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ECE 492

Motor Controller + Modeling Physics Model Memo

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Abstract

This memo provides information about the developed physics model for the fully integrated car using estimated parameters. This model will be used to implement a model in Simulink which will accurately model the behavior of the motor + controller system.

System Description

Based on the data collected and analyzed in the Static characterization report and Dynamic characterization report, a physics model were created using the coefficients found after extensive data analysis.

Static Characterization Model

This equation below which was derived in the static characterization report [1] uses constant inputs of current and torque to determine the speed at which the motor is spinning. Note: this equation provides accurate values for RPM given torque in N-m, not ft-lb.

$$w = \frac{768.75i}{T_L} - 178.56$$

Dynamic Characterization Model

The two equations below which were derived in the dynamic characterization report [2] extend the above-described static model by also taking into account the moment of inertia for the motor system.

$$w =- .006(\frac{dw}{dt}) + \frac{768.75i}{T_L} - 178.56$$

$$i = \frac{T_L(w+178.56+.006(\frac{dw}{dt}))}{768.75}$$

These equations will be implemented in Simulink in order to provide predictions for motor response to given inputs in both static and dynamic cases. They will be useful in order to make predictions for both the rate of discharge of the battery given speed and torque, and car speed given torque and current draw.

Fully Integrated Car Predictions and Simulation

The graph below in **Figure 1** was collected in an experiment where data was collected at a constant power (200A at 89.7V) across the full achievable range for torque and RPM in the current motor setup.

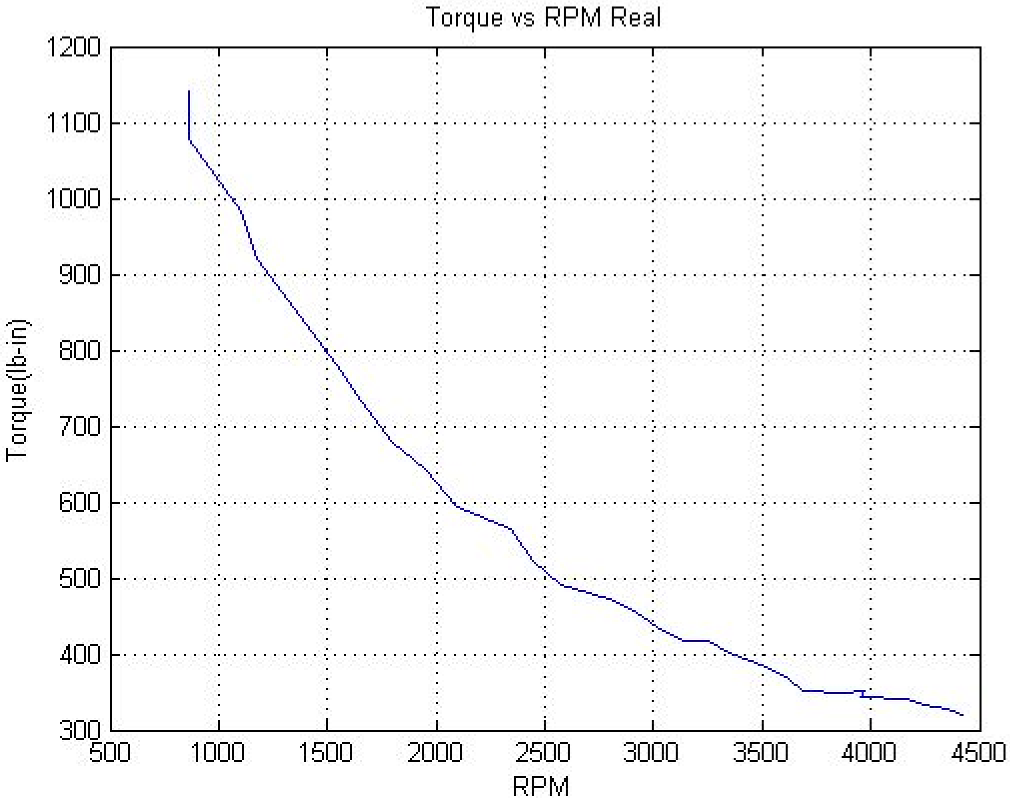

Figure 1

Utilizing this data, a Matlab simulation was created for a fully integrated car using several estimations for parameters **Figure 2.** The weight of the car was estimated by knowing the weight per accumulator pack (80 lbs), and the estimating the weight of the chassis at 330 lbs, while allowing room for a driver (150lbs). Wheel radius is based on the current car developed by mechanical engineers at Lafayette College. These parameters were implemented into several equations which are included in the Matlab code snapshot in **Appendix B.** Gear ratio was determined by running a straight line max throttle test using other parameters and several settings for gear ratio in order to find one which yielded the shortest amount of time to move a fixed distance **Figure 3.** The data required to generate this plot was synthesized using the following equations:

$$M_{CAR} = 12 * W_{Car}/G$$

Where W is the weight of the car in pounds, G is the acceleration due to gravity in in/sec^2, and M is the car's mass in slugs. Those parameters were passed into these equations in order to generate graphs for position, velocity, and acceleration vs. time.

$$T_s(i) = GT_m(i)$$

$$F_{Tr}(i) = T_s(i)/R_W$$

$$A_{CAR}(i) = F_{Tr}(i)/M_{CAR}$$

Where Ts is the torque through the car's shaft, FTr is the tractive force through the car's rear wheel, RW is the radius of the wheel, and Tm and G are the given motor torque and calculated gear ratio values, respectively. All of the values specified as functions of (i) correspond with the torque for the car given as an array corresponding with a fixed time step. Motor torque is the y intercept of Torque/RPM curve (**Figure 1**) - slope*RPM that allows Torque to equal 0 at end of RPM range

Parameter Estimated	**Estimated Value**
Full car weight (inc driver)	800 lbs
Car wheel radius	8 in.
Gear ratio	2.8

Figure 2

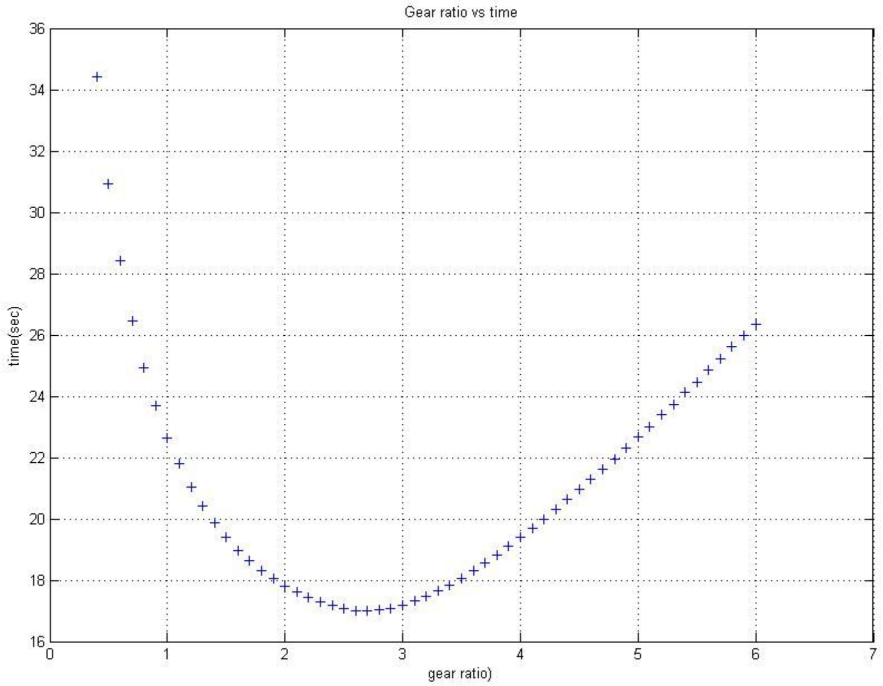

Figure 3

Separately from the Simulink model, this physics model is unable to be verified against known experimental data due to its use of several estimated parameters. However, it will prove useful in answering key questions regarding the predicted behavior of the final car using known data about the motor and controller.

Appendix A: Matlab Code Snapshot

```
%Code to Optimize Gear Ratio for FSAE Vehicle, 2016
%Calvin Murr and Bennett Crawford

% known and specified parameters

%units: pounds, feet, seconds
close all
clear all
grav = 386.4;
u_s = 0.5;
u_k = 0.4;
weight = 800.0; %lb
R_w = 9; %in
m_car = weight/grav;

% Initial Conditions

RPM_m(1) = 0;
RPM_s(1) = 0;
position(1) = 0;
V_car(1) = 0;

delta_t = 0.01;
time(1) = 0;
j=1;

   %From data collected at constant(ish) current, all taken from
   %Full_Range_Static_Test.xlsx saved in this folder
RPM_data = [4420
4345
4250
4167
3950
3970
3882
3685
3618
3490
3350
3251
3137
3014
2926
2790
2570
2445
```

```
2340
2095
1950
1800
1650
1540
1180
1100
860
860];
%RPM

Torque_data = 12* [26.67
27.25
27.8
28.4
28.7
29.3
29.16
29.3
30.62
32.08
33.4
34.7
34.8
36.33
37.8
39.26
40.87
43.5
47
49.5
53.6
56.5
61
65
76.7
82
89.9
95];
%ft-in

%Power Calculations
RPM_data_in_power_units = RPM_data * (2*pi)/(60);%rad/s
Torque_data_in_power_units = Torque_data/12;%ft-lb

Power_angular = (Torque_data_in_power_units.*RPM_data_in_power_units)/550;
%hp
```

```
Voltage = 89.5; %V
Current = [
213
213
213
211
211
209
201
200
200
203
205
206
197
200
202.5
204
200
197.5
203
195
201
198
199
194
201
195.8
202
203]; %A

Power_electrical = Voltage.*Current*.001341; %Hp


%To optimize gear ratio, switch comment to allow GR range, then find
%minimum value GR on Figure 4
% for GR = 2.8;
  for  GR = 0.4:0.1:6.0;
RPM_m = 0;
RPM_s = 0;
position = 0;
V_car = 0;
time = 0;
change=0;

for i = 1:80000;
```

```
if RPM_m(i) < 4500;
    T_m(i) = 95*12 - .017*RPM_m(i)*12; %lb-in, Torque = y intercept of
Torque/RPM curve, - slope*RPM that allows Torque to equal 0 at end of RPM
range
end
if RPM_m(i)>=4500;
 T_m(i)= 0;
end

T_s(i) = GR*T_m(i); %Torque through Shaft
F_tr(i) = T_s(i)/((R_w)); %Tractive Force at rear wheel

%Attempted drag calculation
% C_d = .0002;%Drag Coefficent
% A = 144; %Area of Car Normal to Direction of Travel in inches^2
% rho = .0023769/12^3; %density of air in slugs/ inch^3
% F_d(i) = .5*C_d * V_car(i)^2*A*rho; %Drag Force

A_car(i)= (F_tr(i))/(m_car);

V_car(i+1) = V_car(i) + A_car(i)*delta_t;

% if position(i) >= 568860 && position(i)<=568860.5 && change==0;
%     GR = GR/1.25;
%     change=1;

%---^ necessary if switch gears

position(i+1) = position(i) + V_car(i)*delta_t + 1/2*A_car(i)*delta_t^2;

if position(i) >= 63360/4 && position(i)<=63450/4 %1 mile test
    time_final = time(i);
    Vel_final = V_car(i);
    pos_final = position(i);
end

time(i+1)= time(i) + delta_t;

RPM_s(i+1) = (V_car(i+ 1)/R_w)* (60/(2*pi));
RPM_m(i+1) = RPM_s(i+1)*GR;

end;
optimum(j,1) = GR;
optimum(j,2) = time_final;
optimum(j,3) = Vel_final;
j=j+1;
end;
```

Appendix B:

References

1. https://sites.lafayette.edu/ece492-sp16/files/2016/05/Static_Characterization-1.pdf
2. https://sites.lafayette.edu/ece492-sp16/files/2016/05/Dynamic_Characterization.pdf