complex control algorithms mainly in motion control (closed loop model simulation – rapid control prototyping - code implementation – simulation in HIL - validation)

- **Rapid Control Prototyping (RCP)** as a part of MBD is a process that lets engineers quickly test and iterate their control strategies – automatic code generation to real time system.
dSPACE 1104

- **dSPACE 1104** is a complete real-time control system based on a 603 PowerPC 64-bit floating-point processor running at 250 MHz. For advanced I/O purposes the platform includes slave DSP subsystem based on the TMS320F240 DSP microcontroller (16-bit, 150MHz)

- Real Time Interface allows communication between model developed in Matlab/Simulink and dSPACE1104. Application developed in Control Desk is used as a Graphical User Interface in algorithm control and visualization of the characteristic quantities.
Block structure of the experimental setup

- **dSPACE 1104** Controller board
- **PC**
- **Signal conditioning and isolation**
- **Power converter H-bridge**
- **Power supply**
- **Motor**
- **PWM**
- **A/D**
- **A/D**
- **Inc**
- **Current sensor CMS3005 board**
- **230 V 50 Hz**
- **30 V DC**
Laboratory experimental setup
Laboratory experimental setup - parts

Fig. 3 – Signal isolation board and power converter (inverter)

Fig. 4 – Current sensor board

Fig. 5 – Adaption signal board for speed measurement
Motor current, speed and voltage reconstruction in Simulink model

a) ADC
   DS1104ADC_C5
   ADC 10 [mV] Current 1 [A]
   Current 1

b) Duty cycle
   A phase PWM
   B phase PWM
   C phase PWM
   PWM Stop
   DS1104SL_DSP_PWM3

A) Gain
   Offset
   2.4307
   ADC
   DS1104ADC_C8
   10.95.866
   Udc

B) Position
   Speed [rpm]
   360/500
   Position [°]
   DS1104ENC_POS_C1
   Enc position
   Enc delta position
   1
d) Position [°]
   Speed [rpm]
   360/500
   Position [°]
   DS1104ENC_POS_C1
   Enc position
   Enc delta position
   1
   delta pos
   1=0.25
   speed [rpm]
DC motor parameters

- Motor parameters were estimated applying Nonlinear least square method and Trust-Region-Reflective Algorithm.

### Table 1. - DC PM motor parameters 3418090, NEMA34

<table>
<thead>
<tr>
<th>Motor parameters</th>
<th>Estimated motor parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{an}$</td>
<td>90 V</td>
</tr>
<tr>
<td>$R_a$</td>
<td>1.344 Ω</td>
</tr>
<tr>
<td>$I_{an}$</td>
<td>9 A</td>
</tr>
<tr>
<td>$L_a$</td>
<td>4.5 mH</td>
</tr>
<tr>
<td>$n_n$</td>
<td>3200 rpm</td>
</tr>
<tr>
<td>$J$</td>
<td>$2.6133 \times 10^{-5}$ kgm$^2$</td>
</tr>
<tr>
<td>$K_T$</td>
<td>0.182 Nm/A</td>
</tr>
<tr>
<td>$B$</td>
<td>$2.1886 \times 10^{-5}$ kgm$^2$</td>
</tr>
</tbody>
</table>

$$T_a = \frac{L_s}{R_a} = \frac{4.5 \cdot 10^{-3}}{1.344} = 3.35 \text{ ms}.$$  

$$T_m = \frac{J}{B} = 1.194 \text{ s}.$$
The synthesis of the current loop

Fig. 9 - Block diagram of current loop PI control

Table 1. – PI parameters of the current loop

<table>
<thead>
<tr>
<th>Method</th>
<th>$K_{Pi}$</th>
<th>$K_{li}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensation method</td>
<td>$L_d/K_dT'=0.225$</td>
<td>$R_d/K_dT'=67.2$</td>
</tr>
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The synthesis of the speed loop

Fig. 10 - Block diagram of speed loop PI control

Table 2. – PI parameters of the speed loop

<table>
<thead>
<tr>
<th>Method</th>
<th>$K_{p\omega}$</th>
<th>$K_{I\omega}$</th>
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<tbody>
<tr>
<td>Compensation and modulus optimum methods</td>
<td>$J/2K_T T' = 0.1436$</td>
<td>$B/2K_T T' = 0.1203$</td>
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<td>Symmetrical optimum method</td>
<td>$J/2K_T T' = 0.1436$</td>
<td>$J/2K_T T'^2 = 71.794$</td>
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<td>Tunning PI parameters</td>
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Experimental results - current loop

Fig. 13. - Current loop input-output signals with compensation method (zoomed view – right)
Experimental results-speed loop

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Experimental results - speed loop

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![Graph showing experimental results]
It can be noticed that the increase of the integral gain $K_I$ decreases the rise time, but also increases the overshoot and the settling time, reflecting negatively to the dynamics of the system.
### Experimental results - speed loop

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**Experimental results - speed loop:**
- Ref. Speed
- Measured Speed
- Simulated Speed

**Graphs:**
- Current [A]
- Speed [rpm]

### Tunning PI parameters
- $K_p = 0.012$
- $K_i = 0.015$
- $P\% = 0.996\%$
- $Tr = 38.4\text{ms}$
- $Ts = 63.8\text{ms}$
Conclusion

• In this paper, the educational laboratory setup for real-time cascade control of DC motor based on the dSPACE1104 platform is described. The basic idea in designing and realization of the setup is to provide to students of the Faculty of Technical Sciences in Cacak, who attend the course of Control of electrical drives, another opportunity to practice on the most advanced laboratory equipment used for the control and regulation of electric motors and to get more familiar with RCP and MBD as well.

• Controller synthesis methods were applied to achieve the desired speed responses with the limitation of the motor current and achieving the aperiodicity in the current signal of the assigned dynamic.

• This platform allows students to test analyze different control strategies and configurations. The Rapid Control Prototyping with Simulink models and dSPACE1104 board gives a unique quality of the achieved setup and provides the possibility for its further improvement and upgrading by testing the various control algorithms for AC machines as well.
Thank you for your attention!