

# Frequency response method to derive transfer function of servo motor using Quanser servo plant module and dSPACE software

J Priya<sup>1</sup>, M Vidhya<sup>2</sup>, R Rambrintha<sup>3</sup>, P Venkatesh<sup>4</sup>

<sup>1</sup>Assistant Professor, Dept. of EEE, Bannari Amman Institute of Technology, Sathyamangalam, India

<sup>2</sup>Assistant Professor, Dept. of EEE, Bannari Amman Institute of Technology, Sathyamangalam, India

<sup>3</sup>Assistant Professor, Dept. of EIE, Bannari Amman Institute of Technology, Sathyamangalam, India

<sup>4</sup>Associate Professor, Dept. of EEE, Thiagarajar College of Engineering, Madurai, India

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**Abstract:** 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 load shaft. The objective of the paper is to carry out real time experiment using state of art hardware dSPACE DS1104 R&D controller board in a laboratory education point of view.

**Keywords :** Quanser servo plant (SRV02), Frequency response method (FM), dSPACE R&D controller board (DS1104), Proportional Velocity (PV), Proportional Integral Velocity (PIV).

## 1. INTRODUCTION

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. 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].

### 1.1 Frequency Domain Method

Using this hardware set up 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.

## 2. QUANSER SERVO PLANT

### 2.1 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.

### 2.2 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-1. 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-2.

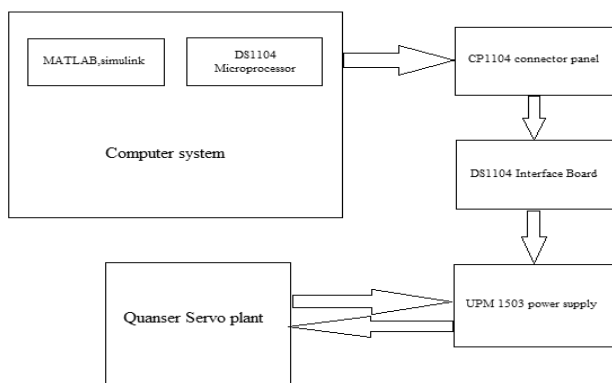


Fig -1: Experimental setup of plant with dSPACE



Fig-2: Experimental set up of SRV02

### 3. THEORETICAL 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,

$$\frac{\Omega_1(s)}{V_m(s)} = \frac{1.53}{0.0253s + 1} \quad [22]$$

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,

$$\tau = 0.0253\text{s} \quad [23]$$

### 4.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 Frequency response method is discussed.

### 4.1 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.

### 5. REAL TIME EXPERIMENT

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.

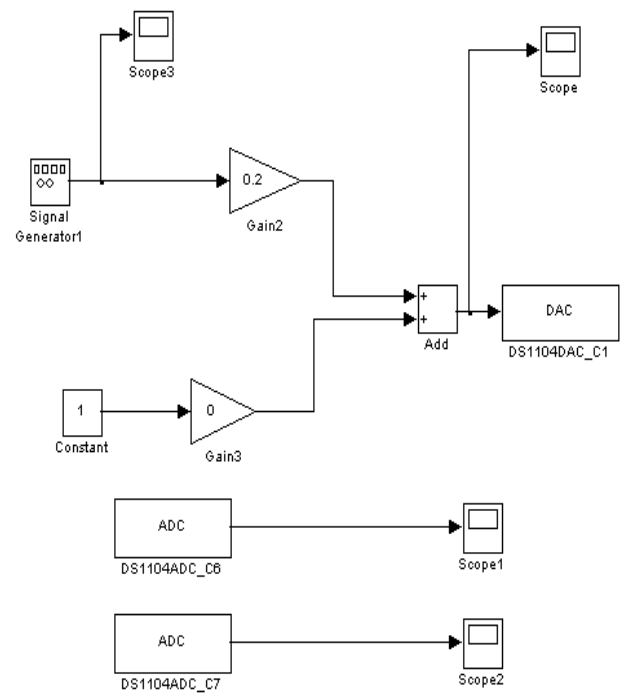


Fig-3: MATLAB diagram for modeling the DC servo motor

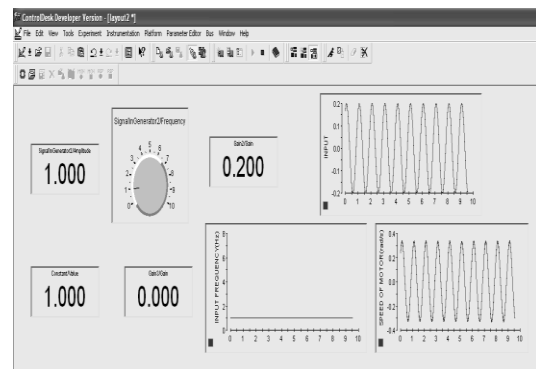


Fig-4: Frequency response of system

### 6. Response of the system

By varying the frequency of the sine wave input maximum speed of motor shaft is calculated and corresponding gain values are obtained which is given in table 1.

**Table -1:** Collected Frequency Response Data

Frequency (Hz)	Input (V)	Max load speed (rad/s)	Gain: (rad/s/V)	Gain (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. TRANSFER FUNCTION

Magnitude of Frequency response of SRV02 plant transfer function,

$$|G_{wl,v}(0)| \left| \frac{\Omega_1(0)}{V_m(0)} \right|$$

where,  $\omega$  is the frequency of the motor input voltage.

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

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

The Gain in dB is,

$$|G_{wl,v}(0)|_{\text{dB}} = 20 \log_{10}(1.6845) = 4.52[\text{dB}]$$

The -3dB Gain is,

$$|G_{wl,v}(\omega_c)|_{\text{dB}} = 1.52[\text{dB}]$$

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

$$\omega_c = 2\pi f_c$$

$$\omega_c = 41.469 \left[ \frac{\text{rad}}{\text{s}} \right]$$

Time constant is,

$$\tau = \left[ \frac{1}{\omega_c} \right]$$

$$\tau = 0.024\text{s.}$$

Thus the transfer function of the system is,

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

### 8. SRV02 POSITION CONTROL

#### 8.1. SRV02 Position Control Specifications

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

$$e_{ss}=0 \tag{11}$$

$$t_p=0.2[\text{s}] \tag{12}$$

$$PO=5["\%"] \tag{13}$$

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

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

Using the expression,

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

The maximum overshoot with a step response of,

$$\theta_d(t) = 0.785[\text{rad}] \tag{16}$$

$$\theta(t_p) = 0.823[\text{rad}] \tag{17}$$

### 8.2. PV Control Design

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

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

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.

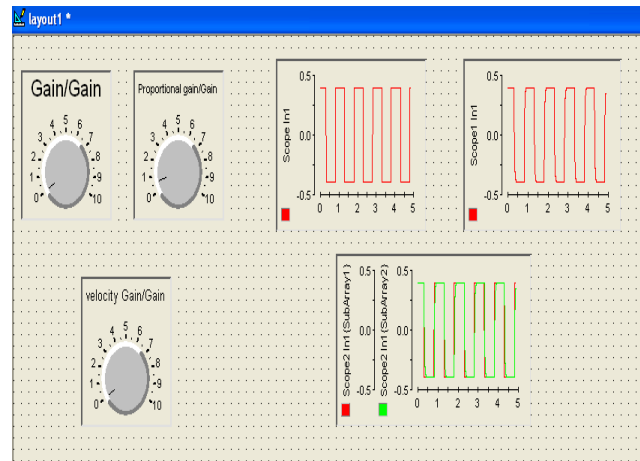


Fig-7: Response of PV Control In dSPACE

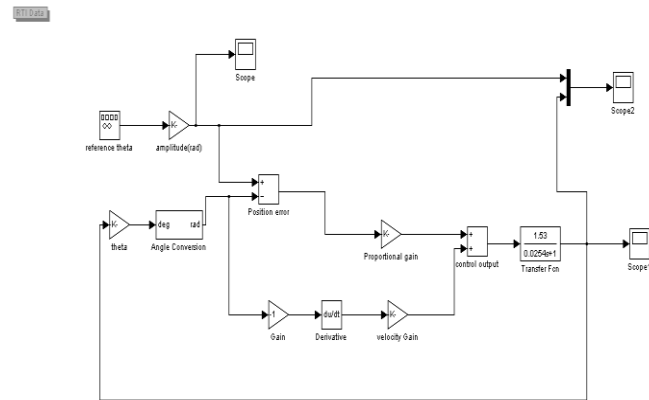


Fig-5: Matlab Model For Position Control of The Servo Motor using PV

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.

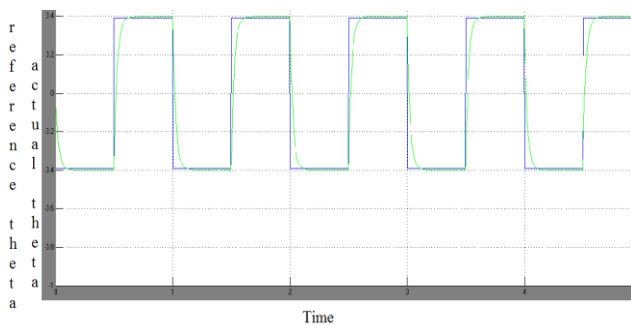


Fig-6: Response of PV Control

### 8.3. PIV Control Design

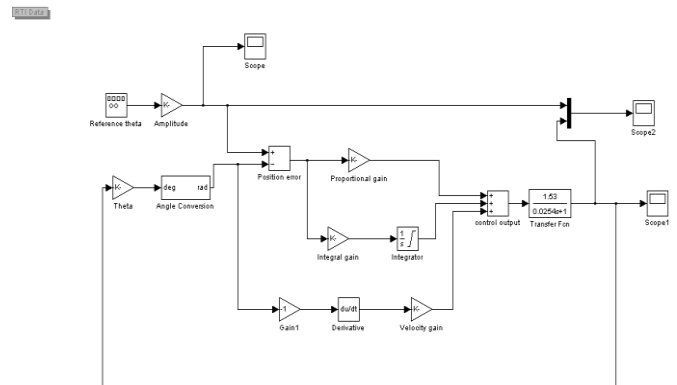


Fig-8: Matlab Model For Position Control Of The Servo Motor using PIV

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.

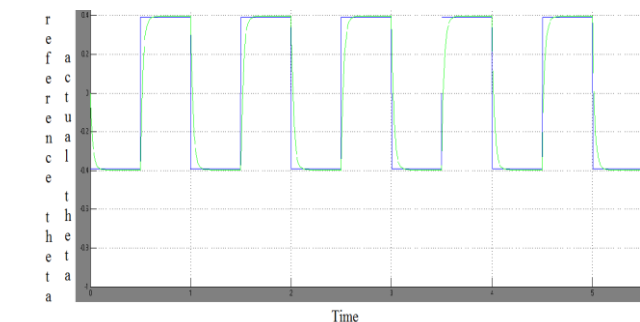


Fig-9: Response Of PIV Control

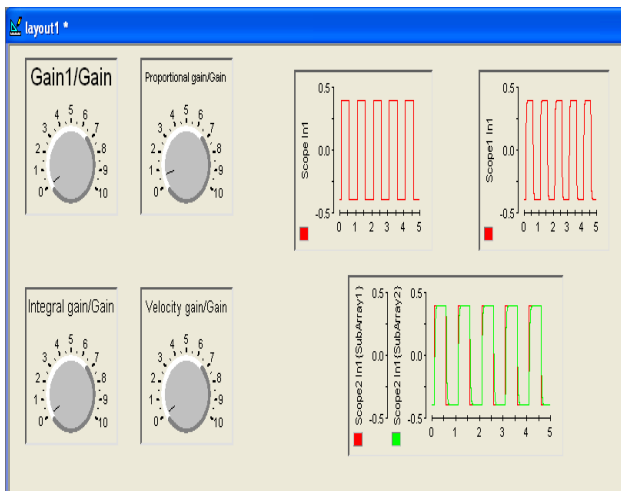


Fig-10: Response Of PIV Control In dSPACE

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

### 9. CONCLUSION

The experiment to derive the transfer function of Quanser Servo motor is carried out with the help of dSPACE software. 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.

Thus from the recorded data transfer function of the Quanser servo plant is experimentally determined using Frequency response method

The following advantages of using the DS1104 controller board for implementation were seen

- a) Less time require for implantation of different control algorithm.
- b) Reconfigurability.
- c) Less external passive components.
- d) Less sensitive to temperature variation.
- e) High efficiency.
- f) Higher reliability and flexibility.

The response of PV and PIV control were compared.

Table- 2: Modeling results summary

DESCRIPTION	SYMBOL	VALUE	UNIT
NOMIANL VALUES			
Open loop steady-state Gain	$K$	1.53	rad/s/V
Open loop time constant	$\tau$	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

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$J_{eq}$	Equivalent moment of inertia	9.76E-05kg-m <sup>2</sup>
$B_{eq}$	Viscous damping coefficient	0.015N.m(rad/s)
$m_{max}$	Maximum output load shaft	5kg
$f_{max}$	Maximum Input voltage frequency	50Hz
$\omega_{max}$	Maximum motor speed	628.3rad/s
$I_{max}$	Maximum input current	1.0A

#### APPENDIX I

SYMBOL	DESCRIPTION	VALUE
$V_{nom}$	Motor input nominal voltage	6.0V
$R_m$	Motor armature resistance	2.6Ω
$L_m$	Motor armature inductance	0.18mH
$k_t$	Motor torque constant	7.68E-03N.m
$\eta_m$	Motor efficiency	0.69
$K_m$	Back emf constant	7.68-03 V/(rad/s)
$J_{m,rotor}$	Motor shaft moment of inertia	3.90E-7 kg-m <sup>2</sup>
$\eta_g$	Gear box efficiency	0.9
$K_g$	Total gear box ratio	14