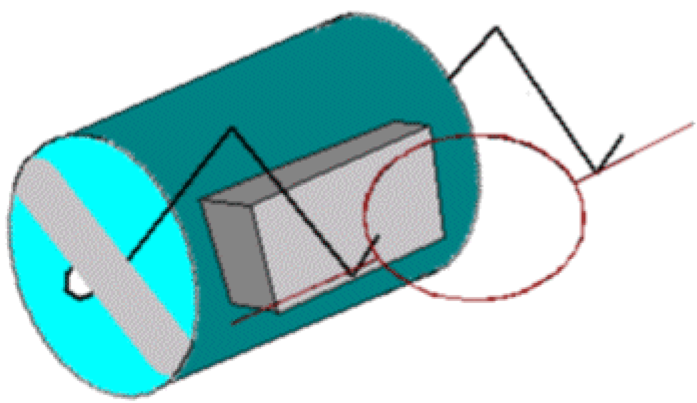
Electronics and Instrumentation

Name _______________ ENGR-4220 Fall 1999 Section ____________

Project 3

Instrumented Beakman's Motor

Beakman's Motor (shown on the TV show *Beakman's World*) makes a very interesting little project. We use this motor in the ECSE course *Fields and Waves I* because it involves some fundamental electromagnetics concepts. It is also used in *Mechatronics* because it is a simple example of a complex electromechanical system. There is some excellent background information and some construction hints at the website http://fly.hiwaay.net/~palmer/motor.html, which is also listed in the helpful info section of the course website under *Beakman's Motor*. Another good reference can be found at http://www.scitoys.com/scitoys/scitoys/electro/electro.html#motor. It is possible to specify several project goals for this motor, depending on its application. Most of the time, this motor is used, as is, in elementary school science fairs. It has also been used for demos done by Prof. Craig, Prof. Connor and others. In recent years, a version of this motor was built by prospective Electric Power Engineering students and their parents. Here, you are asked to make the motor go as fast as possible.



Beakman's Motor
Note the basic components – a D-Cell battery, a rubber band, two paper clips, a ceramic permanent magnet and a coil of wire.

Materials Required: **(Only those items marked with an X will be provided)**

- One D-Cell Battery
- One Wide Rubber Band
- Two Large Paper Clips
- One Circular Ceramic Magnet (or equivalent) **- X**
- Magnet Wire (the kind with enamel insulation) **-X**
- One Toilet Paper Tube
- Fine Sandpaper **(Available in the studio)**
- Optional: Glue, Small Block of Wood for Base, and …
- **DC Power Supplies, Oscilloscope, and other instruments**

Please note: the critical tasks for this project are underlined and in red (on the webpage.)

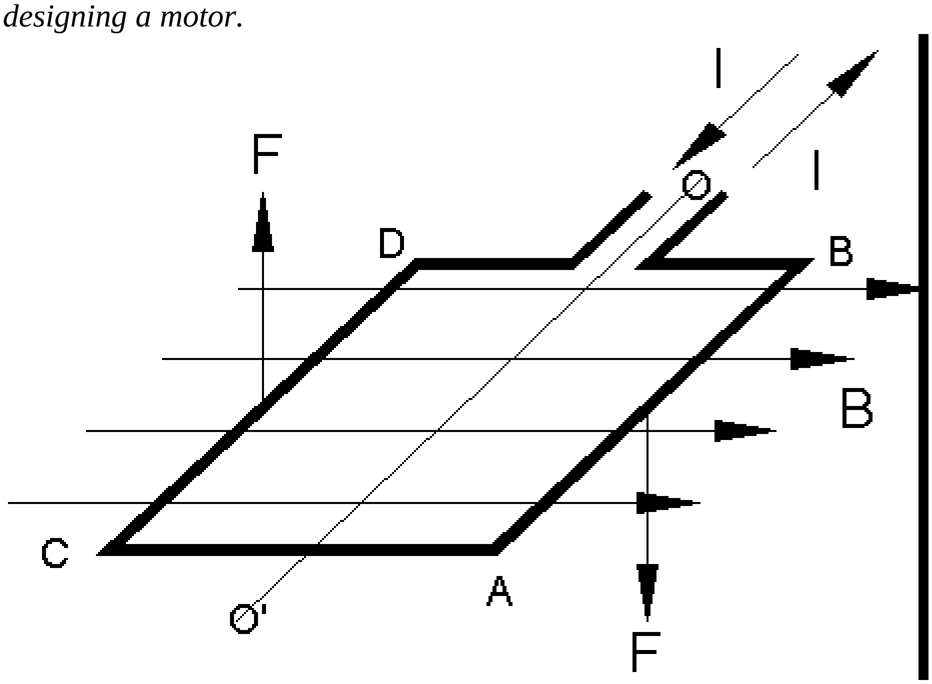
Pre-Project Report (15 points)
Due 17 November at the Beginning of Class

Introduction (1 pt): Introduce and describe the goals of the project.

The purpose of this project is to build the Beakman's motor in such a manner that it rotates faster than is the case with the basic design and to determine the speed of the motor by making measurements of voltages in the motor circuit. An explanation of why the motor works as well as it does must be provided. List at least three educational goals for this project. That is, list at least three topics you might encounter in practical electronic instrumentation that play a significant role in this project.

Design (3 pts): Describe your project design, how it works, how you came up with this particular design, and discuss potential problems. This last item is very important. You should not expect your initial design to be a complete success. Remember that you will have the opportunity to make changes while you build and test your project.

The basic principles of motor operation are included in the website listed above. Each time the coil spins through a single revolution, the commutator turns the current on for half of the cycle and off for half of the cycle. While the current is on, the coil becomes an electromagnet which is either attracted to or repelled by a permanent magnet attached to the battery that powers the motor. By properly orienting the commutator, the coil is given a little push each time it goes by the magnet and it will continue to spin. While this description is adequate to explain generally how the motor works, it is not so useful for actually designing a motor.



A better model involves the forces between current-carrying wires and magnetic fields. The a current-carrying wire experiences a force due to a magnetic field in a direction perpendicular to both the wire and the field, as shown in the figure above. In the most fundamental terms, we express this force as $\vec{f} = \vec{J} \times \vec{B}$, *where f is the force density, J is* *the current density in the wire (J is I divided by the area of the wire) and B is the magnetic field. Most simply, this expression can be written as* $\vec{F} = I\vec{L} \times \vec{B} = ILB\sin\alpha$ *, where I is the current, L is the length of the wire (this is made a vector by multiplying it by the unit vector in the direction of the current flow), and* α *is the angle between the wire and the magnetic field. There is quite a good discussion of the principles behind the DC motor at http://www.micromo.com/03application_notes/tutorial1.asp from Micro Mo Electronics in Clearwater, FL. (The figure above comes from this web site.) It will be useful to read over this material to see how to optimize your motor designs. Something to think about – where would the magnetic be located in the figure showing the forces?*

By monitoring the current to or voltage across the coil, the frequency it spins at can be determined. If the spinning is sufficiently regular, the frequency measurement capability of the oscilloscope can be used for this purpose. If you look at the basic motor design, you can see that placing the oscilloscope leads across the coil should do the trick. However, it is possible to misinterpret the data provided in this manner. Therefore, a second method will also be used on the fastest motors. To make this second method work well, you must cover the hole formed by the coil with a piece of paper. The periodic blocking of a laser beam will then be used to determine the coil speed.

To make the motor work well, there are many issues that have to be addressed. The issues that came up a couple of years ago are listed on another website:
http://hibp.ecse.rpi.edu/~connor/motor_comments.html
A key issue noticed by nearly all motor builders is balance. The better balanced the coil, the faster it turns. To achieve good balance, it has generally been found that a smaller coil will be more stable. This coil will also be able to work closer to the magnet where the magnetic field is larger.

Question: About how many turns of wire should the coil have, according to the design discussion on the first website listed above?

The basic Beakman design calls for a coil diameter to be equal to that of a toilet paper tube. Improved performance should be obtained if a smaller coil is built. How much smaller is hard to determine. Since the larger coil is known to work, reducing the diameter by about 25% should make things better without deviating too much from the basic design. To make the smaller coil work, a smaller battery can be used or the paper clips can be bent in. During construction, it is very important to keep everything as rigid and symmetric as possible.

Note: Motors must be built using a 1.5 volt battery and the magnet wire and magnets available in the studio. Two paper clips must be used to form the cradle for the coil. These paper clips cannot be bent into a closed loop around the coil (as was done in the scitoys design). The top of the cradle must remain open. *Anything else in the basic design can be changed. For example, the coil can be any size with any number of turns using any size wire and the paper clips can be bent into any shape as long as the top of the cradle remains open. Also, other materials can be added. For example, a small wire* *can be used to hold the coil in the cradle as long as it is not connected electrically to the cradle. It is permissible to use one of the DC power supplies while designs are being tested, but final performance testing must be done with both a DC power supply and the battery. Any design ideas that deviate significantly from the basic Beakman's motor should be discussed with Prof. Connor.*

Describe the basic Beakman's motor. Draw a picture if your artistic skills are up to it. Explain in your own words, how it works.

Analysis (3 pts): Discuss why your project should work and support your discussion with calculations, graphs, PSpice simulations, and common sense reasoning, if necessary.

As the coil spins, the current passes through it during half of the rotation cycle. The excitation of the coil is thus like a square wave. The coil is an inductor and a resistor. The connections to the coil have some finite contact resistance, the paper clips or whatever is used to connect the coil to the battery and the battery itself all have some resistance. Energy lost to air drag and coil wobble will look like resistance to the circuit. Also, as the coil spins past the magnet, a small current will be induced in the coil. This current will be in the opposite direction to the applied current. Depending on the relative size of the resistances and inductances, the net effect of all this will either look like an inductance or like a resistance. Whatever the signal looks like, it should repeat every cycle.

Draw a circuit diagram for the motor, including every circuit element you think might prove to be significant in its operation. Show the connections to the oscilloscope and the input impedances of the 'scope as circuit components. Provide values for the circuit components that you can determine using either standard formulas and/or measurements. Explain in your own words, how it works.

Personal Responsibilities (1 pt): A short paragraph should be written describing what each group member contributed to the project design.

Appendix (2 pts): Include any background materials you used in the preparation of your design.

Motor Performance (5 pts): To test out your designs, you must first build a basic Beakman's motor and demonstrate its operation to a TA or instructor. Full credit will be given for any operation. That is, if the motor spins on its own, you receive the 5 points.

Motor Speed _____________ Witnessed ________________

Final Report (10 points)
Due 22 November

Your project report will describe how you implemented your designs, how well they worked, what changes you made, data, and calculations supporting your new designs, if any changes were made.

Half of the Final Report grade will be determined by the speed achieved. A functioning motor will result in at least 2 points. The group with the fastest motor in the class (all 3 sections) will receive 6 points, the group with the slowest operating motor will receive 2 points. Of the remaining groups, those whose motor is among the fastest third will receive 5 points, the next third 4 points and the lowest third 3 points. Motor speeds will be posted on the class website. The remaining 5 points (plus up to 2 points for creative work) for the Final Report grade are distributed as shown below. Note that it is possible for the group with the fastest motor to obtain up to 13 points on this report.

Introduction -- Problem statement.

Restate the purpose of this project in your own words.

Implementation (2 pts) -- Discuss what problems were encountered during the implementation of your project and how you solved them. Include advice you would offer to someone who wished to avoid these problems in the future.

Describe your problems and be as helpful to others as possible.

Final Design (2 pts)-- Describe your final design. Show that the new design works with experimental data. Include schematics. Have your experimental data signed by a TA or instructor.

Motor Speed ______________ Witnessed _______________

To verify that your measurement of motor speed is accurate, repeat the measurement using a DC power supply set at three different voltages: 0.5V, 1.0V, and 1.5V. If your estimate of the battery driven motor speed is correct, it should be consistent with these other measurements. Any speed measurement that can potentially fall into the top category must be checked optically, which requires that the hole in the coil be covered by a piece of paper. Discuss why you think your measurement is indeed correct. That is, describe the method you used to take the data and discuss the features of the data you have obtained. For example, explain the voltage levels observed.

Personal Responsibilities (1 pt) -- A short paragraph should be written describing what each group member did to develop and implement the final design.

Creativity (0-2 pts) – Any creative approaches to implementation or in the final design will be rewarded with up to 2 additional points.