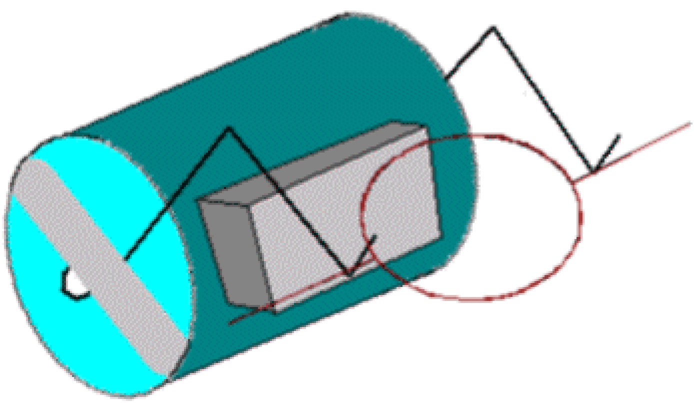
Electronic Instrumentation

ENGR-4300 **Spring 2000** **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**

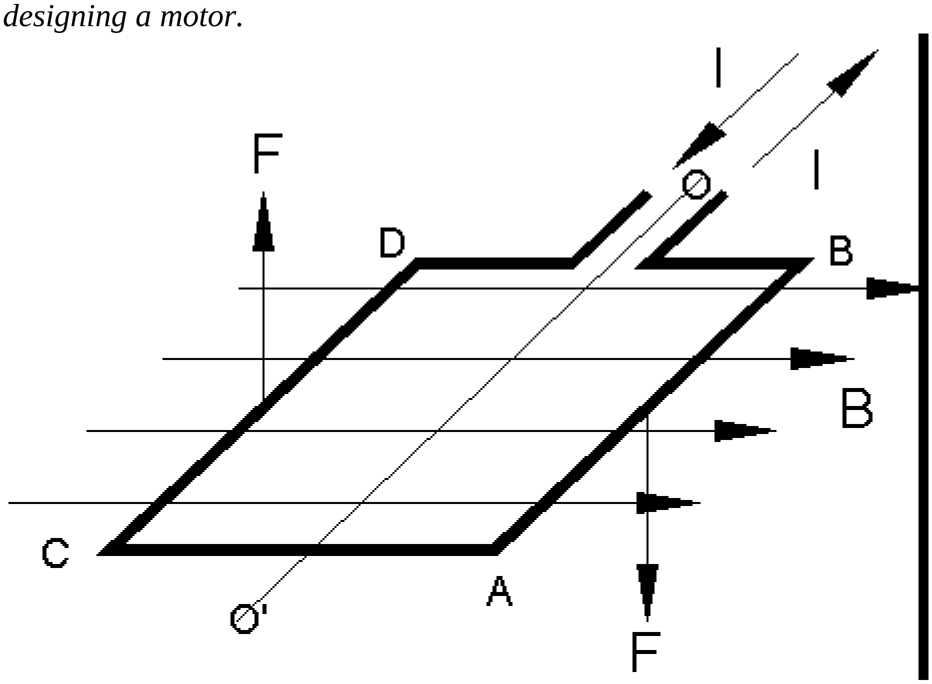
Please note: the critical tasks for this project are underlined and in red (on the webpage.)

Project Report (25 points)
Due 11 April

Introduction

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.

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. 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* $\vec{F} = I\vec{L} \times \vec{B} = ILB \sin a$ *, 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* a *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 magnet 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 using a DC power supply instead of a battery.

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.

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 the battery or with both the battery and the DC power supply if the speed measured exceeds 40 Hz. Any design ideas that deviate significantly from the basic Beakman's motor should be discussed with Prof. Connor.*

Big Hint – *A variation of the method just described for closing the support structure without making electrical contact has been used recently to obtain some very fast speeds. Rather than attaching a small wire to the paper clip to hold the coil in the cradle, many* *students manually press down on the coil axle with two pieces of wire (4-6 inches in length). That is, they hold the two pieces of wire in their hands and press gently down onto the coil axle as close to the support point as possible. This stops the coil from hopping and maintains the connection between the coil and the paper clip support. In effect, they have added a spring (since the pieces of wire are flexible) that keeps pressure on the axle to maintain contact. This idea is highly recommended, since speeds typically increased by at least a factor of two. A somewhat more elegant approach would be to attach one end of these extra wires to a stand and then bend them in such a manner to create a spring that holds the axle down without requiring a person to hold the wires. This will take some adjustment to get right – something that is not required for a human operated spring, since we are capable of adjusting the tension until the best possible speed is achieved. When you test your motor, you should do it first without the extra spring wires. When you add the wires you should see that the motor rotates at a much higher frequency and that the coil remains in contact with the support for a larger fraction of each cycle (that is, that the duty cycle is larger).*

Task #1: 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.

Circuit Model

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.

Task #2: 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.

Basic Motor Performance (5 pts)

Task #3: 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 obtained by Monday 3 April. That is, if the motor spins on its own, you receive the 5 points. Half credit will be given for any motor tested after Monday. It is only necessary that the motor spin long enough to capture a useful signal on the 'scope. This *signal should be printed using the HP-Benchlink software and signed by a TA or instructor.* (Penalty –2 points for no signature on data.)

Motor Speed _____________ Witnessed ________________

Final Motor Performance

Part of your 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 (both 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. To add a bit more competition to this task, the Electrical Engineering students in Fields and Waves I achieved frequencies in excess of 160 Hz this semester using the two-wire spring support idea mentioned above.

Task #4: To test your final design, you must have a motor that spins for at least 30 seconds. It does not have to spin at the same speed during this time. You are free to capture the signal (using the STOP button on the 'scope) at any time during the 30 seconds. Print out your experimental data and have it signed by a TA or instructor. (Penalty –2 points for no signature on data.)

Motor Speed ______________ Witnessed _______________

(Optional) Task #5: If your motor speed (frequency actually) exceeds 40 Hz, you must verify that your measurement of motor speed is accurate by repeating 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. Again, print out your data and have it signed by a TA or instructor. (Penalty – 2 points for no signature on data.)

Discussion

Task #6: In task #2, you developed a circuit model for the motor that should include components representing the battery, paper clips, coil, etc. Using your circuit model, discuss the voltage signal you obtained when testing your motor with the battery. For example, explain the voltage levels observed. Also, discuss any significant differences between the voltage signals obtained for your basic Beakman's motor and your final design. Finally, discuss any ideas for improvements in motor design that you would pursue if you had additional time.

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

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Please list the names of all group members. A TA or instructor will initial a participation box each class day you attend and participate in this project. When you have completed the goals of the project, have a TA or instructor initial under completed. If you are unable to attend class for any reason, you can make up the work during an open shop time. The maximum participation grade is 5 points.

Student Name	Participation	Participation	Completed	Date	Pts

Be sure that you have all of your experimental data signed by a TA or instructor. Also, read this document very carefully and make sure you have done everything you have been asked to do. It is a good idea to highlight each of the tasks listed so you don't miss any.

Task #1: (Description of Beakman's Motor) (3 pts) ________

Task #2: (Circuit Model) (3 pts) ________

Task #3: (Basic Motor Performance)(5 pts) ________

Task #4: (Final Motor Performance) (2-6 pts) ________

Task #5: (Power Supply Test) (0 pts) ________

Task #6: (Discussion) (4 pts) ________

Total (20 pts) ________

Names:

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

Grade: ___________ (Out of 20)