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A DC Motor Speed Control by Selection of PID Parameter using Genetic Algorithm

Heui-Han Yoo† · Yun-Hyung Lee

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Abstract : The aim of this paper is to design a speed controller of a DC motor by selection of a PID parameters using genetic algorithm. The model of a DC motor is considered as a typical non-oscillatory, second-order system. And this paper compares three kinds of tuning methods of parameter for PID controller. One is the controller design by the genetic algorithm, second is the controller design by the model matching method, third is the controller design by Ziegler and Nichols method. It was found that the proposed PID parameters adjustment by the genetic algorithm is better than the Ziegler & Nichols' method. And also found that the results of the method by the genetic algorithm is nearly same as the model matching method which is analytical method. The proposed method could be applied to the higher order system which is not easy to use the model matching method.

Key words : DC motor, non oscillatory second order system, Model matching method, Genetic algorithm, PID controller

1. Introduction

DC motors have been widely used in high-performance electric drives and servo systems. The identification of a parameter for the speed control of DC motor can be determined directly through experimental testing[1]-[3]. However, evaluating the motor parameters directly and individually may not be practical or efficient in many situations. Furthermore, the values of parameters vary according to the operating range, and it is very difficult to find out the exact values of parameters. The PI and the PID controller have been widely used as a control method for the speed control of DC motor in industrial fields because of their simple structure and robust performance in a wide range of operating conditions. Also, recently, new approach for the speed control of DC motor using fuzzy PID controller or neural network PID controller has been proposed[4],[5].

Like this, so far, the major effort has been devoted to develop methods to

† Corresponding Author(Korea Maritime University), E-mail:yoohh@hhu.ac.kr, Tel:051)410-4841
* Korea Maritime University, College of Maritime Sciences, Department of Mechatronics Engineering

reduce the time spent on optimizing the choice of controller parameters[6]-[13]. But, the controller parameters should be changed in order to maintain an optimum operating state if the operating point or the motor parameters are changed. The performance characteristics of this kind of PID controller are changed remarkably by the adjusting of the parameters of the controller. Therefore, this paper deals the comparison between the PID parameters selection methods as the first step to apply for the speed control of DC motor more effectively even when the model does not match the actual DC motor. In this paper, the model of a DC motor is considered as a typical non-oscillatory, second-order system. We propose an adjusting method of PID controller by the genetic algorithm for speed control, and compare with three kinds of methods for the selection of PID parameters. One is the controller design by the genetic algorithm, second is the controller design by the model matching method, third is by Ziegler and Nichols method.

The results of unit-step response show that the method by the genetic algorithm has a better response characteristics in terms of mean square errors compared with Ziegler & Nichols' method. In addition, shows a better speed sensitivity in the unit step responses without overshoot.

2. Modeling of a DC Motor and Control System

Generally, Control system of a DC motor diagram of a DC motor is illustrated as Fig. 1.

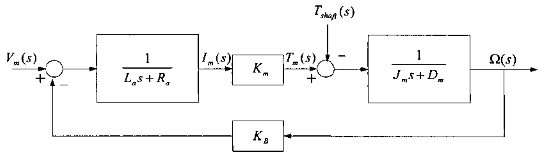


Fig. 1 Block diagram of a DC motor

From Fig. 1, the transfer function of DC motor no-load condition ($T_{shaft}(s)=0$) describes the relationship from input voltage to motor speed is as below.

$$G_p(s)=\frac{\Omega(s)}{V_m(s)}=\frac{K_m}{(L_a s+R_a)(J_m s+D_m)+K_m K_B} \quad (1)$$

The transfer function of a DC motor can be written in time constant form using electrical time constant (τ_e) and mechanical time constant (τ_m) :

$$G_p(s)=\frac{K}{(\tau_e s+1)(\tau_m s+1)},$$ where,

$$K=K_m K_{m'}=K_m\frac{\tau_e\tau_m}{L_a J_m}, \quad (2)$$

$$\tau_e=\frac{2L_aJ_m}{(R_aJ_m+D_mL_a)+\sqrt{R_a^2J_a^2-2R_aJ_mL_aD_m+L_a^2D_m^2-4L_aJ_mK_BK_m}}, \quad (3)$$

$$\tau_m=\frac{2L_aJ_m}{(R_aJ_m+D_mL_a)-\sqrt{R_a^2J_a^2-2R_aJ_mL_aD_m+L_a^2D_m^2-4L_aJ_mK_BK_m}}. \quad (4)$$

The DC motor model is considered as two first order systems with steady state gains (K_m, $K_{m'}$) and time constants (τ_e, τ_m).

2.1. Discrete Model of a DC Motor

A linear model of a DC motor in Fig. 2 is transformed into a discrete model by Z-transform as shown in Fig. 3.

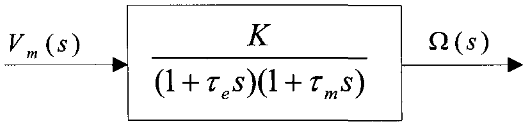


Fig. 2 A linear model of a DC Motor.

In Fig. 3, s and z are a Laplace operator and Z-transform operator respectively, and h is a sampling time. Therefore, a pulse transfer function of input-output is given by

$$\frac{\Omega(z)}{V_m(z)} = \frac{z-1}{z} KZ\left\{\frac{1}{s(1+\tau_e s)(1+\tau_m s)}\right\},$$

$$= \frac{z-1}{z} KZ\left\{\frac{\frac{1}{\tau_e \tau_m}}{s(s+\frac{1}{\tau_e})(s+\frac{1}{\tau_m})}\right\}. \qquad (5)$$

where, Z is a symbol of Z-transformation. In (5), if we let $\frac{1}{\tau_e}=a$, and $\frac{1}{\tau_m}=b$, we have

$$\frac{\Omega(z)}{V_m(z)} = \frac{z-1}{z} KZ\left\{\frac{ab}{s(s+a)(s+b)}\right\}$$

$$= \frac{z-1}{z} K\left\{\frac{z}{z-1} + \frac{bz}{(a-b)(z-e^{-ah})} - \frac{az}{(a-b)(z-e^{-ah})}\right\} \qquad (6)$$

Let $c_1 = -e^{-ah}$, and $c_2 = -e^{-bh}$ and $d = \frac{-ac_1+bc_2}{a-b}$. Rearranging (6),

$$\frac{\Omega(z)}{V_m(z)} = K\frac{(c_1+c_2+d+1)z^{-1} + (c_1c_2-d)z^{-2}}{1+(c_1+c_2)z^{-1}+c_1c_2z^{-2}}$$

$$= \frac{b_1z^{-1}+b_2z^{-2}}{1+a_1z^{-1}+a_2z^{-2}} \qquad (7)$$

where, $a_1 = c_1+c_2$, $a_2 = c_1c_2$, $b_1 = K(c_1+c_2+d+1)$, $b_2 = K(c_1c_2-d)$.

Hence, the discrete output (ω_i) of this system can be expressed by

$$\omega_i = -a_1\omega_{i-1} - a_2\omega_{i-2} + b_1v_{i-1} + b_2v_{i-2} \qquad (8)$$

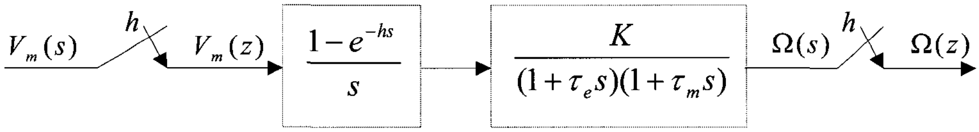


Fig. 3 A discrete model of a DC motor.

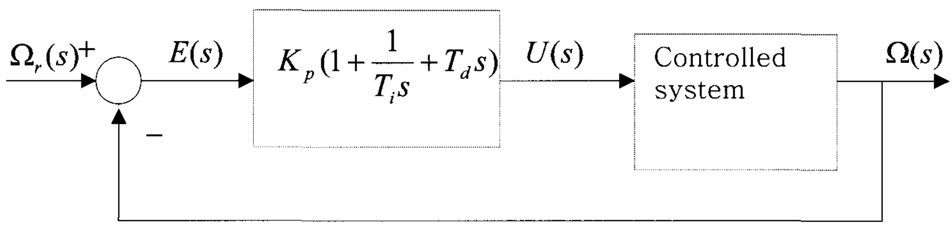


Fig. 4 Speed control system of a controlled plant.

2.2. Discrete Model of a PID Controller

In Fig. 4, If we approximate the ideal PID transfer function $\left(K_p(1+\frac{1}{T_i s})\right)$ using the difference equation, the output of PID controller can be expressed by

$$u(i) = K_p\left[e(i) + \frac{h}{T_i}\left\{\frac{e(0)+e(i)}{2}\right\} + \frac{T_d}{h}\{e(i)-e(i-1)\}\right]. \quad (9)$$

Hence, in order to get $u(i)$ easily through the computer simulation, use the following relation:

$$u(i)-u(i-1) = q_0 e(i) + q_1 e(i-1) + q_2 e(i-2) \quad (10)$$

where, $q_0 = K_p(1+\frac{h}{2T_i}+\frac{T_d}{h})$,

$q_1 = -K_p(1+\frac{2T_d}{h}-\frac{h}{2T_i})$, $q_2 = \frac{K_p T_d}{h}$.

2.3 Adjustment of PID Parameters

2.3.1 Adjustment of PID Parameters by Model Matching Method

Fig. 5 indicates a general block diagram for PID control system which is described by

$$G_p(s) = \frac{K}{(1+\tau_e s)(1+\tau_m s)},$$

$$G_c(s) = K_p(1+\frac{1}{T_i s}+T_d s), \quad (11)$$

$$G_m(s) = \frac{K_a}{(1+\tau_{e0}s)(1+\tau_{m0}s)}, \quad (12)$$

$$\frac{\Omega(s)}{\Omega_r(s)} = G(s) = \frac{G_c(s)G_p(s)}{1+G_c(s)G_p(s)}, \text{if}$$

$$G_p(s) = G_m(s), G(s) = \frac{G_c(s)G_p(s)}{1+G_c(s)G_p(s)} \quad (13)$$

$$T_i = \tau_{e0}+\tau_{m0},\ T_d = \frac{\tau_{e0}\tau_{m0}}{T_i}, K_p = \frac{T_i}{K_o\tau_s} \quad (14)$$

$$G(s) = \frac{1}{(1+\tau_s s)} \quad (15)$$

Here, $G_p(s)$ is the transfer function of an actual DC motor. $G_c(s)$ is that of PID controller consisting of proportional gain (K_p), integral time (T_i) and derivative time (T_d). K in (11) indicates the steady state gain of a DC motor. Actually, it is difficult to determine the exact parameters of $G_p(s)$. Furthermore, if the parameters of PID controller are adjusted according to (14), the overall transfer function $G(s)$ of PID control system is rewritten as (15) that indicates a first order time delay system in which the steady state gain is one and the time constant is τ_s.

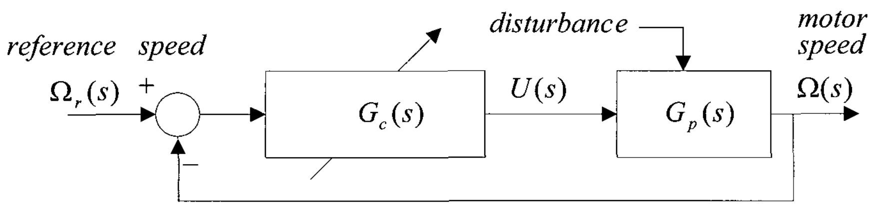


Fig. 5 PID control system of a DC motor

2.3.2 Adjustment of PID Parameters by Genetic algorithm

Genetic algorithms(GAs) are stochastic optimization algorithms that were originally motivated by the natural selection mechanism and evolutionary genetics. A real-code genetic algorithm (RCGA)[14] uses floating point representations in the searching procedure. The chromosomes are the arrays of unknowns instead of bit strings. It works without the need of coding and encoding procedures and hence reduces the computation time. Therefore, RCGA is adapted for the adjustment of PID parameters. In this paper, we consider a first order system as a reference model. Fig. 6 shows a block diagram for the tuning of PID controller using the RCGA and reference model.

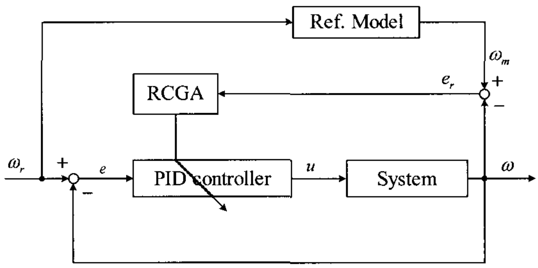


Fig. 6 Optimal adjusting of PID parameter using the RCGA and reference model

Therefore, RCGA is adjusting the PID parameters to minimize the performance index(IAE: Integral of absolute error) to be chosen in the following form:

$$IAE: J(\theta) = \int_0^{t_f} |e_r(t)| dt \qquad (16)$$

Where $\theta = (K_p, \tau_i, \tau_d)$ is the PID parameter's vector and $\omega_m(t) - \omega(t)$ is error between system output and reference model output. Also t_f is integral time.

Control parameters[14] of the RCGA have population size N=20, reproduction coefficient $\eta_i = 1.7$, crossover rate $P_c = 1.0$, mutation rate $P_m = 0.2$. The search space of PID gains is below.

$$0 \le K_p \le K_{pm},\ 0 \le \tau_i \le \tau_{im},\ 0 \le \tau_d \le \tau_{dm}. \qquad (17)$$

Where, K_{pm}, τ_{im} and τ_{dm} are the upper bound value of PID gains.

Fig. 7 shows the tuning process of PID parameters in the case of $\tau_s = 0.01$. Fig. 8 shows the trend of PID parameters change when τ_s is varied from 0.01 to 0.109.

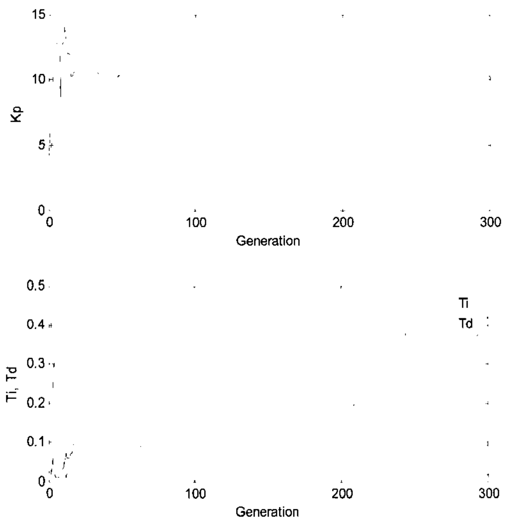
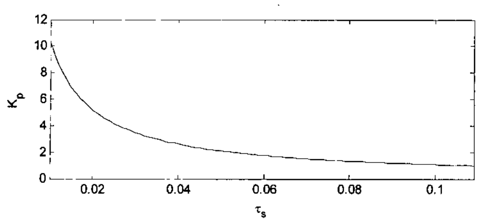
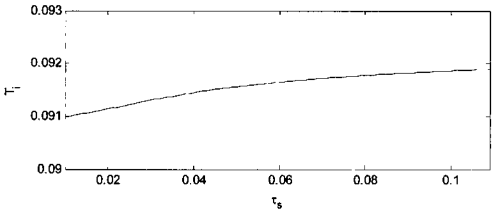


Fig. 7. PID parameter estimation in case of $\tau_s = 0.01$

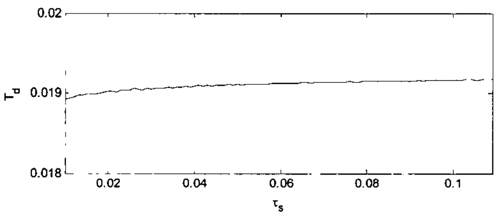
From the results of Fig. 8, it is founded that K_p value is decreased rapidly, but T_i and T_d values have very small variation when τ_s is varied from 0.01 to 0.019.



(a) Proportional gain(K_p)



(b) Integral time(T_i)



(c) Derivative time(T_d)

Fig. 8 The trend of optimal PID parameters

3. Simulation and Results

3.1 Controlled System Specification

The Reliance Electric motor model T18R1010 (5HP) is selected for our present study[15],[16].

The specification of this motor under no-load condition is as follows: v_m=240 [volts] DC, i_m =0.55 [amps] DC, ω=200 [radian/sec](1912 rpm), T_m =20.5 [Nm], K_m=1.14 [Nm/amps], K_B=1.14 [Nm/amps], R_a=0.001 [ohm], L_a=18.7×10^{-3} [henry], J_m=0.12 [Kgm^2], D_m=0.00314 [Kgm^2/second].

3.2 Simulation and Results

The sampling time for simulation is 0.001 second. The simulations were carried out varying τ_s which is the ideal time constant of closed-loop for speed control of a DC motor system in case of PID parameter selection by genetic algorithm or model matching method. Fig. 9 illustrates the comparisons of the unit step responses by the Ziegler and Nichols' method and genetic algorithm or model matching method in case of ideal time constant, $\tau_s = 0.01$ sec.

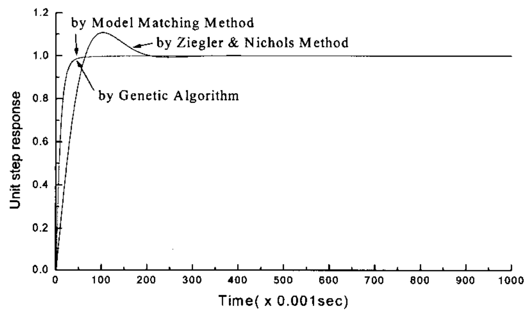


Fig. 9 Comparison of unit step responses

Fig. 9 shows that unit step responses by model matching method or genetic algorithm are better speed sensitivities without overshoot. Fig. 10 indicates the comparison of the mean square errors.

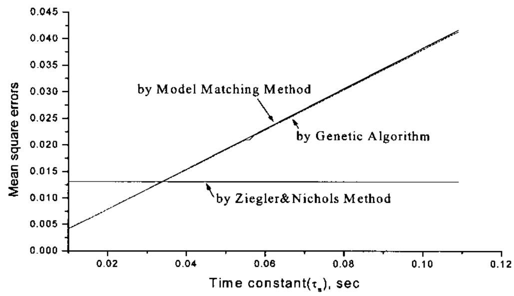


Fig. 10 Comparisons of mean square errors

Fig. 11 shows that when the Ziegler&Nichols's method is adopted, the control inputs are more than the proposed genetic algorithm or model matching method in the region of time constant(τ_s) about 0.044 above.

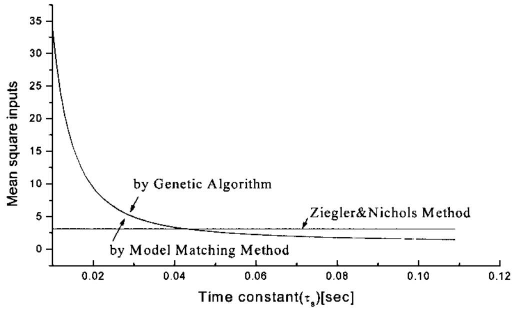


Fig. 11 Comparisons of mean square control inputs.

4. Conclusions

This paper compared three kinds of methods to determine the PID control parameters. It was found that the proposed PID parameters adjustment method is better than the Ziegler and Nichols' method within the range of certain time constant ($\tau_s \leq 0.034$) in terms of the mean square errors and no-overshoot, and that the proposed PID parameter adjustment method is nearly same as the results by the model matching method which is analytical method. Therefore, it was found that tuning method by genetic algorithm is excellent to find out the parameters. In addition, the results by the genetic algorithm shows a better speed sensitivity in the unit step responses without overshoot than that of the Ziegler and Nichols's method. The propose method here could be applied to higher order system which is not easy to use the model matching method, or could be used for the application when a model of a system does not match the actual system.

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Author Profile

Heui-Han Yoo

He worked at the PAL(Pohang Accelerator Laboratory) in POSTECH (Pohang University of Science and Technology in Korea) as a senior researcher from 1991 to 1998. He also worked at the KIMM(Korea Institute of Machinery and Materials) as a senior researcher from 1983 to 1990. Since 1998, he has been with the Department of Mechatronics Engineering, Korea maritime University. His interests are in applications of control theory, particularly to industrial applications.

Yun-Hyung Lee

He received the B.S. and M.S. degree in Marine System Engineering from Korea Maritime University in 2002 and 2004. He is currently working toward his Ph.D. degree in the Department of Mechatronics Engineering, Korea Maritime University.