

**Project 1 (Due: 15 April)**  
**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**

**Design (10 pts)** \_\_\_\_\_

**Analysis (10 pts)** \_\_\_\_\_

**Basic Motor Performance (5 pts)** \_\_\_\_\_

**Motor Speed** \_\_\_\_\_ **Witnessed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Data Plot Printed and Signed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Final Motor Performance (15pts)** *Must be completed by 11 April* \_\_\_\_\_

*Only one test is necessary for a group of 2 students. Two tests are required for larger groups. Additional tests can be done by any group that wishes to improve their performance.*

**Motor Speed** \_\_\_\_\_ **Witnessed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Data Plot Printed and Signed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Motor Speed** \_\_\_\_\_ **Witnessed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Data Plot Printed and Signed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Motor Speed** \_\_\_\_\_ **Witnessed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Data Plot Printed and Signed** \_\_\_\_\_ **Date** \_\_\_\_\_

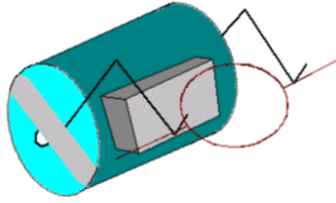
**Motor Speed** \_\_\_\_\_ **Witnessed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Data Plot Printed and Signed** \_\_\_\_\_ **Date** \_\_\_\_\_

**Discussion of Results (5pts)** \_\_\_\_\_

**Personal Responsibilities (5 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. 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://hilaroad.com/camp/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. 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 EI website under *Beakman's Motor*. Another good reference can be found at <http://www.scitoys.com/scitoys/scitoys/electro/electro.html#motor>.

#### 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 or Emory Paper (**Available in the studio**)
- Optional: Glue, Small Block of Wood for Base, and ...

*Please note: YOU MUST NOT SAND THE WIRE DIRECTLY ON THE COUNTERTOPS IN THE STUDIO. The surface has already been damaged by past classes.*

#### **Introduction:** Project Goals.

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. An

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explanation of why the motor works as well as it does (including some modeling) must be provided.

### Basic Design (10 pts)

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.html](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.

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.

*(5 pts) 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.

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*(5 pts) Describe the particular design improvements (over the basic design) you have pursued in your motor. (See the additional comments at the end for some ideas.) Draw a picture of your final design.*

### Analysis (10 pts)

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, etc.) 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. Estimate the emf induced in the coil as it spins. Determine the resulting current and compare this current with the current from the battery.*

### Basic Motor Performance (5 pts)

One of the best ways to begin a design process is to build a simple prototype. Thus, 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, as long as it spins. However, you will need to record your measurement using the Agilent-Intuilink software and have your plot signed by a TA or instructor. If you have trouble making this work, you can sketch your plot and have it signed.

**The motor speeds must be recorded and witnessed on the grade sheet. The signed data plots (obtained with Intuilink) must be consistent with speed recorded on the grade sheet.**

**Final Motor Performance (15 pts)**

A functioning motor will result in a grade of at least 6. The actual grade will be determined by the speed of the motor. The fastest motor in the class (all sections) will have a grade of 18; the slowest operating motor will have a grade of 6. Of the remaining motors, the fastest third will have a grade of 15, the next third a grade of 12, and the lowest third a grade of 9. Motor speeds will be posted on the class website. *Have your experimental data signed by a TA or instructor. This must be completed by 11 April.*

**Motor Speed must be recorded and witnessed on the grade sheet. The signed data plot (obtained with Intuilink) must be consistent with speed recorded on the grade sheet.**

**Discussion (5 Pts)**

Please discuss the features of your data. For example, explain the voltage levels observed in the data using your circuit model. Discuss any odd features that do not seem to be consistent with a simple explanation of the motor. Discuss any problems you encountered and how you overcame them. What did you learn from this experience?

**Personal Responsibilities (5 pts)**

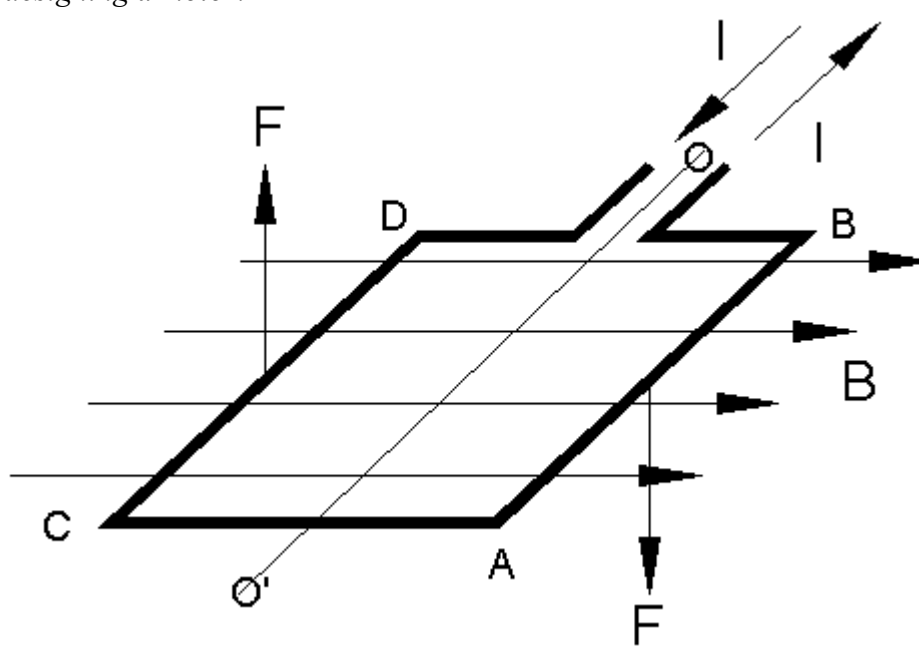
A short paragraph should be written describing what each group member did to develop and implement the final design. It is very important that each member of the group be responsible for some aspect of the design, analysis or testing process. To obtain full credit for this, tasks must be described and assigned to members of the group.

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*Note: Be sure that you turn in the grading sheet with your official signed speeds and all data signed by a TA or instructor with your report.*

**Additional Comments:**

The basic principles of motor operation are included in the websites 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  $\vec{F} = I\vec{L} \times \vec{B} = ILB \sin \alpha$ , 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  $\alpha$  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](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?

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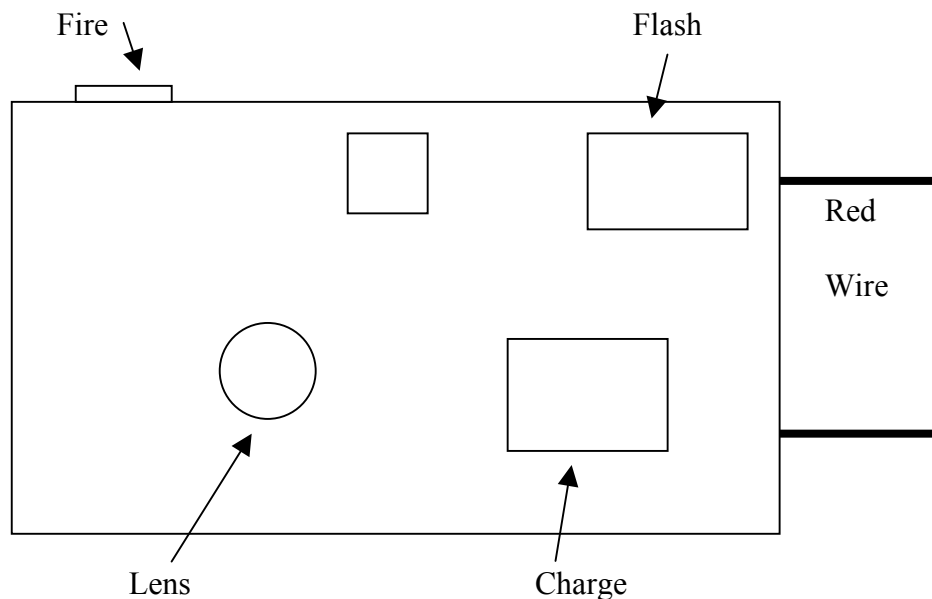
**Big Hint** – A variation of the method described above for closing the support structure without making electrical contact has been used recently to obtain some very fast speeds. Rather than attaching a small wire to the paper clip to hold the coil in the cradle, many students manually press down on 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. Using this idea, speeds typically increased by at least a factor of two. This semester, you are required to use a somewhat more elegant approach and use a spring that requires no human intervention. For example, you can 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. You can use any design you wish for your spring as long as the metal of the spring does not make electrical contact between the coil and the battery. Any kind of insulated wire can be used as long as the insulation is not removed. Using a spring of this type 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 spring. 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).

**Extra Credit – Magnetic Paper Clip Launcher or Beakman’s Motor Modeling**

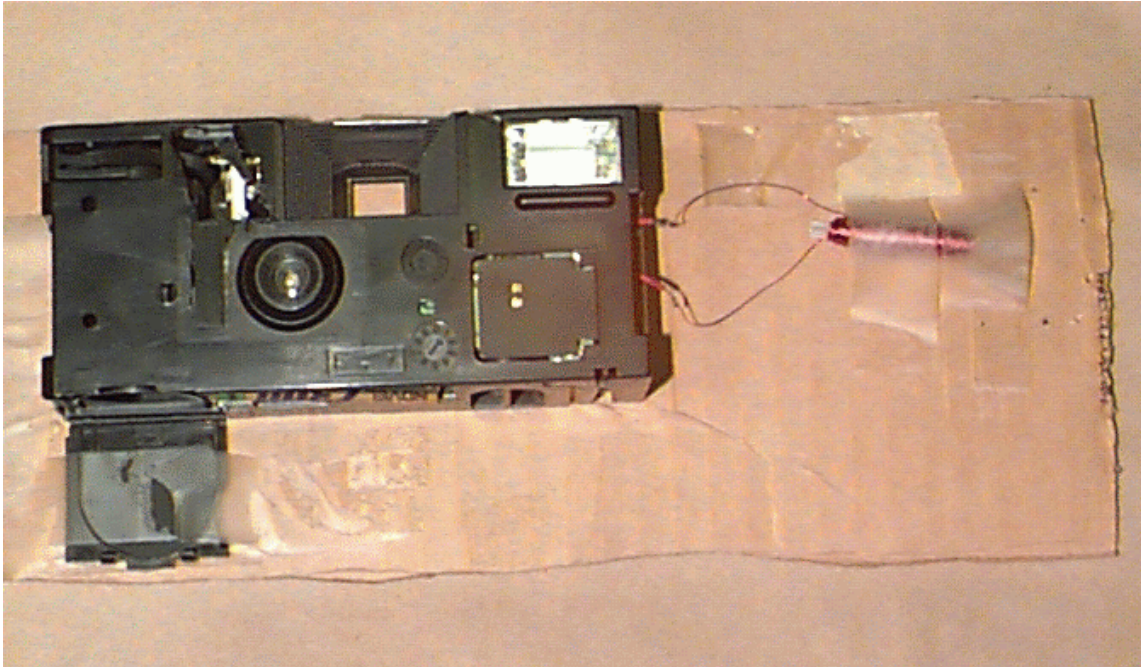
These extra projects can be started when Project 2 is finished. Further information will be provided at that time. The due date will be 23 April. One project is for people who like building things, the other is for those who prefer to deal with more theoretical issues. Only one option may be chosen. Each must be done by no more than 2 students. There will be 2 or 3 testing days announced for the paperclip launcher. The distance the paper clip is launched must be verified by an instructor or a TA.

**Option 1 – Extra Credit:**

It is possible to earn a few extra credit points by building a device that launches pieces of paper clips using a disposable flash camera. Below you should find a simple figure for this project. You are to design and build a coil that is connected to the wire that leads to the flash tube in the camera. . The number of bonus points you get will be equal to the number of feet the projectile travels in excess of 20. The longest distance achieved in the past was about 45 feet. A really cheesy version of this device (see photo below) was able to easily launch a piece of a paper clip 15 feet. You must obtain the camera from an instructor and listen to a tedious explanation of the project and the dangers of dealing with the camera -- it contains a capacitor at 330 volts. Be sure that you have a screwdriver or some similar object that will permit you to short out the cap, should your circuit fail with the cap fully charged. For this project, you are not to use any other energy source or energy storage source except the camera flash unit. You are to focus on designing the best possible coil and leave it at that. Basically, you design a coil to be driven by the flash unit. The coil is connected in series with the usually red wire that feeds the flash. Be sure that the connections are good or the wires will separate in a dramatic fashion.







**Option 2 – Extra Credit:**

The Beakman's Motor is a crude, simple version of a DC motor. As such, its operation is governed by both electrical (circuit) and mechanical equations. Develop a reasonably accurate model incorporating both the electrical and mechanical properties of this motor. Evaluate all parameters in your model and then solve the equations. Finally, compare the solutions to your equations with the actual performance of your Beakman's motors. Suggestion: record the data for at least two versions of the Beakman's motor. It is generally much easier to account for the differences in the performance of two motors than to account for all of the details in the performance of a single motor. Depending on the quality of the models presented and discussed, up to 25 points can be obtained by doing this additional project. Models will be assessed on completeness, accuracy and demonstrated understanding.