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Speed control of DC motor using sliding mode control approach

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Abstract: *This paper presents the sliding mode controller design to regulate the speed control of the direct-current(DC) motor. In this, the sliding surfaces used to derive the different control schemes presented in this work are based on an integral differential equation acting on the tracking-error expression. A new approach for the design of sliding mode controllers based on first-order-plus-dead time model of the system is developed. This approach results in a fixed structure controller with a s et of tuning equations as a function of the characteristic parameters of the model. The controller performance is judged by simulation on model of the DC motor*
Keywords: *DC motor; Sliding mode control, PID controller, single variable; disturbance; robustness*

I. INTRODUCTION

1.1 HISTORY

Variable structure system (VSS) with sliding mode control was first proposed and elaborated in the early 1950's in the Soviet Union by Emelyanov and several co researchers. At the very beginning, VSS is well known as special class of nonlinear systems for solving several specific control task s in second order linear and nonlinear systems. However VSS did not receive wide acceptance among engineering professionals until 1977, the most interesting fact is that robustness has becomes a major requirement in modern control application [1]. The performance of low order control system design, such as with proportional-integral-derivative (PID) controllers is less effective for electomechanical systems such as DC drives. The parametric uncertainty introduced due to plant-model mismatch degrades the overall system performance since these uncertainties are hardly considered in the design of linear controllers like PID. During the past few decades, the robust control system design for plant-model mismatch processes have received considerable attention in control community. Among the established design approaches for robust process control, sliding mode control (SMC) plays an important role because it not only can stabilize certain and uncertain systems but also provide the capability of disturbance rejection and insensitivity to parameter variations [1], [2].

1.2 PRELIMINARIES

The most distinguishing property of vss is its ability to result in very robust control systems. in other words, the system is completely insensitive to parametric uncertainty and external disturbances. due to its excellent invariance and robustness properties, the vss concepts have been developed into practical application mainly in the field of control of dc servo motors [2][3], robotic manipulators [4][5], pm synchronous servomotors, induction motors, aircraft control, spacecraft control and flexible space structure control [6] . These experiments confirm the theoretical results regarding robustness of vss with sliding modes. However, in some of these experimental results [2][4][5], it was found that the resulting control is discontinuous and the chattering phenomenon which can leads to low accuracy in control system. These problems can be solved by replacing a continuous control [4][5] into the computation of the control input (a sign function) as a result, the large error behavior of a system is identical to that with discontinuous control. It can be assumed that, the behavior of the system in small error region as a high gain system and this is similar to that of system with discontinuous control. Hence, this high gain effect of sliding mode control based on vss, suppressed the uncertainties due to parametric variations, external disturbances and variable payloads [5]. Besides that the proper selection of the switching functions will avoid chattering problem in the dc drive systems, hence result in high accuracy control. The choice of switching functions to control the system states, such that current, speed or position has been discussed and examined in detail in literature [7]. in is], the control of a permanent magnet synchronous motor under sliding mode controller has been presented which uses a hyperbolic tangent switching function in order to overcome the chattering problem. Under this control strategy, the dynamic performance of the system can be shaped according to the system specification by an appropriate choice of switching function. It is well known, that the sliding mode control is a popular robust control method. However it has a reaching phase problem and an input chattering problem (as discussed above). these problems cause the sliding mode control (smc) is very conservative to be used with other controller design methods because the state trajectory of the sliding mode control system is determined by sliding mode dynamics, which cannot have the same order dynamics of the original system. this leads to the introduction of robust controller design with novel sliding surface. to overcome the conservatism of the smc, the novel sliding surface has been used which the same dynamics of the nominal original system has controlled by a nominal controller. The reaching phase problem can be eliminated, by using an initial virtual state that makes the initial sliding function equal to zero. Therefore, it is possible to use the smc technique with various types of controller. the proposed controller design with novel sliding surface is discussed in detail in [9]. besides that, as discussed in [10], although smc systems are qualitatively well known for possessing robust performance the quantitative analysis of the robustness and synthesis of the control system to enhance the robust performance, especially against a step load disturbance for dc drive is necessary. The reason why the quantitative analysis is necessary, because of the step load application may vary due to certain factors such as an integral action and smooth control algorithms which are often incorporated in the practical system. in [10], the analysis in terms of the time domain expressions of the transient speed deviation and its maximum value due to a step load application under sliding mode control was performed. as a result, the fast response speed and robust performances can be achieved.

II. MATHEMATICAL MODEL OF A TYPICAL DC MOTOR

The mathematical model of the DC motor is modeled on the parameters from table given below. The BLDC motor provided for this paper is the EC 45 flat Φ 45 mm, brushless, 30 Watt from Maxon motors [12]. The parameters used in the modeling are extracted from the parameters used. Find below in Table I the major extracted parameters used for the modeling task.

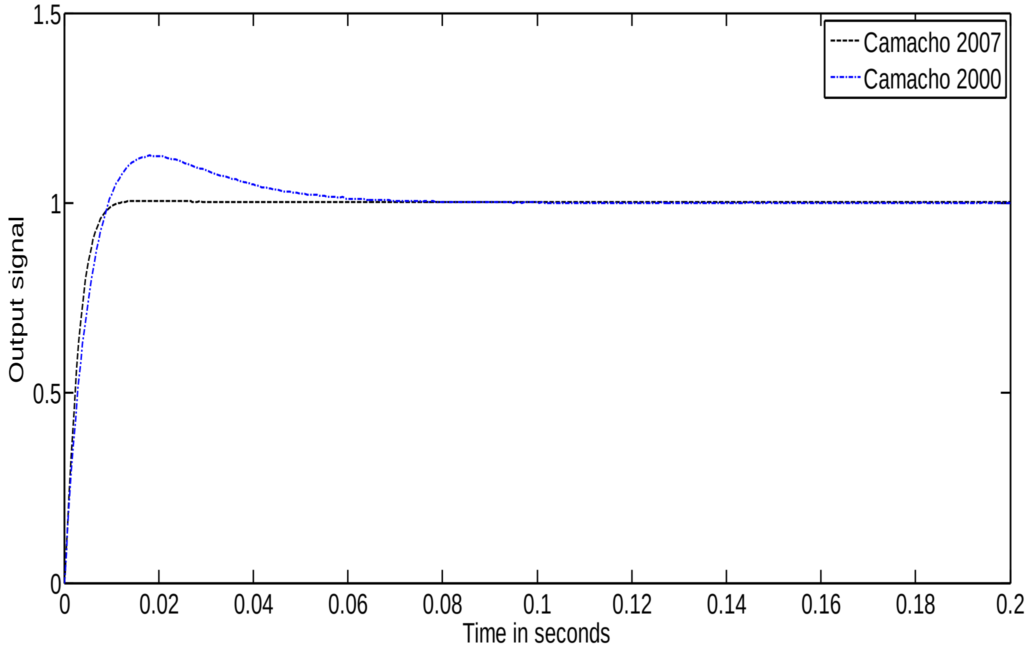

Fig.1output of the motor (speed)

PARAMETERS OF DC MOTOR

Sr. No. Data	Unit	Value
1. Nominal voltage	V	12
2. No load speed	rpm	1200
3. No load current	mA	151
4. Nominal speed	rpm	1200
5. Torque	mNm	59
6. Nominal current	A	2.14
7. Starting current	A	10
8. Max. efficiency	%	77
9. Stall Torque	mNm	255
10. Terminal Resistance	Ω	1.1
11. Terminal Inductance	mH	0.5
12. Torque Constant	mNm/A	24.5
13. Speed Constant	rpm/V	35.4
14. Speed/torque gradient	rpm/mNm	17.6
15. Mechanical time constant	ms	16.1
16. Rotor Inertia	gcm	82.5
17. No. of phase -		3

Table 1

$$G(s) = \frac{1/k_g}{\tau_m \tau_e s^2 + \tau_m s + 1} \quad (1)$$

Where K_g , τ_m and τ_e are the constants and need to calculate.

$$\tau_e = \frac{L}{3R} \quad (2)$$

The term τ_e is calculated using

$$\tau_e = \frac{0.5\times10^{-3}}{3\times1.10} \quad (3)$$

$$\tau_e = 151.51\times10^{-6} \quad (4)$$

The term τ_m is calculated using

$$\tau_m = \frac{3R_\Phi J}{K_g K_t} = 0.0161 \quad (5)$$

Where K_e is

$$K_e = \frac{3R_\Phi J}{\tau_m K_t} = 0.06902 \quad (6)$$

Thus the model of the dc motor in the form of transforms function is

$$G(s) = \frac{14.48}{2.44\times10^{-6} s^2 + 0.0161 s + 1} \quad (7)$$

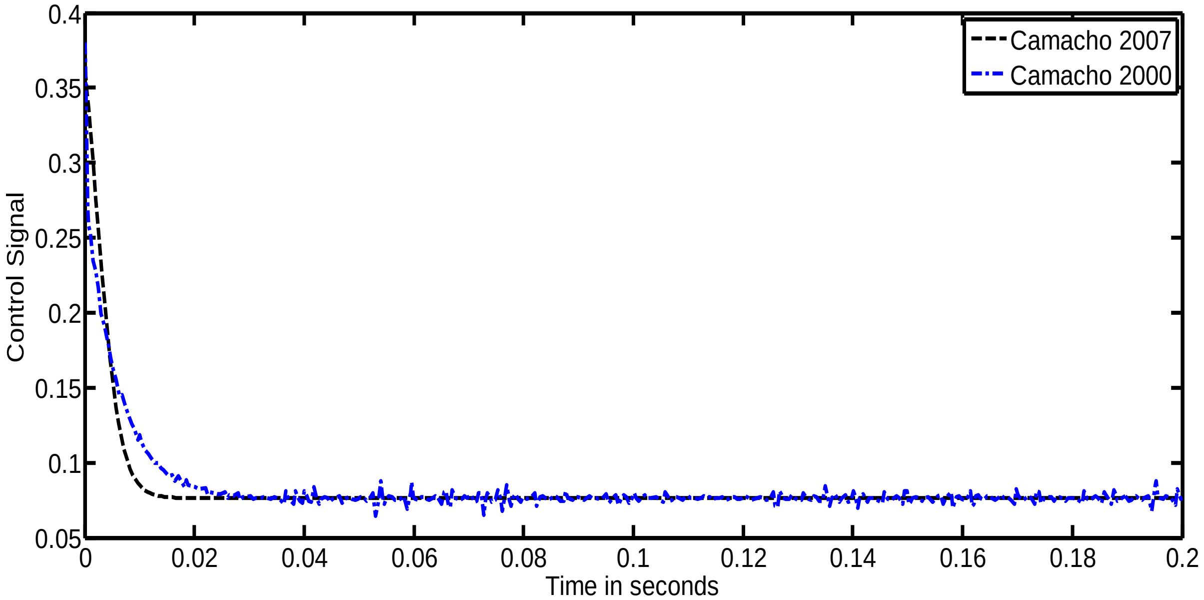

Fig.2 input of the motor (voltage signal)

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III. SLIDING MODE CONTROL

Sliding Mode Control is a technique derived from variable structure control (VSC) which was originally studied by [2]. The controller designed using the SMC method is particularly appealing due to its ability to deal with nonlinear systems and time-varying systems [3-5]. The robustness to the uncertainties becomes an important aspect in designing any control system. The idea behind SMC is to define a surface along which the process can slide to its desired final value; Fig. 3 depicts the SMC objective. The structure of the controller is intentionally altered as its state crosses the surface in accordance with a prescribed control law. Thus, the first step in SMC is to define the sliding surface.

Advantages of SMC

- Robustness is the best advantage of a sliding mode control.
- Sliding mode control can be used for systems with uncertainty.
- In Industries PID controller is most commonly used, but if there is plant model mismatch, the robustness is major issues with PID.
- In SMC, the dynamic behavior of the system may be tailored by the particular choice of switching functions
- In SMC, the closed-loop response becomes totally insensitive to a particular class of uncertainty.

The model of the DC motor, in general form is,

$$\frac{Y(S)}{U(S)} = \frac{K}{\tau_e \tau_m s^2 + \tau_m s + 1} \tag{8}$$

Or

$$Y(s)\left[\tau_e \tau_m s^2 + \tau_m s + 1\right] = KU(s) \tag{9}$$

Taking inverse Laplace, the equation in time domain form is

$$\tau_e \tau_m \ddot{y}(t) + (\tau_m)\acute{y}(t) + y(t) = kU(t) \tag{10}$$

Or

$$\ddot{y}(t) = \frac{1}{\tau_e \tau_m}[-(\tau_m)\dot{y}(t)\tau_e - y(t) + Ku(t)] \tag{11}$$

The sliding surface used by Camacho [2] is

$$\sigma(t) = \lambda_1 e(t) + \lambda_0 \int_0^t e(t)dt + \frac{d}{dt}e(t) \tag{12}$$

Where λ_1=2λ and $\lambda_0 = \lambda^2$ and λ is a tuning parameter, which helps to define the sliding surface .the derivative of 12 is

$$\dot{\sigma}(t) = \lambda_1 \dot{e}(t) + \lambda_0\, e(t) + \ddot{e}(t) \tag{13}$$

The error is e(t)=r(t)-y(t),thus above equation 13 can be written as

$$\dot{\sigma}(t) = \lambda_1[\dot{r}(t) - \dot{y}(t)] + \lambda_0 e(t) + \ddot{r}(t) - \frac{1}{\tau_e \tau_m}[-(\tau_m)\dot{y}(t)\tau_e - y(t) + Ku(t)] = 0 \tag{14}$$

We know from equation 11, $\ddot{y}(t) = \frac{1}{\tau_e \tau_m}[-(\tau_m)\dot{y}(t)\tau_e - y(t) + Ku(t)]$

$$\dot{\sigma}(t) = \lambda_1[\dot{r}(t) - \dot{y}(t)] + \lambda_0 e(t) + \ddot{r}(t) - \frac{1}{\tau_e \tau_m}[-(\tau_m)\dot{y}(t)\tau_e - y(t) + Ku(t)] = 0 \tag{15}$$

The equivalent controller $U_{eq}(t)$ can be obtained from the (15) and given as

$$\frac{\tau_m \tau_e}{K}[(\frac{1}{\tau_e}-\lambda_1)\dot{y}(t)+\frac{y(t)}{\tau_m \tau_e}+\lambda_0 e(t)+\ddot{r}(t)+\lambda_1 \dot{r}(t)]=0 \quad (16)$$

The $U_{eq}(t)$ can be simplified by considering

$$\lambda_1=\frac{1}{\tau_e} \quad (17)$$

It has been shown that this choice for λ_1 is the best for the continuous part of the controller [2].to assure that the sliding surface behave as a critical or over damped system, λ_0 should be

$$\lambda 0 \le \frac{\lambda_1^{2}}{4} \quad (18)$$

The switching controller is taken as

$$U_{sw}(t)=K_d \frac{\sigma(t)}{|\sigma(t)|+\delta} \quad (19)$$

As we know, derivative of reference signal of set point is zero, i.e. $\dot{r}(t)=\ddot{r}(t)=0$ .the total control law is

$$U(t)=U_{eq}(t)+U_{sw}(t) \quad (20)$$

$$U(t)=\frac{\tau_m \tau_e}{K}\left[\frac{y(t)}{\tau_m \tau_e}+\lambda_0 e(t)\right]+K_d \frac{\sigma(t)}{|\sigma(t)|+\delta} \quad (21)$$

Where

$$K_d=\frac{0.51}{|K|}\left(\frac{\tau}{t_d}\right)^{0.76} \quad (22)$$

And $\delta = 0.68+0.12|K|K_D\lambda_1$ (23)

IV. IMPLEMENTATION AND RESULTS

A DC motor is used in simulation to obtain the results of sliding mode control. The results show the effectiveness of the proposed controller and this result are compared with conventional PID controller. Mathworks**T M** MATLAB 7.0.1 is used for simulation. The systems considered are of higher order with time delay. It is clear, that the inputs to the equivalent control law are error signal; reference input signal and output signal. The switching control law is taken as

$$U_{sw}(t)=K_d \frac{\sigma(t)}{|\sigma(t)|+\delta} \quad (24)$$

With $K_{\mathbf{d}}$ = 0.8312 and δ = 1.2917. The parameters of the PID controller are obtained using Zeiglar-Nicholas method. The PID controller is given by

$$G_c(s)=K_p+\frac{K_1}{s}+K_D s=11.327+\frac{1381.34}{s}+0.0232s \quad (25)$$

The performance of the SMC and PID controller in terms of output responses, input responses, error signals is shown in Fig.(2, 3, &4) respectively. The sliding surface is shown in Fig. 3.It is clear from the output responses that both controller gives satisfactory response while the control effort by PID controller, that is control signal by PID controller is non-smooth while those by SMC is smooth.

In order to check the controller performance, the output disturbance d = −0.5r is added at time t = 0.1sec. from the output, input and error signal. It is clear the PID controller can not be used as its signal goes to very high value whenever disturbance occurred.

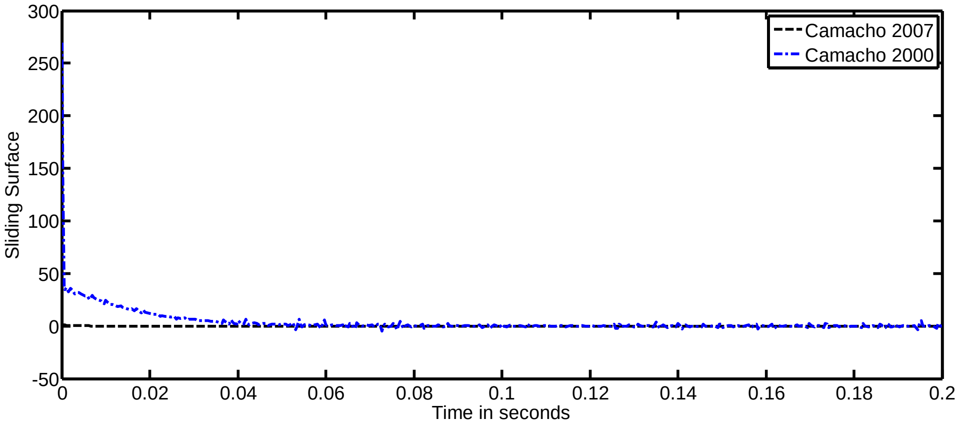

Fig.3 sliding surface

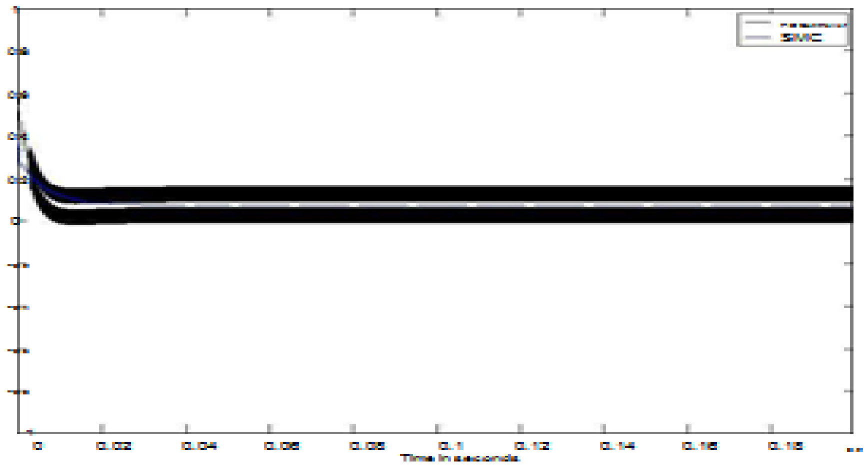
Fig 4 Output Responses

Conclusion

This paper has presented a sliding surface approach for the speed control of DC motor. The advantage of sliding mode approach is that it gives smooth controller action. It has been shown that the performance of the PID controller is comparable in terms of output of the system, but when it comes under the consideration of the controller action, the action given by the PID controller is continuously zig- zag pattern. Again in case of output disturbances, the sliding mode gives the feasible action of the while the PID controller gives very high signal which cannot be implementable in real applications. The SMC gives advantage of robustness against disturbances wither it is in input side or output side of the system. In case of immeasurable disturbances, SMC is more capable and gives satisfied performance. Simulation result s show that the proposed sliding mode control strategy produces satisfactory results with less and smooth control efforts and is effective and promising in the control of uncertain time delay systems.

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