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## DIGITAL CONTROL OF A BRUSHLESS DC SERVOMOTOR ELECTRICAL DRIVE SYSTEMS CLOSED-LOOP CONTROL

BY

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**Abstract.** This paper presents the closed-loop control of a Brushless DC (BLDC) servomotor. The dsPICDEM MC1 development system (with the dsPIC30F6010A microcontroller) and the dsPICDEM MC1L power module, manufactured by Microchip Company, were used.

The control program was developed in C programming language and adapted for microcontroller with MPLAB platform. Therefore, for closed-loop control a digital controller PI type was implemented. The graphical user interface, realized in LabVIEW 8.6 graphical programming language, presents the following facilities: setting of speed controller parameters, speed profiling, establishing of operating regime (constant load or overload), on-line visualization of the main quantities (prescribed and measured speed, and command quantity).

Due to digital controller PI type well chosen and well tuned, the system response at speed step variation is very good. Therewith, the experimental results obtained also show a good „compensation” of disturbance (load torque) which does not happen in open-loop control.

**Key words:** BLDC servomotor; digital control, closed-loop control.

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## 1. Introduction

The most of BLDC servomotors are used in servodrives, so they designed into integrated version with digital control systems which provide speed/position/torque control (Tae-Hyung *et al.*, 2006; D'Souza, 2004; Mathapati, 2007). The regulation within large limits of speed / position requires electrical drive systems (EDS) with high level of automation. Speed/position digital control can be implemented on systems with microcontrollers. High operation speeds, the low cost, the large number of peripheral devices, etc., make microcontrollers to represent the „intelligent” elements from EDS.

Using microcontrollers in electrical drive control circuits is also justified by Hintz & Taback, 1993; Peatmenn, 1998; Cazacu *et al.*, 2010, namely:

- possibility to implement evolved digital control algorithms;
- reducing control circuits time response;
- improving control performances by consideration of some functionality nonlinearity conditions;
- improving control accuracy by reducing some analogical components which can depreciate in time and require corrections, etc.

Taking into account the above mentioned aspects, the paper presents the closed-loop digital control of the BLDC servomotor speed.

## 2. Hardware Aspects

The EDS block diagram is presented in Fig. 1. The system contains:

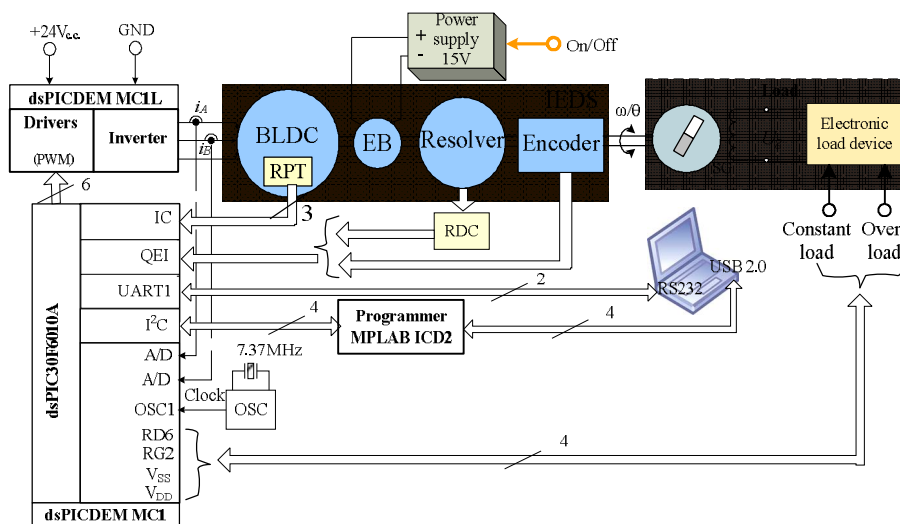


Fig. 1 – EDS block diagram for closed-loop control.

a) an integrated electrical drive system (IEDS) which includes a BLDC servomotor with rotor position transducer (RPT) realized with Hall sensors, a resolver, an encoder with resolution of 4096 PPR, and an electromagnetic brake (EB);

b) dsPICDEM MC1 development system;

c) dsPICDEM MC1L power module;

d) a load controlled device that offers the ability to load the BLDC servomotor with a resistant torque in constant load or overload regime;

e) MPLAB ICD2 programmer/debugger.

Dedicated for EDS control, dsPICDEM MC1 development system generally is designed to operate with dsPIC30F digital controllers family (www.Microchip.com, 2005). The development system has all of peripheral devices that are needed to be integrated in digital control of an EDS, the inverter being independent of it. The interconnection with the rotor position feedback of BLDC servomotor is realized either by the interface with logical signals provided by RPT with Hall sensors, either by encoder's interface (QEI module – Quadrature Encoder Interface). dsPICDEM MC1 development system's clock is provided by a quartz oscillator (7.37 MHz frequency). The block diagram of dsPICDEM MC1 development system is shown in Fig. 2.

The essential element of the development system is the digital controller (16 bits), with signal processor features, dsPIC30F3010A. Its most important characteristics are (www.Microchip.com, 2005):

a) Harvard modified architecture, optimized for C programming language;

b) flexible Addressing modes;

c) 84 base instructions;

d) 144 Kb program memory (Flash), 8 Kb RAM and 4 Kb EEPROM;

e) large number of interrupt sources (44);

f) internally clock with a frequency of 7.37 Hz;

g) dual data fetch;

h) 2 serial ports (RS232 and RS485);

i) 2 CAN modules;

j) 8 PWM channels to command the inverter;

k) 4 modules to generate dead time;

l) 3 inputs for encoder;

m) 16 bits counter related to encoder interface;

n) software possibilities to increase encoder signal resolution;

o) programmable digital noise filters on inputs;

p) 10-bit Analog-to-Digital Converter (A/D, 1 Msps conversion rate);

q) 16 A/D channels.

The human intervention on the unfolding process control is assured by the following elements: the START/STOP, SENS, RESET push buttons, two

potentiometers for speed and maximum current drawn by BLDC servomotor, the UART1 computer serial interface and CAN interface.

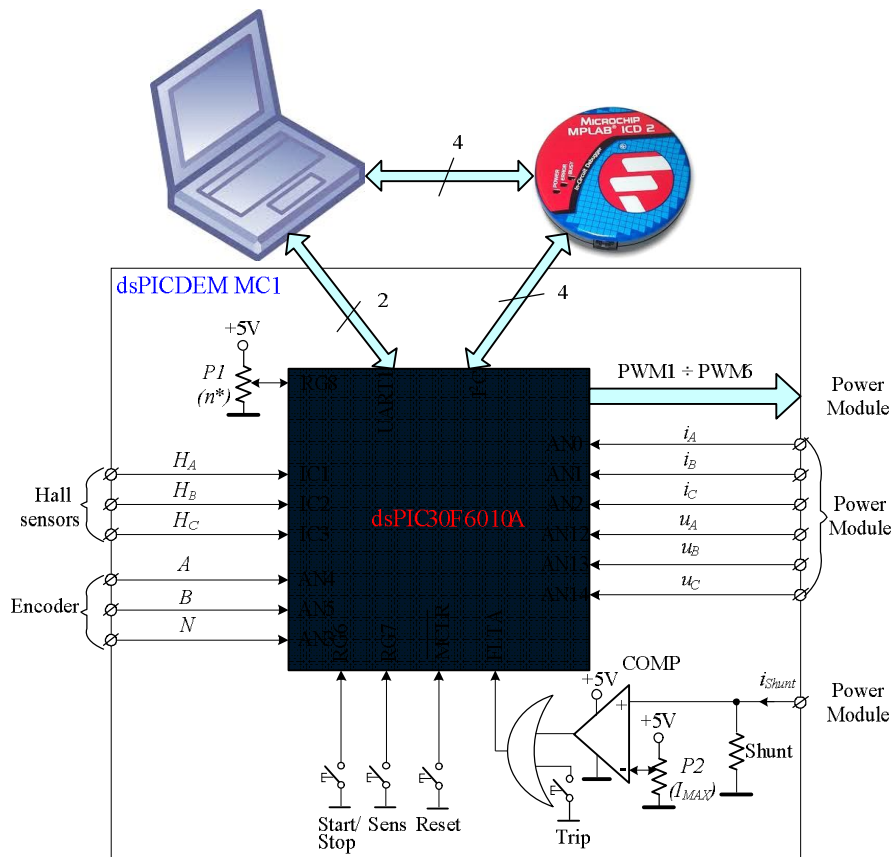


Fig. 2 – dsPICDEM MC1 development system block diagram.

dsPICDEM MC1L power module that feeds the BLDC servomotor, includes an inverter made by 6 MOSFET transistors. Also, dsPICDEM MC1L driver contains a reverse voltage protection circuit and a brake chopper (www.Microchip.com, 2003).

### 3. Software Aspects

The closed-loop control program was developed in C programming language and adapted for microcontroller with MPLAB platform (MPLAB 7.3 software and programmer/debugger MPLAB ICD 2). The flowchart of closed-loop control program is presented in Fig. 3, and in Fig. 4 is described the flowchart of the interrupt routine.

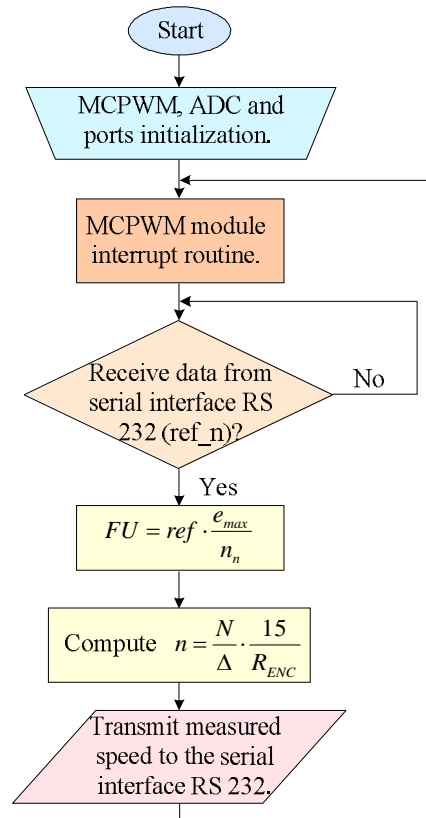


Fig. 3 – Flowchart of main program for closed-loop control.

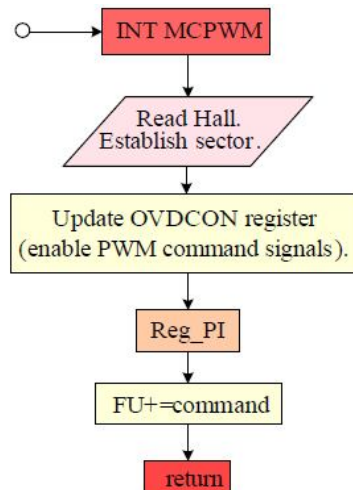


Fig. 4 – Flowchart of interrupt routine.

The digital controller algorithm is PI type and it assures a good dynamic response and a zero error in the stationary state (Sergiu & Dumitrache, 1985)

$$u(k) = u(k - 1) + K_p \left( \frac{T_s}{T_i} + 1 \right) e(k) - K_p e(k - 1), \quad (1)$$

where:  $u(k)$  and  $e(k)$  are, respectively, command quantity and error from actual sample step,  $u(k - 1)$  and  $e(k - 1)$  are the same quantities from last sample step,  $K_p$  is the proportionality constant,  $T_s$  is sample time,  $T_i$  is the integration time.

The flowchart of PI digital controller is shown in Fig. 5.

The real speed of BLDC servomotor was obtained by using the QEI module of microcontroller which is connected to the signals generated by the incremental transducer. QEI module performs the multiplication with 4 of the

information provided by the incremental transducer. The measured speed value is computed with (Cazacu *et al.*, 2010; Ursanu *et al.*, 2010)

$$n = \frac{N}{\Delta} \cdot \frac{60}{4R_{ENC}} = \frac{N}{\Delta} \cdot \frac{15}{R_{ENC}}, \quad [\text{rev./min.}], \quad (2)$$

where:  $N$  is the number of pulses in  $\Delta$  measurement range,  $R_{ENC}$  is the encoder's resolution (including the multiplication by 4 realized by microcontroller).

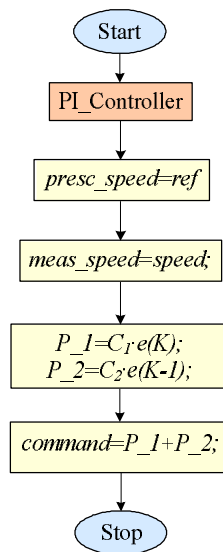


Fig. 5 – Flowchart of PI digital controller.

The graphical user interface was realized in *LabVIEW 8.6* graphical programming language, its LabVIEW diagram being presented in Fig. 6. The realized graphical user interface is presented in Fig. 7. It offers the following facilities:

- a) setting of speed controller parameters;
- b) speed profiling (step variation);
- c) establishing of operating regime (constant load or overload).
- d) visualization of the prescribed/measured speed and command quantity.

#### 4. Experimental Results

The experimental research was performed in the Electrical Drives Laboratory of „Gheorghe Asachi” Technical University from Iași. The general view of the test bench is presented in Fig. 8.

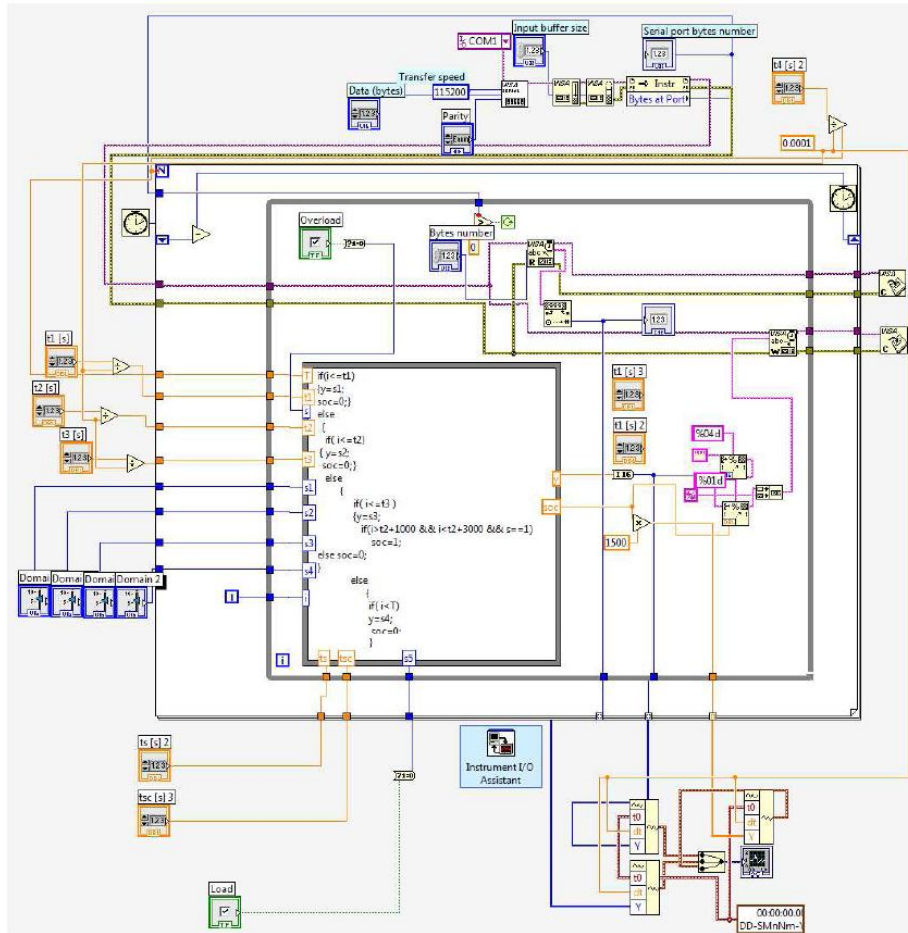


Fig. 6 – LabVIEW diagram for closed-loop control.

The BLDC servomotor from IEDS is three-phased in star connection with 9 slots on stator and 10 poles on rotor. Its nominal parameters are presented in Table 1.

**Table 1**  
*Nominal Parameters of BLDC Servomotor*

Parameter	Value	Unit
Rated voltage, $U_n$	24	V <sub>cc</sub>
Nominal current, $I_n$	3.5	A <sub>cc</sub>
Rated speed, $n_n$	1,725	rpm
Rated torque, $M_n$	0.35	N.m
Rated power, $P_n$	63.5	W
Winding resistance, $R$	0.7	$\Omega$
Winding inductance, $L$	1.3	mH
T.e.m. constant, $k_e$	0.07	V/(rad./s)
Rated efficiency, $\eta_n$	73	%

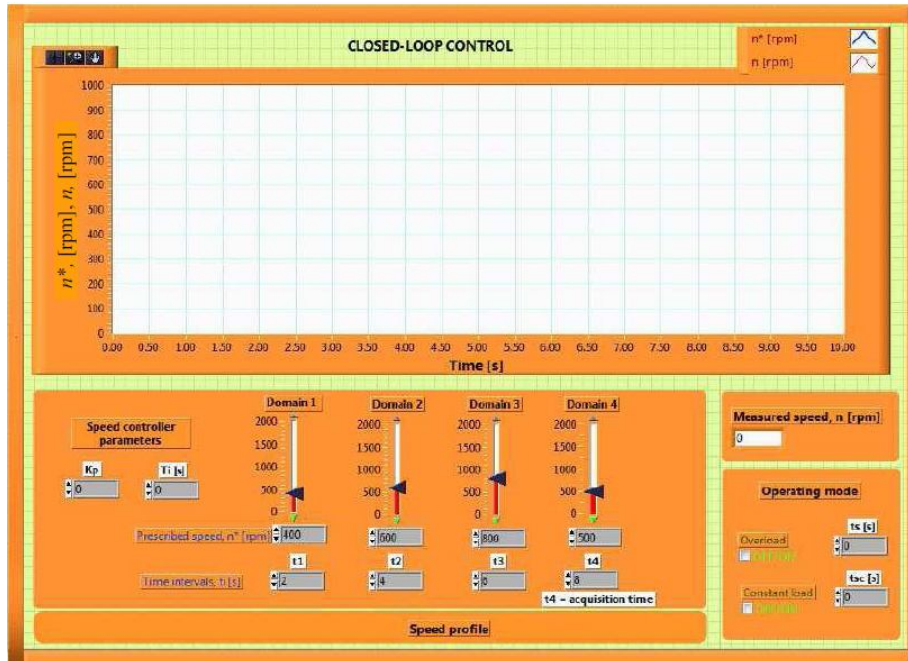


Fig. 7 – Graphical user interface for closed-loop control.

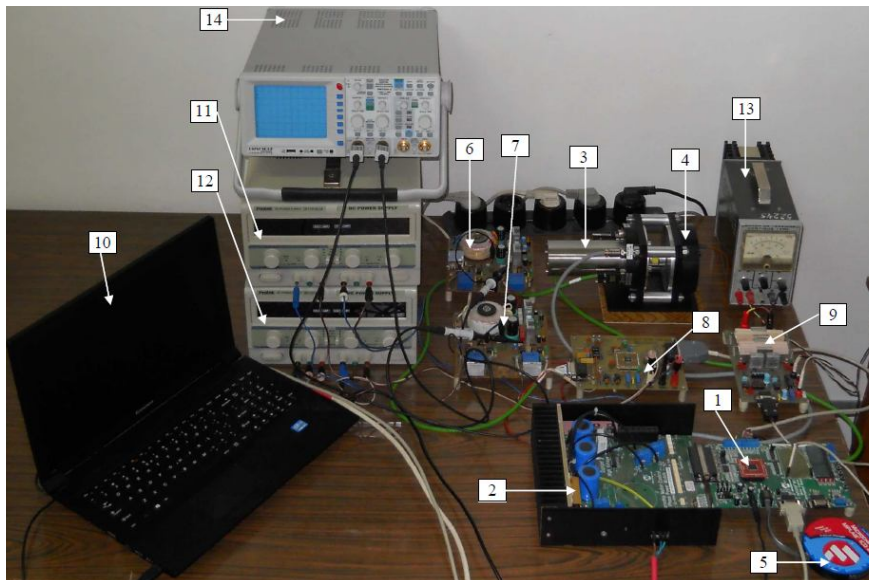


Fig. 8 – General view of the test bench: 1 – development system; 2 – power module; 3 – IEDS; 4 – SG; 5 – MPLAB ICD2 programmer / debugger; 6 – current transducers interface; 7 – voltage transducers interface; 8 – RDC; 9 – electronic load device; 10 – PC; 11, 12, 13 – power supplies; 14 – oscilloscope.



To load the servomotor, a load formed by an electronic load device and a single-phase synchronous generator (SG) was used. Position and speed signals were provided by the incremental transducer manufactured by Allied Motion – Computer Optical Products Inc. Company (resolution of 4,096 pulses/rev.).

The experimental results were obtained in the following working conditions:

- a) step variation of prescribed speed;
- b) overload.

In Figs. 9 and 10 is presented system response and duty cycle at prescribed speed step variation. Due to the fact that the digital controller was correctly chosen and tuned, the system response is very good (good dynamic response and a zero error in the stationary state).

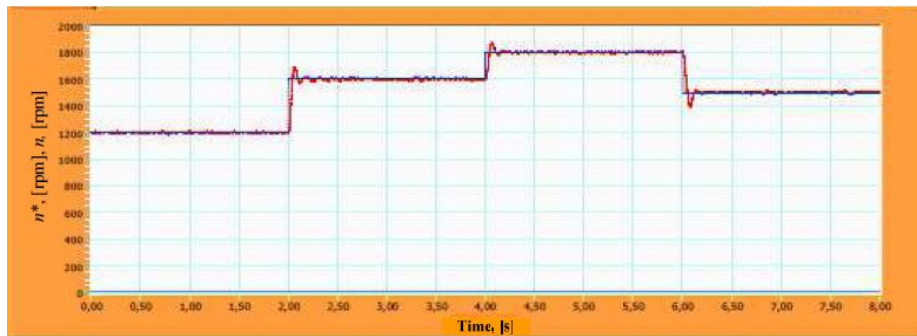


Fig. 9 – System response for prescribed speed step variation.

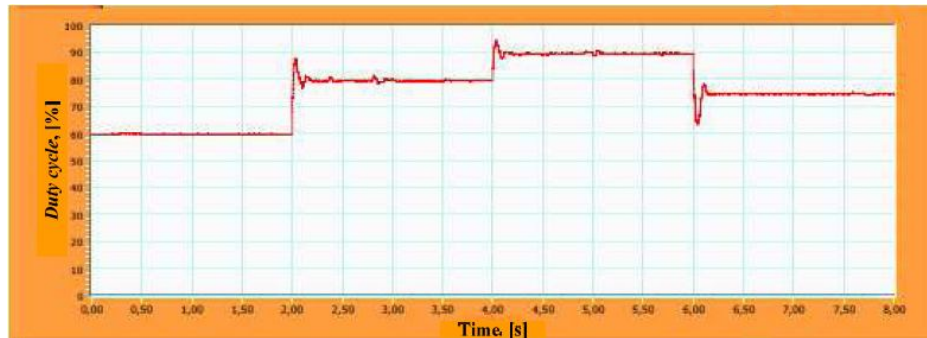


Fig. 10 – Time diagram of duty cycle for prescribed speed step variation.

System's response for overload and evolution of duty cycle generated by digital controller are presented in Figs. 11 and 12. Overload was imposed in 5...6 s interval. The experimental results were obtained for a sample period,  $T_s = 0.0001$  s. Controller parameters which led to these results are  $K_p = 1.21$ ,  $T_i = 0.0141$  and were obtained in an experimentally mode. The obtained experimental results also show a good compensation of disturbance (load torque).

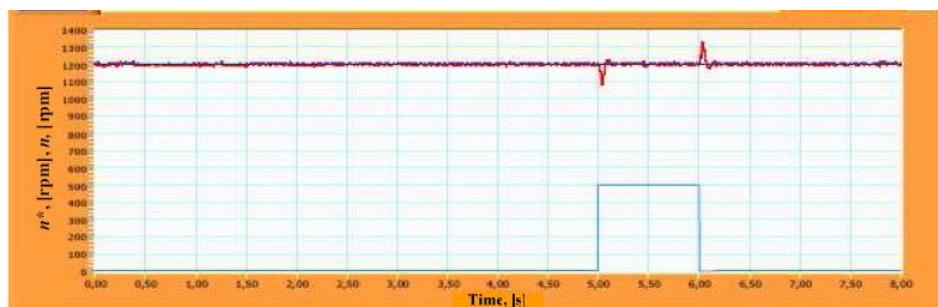


Fig. 11 – System response for disturbance step variation.

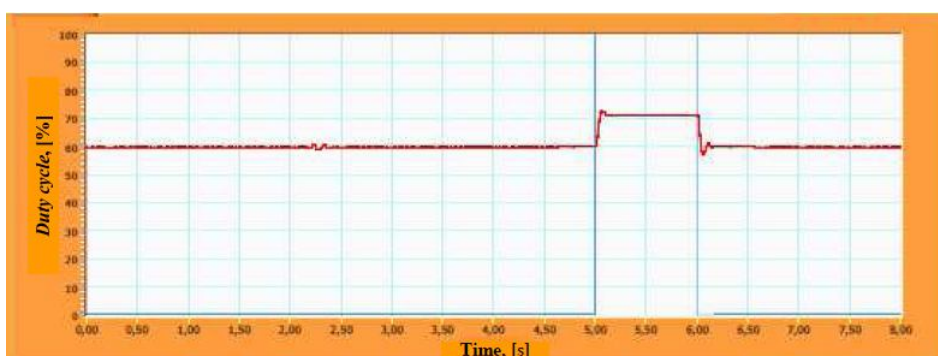


Fig. 12 – Time diagram of duty cycle for disturbance step variation.

## 5. Conclusions

Due to well chosen and well tuned controller, the system response at speed step variation is very good. Therefore, the experimental results obtained also show a good compensation of disturbance (load torque) which does not happen in open-loop control.

## REFERENCES

- Cazacu M., Ursanu Gh., Băluță Gh., *Open-Loop Control of a DC Servomotor*. Bul. Inst. Politehnic, Iași, **LVI (LX)**, 3, s. Electrot., Energ., Electron., 31-70 (2010).
- D'Souza S., *Sensored BLDC Motor Control Using dsPIC30F2010*. Appl. Note AN957, Microchip Inc., 2004.
- Hintz J.K., Taback D., *Microcontroller. Architecture, Implementation and Programming*. McGraw Hill, New York, 1993.
- Mathapati S., *Implementation of Dynamically Reconfigurable Control Structures on a Single FPGA Platform*. Proc. of Power Electron. a. Appl. Conf., 2007, 1-9.
- Peatmenn B. J., *Design with Microcontrollers*. McGraw Hill, New York, 1998.

- Sergiu C., Dumitrache I., *Regulatoare automate*. Edit. Did. și Pedag., București, 1985.
- Tae-Hyung K., Hyung-Woo L., Parsa L., Mehrdad E., *Optimal Power and Torque Control of a Brushless DC (BLDC) Motor/Generator Drive in Electric and Hybrid Electric Vehicles*. Proc. of Ind. App. Conf. – IAS, 2006, 1276-1281.
- Ursanu Gh., Diaconescu Cristina, Băluță Gh., *Closed Loop Control of a DC Servomotor*, Bul. Inst. Politehnic, Iași, **LVI (LX)**, 4, s. Electrot., Energ., Electron., 117-125 (2010).
- \* \* *dsPIC30F6010A Data Sheet*. www.Microchip.com, 2005.
- \* \* *dsPICDEM™ MC1L 3-Phase Low Voltage Power Module User's Guide*, DM300022, www.Microchip.com, 2005.

CONTROLUL NUMERIC AL SISTEMELOR DE ACȚIONARE ELECTRICĂ CU  
SERVOMOTOARE DE CURENT CONTINUU FĂRĂ PERII  
Controlul în circuit închis al turației

(Rezumat)

Se studiază controlul numeric în circuit închis al turației unui servomotor de c.c. fără perii (Brushless DC-BLDC). Au fost utilizate sistemul de dezvoltare dsPICDEM MC1 (cu microcontrolerul *dsPIC30F3010A*) și modulul de putere dsPICDEM MC1L fabricate de Compania Microchip.

A fost realizat programul de comandă a turației în limbajul de programare C care a fost adaptat microcontrolerului cu ajutorul platformei de programe MPLAB (mediul de programare MPLAB 7.3 și programatorul/depanatorul MPLAB ICD 2). Totodată, în cadrul controlului în circuit închis, a fost implementat un regulator numeric de turație de tip PI.

Interfața grafică cu operatorul uman, realizată în limbajul de programare grafică LabVIEW8.6, oferă posibilitatea stabilirii atât a profilului de turație, a parametrilor regulatorului, a regimului de lucru (cu sarcină constantă sau șoc de sarcină) cât și vizualizarea principalelor mărimi (turația prescrisă și cea măsurată, mărimea de comandă).

Datorită regulatorului bine ales și acordat, răspunsul sistemului la modificarea în treaptă a referinței este foarte bun. Totodată, rezultatele experimentale obținute evidențiază și o bună „compensare” a perturbației (cuplul rezistent de sarcină), fapt care nu are loc în cazul comenzii în circuit deschis.

