Simulation DC Motor Speed Control System by using PID Controller

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ABSTRACT
Speed control system is the most common control algorithm used in industry and has been universally accepted in industrial control. One of the applications used here is to control the speed of the DC motor. Controlling the speed of a DC motor is very important as any small change can lead to instability of the closed loop system. The aim of this thesis is to show how DC motor can be controlled by using PID controller in MATLAB. The development of the PID controller with the mathematical model of DC motor is done using automatic tuning method. The PID parameter is to be test with an actual motor also with the PID controller in MATLAB/Simulink. In this paper describe the results to demonstrate the effectiveness and the proposed of this PID controller produce significant improvement control performance and advantages of the control system DC motor.

Keywords: DC motor, PID controller, MATLAB/Simulink

I. INTRODUCTION
DC motors are widely used in industrial applications, robot manipulators and home appliances, because of their high reliability, flexibility and low cost, where speed and position control of motor are required. DC motor is a power actuator which converts electrical energy into mechanical energy. There are several types of applications where the load on the DC motor varies over a speed range. The greatest advantage of dc motors may be speed control.

DC motors are most suitable for sample range speed control and are therefore used in many adjustable speed drives. Because speed is directly proportional to armature voltage and inversely proportional to magnetic flux induced by the poles, adjusting the armature voltage or the field current will vary the rotor speed. The purpose to control the speed of DC motor is to overcome the problem in industry like to avoid machines damages and to avoid slow rise time and high overshoot. This is because when the starting voltage is high, it is not suitable for machine and can make machine damages. So, a controller likes PID is developed to overcome this problem. Despite all the progress in advanced control, the PID remains the most popular controller.

The PID controller is based on very simple ideas. As illustrated in the idealized formula below, the controller output is a combination of three terms. The proportional term reacts to current errors. Past errors are accounted for by the integral term. The derivative term anticipates future errors by linear extrapolation of the error. This thesis is to design a PID controller that can be used to control the speed of a DC motor. Simulate the PID controller with the modelling of the DC motor to have a settling time less than 2seconds and a step response with overshoot of less than 5%. The DC motor speed control system with PID controller by using MATLAB/Simulink.[1]

II. Dc Motor Speed Control System
A. Method of DC Motor Speed Control

The speed control system was implemented for a DC motor. Speed control of DC motor is by two main methods.
1. Armature control method
2. Field control method
➤ Field Control
In this method, the field current or current through stator is varied to control the speed of the motor.
➤ Armature Control
In this method, the armature voltage is varied to control the speed of the motor. [2]
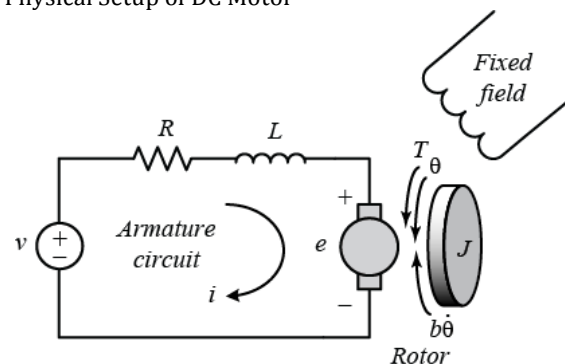
B. Physical Setup of DC Motor

Fig.1 The electric equivalent circuit of the rotor [8]

The electric equivalent circuit of the armature and the free-body diagram of the rotor are shown in the following figure

1. The input of the system is the voltage source (V) applied to the motor's armature, while the output is the rotational speed of the shaft$\frac{d\theta}{dt}$. The rotor and shaft are assumed to be rigid. A viscous friction model, that is, the friction torque is proportional to shaft angular velocity. [2]

TABLE1. The physical parameters for dc motor are:

Moment of inertia of the rotor (J)	0.01 kg.m^2
Motor viscous friction constant (b)	0.1 N.m.s
Electromotive force constant (K$_e$)	0.01 V/rad/sec
Motor torque constant (K$_t$)	0.01 N.m/Amp
Electric resistance (R)	1 Ohm
Electric inductance (L)	0.5 H

C. Transfer Function Equation of Feedback Control System
The torque generated by a DC motor is proportional to the armature current and the strength of the magnetic field. In this example we will assume that the magnetic field is constant. Therefore, the motor torque is proportional to only the armature current i by a constant factor K$_t$ as shown in the equation below. This is referred to as an armature-controlled motor. [3]

$$T = K_t i \qquad (1)$$

Where:
T = torque
K$_t$ = constant factor
i = armature current

The back emf, e, is proportional to the angular velocity of the shaft by a constant factor K_e.

$$e = K_e \dot{\theta} \qquad (2)$$

Where:
e = back e.m.f
K$_e$ = constant factor
$\dot{\theta}$ = angular velocity

In SI units, the motor torque and back e.m.f constants are equal, that is, K$_t$= K$_e$; therefore, we will use K to represent both the motor torque constant and the back e.m.f constant. From the figure above, we can derive the following governing equations based on Newton's 2nd law and Kirchhoff's voltage law.

$$J\ddot{\theta} + b\dot{\theta} = K_i \qquad (3)$$

$$L\frac{di}{dt} + Ri = V - K\dot{\theta} \qquad (4)$$

Where:
J = moment of inertia of the rotor
B = motor viscous friction constant
K$_i$= constant factor
L = electric inductance
R = electric resistance
V = voltage source

Applying the Laplace transform, the above modelling equations can be expressed in terms of the Laplace variable.

$$s(Js + b)\theta(s) = KI(s) \qquad (5)$$

$$(Ls + R)I(s) = V(s) - Ks\theta(s) \qquad (6)$$

The following open-loop transfer function by eliminating $I(s)$ between the two above equations, where the rotational speed is considered the output and the armature voltage is considered the input

$$P(s) = \frac{\theta(s)}{V(s)} = \frac{K}{(Js + b)(Ls + R) + K^2} \text{ (rad/sec/V)} \qquad (7)$$

$$P(s) = \frac{0.01}{(0.01s + 0.1)(0.5s + 1) + 0.01^2} \qquad (8)$$

$$P(s) = \frac{0.01}{0.005s^2 + 0.06s + 0.1001} \qquad (9)$$

Feedback control systems are often referred to as closed-loop control systems. In a closed-loop control system the actuating error signal, which is the difference between the input signal and the feedback signal is fed to the controller so as to reduce the error and bring the output of the system to a desired value. The term closed-loop control always implies the use of feedback control action in order to reduce system error.

Closed loop system:

$$P(s) = \frac{0.01}{0.005s^2 + 0.06s + 0.1101} \qquad (10)$$

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III.   Proportional-Integral-Derivative Controller
The PID circuit is often utilized as a control feedback loop controller and is very commonly used for many forms of servo circuits. PID represents the three control settings of a PID circuit. The purpose of any servo circuit is to hold the system at a predetermined value (set point) for long periods of time.

The PID circuit actively controls the system so as to hold it at the set point by generating an error signal that is essentially the difference between the set point and the current value. The three controls relate to the time-dependent error signal; at its simplest, this can be thought of as follows: Proportional is dependent upon the present error, Integral is dependent upon the accumulation of past error, and Derivative is the prediction of future error.

The results of each of the controls are then adjusts the output of the circuit, u(t). This output is fed into a control device, its value is fed back into the circuit, and the process is allowed to actively stabilize the circuit's output to reach and hold at the set point value. The block diagram below illustrates very simply the action of a PID circuit. One or more of the controls can be utilized in any servo circuit depending on system demand and requirement (i.e., P, I, PI, or PID). [5]
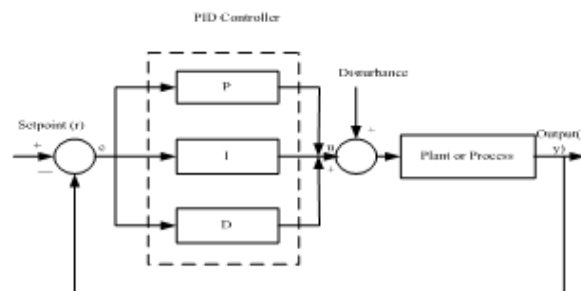

Fig.2 Block Diagram of PID Controller[5]

The output of the PID control circuit, u(t), is given as

$$u(t) = K_P e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t) \quad (11)$$

Where:

u(t)	=	Manipulated	Variable
K_p	=	Proportional	Gain
K_i	=	Integral	Gain
K_d	=	Derivative	Gain
e(t)	=	Error	

A. PID Function

PID is a control method or mode that has three functions or variables. The proportional action dampens process response. The integral corrects for droop. Droop is the difference in process variable between the process set point and the actual process output. The set point is the desired value of process variable. The derivatives minimize the amounts of overshoot and undershoot. Overshoot is the amount of process variable that exceeds the set point value before the process stabilizes. Process stabilization is achieved when the set point and process variable value are equal over a defined period of time. Undershoot is the amount of process variable that falls below the set point value before the process stabilizes.[4]
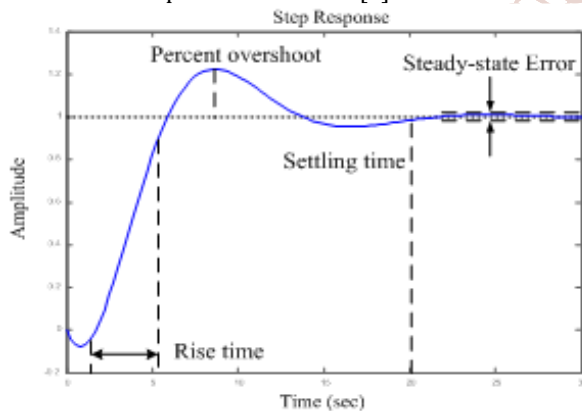

Fig.3 Response of A Typical PID Closed Loop System[4]

Fig.4 Response of A Closed Loop System with Dead-Time[4]

Mathematically, the PID controller can be expressed as in Equation 3.5.

$$u(t) = K_c \left(e(t) + \frac{1}{T_i} \int_0^t e\left(\tau(\tau) + T_d \frac{de(t)}{dt} \right) \right) \quad (12)$$

$$u(t) = K_c \left(e(t) + K_i \int_0^t e\left(\tau(\tau) + K_d \frac{de(t)}{dt} \right) \right) \quad (13)$$

Where u is the control variable and e is the control error (e = y - r). The control variable is thus a sum of three terms: proportional, integral, and derivative. The controller parameters are proportional gain K_P, integral time T_i, integral gain K_i, derivative time T_d, and derivative gain K_d. This PID algorithm can also be represented by the transfer function as in Equation 14. [4]

$$G(s) = K_c \left(1 + \frac{1}{sT_i} + sT_d \right) \quad (14)$$

B. The Characteristics of PID Controller

The general effects of each controller parameter (K_P, K_i, K_d) on a closed-loop system are summarized in the table below. Note, these guidelines hold in many cases, but not all. If want to know the effect of tuning the individual gains, that will have to do more analysis, or will have to perform testing on the actual system.[4]

TABLE 2 Characteristic of PID Controller[4]

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_P	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Decrease
K_d	Small Change	Decrease	Decrease	No Change

C. Design Requirements

First consider that motor at 0.1 rad/sec in steady state for an input voltage of 1 volt. Since the most basic requirement of a motor is that it should rotate at the desired speed, that the steady-state error of the motor speed be less than 1%. Another performance requirement for our motor is that it must accelerate to its steady state speed as soon as it turns on. In this case, to have a settling time less than 2 seconds. Also, since a speed faster than the reference may damage the equipment, to have a step response with overshoot of less than 5%.

In summary, for a unit step command in motor speed, the control system's output should meet the following requirements.
1. Settling time less than 2 seconds
2. Overshoot less than 5%
3. Steady-state error less than 1%

IV. Simulation Result of Dc Motor Speed Control By Using PID Controller

PID controller is one of the most popular control methods. In this paper, DC motor speed is controlled by using PID controller. The speed of the open loop DC motor without PID is investigated firstly. And the speed of the closed-loop DC motor is examined. Finally, the DC motor with P Controller, PI Controller and PID Controller were tested in MATLAB Software.
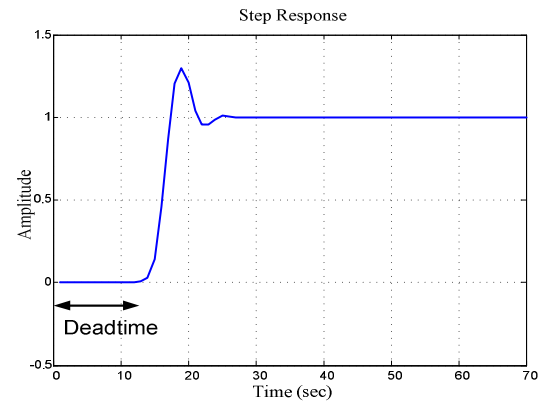
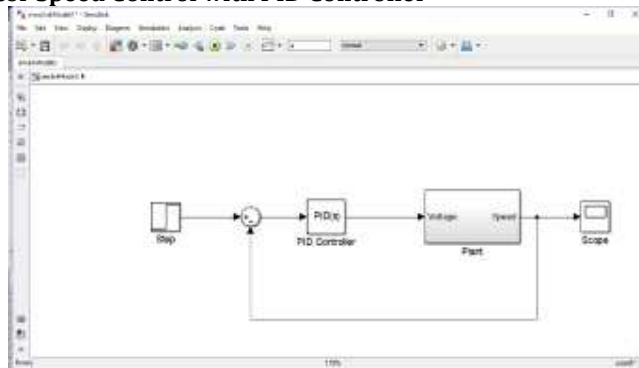**A. Simulink Model of DC Motor Speed Control with PID Controller**

Fig.5 Simulink model of DC Motor control with PID Controller

For this paper, speeds control of DC motor use with PID controller. In Figure 5 was modeled using MATLAB/ Simulink. In simulation, step input is 1 second and output is stable in 3 seconds.
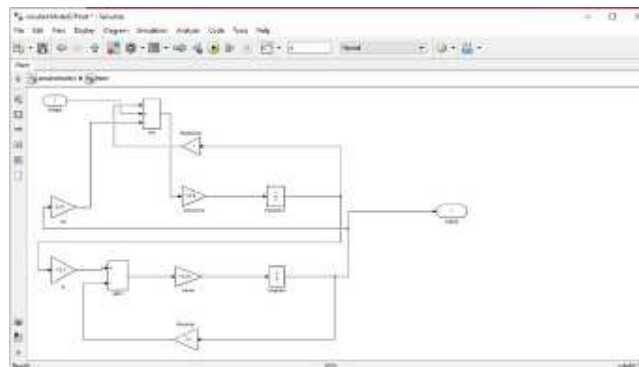
B. Model of DC Motor

Fig.6 Model of DC Motor

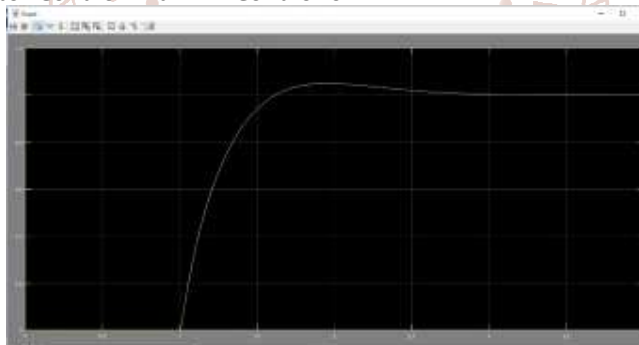**C. Simulink Result of DC Motor Control with PID Controller**

Fig.7 Simulink result of DC Motor control with PID Controller

The above figure was simulated for step input time is 1 second, output time was stable in 3 seconds.
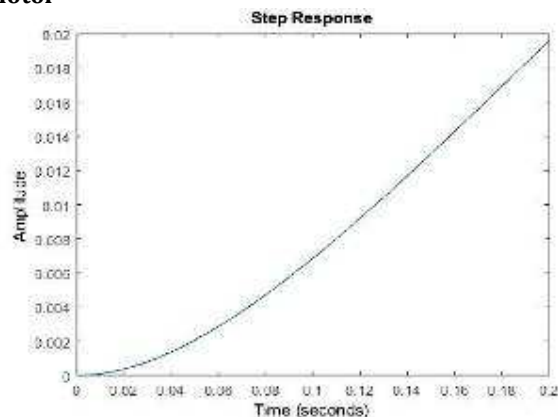
D. Closed Loop Response of DC Motor

Fig.8 Closed Loop Response of DC Motor

TABLE.3 Closed Loop Response of DC Motor

Controller Gain	Rise Time(sec)	Maximum Overshoot (%)	Settle time(sec)	Peak Amplitude
-	-	0	-	0.0196

In a closed-loop control system the actuating error signal, which is the difference between the input signal and the feedback signal, is fed to the controller so as to reduce the error and bring the output of the system to a desired value. The term closed-loop control always implies the use of feedback control action in order to reduce system error.

E. DC Motor with P Controller of PID

TABLE 4 DC Motor with P Controller of PID

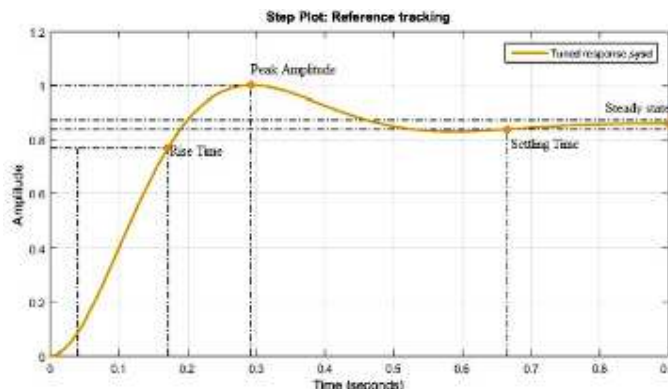| Controller Gain	Rise Time(sec)	Maximum Overshoot (%)	Settle time(sec)	Peak Amplitude
K_P=64.43	0.132	17.2	0.665	1

Fig.9 DC Motor with P Controller of PID

When DC motor speed is controlled with only P controller, overshoot and settling time are over 5% and 2 second.

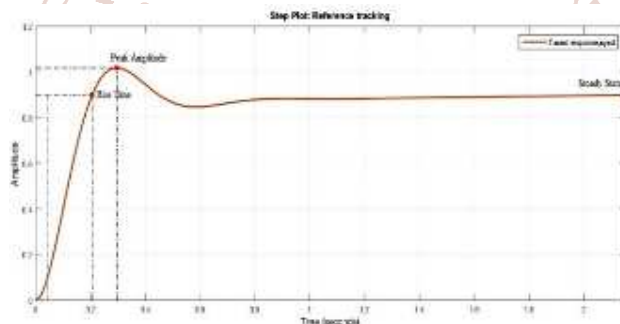### F. F.DC Motor with PI Controller of PID

Fig.10 DC Motor with PI Controller of PID

When DC motor speed is controlled with PI controller, overshoot is under 5% but there is no settling time.

TABLE.5 DC Motor with PI Controller of PID

Controller Gain	Rise Time(sec)	Maximum Overshoot (%)	Settle time(sec)	Peak Amplitude
K_P=64.42	0.132	17.2	0.665	1
K_i= 10.49	0.163	1.83	0	1

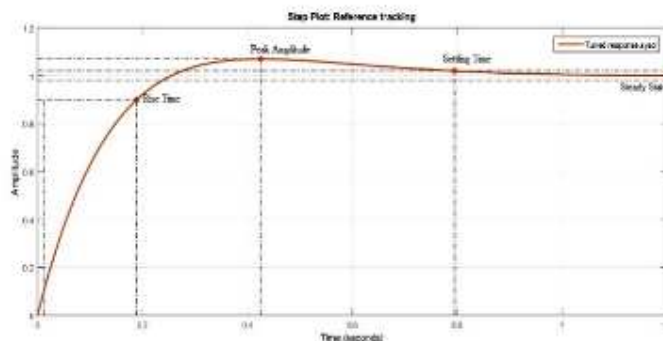### G. DC Motor with PID Controller (Before Tuning)

Fig.11 DC Motor with PID Controller (Before Tuning)

TABLE.6 DC Motor with PID Controller (Before Tuning)

Controller Gain	Rise Time(sec)	Maximum Overshoot (%)	Settle time(sec)	Peak Amplitude
K_P=61.09	0.132	17.2	0.665	1
K_i= 186.6	0.163	1.83	0	1
K_d= 4.36	0.177	6.98	0.794	1.07

When DC motor speed is controlled with PID controller, overshoot and settling time are over 5% and 2 second. So, simulation results to reduce overshoot and settling time by using automatic tuning method.
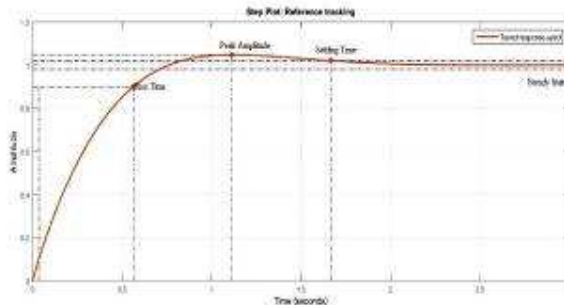
H. DC Motor with PID Controller (After Tuning)

Fig.12 DC Motor with PID Controller (After Tuning)

Controller Gain	Rise Time(sec)	Maximum Overshoot (%)	Settle time(sec)	Peak Amplitude
K_P=17.45	0.132	17.2	0.665	1
K_i= 48.49	0.163	1.83	0	1
K_d= 1.507	0.528	4.73	1.67	1.05

After tuning, overshoot and settling time are under 5% and 2 second. When tuning results of controller gain, rise time and peak amplitude changes. This simulation result is the mathematical simulation of DC Motor speed control system by using PID.

V. Conclusions

The applications of DC motors and drives have used in recent years in the appliance industry and the automotive industry. This paper has discussed aspects of DC motor speed control by using PID controller. To examine the speed control of DC motor, the software package MATLAB/ SIMULINK was used to design the block diagrams and run the simulations.

This paper studies the PID controller for the DC motor speed control system. For better speed control applications DC motor can give a better performance than induction motor and AC motor. PID Controls are commonly used in the industry. The purpose to control the speed of motor is to overcome the problem in industry like to avoid machines damages and to avoid slow rise time and high overshoot. Graphical representation of program gives which clear understanding about the structure and data flow. It is better for control application while MATLAB is better for data manipulation.

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