Names _________________ and _________________ Section _____

Project 1

Beakman's Motor

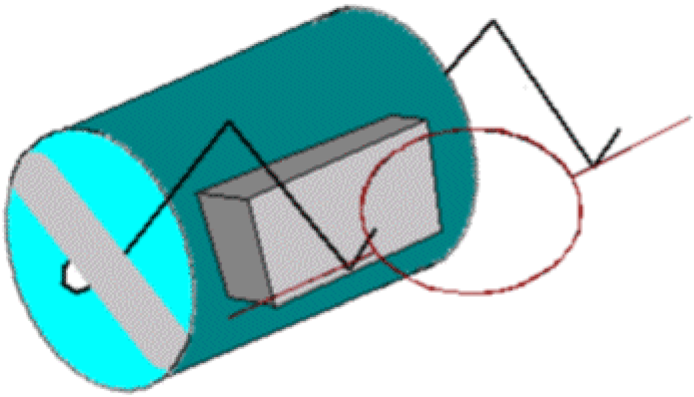
For this project, students should work in groups of two. It is permitted for groups to collaborate, but each group of two must submit a report and build the motor in its basic and final form.

Grading

Introduction (4 pts)	________
Initial Design (8 pts)	________
Modeling and 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 (originally shown on the TV show *Beakman's World*) makes a very interesting little project. We use this motor in the core engineering course *Electronics and Instrumentation* because it involves some instrumentation issues and because it 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 *Electronics and Instrumentation* website under *Beakman's Motor*. (See http://hibp.ecse.rpi.edu/~connor/education/ElecInst.html) 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 E&I webpage under *Hila Projects*. (Going to the E&I webpage is probably worthwhile, since it contains other helpful project info.)

For this project, you are asked to make the motor go as fast as possible and understand why. The general procedure you are to follow is to first build a simple, working version of a Beakman's motor. This is the basic prototyping stage in which you see where the starting point is for your work. Next, you are to develop a model of the basic motor that you can use to assess possible improvements. Then, you will come up with a preliminary design of an improved motor, analyze it with your model and possibly test it. Finally, you are to use what you have learned in your first attempt to develop your final design, analyze it and test it. The final design must be tested, since your grade will be determined, in part, by the speed you obtain.



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 (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 Circular Ceramic Magnet **- X**
Magnet Wire (the kind with enamel insulation) **-X**
One Toilet Paper Tube
Fine Sandpaper **(Available in the studio) - X**
Optional: Glue, Small Block of Wood for Base, and …

Below you will find a description of the various parts of this project. Each contains a general description, possibly some background information and then a list of the specific tasks we expect you to accomplish. The latter will be listed with bullets.

Introduction (4 pts)

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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. In addition, the educational goals of the project are to gain some practical experience with some of the fundamental concepts of electromagnetics.

- *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, qualitatively how it works, how you came up with this particular design, and discuss potential problems. Be sure that you identify how your design differs from the basic motor.*

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. If you have a difficult time figuring out what was your initial design, choose one of your less successful ideas. You should discuss your most successful idea in the final design section. You could also choose to discuss a preliminary version of your final design here as long as there is at least one significant difference between it and your final design.

Note: Motors must be built using a 1.5 volt battery and the magnet wire and magnets provided to you. No other source of power can be used. Anything else in the basic design can be changed. 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. Please be sure that your description of your design makes it clear that you understand this.

Modeling and Analysis (8 pts)

- *Draw a circuit diagram for the basic Beakman's 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.*
- *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. Explain any differences you observe between your predicted and measured parameters.*
- *Identify the circuit components you think will be the most important in the performance of the motor.*

- *Using your model of the basic motor (with any necessary improvements), assess the differences between your preliminary design and the basic motor.*

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 you see on the 'scope using HP-Benchlink. This plot is to be included in your final design section for comparison purposes.

Motor Speed _____________ **Witnessed** ________________

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.*

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. Make a hard copy of what you see on the 'scope using HP-Benchlink.*
- *Apply your motor model, with appropriate modifications, to your final design. Include a new circuit diagram, if necessary.*
- *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 the number of 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)

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.

Motor Speed _______________ Witnessed ________________

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 or in the final design will be rewarded with up to 5 additional points.

Appendix (2 pts)

- *Include any background and/or reference materials you used in the preparation of your design.*

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Some General Comments and Background Information:

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 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

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.hmtl
A key issue noticed by nearly all motor builders is balance. The better balanced the coil, the faster it turns and the easier it is to measure the speed. 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.

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 is 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.