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Sensorless Luenberger Observer Based Sliding Mode Control of DC Motor

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Abstract - *Velocity control of dc motor is an important issue and a shorter settling time is desired. A sensorless velocity control system for dc motor is developed. The system allows fast and precise speed tracking over a wide range of torque. An adaptive sliding mode speed controller is used. The main features of the sliding mode control include its insensitivity to external and internal disturbances matched by the control, ultimate accuracy, and finite-time reaching of the transient. The Luenberger-sliding mode observer is simple and robust when compared with the previously developed observer. The performance of the motor is verified by means of numeric simulations, where good tracking results are obtained.*

***Key Words*: Luenberger-sliding mode observer, dc motor, sensorless control, speed estimation.**

1.INTRODUCTION

In most control systems, there is only parameter information and partial state available through the measured outputs and these often limit the system's performance. A robust observer with high estimation accuracy is required to recover the unknown states and parameters in real time.

Many effective technologies and methods have been developed to solve the state and parameter estimation problems. Such as high-gain observer (HGO) [6], [7], Kalman filter [8]-[11], adaptive observer [12] and sliding-mode-based observer [2]-[5]. The sliding-mode observer(SMO) is an attractive technique because it has the advantages of robustness, simplicity and high state-estimation accuracy, due to its discontinuous feedback mechanism.

A Luenberger-SMO [1], [4], based parameter adaptation method using sliding mode control (SMC), of dc motor is presented in this paper. In these case sensorless control scheme is used because the absence of mechanical sensor reduces the noise problem commonly present in measurements. Finally, a simple luenberger observer is designed, filtering the rotor velocity estimate and giving also an estimate of the load torque. The speed, stator current, and torque errors of the motor drive unit due to parameter variations can be compensated using the developed observer. In addition, the observer is also robust against other parameter deviations. One application of SMC is the control of electric drives operated by switching power converters. Because of the discontinuous operating mode of those converters, a discontinuous SMC is a natural implementation choice over continuous controllers that may need to be applied by means of pulse-width modulation or a similar technique of applying a continuous signal to an output that can only take discrete states.

A Sliding Mode Controller is a Variable Structure Controller (VSC) [13]. Basically, a VSC includes several different continuous functions that can map plant state to a control. Surface and the switching among different functions are determined by plant state that is represented by a switching function.

Although VSC schemes, also including some of the cited references, often use the boundary-layer control approach, this method is not completely satisfactory. Indeed, it solves the problem only partially, particularly when high dynamic performance are required, since the main characteristics of invariance and accuracy of VSC systems are not assured any more. Adaptive control can be used to deal with this problem, however a more general solution is sliding-mode control (SMC) since it can deal with both uncertain linear and nonlinear system efficiently in a unified frame-work.

In this paper, a new adaptive sliding observer for position and velocity sensorless control [8], of a dc motor is proposed. The proposed method is based on the linear model of the dc motor [3], so its stability is easy to be discussed. Furthermore, because the order of the observer's error equation is reduced when the sliding mode occurs with the Luenberger observer. In addition, the observer is also robust against other parameter deviations.

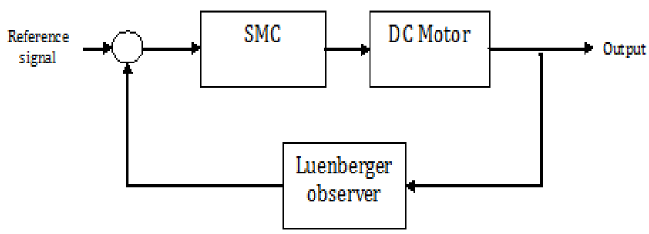

Fig -1: Block Diagram of sliding mode control of dc motor

2. STATE OBSERVER

The state of a dynamic system is a set of physical quantities, the specification of which determines evolution of system. In pole placement approach to design of control system, some immeasurable state variables are estimated using an "Observer". The state-variables of a system might not be able to be measured for any of the following reasons: The location of the particular state variable might not be physically accessible (a capacitor or a spring, for instance), there are no appropriate instruments to measure the state variable, or the state-variable might be measured in units for which there does not exist any measurement device and the state-variable is a derived "dummy" variable that has no physical meaning.

2.1 Observer Model

Consider the system –

$$dx/dt = Ax + Bu$$
$$y = Cx$$

Assume that the state X is to be approximated by the state X' of the dynamic model –

$$dx'/dt = Ax' + Bu + K_e\,(y - Cx')$$
$$dx'/dt = (A - K_eC)x' + Bu + K_e\,y$$

Which represent the state observer .The state observer has y and u as input and X' as output and K_e is the observer gain.

The DC motor state space model is given by:

$$A = \begin{Bmatrix} -2 & -0.02 \\ 1 & -10 \end{Bmatrix} \qquad B = \begin{Bmatrix} 2 \\ 0 \end{Bmatrix}$$

$$C = \begin{Bmatrix} 1 \\ 0 \end{Bmatrix} \qquad D = \begin{Bmatrix} 0 & 0 \end{Bmatrix}$$

The controller that is used is Sliding Mode Controller and the control law for this DC Motor is given by:

$$U = 79.98x1 - x1 \text{ sign } (\sigma\, x1) - 6x2 - x2 \text{ sign } (\sigma\, x2)$$

Where $\sigma = 8x1 + x2$

2.2 Designing State Observer

A state Observer can be designed only and only if observability condition is satisfied. Hence Observability Matrix:

$$N = \begin{Bmatrix} 1 & 0 \\ -2 & -0.02 \end{Bmatrix}$$

Order is 2. Hence system is observable.

2.3 Observer Gain Design(K_e)

For faster transient response, let the observer poles be placed at

$s_1 = -12.12$ and $s_2 = -12.12$

Observer characteristic polynomial:

$s^2 + 12\,s + 20.02 = 0$

i.e. $\mu_1 = 12$, $\mu_2 = 20.02$

Observer Desired characteristic Polynomial:

$s^2 + 24.24s + 167.022 = 0$

i.e. $a_1 = 24.24$, $a_2 = 167.022$

$$K_e = (WN^*)^{-1} \begin{Bmatrix} a_2 - \mu_2 \\ a_1 - \mu_1 \end{Bmatrix}$$

Where N is observability matrix,

W is the matrix of coefficients of characteristic polynomial

$$W = \begin{Bmatrix} 12 & 1 \\ 1 & 0 \end{Bmatrix} \qquad N = \begin{Bmatrix} 1 & 0 \\ -2 & -0.02 \end{Bmatrix}$$

$$K_e = [-0.04 \quad -6.1]$$

3. SIMULATION MODEL

The simulation model of observer based sliding mode control of dc motor is shown in Fig. 3.

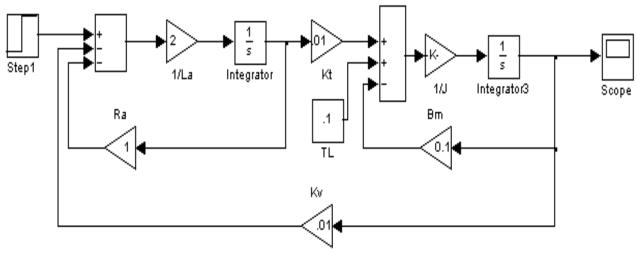

Fig -2: DC Motor model without Luenberger observer

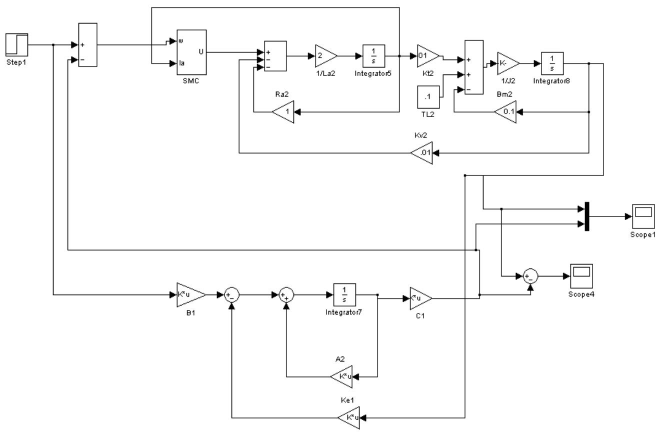

Fig -3: Proposed sensorless Luenburger observer based SMC of dc motor

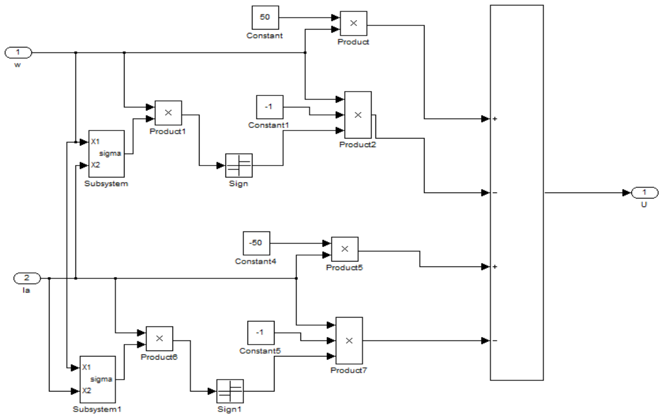

Fig -4: SMC control design

3.1 Simulation Result

Increasing the SMO gains helps to reduce the sensitivity due to SMO inherent robustness. Fig. 5 presents simulation results. The robustness of SMO with large gains regarding the input offset is evident for flux estimation. Unfortunately, large gains produce undesired large chattering, especially in the estimated speed and torque.

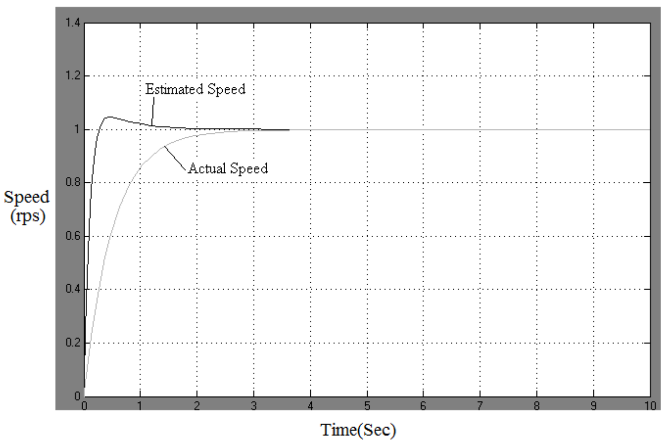

Fig -5: Comparison of actual and estimated speed

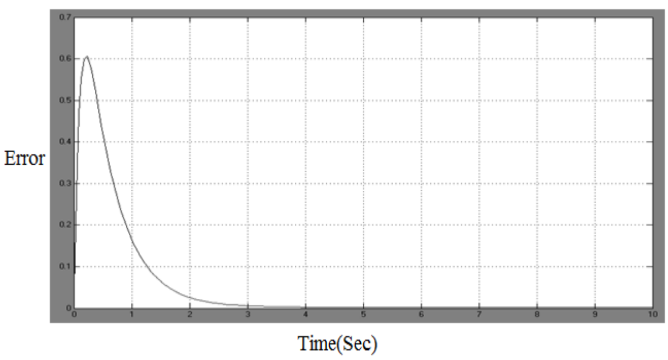

Fig -6: Error between estimated speed and actual speed

4. CONCLUSIONS

The results show that the new SMC controller with sensorless observer gives faster response and lesser settling time. In this paper, sensorless control schemes for DC motor with SMC have been designed. Both schemes use a controller designed using a high order sliding mode twisting algorithm, to track a desired rotor velocity signal and an optimal rotor flux modulus. A simple Luenberger observer allows filtering the rotor velocity estimate and giving the estimate of the load torque. In general, control scheme yield satisfactory results, as verified by numeric simulation. Error is very less because of SMC controller.

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