EEE4117F Flywheel Project –Part B

Prepared by:

NAME	STUDENT NUMBER

Date ______________________________

Department of Electrical Engineering
University of Cape Town

Pre-reading:
Ned Mohan - Power Electronics: Converters, Applications, and Design
Chapter 12 – Sections 12.2.1 and 12.2.3

Laboratory will be open for *Part 2* in the lab from Monday, **16th March 2020**. Slots will be made available at the ***Section Info Tab*** on Vula.

Testing & Performance analysis

In this section, you are required to assemble the various components of the dc motor drive and the flywheel. The tasks will be done in groups (***maximum of five students in a group***). However, the final project hand in will be individual.

PWM (*Instructions for Task 1*)

Pulse Width Modulation (PWM) is a technique that enables the control of an analog circuit using a series of digital pulses. The frequency and length of these pulses determines the *duty cycle* which determines the total power delivered to the circuit. These PWM signals are commonly used to control DC motors.

The average value of a square pulse width modulated signal is given by:

$$V_{av} = \frac{1}{T}\int_0^T V(t)\, dt$$

Determining the Parameters of the DC Machine (*Instructions for Part 1*)

The viscous damping and the rotational inertia of the motor can be calculated using *Equation 4 (from Part 1)* and *Equation 8* respectively. ***(See Appendix A and B)***

$$B = \frac{J}{t_m}$$

$$J_m = \frac{1}{2}\, Mr^2$$

Determining the DC Machine constants

Using the No-load test and by loading the machine at different operating points, the machine constant, $K_a\phi$ can be calculated.

No-load Test

The machine is set up as shown in Figure 1 below and run at different speeds the induced back-emf at the terminals of the machine, corresponding to each of the speeds, is recorded. A graph of back-emf E_a vs. Speed ω_m is plotted. The slope of this graph gives the constant $K_a\emptyset$.

Remember: $E_a = K_a\emptyset\omega_m$

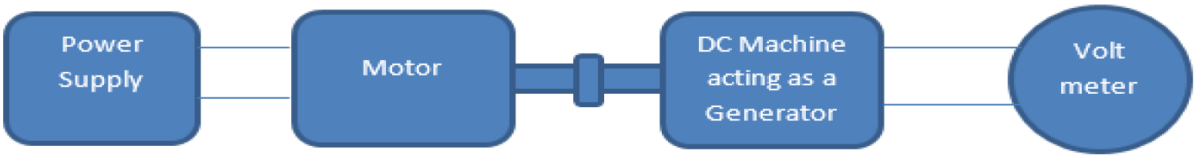

Figure 1 Set-up for the no-load test

Task 1: PWM

Program a microcontroller to produce PWM for the H-bridge; 1 kHz with a duty cycle from 50% to 100%. The voltage to turn on the switches of the H-bridge is approximately 3V. Remember that in practice, it is crucial to ensure that there two switches in the same leg are never closed at the same time. The motor is controlled by an H-Bridge. The H-Bridge accepts two PWM signals, one the inverse of the other.

Question: Why is this so? And how would you solve this problem? *(Explain thoroughly)* You will also be required to append your well documented code for the PWM.

Test the output of the microcontroller on an LED in the lab. You will also need to append screenshots of the readings of your PWM from the oscilloscope to your project.

Task 2:

Connect your microcontroller the drive system.

Run the flywheel to rated speed 300 rpm by slowly increasing your duty cycle. Record the bridge current, bridge voltage, armature current, and the speed in the table provided.

RPM	**Bridge Current**	**Bridge Voltage**	**Armature Current**	**Armature Voltage**	**Torque**
50					
100					
150					
200					
250					
300					

Now perform a run-down test. Let the flywheel run down as the power dissipates over the set resistors. Record the time it takes to decelerate to 0 rpm.

Questions:

1. Plot the graph of Armature Voltage vs. Speed
2. Determine from the graph plotted; $K_a\phi$ and armature resistance Ra.
3. Determine the losses due to the armature winding.
4. Plot the graph of Mechanical losses vs. Speed.
5. Calculate the average bridge losses.

Task 3:

Discuss two application areas of flywheel energy storage system (minimum one A4 page). State features, two advantages and one major drawback of each system.

Appendix A – EEE4099F Flywheel Project

Flywheel specifications

Table 1: Flywheel specification

QUANTITY	VALUE
H (m)	0.18
r_o (m)	0.285
r_i (m)	0.165
Concrete Density, ρ (kg/m^3)	2400
Flywheel Mechanical time constant (mins)	6.1

Figure 1 The flywheel

Machine Specification

Table 2: Machine Specification

QUANTITY	VALUE
Diameter (m)	0.14
Length (m)	0.37
Density (g/cm^3)	7.65
Volume (cm^3)	5695.71
Mass (kg)	43.6
J_m (kgm^2)	0.107
B_m (kgm^2/s)	0.0072

Appendix B: Efficiency of the system.

Driver Losses

□□Input Power $(P_{in}) = V_{in} \cdot I_{in}$
□□Output Power $(P_{out}) = V_{out} \cdot I_{out}$
□□Losses $(P_{losses}) = P_{in} - P_{out}$

Motor Losses

□□Armature Copper Losses $(P_a) = I_a^2 \cdot R_a$
□□Field Copper Losses $\left(P_f\right) = I_f^2 \cdot R_f$
□□Core losses and rotational losses$(P_{core+rot}) = P_{in} - P_{cu} - T_{\omega m}$, where $T = k_a \cdot I_a$

Flywheel Losses

□□The flywheel losses are a sum of the bearing losses and drag losses. These can be calculated as shown below:

Drag Losses: $F_D = F_p + F_f = \left(C_p\rho(V^2/2) \cdot A\right) + \left(C_f\rho(V^2/2) \cdot Bl\right)$

Bearing Losses: $N_R = (1.05 \times 10^{-4}) \cdot M \cdot n$

Where: $M = M_{rr} + M_{sl} + M_{seal} + M_{drag}$

$M_{\boldsymbol{rr}} = G_{rr} \cdot (v \times n)^{0.6}$	- rolling frictional moment
$M_{\boldsymbol{sl}} = \boldsymbol{\mu_{sl}} \cdot \boldsymbol{G_{sl}}$	- sliding frictional moment
$M_{\boldsymbol{seal}} = K_{s1} \cdot d_{\boldsymbol{s}} \cdot \beta + K_s^2$	- Frictional moment due to seal
$M_{drag} = V_m \cdot K_{ball} \cdot d_m^5 \cdot n^2$	- drag frictional moment

G_{rr}: *relies on bearing type, bearing mean diameter, and the dynamic load on the bearing.*

n:	speed (rpm).
v:	kinematic viscosity of lubricant.
K_{s1}:	constant that depends on the type of bearing.
K_{s2}:	constant that depends on bearing and the type of seal used.
Ds:	seal diameter.
β:	an exponent depending on bearing and seal.
V_m:	is a variable and a function of oil level.
d_m:	bearing mean diameter.

$$K_{ball} = \{i_{rw} \cdot K_Z(D + d)\}/\{(D - d) \times 10^{-12}\}$$

I_{rw}:	number of ball bearing rows
K_z:	geometry constant
D:	outside bearing diameter
d:	inside bearing diameter