SPEED CONTROL OF DC MOTOR USING PID AND SMC CONTROLLER

Mr. S. M. Shirsath[1], Dr. B. J. Parvat[2], Ms. Pratibha Sahu[3]

[1] *Assistant Professor, Instrumentation and control Engineering, P.R.E.C. Loni, Ahmednagar, Maharashtra, India,*
[2] *Associate Professor, Instrumentation and control Engineering, P.R.E.C. Loni, Ahmednagar, Maharashtra, India,*
[3] *M.E.Student, Instrumentation and control Engineering, P.R.E.C. Loni, Ahmednagar, Maharashtra, India,*

Abstract

In this paper, PID and SMC controller is used to control speed of DC motor. Sliding mode control (SMC) technique is used to control the speed of DC motor, the performance of the SMC is judged via MATLAB simulations using linear model of the DC motor and known disturbance. SMC is then compared with PID controller. The simulation result shows that the sliding mode controller (SMC) is superior to PID for the speed control of Dc motor. Since the SMC is robust in presence of disturbances, the desired speed is perfectly tracked. The sliding mode control (SMC) can adapt itself to the parameter variations and external disturbances, problem of chattering parameter, resulting from discontinuous controller, is handled by sliding with smooth control action.

Keyword : - *DC motor, PID controller, Sliding Mode Controller(SMC), MATLAB Representation*

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1. INTRODUCTION

The purpose to control the motor speed is to overcome the problem in industry like to avoid machines damages, to avoid slow rise time and high overshoot. This is because when the starting voltage is high, it's not suitable for machine and it can make machine damages. So, a controller likes PID and other controller is developed to overcome this problem. Among all controllers, PID controllers have been widely used for speed control of dc motor. In the all techniques the speed is controlled through the controlling armature voltage, terminal voltage, armature current, and by controlling the current of dc motor. Proportional-Integral-Derivative(PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple and straightforward manner. The purpose of a speed controller is to drive speed. The proportional, integral and derivative controller has been most widely and popular used controller in the process industries due to its simplicity and robustness. Industrial processes are subjected to parameter variations and parameter perturbations. PID controllers are mostly used to regulate the time-domain behaviour of different types of dynamic plants. PID controllers provide good closed loop response characteristics. In control system, sliding mode control is nonlinear control that alters the dynamics behaviour of the system. This can be done by the application of a discontinuous control signal that forces the system to slide along a cross-section of the system's normal behaviour. The main strength of sliding mode control is its robustness. Control law is not a continuous function; sliding mode can be reached in time. Because of its more moderate control action, sliding mode control must be applied with more care. While designing PID and SMC controller for DC motor we have to taken care of some disturbances which may be occurred in the process. First PID controller can be used in the process then we have to apply same procedure for the SMC controller.
Later comparative analysis has been taken under consideration. From the result of simulation model we can discuss the various performances which are designed for the DC motor using PID and SMC controller.

2. MODELLING OF DC MOTOR

A separately excited dc motor has the simplest decoupled electromagnetic structure. A schematic diagram of the separately excited DC motor is shown in Fig.1. The armature controlled method for speed control of DC motor is considered here. The armature current is controlled to generate desired electromagnetic torque and the armature Voltage is controlled for the load. The field excitation is kept constant to produce rated flux. For a constant field excitation the armature circuit electrical equation of a separately excited DC motor is written as:

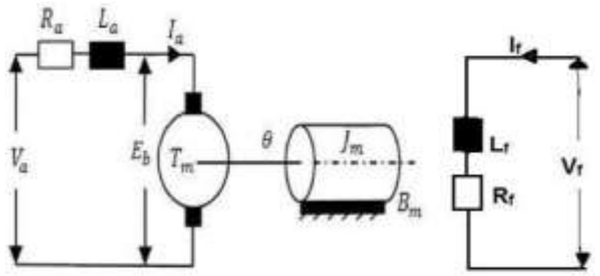


Figure 1: A Separately excited DC motor

$$L_a \frac{dI_a}{dt} + I_a R_a + E_b = E_a \quad (1)$$

where E_a is the Applied Voltage, R_a is the armature resistance, L_a is the Equivalent armature inductance, Ia is current flowing through armature circuit, E_b is the back emf and. The dynamics of the mechanical system is given by the torque balance equation :

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + T_l = T_m = K_t I_a \quad (2)$$

Where T_m is the developed torque, T_l is the load torque, J is the moment of inertia, B is the damping constant, and K_t =Torque constant. E_b represents electromotive force in V given by

$$E_b(t) = K_b\omega(t) \quad (3)$$

Where K_b is the back emf constant in Vs/rad. The input terminal voltage V_a is taken to be the controlling variable. One can write state model with the ω and I_a as state variables and V_a as manipulating variable, as given below

Let $x_1 = \theta$

$x_2 = \dot{x}_1 = \dot{\theta} = \omega$

$x_3 = I_a$

$$\dot{x} = \begin{bmatrix} \dot{\omega} \\ \dot{I_a} \end{bmatrix} = Ax+Bu = \begin{bmatrix} -\frac{b}{J} & \frac{k_t}{J} \\ -\frac{k_b}{L_a} & -\frac{R_a}{L_a} \end{bmatrix} \begin{bmatrix} x_2 \\ x_1 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u \quad (4)$$

Table-1 : Parameters of DC Motor

PARAMETER	SPECIFICATION	VALUE
R_a	Armature resistance	1.2Ω
L_a	Inductance of Armature winding	0.05H
J	Moment of inertia	0.135 Kgm^2/s^2
B	Frictional coefficient	0 Nms
K_t	Torque constant	0.06 Nm/A
K_b	Back emf constant	0.6V

$$\frac{w(s)}{V_a(s)} = \frac{\frac{K_m}{J}}{s^2 + \left(\frac{R}{L} + \frac{b}{J}\right)s + \left(\frac{Rb + K_e K_m}{JL}\right)} \quad (5)$$

Using the parameters given in table 1, transfer function of the DC motor with angular velocity as controlled variable and manipulating variable is determined as given below,

$$\frac{W(s)}{V_a(s)} = \frac{88.76}{s^2 + 24s + 53.25} \quad (6)$$

$$\frac{d^2w}{dt^2} + \left(\frac{R}{L} + \frac{b}{J}\right)\frac{dw}{dt} + \left(\frac{Rb+K_eK_m}{JL}\right)w = \frac{K_m}{JL}w \quad (7)$$

However, if the state variables consider $\overline{x_1}$ =w and $\overline{x_2}$=$\overline{\dot{x_1}}$ =w .The system described by equation (4) by equation (8) will be expressed, Where the only variable is the angular velocity and derivative

$$\dot{x} = \begin{bmatrix} 0 & 1 \\ A_1 & A_2 \end{bmatrix} \begin{matrix} x_1 \\ x_2 \end{matrix} + \begin{bmatrix} 0 \\ \frac{K_m}{JL} \end{bmatrix} (u) \quad (8)$$

$$A_1 = -\left(\frac{Rb+K_eK_m}{JL}\right) \quad (9)$$

$$A_2 = -\left(\frac{R}{L} + \frac{b}{J}\right) \quad (10)$$

3. PID CONTROLLER

PID controller has the optimum control dynamics including zero steady state error, fast response, no oscillations, and higher stability. PID controller is used to eliminate overshoot by using derivative control in addition to PI controller. One of main advantage of PID controller is that it can be used with higher order processes which include more than single energy storage. PID controller tuning seems easy in principle, but in practice it is very difficult problem. If the P-I-D parameters chosen wrong then control process might be unstable, with or without oscillations. For any system the output should be stable, and the process should not oscillate in any condition of set point or disturbances. Proportional, integral and derivative are the basic modes of PID controller. Proportional mode provides a rapid adjustment of the manipulating variable reduces error and speeds up dynamic response Integral mode achieves zero offset. Derivative mode provides rapid correction based on the rate of change of controlled variable. The controller transfer function is given by

$$C_{PID}(s) = K_p(1 + \frac{1}{T_S(s)} + T_d(s)) \quad (11)$$

where, Kp, Ts and Td are the proportional, integral and derivative constants of PID controller respectively. PID controller tuning algorithm is based on Ziegler-Nichols open loop method. And the preference is given to the load disturbance rejection.

4. DESIGN OF SLIDING MODE CONTROLLER

A linear system can be described in the state space as follows:

$$\dot{x} = Ax + Bu \quad (12)$$

Where, XϵR^n, Uϵ R, AϵR^{n*n}, BϵR^n is a full rank matrix where A and B are controllable matrixes and the functions of state variables are known as switching function

$$\sigma = Sx \quad (13)$$

The main idea in sliding mode control is

• Designing the switching function so that $\sigma = 0$ manifold (sliding mode) provide the desired dynamic.

• Finding a controller ensuring sliding mode of the system occurs in finite time First of all, the system should be converted to its regular form:

$$\bar{x}=\text{Tx} \quad (14)$$

where T is the matrix that brings the system to it regular form

$$\dot{\overline{x_1}} = \widehat{A_{11}}\widehat{x_1} + \widehat{A_{12}}\widehat{x_2}$$
$$\dot{\overline{x_2}} = \widehat{A_{21}}\widehat{x_1} + \widehat{A_{22}}\,\widehat{x_2} + \widehat{B_2}u \quad (15)$$

The switching function in regular form is:

$$\sigma = \overline{s_1}\overline{x_1} + \overline{s_2}\overline{x_2} \quad (16)$$

On the sliding mode manifold($\sigma = 0$)

$$\overline{x_2} = -\bar{s_2}^{-1}\bar{s_1}\overline{x_1} \quad (17)$$

From (17) & (15)

$$\dot{\overline{x_1}} = (\overline{A_{11}}\overline{x_1} - \overline{A_{12}}\bar{s_2}^{-1}\bar{s_1}\overline{x_1}) \quad (18)$$

One of matrixes in product: $\bar{s_2}^{-1}\bar{s_1}$ should be chosen arbitrary. Usually (19) is used to ensure that s2 is invertible

$$\bar{s_2} = B_2^{-1} \quad (19)$$

Can be calculated by assigning the Eigen value of (18) by pole placement method. Hence, switching function will be obtained as follows:

$$S=[\bar{s}_1 \quad \bar{s_2}]^T \quad (20)$$

The control rule is :

$$U=u_c+u_d \quad (21)$$

Where, u_c and u_d are continuous and discrete parts, respectively and can be calculated as follows:

$$u_c = -\widetilde{A_{21}}\overline{x_1} - \widetilde{A_{22}}\sigma \quad (22)$$

$$u_d=-k_s sign(\sigma) - k_p\,(\sigma) \quad (23)$$

Where sign is sign function, and are constants calculated regarding to lyapunov stability function. We are going to set the angular velocity over a certain value r, so switching function is

$$\sigma = s_1(x_1 - r) + s_2x_2 \quad (24)$$

If the controller switching function is designed to be placed on the surface σ =0 then Solving equations (24) assume σ =0 w and $\dot{w}$ and are obtained by

$$w = r(1 - e^{\left(\frac{s_1}{s_2}\right)t}) \quad (25)$$

$$\dot{w} = r\left(\frac{s_1}{s_2}\right)e^{\left(\frac{s_1}{s_2}\right)t} \quad (26)$$

As equation (8) it is regular form, so the transformation matrix is equal to the unit matrix Factor s_2 according to equation (19) must be calculated

$$s_2 = \frac{JL}{K_m} \quad (27)$$

Also according to (12-19) 1 s calculated and w Pole placement method using (12-21). Suppose we have to placed system poles λ in so we have

$$\frac{s_1}{s_2} = -\lambda \quad (28)$$

$$\sigma = \frac{JL}{K_m}(-\lambda(w - r) + \dot{w}) \quad (29)$$

A.CONTROLLER DESIGN

If the equation (8) can be rewritten based on the state variables and $X_1=(x_1-r)$ the following is reached

$$\begin{bmatrix}\dot{x}_1\\ \dot{\sigma}\end{bmatrix}=\begin{bmatrix}\widetilde{A_{11}} & \widetilde{A_{12}}\\ \widetilde{A_{21}} & \widetilde{A_{22}}\end{bmatrix}\begin{bmatrix}x_1\\ \sigma\end{bmatrix}+\begin{bmatrix}0\\ 1\end{bmatrix}u_n \quad (30)$$

$$\widetilde{A_{11}}=-\frac{s_1}{s_2}=-\lambda$$

$$\widetilde{A_{12}}=\frac{1}{s_2}$$

$$\widetilde{A_{21}}=A_1 s_1-A_2 S_1-\frac{{s_1}^2}{s_2}=(s_2(A_1+A_2\lambda-\lambda^2)$$

$$\widetilde{A_{22}}=A_2+\frac{s_1}{s_2}$$

$$u_n = {s_2}^{-1}u + A_1 r \quad (31)$$

Thus the relations (21), (22) and (23) controller for the system (30) is designed as follows

$$u_n=-\widetilde{A_{21}}X_1-\widetilde{A_{22}}\sigma-k_s sign(\sigma)-k_p(\sigma) \quad (32)$$

The below equation sets armature voltage feedback based on the derivative of the angular velocity for motor.

$$u=s_2[A_1 r+s_2(A_1+A_2\lambda-\lambda^2)(w-r)+(A_2-\lambda)\sigma+k_s sgn(\sigma)+k_p(\sigma) \quad (33)$$

So the sliding mode controller is

$$u=\frac{JL}{K_m}\left(\frac{Rb+K_eK_m}{JL}\right)w+\frac{JL}{K_m}\left(\frac{Rb+K_eK_m}{JL}\right)+\lambda\left(\frac{R}{L}+\frac{b}{J}\right)+\lambda^2\left(\frac{R}{L}+\frac{b}{J}\right)+\left(\frac{Rb+K_eK_m}{JL}\right)(w-r)+\left(\frac{R}{L}+\frac{b}{J}\right)\lambda-K_s sgn(\sigma)-K_p(\sigma) \quad (34)$$

Switching function of sliding mode controller for DC motor control method according to the relations (34) and (33) are designed .If the motor parameters like table (1),then the controller we will numerically designed as follows

$$\sigma=-1.2(w-r)+0.0112\dot{w} \quad (35)$$

After solving the controller u is given by

U = 0.0112(53.24)w+ 0.0112(53.24)(w-r)-124(σ)-sgn(s) (36)

Where $\boldsymbol{\lambda}$, K_s and K_p parameters are -100, 1, and 0 respectively.

5. RESULTS AND OUTPUTS

The DC motor, a PID controller is attached and the corresponding simulink model and its output for the same reference input of 1000rpm is given below

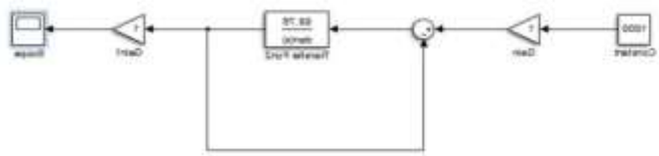
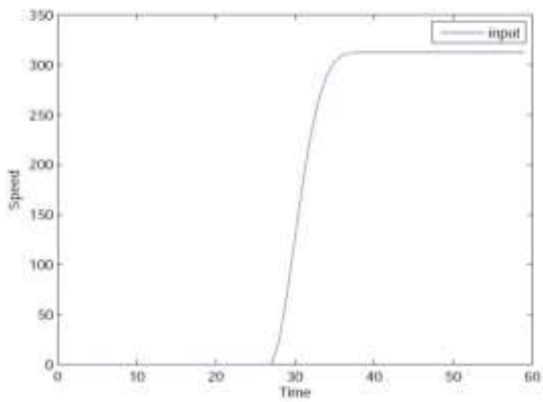


Figure-1.Simulink model of DC motor



Speed vs Time

Figure-2 : Speed response of DC motor

The DC motor, attached and the corresponding Simulink model and its output for the same reference input of 1000rpm is given below

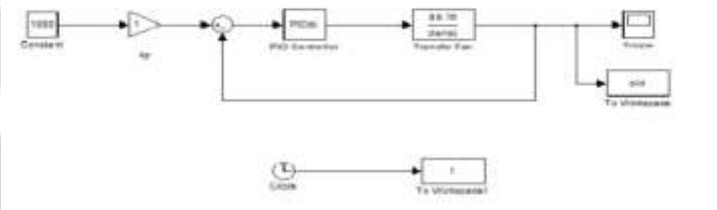
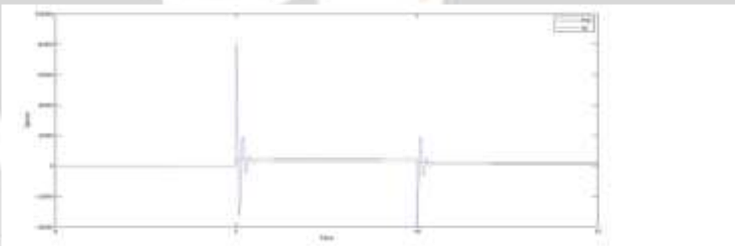


Figure-3 : Simulink model of DC motor with PID

The DC motor, a PID controller is attached and the corresponding Simulink model and its output for the same reference input of 1000rpm is given below



Speed vsTime

Figure-4: Speed response of DC motor with PID controller

The DC motor, a SMC controller is attached and the corresponding Simulink model and its output for the same reference input of 1000rpm is given below

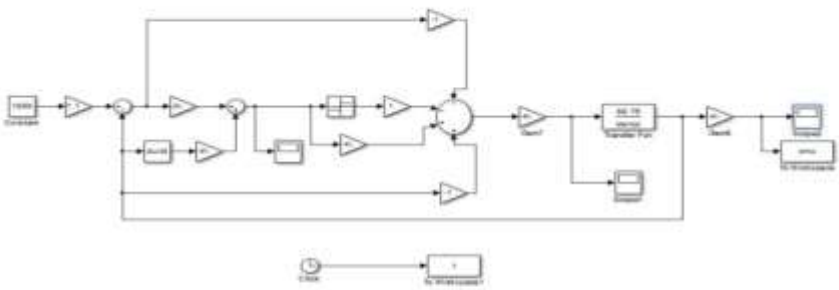
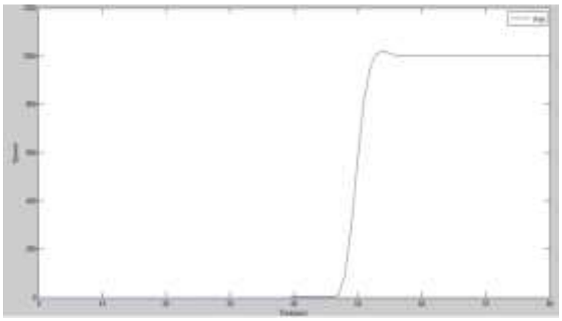


Figure-5: Simulink model of DC motor with SMC controller



Speed vs Time

Figure- 6: Speed response of DC motor with SMC

Comparing the PID, SMC, SMC with PID is attached to DC motor with reference speed of 1000 rpm. The outputs are compared with the settling time.

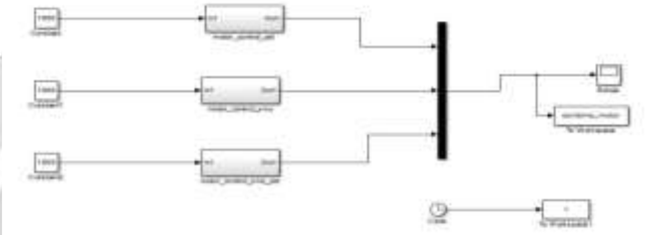
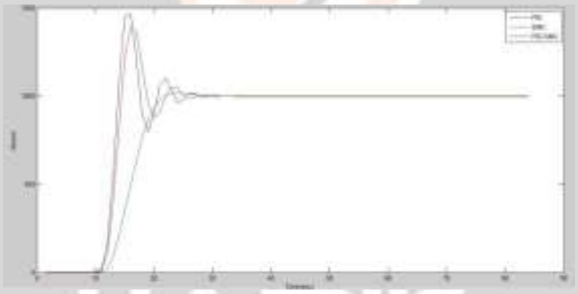


Fig-7: Simulink Model of DC motor combined with PID, SMC, SMC with PID



Speed Vs Time

Fig-8: Speed response of DC motor is done with using PID controller and SMC controller

6. CONCLUSION

Accurate performance of the motor is desired feature for any industrial application. For better performance we have to check the motor performance time to time. The conventional method for calculating output performance are little time consuming. Firstly for controlling speed of DC motor simplified using closed loop system. Then it is used PID controller to control the speed of motor. Sliding mode controller then designed to control the speed of motor. The PID approach algorithm worked satisfactory for the system. The output performance obtained by normalized value in PID is near to accuracy. MATLAB used for simulation purpose of entire project and it is user friendly. As sliding mode control is based on dynamic characteristics, it also took a lack of influence of external disturbances.

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