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ACQUISITION SYSTEM FOR ANALYSIS AND DESIGN OF ELECTRICAL SERVO SYSTEM BASED ON USB DAQ CARD DT9812

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Abstract. *In this paper the acquisition system for analysis and design of electrical servo system based on USB DAQ card 9812 is presented. The acquisition system is used for identification of all components, time and frequency domain analysis and design of position servo system in laboratory conditions. Transfer function and state space model of a DC motor, as object of control, are obtained. Complete system is modeled and tested using MATLAB-SIMULINK. To achieve the predefined objectives phase lead compensator is designed. The obtained results show that proposed acquisition system enables realization of all steps in servo system analysis and design with high quality.*

Key words: *acquisition system, position servo system, identification, DC motor, acquisition card DT9182, phase lead compensator*

1. INTRODUCTION

To exploit computer resources as much as possible, they have to be connected with the real world in an appropriate way. Acquisition cards enable bidirectional communication between the computer and real process. In this paper we deal with the identification, analysis and design of one position servo system in laboratory conditions. For this purpose an acquisition system based on USB DAQ card DT9812 and MATLAB-SIMULINK program package is realized. Using appropriate toolboxes, such as Data Acquisition Toolbox and Control System Toolbox, the modeling, identification, data acquisition, system analysis and design is performed.

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Acquisition card DT9812 (Figure 1) has 8 single ended analog inputs, 8 digital inputs/outputs, 2 analog outputs, external clock and external trigger. Input and output data resolution is 12 bits and cannot be changed. Maximum input and output voltage is ± 10 V. The sample rate is 50 kS/s and it is multiplexed between the channels which are used. The card is connected with the PC and supplied via an usb cable. The structural scheme is presented in Figure 2 [1].

Fig. 1. Acquisition card DT9812

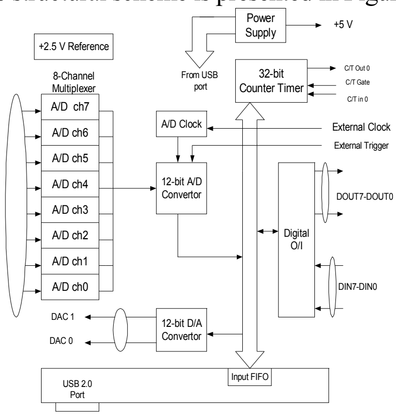


Fig. 2. Structural scheme of the acquisition card DT9812

Installing the appropriate drivers for the acquisition card DT9812 with MATLAB adaptors enables using card resources with Data Acquisition Toolbox from Simulink.

2. Structure of the Acquisition System

The object of control is a DC motor with tacho as the sensor of the shaft angle speed. To perform positional feedback, the signal from tacho is integrated and used as information of shaft position. The bidirectional acquisition process is controlled from SIMULINK. Low power signals from the acquisition card are amplified and then sent to the motor as control inputs. The structural scheme of the acquisition system is shown in Figure 3.

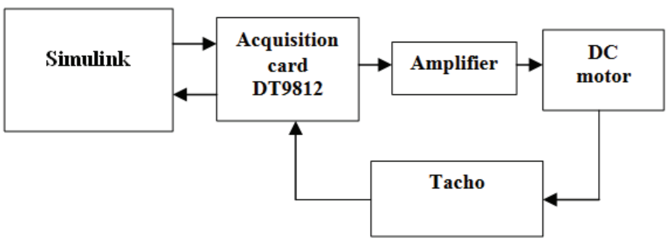


Fig. 3. Structural scheme of the acquisition system

Using Analog Output and Analog Input blocks from Simulink Data Acquisition Toolbox, as shown in Figure 4, communication with acquisition card is performed. The signal from tacho is integrated through discrete time integrator and then compared with the reference from appropriate source block. In such a way negative feedback is closed.

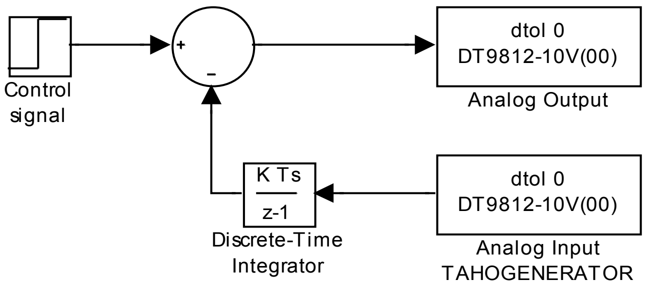


Fig. 4. Simulink model

3. IDENTIFICATION OF DC MOTOR

In this paper DC "Feedback" motor is used, with maximum field and armature excitation of 50V. It is equiped with tachogenerator whose constant is known: K_{tg}=0.0191 V/rad/s. For armature current measuring 1Ω resistor is serial connected in armature circuit. All necessery signals are available on the front panel of the motor as presented in Figure 5.

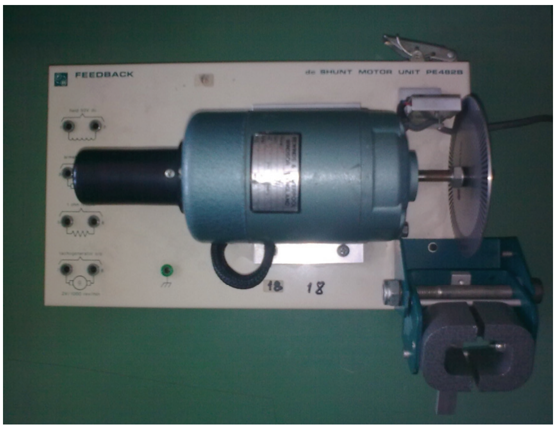
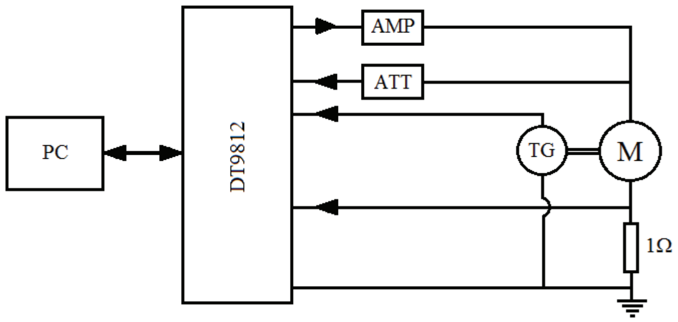


Fig. 5. DC "Feedback" motor

Identification of DC motor transfer function is done using Simulink Parameters Estimation Tools which is based on nonlinear least square method [2]. Pseudorandom binary sequence with appropriate length is used as exitation signal. Properties of pseudorandom binary sequencies and their generation are described in [3]. The armature current and shaft angle speed are measured as output signals. The measuring scheme and recorded signals are shown in Figure 6. AMP and ATT denotes amplyfier and attenuator, respectively. For this purpose "KEPCO" amplyfier is used, with the gain of 10. Potentiometer as voltage attenuator scaled armature voltage linearly with the gain of 0.2.



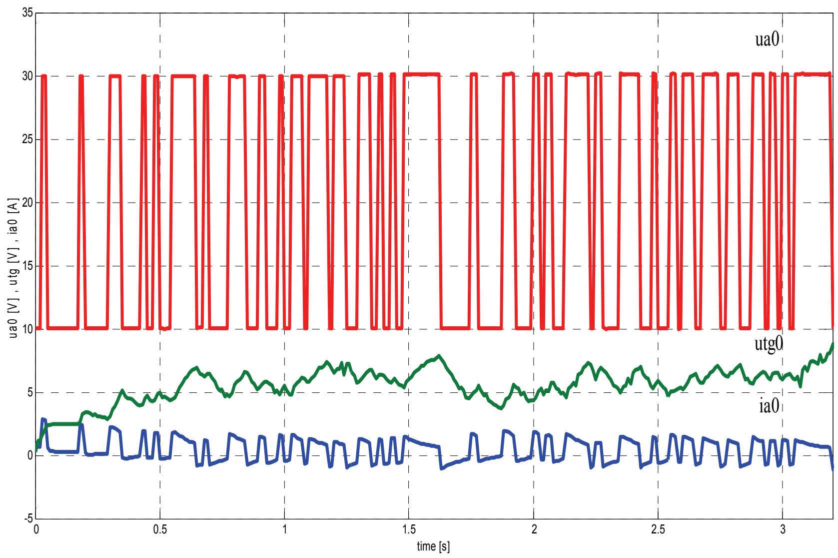


Fig. 6. Measuring scheme and recorded signals

SIMULINK model for identification of motor parameters is given in Figure 7. One input (armature voltage u_{a0}) and two output signals (armature current i_{a0} and tacho voltage u_{tg0}) are defined there. For a complete description of the motor, six parameters have to be estimated and they are given in Table 1. It should be noted that electromotive constant K_{me} and torque constant K_{em} have the same value when expressed in SI units, so the determination of one of them is enough [5]. A dialog window for import of input and output signals, definition of parameters for estimation and estimation process options, is shown in Figure 8.

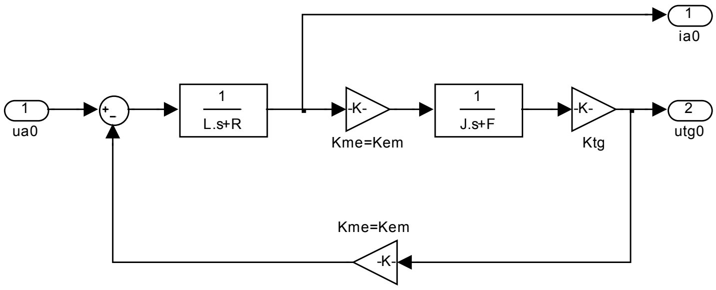


Fig. 7. SIMULINK model for identification

Table 1. Parameters of DC motor

Parameters	Symbol
Armature inductance	L
Armature resistance	R
Motor inertia	J
Viscous friction	F
Torque constant	Kem
Electromotive constant	Kme

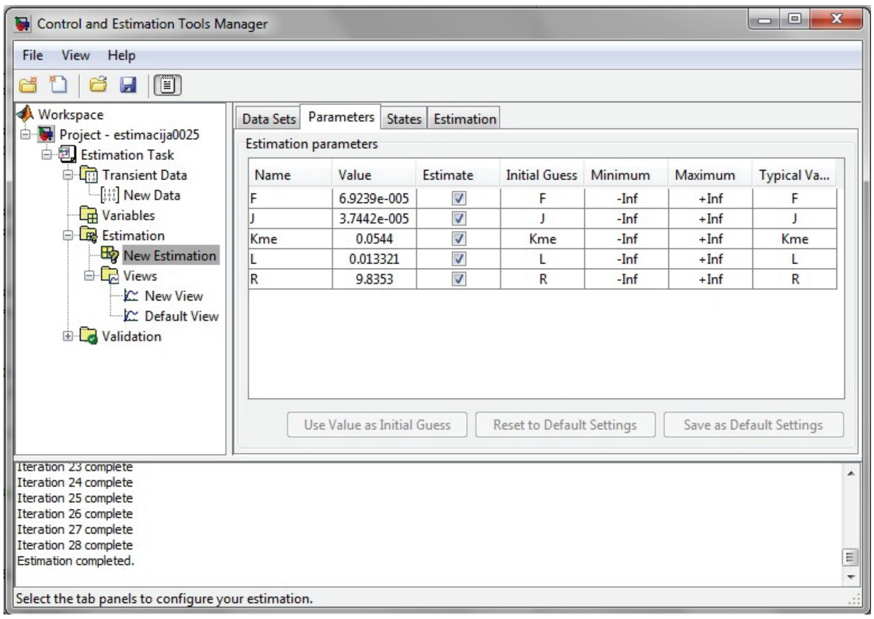


Fig. 8. Dialog window for parameter estimation

After 28 iterations estimation process, with the predefined accuracy, is completed. Parameter trajectories and comparison of simulated and measured responses of the system during the estimation are shown in Figures 9 and 10.

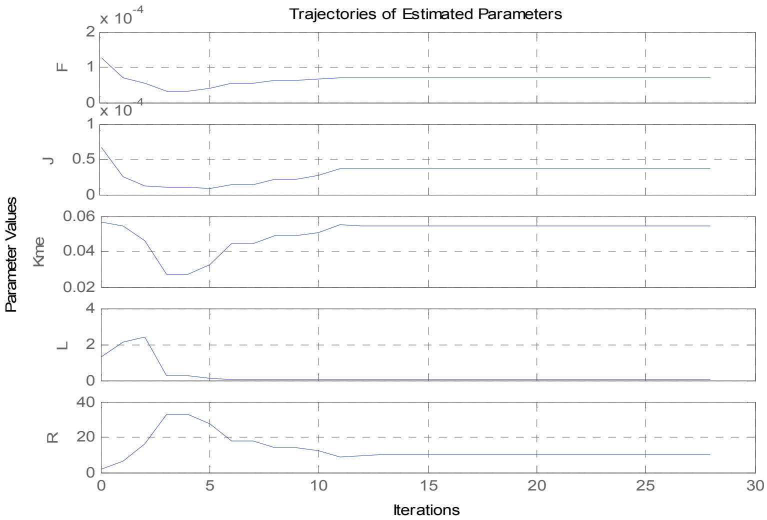


Fig. 9. Trajectories of estimated parameters

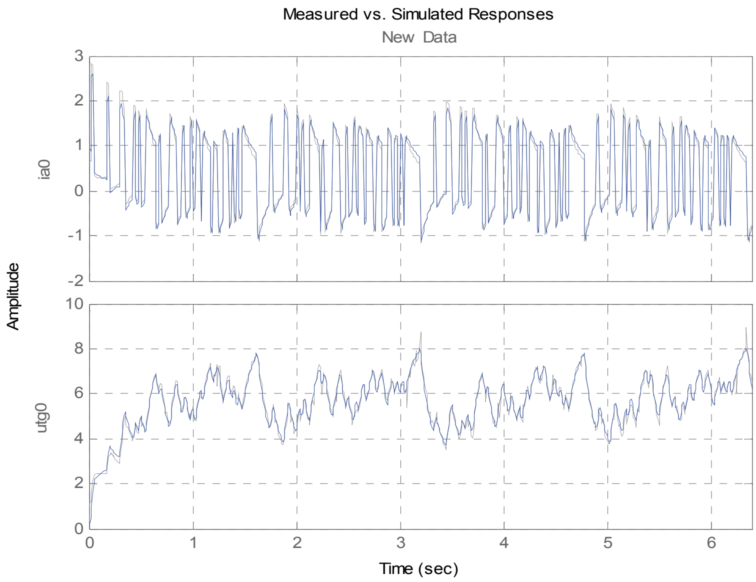


Fig. 10. Measured and simulated responses

As a result we obtained values of DC motor parameters, that are shown in Table 2.

Table 2. Values of DC motor's parameters

Symbol	Values
L	0.013321 H
R	9.8353 Ω
J	$3.7442*10^{-5}$ kgm^2
F	$6.9239*10^{-5}$ $kgm^2/(rad/s)$
Kme	0.0544 V/(rad/s)
Kem	0.0544 Nm/A

Based on the estimated parameters, the DC motor transfer function is calculated [4]:

$$G_m(s) = \frac{79.76}{0.00075s^2 + 0.5442s + 5.33} \quad (1)$$

As the electrical time constant (T_{el} = L/R) is much smaller than the mechanical (T_{meh} = J/F), transfer function can be approximated by first order function [4]:

$$G_m(s) = \frac{14.96}{0.1015s + 1} \quad (2)$$

The step responses of identified transfer function (dash line) and a real motor (solid line) are shown in Figure 11. As we can see, the responses are quite similar, which confirm the quality of the identification. The excitation step was 20 V.

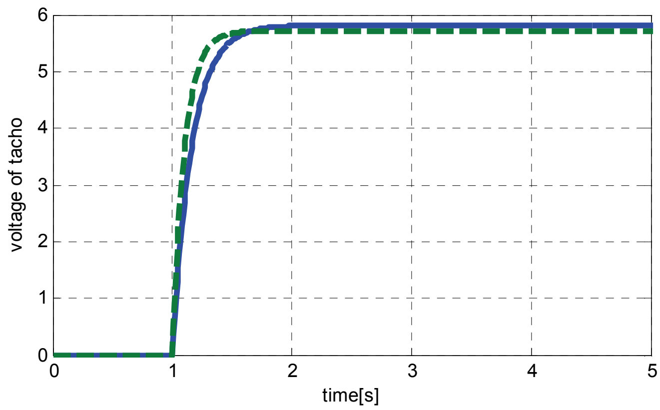


Fig. 11. Step responses of identified transfer function and a real motor

Now, open and closed loop transfer functions of the positional servo system can be calculated:

$$W(s) = K_p K_{tg} G_m(s) \frac{1}{s} = \frac{2.8574}{s(0.1015s+1)} \tag{3}$$

$$F(s) = \frac{W(s)}{1+W(s)} = \frac{28.15}{s^2+9.85s+20.15} \tag{4}$$

Experimentally recorded step response of the positional servo is shown in Figure 12.

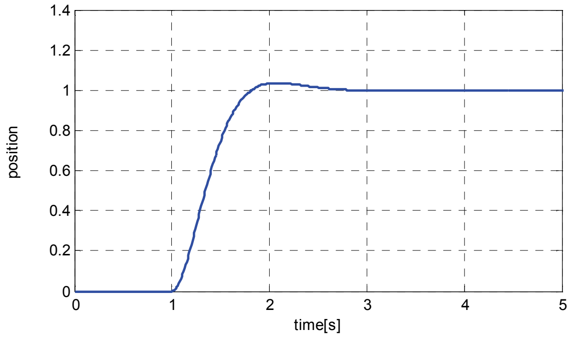


Fig. 12. Step response of positional servo

4. DESIGN OF THE COMPENSATOR

In order to improve the characteristics of the positional servo we decided to design a compensator using a loop-shaping design approach. The term "loop shape" refers to the shaping of the open loop transfer function W(s) in frequency domain using Bode plots [6]. Figure 13 shows Bode diagrams of open loop transfer function of position servo. In the figure it can be seen that the intersection frequency of the system is 2.79 rad/s and that the spare phase of the system is 74.

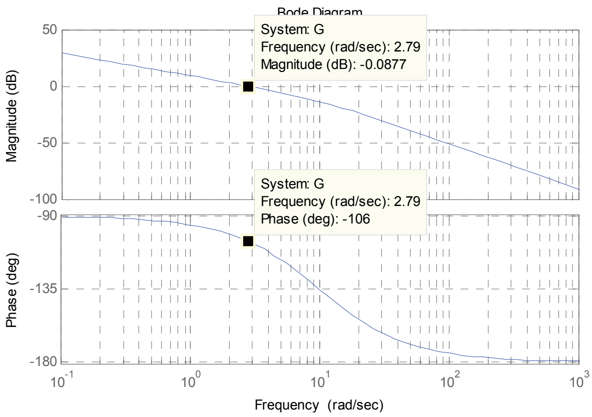


Fig. 13. Bode diagrams of the system

Design objectives for compensator design are: settling time less than 0.5 seconds and the overshoot less than 20% in step response. Those requirements can be achieved with a compensator which has the form:

$$K(s) = K_k K_{lead}(s) = K_k \frac{1 + s / w_n}{1 + s / w_p} \tag{5}$$

where: K_k – is proportional gain, for increasing the speed response, $K_{lead}(s)$ – is phase lead part of the compensator, for reducing the overshoot and increasing the phase margin of the complete system [6].

Following the design algorithm, the parameters of phase-lead compensator are calculated and given in Table 3[6].

Table 3. Values of compensator's parameters

Parameter	Values
K_k	20
w_n	21 rad/s
w_p	212 rad/s

Open loop transfer functions of position servo with compensator have the following form:

$$W_k(s) = K(s)W(s) \tag{6}$$

and the Bode diagrams of the compensated system are shown in Figure 14. The intersection frequency increased to 30.7 rad /s, and thus the speed of the system response. The phase margin stays at a satisfactory value of 58 °.

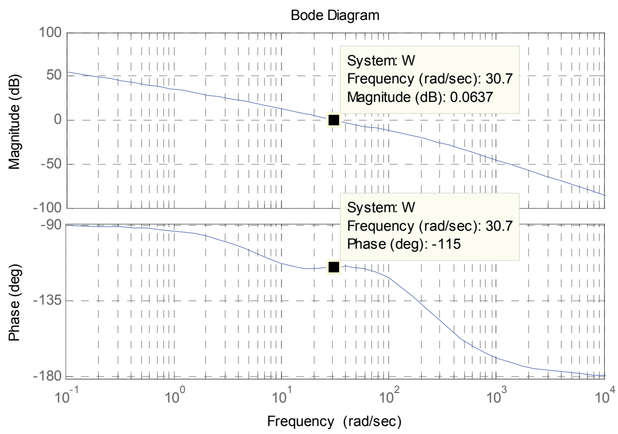


Fig. 14. Bode diagrams of the compensated system

Using step invariant method with discretization period Td = 0.002 s, the discrete transfer function of compensator is obtained [7]:

$$K(z) = 201.9\frac{(z-0.9658)}{(z-0.6544)} \tag{7}$$

The compensator is modeled in the Simulink and implemented in the loop, as presented in Figure 15.

Comparative responses of the systems with and without compensator are shown in Figure 16. It can be noticed that the system with a compensator (dashed line) has a faster response, less than 0.5 seconds and the overshoot less than 20%, which means that the desired design goals are achieved.

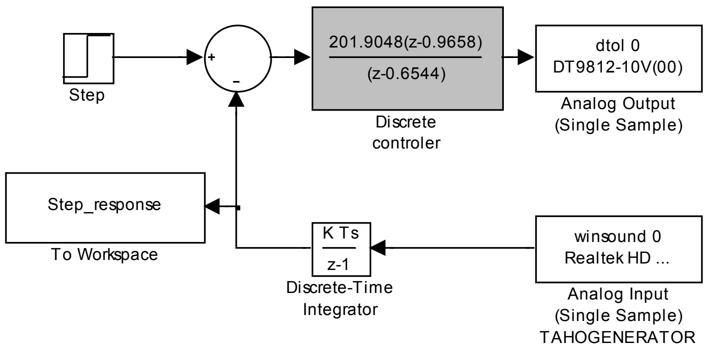


Fig. 15. Positional servo system with compensator

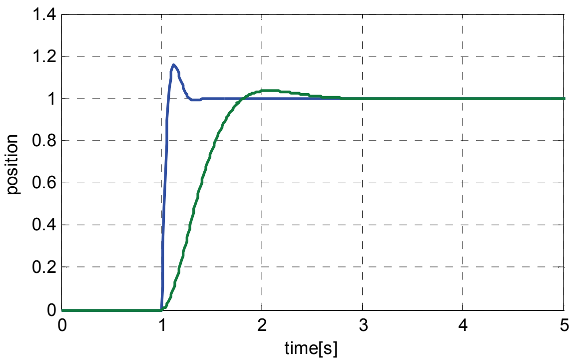


Fig. 16. Step responses of position servo with and without compensator

5. Conclusion

In this paper one acquisition system and capabilities of its application in solving different problems in analysis and design of servo systems are presented. It was shown that the acquisition card DT9812 with its performances can successfully be used for acquisition of signals whose dynamic characteristics are typical for servo systems. Also, MATLAB-SIMULINK software enables a lot of specialized tools for identification, analysis and syntheses of servo systems. One concrete electrical position servo system is analyzed and a phase lead compensator is designed whose implementation improved the performances of the complete system. The obtained results show that the application of the proposed acquisition system gives an opportunity to implement the more complex algorithms. The main directions of further work will be an implementation of different control algorithms on the platforms like microcontroller or FPGA boards for work in real time.

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AKVIZICIONI SISTEM ZA ANALIZU I PROJEKTOVANJE ELEKTRIČNOG SERVOSISTEMA ZASNOVAN NA USB AKVIZICIONOJ KARTICI DT9812

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U radu je opisan akvizicioni sistem za analizu i projektovanje električnog servosistema zasnovan na akvizicionoj kartici DT9812. U laboratorijskim uslovima, primenom akvizicionog sistema, izvršena je identifikacija komponenti, analiza u vremenskom i frekventnom domenu i projektovanje pozicionog servosistema. Kao objekat upravljanja korišćen je motor jednosmerne struje, čija je prenosna funkcija identifikovana. Pomoću programskog paketa MATLAB-SIMULINK izvršeno je modelovanje i verifikacija dobijenih funkcija prenosa. U cilju poboljšanja performansi sistema isprojektovan je phase lead kompenzator. Kvalitet dobijenih rezultata pokazao je mogućnost primene ovakvog akvizicionog sistema u svim koracima analize i projektovanje servosistema.

Ključne reči: *akvizicioni sistem, pozicioni servosistem, identifikacija, motor jednosmerne struje, akviziciona kartica DT9812, "phase lead" kompenzator.*