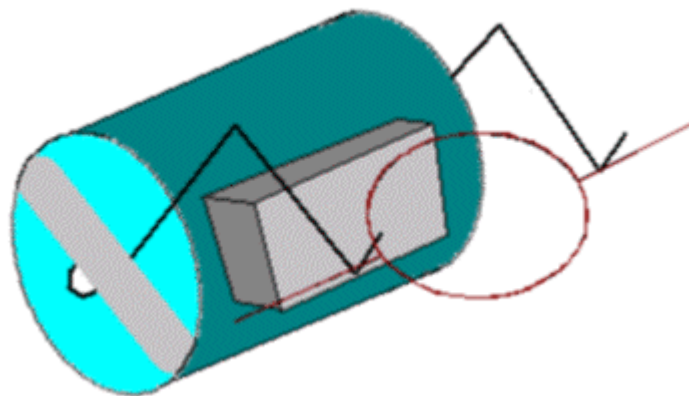


Project 1 (Due: 22 October)
Beakman's Motor

For this project, students can work in groups of two to four. A group of three or four must produce and test at least two distinctly different final motor designs. However, they need only write one report. Groups of two need only do one motor design. No reports will be accepted from single students.

Grading

Introduction (4 pts)	_____
Initial Design (8 pts)	_____
Analysis (8 pts)	_____
Basic Motor Performance (4 pts)	_____
Implementation (7 pts)	_____
Final Design (8 pts)	_____
Performance (7 pts)	_____
Personal Responsibility (2 pts)	_____
Creativity (0-5 pts extra credit)	_____
Appendix (2 pts)	_____
Total (50 pts)	_____



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.

Beakman's Motor (originally shown on the TV show *Beakman's World*) makes a very interesting little project. We use this motor in the core engineering course *Electronic Instrumentation* because it involves some interesting instrumentation issues and because it is a very good example of a system that is both electrical and mechanical. It is also used in *Mechatronics*. 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 *Electronic Instrumentation* website under *Beakman's Motor*. (See <http://hibp.ecse.rpi.edu/~connor/education/ElecInst.html> or click on courses on the instrumentation studio website.) There is a second source of information on this motor also available directly at <http://fox.nstn.ca/~hila/projects/magnet.html> or through the EI webpage under *Hila Projects*. Going to the EI webpage is probably worthwhile, since it contains other helpful project info. It is possible to specify several 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, prospective Electric Power Engineering students and their parents built a version of this motor. Here, you are asked to make the motor go as fast as possible and develop a model that explains its improved performance.

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

- One D-Cell Battery (this can be replaced by any other 1.5 volt battery)
- One Wide Rubber Band
- Two Large Paper Clips (these must be included in your design)
- One Ceramic Magnet - **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 ...

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

Introduction (4 pts): 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 much faster than is the case with the basic design and to determine the speed of the motor by making measurements of currents and voltages in the motor circuit. A detailed explanation of why the motor works as well as it does (including some modeling) must be provided. List at least three educational goals for this project. That is, list at least three topics you might encounter in practical electromagnetics that play a significant role in this project.

Initial Design (8 pts): Describe your initial project design, how it works, how you came up with this particular design, and discuss potential problems. This last item is very important.

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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. By monitoring the current 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. When motors appear to be spinning particularly fast, this measurement can become unreliable. To help confirm the accuracy of the measurement, it is necessary to operate motors at reduced voltage. For this purpose, the DC power supplies will be used (see the final testing section of this document).

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. Some very creative ideas have been pursued in motor design, particularly in the past year.

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.

Describe the basic Beakman's motor. Draw a picture if your artistic skills are up to it.

***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. The top of the cradle must remain open.** No other source of power can be used. Anything else in the basic design can be changed and 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 a battery. The DC supplies will be used to confirm the accuracy of the speed measurement.*

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Describe the particular design improvements (over the basic design) you have pursued in your motor.

Analysis (8 pts): Discuss why your initial design should work and support your discussion with calculations, graphs, PSpice simulations, reference materials and/or common sense reasoning.

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 current will be induced in the coil, just as dropping the magnet through the coil can produce a current. 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, but probably not both. It can be useful to simulate the parallel combination of a resistance and an inductance excited by a square wave, to see what the signal might look like. However, it is probably most efficient to do this after the signal has been observed by picking the L and R that give the observed signal. Whatever the signal looks like, it should repeat every cycle.

Draw a circuit diagram for the motor, including every possible circuit element (resistors, inductors, voltage or current sources, capacitors, ...) 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. Identify the circuit components you think will be the most important in the performance of the motor. Determine values for each of the components in your circuit. This can be done using a combination of analysis, experiment, finding published values or judicious guessing. Whenever possible, provide both analysis and experiment.

Basic Motor Performance (4 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 4 points. However, you will need to record your measurement by producing a plot of what the 'scope measured using HP-Benchlink. This plot is to be included in your final design section for comparison purposes.

Motor Speed _____ **Witnessed** _____

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Implementation (7 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 (8 pts)-- Describe your final design, what needed to be changed and why. Show that the new design works with experimental data from your hardware and simulations or paper-and-pencil analysis. Include schematics. Compare the performance of your final design with that of the basic motor and any other designs you built. Label and discuss the various features of your measured data. Discuss why you think your measurement of speed is accurate. Since you have a measurement of the rotating speed of the coil and you know how many turns in your coil, you should be able to estimate the amount of flux being linked by your coil and compare it with the properties of the magnets we are using. Have your experimental data signed by a TA or instructor.

Performance (7 pts) – *A functioning motor will result in a grade of at least 2. The actual grade will be determined by the speed of the motor. The fastest motor in the class (both sections) will have a grade of 8; the slowest operating motor will have a grade of 2. Of the remaining motors, the fastest third will have a grade of 7, the next third a grade of 5, and the lowest third a grade of 3. Motor speeds will be posted on the class website. 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.

Discuss why you think this 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 (2 pts) -- A short paragraph should be written describing what each group member did to develop and implement the final design.

Creativity (0-5 pts) – Any exceptionally creative approaches to implementation, analysis and/or design will be rewarded with up to 5 additional points.

*Please note that this category is reserved for **exceptionally creative work**.*

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

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