Brushless DC Motor Equivalent Circuit and Performance

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Performed: Remotely March 16th
Written: April 15th 2020

1 INTRODUCTION

The objective of this lab was to understand the parameters and equivalent circuit of a brushless DC Motor and how it is similar to a synchronous machine. The lab also goes through speed control of the machine and how voltage can be varied to do so.

All data/measurements taken are provided in the appendix at the bottom of the document.

2 RESULTS

2.1 *Motor Characterization*

In this section we go through and measure different parameters of the motor to develop our equivalent circuit.

$r_\triangle$ can be found by averaging the 3 line-to-line resistances and dividing it by two thirds.

Table 1: Stator resistance

Phase	Resistance (ohms)
Red-Blue	.9
Red-Black	.9
Black-Blue	.9

$$r_\triangle = \frac{.9}{2/3} = 1.35$$ **Equation 1.**

The 2/3 factor arises from the fact that it is 1R in parallel with 2R in series which comes out to 2R/3.

To measure the self inductance we can use the data from exclusively exciting 2 phases at a time and getting the following data:

Table 2: Self Inductance Data

Phase	Voltage (V)	Current (A)	Power (W)
Red-Blue	2.361	3.04	6.29
Black-Red	2.28	2.94	5.89
Blue-Red	2.32	2.89	6.06

To find L_s we can use the following equations:

$$X_s = \frac{V}{I} * \sin(angle) * 2 = .738$$ **Equation 2.**

Then we can find L_s by dividing by the frequency:

$$L_s = \frac{X_s}{2 * \pi * 60} = 0.00196H$$ **Equation 3.**

$$r_s = \frac{V}{I} * \cos(angle) * 2 = 1.37$$ **Equation 4.**

Compared to our Line measurement of r_s the error is very low:

$$Error = \frac{1.35 - 1.37}{1.35} * 100 = 2$$ **Equation 5.**

Next, we can measure the voltage across the motor terminals and use the dyno to drive the motor to acquire λ_m.

$$\lambda_m = \frac{E_a}{speed}$$ **Equation 6.**

Table 3: Flux Linkage

Phase	Voltage (V)	Speed (rad/s)	λ_m
Red-Blue	5.35	527.78	0.0101
Blue-Red	5.3	518.93	0.0102
Black-Red	5.35	523.77	0.0102

Averaging these values we get a finalλ_m = .0102

2.2 *Motor Performace*

In this section we run the motor at various loads and voltages and see its performance.

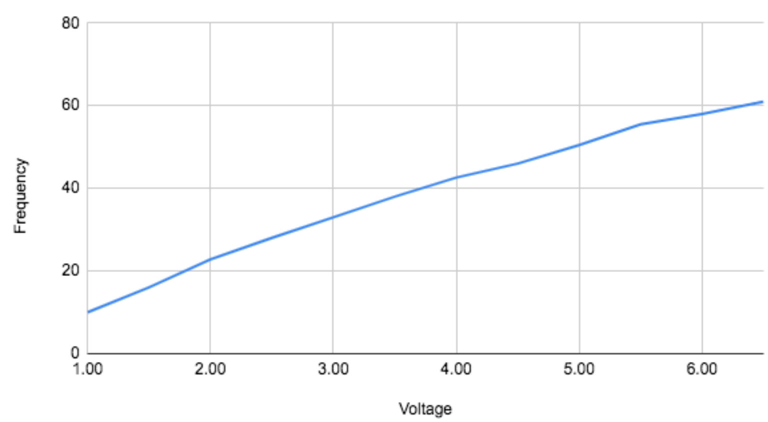
To control the speed we can control the input voltage to the motors and the data is visible here:

Table 4: Speed vs. Voltage

Voltage (V)	Frequency (Hz)
7	61
6.5	58
6	55.5
5.5	50.5
5	46
4.5	42.6
4	38
3.5	33
3	28
2.5	22.8
2	16
1.5	10
1	0

Plotting this data we get the following graph:

Figure 1: Speed vs. Voltage



Clearly the input voltage is a great way to control the speed as it is almost linear and very easy to change.

Next we measure the armature resistance of the motor by reading the resistance at many different points in rotation. The average comes out to 2.8 ohms.

Then we proceed to do a loaded operation and get the following results:

Table 5: Loaded Operation

Load Current	Frequency (Hz)	Vab (V)	Vcb (V)	Power In (W)	Ia (A)	Ib (A)	Power Out (W)	Ouput Current (A)
0	85	7.29	6.89	21.62	3.79	3.34	.1	.03
.1	84	7.30	6.9	21.97	3.36	3.29	.5	.13
.2	83	7.28	6.89	22.59	3.69	3.28	.8	.23
.3	82	7.26	6.86	23.18	3.69	3.28	1.1	.33
.4	81	7.24	6.81	23.8	3.71	3.31	1.3	.43
.5	79	7.22	6.81	24.6	3.73	3.34	1.4	.53
.6	78	7.19	6.79	25.4	3.75	3.36	1.5	.63
.7	77	7.17	6.77	26.1	3.77	3.38	1.6	.73
.8	75.5	7.16	6.74	26.7	3.79	3.39	1.7	.83

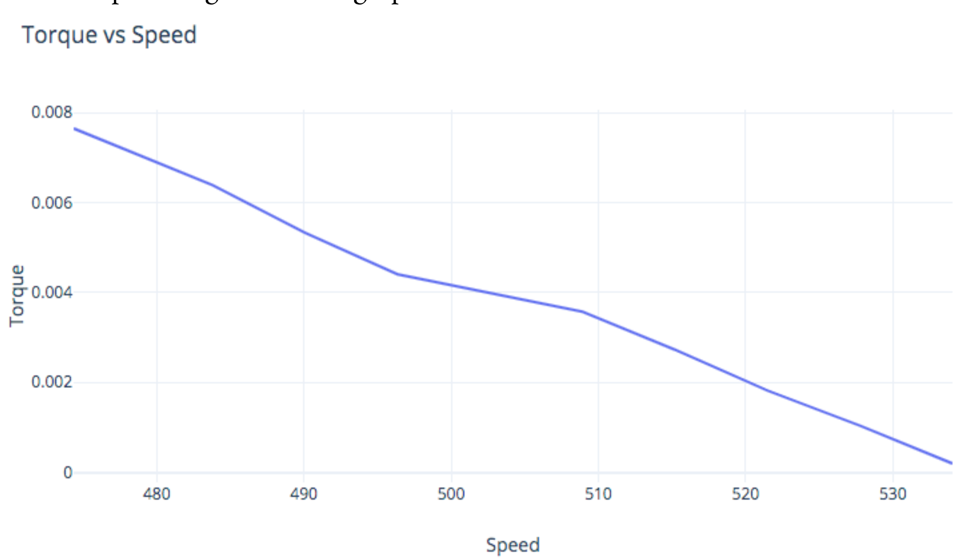
From this we can the load torque:

$$T_{\mathrm{L}} = \frac{P_{\mathrm{out}} + {i_{\mathrm{a}}}^2 \cdot r_{\mathrm{a}}}{\omega_{\mathrm{rm}}}$$ **Equation 7.**

Table 6: Load Torque

Load Current	Frequency (Hz)
0	.00019
.1	.0010
.2	.0018
.3	.0027
.4.	.0036
.5	.0044
.6	.0053
.7	.0064
.8	.0076

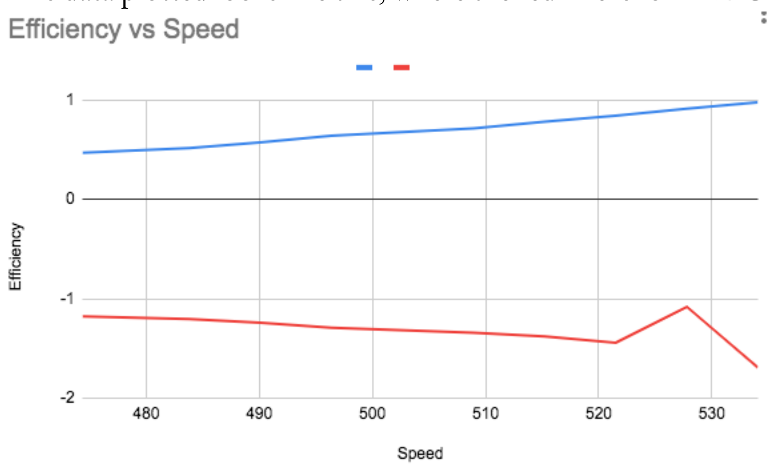
This data plotted gives us this graph:



Current	Speed	Efficiency Brushed DC motor	Efficiency BLDC
0.1	534.0707511	0.9754194304	-1.69077729
0.5	527.7875658	0.9135423518	-1.08115066
0.8	521.5043805	0.8437750496	-1.441133466
1.1	515.2211952	0.782962731	-1.378999353
1.3	508.9380099	0.7151816561	-1.342210294
1.4	496.3716393	0.6402868485	-1.290538415
1.5	490.088454	0.5744221313	-1.242249016
1.6	483.8052687	0.5174443424	-1.20545
1.7	474.3804907	0.4684589354	-1.178824157

We can also find the efficiency of the machine for each data point and it gives us this table:

This data plotted looks like this, where the red line is for BLDC and blue is for brushed DC motor:



Finally we are asked to explore the reason for the position feedback. The need comes from the fact of knowing which winding to excite in order to keep spinning and control the speed. Without knowing the rotor position the windings cannot be excited correctly and the motor won't function.

3 CONCLUSION

This lab gave us a good look into BLDC machines and how they are operated to work like we want. The experiments we did showed the different power characteristics of the machine operated in different modes. This lab was a little more difficult and the report was definitely very challenging. The video was well presented but did not answer all the questions I would have asked in class, but it is a very good remote substitute.

4 REFERENCES

[1] P.W. Sauer, P.T. Krein, P.L. Chapman, *ECE 431 Electric Machinery Course Guide and Laboratory Information*, University of Illinois at Urbana-Champaign, 2005.

5 APPENDIX

Raw Data: All the data used is presented in the tables.