Flywheels as Batteries

Undergraduate Author: Colin Choudhary

Faculty Advisors: James Overduin, Jeffery Klupt

Department of Physics, Astronomy, and Geosciences, Towson University, Towson, MD, 21252

Abstract

- Investigates application of flywheels in clean energy storage
- Converts electrical potential from a power supply to rotational kinetic energy (KE_R) through electromagnetic propulsion
- Converts rotational kinetic energy into electric potential through induction of electric and magnetic fields (EMF) in conducting coils
- Supplies voltage to a light emitting diode (LED). This process exhibits the functionality of flywheels as batteries
- Analyzes relationship between angular velocity and magnitude of induced EMF with PASCO interface
- Measures efficiency of prototype flywheel as a battery with Arduino code and interface

Background

- A flywheel is a mass that is capable of spinning in order to store kinetic energy. Often circular, these devices focus mass distribution the furthest away from center as possible in order to generate the greatest moment of inertia, or effectively, the greatest rotational kinetic energy when spinning, seen by eq. 1 [2]
- Later, this rotational kinetic energy can be converted into a usable current through inductance seen by eq. 2 [5]

Rotational Kinetic Energy

- KE_R: rotational kinetic energy
- m: mass
- R: flywheel radius
- ω: omega; angular velocity
- I: moment of inertia

$$KE_R = \left(\frac{1}{2}mR^2\right)\omega^2 = I\omega^2$$

Equation 1 [2]

Faraday's Law

- Ɛ: EMF
- N: number of turns in coil
- ΔΦ : change in flux
- Δ t: change in time

$$\mathcal{E} = N\frac{\Delta\Phi}{\Delta t}$$

Equation 2 [5]

Induced EMF

- Voltage measured with oscilloscope (Fig. 1)
- As magnet moves into coil field, EMF increases, as it exits, EMF decreases
- Root Mean Square voltage (RMS) = 2.293 v

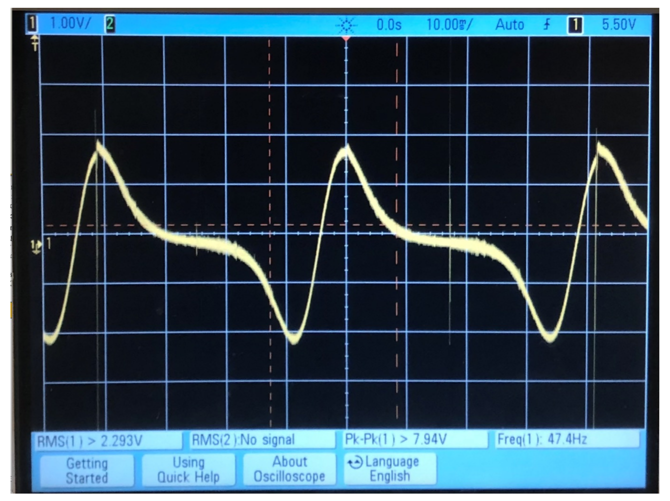


Fig. 1: induced EMF on oscilloscope screen when flywheel is spinning down

Circuit Schematic

- Reed Switch: magnetic field interacts with reed switch and signals coils to propel flywheel; positioned $\approx< \frac{\pi}{2}$ radians away from coil in order to propel sequential magnet (Fig. 2)
- Power Supply: supplies current to coils; interchangeable with solar panel or hand crank
- Diode: clamps circuit to 12 volts so that back EMF does not fry equipment

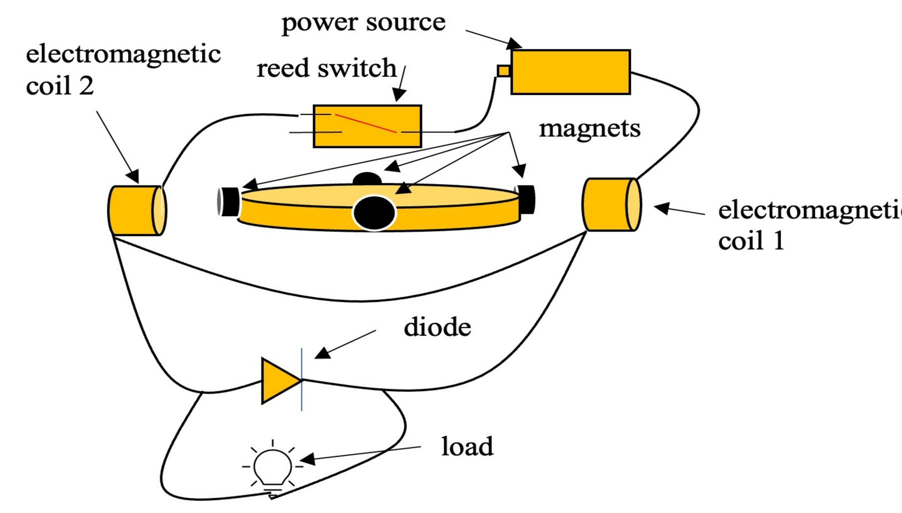


Fig. 2: flywheel apparatus diagram

Apparatus

- Setup (Fig. 3): The flywheel, coils, reed switch, and photogate are set up her to collect data
- A 2 cm flag (sticky note) is wedged between magnets to block the the photogate's light beam so that the speed of the magnets can be measured as the flywheel rotates

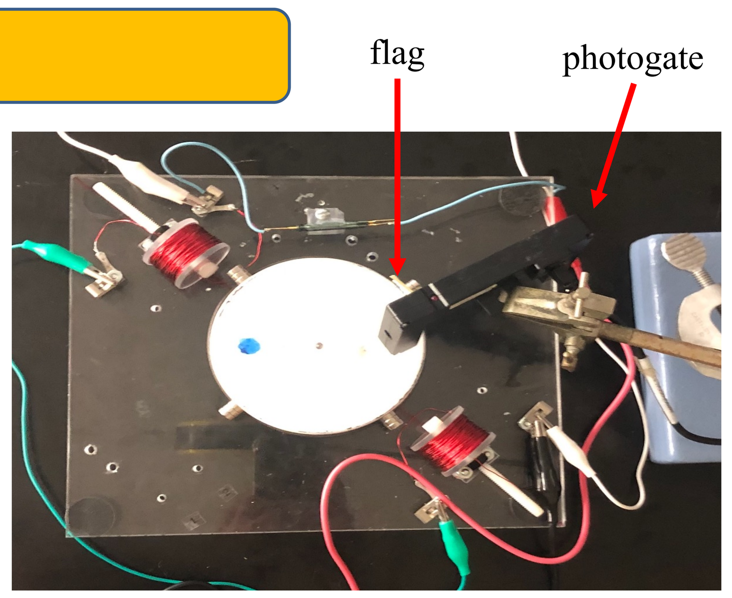


Fig. 3: flywheel apparatus

Arduino

- We used an Arduino to measure an efficiency of 6%, which compares poorly to figures as high as 90% for large-scale industrial models [3]

$$P_{in} = \frac{work}{\Delta t} = \frac{\Delta KE_R}{\Delta t}$$
$$P_{out} = \mathcal{E}(I)$$

Equation 3 [1]

$$Efficiency = \left(\frac{P_{out}}{P_{in}}\right) * 100\%$$

Equation 4 [1]

```
if ((t - tlast1) <= timeinterval1) {
  if ((t-tlast) <= timeinterval) {
    state=digitalRead(sig);
    if (state==HIGH && lastState==LOW) {
      ++count;
      Serial.println(count);
    }
    v = pow(5*(analogRead(A0)/1023),2) + vlast;
    lastState=state;
    vlast = v;
    ++vcount;
    }
  else {
    volts = v;
    rms = sqrt(v/vcount);
    rpm = (count*60/(12*4*2));
```

This portion of my code counts how many signals the reed switch has received over a time interval allowing it to calculate the RPM. It also calculates RMS based on measured voltages.

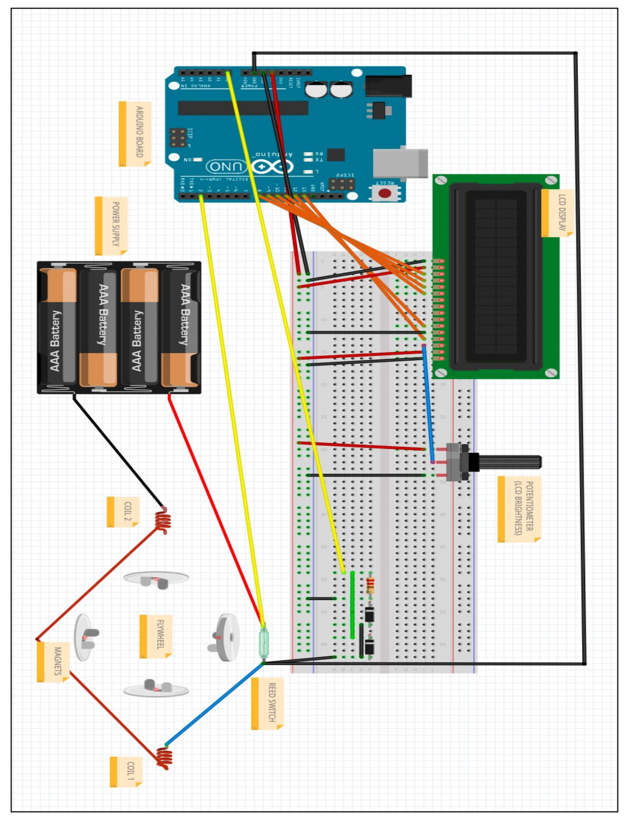
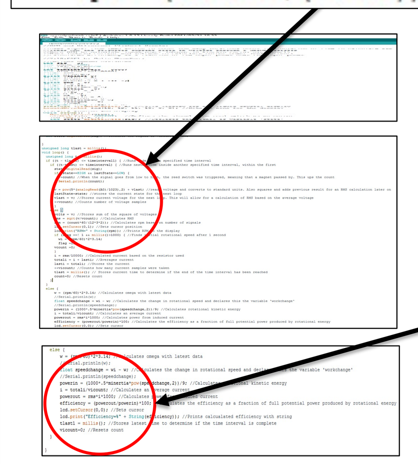


Fig. 4: Arduino circuit diagram

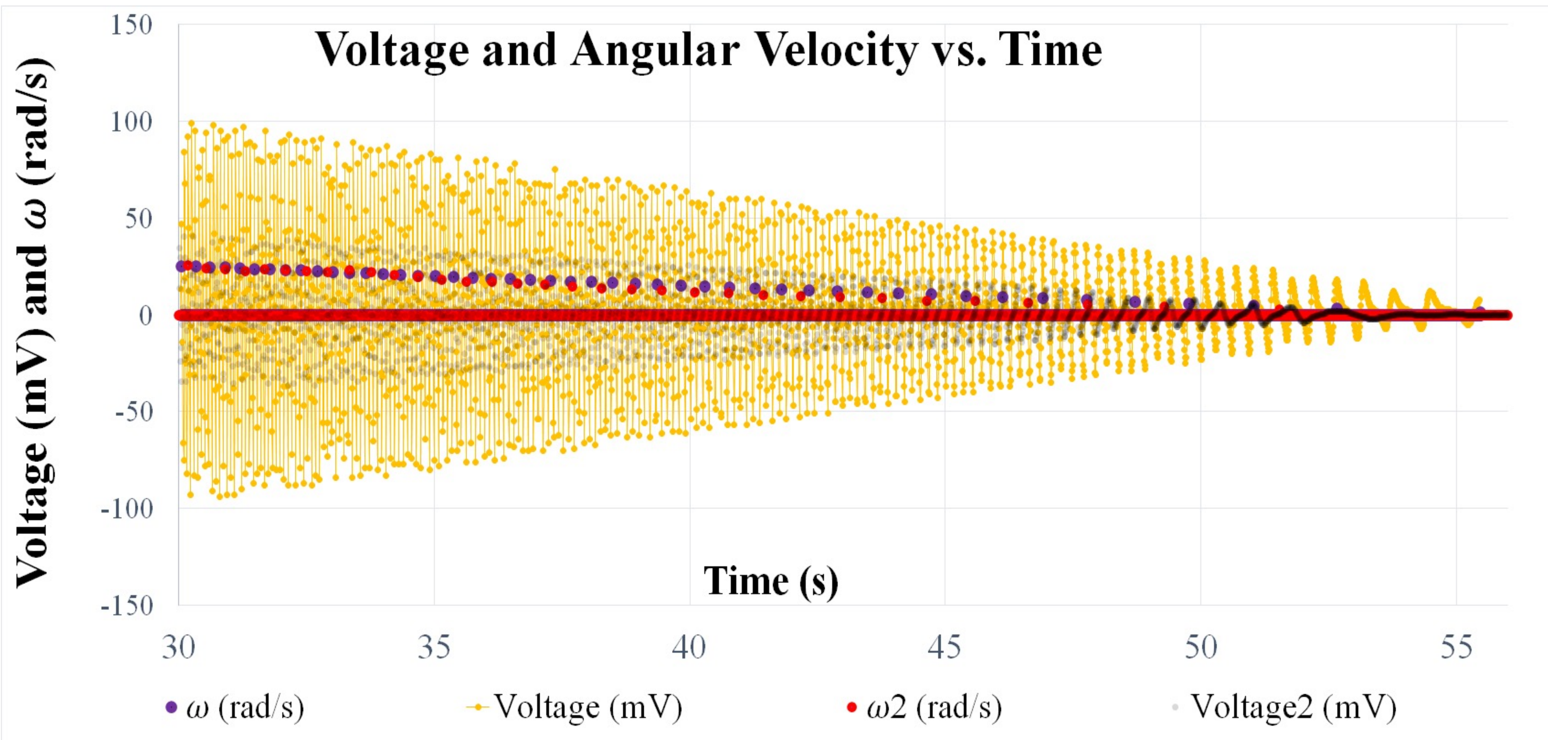


```
else {
    w = (rpm/60)*2*3.14;
    float speedchange = wi - w;
    powerin = (1000*.5*minertia*pow(speedchange,2))/9;
    i = totali/vicount;
    powerout = rms*i*1000;
    efficiency = (powerout/powerin)*100;
    lcd.setCursor(0,0);
    lcd.print("Efficiency=%" + String(efficiency));
    tlast1 = millis();
    vicount=0;
```

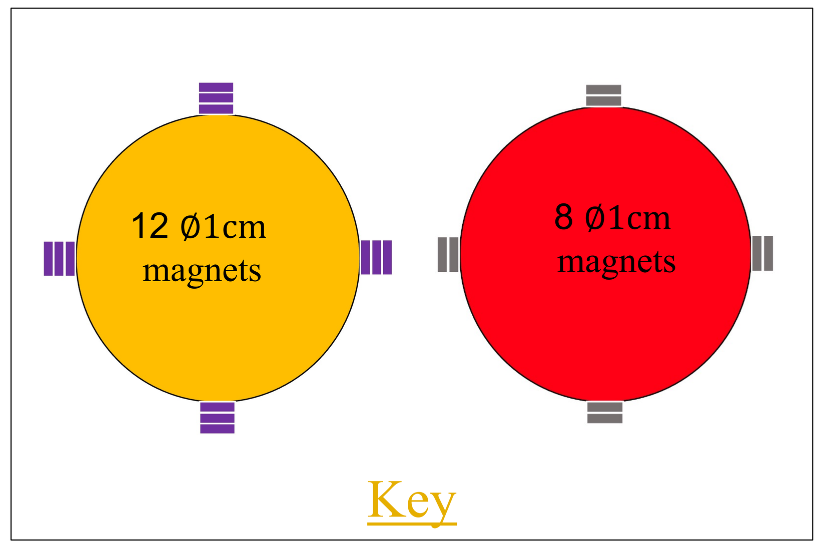
Fig. 5: Arduino sketch coded by Colin Choudhary

This portion of my code calculates efficiency based on the eq. 3 and 4.

Preliminary Results



- Fig. 6 shows our results for induced voltage (in mV) superimposed on the angular velocity of the flywheel (in rad/s)
- By placing fewer magnets on the flywheel, the induced current was noticeably less (red and grey) than that of the flywheel with a greater number of magnets (orange and purple)



- Although the angular velocities was similar (see red and purple dotted lines) between the two, the induced EMF was noticeably less than that of the flywheel with more magnets (see grey dots compared to orange dots) presumably due to the lower strength of magnetism

Application and Future Work

- The basic experimentation here shows how rotational kinetic energy can be applied in energy storage with the application of induced EMF
- With an ever-growing consumption of energy, it is more crucial than ever to initiate innovative ways to sustainably store every bit of harnessed energy
- Applying the principles experimented with here will allow us to sustainably add stability to our power grid

Fig. 7: large-scale flywheel battery facility operated by Amber Kinetics in California [6]

References

[1] Krause, T. (2021, June). *Power Related to Flywheels. Discussion on Power Related to Flywheels*. Towson; Smith Hall.

[2] Moebs, W., Ling, S. J., & Sanny, J. (2016, August 3). *10.4 moment of inertia and rotational kinetic energy*. University Physics Volume 1. https://opentextbc.ca/universityphysicsv1openstax/chapter/10-4-moment-of-inertia-and-rotational-kinetic-energy/.

[3]SparkFun Electronics. (2017). *SparkFun inventor's kit for Arduino* (Vol. 4).

[4] Wicki, S., & Hansen, E. G. (2017). Clean energy storage technology in the making: An innovation systems perspective on flywheel energy storage. *Journal of cleaner production*, *162*, 1118–1134. https://doi.org/10.1016/j.jclepro.2017.05.132

[5] Tocci, R. J. (1983). Introduction to electric circuit analysis. Merrill.

[6] Tullis 2013, "Boxcar Energy," Slate.com (2013); https://slate.com/technology/2013/03/energy-storage-technology-batteries-flywheels-compressed-air-rail-storage.html (accessed 7/27/2021)

[7] Wicki, S., & Hansen, E. G. (2017). Clean energy storage technology in the making: An innovation systems perspective on flywheel energy