

Speed Control of DC Motor using Digital Control System

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Abstract—The DC Motors have been popular in the industry control area for a long time owing to their simple design and reliability. They are widely used in many industrial applications where wide speed ranges are required and therefore they are used in many adjustable speed drives. This paper is to design a digital control system using MATLAB/SIMULINK for controlling the speed response of a DC Motor. Discrete PID Controller is integrated with DC Motor to form a digital control system. PID tuning is performed with the help of MATLAB/SIMULINK for achieving the desired result. Mathematical modeling of DC Motor have been presented and finally the simulation results for the speed control of DC Motor using PID Controller have been presented.

Keywords—DC Motor, PID Controller, PID tuning.

I. INTRODUCTION

DC Motor is a power actuator which transforms electrical energy into mechanical energy. DC motors have a rotating armature winding (winding in which a voltage is induced) but non-rotating armature magnetic field and a static field winding (winding that produce the main magnetic flux) or permanent magnet. Different connections of the field and armature winding provide different inherent speed/torque regulation characteristics. The speed of a DC motor can be controlled by changing the voltage applied to the armature or by changing the field current. The introduction of variable resistance in the armature circuit or field circuit allowed speed control. Modern DC motors are often controlled by power electronics systems called DC drives. The speed torque characteristics of DC motors are much more superior to that of AC motors and also DC motors provide excellent control of speed for deceleration and acceleration. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved. In these applications, the motor should be precisely controlled to give the desired performance. They are widely used in industrial applications such as Electric cranes, Electric vehicles and Robotic Manipulators due to simple and continuous control characteristics. The term speed control is used for speed variations carried out automatically or manually. There are several conventional and numeric controller types like Proportional Integral (PI), Proportional Integral Derivative (PID), Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Genetic Algorithm, particle swarm optimization etc. PID controller operates the majority of the control system in the world. In industries 95% controllers are PID type because of simplicity, applicability and ease of use offered by them.

II. PID CONTROLLER

PID controller uses three basic behavior types or modes: P - Proportional, I-Integral, D-Derivative. A PID Controller has the general form-

$$u(t) = K_p \cdot e(t) + K_i \int_0^t e(\tau) \cdot d\tau + K_d \cdot \frac{de}{dt}$$

where,

K_p = Proportional Gain

K_i = Integral Gain

K_d = Derivative Gain

PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant T_i , which increases speed of the controller response. There are a number of different PID controller structures. Different manufacturers design controllers in different manner. However, two topologies are most often used:

- Parallel (non-interactive)
- Serial (interactive)

The order of the PID controller is low, but this controller has universal applicability; it can be used in any type of SISO system, e.g. linear, nonlinear, time delay etc. Many of the MIMO systems are first decoupled into several SISO loops and PID controllers are designed for each loop. However, for proper use, a controller has to be tuned for a particular process i.e. selection of P, I, D parameters are very important and process dependent. Unless the parameters are properly chosen, a controller may cause instability to the closed loop system.

A. PID Tuning

Tuning is adjustment of control parameters to the optimum values for the desired control response. Stability is a basic requirement. However, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another. PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, some of them are:

- Manual Tuning method

In manual tuning method, parameters are adjusted by watching system responses. K_p , K_i , K_d are changed until desired or required system response is obtained. Although this method is simple, it should be used by experienced personal.

- Ziegler–Nichols Tuning method

This method was introduced by John G. Ziegler and Nathaniel B. Nicolas in the 1940s. The Ziegler-Nichols closed loop method is based on experiments executed on an established control loop (a real system or a simulated system).

Control Type	K_p	K_i	K_d
P	$0.5 * K_u$	-	
PI	$0.45 * K_u$	$1.2 * K_p / T_u$	-
PID	$0.6 * K_u$	$2 * K_p / T_u$	$K_p * T_u / 8$

where, K_u is the ultimate gain and T_u is the oscillation period.

- PID Tuning Software methods

There is some prepared software that can easily calculate the gain parameters. Some examples are- MATLAB, BESTune, EXPERTune etc.

III. DC MOTOR

The equivalent circuit of a DC Motor armature is based on the fact that armature winding has a resistance R_a , a self inductance L_a and an induced emf. This is shown in Fig.1.

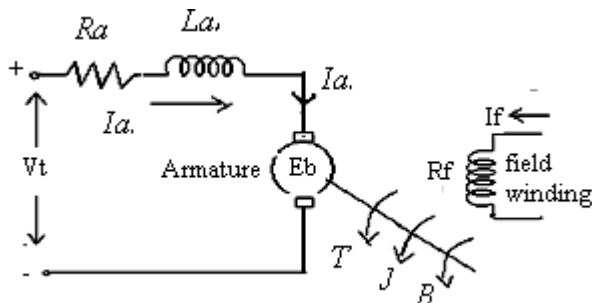


Fig.-1 DC Motor

The terminal relationship is written as

$$V_t = E_b + R_a \cdot I_a + L_a \cdot \frac{dI_a}{dt} \tag{1}$$

In steady state the armature current is zero and hence the rate of change of the armature current is zero.

$$V_t = E_b + R_a \cdot I_a \tag{2}$$

The air gap power is expressed in terms of the electromagnetic torque and speed as

$$P_a = \omega_m T = E_b \cdot I_a \tag{3}$$

Hence the electromagnetic torque is expressed as

$$T = \frac{E_b \cdot I_a}{\omega_m} \tag{4}$$

But, $E_b = K_b \cdot \omega_m$

Therefore, $T = K_b \cdot I_a$ (5)

For simplicity, the load is modeled as a moment of inertia J , with a viscous friction coefficient B . Then the acceleration torque T_a is given by

$$T_a = T - T_l = J \cdot \frac{d\omega_m}{dt} + B \cdot \omega_m \tag{6}$$

where T_l is the load torque. Eq.(1) and eq.(6) constitute the dynamic model of DC Motor with load. Taking Laplace Transform of eq. (1) & (6) we get

$$I_a(s) = \frac{V(s) - K_b \cdot \omega_m(s)}{R_a + s \cdot L_a} \tag{7}$$

$$\omega_m(s) = \frac{K_b \cdot I_a(s) - T_l(s)}{B + sJ} \tag{8}$$

IV. MATLAB-SIMULINK

Fig.-2 shows the Simulink Model of a DC motor which is used as a subsystem in fig.-3. The model is constructed with the elements in Simscape and Simelectronics Library.

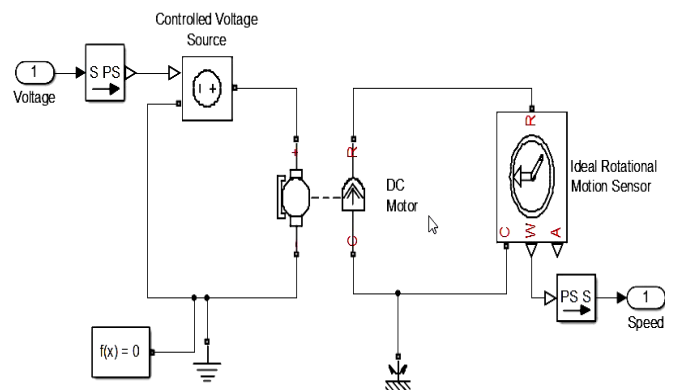
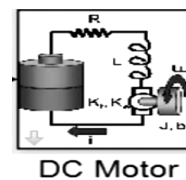


Fig.-2 Simulink Model Of DC Motor

Now the Simulink Model shown in Fig.2 is created as a subsystem for the Block shown in Fig-3.



DC Motor

Fig.-3

DC Motor is now integrated with Discrete PID Controller to form a Digital Control System as shown in Fig.-4

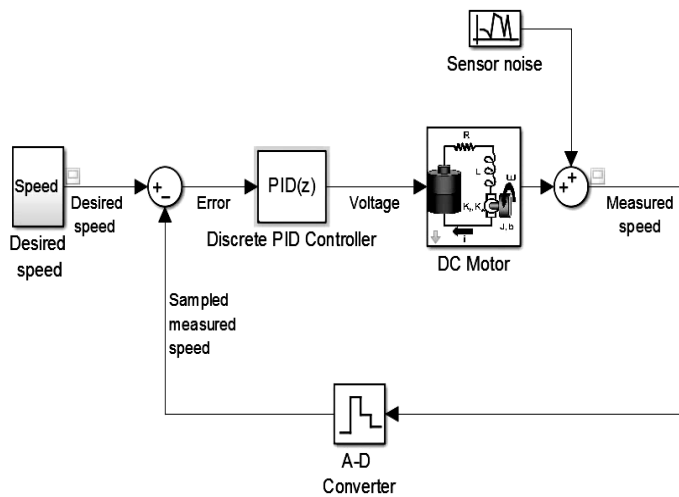


Fig.-4 Digital Control System

The above control system is now simulated in MATLAB for obtaining the speed control without PID Tuning. Results are as shown in Fig.-5

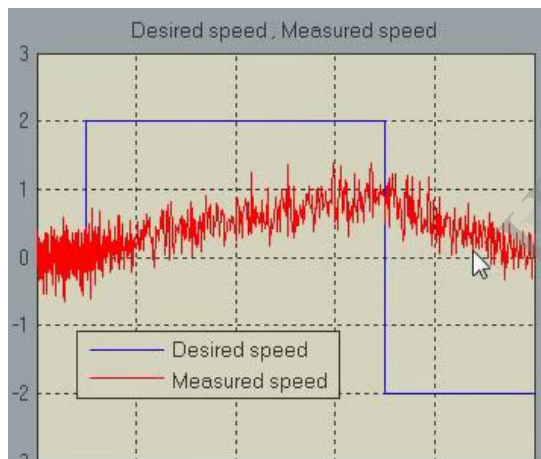


Fig.-5

As it can be seen in Fig.-5 that the measured speed is not same as desired speed so now we will tune the PID Controller with the help of PID tuner in MATLAB. Final Result is shown in fig.-6



Fig.-6

V. CONCLUSION

Mathematical model of DC Motor have been presented. PID Controller is introduced and different types of PID Tuning Rules have been discussed. Speed control of DC Motor is achieved by properly tuning PID Controller in MATLAB/SIMULINK and the simulation results are presented.

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