Eng. & Tech. Journal, Vol.28, No. 5, 2010

D.C. Servo Position Control Parameter Estimation

Dr. Saad T. Kurdi* & Nihad M. Ameen**

Received on:1 /3 /2009
Accepted on:3 / 12/2009

Abstract

Open-loop and closed-loop position control systems are obtained using dc motor. The open-loop uses an estimation of controller parameters to perform the position control where the closed loop position control systems uses a cascade controller to maintain the desired position. Controllers are designed using Matlab/Simulink simulation package. The objective is to design a position controller which will be able to drive the motor at a specified constant velocity which might gives the motor some constant torque. The results obtained from the open-loop position control system parameters estimation shows better performance specification in the control tasks, such as rise time and overshoot. The cascade closed-loop position control system shows an improvement in performance when use the values of estimated parameters.

ايجاد قيم المعاملات لنظام سيطرة الموقع باستعمال محركات السيرفو

الخلاصة

نظام السيطرة ذوالحلقة المفتوحة وأنظمة سيطرةِ ذات التغذيه الخلفيه تم اختيارها لتصميم منظومة سيطرة تقوم بتحديد موقع توقف محرك التيار الثابت. تَستعملُ الحلقةُ المفتوحةُ تقديرمعاملات جهاز السيطرة لتوجيه المحرك الى الموقع المطلوب بينما تستعمل أنظمة السيطرةِ ذات التغذيه الخلفيه سيطرة تتابعيه لإبْقاء المحرك على الموقع المطلوب. نظام السيطرة صمَّمَ بإستعمال رزمة محاكاةِ ماتلاب. الهدف هو تصميم جهاز سيطرة موقع الذي سيكون قادرا على قيادَة المحرك في حدود سرعة ثابتة التي قدْ تعطي المحرّك بَعْض عزم اللي الثابت. النَتائِج التي تم الحصول عليها بايجاد قيم المعاملات لنظام السيطرة ذوالحلقة المفتوحة اعطت مواصفات افضل في أداء مهام السيطرة مثل زمن الاستجابة والقيمة القصوى للاستجابة. تم تحسين اداء نظام السيطرة ذوالتغذيه الخلفيه باستعمال قيم المعاملات المستنبطه من نظام السيطرة ذوالحلقة المفتوحة.

1.Introduction

Instead of using sophisticated feedback control, they are often run open loop using mechanical stops or limit switches. Sophisticated robots use closed loop position systems for all joints. The robot position is controlled by a dedicated computer-based controller where this unit is also capable of translating human instructions into the robot program during the "teaching" phase [1]. In 2002 Corrado Guarino presents an inversion-based approach to the design of a dc motor-position servo system using the recently developed transition polynomials, a dynamic inversion procedure is established to determine a feed forward command signal to achieve high-performance position transfers. It is shown how to improve the servo performances. Moreover, the methodology can easily comply with a voltage saturation avoidance constraint. Experimental results on a standard test bench highlight the effectiveness of the dynamic inversion idea [2].

* Electromechanical Engineering Department, University of Technology/Baghdad
**Electrical and Electronic Engineering Department, University of Technology/Baghdad

The parameters are adjusted by the static model in such away that the error becomes small. The problem is to determine the adjustment mechanism which brings the error to zero for all command signals. The plant with large parameter variations are difficult to control and may have some unstable behavior or will not respond. By using the optimization of the controller parameters the performance can be improved. The open-loop control law has no idea what the output is doing, and it marches on as if everything is working according to an idealized mode. The novel method is to use feedback. Here the output is read by sensors, which may themselves be modeled by differential equations.

2.Mechatronic Actuation Modules

A mechatronic system spans over mechanical engineering, electrical engineering, and control engineering and computer science. Mechatronic actuation module is defined as a self contained physically integrated system that consists of an electric machine, a transmission (e.g. gears or screw), sensors, a low level motion controller and a motor drive unit. In order to reach an optimal design of an integrated mechatronic system, first the electric machine model is presented and analyzed. Then physical component models of motor driver are presented. Finally the dynamic aspects are investigated and the low level controller and position sensor are integrated into the methodology. The methodology is based on two types of component models, dynamic and static models. The static models are algebraic expressions which make it possible to derive the optimal physical parameters of all the components without having to simulate them. This optimal parameters set is then used in the dynamic simulation model. The dynamic system model is based on differential equations needs to be simulated to describe the component behavior as a function of time [3]. The optimization methods have been based on an analytic technique where the optimum either is simply read directly out of a graph or calculated with the help of differential calculus. When non-linear dynamic phenomena and control performance evaluation included into the analysis it is necessary to introduce a more 'advanced' numerical optimization methods such as the integral of square error (ISE) [3]. Many of the parameters used in the dynamic simulations are derived with the static component models. So the small errors can affect the results from the dynamic simulations greatly. It is possible to obtain more correct results after a few iterations of the design cycle, having a prototype or previous version of the system that may be used for parameter identification.

3. Modeling of DC Machine and Mechanical Load Combinations

DC motors have speed-control capability, which means that speed, torque, and even direction of rotation can be changed at any time to meet new conditions. Control motors are not usually operated at a single voltage because varying the voltage is a way of controlling the power (and therefore speed). As the voltage increases, the stall torque and no-load speed also rise. The mathematical model of a dc motor at fixed position of the motor shaft can be expressed by these equations [4].

$$v_a = e_a + i_a R_a + L_a \frac{di_a}{dt} \quad ...(1)$$

Ra is the armature resistance (Ω); La is the armature inductance (H) and e_a is the back EMF which is dependent on the motor angular velocity

$$e_a(t) = k_E w_m(t) \quad ...(2)$$

k_E is the back EMF constant (V/rad/s); w_m is the angular velocity (rad/s)

$$V_a(s) = E_a(s) + (R_a + L_a S) I_a(s) \quad ..(3)$$

$$I_a(s) = \frac{V_a(s) - E_a(s)}{(R_a + L_a S)} \quad ..(4)$$

Dynamic equation

$$T_{em}(s) = k_T I_a(s) \quad ...(5)$$

$$J_{eq} = J_m + J_L \quad ...(6)$$

$$T_{em} = J_{eq} \frac{dw_m}{dt} + B_m w_m + T_L \quad ..(7)$$

T_{em} is the internally generated torque, k_T is the torque constant (N.m/A), J_m is the motor moment of inertia and J_L is the load moment of inertia $J_{eq} = J_m + J_L$ is the rotor inertia (kg.m^2), and $(B_m w_m)$ is the viscous friction torque. Assume that the load torque (T_L) is equal to zero. Then the equation 7 becomes

$$w_m(s) = \frac{T_{em}(s)}{J_{eq} S + B_m} \quad ...(8)$$

The block diagram for dc motor is shown in figure (1).

4.Cascade closed loop position control system

In closed loop control position system the feedback signal is subtracted from the set point at the comparator, by subtracting the actual position from the desired position we get the system error. The controller minimizes the error [5]. A control strategy used is enables the controller to turn the actuator on or off. Figure (2) shows the Matlab/Simulink for the cascade closed loop position control system. The response of the closed loop system is shown in figures (3) and (4), where KT = KE = 0.1, Ra = 2 Ω, La = 5.2 mH, Jeq = 1.5 x 10-4 kg.m^2, Bm = 0.001. From the result obtained it is noticed that the actual position can follow the desired position with some oscillation around the desired position that can cause a true problem where the overshoot is relatively high (about 30 %) and the speed of the motor is varied which causes an unstable torque. The desired performance of the closed-loop system with no overshoot should be concerned. To provide a stable control system the controller is designed with a perfect estimation of the process parameters.

5.Open-Loop Control System with parameter estimation

In Open-Loop Control Systems shown in figure (5), the controller never actually knows what the actuator did because there is no feedback. This system absolutely depends on the controller knowing the operating characteristics of the actuator [6].

6.DC Motor drive unit

To drive the motor, an interface circuit is required to convert the low-level motor control signal from the controller into a signal strong enough to run the motor. The classical way to do this is with an analog drive. In this method, a linear power amplifier amplifies the drive signal from the controller and gives the motor a “strengthened” analog voltage. Figure (6) shows a motor-driver circuit. Insulated Gate Bipolar Transistor (IGBT) used to drive the motor in matlab/simulik design. IGBT has a high switching frequency, lower conduction losses than MOSFET and high current and voltage rating. The reference input signal can produce the on-off time and the direction of the control task, while the amplitude of output signal is proportional to the DC voltage source. The open-loop control design may well work, but it has some inherent problems. The first problem is the disturbance; which may cause the output of the plant to deviate significantly from the reference trajectory. Another problem arises with plant uncertainties [4]. To overcome these problems; one models the plant, typically via differential equations and make an idealization of the plant’s actual behavior. Estimation of the actuator parameters with a suitable optimization strategy are one of the best methods for idealization of the plant’s actual behavior.

7.Estimation of Actuator Parameters

Servo system monitors the condition of output variables and comparing it to an input command and making adjustments to maintain equality, the most common controlled output variables are position, speed and torque. It is possible to have more than one controlled variable or to switch from one variable to another during operation. Optimization strategy uses an integral of square error (ISE) for adjusting the parameters in which the adjustment rate not depends on the magnitude of the test signal. The design parameters selected and initial values are obtained assuming that the controlled variables are continuous (the input caused the controlled variables is able to remains constant or to change in linear or step mode). The following equations represent the integral of square error (ISE) optimization procedure [7].

$$f(x,t)=\int e^2(t,b.b)dt. \qquad ..(9)$$

$e = y - y_m$

$b = process\ parameter$

$b = the\ corresponding\ model$

$parameter$

$$\nabla_B E=\frac{\partial E}{\partial b}=2\int_{t1}^{t2} e(t,b,b)\frac{\partial e}{\partial b}dt..(10)$$

Estimation and Validation test signals is shown in figure (7) is chosen as an input signals for the controller. The first iteration shows the desired and actual response in figure (8). The correction of the motor position rotation is improved after the first iteration figure (9) where the measured and simulated response becomes closer [8].

After a few iterations more correct results obtained. The estimation of controller parameters after the 7th iteration shows that the measured and simulated responses are identical, figure (10). The trajectories of estimated parameters are shown in figure (11). The estimated parameters are illustrated in table (1).

8.Simulation Results

The simulation result shown in figure (12), shows the system response to a unit step input for one second time period, the result shows that the dc motor is rotates 3.9 rad with an angular velocity 3.9 rad/sec and 0.03 N.m torque. By increasing the time to two seconds that will cause an increasing of angular position by 3.9 rad while the amplitude of the angular velocity and the corresponding torque wont effect. This means that we obtain a position controller with a constant velocity which leads to a constant torque. It is noticed that the motor speed effected directly by the amplitude of the dc voltage source of the drive unit. We can reverse the motor angle of rotation by reversing the input signal which cause a rotation of dc motor in opposite direction with the same value of angular velocity, the angular velocity and torque will remains at the same vale but in –ve sign. Figure (13) shows the response with a 1.5 second step input in forward and reversed direction of rotation with a corresponding angular velocities and torque. With a constant velocity of rotation we can reach any position directly or with any desired time delay by varying the frequency of input signal. The input signal can produce a sequence of tasks at the same manner. It is noticed that the amplitude of the input signal will not affect the speed of rotation. Assume that the controller is directed to move from 0 to 10 rad, by knowing the characteristics of the process, a desired pulses send to the motor; the motor will rotate exactly 10 rad at the rated speed and stop. We can also control the reverse position by send a negative input signals, as shown in figure (14) which shows the angular position, motor speed and motor torque for a two different input signals. The other method is to use feedback by adding a feedback sensor. The system response for a unit step input is shown in figure (15). The simulation results for a controller by adding a feedback sensor shows the fast and stable transient response. The actual position reach the desired value at a relatively low rise time, with no overshoot and zero steady state error that make it a good response and can be used in different control applications such as grinding, handling and gripping. The angular velocity of the rotating shaft will be stable and have no oscillation that will cause a constant torque (Te).

Conclusions

DC Servos are attractive for use in mechatronics, because they are relatively inexpensive, have a controllable torque, easily be modified to produce continuous shaft rotation at relatively slow speeds, decent amount of accuracy and they can easily be controlled by a microcontroller. Comparing the controller with the cascade controller, the simulation shows improvement in system behavior caused by optimization procedure using parameters estimation in static model.

References

[1]Alcherio Martinoli, "Swarm Intelligence in Autonomous Collective Robotics", Ph. D. Thesis, 1999. [2]Corrado Guarino Lo Bianco and Aurelio Piazzi, "A servo control system design using dynamic inversion", University of Parma, Italy, copyright by Elsevier Science Ltd. 2002.

[3]Fredrik Roos, "Towards a Methodology for Integrated Design of Mechatronic Servo System",

Royal Institute of Technology, Stockholm, 2007.
[4]An Engineering Handbook by Electro-Craft Corporation, "DC Motors Speed Controls Servo Systems", First published by Pergamon Press Ltd. United State of America, 1977.
[5]Imre Benyo, "Cascade Generalized predictive control ", oulu university, Finland, acta university press, 2006. [6]Roland S. Burns, "Advanced Control Engineering", university of Plymouth. Jordan Hill Inc, UK, 2001. [7] Thomas R. Cuthbert, JR., "Optimization using Personal Computers ", John Wiley & Sons, United State of America, 1987 [8]Pieter Eykhoff, "System Identification parameter and state estimation", Great Britain by J.W. Arrowsmith Ltd, 1979.

Table (1) Estimated parameters after the 7th iteration

Parameters	Initial guesses	Estimated values	Units
Back emf constant (KE)	0.0134	0.07272	(V/rad/s)
Motor torque constant (KT)	0.0134	0.07272	(N.m/A)
Rotor Inertia (J)	0.57 e-6	9.5299 e-6	(kg.m^2)
Armature Resistance (Ra)	1.9	1.9428	(Ω)
Armature Inductance (La)	0.065 e-3	2.033 e-3	(H)
Viscous friction (Bm)	0.008	0.039024	

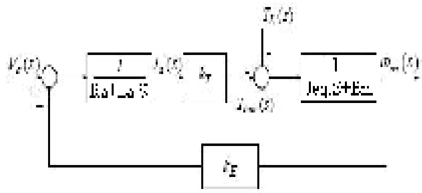

Figure (1) Block diagram for dc Motor

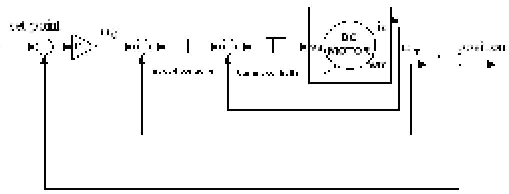

Figure (2) Cascade closed loop Position control system

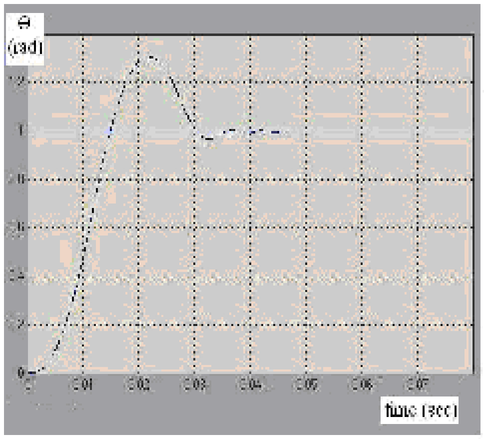

Figure (3) Desired and actual position

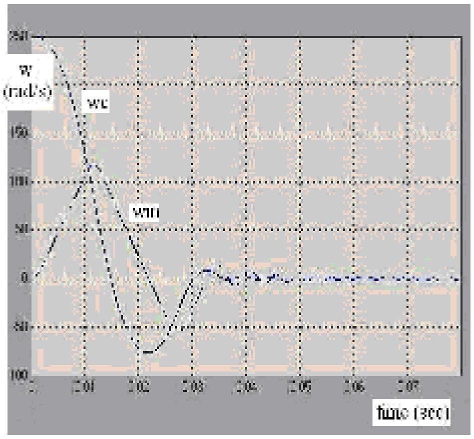

Figure (4) Desired and actual speed

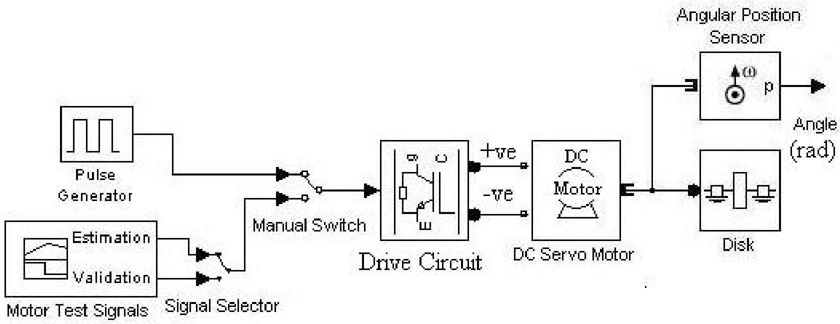

Figure (5) DC Servo position control system

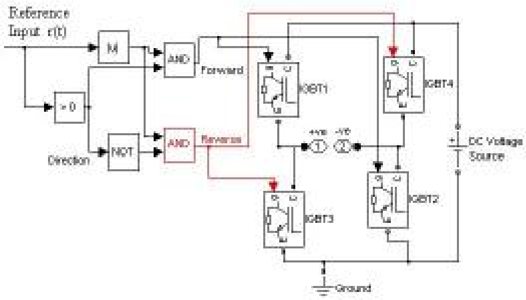

Figure (6) DC Motor drive unit

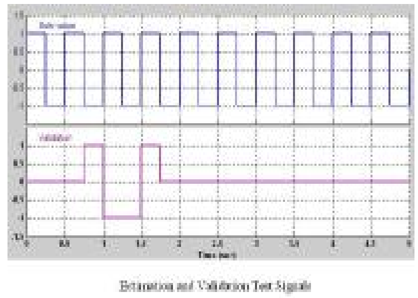

Figure (7) Estimation and Validation test

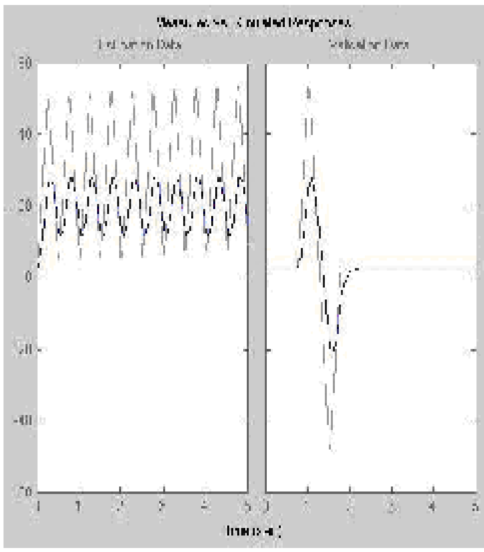

Figure (8) Measured and Simulated responses

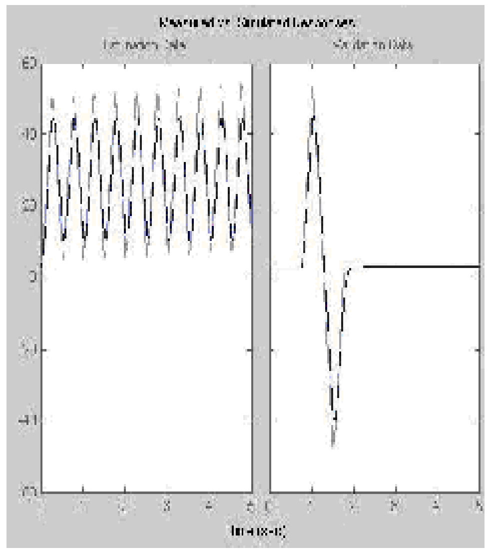

Figure (9) Measured and Simulated responses at the 1st iteration

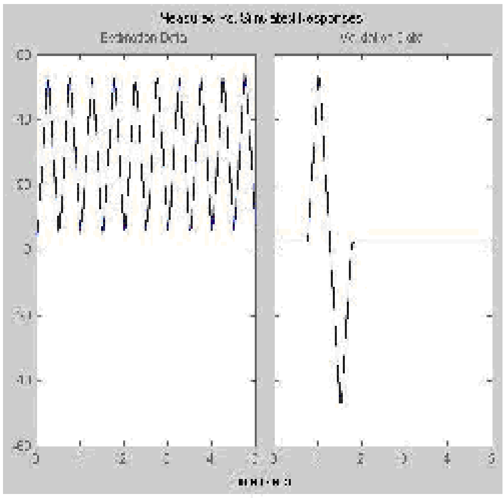

Figure (10) Measured and Simulated responses at the 7th iteration

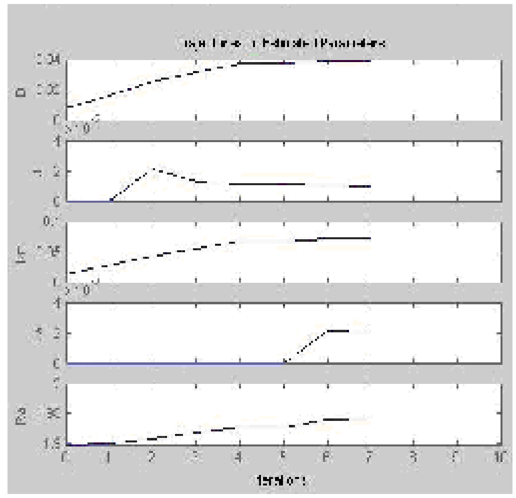

Figure (11) The values of estemated parameters

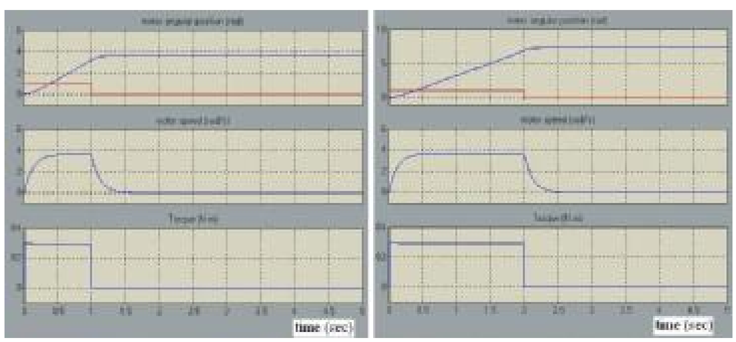

Figure (12) System Response to a unit step input

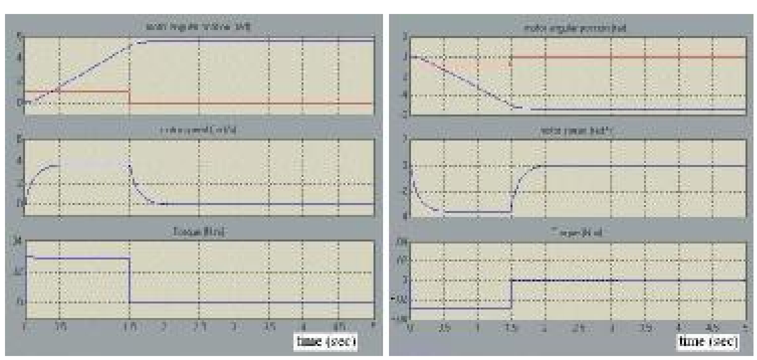

Figure (13) Positive and Negative step input response

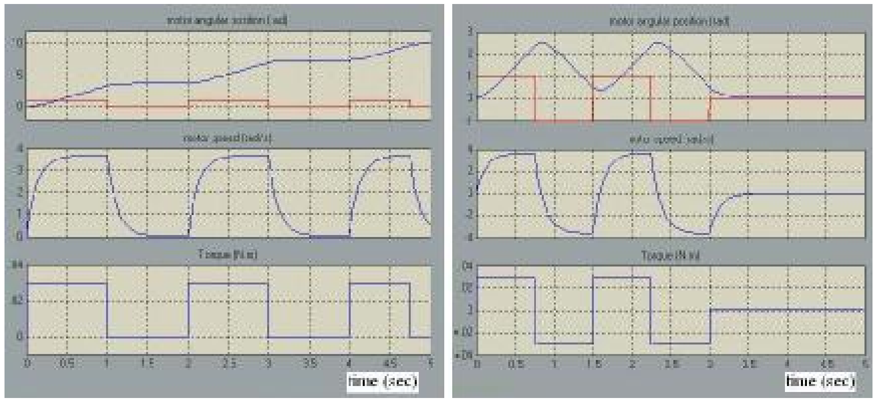

Figure (14) the angular position, motor speed and motor torque for Two different input signals

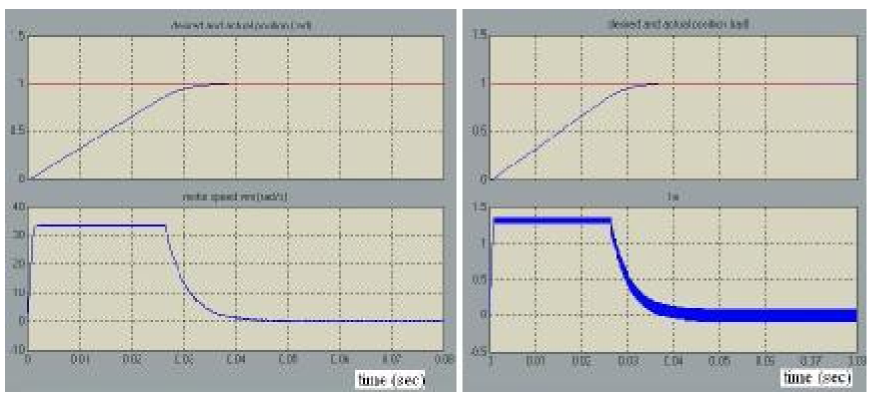

Figure (15) Closed-loop position control system response