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Analysis of Speed Control of DC Motor using Various Controllers

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Abstract- **This paper presents the design of various controllers like P, PI, PD, PID used to supervise the speed response of the DC Motor. PID Controllers are widely used in an industrial plants because of their simplicity and robustness. The purpose of developing a simulation using P, PI, PD, PID Control system is to get the steady state and transient response of the system. This paper focuses modelling of separately excited DC motor and simulated using MATLAB/SIMULINK and compares the step response of the system using various controllers.**

Index Terms- Speed Control, DC Motor, P, PI, PD, PID Controller.

1. INTRODUCTION

DC Motor plays a fundamental role in research and laboratory experiments because of their simplicity and low cost. DC motor is a power actuator which converts electrical energy into mechanical energy. Direct Current (DC) motors have variable characteristics and are used extensively in variable-speed drives. DC motor can provide a high starting torque and it is also possible to obtain speed control over wide range. 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 [1].
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 to 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. 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. These applications may demand high-speed control accuracy and good dynamic responses. The term speed control stand for intentional speed variation carried out manually or mechanically. DC motors are most suitable for ample 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. So, it is important to make a controller to control the speed of DC motor in desired speed. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute many tasks [2].

There are several types of controllers are used to control the speed of DC Motor. It may be Conventional controllers, Proportional Integral Controller, PID Controller, Ziegler-Nichols, Neural Network Controller, and Fuzzy Logic Controller. In industries 90% controllers are PID type because of its simplicity, applicability and ease of use offered by the PID controller. At the same time PID controller has some disadvantages namely; the undesirable speed exceed, idle response and sensitivity. The performance of this controller depends on the precision of system models and parameters [3-4].

II. MATHEMATICAL MODELLING OF DC MOTOR

DC motor system is a separately excited DC motor, which is often used to the velocity tuning and the position adjustment. The equivalent circuit of the DC motor using the armature voltage control method is shown in Fig. 1. [5].

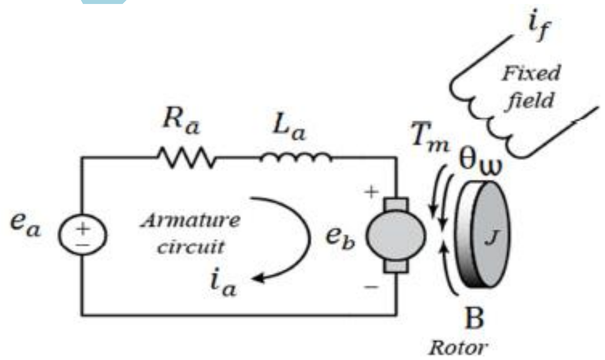

Fig. 1. : Equivalent Circuit of the DC Motor

Where
Ra: armature resistance (Ω)
J: rotor inertia (kgm2)
La: armature inductance (H)
B: friction constant (Nms/rad)
Ia : armature current (A)
Kb: EMF constant (Vs/rad)
Ea: input voltage (V)
Kt: torque constant (Nm/A)
eb: back electromotive force (V)
Tm: motor torque (Nm)
ω: angular velocity of rotor (rad/s)
This system is modeled by summing the torques acting on the rotor inertia and integrating the acceleration to give the velocity. Also, Kirchhoff's laws will be applied to the armature circuit.

$R_a I_a + L_a \frac{dI_a}{dt} + e_b = e_a$ .... (1)

$J \frac{d^2\theta}{dt^2} + B \frac{d\theta}{dt} = T$ .... (2)

The motor torque, T, is related to the armature current, Ia, by a constant factor Kt. The back emf, Eb, is related to the rotational velocity by the following equations:

$T = K_t Ia$ .... (3)

$e_b = K_b \frac{d\theta}{dt}$ .... (4)

Where 'Kt' is armature constant and 'Kb' is motor constant. The transfer function of the system is given by the equation

$G(s) = \frac{\omega(s)}{Ea(s)} = \frac{Kt}{((La*s+Ra)(Js+B)+KbKt)}$ ....(5)

The block diagram representation of speed control of DC Motor I shown in Fig. 2.

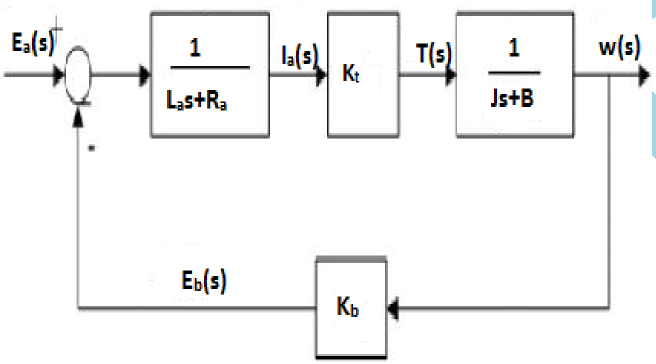

Fig. 2. Block diagram of DC Motor

III. DESIGN REQUIREMENTS

First consider that the uncompensated motor rotates 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, we will require 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, we want it to have a settling time less than 2 seconds. Also, since a speed faster than the reference may damage the equipment, we want 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.

- Settling time less than 2 seconds
- Overshoot less than 5%
- Steady-state error less than 1% [5].

The specifications of DC Motor is as shown in Table I.

TABLE I: Specifications of DC Motor

PHYSICAL PARAMTERS	VALUES
Moment of Inertia (J)	0.01 kg m^2/s^2
Damping ratio of mechanical system (B)	0.1Nms
Electromotive force constant (K_b=Kt)	0.01Nm/Amp
Electric Resistance (R)	1Ω
Electric Inductance (L)	0.5 H

IV. CONTROLLER DESIGN

A.P-Controller

In the proportional control algorithm, the controller output is proportional to the error signal, which is the difference between the set point and the process variable. In other words, the output of a proportional controller is the multiplication product of the error signal and the proportional gain.
This can be mathematically expressed as

$u(t) = K_p e(t)$ ....(6)

Where u(t) is the output of the controller; e(t) is the input of the controller; Kp proportional Constant. The Block diagram of P-Controller is shown in Fig. 3.

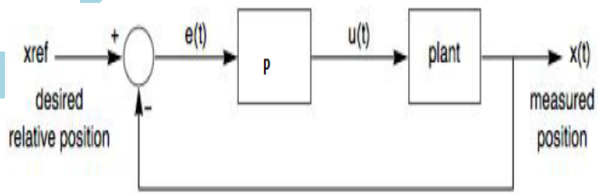

Fig. 3. Block Diagram of P-Controller

P-Controller is used in first order processes with single energy storage to stabilize the unstable process. The main usage of the P-Controller is to decrease the steady state error of the system. As the proportional gain factor K increases, the steady state error of the system decreases and provides smaller amplitude and phase margin, faster dynamics satisfying wider frequency band and larger sensitivity to the noise. We can use this controller only when our system is tolerable to a constant steady state error. In addition, it can be easily concluded that applying P controller decreases the rise time and after a certain value of reduction on the steady state error, increasing K only leads to overshoot of the system response. P control also causes oscillation if sufficiently aggressive in the presence of lags and/or dead time. The more lags (higher order), the more problem it leads. Plus, it directly amplifies process noise [6].

B.PI-Controller

The combination of proportional and integral control action is called PI control action. In this type of controller, output of the controller is directly proportional to combination of error signal and integral of error signal. This can be mathematically expressed as

$u(t)=K_p e(t)+K_i \int e(t)dt$…………………(7)

Where u(t) is the output of controller; e(t) is the error signal; Kp is Proportional gain; Ki is Integral gain. Fig.4 shows the block diagram of PI-Controller.

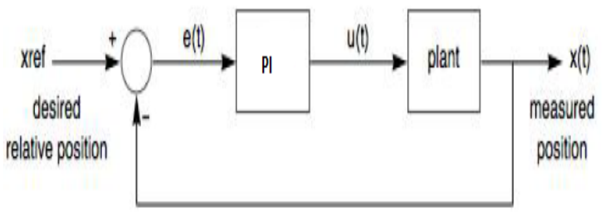

Fig.4. Block Diagram of PI-Controller

PI-Controller is mainly used to eliminate the steady state error resulting from P-Controller. However, in terms of the speed of the response and overall stability of the system, it has a negative impact. This controller is used in areas where speed of the system is not an issue. Since PI-Controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations. If applied, any amount of I guarantees set point overshoot [6-7].

C. PD-Controller

The combination of proportional and derivative control action is called PD control action. In this type of controller, output of the controller is directly proportional to combination of error signal and derivative of error signal. This can be mathematically expressed as

$u(t)=K_p e(t)+K_d \frac{de(t)}{dt}$……………………(8)

Where u(t) is the output of controller; e(t) is the error signal; Kp is Proportional gain; Kd is Derivative gain. Fig. 5 shows the block diagram of PD-Controller.

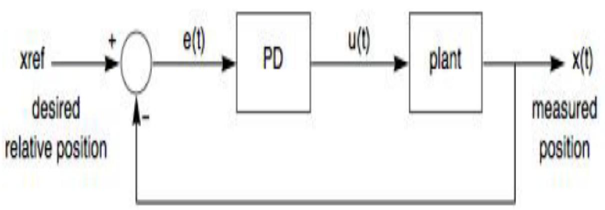

Fig. 5. Block Diagram PD-Controller

The aim of using PD-Controller is to increase the stability of the system by improving control since it has an ability to predict the future error of the system response. In order to avoid effects of the sudden change in the value of the error signal, the derivative is taken from the output response of the system variable instead of the error signal. Therefore, D mode is designed to be proportional to the change of the output variable to prevent the sudden changes occurring in the control output resulting from sudden changes in the error signal. In addition, D directly amplifies process noise therefore D-only control is not used [6-7].

D.PID-Controller

The combination of proportional, integral and derivative control action is called PID control action. In this type of controller, output of the controller is directly proportional to the combination of error signal, integral of error signal and derivative of error signal. This can be mathematically expressed as

$u(t)=K_p e(t)+K_i \int e(t)dt+K_d \frac{de(t)}{dt}$……….(9)Where u(t) is the output of controller; e(t) is the error signal; Kp is Proportional gain; Ki is Integral gain and Kd is Derivative gain. Fig. 6 shows the block diagram of PID controlled plant. PID Controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed-loop response characteristics.

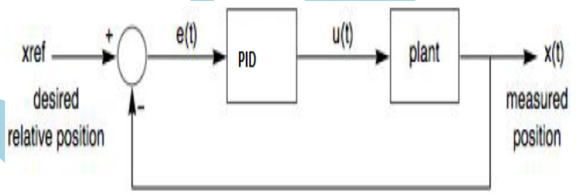

Fig. 6 Block Diagram of PID controller

It can be assumed that the plant is a DC motor whose speed must be accurately regulated. The PID controller is placed in the forward path, so that its output becomes the voltage applied to the motor's armature, the feedback signal is a velocity, measured by a tachometer. The corresponding three adjustable PID parameters are most commonly selected to be

- Controller gain- Increased value gives more proportional action and faster control
- Integral time- Decreased value gives more integral action and faster control
- Derivative time- Increased value gives more derivative action and faster control

Although the PID controller has only three parameters, it is not easy, without a systematic procedure, to find good values for them. In fact, a visit to a process plant will usually show that a large number of the PID controllers are poorly tuned. PID Controller includes all the three control actions i.e. proportional, integral and derivative.

- A PID controller calculates and outputs a corrective action, which corrects the error between the process output and the desired set point that adjusts the process accordingly and rapidly.
- The output of the controller or the manipulated variable is obtained by adding P, I and D components and their associated coefficient.

Consider the feedback system architecture that is shown in Fig.7. where it can be assumed that the plant is a DC motor whose speed must be accurately regulated.

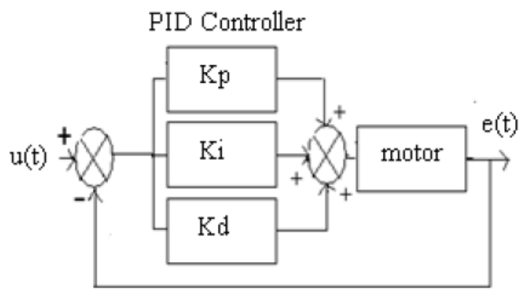

Fig.7. Block diagram of PID Controller

PID Controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the PID Controller is that it can be used with higher order processes including more than single energy storage [6-8].

V. MATLAB SIMULATION RESULTS

In this paper, a model of a separately excited DC motor has been designed and implemented in MATLAB along with the P Controller, PI Controller, PD Controller and PID Controller. Fig.8, Fig.9, Fig.10 and Fig.11 shows the responses of P, PI, PD and PID Controller respectively. Table II shows the combined results of all the controllers.

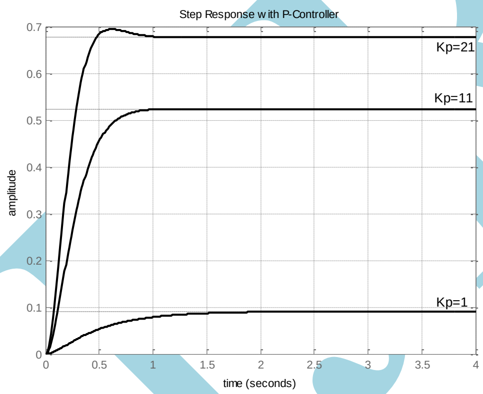

Fig.8 Response of P-Controller for different values of Kp

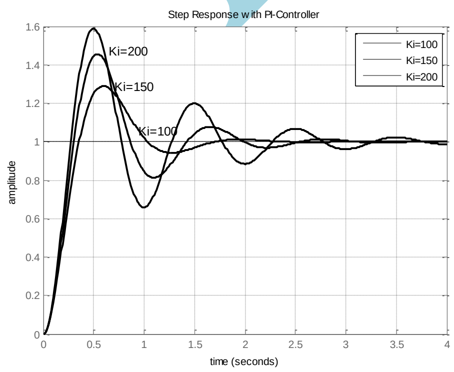

Fig.9 Response of PI-Controller for different values of Ki

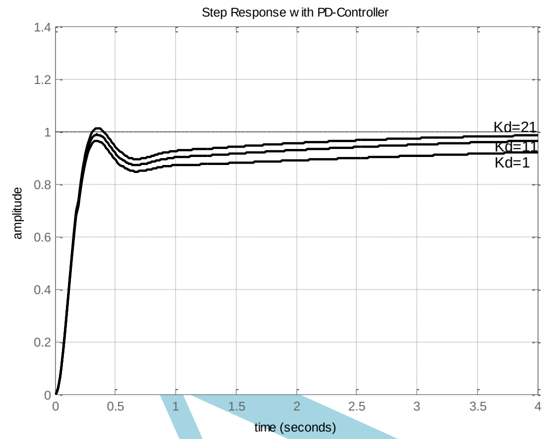

Fig.10 Response of PD-Controller for different values of Kd

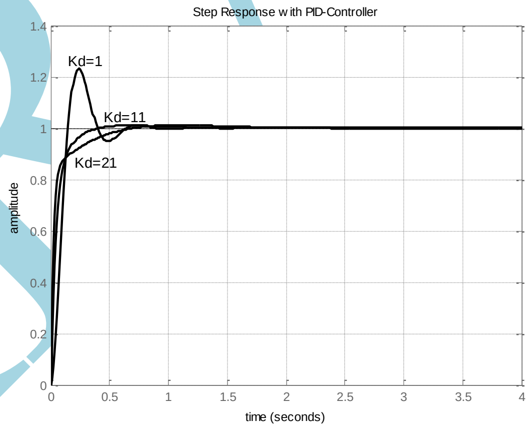

Fig.11 Response of PID-Controller for different values of Kd.

Table II: Comparisions of step response of P, PI, PD, PID Controllers

Parameters	Types of Controllers			
	P	PI	PD	PID
Rise time	0.29	0.18	0.19	0.16
Settling time	0.71	3.57	3.54	0.50
Overshoot	2.48	58.6	1.02	1.11
Peak time	0.61	0.48	0.35	1.08
Steady state error	0.67	0	0	0
Step response	stable	stable	stable	More stable

VI. CONCLUSION

In this paper, modelling of separately excited DC motor has been presented and performance analysis of various controllers has been studied and analyzed using MATLAB / SIMULINK. In industries 90% controllers are PID type because of its simplicity, Applicability and ease of use offered by the PID controller. By proper tuning the values of Kp, Ki and Kd we can improve the performance characteristics. Also, we can employ Ziegler-Nichols tuning method, Fuzzy logic control method and neural network control method to improve the performance results.

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