Implementation of PV and PIV Control for Position Control of Servo Motor

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Abstract— the objective of the paper is to implement PV and PIV control for position control of servo motor. A Quanser servo plant module and dSPACE software with the DS1104 R&D controller board is used in the experiment to derive transfer function of servo motor that describes the load shaft position with respect to the motor input voltage using frequency response method and to develop a feedback system that controls the position of the rotary servo plant.
Key words: Quanser servo plant (SRV02); Frequency response method (FM); dSPACE R&D controller board (DS1104); Proportional Velocity (PV); Proportional Integral Velocity (PIV)

I. Introduction

Generally in all universities in India and worldwide Quanser servo plant with the Quanser Q4 or Q8 board and Wincon software is used to construct laboratory experiment as discussed in [1] and [2]. Since there are some limitations in using this software it is proposed to use the dSPACE software with the DS1104 R&D controller board to obtain better position and speed control of the plant with the help of [3] and [4].

The Quanser servo plant consists of a DC motor and internal gear boxes which makes it suitable for control of nonlinear systems. Since the plant is used for control objective, accurate modeling of the system is mandatory. In order to find the experimental transfer function of the SRV02 an experimental set up is developed which consists of dSPACE software, DS1104 interface board and UPM power supply module. The UPM provides continuous input to the SRV02. The Quanser servo plant is interfaced with the PC which consists of the dSPACE software, using the DS1104 R&D controller board, CP1104 connector panel and a UPM power supply module as in [4].

The transfer function of the Quanser servo motor is determined using Frequency domain method, which is a grey box method of modeling a system with the help of [5], [6] and [7]. The results obtained using both methods are tabulated with the theoretical transfer function of the Quanser servo motor. Tracking the position of DC servo motor is performed and PV, PIV control responses are obtained.

II. Quanser Servo Plant

A. *SRV02 description:*

The SRV02 figured in Fig. 1 is provided with DC motor that is encased in a solid aluminum frame and equipped with a planetary gearbox. It comes with a potentiometer sensor that can be used measure the angular position of the load gear. The SRV02 device can also be fitted with an encoder for digital measurement and a tachometer to measure the speed of the load gear. The different options enables users to work with both analog and digital position measurements as well as measuring the angular rate using a tachometer.

The SRV02 incorporates a Faulhaber coreless DC motor that is high efficiency and low inductance motor with a small rotor inductance. Thus it can obtain much faster response than a conventional DC motor. The Quanser servo motor can be used stand-alone for several experiments but it also serve as a base component for several add-on modules.

Fig. 1: Top and Front view of Quanser servo plant

B. *UPM Power supply module*

UPM 1503 shown in Fig. 2 is used to provide continuous input to the Quanser servo plant. The UPM amplifies the input signal from the DS1104 interface board and provides an input of 12v to the Quanser servo plant.

Fig. 2: Front view of UPM 1503

III. INTERFACE SRV02 WITH DSPACE SOFTWARE

The dSPACE is a real time simulation system that consists of a set of hardware and software as shown in Fig. 3. Initially the dSPACE software should be installed in the system. An interface board will be provided with the hardware components which have to be placed in the PCI slot of PC. Through this interface board the CP1104 connector panel will be connected for connection between the external hardware which is shown in Fig. 4.

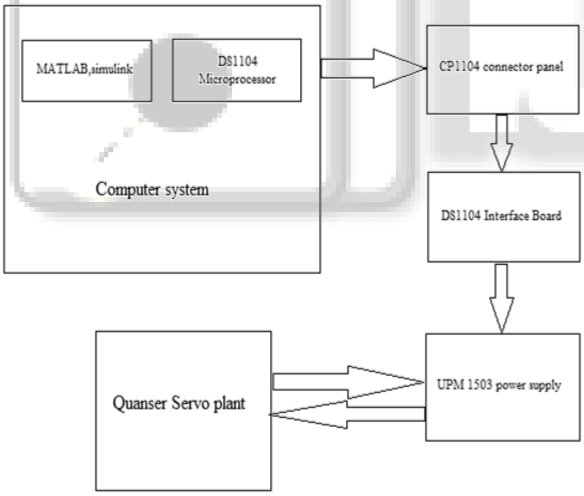

Fig. 3: Experimental setup of plant with dSPACE

A. Connecting DC Motor To UPM:

- "To Load cable": This connector uses a 6 pin DIN / 4 pin DIN, and goes from the amplifier to the actuator in the plant. One end of the cable has six pins, and the other has four so it is matched appropriately. This cable then transfers power to the plant and the analog control input to the plant.
- S1 & S2: A 6 pin-mini-DIN to 6 pin-mini-DIN is connected between the motor S1& S2 connector and the UPM. This carries the response of the servo motor to UPM.
- S3: This is also connected by the 6 pin-mini-DIN to 6 pin-mini-DIN which carries the tachometer reading.


Fig. 4: Experimental set up of SRV02

B. Connecting UPM and DS1104 Board:

- From D/A: A 5 Pin Din-mono / RCA cable is used to connect one analog output from the dSPACE board to the plant. This cable will be referred to as the "D/A cable," and it is black. The RCA termination is hooked up to the data acquisition board and the 5 Pin Din-mono is connected to the power module.
- To A/D: A 5 Pin Din-stereo / 4 x RCA cable is used to connect all 4 of the analog inputs to the dSPACE card. The cable is known as "To A/D cable," and it is a black cable. The RCA termination (like for your stereo) is going to be connected to the data acquisition board and the 5 Pin Din-stereo is going to be connected to the power module.

C. Connecting CP1104 to DS1104 Board:

- The analog input to the SRV02 is given from DACH1 pin in the CP1104 board.
- This signal will be present in the P1A 31 pin of DS1104 board and from the analog output #0 the signal is given to the "From D/A" connector.
- The analog output from the SRV02 is given to UPM through S1 & S2 signals.
- This signal is given to the DS1104 board in analog input port. The analog signal is taken from the pin P1A50 and P1B50 in the interface board and given to the ADCH4 and ADCH5 channels.
- To get the tachometer signal the pin 33 of P1A is connected with ADC6 channel. From this channel the speed of the Quanser servo motor will be recorded which will be useful for deriving the experimental transfer function of the system.

IV. THEORITICAL TRANSFER FUNCTION OF QUANSER SERVO MOTOR

The angular rate $\Omega_1(s)$ of the SRV02 load shaft with respect to the input motor voltage $V_m(s)$ can be described by the following first order transfer function,

$$\frac{\Omega_1(s)}{V_m(s)} = \frac{1.53}{0.0253s + 1}. \qquad (1)$$

The transfer function model is derived analytically from electrical and mechanical equation of the motor which is obtained from first principles.

Thus the Steady state gain of the system is,

$$K = 1.53\left[\frac{\text{rad}}{\text{sV}}\right].$$

Time constant is,

$$\tau = 0.0253\ \text{s}$$

V. Modeling of SRV02 Plant Experimentally

A linear model of the system can also be determined by experimental approach. The idea is to observe how a system reacts to different inputs and change structure and parameters of a model until a reasonable fit is obtained. The inputs can be chosen in many different ways and there is a large variety of methods. The two methods, Frequency response and Bumptest method are discussed.

A. Frequency response method:

In this method a sine wave input with a set amplitude and frequency is given to the servo motor. The output will be sinusoid with the same frequency but with different amplitude. By varying the frequency of the sine wave and observing the resulting outputs, bode plot of the system can be obtained.

From bode plot the steady state gain, i.e. the DC gain, and the time constant of the system can be determined.

1) Real time experiment:

A sine wave of varying frequency is fed to the DC motor as shown in Fig. 5 and the resulting maximum speed of the shaft is calculated. Bode plot of the system is constructed using the data collected from the control desk which is shown in Fig. 6 and the model parameters are calculated.

– In the Simulink library, the signal generator block is selected and following parameters are ensured:

Wave form: sine
Amplitude: 0.0
Frequency: 1.0
Units: Hertz

– The Amplitude (V) slider gain is set to 0.0V.
– The offset (V) block is set to 0.2V.
– Input is given to the DC motor through DS1104 DAC channel1.
– Response from the motor is obtained from DS1104 ADC channel6.
– Speed of DC motor is obtained from DS1104 ADC channel 7.
– Now the MATLAB file will be transferred to dSPACE environment by selecting incremental build option.
– When this input is given to the SRV02 unit it should begin rotating in one constant direction.
– Then the offset is set to 0.0V and slider gain is set to 0.2V.

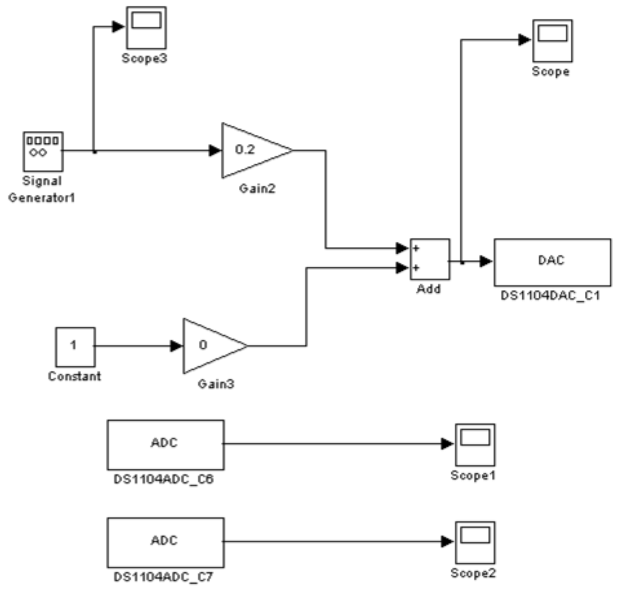

Fig. 5: MATLAB diagram for modeling the DC servo motor

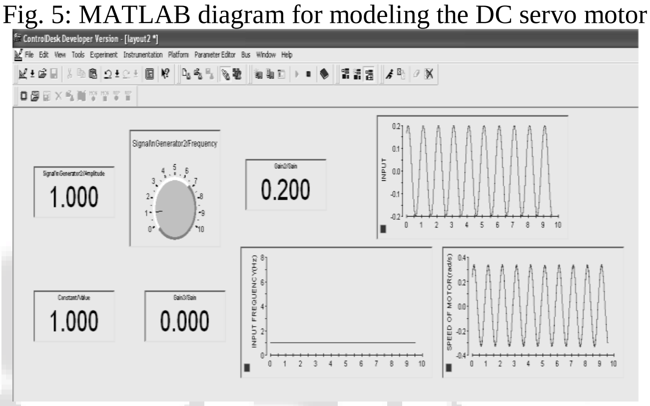

Fig. 6: Frequency response of system

2) Response of the system: By varying the frequency of th sine wave input maximum speed of motor shaft is calculated and corresponding gain values are obtained which is given in table 1 :

Freq (Hz)	Input (V)	Maximum Load Speed (rad/s)	Gain: (rad/s/V)	Gain: (rad/s/V,dB)
0	0.2	0.3369	1.6845	4.52
1	0.2	0.3247	1.6235	4.20
2	0.2	0.3228	1.6140	4.16
3	0.2	0.2832	1.4160	3.02
4	0.2	0.2637	1.3185	2.40
5	0.2	0.2466	1.2330	1.82
6	0.2	0.2275	1.1375	1.14
7	0.2	0.2041	1.0205	0.17
8	0.2	0.1924	0.9620	-0.34

Table 1: Collected frequency response data

3) Transfer function: Magnitude of Frequency response of SRV02 plant transfer function,:

$$\left|G_{wl,v}(0)\right|\left|\frac{\Omega_l(0)}{V_m(0)}\right|. \qquad (2)$$

where, is the frequency of the motor input voltage.

Thus for f=0Hz the maximum load speed is 0.3369 and the voltage is 0.2V. Therefore Gain is,

$$\left|G_{wl,v}(0)\right| = 1.6845\left[\frac{rad}{sV}\right]. \quad (3)$$

The Gain in dB is,

$$\left|G_{wl,v}(0)\right|_{dB} = 20\log10(1.6845) = 4.52\,[dB]. \quad (4)$$

The -3dB Gain is,

$$\left|G_{wl,v}(\omega_c)\right|_{dB} = 1.52\,[dB]. \quad (5)$$

From the bode plot the cut-off frequency is f_c=6.6 Hz.

$$\omega_c = 2\pi f_c. \quad (6)$$

$$\omega_c = 41.469\left[\frac{rad}{s}\right]. \quad (7)$$

Time constant is,

$$\tau = \left[\frac{1}{\omega_c}\right]. \quad (8)$$

$$\tau = 0.024s. \quad (9)$$

Thus the transfer function of the system is,

$$\frac{\Omega_1(s)}{V_m(s)} = \frac{1.52}{0.024s + 1}. \quad (10)$$

VI. SRV02 POSITION CONTROL

A. SRV02 Position Control Specifications:

The time domain specifications for controlling the position of the SRV02 load shaft are,

$e_{ss}=0$ (11)

$t_p=0.2[s]$ (12)

PO=5[“%”] (13)

Thus when tracking the load shaft reference, the transient response should have a peak time less than or equal to 0.2 seconds, a over shoot less than or equal to 5% and the steady state response should have no error.

Calculate the maximum overshoot of the response (in radians) given a step set point of 45degrees, or

$$\theta_d(t) = \frac{\pi}{4} \quad (14)$$

Using the expression,

$$\theta(t_p) = \theta_d(t)\left(1 + \frac{PO}{100}\right) \quad (15)$$

The maximum overshoot with a step response of,

$$\theta_d(t) = 0.785[rad] \quad (16)$$

$$\theta(t_p) = 0.823[rad] \quad (17)$$

B. PV Control Design:

1) Closed Loop Transfer Function:

The proportional-velocity (PV) Compensator used to control the position of the SRV02 has the structure,

$$V_m(t) = k_p\left(\theta_d(t) - \theta_l(t)\right) - k_v\left(\frac{d}{dt}\theta_l(t)\right) \quad (18)$$

Where k_p is the proportional control gain, k_v is the velocity control gain, $\theta_d(t)$ is the set point of reference load angle, and $\theta_l(t)$ is the measured load shaft angle, and V_m is the SRV02 input voltage.

2) Matlab Model for Position Control of the Servo Motor

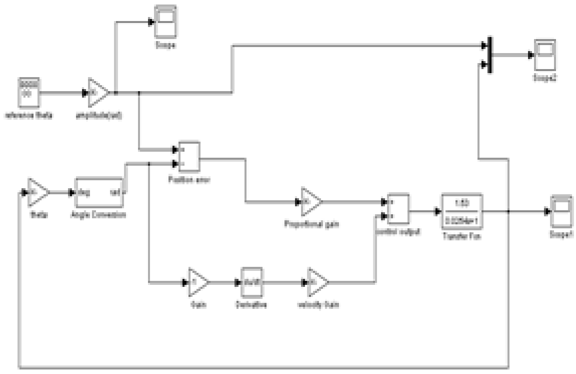

Fig. 7: Model for PV Control

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.

Response of PV Control

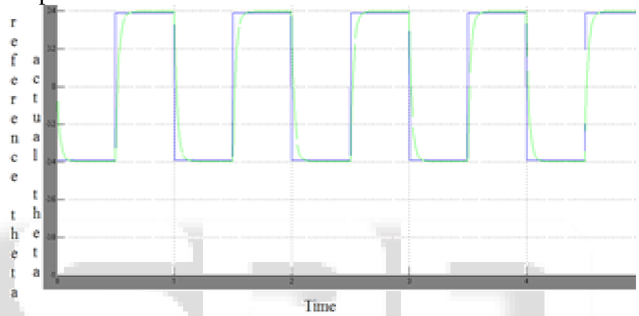

Fig. 8: PV control

Response of PV Control In dSPACE

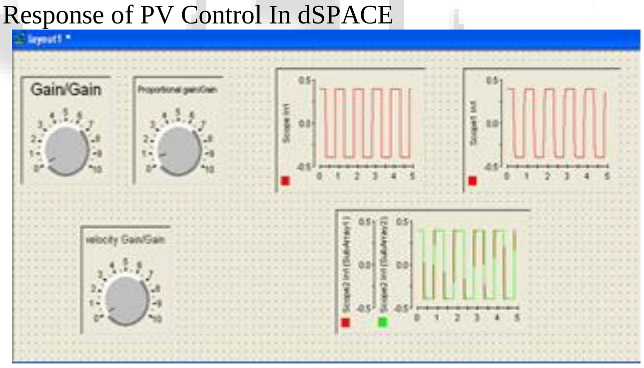

Fig. 9: PV control in dSPACE

PIV Control

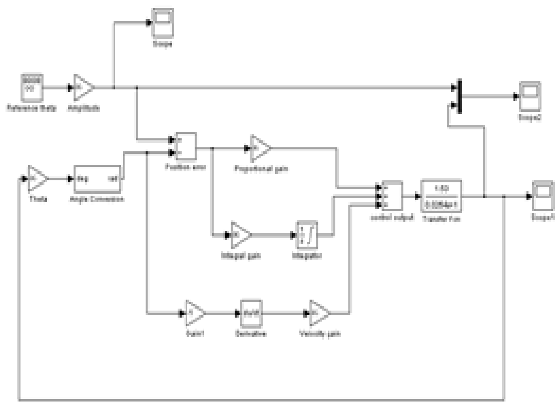

Fig. 10: PIV control

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.

Response of PIV Control

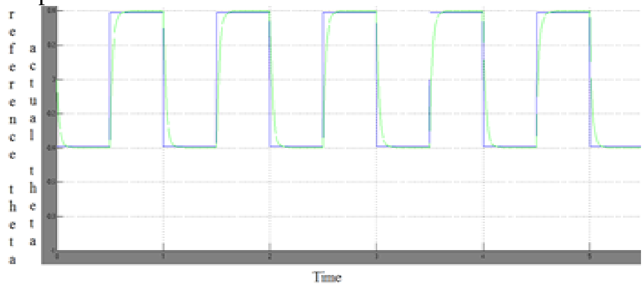

Fig. 11: PIV control

Response Of PIV Control In dSPACE

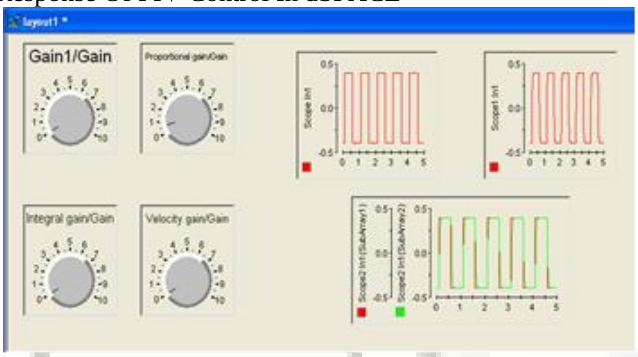

Fig. 12: PIV control in dSPACE

VII. CONCLUSION

The experiment is carried out to check the response of the PV and PIV controller for position control of servo motor, which had greatly minimized the steady state error and peak over shoot of the Quanser Servo motor.

Input to the system is given through the DS1104 board and the response of the system is recorded using the dSPACE software. The interfacing procedure of SRV02 plant with UPM, dSPACE hardware and software is clearly explained. Since the Quanser Servo motor is a non-linear system theoretical design of transfer function and controller which is a black box approach will not support in accurate control of the plant. The transfer function that is derived practically is utilized to develop the PV and PIV controller for position control of the Quanser servo motor.Thus from the recorded data transfer function of the Quanser servo plant is experimentally determined. The response of PV and PIV control were compared

Description	Symbol	Value	Unit
Nomianl Values			
Open Loop Steady-State Gain	K	1.53	Rad/S/V
Open Loop Time Constant	τ	0.0253	S
Frequency Response Modeling			
Open Loop Steady-State Gain	$K_{e,F}$	1.52	Rad/S/V
Open Loop Time Constant	$\tau_{e,f}$	0.024	S

Table 2: Modeling results summary

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