EXERCISE-1(B)

MODELING OF A SERVO MOTOR THOUGH SYSTEM IDENTIFICATION AND FIRST PRINCIPLES AND VALIDATION OF THE MODELS

DATE: REGISTER NUMBER:

PREREQUISITE KNOWLEDGE:

- Fundamentals of modelling, system identification and simulation procedures
- Use of standard test signals and their relevance in the response analysis of systems
- Working with physical sensory signals of real systems, validation of models by comparing the simulated response and actual of response of systems
- Basics of modelling, simulation and experimental validation of models in MATLAB & SIMULINK environment.

OBJECTIVES:

- To acquire, process and interpret physical signals of system under study.
- To learn the system identification techniques for estimating models of actual systems.
- To learn the modeling and simulation of dynamic system using software platforms.
- To validate the models obtained by both system identification and first principles methods with the actual response of physical plant.

PRE-LAB READINGS:

QUADRATURE ENCODER:

Like rotary potentiometers, encoders can also be used to measure angular position. There are many types of encoders but one of the most common is the rotary incremental optical encoder, shown in Figure 1. Unlike potentiometers, encoders are relative. The angle they measure depends on the last position and when it was last powered. It should be noted, however, that absolute encoders are available.

Figure 1. Digital incremental rotary optical shaft encoder

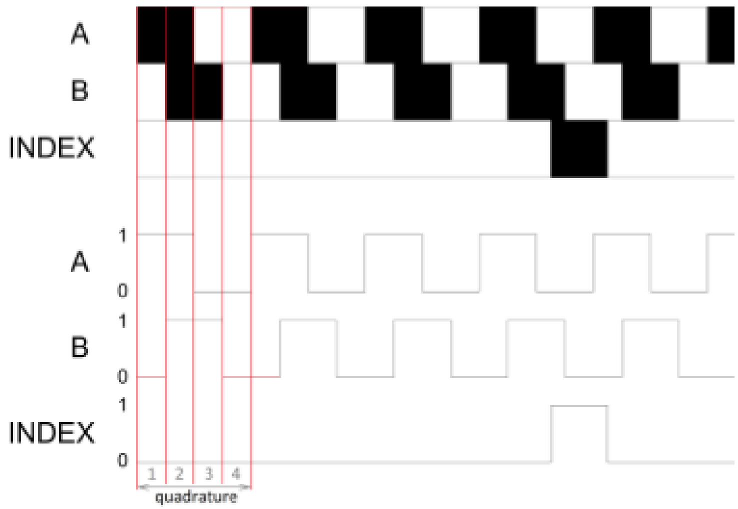

Figure 2. Digital incremental rotary optical shaft encoder signals

The encoder has a coded disc that is marked with a radial pattern. This disc is connected to the shaft of the DC motor. As the shaft rotates, a light from a LED shines through the pattern and is picked up by a photo sensor. This effectively generates the A and B signals shown in Figure 2. An index pulse is triggered once for every full rotation of the disc, which can be used for calibration or homing a system.

The A and B signals that are generated as the shaft rotates are used in a decoder algorithm to generate a count. The resolution of the encoder depends on the coding of the disc and the decoder. For example, a single encoder with 256 lines on the disc can generate a total of 256 counts for every rotation of the encoder shaft. However, in a quadrature decoder as depicted in Figure 2, the number of counts (and thus its resolution) quadruples for the same line patterns and generates 1024 counts per revolution. This can be explained by the offset between the A and B patterns: Instead of a single strip being either on or off, now there is two strips that can go through a variety of on/off states before the cycle repeats. This offset also allows the encoder to detect the directionality of the rotation, as the sequence of on/off states differs for a clockwise and counter-clockwise rotation.

SYSTEM IDENTIFICATION:

System identification is a method by which the models/parameters of the plants are estimated through experimentation and estimation. System identification is broadly classified in to three categories. Viz Black-box identification, grey-box identification and white-box identification. Refer the text book and materials provided for more details about system identification techniques and algorithms.

The bump test is a simple white box system identification based on the step response of a stable system. A step input is given to the system and its response is recorded. As an example, consider a system given by the following transfer function:

$$\frac{Y(s)}{U(s)} = \frac{K}{(\tau s + 1)}$$

The step response shown in Figure 3 is generated using this transfer function with K = 5 rad/V.s and τ = 0:05 s.

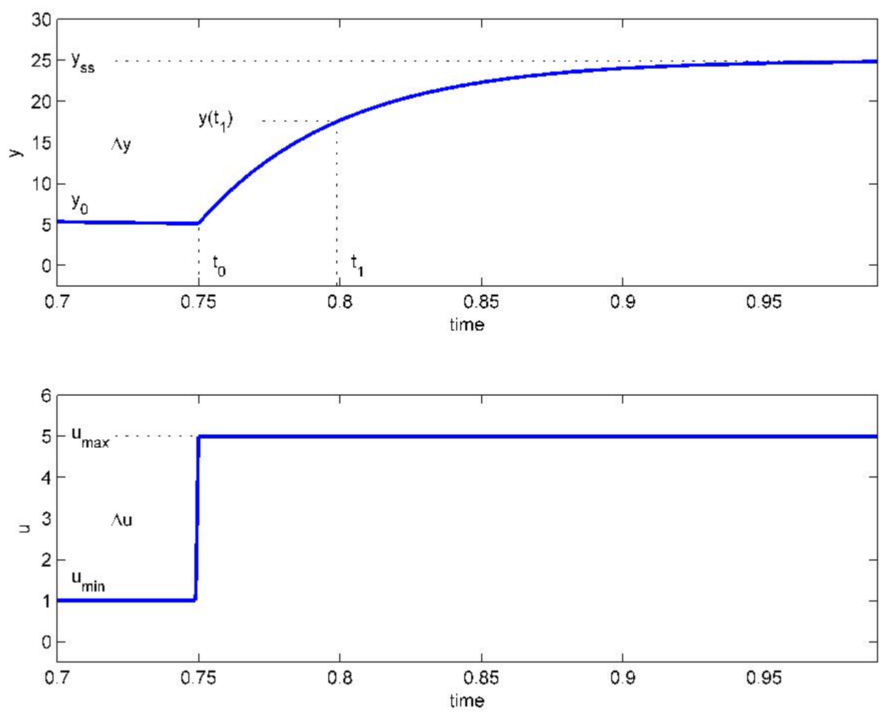

Figure 3. Input and output signal used in the bump test method

The step input begins at time t_0. The input signal has a minimum value of u_{min} and a maximum value of u_{max}. The resulting output signal is initially at y_0. Once the step is applied, the output tries to follow it and eventually settles at its steady-state value y_{ss}. From the output and input signals, the steady-state gain is

$$K = \frac{\Delta y}{\Delta u}$$

where $\Delta y = y_{ss} - y_0$ and $\Delta u = u_{max} - u_{min}$. The time constant of a system τ is defined as the time it takes the

system to respond to the application of a step input to reach 1 - 1/e =63.2% of its steady-state value.

For the figure 3, $t_1 = t_0 + \tau$

Where $y(t_1) = 0{:}632\Delta y + y_0$

Then, we can read the time t_1 that corresponds to $y(t_1)$ from the response data in Figure 3. From this, the model time constant can be found as: $\tau = \mathrm{t1} - \mathrm{t0}$.

PRE-LAB TASKS:

TASK-1: Processing the pulses from encoder and converting them in to angular displacement and speed.

- The quadrature encoder attached to the shaft of the Qube servo produces 512 pulses during every revolution. The quadrature decoding function namely 'HIL Read Encoder Time base' in QUARC software returns a count value of 2048 every revolution in quadrature mode. Find the sensor gain/scaling factor that can be used to convert the count value in to angular displacement of shaft in degrees.

- In order to get speed from the angular displacement of the motor, differentiation is applied. This may result in increased noise as the discontinuities in the pulses get aggravated. To mitigate this noise, a low pass filter could be applied to attenuate this high frequency noise. Derive the generic first order transfer function of low pass filter with a cut-off frequency, ω_c

TASK-2: System Identification through bump test method

- Familiarize with the bump test method by going through pre-lab readings.

TASK-3:

- Derive differential equations governing the Quanser Qube servo system with the following specifications given in Table 1. using basic principles.

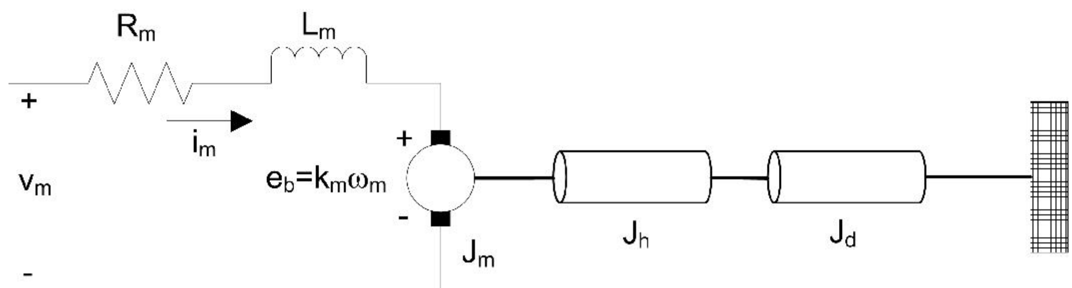

Figure 4. Block Diagram of Quanser Qube Servo Motor

Symbol	Description	Value
DC Motor		
R_m	Terminal resistance	8.4Ω
k_t	Torque constant	0.042 N.m/A
k_m	Motor back-emf constant	0.042 V/(rad/s)
J_m	Rotor inertia	4.0×10^{-6} kg.m^2
L_m	Rotor inductance	1.16 mH
m_h	Load hub mass	0.0106 kg
r_h	Load hub mass	0.0111 m
J_h	Load hub inertia	0.6×10^{-6} kg.m^2
Load Disk		
m_d	Mass of disk load	0.053 kg
r_d	Radius of disk load	0.0248 m

Table 1. Quanser Qube Servo Motor Specifications

IN-LAB TASKS:

TASK-1: Develop a SIMULINK model to measure and display the angular displacement and speed

- Create a Simulink model with provision to apply a square wave (with 1-3 V at 0.4 Hz) to the motor through the “HIL Write Analog” function and read the count value of the encoder using “HIL Read Analog” function in QUARC software.
- Plug in the sensor gain you computed under pre-lab task 1 using a gain block in series with the “HIL Read Analog” function to get the angular displacement in degree from the count value. Further, to get the speed, differentiation should be applied on angular displacement. Display the angle and speed on scopes and zoom in the speed trace to inspect the noise resulted because of this differentiation process. Attach both displacement trace and speed trace. Also attach the zoomed in speed trace to illustrate the noise due to the differentiation.
- Now, include the low pass filter transfer function that you have already derived with cut off frequency starting at 50rad/sec to remove the noise. Vary the cutoff frequency from 10-200 rad/s and analyze the speed trace. Attach the filtered speed trace. Also include the complete SIMULINK model including sensor gain, differentiation and filter.

TASK-2: Obtain the estimated model of the QUBE servo through bump test system identification

- Apply a 2V step signal to the motor in the SIMULINK model you made in TASK-1 and display both voltage and speed on scopes.
- Import the voltage and speed in MATLAB and plot them conveniently such that you measure K and τ interactively from the plots. Now, write the transfer function model with the estimated values and this is called estimated model of the motor obtained by bump test system identification.
- Include this transfer function in parallel to the existing model in order to display the actual response of motor and simulated response of the model which you have just obtained by bump test method. Validate the estimated model by comparing its response with the actual response the motor. If the responses are almost same, then the estimated model is accurate representation of the motor. Attach all the plots and SIMULINK model.

TASK-3:

- Declare all the motor variables with the values based on the specifications from Table-1. Create the subsystem of Qube Servo in Simulink based on the equations you derived using basic principles with the declared variables. Place this subsystem in parallel with the model you have already created in Task-2. By now, you have the actual motor, its model estimated by bump test and the model derived based on first principles. You can validate the obtained models of motor by simulating and comparing their responses with the actual response of motor. Attach all the plots and Simulink models. Write a detailed inference based on whatever you have observed during this exercise.

ADDITIONAL TASKS/LEARNING FOR BONUS MARKS:

- Explore the system identification tool box provided in SIMULINK. Learn and apply other advanced system identification procedures.
- Check if the developed models were reasonably accurate representations. If not, learn what aspects of systems were assumed negligible to arrive at such approximate and simplified versions. Analyze whether those assumptions are always valid or not. Present deeper understanding about the trade off among model accuracy, order of the system, simulation time/complexity and system needs.
- Conduct a detailed literature survey and present your view about the complexity and practical limitations of obtaining models based on first principles and models based on system identification.
- Apply the knowledge you have gained to obtain the model of any other DC motors available with you or available in lab. You may also apply this procedure for obtaining models of even more complex systems such as VTOL, Quadcopter and to name the few.

RESULTS & INFERENCES:

Evaluation Component	Maximum Marks	Marks Obtained
Pre-lab Tasks	10	
In-Lab Tasks	20	
Post-lab Tasks	10	
Bonus Tasks	10	
Signature of Faculty with Date		

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