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Time Response Analysis of DC Motor using Armature Control Method and Its Performance Improvement using PID Controller

D Vimalakeerthy

Department of Electrical Power Engineering, Nizwa College of Technology, Nizwa, Oman
vimalakeerthy@gmail.com

ABSTRACT

For the past years DC motors are widely used in industries. There mainly preferred due to the fact that they offer good speed controllability. Most of the applications require precise speed control and accurate dynamic performance. A normal DC motor available in the market can not satisfy the requirement of the industry due to the problem of torque controllability. Hence in order to improve the dynamic response of the DC motors controllers are introduced. In this paper the actual timer response of the DC motor is experimentally determined using the transfer function and the time response analysis is done by the introduction of different types of controllers. From the analysis an efficient controller is proposed. Matlab simulink is used as the analytical tool to measure the time response of DC motor.

Key words: DC motor, Time response, PID Controllers

INTRODUCTION

In recent years DC motors are widely used in robotics because of their small size and high energy output. They are excellent for powering the drive wheels of a mobile robot as well as powering other mechanical assemblies. It is often demanded in the industries that the drive should have efficient speed control in lesser time and steady state performance as quick as possible [1]. In order to improve the time response of the DC motor controllers has been introduced in this paper. A detailed analysis of the controllers illustrates the effectiveness of the improvement in both transient state and steady state behavior of the DC motor. For analytical purpose the individual effect of each controller the following cases has been discussed.

- Proportional Controller
- Derivative Controller
- Integral Controller
- Proportional plus Derivative Controller
- Proportional plus Integral Controller
- Proportional, Integral & Derivative Controller

MATHEMATICAL MODEL

In order to measure the time response of a DC motor it is necessary to obtain transfer function of the DC motor. Transfer function is obtained by conducting the speed control test on the DC shunt motor [2]. In this paper speed control of the DC motor by armature control method is proposed. The transfer function equations are obtained using the mathematical equations as given below.

The DC motor mathematical equations consist of Electrical model and mechanical model. The Electrical equations of DC motor is given by

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

$$E_b = K_b \frac{d\theta}{dt} \tag{2}$$

where, V_a is the armature voltage, I_a is the armature current, E_b is the back emf and K_b is the back emf constant

Mechanical equations are given by,

$$T = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} \quad (3)$$

$$T = K_t I_a \quad (4)$$

where, J is the moment of inertial of the DC motor, B is the friction in rotating parts of the motor, T is the torque and K_t is the torque constant.

On combining the electrical and mechanical equations the transfer function equation obtained is as below

$$\frac{\theta(s)}{V_a(s)} = \frac{K_t}{(R_a + sL_a)(Js^2 + Bs) + K_b K_t s} \quad (5)$$

From the transfer function model the time response analysis can be performed.

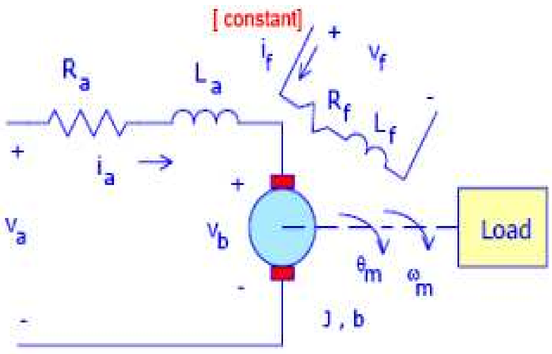

Fig. 1 Mathematical model of DC Motor

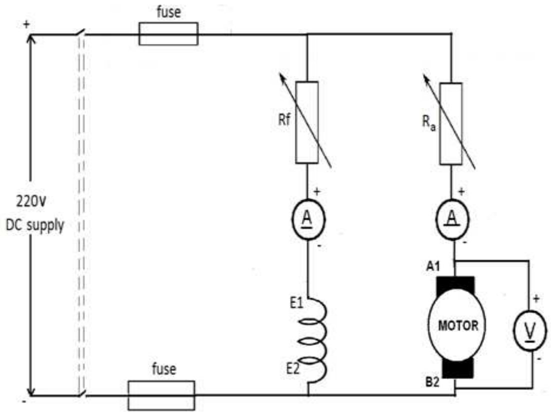

Fig. 2 Experimental circuit for speed control test

EXPERIMENTAL EVALUATION OF TRANSFER FUNCTION OF DC MOTOR

The speed of a DC motor is directly proportional to armature voltage and inversely proportional to flux in the field winding. In armature controlled DC motor the desired speed is obtained by varying the armature voltage [3][4]. This speed control system is electro mechanical control system. The electrical system consists of armature and field current. The mechanical system consists of rotating part of the motor and the load connected to the shaft. The experimental circuit for conducting speed control test is shown in Fig. 2. The following table 1 shows the readings taken for the experimental analysis.

Table -1 Experimental Readings of DC Motor

S.No.	I_a	E_a	N (rpm)	E_b	ώ	T
1	0.517	204	3000	202.24	314.15	0.33
2	0.512	201	2970	199.25	311	0.32
3	0.505	198	2920	196.28	305.78	0.32
4	0.499	191	2830	189.3	296.35	0.31
5	0.492	184	2740	182.32	286.93	0.31

Back EMF Constant

The value of back emf constant is evaluated by plotting a graph between speed versus back emf as shown in Fig. 3. By calculating the slope of the graph back emf constant K_b is calculated.

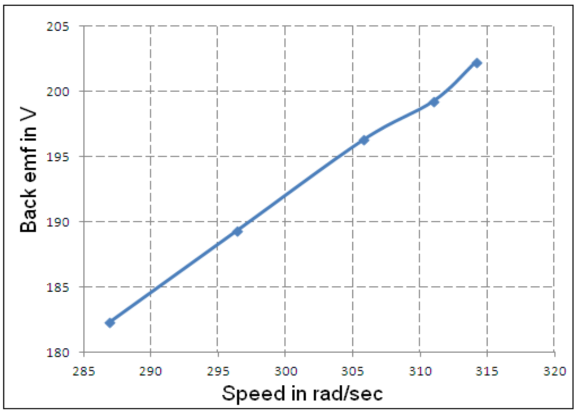

Fig. 3 Variation of speed Vs backemf

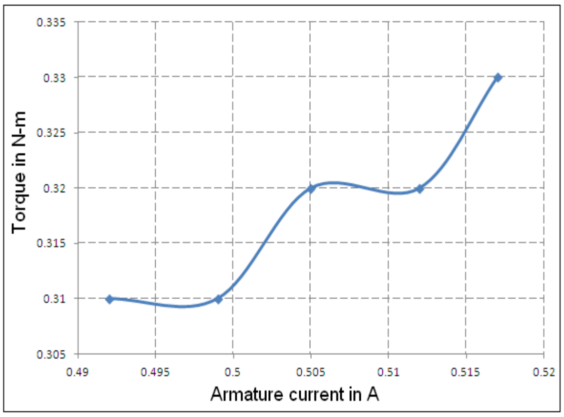

Fig. 4 Variation of armature current Vs Torque

Torque Constant

Torque constant is calculated by drawing a graph between armature current Vs torque as shown in Fig. 4**.** The torque constant is calculated by finding the slope of the graph plotted.

TIME RESPONSE ANALYSIS

Time response analysis of a given system can be determined by converting the transfer function equation to the variables in terms of time by taking inverse Laplace transformations. From the equation various time domain specifications such as delay time, rise time, peak time and settling time can be calculated. Initially the time response of the original motor was calculated using MATLAB and the variation of amplitude with respect to time on the application of step input signal is shown in Fig. 5. It is observed that the system takes 8 seconds to 10 seconds to settle to its final value. During that time the DC motor may not operate at the desired speed.

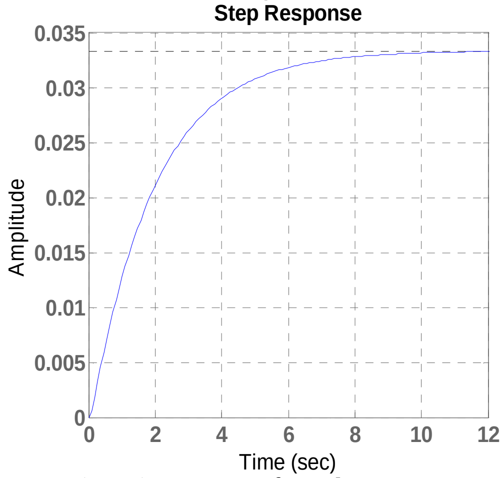

Fig. 5 Time response of actual DC motor

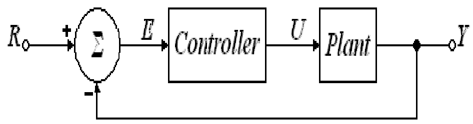

Fig. 6 Controller Block Diagram

Controllers

Controllers are designed to eliminate the need for continuous operator attention. Cruise control in a car and a house thermostat are common examples of how controllers are used to automatically adjust some variable to hold a measurement (or process variable) to a desired variable (or set-point)

- When utilizing the PID algorithm, it is necessary to decide which modes are to be used (P, I or D) and then specify the parameters (or settings) for each mode used.
- Generally, three basic algorithms are used: P, PI or PID.
- The variable being controlled is the output of the controller (and the input of the plant):
- The output of the controller will change in response to a change in measurement or set-point (that said a change in the tracking error)

P - Controller

The proportional term produces an output value 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 constant.
The proportional term is given by:

$$P_{out} = K_p e(t) \tag{6}$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change. Fig. 7 shows the variation of the amplitude with respect to time when P controller is added to the DC motor. It is observed that on adding P Controller setting time is decreased by the system presents more peak overshoot.

D - Controller

Plot of PV vs time, for three values of Kd (Kp and Ki held constant) The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain Kd. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, Kd.
The derivative term is given by:

$$D_{out} = K_d \frac{de(t)}{dt} \tag{7}$$

Derivative action predicts system behaviour and thus improves settling time and stability of the system. Derivative action is seldom used in practice though - by one estimate in only 20% of deployed controllers because of its variable impact on system stability in real-world applications. For example, in the presence of severe measurement noise the derivative action will be erratic and can actually degrade control performance or stability. Large, sudden changes in the measured error (which typically occur when the set point is changed) cause a sudden, large control action stemming from the derivative term, which goes under the name of derivative kick. This problem can be ameliorated to a degree if the measured error is passed through a linear low-pass filter or a nonlinear but simple median filter. Fig. 8 shows the variation of the amplitude with respect to time when D controller is introduced to the DC motor. It is seen that the peak overshoot is decreased and the amplitude is increased but the steady state value of the motor is falling. Hence D controller only improves the transient response but creates a negative impact on steady state response.

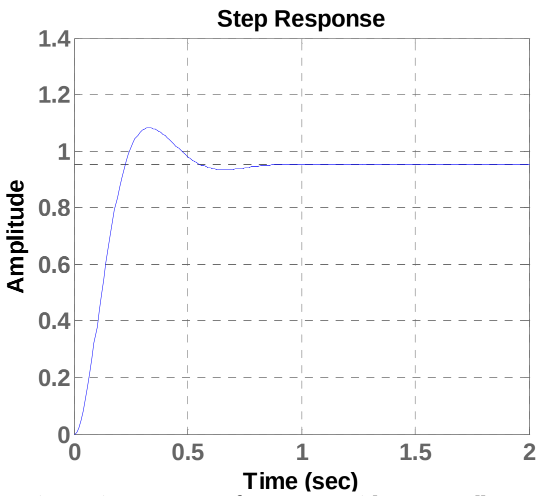

Fig. 7 Time response of DC motor with P-Controller

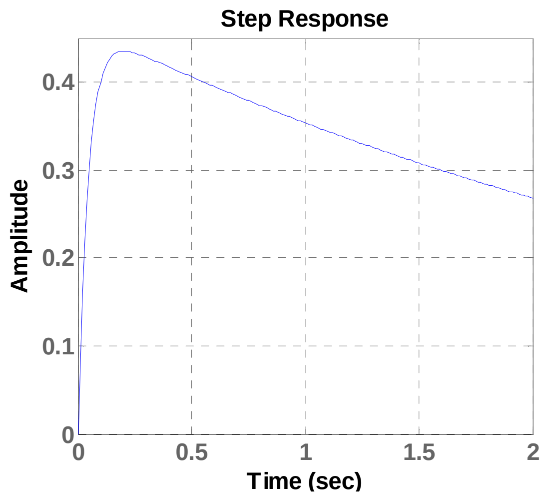

Fig. 8 Time response of DC motor with D-Controller

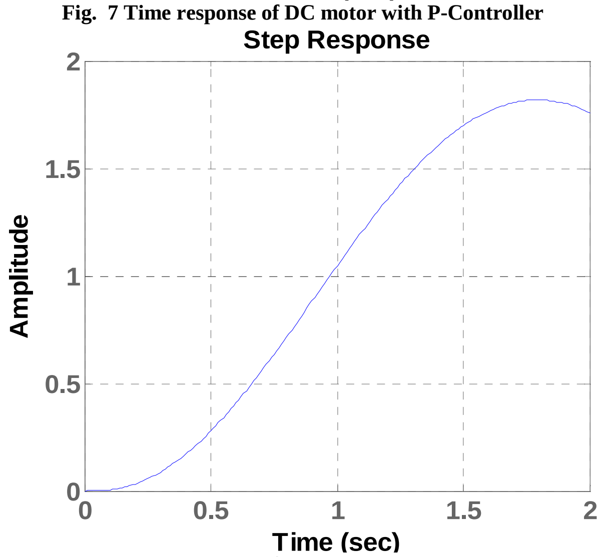

Fig. 9 Time response of DC motor with I-Controller

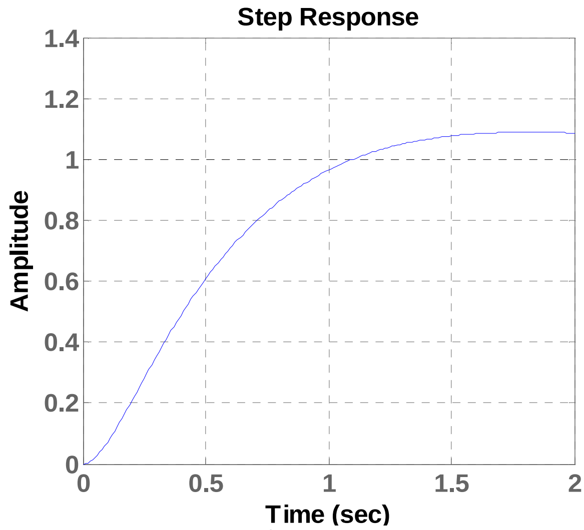

Fig. 10 Time response of DC motor with PI-Controller

I - Controller

Often control systems are designed using Integral Control. In this control method, the control system acts in a way that the control effort is proportional to the integral of the error.

$$I_{out} = K_I \int e(t)dt \tag{8}$$

Fig. 9 shows the time response of the DC motor on adding Integral controller. It is seen that the amplitude of the system is increased and the steady state response is reached after a time delay.

PI- 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. The PID controller block is reduced to P and I blocks only

The proportional and integral terms is given by:

$$PI_{out} = K_p r(t) + K_I \int e(t)dt \tag{9}$$

Fig. 10 shows the time response of DC motor with PI controller. It is observed that the settling time is reduced gradually without losing the steady state value when compared to I controller.

4.6 PD Controller

The performance of the DC motor is analysed with the combination of proportional plus derivative controller. The mathematical equation is given by

$$PD_{out} = K_p r(t) + K_d \frac{de(t)}{dt} \qquad (10)$$

The time response is as shown in Fig. 11. It is analysed that the speed of the response is increased significantly but the steady state value drastically increases without settling in finite period of time.

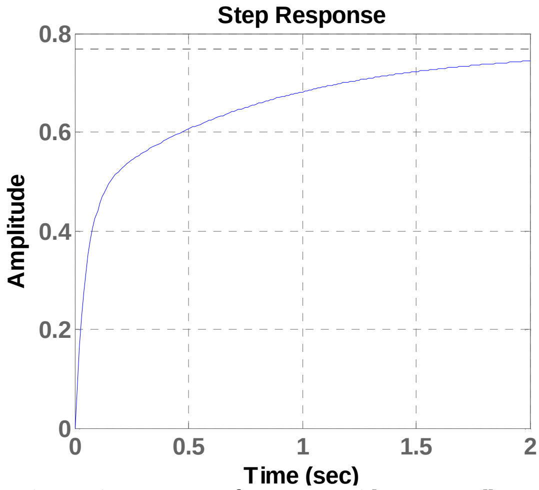

Fig. 11 Time response of DC motor with PI-Controller

PID Controller

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. 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 in outputs by adjusting the process control inputs. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element.

The mathematical equation governing PID control is given by:

$$PID_{out} = K_p r(t) + K_I \int e(t)dt + K_d \frac{de(t)}{dt} \qquad (11)$$

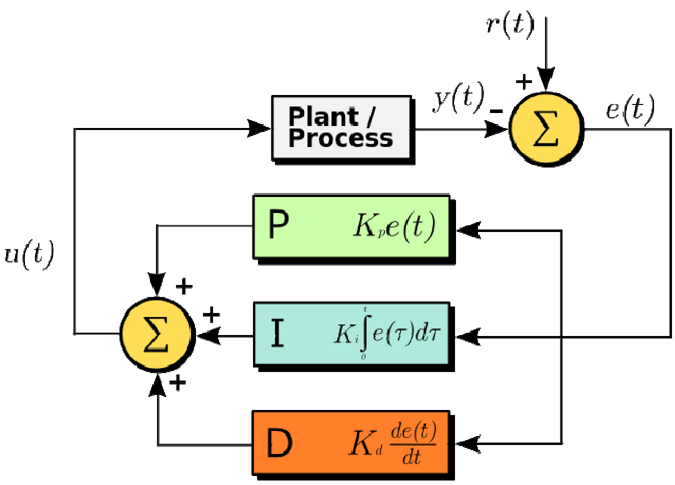

Fig. 12 Block diagram of PID-Controller

From the time response graph obtained Fig. 13 it is evident that on combining proportional, integral and derivative controllers the steady state response as well as the transient response of the system increases and seems to be the best controller for improving DC motor performance.

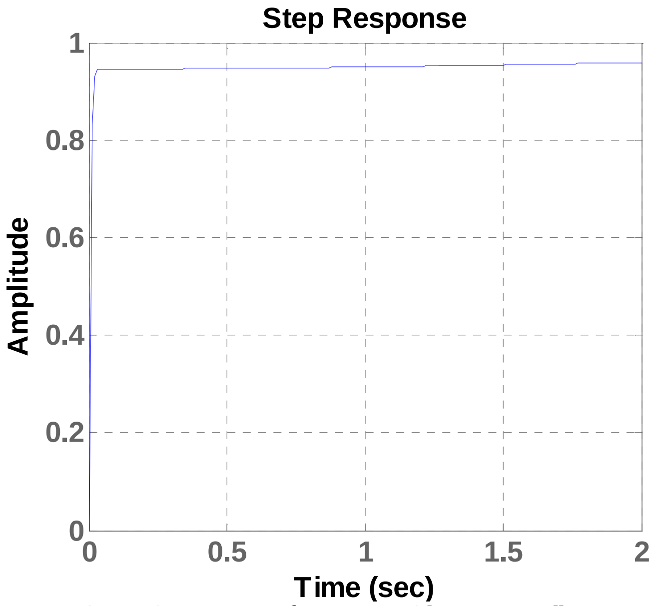

Fig. 13 Time response of DC motor with PID-Controller

CONCLUSION

The transfer function of the DC motor was experimentally determined using speed control of motor using armature control method. From the result the time response of the actual machine was determined. It is observed that the original machine takes more time to settle to a steady value. Different types of controllers are introduced for the existing motor model and the time response was calculated using MATLAB. It is found that on using the PID controller both steady state response and transient response of DC motor was improved.

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