EEE4117F Flywheel Project –Part A

Prepared by:

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1. Introduction

This project is divided into two major parts, namely: the analysis/sizing of the flywheel and the practical section. Read through the document carefully and answer the questions at the end of the document. In this first part of the project, familiarise yourself with the flywheel and the calculation of its parameters.

2. Analysis (Sizing of the Drive Components)

This section explains the concept of the flywheel as an energy storage device and provides the student with the information required to answer the questions that follow at the end. An answer sheet should be submitted no later than ***Friday 13th March 2020, at 14h00, in the EEE4117F submission box in Level 3, opposite the White Lab entrance.***

2.1. Modelling the Flywheel

A flywheel is a mechanical device that stores kinetic energy which can be used for various applications such as maintaining constant energy flow for an intermittent energy source, provision of power at a rate beyond the capability of an energy source and control of the orientation of a mechanical system.

In the case of the flywheel being used as a backup power supply, a motor is normally used to accelerate the flywheel up to a specified speed and the same motor is also used to convert the kinetic energy in the flywheel to electrical energy as illustrated in the figure below.

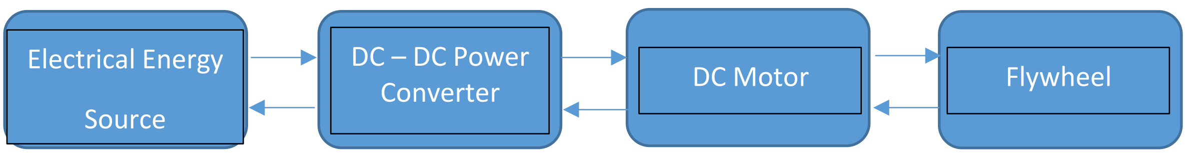

Fig. 1: Flow diagram showing a DC Motor Drive coupled to a Flywheel.

2.2. Determination of the parameters of the flywheel

The energy stored in a flywheel with a rotational inertia of $J\ (kg.m^2)$, rotating at ω (rad/s) is given by:

$$Rotational\ Kinetic\ Energy\ (KE) = \frac{1}{2} J \cdot \omega^2 \qquad Equation\ 1$$

$$Rotational\ Inertia\ (J) = \int r^2\ dm \qquad Equation\ 2$$

Where, r is the distance from the pivot point and m is the mass of the rotating object. For standard shapes such as cylinders and spheres, the integral in *Equation 2* has already been solved and these results are stated in *Figure 2*. For more complex shapes the rotational inertia can be calculated by dividing the complex shape into a series of more simple shapes and summing the rotational inertias of each simple shape.

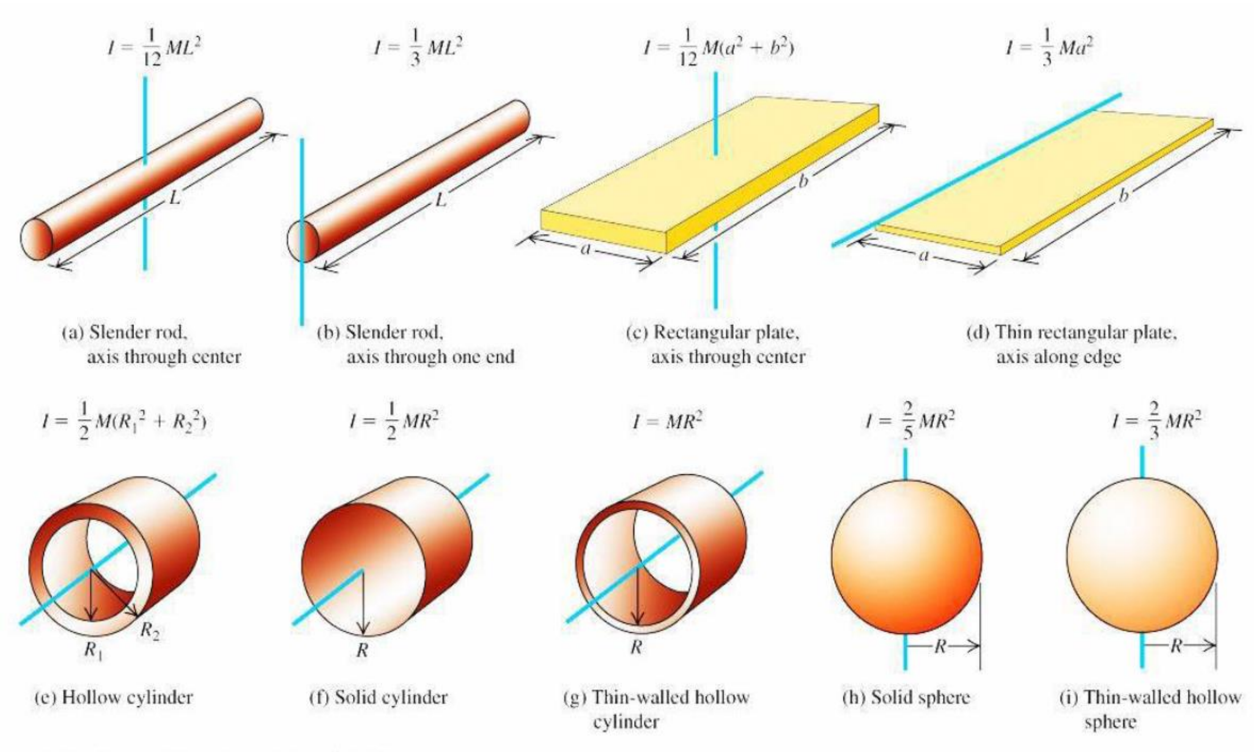

Fig. 2: Moments of Inertia of various bodies.

The shapes shown in *Figure 2* can be used to model the shape of various flywheels. If the density of the material used to make the flywheel is known, then mass (*M*) for the various shapes in *Figure 2* can be calculated using *Equation 3*. **In this project you will be required to select the shape that best approximates the flywheel given in the Appendix A**.

$$M = \int \rho\, dV \qquad Equation\ 3$$

If the mechanical time constant (t_m) of the flywheel is known, the viscous damping (B) can be can be calculated by using *Equation 4* below. *(See Appendix A).*

$$B = \frac{J}{t_m} \qquad Equation\ 4$$

Having determined the rotational inertia and the viscous damping, the torque required to accelerate the flywheel up to a speed ω in *t* second can be calculated using *Equation 5*.

$$T_{em} = [J_m + a^2 J_L]\frac{\dot{\omega}_L}{a} + [B_m + a^2 B_L]\frac{\omega_L}{a} + aT_{wL} \qquad Equation\ 5$$

2.3. Matching the load to the motor

2.3.1. Determining the rated power and rated armature current

After calculating the torque required to accelerate the flywheel to its rated speed, the ratings for the motor can now be calculated. Assuming that the motor will be powered from the mains (220 V), the rated power $Prated$ and rated armature current $Irated$ for the motor can be calculated as follows:

$$\boldsymbol{P_{rated} = T\omega_{rated}} \qquad Equation\ 6$$

$$\boldsymbol{I_{rated} = \frac{P_{rated}}{V}} \qquad Equation\ 7$$

2.3.2. Questions

1. Calculate the rotational inertia, J_L, of the flywheel.
2. Calculate the viscous damping, B, of the flywheel.
3. Determine the electromagnetic torque, T_{em}, required by a motor to accelerate the flywheel to its rated speed of 1500 rpm in 15 minutes ***(Ignore drag losses).***
4. Calculate the maximum energy (in kWh) that can be stored in the flywheel.
5. Assume the flywheel is connected to a 10W dc load. How long will it take the flywheel to completely discharge?

Appendix A: Flywheel and Motor Specifications

Table 1: Flywheel Parameters

Quantity	Values
H	0.18 m
r_0	0.285 m
r_i	0.165 m
ρ	2400 kg/m^3
t_m	6.1 mins

Fig. 3: The Flywheel

Table 2: Motor 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: $M = M_{rr} + M_{sl} + M_{seal} + M_{drag}$

$M_{rr} = G_{rr} \cdot (v \times n)^{0.6}$ - rolling frictional moment

$M_{sl} = \mu_{sl} \cdot G_{sl}$ - sliding frictional moment

$M_{seal} = K_{s1} \cdot d_s \cdot \beta + K_s^2$ - 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