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A PID Controlled Real Time Analysis of DC Motor

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ABSTRACT: Conventional PID controllers are used to control the dc motor for various industrial processes from many years due to their simplicity in operation. PID controllers require mathematical models to control the plant for different process control applications. In this paper worked out, speed control analysis of DC motor using PID controller. Speed control of separately excited dc motor is done using armature voltage control method. PID controller basics are briefed and various tuning methods of PID controller are explained. Mathematical modelling of dc motor is done and is simulated in Simulink. The control system consisting of PID controlled dc motor is also simulated in Simulink. Response of dc motor is recorded as simulation result when step input is provided as reference signal. Thereby, performance analysis of dc motor with PID controller is performed by calculating various response parameters such as maximum overshoot, rise time, settling time, etc.

Keywords- DC motor, PID controller, Tuning methods.

I. INTRODUCTION

DC machine is a highly versatile and flexible machine. It can satisfy the demands of load requiring high starting, accelerating and retarding torques. A dc machine is also easily adaptable for drives with range of speed control and fast reversal. They are widely used in industrial applications. The DC motors are used in rolling mills, in traction and in overhead cranes. They are also employed in many control applications as actuators and as speed or position sensors[2]-[6]. In such applications, as that of position sensors and robotics, drives‟ performance must precisely follow the desired performance. A number of control schemes such as proportional (P), proportional integral (PI), proportional derivative integral (PID), adaptive and fuzzy logic controller (FLCs) are used for control of speed of DC motors. The proposed controller system uses the PID control scheme for speed control of dc motor[1].

PID controllers due to their simplicity are widely used in industrial applications for speed and position control of dc motor for several years. Due to its simplicity, clear functionality, applicability and ease of use offered, PID controllers are used in more than 95% of the industrial process control applications[9]. If the PID parameters are tuned properly they provide robust and reliable performance for most systems. In this paper, PID controller is used to control the speed of dc motor and hence its performance evaluation is done. As PID controllers require mathematical model of the system to be controlled, hence mathematical model of separately excited dc motor is derived and is simulated in Simulink[12].

II. MATHEMATICAL MODEL OF DC MOTOR

In armature voltage control scheme for separately excited dc motors, voltage applied to armature is varied without varying the voltage applied to the field. Equivalent model of dc motor is shown in following figure..

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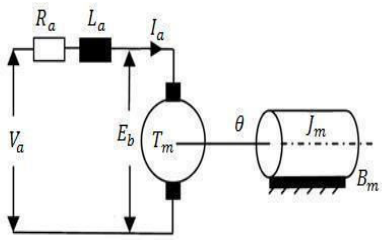

Fig. 1: DC motor model

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

$$e_b(t) = K_b.w(t) \quad (2)$$

$$T_m(t) = K_t.i_a(t) \quad (3)$$

$$T_m(t) = J_m.\frac{dw(t)}{dt} + B_m.w(t) \quad (4)$$

Where, Va = armature voltage (V)
Ra = armature resistance(Ω)
La = armature inductance (H)
Ia = armature current (A)
Eb = back emf (V)
W = angular speed (rad/s)
Tm= motor torque (Nm)
θ = angular position of rotor shaft (rad)
Jm = inertia of rotor (Kg-m2)
Bm = viscous friction coefficient (Nms/rad)
KT = torque constant (N-m/A)
Kb = back emf constant (V/rad)

Let us combine the upper equations together:

$$v_a = R_a.i_a(t) + L_a.\frac{di_a(t)}{dt} + K_b.w(t) \quad (5)$$

$$K_t.i_a(t) = J_m.\frac{dw(t)}{dt} + B_m.w(t) \quad (6)$$

Laplace transforms of (5) and (6) are

$$V_a(s) = R_a(s).I_a(s) + L_a.I_a(s).s + K_b.W(s) \quad (7)$$

$$K_t.I_a(s) = J_m.W(s).s + B_m.W(s) \quad (8)$$

If current is obtained from (8) and substituted in (7) we have

$$V_a(s) = W(s).\frac{1}{K_t}.[L_a.J_m.s^2 + (R_a.J_m + L_aB_m).s + (R_a.B_m + K_b.K_t)] \quad (9)$$

Then the transfer function which relates rotor speed and applied armature voltage is given as:

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$$\frac{W(s)}{V_a(s)} = \frac{K_t}{[L_a.J_m.s^2+(R_a.J_m+L_a.B_m).s+(R_a.B_m+K_b.K_t)]} \quad (10)$$

Then the transfer function between shaft position and armature voltage at no-load is:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_t}{[L_a.J_m.s^3+(R_a.J_m+L_aB_m).s^2+(R_a.B_m+K_b.K_t).s]}$$

The model of dc motor presented in this paper is simulated in MATLAB/Simulink, from its characteristic differential equation and it is shown in Figure 2

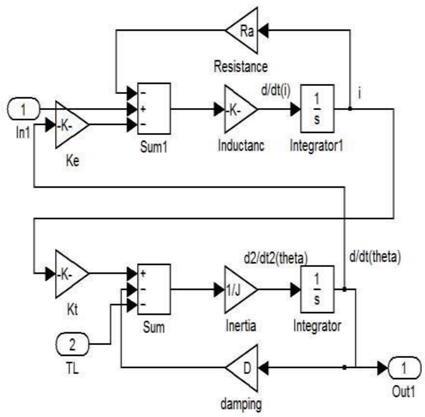

Fig 2: Simulink model of dc motor

III. PID CONTROLLER

Although being an old control technique, PID control scheme is extensively used in control systems for various control applications. The combination of proportional, integral and derivative control action is called PID control action and the controller is called three action controllers [7]. Although PD control deals neatly with the overshoot and rising problems associated with proportional control it does not reduce the problem with the steady-state error. Hence, PID controllers are used to reduce the steady-state error apart having the advantages of PD controllers. In PID controllers, we need to adjust three parameters i.e. proportional gain (Kp), integral gain (KI) and derivative gain (KD) to achieve the desired control performance. The PID controller system block diagram of this paper is shown in Fig 3 [5].

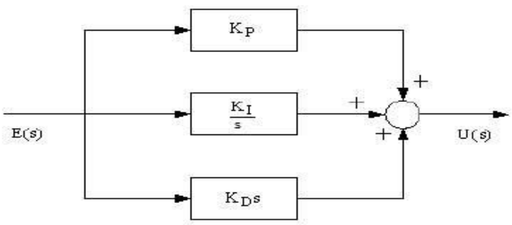

Fig 3. PID controller system block diagram.

The relationship between the input e(t) and output u(t) can be formulated in the following

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$$U(t) = K_p e(t) + K_I \int_0^t e(t)\,dt + K_D \frac{de(t)}{dt}$$

The transfer function is expressed as follows

$$C(s) = K_p + \frac{K_I}{s} + K_D s = \frac{U(s)}{E(s)}$$

The DC motor speed control using PID controller system block diagram is shown in Fig 4

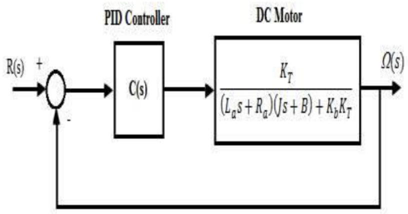

Fig. 4 PID DC motor speed control system block diagram

IV. DESIGN OF PID CONTROLLER

There are many methods proposed for tuning of PID controller:

- Process reaction curve (Open-loop)
- Ziegler Nichols method (Closed-loop)
- Tyreus and Luyben

Process reaction curve (Open-loop): This is a manual procedure which is based on measuring the step response of the system .The input variable r(t) is changed from to ;the output c(t) is monitored carefully and the step response recorded on a chart recorder in Fig 6. Here r(t) should be as small as possible. On the recorded output, draw a tangent to enable the following measurements [4]:

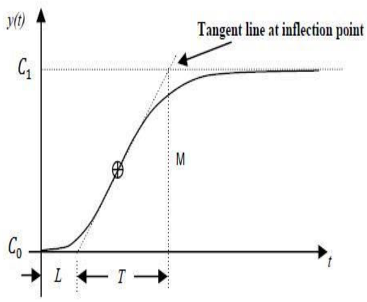

Fig. 5 shows step response of the plant.

- Effective time delay in the system response „L";
- Recorded output change, M=C1-C0;

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- Measurement of „T";
- P = percent change in correction unit
- M (measured variable) = percent of full scale range
- R (reaction rate) = maximum gradient of the graph

Empirical relationships in terms of for P, PI, and PID are by process reaction curve is given in Table.1

Table.1 shows process reaction curve parameters.[4]

Type of controller	K_p	K_I	K_D	τ_I	τ_D
P	—	-	-	-	-
PI				-	3.33L
PID	-	-	0.5L	2L	0.5L

-

Ziegler Nichols method (Closed-loop): Another method to tune PID parameters is Ziegler-Nichols frequency response method. The procedure is as follows:

1. Increase KP until system response oscillates with a constant amplitude and record that gain value as Ku (ultimate gain).
2. Calculate the oscillation period and record it as Tu
3. Tune parameters using Table 2 [13]

Table 2 shows Ziegler Nichols parameters [13]

Type of controller	K_p	K_I	K_D
P	0.5 K_u	-	-
PI	0.45 K_u	1.2 / T_u	-
PID	0.6 K_u	2/ T_u	T_u/8

Tyreus and Luyben: A modification to the above Ziegler-Nichols tuning parameters was made by Tyreus and Luyben shown in Table.3 [4]

Table.3 shows Tyreus and Luyben parameters

Type of controller	K_p	K_I	K_D
PI	—	2.2P_u	
PID	—	2.2P_u	—

V. DESIGN OF REAL TIME PID CONTROLLER

Figure 6 shows the block diagram of the real-time digital PID controller, where R(s) is the reference input, y(s) is the system output, C(s) is the controller transfer function, and H(s) is the feedback loop (sensor) transfer function.

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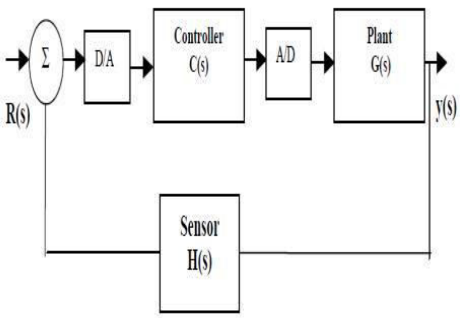
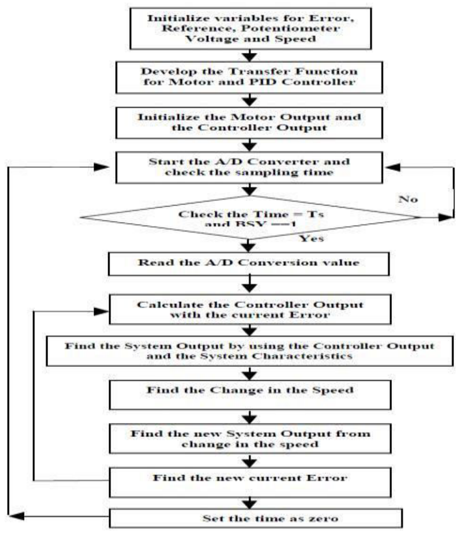


Discrete PID controller structure

There are two possible ways to control the speed of the motor viz. open loop control and closed loop control. In open loop control, the control value is not dependent on the output or the speed of the motor, whereas in closed loop control in which the control value is dependent on the speed of the motor. In the real-time speed control approach a closed loop speed control with a digital PID controller is designed. A potentiometer is used as the reference command signal to set the input voltage at various levels as required. Further, the control value obtained from microcontroller is utilized to generate the average output voltage for adjusting the duty cycle in order to maintain constant motor speed.



Algorithm flowchart

Figure shows the flowchart of the algorithm that was developed. The controller equations are loaded into the flash memory of the first microcontroller. For simulation purposes, the transfer function equations of the motor were loaded into the flash memory of the second microcontroller. At first, the system output from the transfer function was utilized to generate the controller value from the microcontroller1. The motor speed is read at fixed intervals using the A/D converter of microcontroller1, and the digital inputs were converted into a CAN data frame for two bytes. The object consists of these two bytes and an 11-bit identifier 0x111. This data is then transferred to the CAN bus which is identified by the CAN bus monitor as the system output. Microcontroller2 waits for a CAN message with identifier 0x111.Therefore, as soon as the above object with identifier 0x111 appears on the CAN bus, it

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is captured by microcontroller2. Microcontroller uses this received data to generate the controller value. The controller value is calculated using the difference between the reference speed (based on the potentiometer setting) and the actual speed measured by microcontroller1. This error is then used to generate the PID constants, which in turn develops the duty cycle (D) equivalent for the discrete closed loop control

VI. SIMULATION AND RESULTS

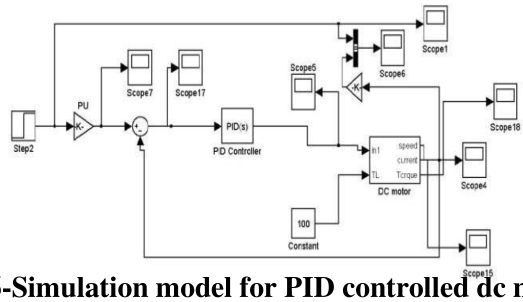

Fig.6-Simulation model for PID controlled dc motor

Above figure shows the simulation model of control system of speed control of dc motor using PID control. Difference between the reference speed and the actual motor speed is provided as an input to the PID controller.

As the error input increases controller adjusts its output parameters accordingly so as to reduce the error between the desired and actual speed.

A typical procedure to tune a PID controller using Ziegler Nichols method would be:

1. Increase KP until system response oscillates with a constant amplitude and record that gain value as Ku (ultimate gain).
2. Calculate the oscillation period and record it as Tu [11]

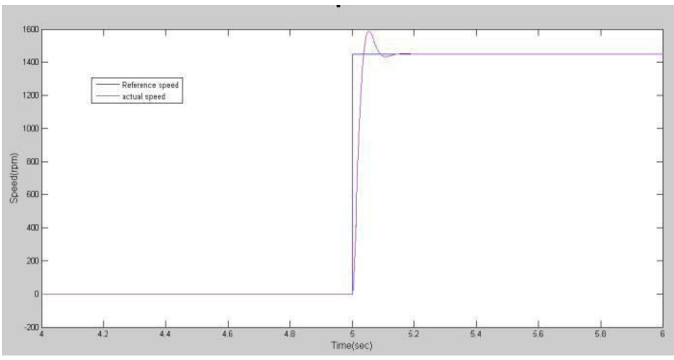

Fig. 7-Step response of PID controller

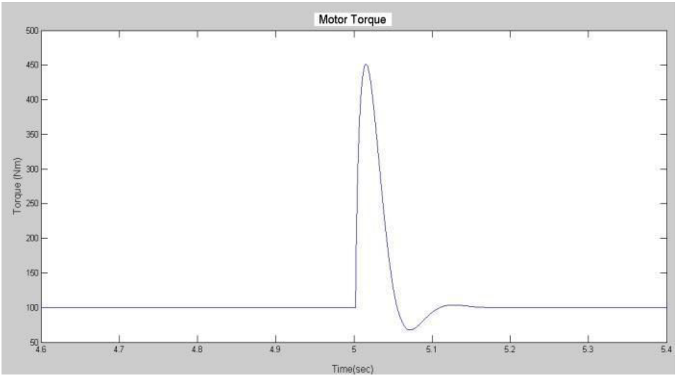

Fig. 8-Motor torque of dc motor using PID controller

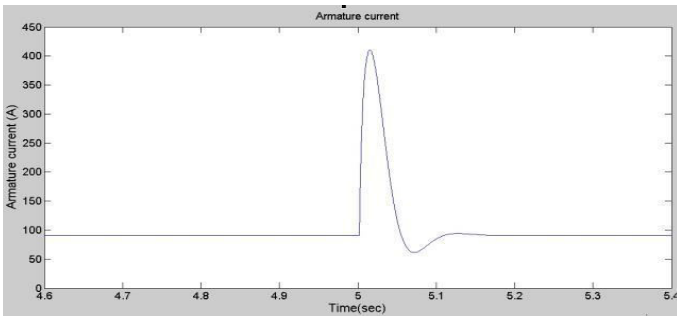

Fig. 9-Motor torque of dc motor using PID controller

Figure.1 above shows the speed response of dc motor using PID controller when step input is applied as reference signal. As it is clear from the response curve that an overshoot is obtained along with certain oscillations around reference signal. However overshoot can be reduced by increasing the derivative gain but the rise time also increases as a consequence. Hence, there exists a compromise between overshoot and the speed of response i.e. rise time which means that we have to sacrifice one for improving another.

From the above graph of speed response following parameters can be calculated to evaluate the performance of PID controller:

Table.3 shows time response parameters of PID controller

% overshoot	Rise time	Settling time
9.36	0.0255	0.0812

VII. CONCLUSIONS

In this paper PID controller is designed for speed control of dc motor. From the analysis been done it is clear that PID is a simple controller based on the mathematical model of the system to be controlled. It successfully overcomes the drawback of proportional-derivative (PD) controller of steady-state error as steady-state error is zero in PID controllers. However while reducing steady-state error to zero an overshoot is observed. However overshoot can be reduced by increasing the derivative gain but the rise time also increases as a consequence. Hence, there exists a compromise between overshoot and the speed of response i.e. rise time which means that we have to sacrifice one for improving another. Overall, PID controller gives best speed response of all the linear controllers of its class. It is

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simple to implement and control the process using PID controllers.

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