University Physics 2: PHYS222

Lab 11: Electrical Generator

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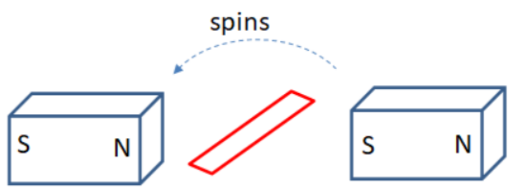
1 Introduction

If anyone has ever taken a long trip up to Duluth and visited Minnesota near the border of Canada, you may have noticed that there becomes less and less power lines going to houses . This is mainly due to the off-grid production of electricity and *voltage* in the houses either due to solar panels or *waterfalls*. The big picture of electricity production via waterfalls is that a paddle wheel turns a coil of wire that is wrapped an N number of times into a small loop. The coil spins at a constant rate[1], between two large permanent magnets which create a B-field. The loops each have a cross-section area of A. Suppose I wanted to live off grid, what is the rate at which the coil must turn ω (units of $1/s$), in order to get out 120 Volts? You can help me by finding the correct symbolic relation, and by modeling this scenario with Helmholtz coils. [2]

?| What is the Induced EMF created in the loop via the spin in a magnetic field?

Equipment:

- Two power supplies. One to run current through the circular coils, and one to spin the square wire loop (found in-between the Helmholtz coils).
- Rubber band and Electric Motor to spin the square loop
- LabPro Interface with voltage probes
- Field Probe, Logger Pro and Computer
- Field Probe Holder



2 Prediction

Predict the amplitude of induced EMF. Your prediction can depend on the area of the flip coil A (measure it), the magnetic field of the magnets B (known from previous lab exam and CYU), angular velocity of the coil (usually symbolized as ω), and number turns of wire in the coil N.

[1] By constant rate, we mean constant angular velocity ω.
[2] BIG NOTE: EMF and voltage are the same thing!

Make a rough graph of the amplitude of the voltage versus the angular velocity at which the “flip" coil turns. In terms of the given quantities in the problem, what is the slope of this line (what terms are included in m)?

3 Pre-Lab Questions

1. Draw a diagram of the problem and label all of the known quantities.

   (a) Identify all quantities acting, or produced, by the spinning coil (put the B-field, angular velocity, lengths/distances...)

   (b) Label the velocity v, of the sides of the loop.

   (c) Make sure to identify **directions** of all the quantities above.

2. As hinted above, we are using *Force.* As we just learned, we can compute the work being done by by an magnetic field.

   (a)The electrons in the loop ove with the wires, so they have a velocity. Here there is a magnetic force F_B on them. Label the direction of this force on the parts of the loop.

   (b) Write down the force equation for this scenario (including angle) and plug it in into the work-integral and simplify.

   (c) What are the integral bounds for this work integral?

3. We can see a glaring issue, what is the angle θ? *(Hint: recall from mechanics the relationship between velocity, angle, and distance when dealing with rotational mechanics? Remember, we are given ω.)*

4. What about the velocity v? What is the relationship between ω and v? *(Hint: along with the hint above, you can also use units to find the relationship...)*

5. Plug in these relationships for θ and v and notice that we have two different lengths. Are they related, perhaps either as the length, area, volume, or surface area of the rectangle?

6. Recall again that we know the EMF is given by $EMF = W/q$. Simplify your relationship.

7. Hang on, we have forgotten a term, the number of coil turns N. Where should this be placed?

8. Finally, this is more for help with measuring and understanding what we meant by the amplitude, a function that *oscillates* usually has the form of an amplitude multiplied to some trigonometric function:

$$f(\theta) = (Amp) * sin(\theta). \tag{1}$$

9. Also, construct a prediction graph now of amplitude vs angular velocity by using "dummy-data."

4 Exploration

To do this lab, the plan is to:

- Use the Helmholtz coils to make the uniform magnetic field.
- Use a motor to spin the loop at a constant rate.
- Obtain EMF vs t data with Logger Pro.
- From that data, fit a trendline to determine the amplitude and frequency. This will be one data point that you will use to construct the amplitude vs frequency graph.
- Take enough data to make the entire amplitude vs angular velocity graph.

5 Data, Results, and Analysis

How do we setup the coil?

To turn the small coil at a constant angular velocity we will be using an electric motor. I know, it seems kind of pointless to generate electricity by using an electric motor but for the sake of the experiment it is much easier to do it this way then the way they do it in real electric generating plants (with steam turbines). Anyway, find a way to anchor the electric motor and "hook up" the motor to the small turning coil with a rubber band.

You will use a power supply to run the electric motor. For the power supply that controls the motor: turn the voltage all the way down (counterclockwise) and turn the current all the way up (clockwise). Then turn the power supply on and, using the 'voltage' control knob, see if you can turn the small coil of wire.

How do we take data?

Next, you need to start taking readings of the voltage as a function of time. To do this use the Logger Pro software on your computer and the Lab Pro interface with the "voltage probe" (basically just two wires with clips on the end). Hook the voltage probe up to either side of the small coil. You should notice that the small flip coil has two wires that are accessible for measuring the voltage. The access points are at the base of the flip coil's stand. Examine the apparatus and note how you are able to access (or measure) the voltage on the coil even though it is turning.

Once you have everything setup, try generating some voltage and use your computer to measure the output as a function of time. What does the voltage as a function of time look like? Draw a rough graph. Based on your answers to the prelab questions, is it what you expected? Indicate the amplitude on your graph. You can actually measure data points on the graph by going to the "Analyze" pull down menu and choosing "Examine".

How will you measure the angular velocity of the coil from your velocity versus time data? (Hint, see your answer to the last prelab question).

Data and results:

Take enough data so that you can make a plot of the amplitude of the EMF versus the angular velocity so you can fit your line and test your prediction.

6 Conclusions/Summary

Can you predict the EMF induced on the coil as it turns at a constant rate (i.e. a constant angular velocity)?

What factors determine the induced EMF?

7 Check Your Understanding

Unless otherwise indicated, the criteria for receiving full credit on each answer is first, is the answer correct, and second, you have convinced me you know how to complete the problem in a manner that utilizes **only** the equation sheet, or reference an equation we have used previously in lecture or lab.

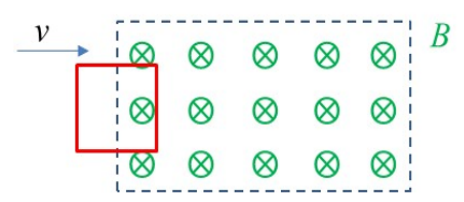
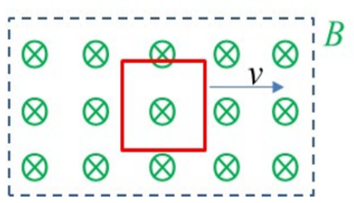
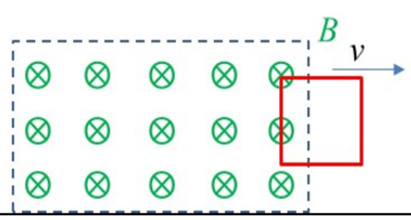
1. For the setup from lab:

   (a) What is the orientation of the loop, relative to the magnetic field, when the EMF is the largest? Draw a picture.

2. A stationary coil is in a magnetic field that is changing with time. Does the emf induced in the coil depend on the actual values of the magnetic field?

3. A square loop whose sides are $6.0cm$ long is made with copper wire of radius $1.0mm$. If a magnetic field perpendicular to the loop is changing at a rate of $5.0mT/s$, what is the current in the loop? *(Hint: you will need the equation for what resistance is R since $\sigma = 1.7 \times 10^8\ \Omega m$ and $EMF = V = IR$. Also, $EMF \sim dB/dt$ but I am missing a few terms...)*

4. A square wire loop (length of side $= 0.4cm$) with a total resistance of 8Ω (not shown as a resistor, but its implied), is pushed, at a constant velocity of $5m/s$, into a region where a constant magnetic field of $B = 0.25T$ points into the page as shown. Consider the following three cases:

		
Case A: Just entering the B field region.	Case B: Completely inside the B field region	Case C: Exiting the B field region.

   (a) What is the current (direction and magnitude) produced in the loop in case A?

(b) What is the current (direction and magnitude) produced in the loop in case B?

(c) What is the current (direction and magnitude) produced in the loop in case C?

5. (Challenge): A rod of mass m and resistance R is attached to frictionless rails in the presence of a magnetic field of magnitude B pointing out of the page, as shown in the diagram below. The rod and rails form a closed electrical circuit. If the rod is launched from $x = 0$ with velocity v_0 to the right, at what time t is the velocity of the rod v_0/e? *(Hint: Once you find the EMF, you will want the power $P = (EMF)^2/R$, and know that Power is equal to the time-derivative of work, and work is: $W = \Delta KE$. Yes, you will have to use the calculus that you have learned...)*