Department of Mechanical Engineering
Cleveland State University

MCE 403/503: Modeling and Simulation of Mechatronic Systems
Final Project - Fall 2010
-Modeling and Experimental Parameter Estimation of Hybrid-Electric Bicycle-

REPORT DUE ON 12/17/2010 BY 5PM. Email Simulink and M-files to instructor.
Note: A zipped file has been uploaded to the course website containing several experimental data files:
`http://academic.csuohio.edu/richter_h/courses/mce503/bikedata.zip`

1 Bond Graph

You will prepare a bond graph with an **effort** source at the pedals (torque). This source is in addition to friction torques at the rear and front hubs and total resistance force at the center of mass (due to grade and rolling resistance). Construct a bondgraph for the bicycle including the following:

1. Overall mass M
2. Variable gear ratio from pedals to rear wheel g, defined as velocity of the rear wheel divided by velocity of the pedals.
3. Rear wheel inertia J_r and hub friction T_{fr} as an external source of torque.
4. Front wheel motor: combine the front wheel inertia and motor inertia into one, J_f. Include friction as an external source of torque T_{ff}. Consider a combined electrical resistance R_e, but not inductance. The torque constant is α.
5. Road elevation and rolling resistance: as done in the second midterm. The overall force is F_h
6. Batteries: Model as a capacitor C_b in series with the combined resistance R_e. Point the arrow away from the capacitor to imitate a source.

1.1 Equation Derivation

Hand derivation is recommended, but 20-sim may be used with care.

1. Let the states be q of the capacitor and momentum p of the rear wheel.
2. Let the inputs be the 4 sources of effort.
3. Let the outputs be: traveling speed, battery current, battery state (q) and pedaling speed
4. Derive the state equations symbolically, including appropriate output equations. Give matrices A,B,C and D.

2 Parameter Calculations

You will combine all experimental data to obtain all the necessary model parameters.

2.1 Instrument Sensitivities and Some Constants

1. Small load cell sensitivity: 118.21 N/V (used to weigh bike and for torque test)
2. Wheel radius: r=0.3345 m
3. Bike mass (no rider) M_b=40.257 kg
4. Battery capacitance C_b=864 F
5. Moment arm of torque measuring device: 24.83 in

6. Idle current: 0.044 A
7. Mean rolling resistance coefficient: 0.0045 (multiply by total weight to find rolling resistance in N).
8. Range of gear ratios : g: 1.2 to 4.6

2.2 Torque constant

Matlab file `torquetest120110.mat` contains a matrix T with 10 rows and 3 columns: current in A, load cell voltage and battery voltage. Calculate the torque using the data in the second column, the load cell sensitivity and the moment arm. Discount the idle current from the data in the first column and perform linear regression between current and torque to find α in N-m/A

2.3 Rear Wheel Spindown Test

Matlab file `rear_spindown.mat` contains two variables: `rear_pulse` and `t`. Each complete cycle corresponds of a rotation of 60 degrees. Plot the pulses against time and obtain the times required to rotate 60 degrees near 1 second, 2 seconds, etc. until covering the 10 seconds. Calculate the angular speeds in rad/s from these times. Plot the angular speed of the wheel as a function of time. You should get a fairly constant slope (deceleration). Calculate the deceleration in rad/sec^2.

The static friction torque measurement indicated that a weight of 0.8388 N at a radius r was required to balance the friction torque. Use this information and the deceleration to find the moment of inertia of the rear wheel, J_r in kg-m^2 and the friction torque, T_{fr} in N-m.

2.4 Front Wheel Spindown Test: Method 1

Matlab file `front_spindown.mat` contains to variables: `front_wheel` and `t`. The first variable is a series of pulses occurring once per revolution. Plot the pulses against time and obtain the times per revolution. Convert to angular speed in rad/s and plot against time. Use linear regression to find the slope of the linear portion of the angular speed trace (deceleration).

The static friction torque measurement indicated that a weight of 2.2073 N at a radius r was required to balance the friction torque. Use this information and the deceleration to find the moment of inertia of the front wheel, J_f in kg-m^2 and the friction torque, T_{ff} in N-m.

2.5 Front Wheel Spindown Test: Method 2

The wheel was spun at 433 rpm and allowed to come to rest, decelerated by the friction torque. The time to reach zero speed was measured as 10.8 seconds. Then, an additional inertia J_a was attached to the rim, with value $J_a = 0.0187$ kg-m^2. The initial speed was again 433 rpm, and the final speed zero. The time to reach zero was 12.8 with this added inertia. Set up a system of two equations to find the unknowns J_f and T_{ff}, as explained in class. Compare values with Method 1.

3 Equivalent Electrical Resistance

A resistance R_e is considered that includes all electrical power losses due to the efficiency of control circuitry, motor and the copper resistance. The front wheel was suspended and accelerated to a constant speed of 373 rpm. Only friction torque is acting on the wheel, resulting in a mechanical power P_{mech}. Calculate this number in Watt, using the highest T_{ff} from the two methods. At this condition, the current flowing from the battery was 0.85 A, and the voltage was 51 V. This gives a higher power figure, P_{elec}. Calculate the power difference ΔP in Watts. We assume that ΔP is all dissipated as the 0.85 A flow through a resistance R_e. Use:

$$\Delta P = i^2 R_e$$

to calculate R_e in ohms. Also calculate the efficiency of the conversion from battery power to mechanical power under these conditions.

4 Summary of Calculations

Present a table with quantity label, units and value for each and every one of the parameters found above.

5 Simulation

Set $g = 1.2$ and consider a 700 N rider. Take the average of J_f and T_{ff} from the two methods and the calculated values for α, J_r and T_{fr}, together with the other given constants. Find matrices A, B, C and D numerically. Since all inputs will be constant, a very simple Simulink diagram will be used (see Fig 1) Use a state-space block from the Continuous menu and enter symbols for the 4 matrices, which should be loaded in the workspace. The initial condition vector has zero for the rear wheel momentum and q_0 for the initial battery state. Calculate $q_0 = 50C_b$ (50 volts times the battery capacitance). Use mux and demux blocks from the Signal Routing menu to assemble the input vector and split the output vector for plotting. Note that A is 2-by-2, B is 2-by-4, C is 4-by-2 and D is 4-by-4. The initial state vector must be 2-by-1. Use constant blocks for all 4 inputs.

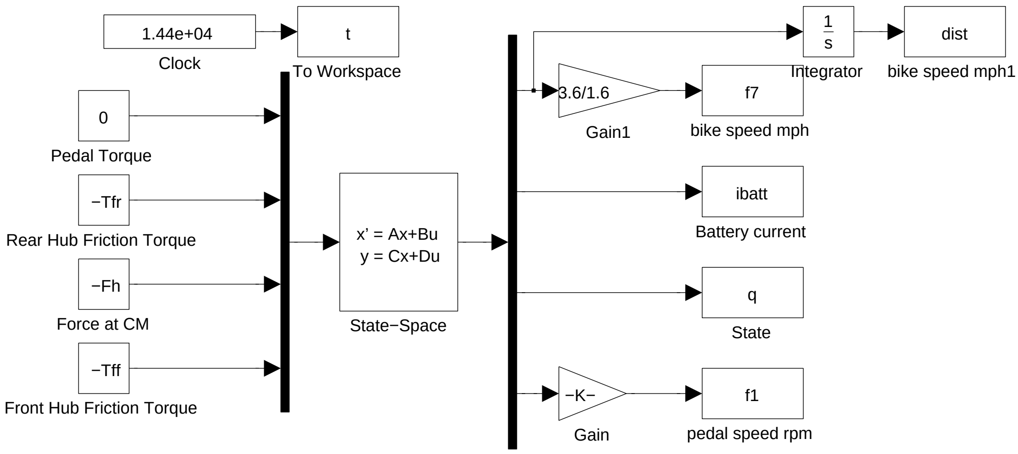

Figure 1: Sample Simulink Diagram

If you are using the figure as a reference, please take special care in following the ordering of the input and output vector elements (reflected in matrices B, C and D).

5.1 Calculating True Battery Voltage

As explained in the electric vehicle case study posted in the course website, the reversed arrow for the C element requires special interpretation. To calculate battery charge history use

$$q_{batt} = 2q_0 - q$$

where q is the state from the simulation. Then calculate battery voltage as q_{batt}/C_b. Simulate until this voltage has dropped to 40 V. Submit the following plots as a function of time:

1. Battery voltage
2. Battery current
3. Travel speed in mph
4. Pedal speed in mph
5. Distance traveled in miles.

Answer the following question: the torque at the pedals was set to zero. However the pedals rotate. Explain which element is missing in this bike model.