"dSPACE DSP DS-1104 based State Observer Design for Position Control of DC Servo Motor"

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ABSTRACT

This paper presents the design of a state observer for position control of a DC servo motor. The observer is designed using the Luenburger observer technique. The control scheme is designed using pole placement technique and the system is simulated on MATLAB/Simulink. Implementation of the same is on dSPACE DSP DS-1104 controller board with dc servo motor. Using controller board for design and implementation of state observer reduces the time required for design and testing when compared to other techniques. Results show that position control using this proposed method is more effective than other traditional methods such as PI, PIV control.

INTRODUCTION

DC servomotors are widely used in the field of automated equipment such as industrial robot, numerically controlled fabrication machines, and intelligent printers and plotters. In these applications, it is required that the predetermined position should be acquired from the preceding position within a short period of time. Hence it becomes necessary to control the amount of electric voltage supplied to the servomotor by continuously detecting the position and speed of shaft.

A state observer is a subsystem that models a real system in order to provide an estimate of its internal state, given measurements of the input and output of the real system. It is typically a computer-implemented mathematical model. In this paper the state observer is designed for the DC servo motor and its performance is compared with the PV, PIV control.

Recently, software tools for real-time control became available. Using these software tools it is possible to output values while the simulation program is running, and also to add signals obtained from external sensors. This scheme is known as "hardware in the loop" simulation. Control and supervisory strategies are designed graphically in the Simulink block diagram environment. Then, control algorithms are downloaded to a real-time prototyping system, instead of designing specific hardware. However, a complete and integrated environment is required to support a designer throughout the development of a control system, from initial design phase until the final steps of code generation. In response, several rapid control prototyping modules have been proposed using MATLAB/Simulink.

Controller board like dSPACE DS1104 is appropriate for motion controls and is fully programmable from the MATLAB/Simulink environment. The dSPACE uses its own real-time interface implementation software to generate and then down load the real-time code to specific dSPACE boards. It enables the user to design digital controller simply by drawing its block diagram using graphical interface of Simulink.

In the paper the model of the plant and the control algorithm is developed using MATLAB/Simulink module. The code for the dSPACE board is generated using the Real Time Workshop toolbox. The Real-Time Workshop produces code directly from Simulink models and automatically builds programs that can be run in a variety of environments, including real-time systems and stand-alone simulations. After downloading the software in the real time platform the data and system parameters can be observed and modified using ControlDesk. The software allow to create graphic user interfaces using predefined objects like plots, buttons, sliders, labels, etc.. The main features of this environment are: 1) controller code can be generated automatically for hardware implementation; 2) different languages can be used to describe different parts of the system; 3) Simulink block diagrams can be used to define the control structure; 4) controller parameters can be tuned online while the experiments are in progress without having to rebuild and download a new Simulink model to the DSP board; and 5) ease of operation especially by means of a simple graphical user interface.

MODELLING OF DC SERVO MOTOR

The mathematical model of system is analyzed by considering a simplified equivalent circuit of dc servo motor.

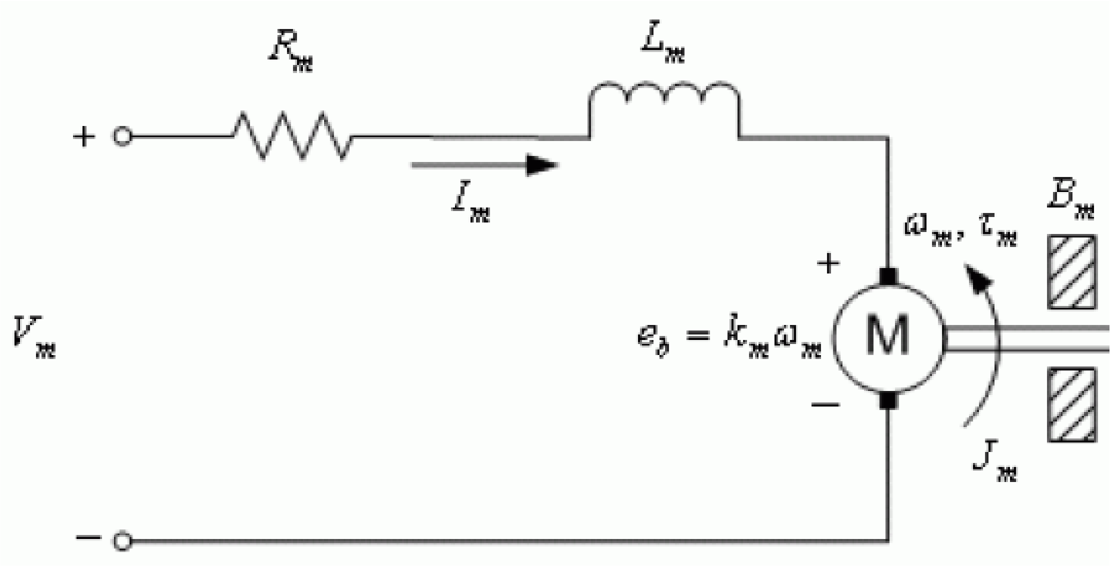

Fig 1. DC servo motor armature circuit

Where, R_m= motor terminal resistance,
L_m= motor terminal inductance,
I_m = the amount of current that run through motor leads,
V_m = motor voltage,

Applying KVL to figure 1,

$$V_m(t) - R_m I_m(t) - L_m\left(\frac{d}{dt} I_m(t)\right) - e_b = 0 \qquad (1)$$

Substituting, $e_b = k_m \omega_m$ and assuming that current through the motor is constant, so rate of change of current is zero,

$$V_m(t) - R_m I_m(t) - K_m\, \omega_m(t) = 0 \qquad (2)$$

Where, K_m = back-emf constant of the motor,
ω_m= speed of the motor shaft,

Simplifying,

$$I_m(t) = -\frac{-V_m(t) + K_m \omega_m(t)}{R_m} \qquad (3)$$

Trasfer function of of servo motor is given by equation,

$$\frac{\theta(s)}{Vm(s)} = \frac{K}{s(\tau s+1)} \qquad (4)$$

Where, $\tau = \frac{J_{eq}}{B_{eq}}$ and $K = \frac{A_m}{B_{eq}}$ (5)

Where, θ = position of the motor shaft,
τ = time constant of motor,
K = motor constant,
J_{eq}= equivalent moment of inertia,
B_{eq}= equivalent viscous damping,
A_m= actuator gain parameter,

Converting motor transfer function given by equation into state space form,

$$\begin{bmatrix} \dot{\theta}(s) \\ \dot{\omega}_m(s) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 1/\tau \end{bmatrix} \begin{bmatrix} \theta(s) \\ \omega_m(s) \end{bmatrix} + \begin{bmatrix} 0 \\ K/\tau \end{bmatrix} V_m(s) \tag{6}$$

$$y(s) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} \theta(s) \\ \omega_m(s) \end{bmatrix} \tag{7}$$

In this work, the parameters of the system were tested with a plant model of the DC servo motor system with the detail given in resultant equation matrix corresponding to Eq. (6) and (7) which are referred to the general equations (8) and (9) can be achieved as follows,

$K = 1.53$
$\tau = 0.0254$ sec.

$$\begin{bmatrix} \dot{\theta}(s) \\ \dot{\omega}_m(s) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -39.37 \end{bmatrix} \begin{bmatrix} \theta(s) \\ \omega_m(s) \end{bmatrix} + \begin{bmatrix} 0 \\ 60.236 \end{bmatrix} V_m(s) \tag{8}$$

$$y(s) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} \theta(s) \\ \omega_m(s) \end{bmatrix} \tag{9}$$

STATE OBSERVER:

A state observer is a system that models a real system in order to provide an estimate of its internal state, given measurements of the input and output of the real system. It is typically a computer-implemented mathematical model. In most practical cases, the physical state of the system cannot be determined by direct observation. Instead, indirect effects of the internal state are observed by way of the system outputs.

For continuous time linear system,

$$\dot{x} = Ax + Bu \tag{10}$$

$$y = Cx \tag{11}$$

Where, $x \in R^n$, $u \in R^m$, $y \in R^r$.

For such linear system observer equation is given by,

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - \hat{y}) \tag{12}$$

$$\hat{y} = C\hat{x} \tag{13}$$

Observer error is defined as.

$$e = x - \hat{x} \tag{14}$$

Differentiating equation (14)

$$\dot{e} = \dot{x} - \dot{\hat{x}} \tag{15}$$

Using equation (10) and (12) into (15) we get,

$$\dot{e} = Ax + Bu - [A\hat{x} + Bu + L(y - \hat{y})] \tag{16}$$

Further simplifying the equation,

$$\dot{e} = A(x - \hat{x}) - L(y - \hat{y}) \tag{17}$$

Using equation (13) and (14) into (17),

$$\dot{e} = A(x - \hat{x}) - LC(x - \hat{x}) \tag{18}$$

$$\dot{e} = (A - LC)e \tag{19}$$

Solution of this equation is given by,

$$e(t) = exp^{(A-LC)} e(0) \tag{20}$$

The Eigen values of the matrix (A – LC) can be made arbitrary by appropriate choice of the observer gain L, when the pair [A,C] is observable (Observability condition holds). So the observer error e → 0 when t → ∞.

System describe by above equation is observable if and only if the n x nr matrix, $[C^* \;\vdots\; A^*C^* \vdots \;...\; \vdots\, (A^*)^{n-1} C^*]$ is of rank n. This matrix is called the Observability matrix.

Design of Plant Gain and Observer Gain:

For plant gain characteristic equation become,

$$|SI - A + BK| = (S - \mu_1)(S - \mu_2) \ldots (S - \mu_n) \tag{21}$$

Where, $\mu_1 ,\mu_2, \ldots.\mu_n$ desired closed loop pole location of plant.

K is state feedback gain matrix.

For observer gain characteristic equation become,

$$|SI - A + LC| = (S - \mu_{1ob})(S - \mu_{2ob}) \ldots (S - \mu_{n0b}) \tag{22}$$

Where, $\mu_{1ob} ,\mu_{2ob}, \ldots.\mu_{nob}$ desired closed loop pole location of observer.

We have design observer gain in such a way that observer respond 5 to 10 times faster than plant response. One should consider that faster respond system required more energy to control and heavier actuator to control. Desired dominant pole location should be far away from the $j\omega$ axis.

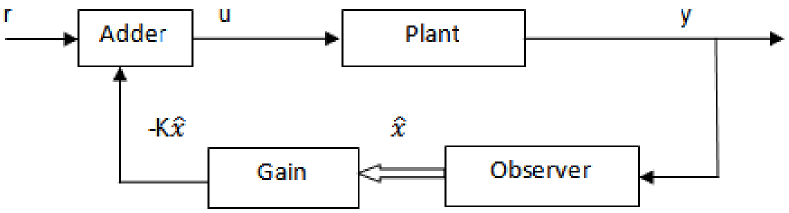

Fig. 2 Block diagram of Observer Implementation

dSPACE DS 1104 R&D Controller Board

The DS1104 R&D Controller Board is a standard board that can be plugged into a PCI slot of a PC. The DS1104 is specifically designed for the development of high-speed multivariable digital controllers and real-time simulations in various fields. It is a complete real time control system based on a 603 PowerPC floating-point processor running at 250MHz. For advanced I/O purposes, the board includes a slave-DSP subsystem based on the TMS320F240DSP microcontroller. For purpose of rapid control prototyping, DAC, encoder interface module of the connector panel. Provide easy access to all input and output signals of the board.

The control program is written in Simulink environment combined with the real-time interface of the DS1104 board. The main ingredient of the software used in the laboratory experiment is based on MATLAB/Simulink programs. The control law is designed in Simulink and executed in real time using the dSPACE DS1104 DSP board. Once the controller has been built in Simulink block-set, machine codes are achieved that runs on the DS1104'TMS320F240 DSP processor. While the experimental is running, the dSPACE DS1104 provides a mechanism that allows the user to change controller parameter online. Thus, it is possible for the user to view the real process while the experiment is in progress.

ControlDesk developer version 3.5, dSPACE's experiment software, provides all the functions to control, monitor and automate experiments and makes the development of controllers more effective. The graphical user interfaces to control manually the real time simulation. Many well-structured layouts enable the user to gain full control over the system. ControlDesk allows users to generate convenient, graphical user interfaces (layouts) with a great variety of control elements, from simple GUI elements (push-buttons, displays, radio buttons, etc.) to complex plotters and photorealistic graphics. This virtual environment allows the user not only to control or monitor any control algorithm parameter during the real time simulation, but also to access any I/O signal connected to the hardware components.

EXPERIMENTAL SETUP

The experimental set-up, implemented to a DC servo motor as the detail as follows: 5 Watt and 1000 rpm. The position of motor shaft is measured by optical encoder which is given to the encoder interface module of ds 1104 controller board. It also generates speed of motor shaft using delta position output. Pulses coming from encoder are converted into angular shaft position in Simulink. Output of observer is given to the DAC. This control input is applied to the motor for precised position control.

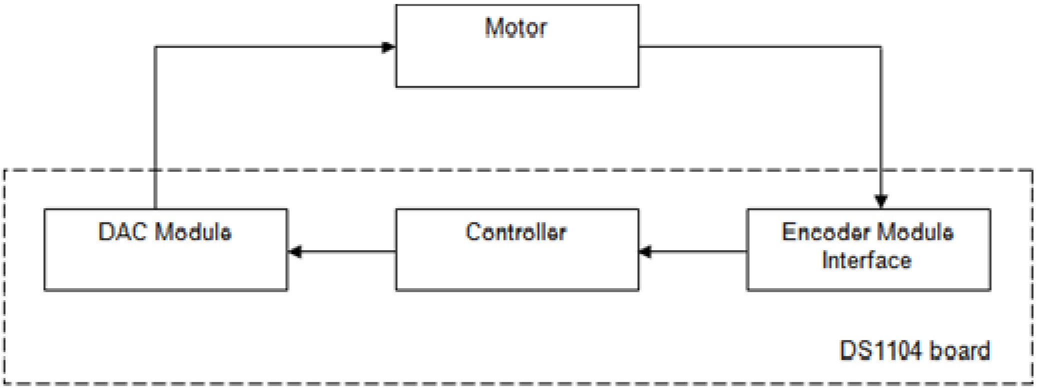

Fig.3 Interfacing diagram of DC servo motor with DS1104 controller board.

OVERALL SYSTEM PERFORMANCE

PV Control:
This control multiplies error by proportional gain and differentiates the output which gives velocity. It is then multiplied by velocity gain and added for generating control input. Due to differentiator unwanted spike produced into controlled input can be suppressed by adding integral control. The performance and control strategy of PV control for positioning of DC servo motor shown in figure 4 and 5.

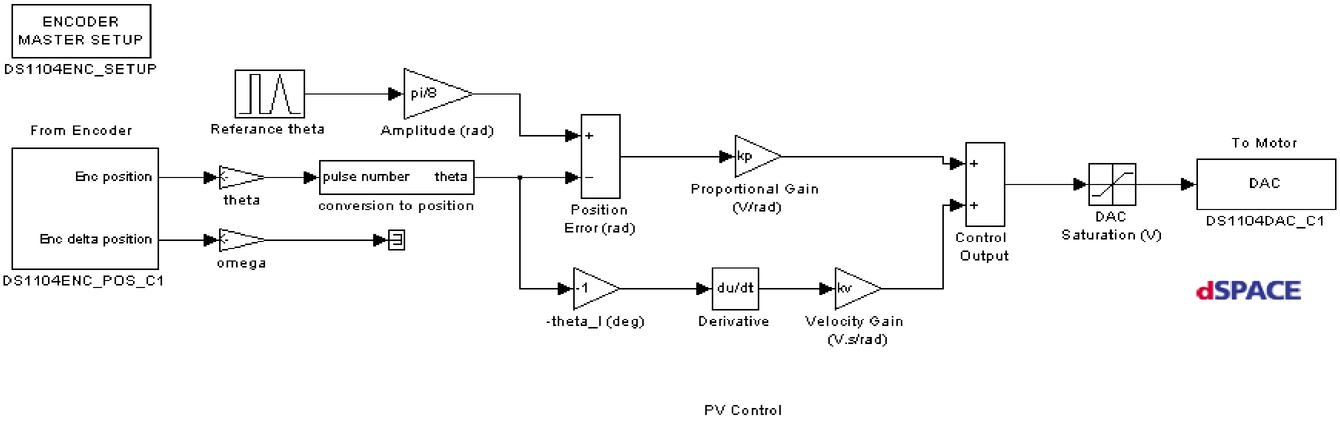

Fig.4 Simulink diagram of PV control

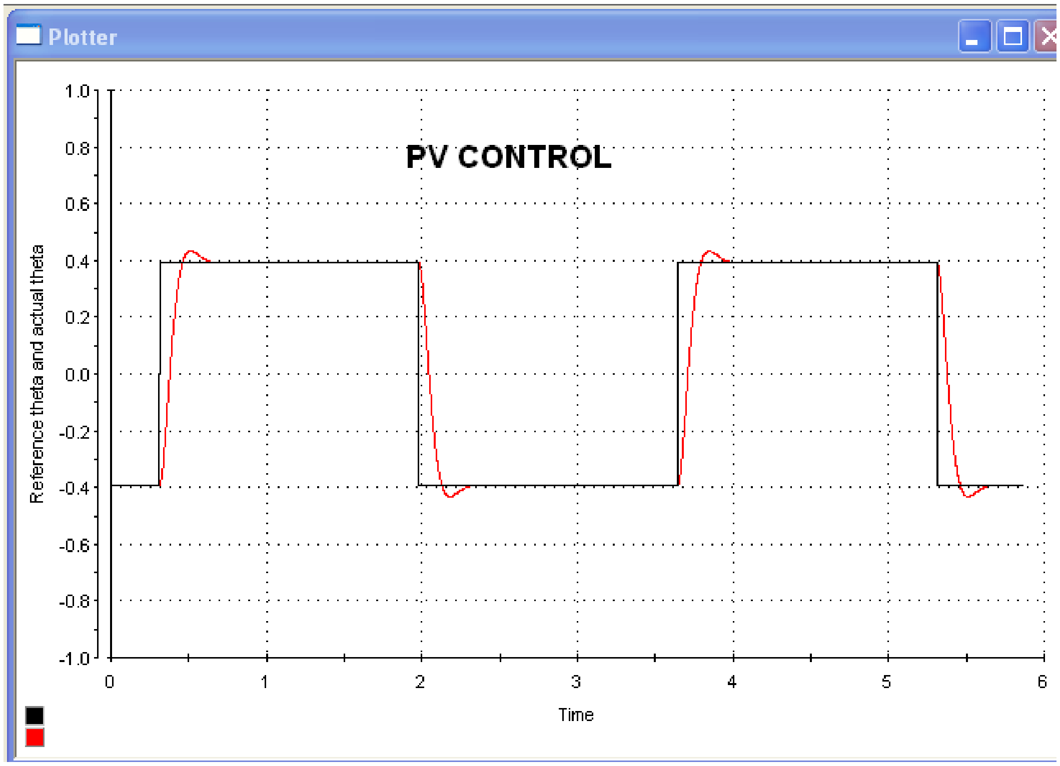

Fig.5 Response of PV Control

PIV Control:

Adding an integral control can help to eliminate any steady state error. It also suppress spike due to velocity feedback. System response can be improved by integrating the error. But addition of integral control causes large overshoot in the output. The performance and control strategy of *PIV* control is shown in figure 6 and 7.

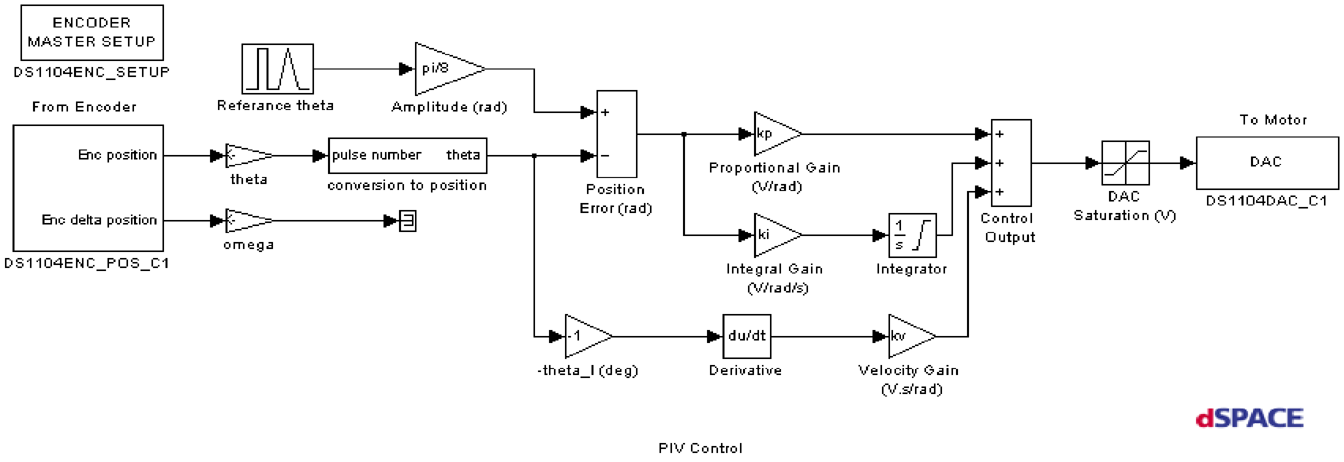

Fig.6 Simulink diagram of PIV Control

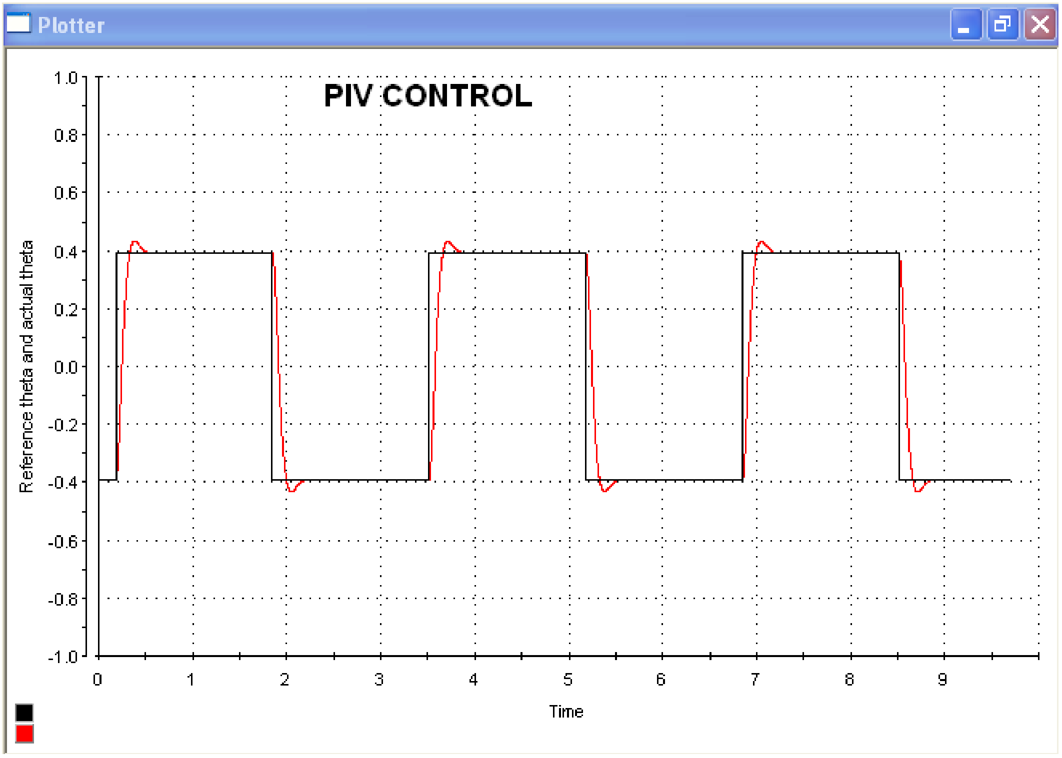

Fig.7 Response of PIV Control

State Observer:

State observer is the subsystem which reconstruct state vector of the plant. It give us more freedom for control our states of plant by placing closed loop poles at desired location according to our damping ratio and natural frequency requirement. Reduced settling time and peak overshoot is satisfactorily achieved by this method. It gives us better response as compared to other method with no load condition and we can precisely control position. The performance and control diagram of state observer is shown in figure 8 and 9.

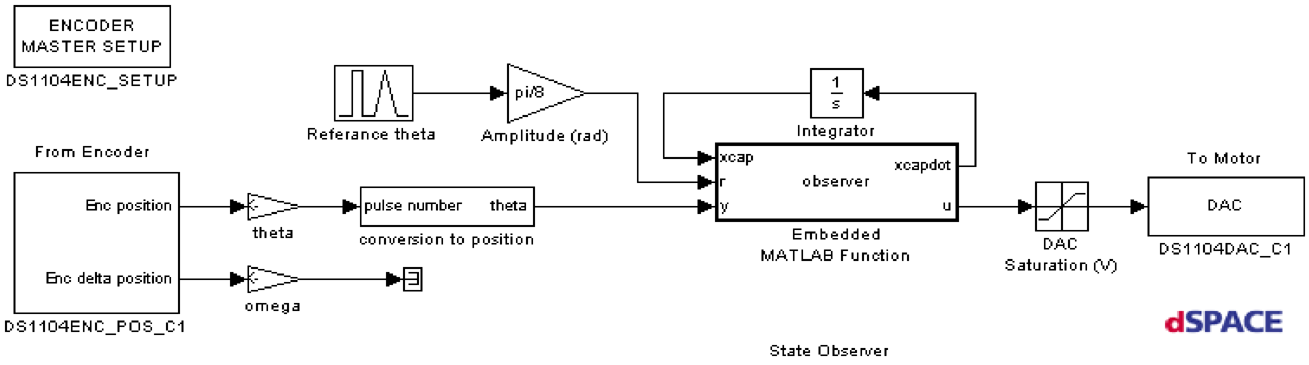

Fig.8 Simulink diagram of State Observer

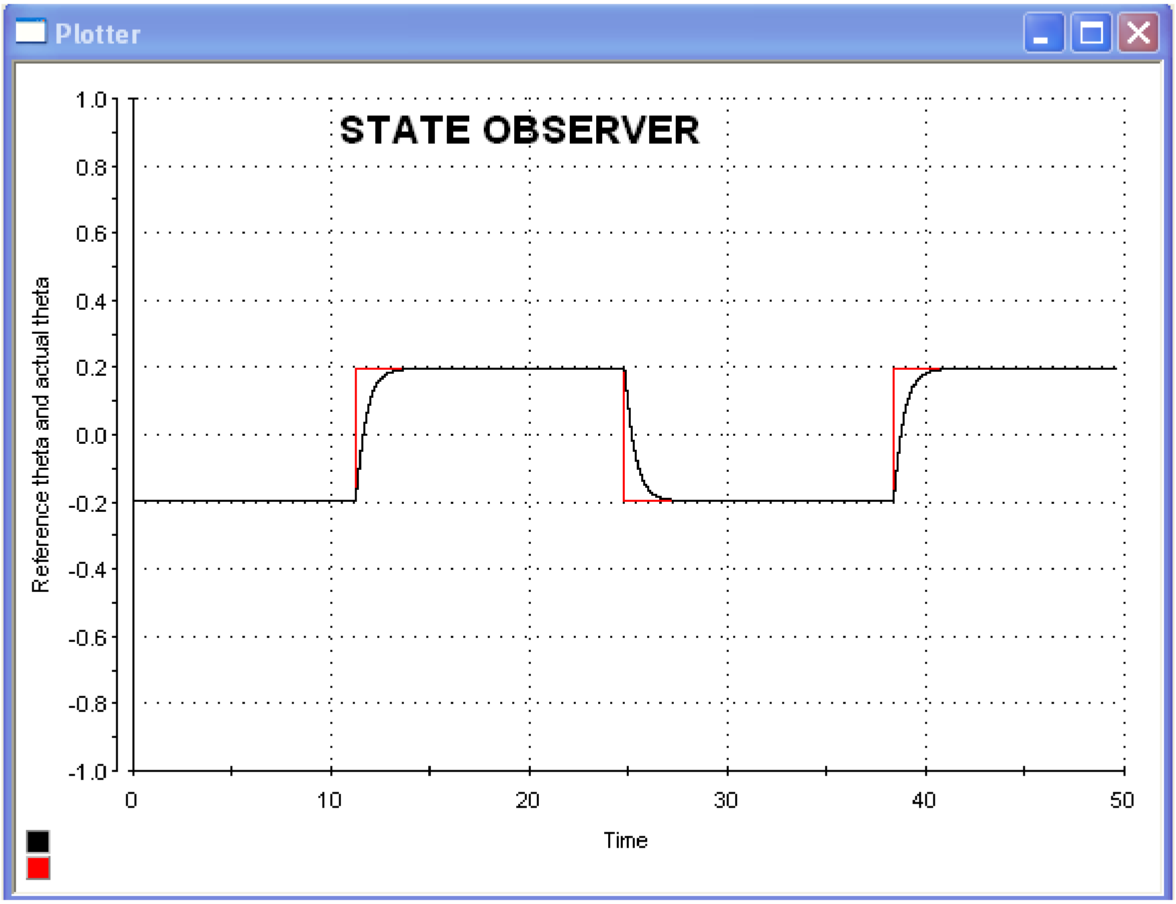

Fig.9 Response of Sate Observer

CONCLUSION

In this paper we have provided a systematic design procedure for state observer method for positioning DC servo motor. The following advantages of using the ds1104 controller board for implementation were seen

- Less time require for implantation of different control algorithm.
- Reconfigurability.
- Less external passive components.
- Less sensitive to temperature variation.
- High efficiency.
- Higher reliability and flexibility.

Also the comparison of PV, PIV control with state observer shows that the precise position control can be achieved using state observer.

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