Lab 4: PMSM Characterization

EE595S

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Machine to Characterize

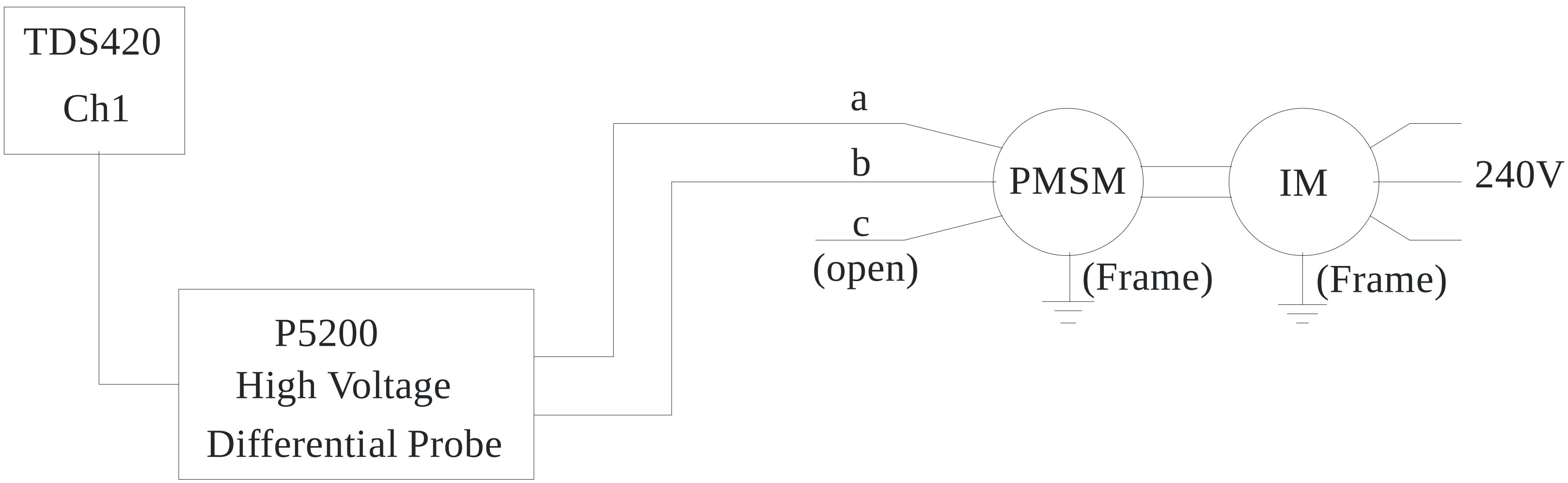
- Reliance Electric
- 1 Hp Continuous at 2000 RPM
- Maximum Speed 5500 RPM
- Inertia: 0.012 Lb-in-sec^2
- Continuous Stall Torque: 31.5 Lb-in
- Peak Torque: 94.5 Lb-in
- Rated Current 3.3 A rms
- Torque Constant 3.2 Lb-in/A/Phase

Step 1: DC Resistance

- Measurement of DC Resistance Using 4-Wire Measurement
- Use Agilent 34401 Digital Voltmeter in Four Wire Mode
- Phase Resistance is ½ Average of Line-to-Line Resistance

Step 1: DC Resistance

Step 2: Phase Assignment / Back EMF



Caution: **Line-to-line voltage can be fatal**.
Note position of E-Stop.
You cannot measure voltage without P5200!
Use electrical tape to cover connections.
Cover all bare wires.

Equipment

- TDS420A Digitizing Osciliscope
  - Used For Data Acquisition
- P5200 High Voltage Differential Probe
  - Used to Make Differential, Isolated, High Voltage Measurements.
  - Never Measure Voltages Without This Probe !
  - Divide By 50 and By 500 Settings

TDS420A

- Acquire Menu
  - Sample *
    - Simply samples and plots
  - Peak Detect
  - High Res *
    - Oversamples and averages
  - Envelope 10
  - Average 16 *
    - Averages over cycles, not points

*Most Commonly Used

TDS420A

- Horizontal Menu
  - Select Fit to Screen
  - Record Length (Make Sure to Get Enough Points)
- Vertical Menu
  - Coupling
    - DC (USE ALMOST ALL THE TIME)
    - AC
    - GND (For eliminating Offsets)

Comments on Open Circuit Back EMF

$$\left.\begin{bmatrix} v_{ab} \\ v_{bc} \\ v_{ca} \end{bmatrix}\right|_{o.c.} = \sqrt{3}\lambda_m^{'}\omega_r \begin{bmatrix} \cos(\theta_r + \pi/6) \\ \cos(\theta_r + \pi/6 - 2\pi/3) \\ \cos(\theta_r + \pi/6 + 2\pi/3) \end{bmatrix}$$

Phase Assignment

- Label the A-Phase (Arbitrary)
- Use IM to Rotate Machine in CCW Direction (Viewed From Front)
  - Use the Paper Test
  - If Going in Wrong Direction; Interchange Leads on IM
- Label B- and C- Phase So v_{bc} 120^o Behind v_{ab}
- Clearly and Semi-Permanently Label Phases

Calculation of $\lambda_m^{'}$

- Spin Machine at Constant Speed and Measure Open Circuit Line-to-Line Voltage
- Under These Conditions, Note That

$$v_{ab} = \sqrt{3}\lambda_m^{'}\omega_r \cos(\omega_r t + \pi / 6)$$

- Measuring the Frequency, We Get Speed
- Measuring the Amplitude, We Get $\lambda_m^{'}$
- Estimate By Hand; Also Record Waveform and Do Fourier Analysis. Use Fund to Get $\lambda_m^{'}$

TDS420A: Procedure to Save Data

- From Matlab Window:
- [data,deltat,points]=
  scoperead2(channel,gpib_address,scale,plt)
    - data = vector of data points
    - deltat = time between data points
    - point = number of data points
    - channel = channel
    - gpib_address = 4
    - scale = your scale
    - plt = plot number, if you want one

Step 3: D-Axis Inductance / Frequency Response

- Disconnect PMSM from IM
- Position Rotor
  - Connect b- and c-phases together
  - Put a dc, less than rated current into a-phase (out of b- / c- phase) [Use LCR Meter]
  - The rotor will turn to position of 90 degrees electrical.

Measurement of D-Axis Parameters

- With Machine At Standstill, Measure Small Signal Impedance from a-phase (+ node) to b/c phase (- node).
- It can be shown that

$$i_{ds}^{r} = i_{as} \qquad v_{ds}^{r} = \frac{2}{3} v_{ab} \qquad Z_d = \frac{2}{3} \frac{\tilde{v}_{ab}}{\tilde{i}_{as}}$$

- It can also be shown that

$$Z_d = r_s + j\omega L_d$$

Experimental Characterization

- Be Sure to Calculate Peak Current
- Use the LCR Meter to Provide DC Current
- DO NOT DISCONNECT LCR METER WHILE BIAS IS ACTIVE - THIS COULD HURT THE INSTRUMENT (APPROXIMATE COST $ 40 k)
- Bias Level Must Be Selected With Care
- Perturbation Level Must Be Selected With Care

Frequency Sweep

- Measure At

20.0, 35.6, 63.2, 113, …

200, 356, 632, 1130, …

2000, 3560, 6320, 11300, 20000

- Use Bias Currents Corresponding to q- and d-axis currents of 0 A, 1 A, 2 A

Step 4: Measurement of Q-Axis Parameters

- Lock the Rotor in Position From D-Axis Test
- Use the b-phase for the positive terminal and the c-phase for the negative terminal. Leave the a-phase open circuited
- Under these conditions:

$$v_{qs}^{r} = \frac{1}{\sqrt{3}} v_{bc} \qquad i_{qs}^{r} = \frac{2}{\sqrt{3}} i_{bs} \qquad Z_q = \frac{1}{2} \frac{\tilde{v}_{bc}}{\tilde{i}_{bs}} \qquad Z_q = r_s + j\omega L_q$$

Lab 4 Deliverables

- Resistance
  - Value for Stator Resistance
- Back EMF
  - Labeling of Phases
  - Fit of Fundamental to Measured
  - Value of $\lambda_m^{'}$

Lab 4 Deliverables

- D-Axis Inductance, Resistance Plotted Versus Frequency For All Bias Levels (Frequency on Log Scale)
- Your Estimate of L_d
- Plot Bode Plot (Magnitude and Phase of Measured Impedance, and of Predicted Using Your Stator Resistance and L_d)
- Repeat for Q-Axis

Lab 4 Questions

- Find the Fundamental Component of the Back EMF. How Well Is the Back EMF represented by its fundamental component (Overlay Plots)
- Determine the Parameters of the Machine
- Calculate L_q, L_d, and λ_m based on the geometrical parameters of the machine. How do they compared to measured values ? Note: I have estimated L_{lp} and L_{lm} at 1.2 mH and -0.20 mH, respectively.

Lab 4 Comments

- You should be sure you understand all procedures and why things work out the way they do – especially in regard to positioning the rotor