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# SPEED CONTROL OF SEPARATELY EXCITED D.C. MOTOR

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**ABSTRACT**

*This paper presents the speed control of a separately excited dc motor "A separately excited DC motor has a regulated or unregulated power supply that supplies power to the field winding that is completely independent from the power supplied to the armature". Conventional controllers are generally used to control the speed of the separately excited DC motors in various industrial applications. It is found to be simple and high effective if the load disturbances are small. So there will be drawback of Conventional controllers when high load has been applied to the DC motor. The system has been implemented using MATLAB/Simulink software. The simulations results show that presenting controller give good performance and high robustness in load disturbance. This paper is to design PID controller to supervise and control the speed response of the DC motor and MATLAB program is used for calculation and simulation PID controllers are widely used in a industrial plants because of their simplicity and robustness. Industrial processes are subjected to variation in parameters and parameter perturbations. We are choosing PID parameters and discussed.*

***Keywords:* Dc motor, PID controller, MATLAB representation**

## I. INTRODUCTION

The DC motors have been popular in the industry control area for a long time, because they have many good characteristics, for example: high start torque characteristic, high response performance, easier to be linear control etc. The speed of a DC motor is given be the relationship

$$N = \frac{(V - IaRa)}{k\Phi}$$

This Equation show that the speed is dependent on the supply voltage V, the armature circuit resistance Ra, and field flux Φ, which is produced by the field current. This paper describes the MATLAB/ SIMULINK of the DC motor speed control method namely field resistance, armature voltage, armature resistance control method and feedback control system for DC motor drives When speed control over a wide range is required, combination of armature voltage control and field flux control is used. This combination permits the ratio of maximum to minimum speed to be 20 to 40. With closed loop control, this range can be extended up to 200.The parameters of the PID controller $k_p$, $k_i$ and $k_d$ (or $k_p$, $T_i$ and $T_d$) can be manipulated to produce various response Curves from a given process

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## II. SEPARATELY EXCITED DC MOTOR

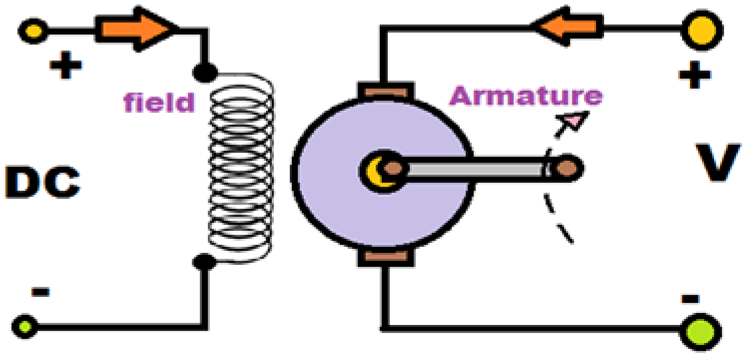


**Fig-1**

In case of Separately excited dc motor the field coil is energized from a separate DC voltage source and the armature coil is also energized from another source. Armature voltage source may be variable but, independent constant DC voltage is used for energizing the field coil. So, those coils are electrically isolated from each other, and this connection is the specialty of this type of DC motor.

### 2.1 Mathematical model and control theory

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

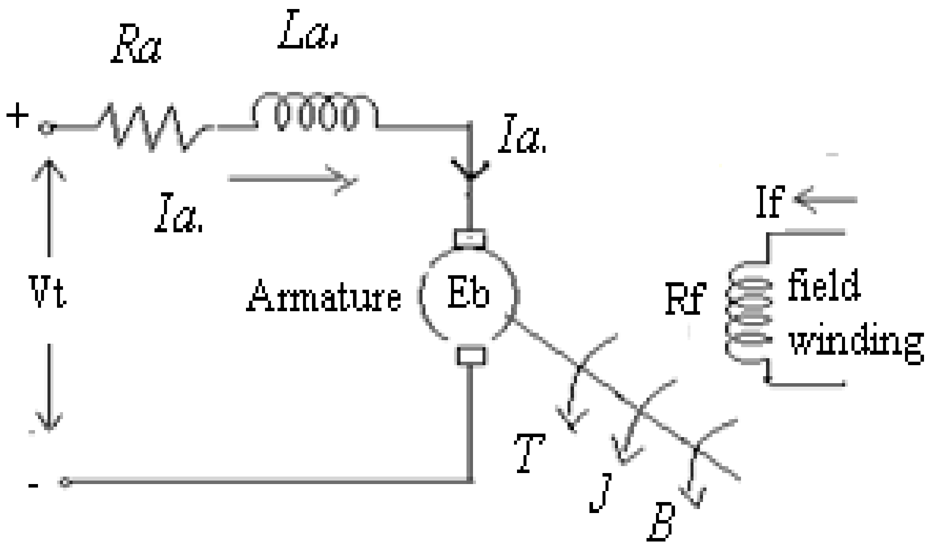


**Fig- 2**

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## 2.2 Parameters Of separately excited dc motor

Ra=Armature Resistance,

La=Armature self inductance caused by armature flux,

ia= Armature current,

if= field current,

Eb=Back EMF in armature,

V =Applied voltage,

T=Torque developed by the motor,

θ = Angular displacement of the motor shaft

J =Equivalent moment of inertia of motor shaft & load referred to the motor,

B= Equivalent Coefficient of friction of motor shaft & load referred to the motor

## 2.3 Mathematical modelling of separately excited dc motor

The DC motors are generally used in the linear range of the magnetization curve. Therefore, air gap flux Φ is proportional of the field current i.e

$$\Phi \,\alpha\, i_f$$

$$\Phi = k_f\, i_f \qquad (1)$$

Where $k_f$ is a constant

The torque T developed by the motor is proportional to the armature current and air gap flux i.e.

$$T \,\alpha\, \Phi\, i_a$$

$$T= k_a \Phi i_a$$

$$T=k_a k_f i_f i_a$$

$$T=k i_f i_a \qquad (2)$$

Where k is motor constant

The motor back EMF being proportional to speed is given as

$$Eb \,\alpha\, \Phi w$$

$$Eb=k_b\, w$$

$$Eb=k_b \frac{d\theta}{dt} \text{......}(3)$$

Where $K_b$ = back emf constant

Applying KVL in the armature circuit

$$V = \mathrm{Ra\ ia} + La\frac{dia}{dt} + Eb \text{........}(4)$$

And the dynamic quation with moment of inertia & coefficient of friction will be

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$T = J\frac{d2\theta}{dt2} + b\frac{d\theta}{dt}$ .......... .(5)

And with load torque

$T=J\frac{d2\theta}{dt2} + b\frac{d\theta}{dt} + Tl$ .......(6)

Take the laplace transform of equation of (2) ,(3), (4) and (5)

T(S)=Kia(S)

Eb(S)=KbSθ(S)

$V(S)=Ia(S)(Ra+SL_a)+Eb$

V(S)-Eb(S)=Ia(S)(Ra+Sla)

$T(S)=(JS^2+SB)\theta(S)$

T(S)=(JS+B)Sθ(S)

T(S)=(JS+B)W(S)

$T(S)=KI_a(S)$

## 2.4 Block diagram of armature controlled d. c. Motor

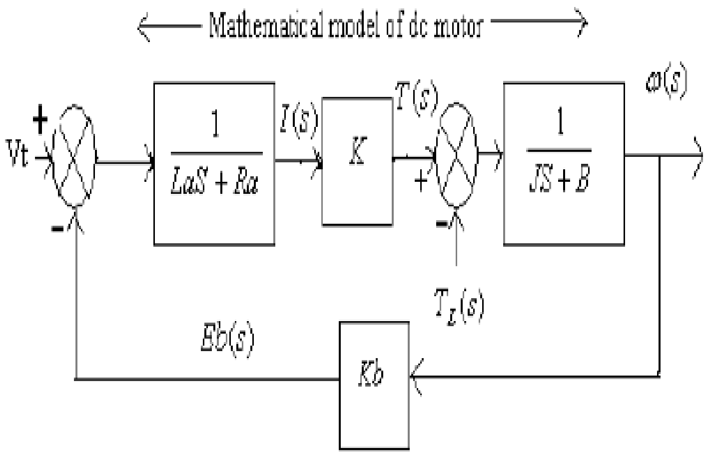


Fig- 3

Field controlled dc motor is open loop while armature controlled is closed loop system. Hence armature controlled dc motor are preferred over field controlled system. For small size motor field control is advantageous because only a low power servo amplifier is required while the armature current which is not large can be supplied from an expensive constant current amplifier. For large size motor it is on the whole cheaper to use armature control scheme. Further in armature controlled motor, back emf contributes additional damping over and above that provided by load friction

### 2.4.1.Transfer function of armature controlled d. c. Motor

The transfer function of DC motor speed with respect to the input voltage can be written as follows

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$$G(S) = \frac{W(S)}{V(S)} = \frac{K}{(Ra+SLa)(JS+B)+KKb} \text{ .........(7)}$$

**From equation (7) the armature inductance is very small in practices, hence, the transfer function of DC motor speed to the input voltage can be simplified as Follows,**

$$G(S) = \frac{W(S)}{V(S)} = \frac{Km}{\mu S+1} \text{ ......(8)}$$

**Where,**

$Km = \frac{K}{RaB+KbK}$ **is the motor gain and**

$\mu = \frac{RaJ}{RaB+KKt}$ **is the motor time constant**

**2.4.1.1 MATLAB representation of transfer function of armature controlled d. c. Motor**

We can represent the above open-loop transfer function of the motor in MATLAB by defining the parameters and transfer function as follows. Running this code in the command window produces the output shown below.

```
J = 0.01;
B = 0.1;
K = 0.01;
Ra = 1;
La = 0.5;
s = tf('s');
P_ motor = K/((J*s + B)*(La*s + R)+K^2)
```

```
P_ motor =
          0.01
  ---------------------------
  0.005 s^2 + 0.06 s + 0.1001

Continuous- time transfer function.
```

**2.4.1.2 MATLAB representation of state space of armature controlled d. c. Motor**

We can also represent the system using the state-space equations. The following additional MATLAB commands create a state-space model of the motor and produce the output shown below when run in the MATLAB command window.

```
A = [-B/J   K/J
```

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```
   -K/La   -Ra/La];
B = [0
   1/La];
C = [1   0];
D = 0;
Motor _ ss = ss(A,B,C,D)
```

```
motor_ss =
 a =
        x1     x2
  x1    -10      1
  x2  -0.02     -2
 b =
     u1
  x1   0
  x2   2
 c =
     x1  x2
  y1   1   0
 d =
     u1
  y1   0
```

Continuous- time state-space model.

The above state-space model can also be generated by converting your existing transfer function model into state-space form. This is again accomplished with the ss command as shown below.

```
motor_ss = ss(P_motor);
```

## III. CONTROLLER

A controller is a device, may be in the form of analogue circuit, chip or computer that monitors and physically alters the operating conditions of a given dynamical system. From the past decades, the importance of the control system has been increased due to the increment in complexity of the system under control and to achieve optimum performance of the system. The block diagram of closed-loop separately excited dc motor is shown in Figure below.

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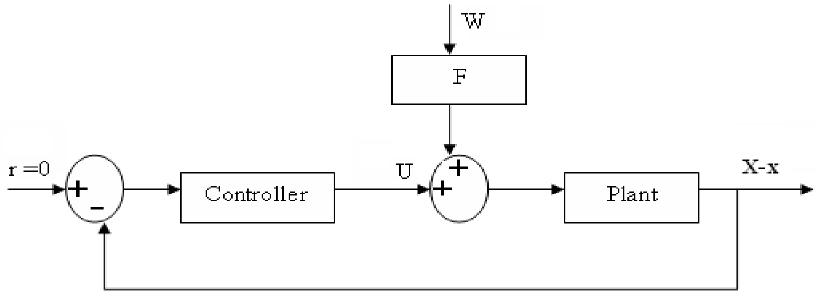
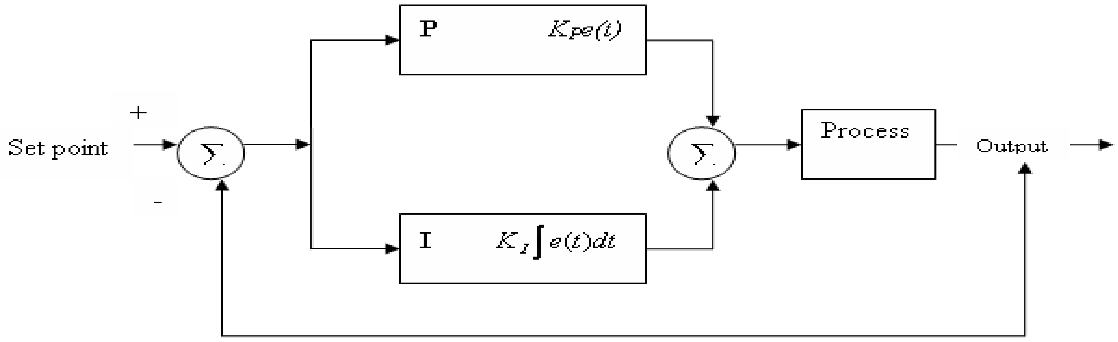



### 3.1. Proportional-Integral Controller

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. *C*(*s*) the transfer function of PI controller has the form of

$$C(s) = K_P + K_I/S \qquad (1)$$




**Block Diagram of PI controller**

Where, KP is proportional gain and KI is an Integral gain. The proportional term (sometimes called gain) makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant Kp, called the proportional gain. The contribution from the integral term sometimes called reset is proportional to both the magnitude of the error and the duration of the error.

### 3.2 Proportional-Integral-Derivative Controller

A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems - a PID is the most commonly used feedback controller.

A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In this section, the method to obtain the controller for the car suspension system is described when a PID scheme is used to perform control actions and *C*(*s*) the transfer function of PID controller has a form

$$C(s) = K_P + K_I/S + K_D S \qquad (2)$$

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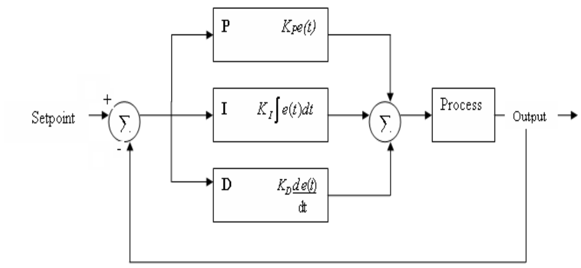
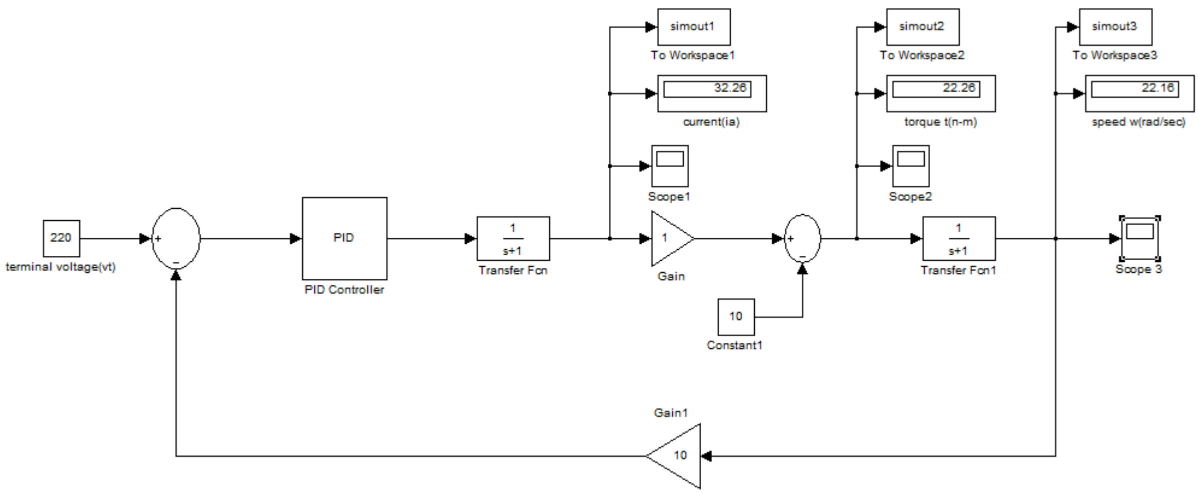



**Block Diagram of PID controller**

The PID controller calculation involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D.

## IV. MATLAB REPRESENTATION AND SYSTEM RESPONSE




The combination of proportional, integral and derivative control action is called PID action control and the controller is called three action controllers. Here the proportional part of the control action repeats the change of error and derivative part of the control action adds an increment of output so that proportional plus derivative action is shifted ahead in time. The integral part ads a further increment of output proportional to the area under the deviation line. The combination of proportional, integral an derivative action may be made in any sequence as shown. Now, we increase the gain Kd, with Kp=5; Ki=10. All results are illustrated in the Table 3 and the corresponding plots are shown in Fig .From the results we see that the rise time increase from (0.50 sec to 0.82sec) for (Kd=1 to Kd=4) and the overshoot from (23% to 12%) and there is small change in the settling time. Hence the steady state error is completely zero.

| **Kd** | **Rise Time(sec)** | **Maximum Overshoot** | **Steady State Error** | **Peak Amplitude of Velocity (red/sec)** |
|---|---|---|---|---|

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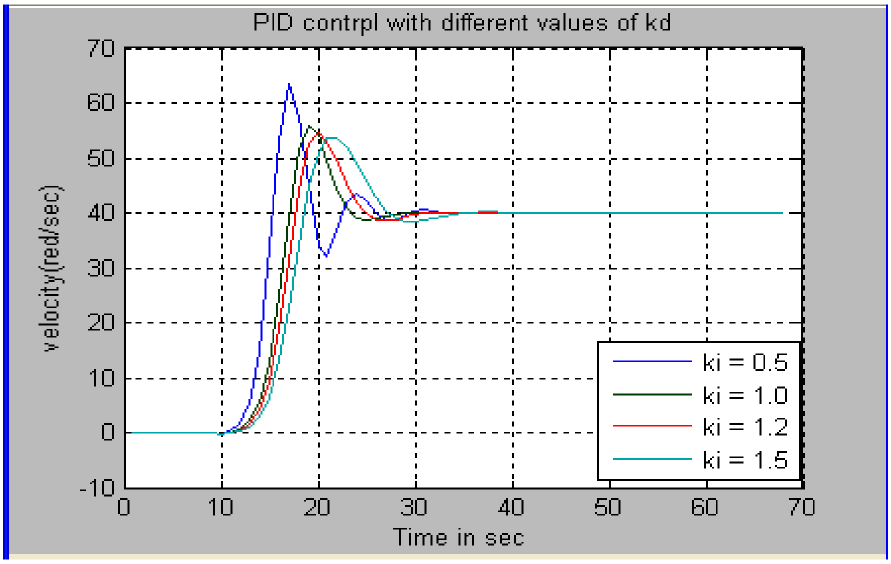
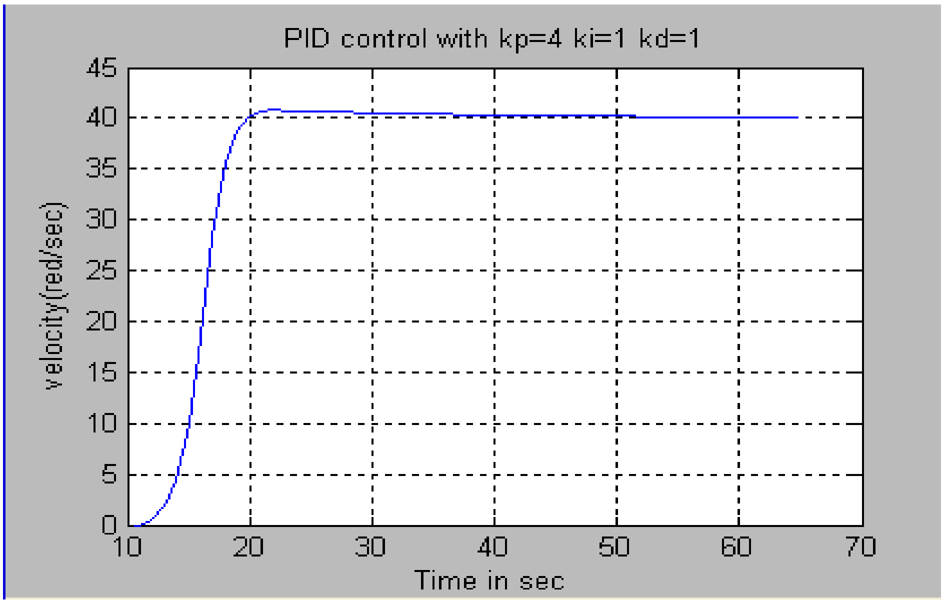
| | | (%) | | |
|---|---|---|---|---|
| 1 | 0.50 | 23.39 | 0 | 40 |
| 2 | 0.65 | 15.95 | 0 | 40 |
| 3 | 0.71 | 14.52 | 0 | 40 |
| 4 | 0.82 | 12.58 | 0 | 40 |

**Table – 1 PID Control**




So now we know that if we use a PID controller with: Kp=4,ki=1 and Kd=1; all our design requirements will be satisfied and the response looks like




**PID controller with: Kp=4,Ki=1 and Kd=1**

Effects of PID controllers parameters kp, ki and kd on a closed loop system are summarized in the table below.

| Closed loop Response | Rise Time(sec) | Maximum Overshoot(%) | Settling Time(sec) | Steady State Error |
|---|---|---|---|---|
| As increase of $K_P$ | Decrease | Increase | Small change | Decrease |
| As increase of $K_I$ | Decrease | Increase | Increase | Eliminate |
| As increase of $K_D$ | Small change | Decrease | Decrease | Small change |

**Table- 2**

## V. CONCLUSION

Accurate performance of a motor is desired feature for any industrial application. As the age of motor increases its performance also deceases with aging, so it is desired to evaluate the performance of motor from time to time for efficient operation. The conventional method for calculating output performance indices are quite time consuming. The PID based approach algorithm worked satisfactory for the test system. The important observations made during the studies are

1) The solution time for proposed PID approach is only a fraction of time taken by conventional algorithm.

2) A proportional controller Kp will have the effect of reducing the rise time and reduce but never eliminate the steady state error.

3) An internal controller Ki will have the effect of eliminate the steady state error but it may make the transient response worse.

4) A derivative controller Kd will have the effect of increasing the stability of the system and reducing the overshoot and improve the transient response.

5) The output performance obtained by normalized value in PID is very close and near to accuracy.

6) MATLAB used for simulation of entire project is sophisticated and user friendly software.

It must be mentioned that the efficiency of the speed algorithm can be improved by using more efficient learning techniques and dynamic weight selection algorithm.

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