Individual Assignment

Practice Modelling and Simulation

Author	*Date*
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Module	Deadline
System modelling	April 9, 2021

1. Introduction

An electric two-wheeler is propelled by electric motor(s), using energy stored in rechargeable batteries. The chosen motor should be powerful enough to deliver required vehicle performance. For this case a DC motor is to be researched. It is an electromechanical machine that converts electrical energy, supplied by battery, into mechanical energy. A simplified electric circuit of DC machine is shown in figure 1.

2. Problem definition

Investigate whether the DC motor is capable of propelling the vehicle for the given load condition(s).

3. Simulink modelling

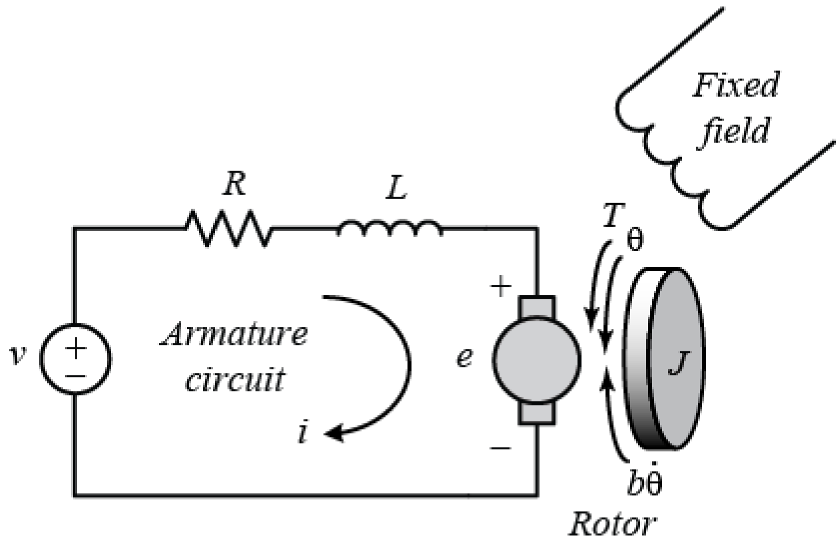

Figure 1: DC motor electrical circuit

DC motor’s electrical dynamics is described by the following equation:

$$v = Ri(t) + L\frac{di(t)}{dt} + K_b\frac{d\theta(t)}{dt}$$

Where:

- v(t): Motor's input voltage [V].
- R: Armature resistance [0.03 Ω].
- L: Armature inductance [2.5 mH]
- i(t): Motor's armature current [A].
- K_b: Back-emf constant [0.35 V.s/rad].

And the mechanical dynamics of DC motor is represented by the following equation:

$$J\frac{d\dot{\theta}(t)}{dt} = K_t\, i(t) - \ b\frac{d\theta(t)}{dt} - \ T_L$$

Where:

- J: Moment of inertia of the shaft and load [0.5 * 10^{-3} Kg.m_2].
- K_t: Motor's torque constant [0.9 Nm/A].
- b: Bearing's friction coefficient [0.24 Nm.s/rad]

- T_L = load torque [Nm].

And,

$T_L = F_L . v. i . r$

Where:

- v = vehicle velocity [m/s]
- i = transmission ratio [0.2]
- r = dynamic wheel radius [0.3 m]

Furthermore, the simplified dynamics of the road load acting on vehicle is described as:

$$F_L = W + X\,v^2 + Y\frac{dv}{dt} + Z.\sin\alpha$$

Where:

- W= rolling resistance [45 kg.m/s^2]
- X = 0.46 [kg/m]; *B.v^2 = aero dynamic drag [N]; v = vehicle velocity [m/s]*
- Y = mass [300 kg]
- Z = weight [3000 N]; $D.\sin\alpha = gradient\ force\ [N]$; $\alpha = slope\ angle\ in\ radians$
- F_L = load force [N]

Your work will be graded on the following aspects:
• Correct and clearly commented and sectioned MATLAB script.
• Correct and clean modelled equations in Simulink.
• One click run system. One click in the MATLAB editor should simulate Simulink model and should generate all necessary graphs.
(Note: The assessor will not make any changes in the files to run a different scenario. The model will be considered incomplete without this)

4. Verification

Under verification, model is simulated for various scenarios and results are observed to check the consistency with existing knowledge of the system. Verification ensures that the model has been translated well from differential equation into Simulink.
For the verification following parameters can be used:

a. Scenario 1:

A step rise in the input voltage at 0.1 second from 0 to 48 V
A constant input of velocity = 0 [kmph]
A constant input of road slope = 0 [degree]

Run the <u>simulator for 0.4 seconds</u> and show the motor current and angular speed graph as a function of time. Is this behaviour expected? Why? Why not? Comment on the graph.

b. Scenario 2:

A step rise in the input voltage at 0.1 second from 0 to 48 V
A ramp input of velocity at 0.5 second. From 0 [kmph] to 36 [kmph], slope of ramp input = 1.
A step input of road slope from 0 to 3 degrees at 0.5 second.
Pay attention to the units.

Run the simulator for 30 seconds and show the current and angular speed graph as a function of time. Comment on the graph(s).

c. Chose a different velocity input to represent vehicle velocity from 0 [kmph] to 36 [kmph] and simulate the scenario for 50 seconds. Plot meaningful results and comment.

• Your explanation(comments) should include answers to the following questions:
– Why did you choose the specific outputs?
– Does the output make sense? What makes you think it is correct or wrong. Is it something you expected? If yes, why did you expect it and if no, why did you not.
– comment on the system behaviour.
The following outputs plots should be generated from the simulation:
- a figure displaying the input
- a figure displaying the chosen outputs(if all of them are required).

Your work will be graded on the following aspects:
• Correct and clear plots(with a proper title, axes, legends, units and meaningfulness of the values) of the outputs and inputs.
• Correct and critical comments on the behaviour of the system.
• Correct and reasonable choice of input and outputs.
• Critical and clear conclusion on the results.

5. Validation

Model validation can be done by comparing it with the test data. In case the text data is not available, sensitivity analysis can be performed to know the bounds of the system along with its behaviour. In this case, you validate using both the approaches:

a. Import the data file ”InputOutputData.xlsx” of the test results and match them with the obtained model results, choose the vehicle parameters given above. In case you find deviations(which is the most obvious case), comment on why could these deviations be present and because of what reasons. Use the input data from the imported data to run the simulation and compare the model results with the actual results.

b. Make a sensitivity analysis of 10% increase and decrease of the parameters (one parameter at a time) ‘J’, ‘b’ and ‘i’ on the outputs of the system. Choose outputs wisely and comment on why you chose the outputs.

6. State space

Create the state space for the system (Hint: It would be wise to create a state-space for each subsystem separately). Find the A, B,C and D matrix for this system and model it in Simulink to match the results with the differential equation model. What do you observe?

7. Transfer function

After you have achieved the state space, use MATLAB to convert the state space into the transfer function (or create a transfer function of the entire system from scratch). Match the results of the transfer function with the state space and the differential equation model and comment. Is it possible to obtain a single equivalent transfer function of the system?

8. Bonus question

- Determine what is the maximum velocity of the vehicle on a flat road. Explain briefly what changes are made and plot the necessary graphs.
- Investigate the boundaries of solver step size in 'fixed step solver'. Why the model shows an error at step size above 0.005 seconds.

9. Deliverables

The modelling should be done in version 2018a or above.

• Single m-file containing all pre-processing commands, simulation commands and post-processing commands with proper comments and structure.

• All the necessary files required to run the model.

• A PDF-file (report) discussing all the necessary steps. This is done with respect to:

- Verification and validation of the model
- Necessary and readable figures generated by the m-file
- The state space, and
- The transfer function for the system
- Conclusion
- Analysis on the bonus part (if attempted)

10. Assessment

Individual assignment will be assessed only if it meets the following conditions:

• The deliverables are handed in as a soft-copy before or on the day of the deadline (April 9, 2021) to the respective lecturer in HANDIN app.

Lecturers:

- Nikhil Muthakana
- Sanket Dutta
- Aishwarya Aswal

• All files are delivered in one zip file. <u>The report should be in pdf format and not longer than 8 pages</u> including the cover page but excluding bonus question.

• The report is properly structured and professionally formatted.

• Copying other student's work is considered fraud and will be reported to the exam committee.

11. Marking scheme

Deliverables are assessed according to the following criteria:

• Correct and organized model in Simulink (15p)

• Correct and logical coding in MATLAB (15p)

• Correct and complete visualisation (10p)

• Correct verification (20p)

• Correct validation (20p)

• Correct State Space (10p)

• Correct Transfer function (10p)

• Correct Bonus question (max 10p)