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PI Control Based DC Drive Speed Controller Responses for Small Load Torque Variation

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Abstract

The separately excited Direct current (DC) motors with conventional Proportional Integral (PI) speed controller is generally used in industry. This can be easily implemented and are found to be highly effective if the load changes are small. However, in certain applications, like rolling mill drives or machine tools, where the system parameters vary substantially and conventional PI or PID controller is not preferable due to the fact that, the drive operates under a wide range of changing load characteristics. Here in this paper a speed response is analyzed using PI control for a separately exited dc drive. The responses of steady state error, speed overshoot etc. are analyzed for a separately excited dc drive with small changes in load torque using the said controller. Performances of these controllers are verified by simulation in MATLAB.

Keyword: Proportional Integral (PI) speed controller, conventional PI or PID, steady state error, speed overshoot.

Introduction

The principle of speed control for dc motors is developed from the basic emf equation of the motors. Torque, flux, current, induced emf, and speed are normalized to present the motor characteristics. Two types of control are available: armature control and field control. In this paper the armature control is used to describe the said control logic. Basically armature voltage is controlled to control the speed of the motor.

In this paper a control logics (PI) is developed in MATLAB and is applied to the motor. The mathematical model of a separately excited DC motor is prepared. Basically this mathematical model is used in MATLAB to simulate the motor responses. In this paper the responses like peak overshoot, settling time, oscillation w.r.t. set value etc. of the motor using the said logic is analyzed due to introduction of load torque variation. If in runtime of the motor the load torque of the motor varies the speed also varies, if load torque increases the motor speed decreases and if load torque decreases then motor speed increases. So to control the speed at a desired set point level different control logics are introduced. But in point of view of different response parameters, these logics have some demerits in different situations i.e. for a particular response parameter some logics are well equipped but for another response parameter these logics may not be so good.

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desired set point level different control logics are introduced. But in point of view of different response parameters, these logics have some demerits in different situations i.e. for a particular response parameter some logics are well equipped but for another response parameter these logics may not be so good.

Description

The basic block diagram of control strategy of a DC motor is shown in fig-1. Depending upon the error speed the controller (here PI controller which shown in fig-1) calculate a compensating value time to time and control the signal by which the motor is to be control.

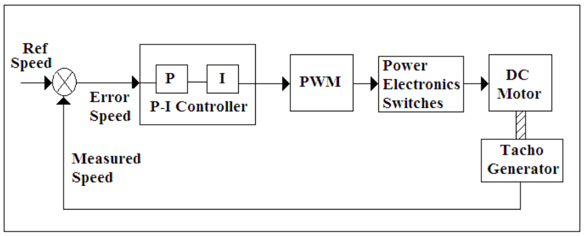

Fig.-1 Block diagram of a DC motor control strategy

The ideal version of the PI controller is given by the formula

$$u(t) = k_p e(t) + k_i \int_{t-T}^{t} e(t)dt \quad \text{.... (1)}$$

Where u is the control signal, T is the time interval for which integration have to done and e is the control error (e = r − y). The reference value, r, is also called the set-point. The control signal is thus a sum of two terms: a proportional term that is proportional to the error, an integral term that is proportional to the integral of the error. The controller parameters are proportional gain k_p and integral gain k_i. [1-4]

Mathematical Modelling of Separately Excited DC Motor

List of abbreviations of DC motor parameters:

Va is the armature voltage. (In volt)
Eb is back emf the motor (In volt)
Ia is the armature current (In ampere)
Ra is the armature resistance (In ohm)
La is the armature inductance (In henry)
Tm is the mechanical torque developed (In Nm)
T_L is the load torque (In Nm)
Jm is moment of inertia (In kg/m²)
Bm is friction coefficient of the motor (In Nm/(rad/sec))
ω is angular velocity (In rad/sec)

For a DC motor

$$\omega \alpha \frac{V_a - I_a R_a}{\phi} \quad \text{...... (2)}$$

$$\Rightarrow \omega = \frac{V_a - I_a R_a}{K_a \phi} \quad \text{...... (3)}$$

Where ϕ = Field flux per pole (in wb)
K_a= Armature constant = PZ/2πA
Where P = No. of pole
Z = Total no. of armature conductor
A = No. of parallel path

For a separately excited DC motor
The armature voltage equation is

$$V_a = E_b + I_a R_a + L_a \frac{dI_a}{dt} \quad \text{.......(4)}$$

Now the torque balance equation is

$$T_m = J_m \frac{d\omega}{dt} + B_m \omega + T_L \quad \text{.......(5)}$$

Neglecting the friction the torque balance equation will be

$$T_m = J_m \frac{d\omega}{dt} + T_L \quad \text{.......(6)}$$

Also

$$E_b = K_a \phi \omega \quad \text{......(7)}$$

and $T_m = K_a \phi I_a$ ......(8)

Now taking Laplace Transform
From equation (4)

$$I_a(S) = \frac{V_a(S) - E_b(S)}{R_a + L_a S}$$

$$\Rightarrow I_a(S) = \frac{1/R_a}{1 + \frac{L_a}{R_a} S}(V_a(S) - E_b(S)) \quad \text{.......(9)}$$

From equation (5)

$$\omega(S) = \frac{T_m(S) - T_L}{J_m S} \quad \text{.......(10)}$$

From equation (7) and (8)

$$E_b(S) = K_a \phi \omega(S) \quad \text{......(11)}$$

and $T_m(S) = K_a \phi I_a(S)$ ......(12)

[for separately excited DC motor armature control operation, the flux ϕ is assumed constant]

Specifications of a DC motor for which the simulation is being done.

Armature resistance (Ra)	0.5Ω
Armature inductance (La)	0.02 H
Armature voltage (Va)	200 V
Mechanical inertia (Jm)	0.1 Kg.m^2
Rated speed	1500 rpm
Back emf constant (K_a ϕ)	1.25 V/rad/sec

Putting these values in eq. (9)

$$I_a(S) = \frac{2}{1+0.04S}(V_a(S) - E_b(S)) \quad ......(13)$$

Putting these values in eq. (10)

$$\omega(S) = \frac{1}{0.1S}(T_m(S) - T_L) \quad .....(14)$$

Putting these values in eq. (11) & (12)

$$E_b(S) = 1.25\omega(S) \quad ......(15)$$

$$T_m(S) = 1.25 I_a(S) \quad ......(16)$$

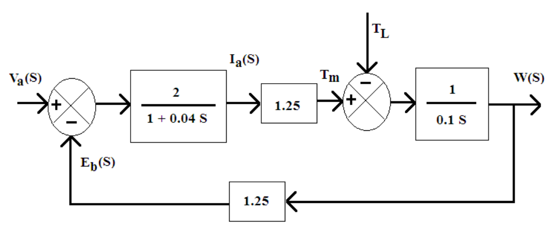

Fig.-2 Block diagram of a DC motor model

Matlab Simulation

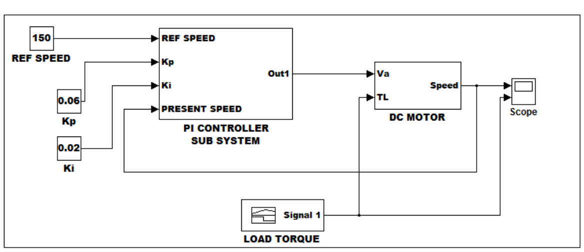

Fig.-3 Block diagram of MATLAB Simulation

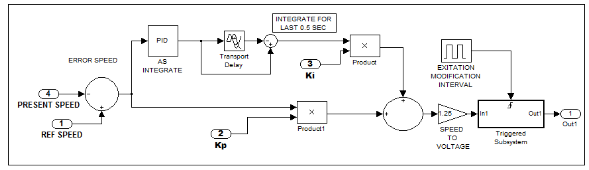

Fig.-4 Subsystem of PI Controller

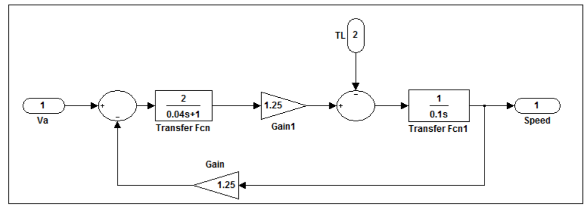

Fig.-5 Subsystem of DC motor

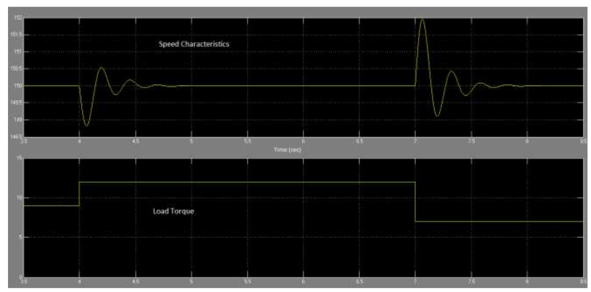

Fig.-6 Speed (rad/sec) Response shown in the upper graph with variation of Load torque(N-m) shown in lower graph

Simulation Parameters
Total simulation time = 8.5 sec Simulation sample time = 0.0001 sec
Sample taken to plot from 3.5 to 8.5 sec
Load Torque Variation 0 sec to 4 sec 9 N-m 4 sec to 7 sec 12 N-m (Load increases) 7 sec onward 7 N-m (Load decreases)
Reference speed 150 rad/sec
Kp=0.06 and Ki=0.02
Axis of speed in the graph ranges from 148.5 to 152 rad/sec, axis of Load torque ranges from 0 to 15 N-m.

Conclusion

Form the above response graph shown in fig-6 it is observed that load torque increases from 9 N-m to 12 N-m at time 4 sec and due the enhancement of the load, the speed of the motor is starting to decrease but within a fraction of second the controller starts controlling the situation. From the speed response graph it is clear that speed is being settled within 1 sec. That means the settling time is less than 1 sec. But to control the speed due to sudden change in load speed overshoot is observed and also the oscillation of the speed with respect to reference speed i.e. 150 rad/sec is found. After that at time 7 sec when load falls from 12 N-m to 7 N-m the similar nature of the responses is found. Due to decrease in load suddenly speed increases then controller controls. Here for small load torque variation the overshoot of the speed is quite low but in those cases where the load torque varies abruptly the PI controller may not give better response. In those cases PID or optimized PI may give better responses.

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