LAB 4: DC MOTOR MODELING via STEP RESPONSE

Course Number	**MENG 3510**
Course Title	**Control Systems**
Semester/Year	**Winter / 2025**

Lab/Tutorial Report No.	**Lab 4**
Report Title	**DC Motor Modeling via Step Response**
Section No.	0NA
Group No.	2
Submission Date	
Due Date	

Student Name	Signature*	Total Mark
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		/50
		/50
		/50

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LAB 4 Grading Sheet

Student Name: Michael McCorkell	**Student Name:**
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Transfer Function Modeling from Step Response	**/45**
General Formatting: **Clarity, Writing style, Grammar, Spelling, Layout of the report**	**/5**
Total Mark	**/50**

LAB 4: DC MOTOR MODELING via STEP RESPONSE

OBJECTIVES

- To indentify a transfer function model experimentally using step response
- To compare the identified model with the results of first principles modeling

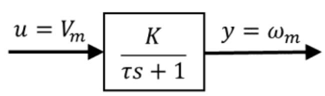
FUNDAMENTALS

The **step response test** can be used to experimentally identify the numerical parameters of a stable system modeled by a first-order transfer function model. This is useful if certain model parameters, for instance the motor constant k_m or mass moment of inertia J_{eq}, are either unknown or difficult to measure, or some nonlinear characteristics may not be included in the theoretical model.

The DC motor voltage-to-speed relation can be modeled using a **first-order** transfer function:

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

where K is called the **steady-state gain**, or **DC gain**, and τ is the **time constant** of the system. In this case, the measured output, y, is **angular speed** of the disc and the input, u, is the **voltage** applied to the DC motor on the rotor.



For example, the step response shown in **Figure 1** was generated using for a system with the steady-state gain and time constant parameters with $K = 5$ rad/s/V and $\tau = 0.05$ s.

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 output signal starts initially at y_0 and once the step is applied, the output settles to a steady-state value of y_{ss}.

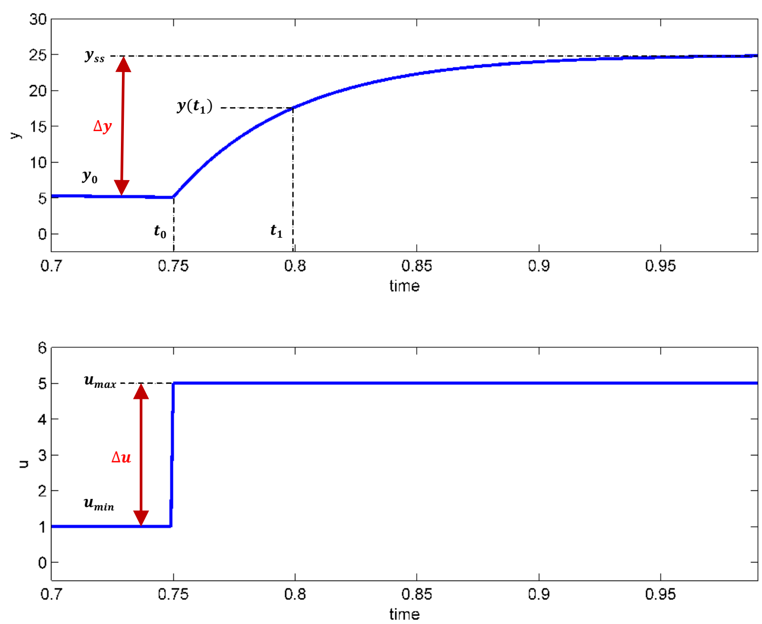


Figure 1 - Step response of system with $K = 5$ and $\tau = 0.05$.

The **steady-state gain** can be used to determine the output of the system once it has reached steady-state conditions for a given input signal. It can be found from the input and output signals of the response as follows:

$$K = \frac{\Delta y}{\Delta u} \tag{2}$$

where $\Delta y = y_{ss} - y_0$ is the difference between the steady-state and initial output of the system, and $\Delta u = u_{max} - u_{min}$ is the amplitude of the step input.

The **time-constant** characterizes the system's transient response and is defined as the time it takes for the output of the system to reach 63.2% of its steady-state output. It shows how fast the system responds to an applied input. The time constant can be determined from the output response as follows:

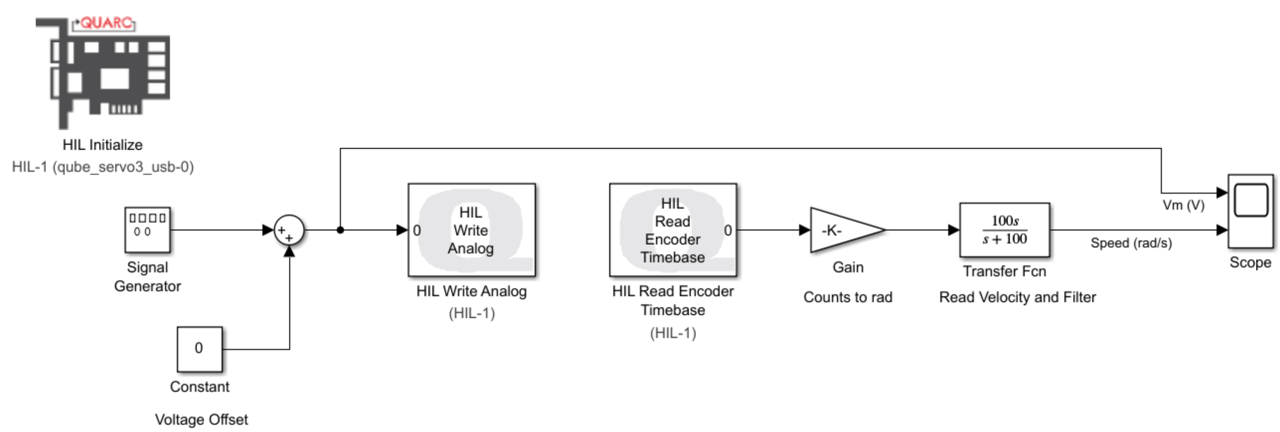
$$\tau = t_1 - t_0 \tag{3}$$

where t_0 is the time when the input is applied to the system and t_1 is the time at which the system output reaches 63.2% of its steady-state output, or $y(t_1) = (1 - e^{-1})\Delta y + y_0 = 0.632\Delta y + y_0$, as illustrated in **Figure 1**.

Transfer Function Model Identification from Step Response

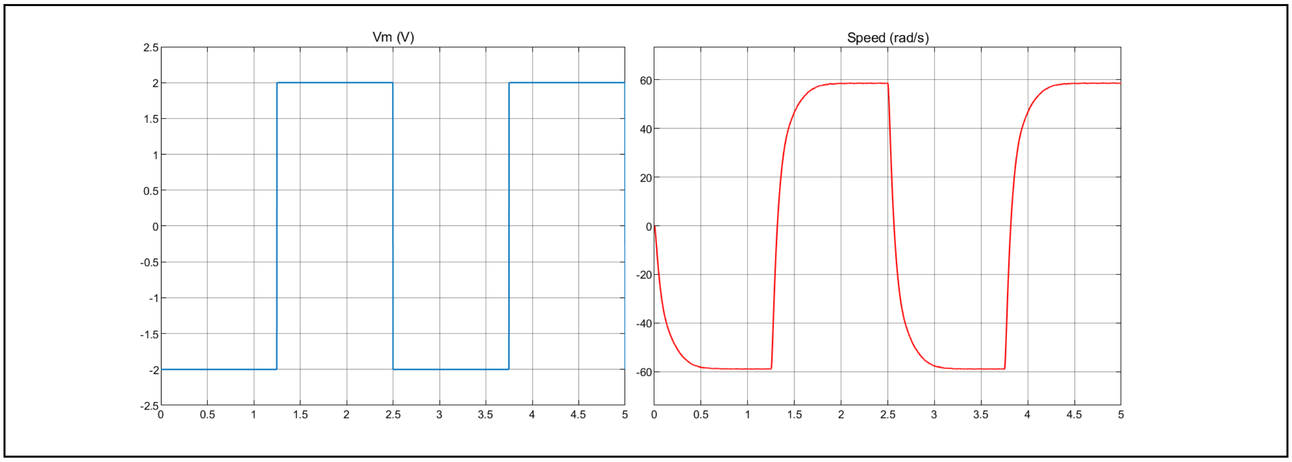
1. Similar to the method in **Lab 2**, create the following system in **Simulink** to apply step inputs with different offset levels to the servo DC motor and record the resulting angular velocity.

   ***Remark**: We are using a differentiator s cascade with a low-pass filter $100/(s + 100)$ to obtain the speed of the motor, and a conversion gain of $2\pi/2048$ to convert the number of counts to rad at the encoder output.*



2. Open the **HIL Initialize** block and set the **Board type** to **qube_servo3_usb**.
3. Click on the **Model Settings** icon in the **MODELING** tab to open the **Configuration Parameters** window. Click on the **Solver** drop down menu and select the **Type** of **Fixed step** and set the **Solver** to **ode1** solver. Then click **OK**.
4. Set the **Signal Generator** to generate a **square** waveform with the **amplitude** of **2V** and **frequency** of **0.4Hz**.
5. Set the **Constant** block to **zero**, to have a **0V voltage offset**. In this case the applied input is a step input from **-2V** to +**2V** passing the **dead zone** area. The DC motor will rotate in both **CW** and **CCW** directions.
6. **Save** the Simulink file as **Lab4.slx**. Set the **Stop Time** to **5 seconds**. **Run** your code.
7. Open the **Scope**. Provide the **scope plots in the side-by-side format with white background** below:

Motor Input Voltage (V) & Disk Angular Speed (rad/s) – (Input -2V to +2V)



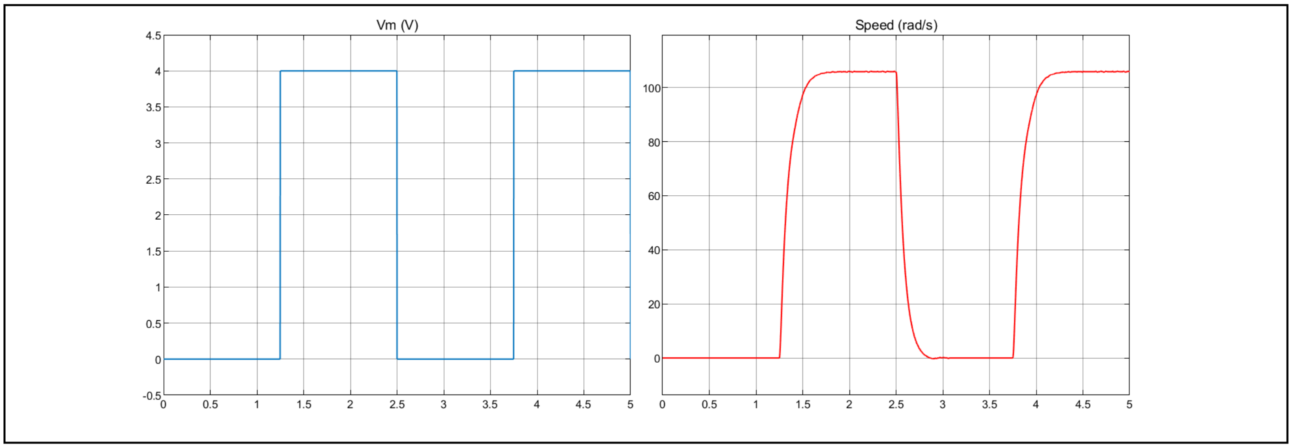
8. Using the **Scope** *Cursor Measurement tools*, read off the steady-state value and the required times to collect data and calculate the parameters K (**DC gain**) and τ (**time constant**) and provide the values and the identified **transfer function** model. Complete the first row of **Table 1**.

Table 1

Applied Input	Rotation (CW /CCW)	Δu (V)	Δy (rad/s)	DC Gain (rad/s/V)	Time Constant (sec)	Transfer Function Model
+2V to -2V (Offset = 0V)	CW & CCW	4	117.7	29.425	0.110 s	**Model 1** $\frac{29.425}{0.110s+1}$
0V to +4V (Offset = +2V)	CW	4	105.9	26.475	0.114 s	**Model 2** $\frac{26.475}{0.114s+1}$
+1V to +5V (Offset = +3V)	CW	4	97.35	24.3375	0.099 s	**Model 3** $\frac{24.3375}{0.099s+1}$
0V to -4V (Offset = -2V)	CCW	4	106.1	26.525	0.099 s	**Model 4** $\frac{26.525}{0.099s+1}$
-1V to -5V (Offset = -3V)	CCW	4	97.07	24.2675	0.138 s	**Model 5** $\frac{24.2675}{0.138s+1}$

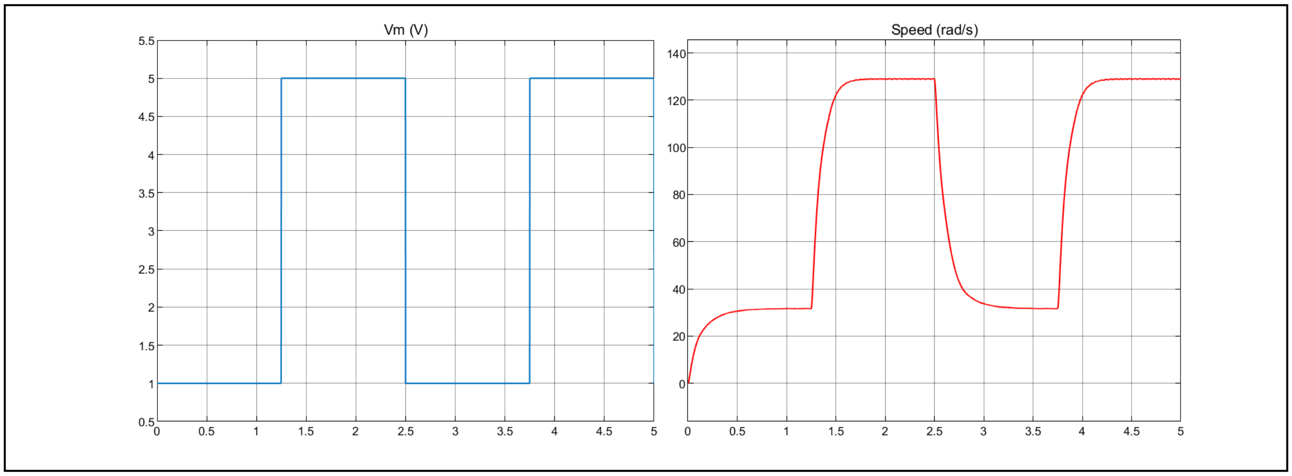
9. Set the **Constant** block value to **2**, to apply a **+2V voltage offset**. In this case the applied input is a step input from **0V** to +**4V**.
10. **Run** your code for **5 seconds**. Open the **Scope**. Provide the plot below and calculate the required parameters. Inserts the values in the second row of **Table 1**.

Motor Input Voltage (V) & Disk Angular Speed (rad/s) – (Input 0V to +4V)

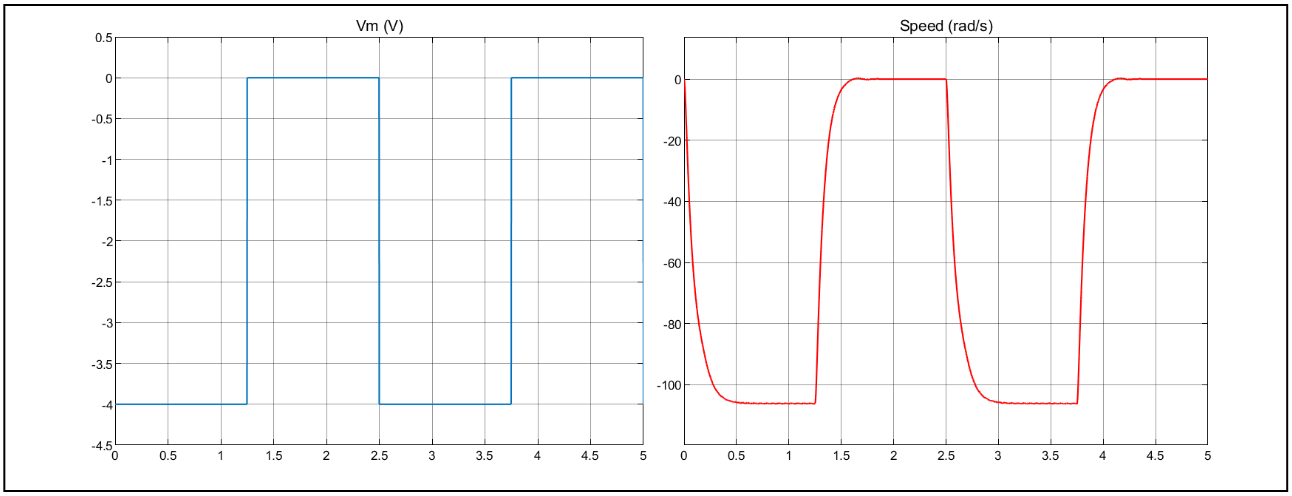


11. Change the **voltage offset** to the given values in **Table 1** to generate different step inputs. **Run** your code for **5 seconds** in each case, do the calculations and complete the required parts of **Table 1**. Provide your graphs below.

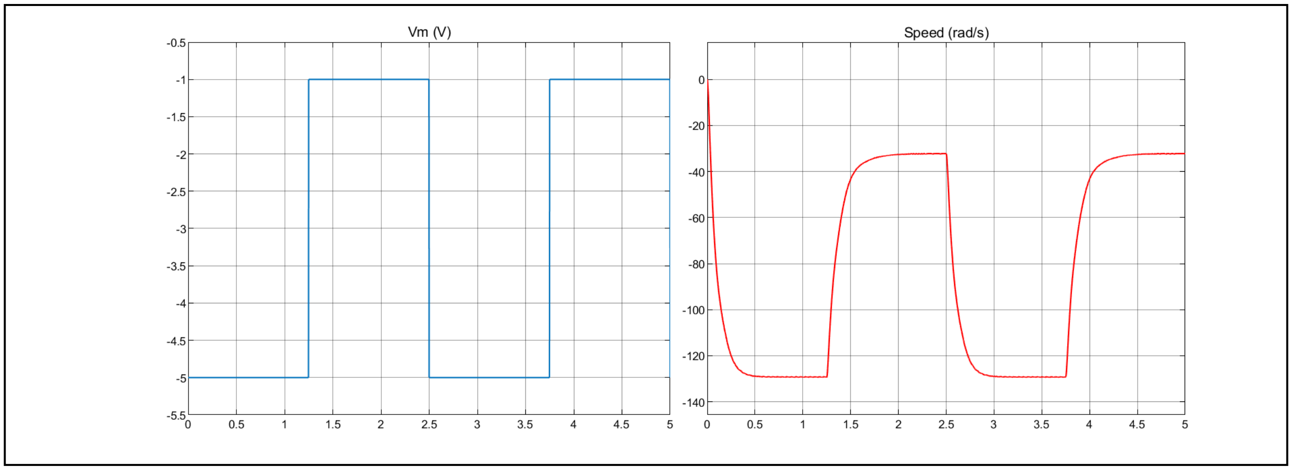
Motor Input Voltage (V) & Disk Angular Speed (rad/s) – (Input +1V to +5V)



Motor Input Voltage (V) & Disk Angular Speed (rad/s) – (Input 0V to -4V)



Motor Input Voltage (V) & Disk Angular Speed (rad/s) – (Input -1V to -5V)



12. Compare the identified transfer function models in **Table 1**. Are they consistent with each other? If there is a difference between them, what could cause this difference? Which model provides a better approximation of the real system?

Model 2 and Model 4 have a close similarity since one is rotating CW and the other CCW, the single difference is that of the time constant. Same goes for Model 3 and Model 5.

The Model that represents closely to the real system would be Model 3 because it avoids the dead zone but the values it has are closer to the approximation for the real system. We can select different models depending on the operation conditions. For example, difference in vibrations and criteria's etc.

13. Compare the identified transfer function models in **Table 1** with the one you obtained from the mathematical modelling in **Lab 3**. Which one is more consistent with the mathematical model in **Lab 3**? Why? Justify your answer.

The transfer function that I found to be more consistent with the mathematical model in Lab 3 would be Model 3 which is $\frac{24.3375}{0.099s+1}$. In lab 3 it is assuming an ideal system whereby model 3's transfer function has system disturbances like variation in power supply, friction and other external factors.

14. **Stop** the model.
15. **Power OFF the QUBE-Servo 3 system.**