ME 211 – Modeling and Analysis of Dynamic Systems

TWO FLYWHEEL SYSTEM MODELING COURSE PROJECT

The objective of this course project is to model and analyze a system consisting of a DC motor and two flywheels, simulate the model for different input voltage signals, and compare the simulation and experimental results. One flywheel is directly attached to a DC motor and the second flywheel is attached to the first flywheel via a torsional spring. See Figure 1. Encoders are attached to the DC motor and second flywheel to measure their angular positions. A command voltage is sent from a computer processor via an analog output board to a pulse width modulator (PWM) and the PWM sends a voltage to the motor. The PWM may be modeled as an amplifier with a gain $K_a = 2.4$. The incremental encoders send pulses back to a counter/timer board on the computer that determines the angular positions of both flywheels. The file **motor.pdf** on the course website contains the motor specifications. The moment of inertia of the motor, shaft 1, and flywheel 1 is $J_1 = 1.95 \cdot 10^{-6}$ kg·m^2. The viscous friction coefficient of the motor, shaft 1, and flywheel 1 is $B_1 = 1.4 \cdot 10^{-6}$ N·m/(rad/s). The spring stiffness is $K = 1.0 \cdot 10^{-2}$ N·m/rad. The moment of inertia of the encoder, shaft 2, and flywheel 2 is $J_2 = 2.5 \cdot 10^{-5}$ kg·m^2. The viscous friction coefficient of the encoder, shaft 2, and flywheel 2 is $B_2 = 1.0 \cdot 10^{-7}$ N·m/(rad/s). Complete the following tasks:

1. Symbolically determine a set of first order differential equations describing the system dynamics.
2. Symbolically determine the transfer function relating the angular position of the second flywheel to the command voltage. Ensure the coefficient multiplying the highest power in the denominator is one.
3. Create a Matlab Simulink simulation of the two flywheel system. Provide a screen shot of the Simulink block diagram in your report. The course website has the following files posted on it: **step.txt**, **ramp.txt**, **sine2.txt**, **sine4.txt**, **sine10.txt**, **sine20.txt**, **sine30.txt**, and **sine50.txt**. These files contain data for separate experiments where a command voltage was output from the computer processor and the resulting angular positions of both flywheels were measured. Each file contains four columns: the first is time in s, the

second is the first flywheel angular position in rad, the third is the second flywheel angular position in rad, and the fourth is the command voltage in V. The data are sampled at a constant rate. For each data file, use the command voltage as the input to your Matlab Simulink model and simulate the angular positions of both flywheels. For each experiment make a figure with three subplots. The first subplot is the angular position of the first flywheel versus time. The second subplot is the angular position of the second flywheel versus time. The third subplot is the command voltage versus time. The first and second subplots should contain two lines: one for the simulation and one for the experimental data. For these two subplots include a legend and clearly distinguish the lines.

4. Using the transfer function in Task 2, determine the location of the finite poles and finite zeros. For each real pole, what is its time constant, rise time, and 2% settling time? For each complex conjugate pair of poles, what is their natural frequency, damping ratio, rise time, 2% settling time, peak time, and percent overshoot?
5. Using the transfer function in Task 2, analytically determine the transfer function's frequency response. Using the data from the sinusoidal experiments, experimentally determine the frequency response for those specific frequencies. Make a figure with two subplots. The first subplot is the analytical and experimental magnitude frequency responses. The second subplot is the analytical and experimental phase frequency responses. Both subplots should contain a line for the analytical frequency response and distinct markers for the experimental frequency response. The subplots should include a legend.
6. Discuss the results. This discussion should include a comparison of the simulation and experimental results for each experiment and the frequency responses.
7. Discuss the strengths and weaknesses of this course project including the analysis, simulation, and experimental components. Did the course project help you to learn the material better? Explain why or why not.

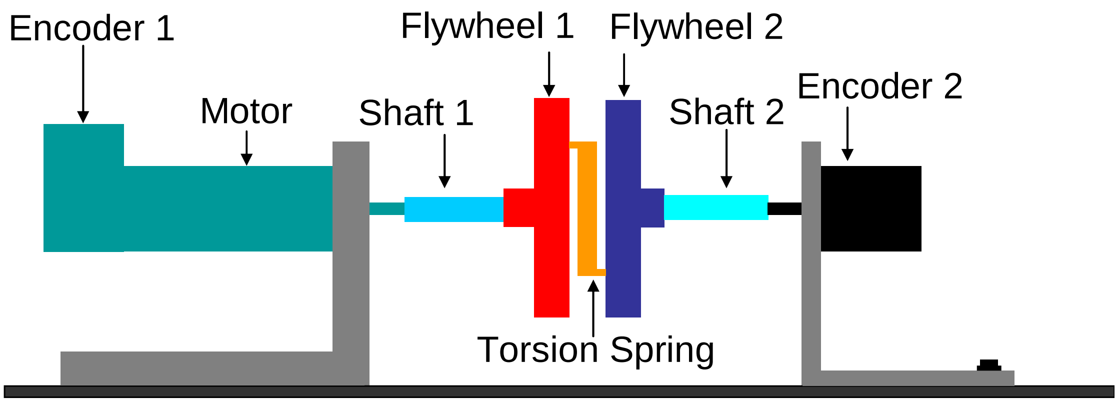

Figure 1: Two Flywheel System Schematic

Report Format

The report must be created in a word processing package, include page numbers, and be written clearly and concisely. Documents must be printed on a laser printer, equations must be created in an equation editor and numbered, plots must be numbered and contain a descriptive caption and units, axes must be labeled and contain units, diagrams must be drawn with a software package, and major sections and subsections of the report must be clearly denoted. The deliverables are a hard copy of the report, an electronic copy of the report, and an electronic copy of the Matlab Simulink simulation. The report must contain the following sections:

<u>Title Page</u>: The Title Page includes the following information: project title, student's names, ID numbers, and email addresses, course title, instructor's name, and date.

<u>Abstract</u>: The Abstract provides a brief overview of the report that includes a clear, concise explanation of the problem, approach, and results.

<u>Introduction</u>: The Introduction is an explanation of problem. You may paraphrase what is given above.

<u>Approach and Results</u>: The Approach and Results section is a detailed description of methods that are used to solve the problem and the resulting outcomes. Each task will be a subsection in this section. Simulation and experimental plots should be provided. Put multiple plots on one page when possible. Each plot must be numbered and contain a descriptive caption. Each axis must be labeled and have units. If multiple lines are on a graph, a legend must be provided and each line must be clearly distinguished.

Discussion: The Discussion section provides a rich discussion of the project outcomes. Do not simply state what you see in the graphs. Interpret the results.