Experiment 1
Bicycle Performance Characterization
ECE 482

The objectives of this experiment are:

- To define the requirements on the power electronics to be designed throughout the semester
- To understand how power electronics capabilities relate to the bicycle capabilities
- To characterize and find numerical parameters for the modeling of bicycle hub motors
- To become familiar with use of lab equipment

Section I of this experiment procedure deals with the characterization of the motor, while section II covers simulation and hand analysis of electric bicycle mechanics.

Useful conversions:

- 1 mph = .44704 m/s
- 1 lb = 2.2 kg
- 1 in = 2.54 cm
- v [m/s] / r_w [m] = n [rev/s]
- v [m/s] / r_w [m] * 2π = ω [rad/s]
- F [N] * r_w [m] = τ [Nm]

I. Motor Characterization

In this portion of the experiment procedure, perform tests on the electric hub motor in order to determine the motor characteristics. Known characteristics of the motor are:

<u>Motor Characteristics</u>

- Three Phase
- Permanent Magnet
- Outer-rotor
- Non-geared, direct drive
- BLDC-style windings (i.e. not sinusoidal distribution of turns)

The motor winding voltages can be modeled using the following set of equations

$$v_a = ri_a + L\frac{di_a}{dt} + \lambda_M \omega_r \cos(\theta_r)$$
$$v_b = ri_b + L\frac{di_b}{dt} + \lambda_M \omega_r \cos\left(\theta_r - \frac{2\pi}{3}\right)$$
$$v_c = ri_c + L\frac{di_c}{dt} + \lambda_M \omega_r \cos\left(\theta_r - \frac{4\pi}{3}\right)$$

where only the winding self inductances are considered. Note that ω_r is the electrical frequency, which relates to the mechanical frequency ω_m as

$$\omega_r = \frac{P}{2}\omega_m$$

where P is the number of poles.

The following characteristics need to be determined, through any series of tests you find appropriate

- Number of Poles P
- Delta or Wye termination
- Winding DC Resistance r
- Winding Low-Frequency Inductance L
- Flux Linkage λ_m

Record all experimental results which are used to solve the parameters. Explain, in your lab report, which parameters are solved in each test, why the test was chosen, and how the parameters were obtained from the test result

Each lab station has two multimeters. A single RLC meter and a single multimeter with 4-wire ohmmeter capability are shared among all stations. When measuring resistance, be sure to use Kelvin (i.e. 4-wire) measurement techniques to mitigate the influence of test probe leads. An example illustrating this is given in Fig. 2. Use these same techniques whenever you are making a precise DC voltage or resistance measurement.

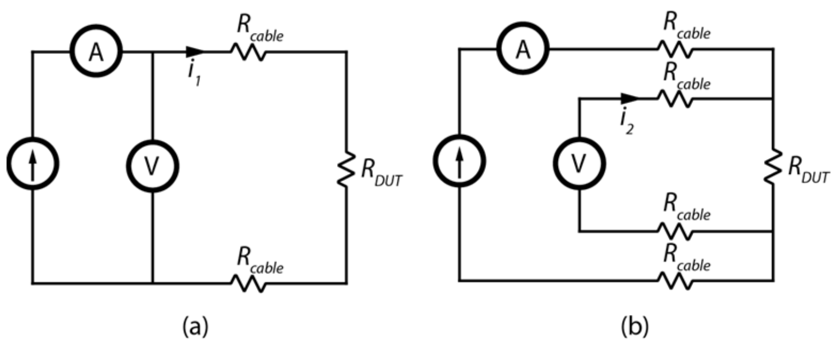

Figure 2: Two wire resistance measurement (a), and (b) Kelvin measurement. In the two-wire case, the measured resistance is R_{meas} = V/A = $R_{DUT} + 2R_{cable}$. In (b), because the voltmeter presents a large impedance, $i_2 \approx 0$ and $R_{meas} = R_{DUT}$.

The motor may be tested while stationary or manually spun on its stand; In all tests, the hub motor windings (V_A, V_B, and V_C) are to remain open-circuited; their voltages may be measured, but no voltage or current may be applied to them.

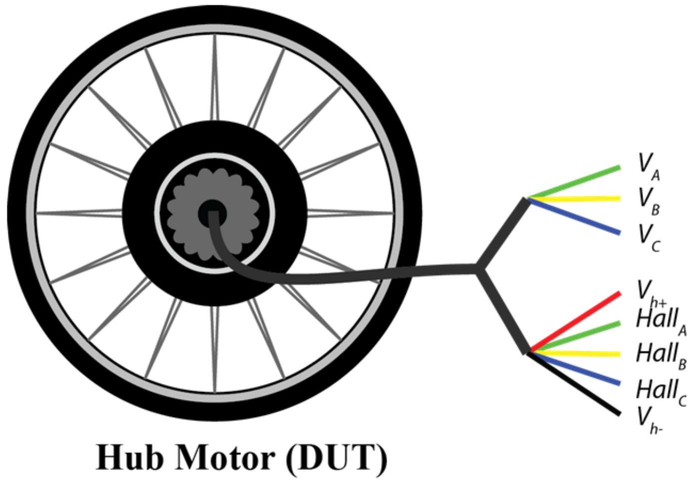

Figure 3: Motor connections diagram for experiment 1

The hub motor has a total of 8 electrical connections which may be made. The lower-gauge (larger diameter) wires comprise the three winding terminations of the motor. The higher-gauge wires connect internally to three digital-output hall sensors which may be used to determine rotor position, which will not be used until latter experiments.

Using the provided Simulink model, `PMSMMotor_Unloaded.mdl`, plug in your measured parameters and verify that the model behaves as expected. In your report, include screenshots from the Simulink model simulation and oscilloscope waveforms from your motor when spun manually which show that your selection of P and λ_m correctly match the observed waveforms.

II. Vehicle Dynamics

The goal of this portion of the experiment is to determine the physical requirements of the electric bicycle drivetrain in order to meet specified performance metrics.

- Top speed of 15 mph or greater
- Ability to travel up a 5% grade at a speed of at least 5 mph
- 0-15 mph acceleration time less than 30 sec

You may use $A_v = 0.5\ m^2$ or estimate your own frontal area on a bicycle. The bicycle weight is approximately 50 lbs. Additionally, for the rider weight, you may use your own weight or design for a 250 lb rider.

Additional characteristics of the bicycle and road conditions are:

- $C_d = 0.65$
- $C_r = 0.013$
- $\rho = 1.204\ kg/m^3$
- wheel diameter $2r_w = 700$ mm

Using the motor parameters found in section I, the mechanical power which is transferred to the rotor is

$$P_m = P_e = i_a \lambda_M \omega_r \cos(\theta_r) + i_b \lambda_M \omega_r \cos\left(\theta_r - \frac{2\pi}{3}\right) + i_c \lambda_M \omega_r \cos\left(\theta_r - \frac{4\pi}{3}\right)$$

If the currents i_a, i_b, and i_c comprise a balanced three-phase system,

$$i_a = I\cos(\theta_r + \varphi)$$
$$i_b = I\cos\left(\theta_r + \varphi - \frac{2\pi}{3}\right)$$
$$i_c = I\cos\left(\theta_r + \varphi - \frac{4\pi}{3}\right)$$

and when φ=0, it can be shown that

$$\frac{P_m}{\omega_m} = \tau_m = \lambda_M \frac{P}{2}\frac{3}{2} I \qquad (1)$$

which relates the AC peak current of the motor drive to the motor torque. Finally, the battery used in the electric bicycle platform has a maximum current of

$$I_{batt,max} = 19 \text{ A}$$

In order to simplify component selection and converter design, we will assume that this is also the maximum current anywhere in the system. This, in turn, determines the maximum torque produced by the motor. The maximum torque also relates v_b and P_v.

Solve the minimum motor power P_v necessary to meet all of the performance specifications listed above using both approximate hand calculations *and* using Matlab/Simulink without conservative estimates.

Using the provided Simulink model, `PMSMMotor_loaded.mdl`, again update the motor parameters to match your derived parameters in Section I. By setting the motor speed and peak current in each of the phases, simulate the behavior of the motor when the electric bicycle is cruising at 15 mph on a flat road. What is the peak voltage on each phase winding?