SLIDING MODE CONTROLLER DESIGN FOR CONTROLLING THE SPEED OF A DC MOTOR

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ABSTRACT: **The objective of this paper is to control the speed of a DC motor efficiently by using SMC. Model of a separately excited DC motor has been choose. First PID controller is used for the speed control of the motor (both linear and non-linear model) and then SMC is used for the same non-linear model. The modeling and simulation has been done in MATLAB. The observations shows that SMC gives better results as compared to PID. While PID is not capable to give the desired result satisfactorily in case of non-linear systems, SMC has robust nature in presence of such disturbances.**

KEY WORDS: **Sliding mode controller, chattering, non-linearity in dc motor, modeling of dc motor.**

I. INTRODUCTION

DC motors have been widely used in industrial, agricultural and domestic sectors with various applications. Different fields require different speed ranges of the motors with different ranges of load changes. Usually where a higher speed of dc motor is required, the non – linear factors of the motor are neglected since these factors do not affect much. Also, in such cases, conventional controllers such as PI (Proportional-Integral) controller and PID (Proportional-Integral-Derivative) controller are effective.

When we come across non-linear systems the above controllers are likely to fail, they do not provide the desired output in desired time. For this reason, some better approach has to be taken. In this paper, SMC (Sliding Mode Controller) is that approach, a controller which has ability to work satisfactorily under linear as well as non-linear factors of the system.

This paper has taken two types of non-linearities that are present in a DC motor. One of them is friction that occurs in the motor itself and the other non-linear factor is backlash. Backlash is generated at the gear box which is driven by the motor.

When the motor is required at low speed level such as in chemical processing application in industries, the non-linear factors do affect the output of the system that can not be eliminated by the conventional controllers in real time. SMC is designed for avoiding such uncertainties. It has many advantages over PID controller. Some of them are robustness, disturbance rejection and independent of he system parameters. The results shown in the paper proves that SMC is much better than PID for the speed control of a DC motor especially when the non-linear model of the motor is considered

II. SLIDING MODE CONTROL (SMC)

Sliding mode controller works by switching the trajectory of the system from one structure to other and in between sliding on a specific line, plane or surface in state space. The motion of the system trajectory along a chosen path in state space is called the sliding mode and the controller designed with the aim to achieve the slid- ing motion is called sliding mode controller. The path such chosen is called the sliding surface or switching surface.

While choosing the sliding surface, there are some requirements that has to be taken care of. The system stability has to be confined to the sliding (switching) surface. Also, the system trajectory should converge to the sliding surface within finite time

REQUIREMENT I.

System stability: Consider the following system dynamics

$\dot{x}_1 = A_{11} x_1 + A_{12} x_2$ -1

$\dot{x}_2 = A_{21} x_1 + A_{22} x_2 + Bu$ -2

Let the sliding function chosen be :

$s = Cx_1 + x_2 = 0$ -3

Equation 1 can be rewritten as:

$\dot{x}_1 = A_{11} x_1 - A_{12} Cx_1 = (A_{11} - A_{12}C)x_1$ -4

Taking $C > 0$ such that the solution of equation 4 lies to the left hand side of the phase plane, the dynam- ics of x_1 can be made stable at the sliding surface. From equation 3 the dynamics of x2 already becomes stable at the sliding surface. Thus this sliding surface validates the first requirement.

REQUIREMENT II.

Convergence to s = 0 : For this requirement to be ful- filled, the **reachability condition** has to satisfied which states that in order to make sure that sliding mode starts at some time $t > 0$, irrespective of the initial state x(0), we should be sure that the state trajectory is always moving towards $s = 0$, for $s \neq 0$.

$d(s^2)/dt < 0$ -5

As the state trajectory comes closer to the sliding surface, the rate of convergence becomes slow. So along with reachability condition, there is one more condition called **η condition** that ensures the conver- gence of the trajectory towards s = 0 within finite time as the trajectory approaches towards the same. For the example taken above, its η condition can be written as:

$d(s^2)/dt < -\eta|s|$ -6

When the state trajectory changes its structure from one path to other ie; as it is on the verge to slide on the sliding surface, due to the stronger condition been applied to it, the transition from one structure of the path to the other is not smooth. In fact it forms a zig -zag path along the sliding surface. This happens due to the practical limitations of the devices used for the measurements. Such an undesirable phenomenon is known as chattering.

Chattering occurs due to the presence of the sig- num function used in the controller. Hence, to avoid or reduce chattering, signum function has to be replaced by some smoother functions may be tangent function or saturation function. Many types of functions have been used in different papers for reducing the chattering ear- lier and many are still working on it.

-2 -1 $\dot{x}_2 = A_{21} x_1 + A_{22} x_2 + Bu$ -2

-3

III. DC MOTOR (LINEAR MODEL)

DC motors have a wide area of application in all sorts of sectors, be it industrial, agricultural or domes- tic. Moreover, they have been used in scientific re- search and technology works too. The electric circuit of the DC motor is shown in Fig. 1. Objective here will be controlling the speed of the motor through arma- ture voltage.

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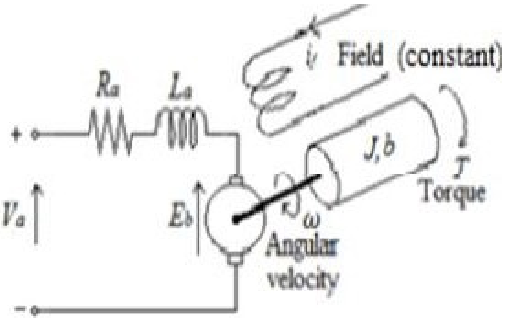

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Figure 1. Electric circuit of DC motor

The parameters shown in figure 1. are given below:

V_a : armature voltage (input to the motor)

R_a : armature resistance

L_a : armature inductance

E_b : back emf

ω : angular velocity (output of the motor)

i_f : field current
J : moment of inertia
b : constant of moment of inertia
T : torque produced

The motor rotates with a constant speed which is gained by balancing the load torque and the torque produced by the motor. The motor is excited by the field current with input as armature voltage applied at the terminals. This induces a voltage in the motor known as back emf. The output speed of the motor rotates the shaft attached to it which is actually the load.

The equations that govern the working of the motor are written as:

Torque in terms of shaft parameters:

$$T = J(d\omega/dt) + B\omega \qquad -7$$

Torque produced by armature current:

$$T = K_t\, i_a \qquad -8$$

Now applying KVL in the circuit shown in figure 1., we get:

$$V_a - E_b = R_a i_a + L_a(di_a/dt) \qquad -9$$

$$(di_a/dt) = V_a/L_a - E_b/L_a - (R_a/L_a)\, i_a \qquad -10$$

$$\text{Where ,} \quad E_b = K_b\, \omega \qquad -11$$

$$\text{And ,}(d\omega/dt) = -(b/J)\omega + (K_t/J)\, i_a \qquad -12$$

With ω and i_a as state variables, V_a as the input, the state model of the motor can be represented by equations 10 and 12. Finally by putting the values in equations 11 and 12, the system model becomes:

$$(d\omega/dt) = -\omega + 47.9041916\, i_a \qquad -13$$

$$(di_a/dt) = -66.66667\omega - 50i_a + 83.3333V_a \qquad -14$$

Equations 13 and 14 are obtained by using the following values:

$R_a = 0.6\Omega$ $\quad$ $L_a = 0.012H$
$K_t = 0.8Nm/A$ $\quad$ $K_b = 0.8Vs/rad$
$J = 0.0167Kgm^2/s^2$ $\quad$ $b = 0.0167$

Simulink model of DC motor (linear) is shown in figure 2. below.

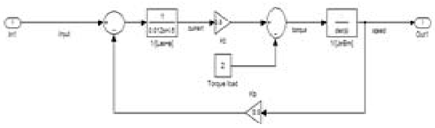

Figure 2. Simulink model of DC motor (linear)

IV . DCMOTOR(NON-LINEARMODEL)

Two non-linearities considered in this paper are friction and backlash. Friction has three components namely static friction, coulomb friction and viscous friction. Whenever two surfaces are in contact they are having some static friction which one surface has to overcome so as to move. Static friction is also called stiction. As the surface of one object starts to move it glides over the other object with some velocity and in a direction. Opposite to this velocity and direction, coulomb force is always present which is independent of the magnitude of the velocity. It depends on the nature (properties) of the two surfaces in contact. The static friction is greater than the coulomb friction. The friction proportional to the velocity is viscous friction. It has the same direction as that of the moving object ie; the velocity. Below is a figure describing the relationship between the three components of the friction and the velocity.

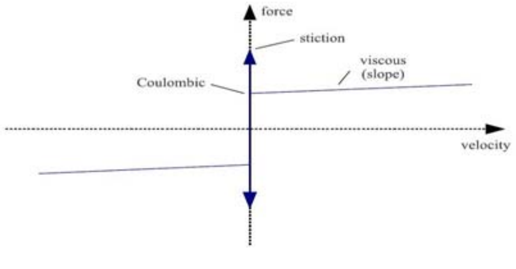

Figure 3. Friction - velocity plot

Backlash occurs in every mechanical system that has some movement. It is like hysteresis (that occurs in electric systems), but in mechanical systems. When the motor drives the shaft, it rotates with certain speed and the gear box attached produces backlash. The plot of input angle (driving motor angle output) vs output angle (driven shaft angular position) is shown below in figure 4.

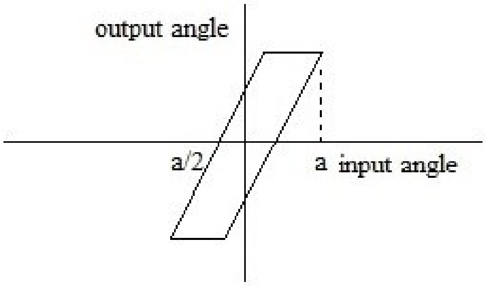

Figure 4. Backlash in gear box

Here 'a' is the perpendicular distance between the teeth of the motor driving the shaft and the shaft been driven (as an example).

The Simulink model of DC motor is taking into consideration the friction and backlash non-linearities, is shown in figure 5. Below

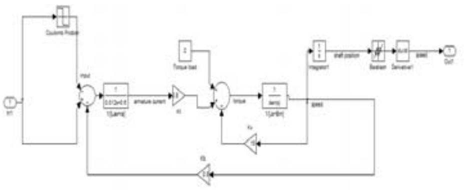

Figure 5. Simulink model of DC motor (non-linear)

V. CONTROLDESIGN

Take $x_1 = \omega(t)$; $x_2 = x_1$; $u = V_a$

The system then becomes:

$\dot{x}_1 = x_2$ -15

$\dot{x}_2 = -51.39\, x_1 - 51\, x_2 + 3992.015\, u$ - 16 $y = x_1$

-17

Selecting the sliding surface as:

$$s = Ce + x_2 = 0 \qquad -18$$

where C is negative and

e = reference speed - actual speed e = $r - x_1$

The controller 'u' is defined as:

$$u = \begin{cases} K, & s < 0 \\ -K, & s > 0 \end{cases} \qquad -19$$

where K should be a positive value. In the simulation given below, $K = |C|$.

VI. SIMULATION RESULTS

First comparison between the output of PID controller for DC motor linear and non - linear model has been done. Then the results of PID and SMC for non - linear DC motor model are compared

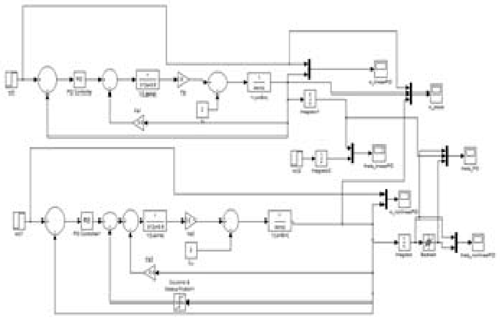

Figure 6. Modeling of PID controller for DC motor speed

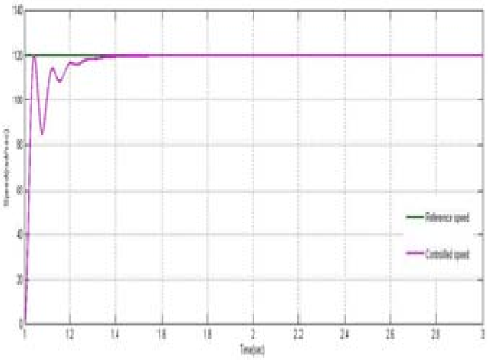

Figure 7. Speed control of linear DC motor model using PID controller

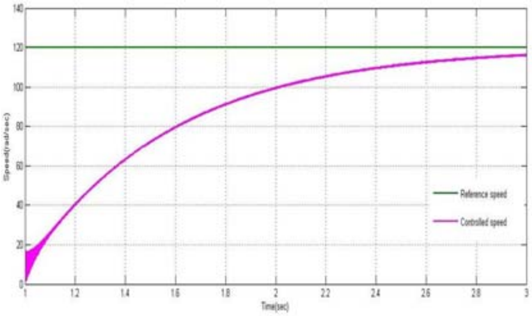

Figure 8. Speed control of non-linear DC motor model using PID controller

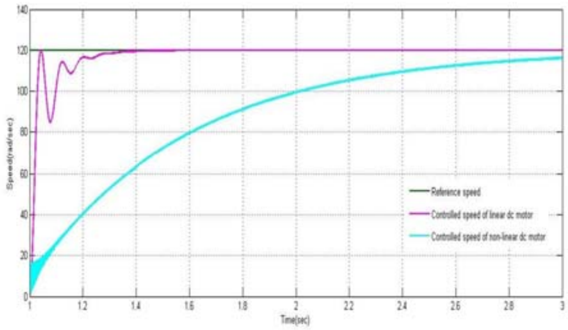

Figure 9. Speed control of DC motor using PID controller

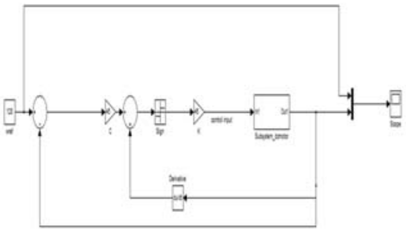

Figure 10. Modeling of SMC for DC motor speed

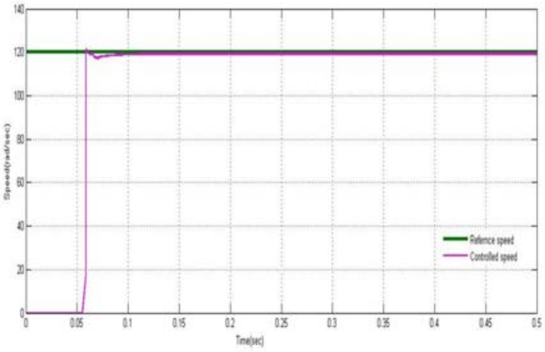

Figure 11. Speed control of DC model (non-linear) using SMC

VII. CO NCLUSI O NS

In this paper conventional controller PID and a different approach SMC have been applied for speed control of DC motor. As far as linear model of the motor is concerned, PID is capable to control the speed within desirable time and er- rors under limitations. But when it comes to con- trol the speed under the presence of non- linearities, SMC is far better than PID. However, results of PID controller can be improved by changing the gains of P, I, D terms but SMC proves to be efficient than PID controller, be it in terms of peak overshoot or the settling time

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