D.C. Servo Position Control Parameter Estimation

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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.

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].
The parameters are adjusted by the static model in such a way 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].

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\[ v_a = e_a + i_a R_a + L_a \frac{di_a}{dt} \] (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

\[ e_a(t) = k_E w_m(t) \] (2)

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

\[ V_a(s) = E_a(s) + (R_a + L_a)I_a(s) \] (3)

\[ I_a(s) = \frac{V_a(s) - E_a(s)}{(R_a + L_a)} \] (4)

Dynamic equation

\[ T_{em}(s) = k_T I_a(s) \] (5)

\[ J_{eq} = J_m + J_L \] (6)

\[ T_{em} = J_{eq}\frac{dw_m}{dt} + B_m w_m + T_L \] (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.m²), 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

\[ w_m(s) = \frac{T_{em}(s)}{J_{eq}S + B_m} \] (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, \( L_a = 5.2 \) mH, \( J_{eq} = 1.5 \times 10^{-4} \) kg.m², \( B_m = 0.001 \). 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].

\[ f(x,t) = \int e^2(t,b,\beta) \, dt \]  \hspace{1cm} (9)

\[ e = y - y_m \]

\[ b = \text{process parameter} \]

\[ \beta = \text{the corresponding model parameter} \]

\[ \nabla_b E = \frac{\partial E}{\partial \beta} = 2\int_{a}^{b} e(t,b,\beta) \frac{\partial e}{\partial \beta} \, dt \]  \hspace{1cm} (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 \( i \) 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**


Table (1) Estimated parameters after the 7th iteration

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<th>Parameters</th>
<th>Initial guesses</th>
<th>Estimated values</th>
<th>Units</th>
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<td>Back emf constant (KE)</td>
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<td>0.07272</td>
<td>(V/rad/s)</td>
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<td>Motor torque constant (KT)</td>
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<td>(N.m/A)</td>
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<td>Rotor Inertia (J)</td>
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<td>Armature Resistance (Ra)</td>
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<td>Armature Inductance (La)</td>
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<td>Viscous friction (Bm)</td>
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<td>0.039024</td>
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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
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Figure (6) DC Motor drive unit

Figure (7) Estimation and Validation test

Figure (8) Measured and Simulated responses

Figure (9) Estimated and Simulated responses at the 1st location
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