Department of Mechanical Engineering
Cleveland State University

MCE 403/503: Modeling and Simulation of Mechatronic Systems
Second Midtem Exam - Fall 2010
-Take-Home Portion-

Reports and simulation files due Monday, November 15 2010
You will simulate the operation of a bicycle using the simple model derived in class with realistic parameters and simulation software. Consider a standard road bicycle powered by a rider traveling on a surface with varying grade. The grade is zero for the first 300 m. Then it becomes 2 percent for the rest of the ride. The rider starts in low gear (small chainring and large rear sprocket) and shifts sequentially to the next-highest gear at 5-second intervals. The small chainring is 69 teeth and the large one is 74 teeth. The sprockets are 11,12,13,14,15,17,19,21,23 and 25 teeth. Consider that the rider applies a constant torque of 25 Nm for the duration of the ride. The total duration of the ride is 120 seconds.

a. Prepare the bond graph including tire inertias and adjustable gear ratio between pedals and rear wheel. Also include the effect of grade and tire rolling resistance (a force of 6 N applied at the center of mass opposite to the direction of travel).

b. Use the numerical values of Table 1 for the bike parameters. You may derive the differential equations by hand or use 20-sim to obtain code that can be modified and used in Matlab/Simulink.

c. Once the model has been represented in Simulink, add the necessary blocks to implement the grade variation and the gear shifting sequence used by the rider.

d. Simulate the ride and calculate:

   (a) The distance traveled in m.

   (b) Plot pedal rpm as a function of time.

   (c) Plot the power exerted by the rider at the pedals as a function of time (Watt vs. seconds)

   (d) The calories spent by the rider (integrate the power at the pedals and convert to Kcal)

   (e) Suppose a carbon fiber frame upgrade is being considered for $400, which reduces the overall weight by 1 kg. Repeat the simulation and re-plot the power chart and comment.

Parameter	Value	Units
Front Wheel I	0.0885	kg-m^2
Rear Wheel I	0.0967	kg-m^2
Wheel radius	35	cm
Bike weight	9	kg
Rider weight	81	kg

Table 1: Bicycle Parameters

Notes on using 20-sim

1. When building the bond graph in 20-sim, use SE and TF instead of MSE and MTF for the road grade and gear inputs. You will be able to make them variable once you're working in Simulink.

2. 20-sim is unable to obtain models with several inputs/outputs. This model has two inputs: pedal torque and gravity force due to road grade. You will need to obtain the model equations twice. First define the input as the effort of the torque SE and copy-paste the B matrix. The code will show B(1,1). Then repeat the process, defining the input as the effort of the grade SE and copy-paste the B matrix. Change this second formula to B(1,2). Your overall B matrix will have 1 row and 2 columns.

3. The state derivative function will be something like:

   `function pdot=stateder_bike(p,gear,theta,torque)`.

   Edit the constant values to reflect Table 1. Include code to calculate the force at the center of mass (`Fh`) using `theta`, the total mass and $g = 9.8$ m/s^2. Include the rolling resistance force here as well. Finally, calculate the state derivative as `pdot=A*p+B*[torque;Fh]`

4. Use the class example posted on the course webpage for a Simulink template. Add appropriate multiply and divide blocks to calculate the quantities to be plotted (power at the pedals is calculated multiplying the corresponding flow and effort).

General hints

1. Pay attention to the inertia variable chosen by 20-sim to be the state. You need to find appropriate output equations as a function of this state for the variables to be plotted.

2. Pay attention to the definition of transformer modulus (20-sim uses the same definition as KMR and the class notes).

3. Calculate all possible gear ratios and sort the list in ascending order. Include these values using the signal builder or any other way you see fit.

4. Be very careful with units!. The instructor has verified and executed the simulation and the results are very realistic. Expect a peak pedal power near 120 W and a sharp decrease in speed when the 2% grade sets in.