MEEN 432 – (Introduction to) Automotive Engineering

Spring 2026

Instructor: Dr. Arnold Muyshondt

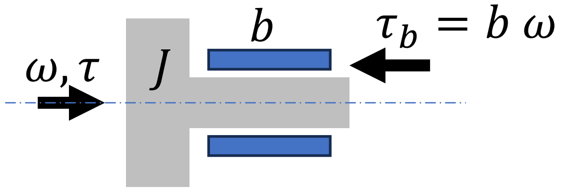
Project 1: Basics of Numerical Simulation

- Objective: Learn about numerical simulations broadly, and specifically learn to use Matlab and Simulink.
- Weekly commits need to be in by Saturday 11:59PM.

Project Description

- Model and simulate a simple dynamic system S_1 consisting of an inertia on a shaft on a bushing
  - Study the impact of the component parameters (inertia, damping, etc.) and simulation parameters (integration method, step time, etc.) on the simulation performance (accuracy, speed, etc.)
- Model another similar system S_2 and explore the implications when the two systems need to be coupled
- Detailed weekly instructions are provided for Project 1 – they will NOT be provided in such detail for Project 2 and 3
- Weekly progress will be evaluated ONLY on commits made to the repository (emails and other messaging methods will not be accepted)
- Commits need to have a well defined “README” that provides with the TA enough instructions on how to “run”/”view” your progress.

Part 1: (with System S_1 alone)

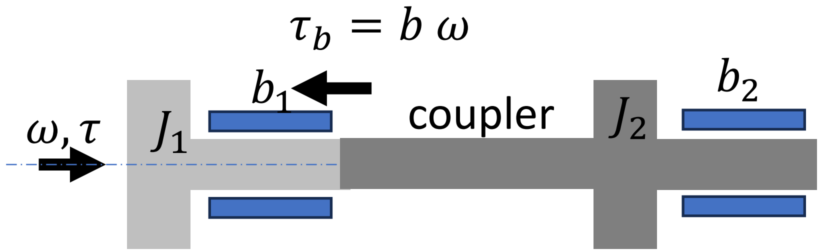


- The system S_1 consists of an shaft of inertia J $\left(\mathrm{kg\,m^2}\right)$ rotating in a bearing that has a viscous damping coefficient b $\left(\frac{\mathrm{Nms}}{\mathrm{rad}}\right)$ at angular velocity ω $\left(\frac{\mathrm{rad}}{\mathrm{s}}\right)$. An external torque τ (Nm) is applied, and the shaft starts from an initial angular velocity of ω_0 $\left(\frac{\mathrm{rad}}{\mathrm{s}}\right)$
  - Use SI units unless specified otherwise (or you have a good rationale that you can defend)

Part 1

1. Create a model of a Inertia-Rotational Damper system (S1) shown above:
    a. Each component (Inertia, Rotational Damper) needs to be in a separate MATLAB function
    b. The components should be parameterized (I.e. not hardcoded) so the parameters can be set from the command line or from scripts
    c. The integrators should be explicitly captured outside of the MATLAB functions
    d. Collect the Inertia and Rotational Damper in a subsystem
    e. Save needed signals to the workspace
2. Simulate the system (from a script) under the following conditions:
    a. Initial Conditions: [w_0 = 10.0, 0.0 rad/s]
    b. Rotational Inertia: [J1 = 100, 0.01 kg-m^2]
    c. Damping Coefficient: [b = 10, 0.1 N-m-s/rad]
    d. Applied Torque:
        a. Constant: [A = 0.0, 100 N-m]
        b. Sinusoidal: sin(wt), w = frequency = 0.1, 100 rad/s
    e. Integration Method:
        a. Fixed Time Step: (0.001, 0.1, 1 s)
            i. Euler
            ii. Runge Kutta 4^{th} order
        b. Variable Time Step:
            i. Ode45
            ii. Ode23tb
    f. Total Simulation Time of 25s
3. For each of the simulation above capture the following, using appropriate scripting:
    1. All the simulation variables (rotational speed and position of inertia, actuation force, damping force)
    2. The CPU time taken for simulation
    3. The maximum error between the simulated rotational and the theoretical rotational speed (for step inputs only). For sinusoidal inputs, use the solution from runge kutta 4th order, with DT = 0.001.
4. Complete the simulations and prepare the follow plots:
    1. Max simulation Error vs time step, for the different fixed time step Integration methods
    2. CPU Time taken vs time step, for the different fixed time step integration method
    3. Max simulation Error vs CPU Time taken for the simulation, for each of the different integration methods (both fixed time step and variable time step)
    4. Contour plots of constant system eigen values with Max Sim Error on y axis and CPU time on x axis.
    5. Contour plots of constant input frequencies with Max Sim Error on y axis and CPU time on x axis.

Part 2



Should the “coupler” be modeled as a stiff spring?

Now you want to connect the two systems S1 and S2 to get the new system S12

1. Create a model for S2. How would you "combine" the two systems? Consider the following two options:
    1. Option 1: Model the long shaft as a flexible shaft, using a stiffness element k.
    2. Option 2: Combine the equations of the two shafts and write a single new model, that has the combined inertia and damping of the two individual systems.
    3. Option 3: Pass the inertia of system S1 to S2 as well as the responsibility of integration to S2 (as will be discussed in class).
2. For each of the options simulate with the following parameter selections:
    1. J1 = 100, b1 = 1; J2 = 1, b2 = 1; Consider constant step inputs 1 and 100
    2. For option 1, consider k = 10, 100 and 1000
3. Perform simulations with ode1, ode4 for time steps 0.1 and 1, as well as ode45
4. Plot: Shaft speed (for option 1, shaft speeds at either end of the stiffness) vs time. Compare the three options together, for various stiffnesses.
5. Tabulate: CPU time for the different options. 5. In all the above, add appropriate legends.