A NOVEL SPEED CONTROL OF DC MOTOR USING SLIDING MODE TECHNIQUE

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Abstract
Direct Current (DC) motors have been used extensively in industry mainly because of the simple strategies required to achieve good performance in speed or position Control applications. Due to the robustness of Sliding Mode Control (SMC), especially against parameters variations and external disturbances, and also its ability in controlling linear and nonlinear systems. This paper deals with the sliding mode control adjustment of a speed control for DC motor. Firstly, the paper introduces the principle of sliding mode control method. Then, design a controller for DC motor after that the comparison between PID and SMC is made on the real model of the DC motor . The main result of the paper is the analysis the terminal sliding mode control. After obtaining the entire model of speed control system, Performance of these controllers has been verified through simulation results using MATLAB/SIMULINK software. The simulation results showed that SMC was a superior controller than PID controller for speed control of a separately excited DC motor.

1. INTRODUCTION

DC motors are widely used in robotic and industrial equipment where high accuracy is needed. In some cases the uncertain conditions encounter the DC motor control to some difficulties. Hence, DC motor control has been stimulated a great deal of interest from several decades ago up to now [1] DC motors are identified as adjustable speed machines for many years and a wide range of options have evolved for this purpose. D.C motor is considered as a SISO (Single Input and Single Output) system which has speed characteristics and is compatible with most mechanical loads. By proper adjustment of the terminal voltage [3] the mentioned characteristic makes a D.C motor controllable over a wide range of speeds. In this article speed of DC motor control by using sliding mode controller.

2. SLIDING MODE CONTROL

Sliding mode control concepts have subsequently been utilized in the design of robust regulators, tracking system, state observers, model reference systems and fault detection schemes. The ideas have successfully been applied to problems as diverse as control of electric motors, aircraft and space craft flight, control of flexible structure, robot manipulators, and chemical processes. In general, the phase trajectory of a sliding modecontrol can be investigated in two parts, representing two modes of the system as shown in Figure 2.

- The first part, the trajectory starting from anywhere on the phase plane moves toward sliding surface and reaches the surface in finite time. This is known as reaching, hitting, or non-sliding phase and the system is sensitive to parameter variations and disturbance rejection in this part of the phase trajectory.
- The second part is the sliding phase in which the state trajectory moves to the origin along the sliding surface and the states never leave the sliding surface. During this period, the system is defined by the equation of the sliding surface and thus it is independent of the

system parameters and external disturbances.

In general, the sliding mode controller design approach usually consists of two steps. First, the sliding or switching surface(s) is designed such that the system motion in sliding mode satisfies design specifications. Second, a control law is designed making the switching surface attractive to the system state. Sliding surface can be either linear or nonlinear. For simplicity, only a linear sliding surface is used in this paper below figure (2) shows state trajectory in sliding motion.

In the figure (1) the upper arrow indicates the state trajectory and the lower arrow i.e. trajectory on dotted line is sliding surface.

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

$\dot{x}$ = Ax+Bu (1)

Where x∈ R^n , u ∈R, A∈R^{n*n},and$B$∈R^n and B is full rank matrix. A and B are controllable matrixes. The functions of state variables are known as switching function:σ=sx (2)

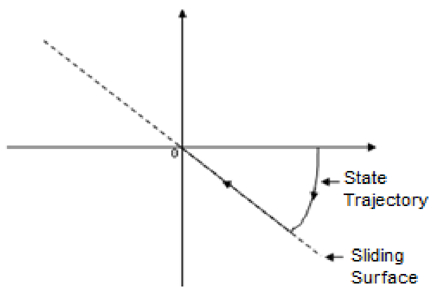

Figure 1: Phase portrait of a sliding motion.

The main idea in sliding mode control are[1]:

- 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:

$\bar{x}$ = Tx (3)

T is the matrix that brings the system to its regular form

$\dot{\overline{x_1}}$=$\overline{A_{11}}\overline{x_1}$+$\overline{A_{12}}\overline{x_2}$ (4)

$\dot{\overline{x_2}}$=$\overline{A_{21}}\overline{x_1}$+$\overline{A_{22}}\overline{x_2}$ + $\overline{B_2}u$ (5)

The switching function in regular form is:
$\sigma = s_1\,\overline{x_1}$+$s_2\,\overline{x_2}$

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

0=$s_1\,\overline{x_1}$+$s_2\,\overline{x_2}$

$\overline{x_2}$= -$s_2{}^{-1}s_1\,\overline{x_1}$(6)

From(6)&(4)

$\dot{\overline{x_1}}$=$\overline{A_{11}}\overline{x_1}$ - $\overline{A_{12}}s_2{}^{-1}s_1\,\overline{x_1}$

$\dot{\overline{x_1}}$= ($\overline{A_{11}}$-$\overline{A_{12}}s_2{}^{-1}s_1$)$\overline{x_1}$(7)

One of matrixes in product:$s_2{}^{-1}s_1$ should be chosen arbitrary. Usually (8) is used to ensure that s_2 is invertible:
s_2 =$B_2{}^{-1}$(8)

s_1 can be calculated by assigning the Eigen value of (7) by pole placement method. Hence, switching function will be obtained as follows:

S=[s_1 s_2]T (9)
The control rule is:
$u = u_c$+u_d(10)

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

u_c = - $\widetilde{A}_{21}$ x_1 - $\widetilde{A}_{22}\,\sigma$(11)

u_d = -$K_s$sgn σ - $K_p\sigma$(12)

Where sgn is sign function.K_s , and $K_p$are constants calculated regarding to lyapunov stability function.

3 Modelling of Dc motor:

The state space model of DC motor is as follows.

$$\dot{x} = \mathrm{Ax+Bu} = \begin{bmatrix} -\frac{b}{J} & \frac{k_m}{J} \\ -\frac{k_e}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u (13)$$

In this equation x is two dimensional vector
$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$
Where

x_1= angular velocity of shaft.

x_2= armature current.

$u$is the armature voltage.

R= resistance of armature coil.

L= inductance of the armature coil.

k_e= velocity constant.

k_m= torque constant.

J= moment of inertia.

b is viscous friction coefficient.

By using the Laplace transform of (13), the transfer functions of system according to angular speed of shaft (ω (s)) and armature voltage (U(s)) can be calculated:

$$\frac{\bar{\omega}(s)}{U(s)}=\frac{\frac{k_m}{JL}}{\left[s^2+\left(\left(\frac{b}{J}\right)+\left(\frac{R}{L}\right)\right)s+\frac{(Rb+k_e k_m)}{JL}\right]}(15)$$

$$\frac{d^2\omega}{dt^2}+\left(\left(\frac{b}{J}\right)+\left(\frac{R}{L}\right)\right)\frac{d\omega}{dt}+\frac{(Rb+k_e k_m)}{JL}\omega=\frac{k_m}{JL}u(16)$$

However, if the state variables consider$\overline{x_1}=\omega and$ $\overline{x_2}=\dot{\overline{x_1}}=\dot{\omega}$.The system described by equation (14) by equation (17) will be expressed, Where the only variable is the angular velocity and derivative.

$$\begin{bmatrix}\dot{\overline{x_1}}\\ \dot{\overline{x_2}}\end{bmatrix}=\begin{bmatrix}0 & 1\\ A_1 & A_2\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}0\\ \frac{k_m}{JL}\end{bmatrix}u(17)$$

Where

$$A_1=-\left(\frac{(Rb+k_e k_m)}{JL}\right)(18)$$

$$A_2=-\left(\left(\frac{b}{J}\right)+\left(\frac{R}{L}\right)\right)(19)$$

Design of the switching function:

We are going to set the angular velocity over a certain value r, so switching function is

$$\sigma=s_1\,\overline{(x_1}\text{-r})+s_2\,\overline{x_2}(20)$$

If the controller switching function is designed to be placed on the surface $\sigma=0$then Solving equations (20) assume $\sigma=0$, $\omega$and$\dot{\omega}$are obtained by

$$\omega=\text{r-}e^{-\frac{s_1}{s_2}t}(21)$$

$$\dot{\omega}=\frac{s_1}{s_2}e^{-\frac{s_1}{s_2}t}(22)$$

As equation (17) it is regular form, so the transformation matrix is equal to the unit matrix Factor s_2 according to equation (8) must be calculated

$$s_2=B_2^{-1}$$

This gives

$$s_2=\frac{JL}{k_m}(23)$$

Also according to (1-8) 1 s calculated and w Pole placement method using (1-10) .Suppose we have to placed system poles inλso we have

$$\frac{s_1}{s_2}=-\lambda(24)$$

As (21), (22) and (24) shown □determines the speed of convergence of the system output So it is better to choose a small negative value Thus, the switching function was designed as follows

$$\sigma=\frac{JL}{k_m}(-\lambda(\omega-r))+\dot{\omega}) \qquad (25)$$

B. Controller design:

If the equation (17) can be rewritten based on the state variables σ and $X_1=\overline{(x_1}$-r) The following is reached

$$\begin{bmatrix}\dot{X_1}\\ \dot{\sigma}\end{bmatrix}=\begin{bmatrix}\tilde{A}_{11} & \tilde{A}_{12}\\ \tilde{A}_{21} & \tilde{A}_{22}\end{bmatrix}\begin{bmatrix}X_1\\ \sigma\end{bmatrix}+\begin{bmatrix}0\\ 1\end{bmatrix}u_n(26)$$

That (26) has the following parameters and variables.

$$\tilde{A}_{11}=\lambda=-\frac{s_1}{s_2}(27)$$

$$\tilde{A}_{12}=\frac{1}{s_2}(28)$$

$$\tilde{A}_{21}=A_1+A_2\lambda-\lambda^2(29)$$

$$\tilde{A}_{22}=A_2-\lambda(30)$$

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

Thus the relations (10), (11) and (12) controller for the system (26) is designed as follows.

u_n=- $\tilde{A}_{21}X_1$-$\tilde{A}_{22}$σ -$k_s$sgn(σ)-k_pσ (32)

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

U=-s_2 [A_1r+s_2 (A_1+$A_2\lambda$ - λ^2) (ω-r)+(A_2-λ)σ +$k_s$sgn(σ)+k_pσ(33)

Put A_1r=$A_1\omega$- A_1 (ω-r) in eqn (33) we have

U=-$s_2\{[A_1\ \omega + [s_2\ (A_1 + A_2\lambda\ -\ \lambda^2) -$ $A1\omega$−r+$(A2-\ \lambda+kp)$σ+ kssgn(σ)(34)

So the sliding mode controller is

U= $\frac{JL}{k_m}\left\{\left(\frac{(Rb+k_e k_m)}{JL}\right)\ \omega +\right.$ $[JLkm(Rb+kekm)JL+bJ+RL\lambda+\lambda2-(Rb+kekm)JL]\omega$−r+($bJ+RL+\lambda-kp$)σ−$ks$sgn(σ)(35)

C. Switching function and controller design for a real motor

Switching function of sliding mode controller for DC motor control method according to the relations (35) and (33) are designed.If the motor parameters like table (1),then the controller we will numerically designed as follows

σ =.0924*10^{-4}(ω-r) +.0924*$10^{-6}\dot{\omega}$ (36)

U= (.0924*10^{-6})(3675896.1 ω − 3675895.1(ω − r))+7491.256 σ - $sgn(\sigma)$(37)

Figure 1 scheme of the controller equation (36) shows

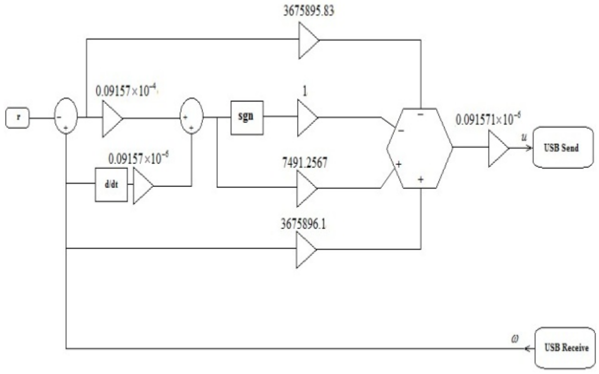

Figure 1: DC motor controller parameters (Table1) sliding mode control method.

MATLAB simulation results:

To evaluate the performance of the sliding mode control (SMC), it is compared with PID controller. A maxon motor is used in all experiments. The parameters of this motor is shown in table1

Parameter	Value
R	7.17 Ω
L	0.953*$10^{-3}H$
k_e	0.29Vs
k_m	46*10^{-3} NmA^{-1}
J	4.46*10^{-6} Kgm^2
B	2.99*10^{-4} Nms
λ	-100
k_s	1
k_p	0

The matlab model and response of the real plant is given below

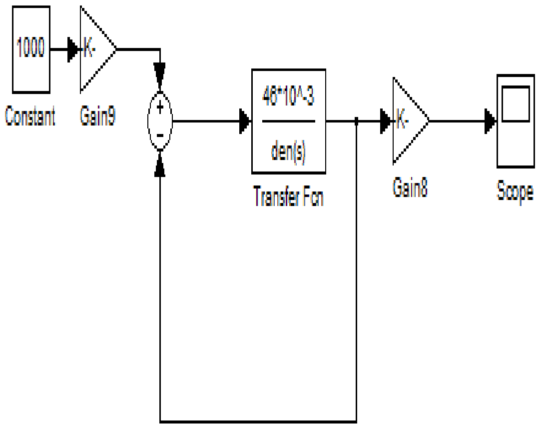

Figure2.simulink model of real pant.

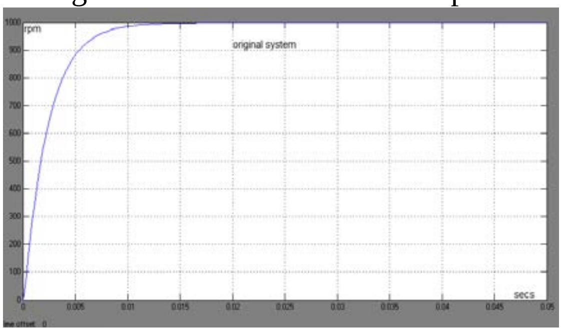

Figure5.response of original plant

Block diagram of the sliding mode controller implemented with the relations (36) and (37) in the matlab SIMULINK (figure6) is displayed below

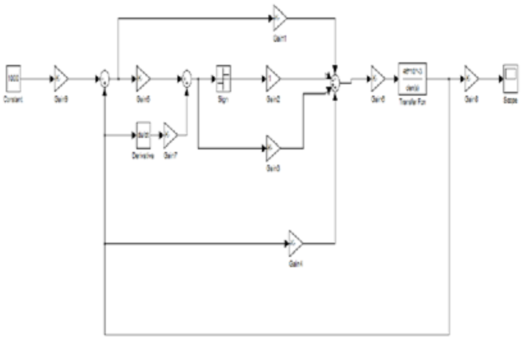

Figure6.dcmoter model sliding
mode controller is implemented in simulink.

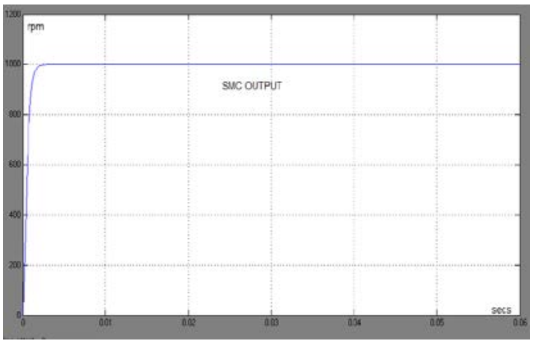

Figure7: the output scope of smc

Figure.8 below shows the block diagram of PID controller for the same motor in simulink mat lab model and its output displayed below Figure8.

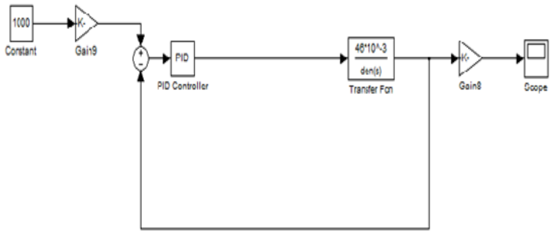

Figure8. Block diagram of PID controller

In simulink mat lab model.

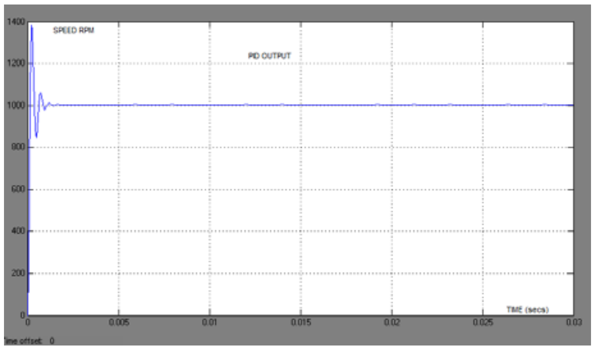

Figure9: PID output

Figure (10) & figure(11) shows comparison between SMC and PID along with original system Simulink model and its output is given

Controller	Under Shoot(%)	Peak Overshoot (%)	Steady state error	Settling time in millisecs
PID	18	39	0	3.6
SMC	0	0	0	9.6
PD	22	45	0	5.2

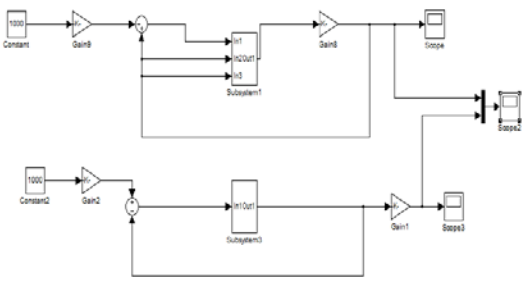

Figure10.combined smc&pid block diagram

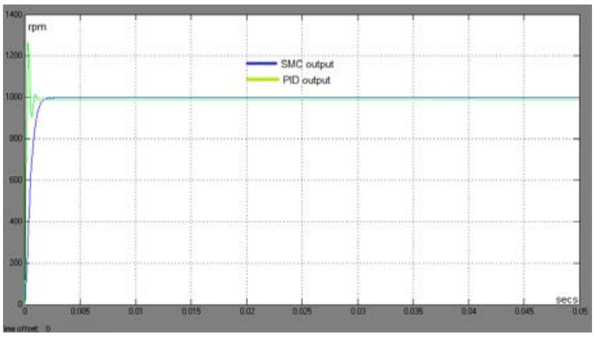

Figure7.smc&pid output

Now another Comparison is made original system along with sliding mode controller,pid and pd controllers corresponding simulink model and its output are given below

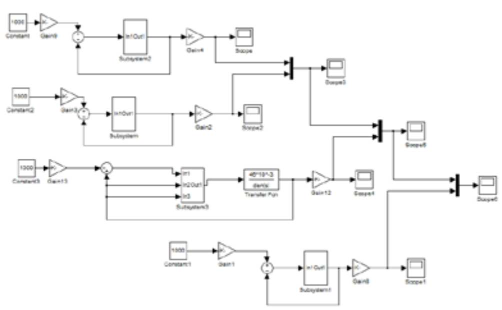

Figure12.original system along with sliding mode controller, pid and pd controllers corresponding simulink model

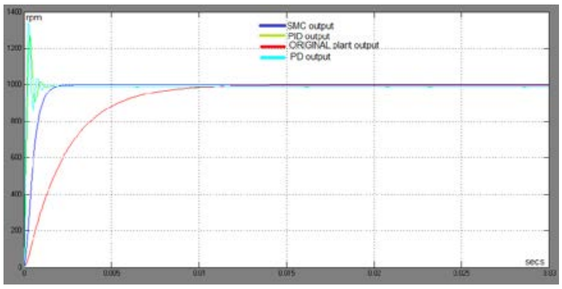

Figure13 output scope of figure12

From above figure following observations are made regarding its characteristics given below

CONCLUSION

In this paper sliding mode control (SMC)Proposed to speed control of DC motor. At first for controlling speed of DC motor a simplified closed loop is utilized. Then DC motor is modelled after that speed controller is designed. As sliding modecontrol is based on the system Dynamic characteristics also it took a lack of influence of external disturbances from user as result it worked more useful and results confirms that used sliding mode control for speed control ismore efficient in comparison with PID and PD controller.

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