# Electrostatic motor

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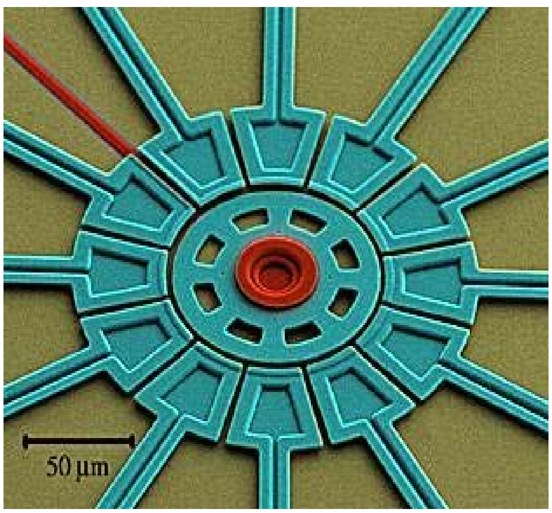
**Principle:** This type of motor is based on Coulomb forces, and its energy output is related to the change in **electrostatic energy** that occurs when charges are moved between the terminals of a high-voltage (HV) supply. This is different from a regular motor, which is based on magnetic forces and the change of **magnetic-dipole energy** in a magnetic field.

**Discussion:** Electrostatic motors are quite limited in how much total power they can provide. Since they can be made very small, they have niche applications in MEMS devices where regular motors with coils would be too large, and where specific power (power per volume) is more important than the power itself.




Scanning Electron Micrograph (SEM) image of a salient-pole electrostatically actuated micromotor made from polycrystalline silicon using surface micromachining techniques. The central rotating element of the motor (e.g., the rotor) is the circular structure in the middle (shown in blue) held to the substrate by the central bearing (which is shown in red). Properly phased voltage potentials are placed on the motor stators (typically 120 degrees advanced in phase sequentially around the stators), which are equally spaced around the perimeter of the rotor (also shown in blue) and these applied voltages on the stators cause the central rotor to turn around the bearing at extremely high angular velocities. This device was made through the MEMS and Nanotechnology Exchange fabrication network. (Figure caption and picture from http://www.mems-exchange.org)

The maximum possible power, $P_{\max}$, derived from an electrostatic motor can be estimated as $P_{\max} \approx fV \frac{\epsilon_o \epsilon_r}{2} E^2$ , where $f$ is the rotation frequency, $V$ the field volume, $\epsilon_r$ the dielectric constant of the filling, and $E$ the peak electric field. For the demonstration model described below, the field volume is about 0.2liter=$2\text{x}10^{-4}\text{m}^3$, the maximum frequency about 10 Hz, the electric field about 4kV/cm and $\epsilon_r = 1$, leading to an estimate of $P_{\max}$ ≈15mW. Since the total motor volume is of order one liter, the specific maximum power is $\frac{\text{P}_{\max}}{\text{V[motor]}} \approx 10\text{mW/liter}$.

Technically useful implementations maximize the electric field and the dielectric constant by employing a dielectric with high dielectric strength. Also, the rotation frequency of a small motor can be made quite high. For a hypothetical motor with a field volume V=$(100\mu\text{m})^3$ rotating at $f$=100Hz , filled with $SiO_2$ ($E_{\max}=10^7$V/cm, $\epsilon_r = 4$) we estimate P=1.8mW. However, assuming that the motor has a volume of ten times the field volume, we estimate a specific power of $\frac{P_{\max}}{V(\text{motor})} \approx 1.7\text{x}10^5 \text{W/liter}$. This is about 240 horsepowers per liter!

## Demonstration model

There's quite a variety of demo devices advertised on the internet; here are links to just a few. If you want to read more, you'll get numerous results if you search for "electrostatic motor".

http://amasci.com/emotor/emot1.html
http://en.wikipedia.org/wiki/Electrostatic_motor
http://www.instructables.com/id/Build-an-Electrostatic-Motor/

It mostly depends on preference and availability of materials which kind you want to build. An important principle your design should incorporate is that it should allow you to fine-tune the spark gaps to sub-mm precision. This is particularly important for operating voltages below 10kV. To keep it safe, cheap and simple I suggest using a negative-ion generator power module as a HV source. These are available for around $10, sometimes less, and produce up to about 10kV negative voltage at low currents (in the micro-A range).

### General Safety:

- **Do not use a HV supply rated at high currents! (0.1mA or so would already be quite high at that voltage).**
- **A low-current supply can build up a lethal charge over time when connected to a large HV capacitor. Thus, do not employ any high-voltage capacitors with more than a few nF (nano-Farad) of capacitance.**
- **If you carry any medical electronics you should not be near any HV device.**
- Keep computers, cell phones and other electro-statically sensitive equipment away from HV devices.

### Safe operation of this device:

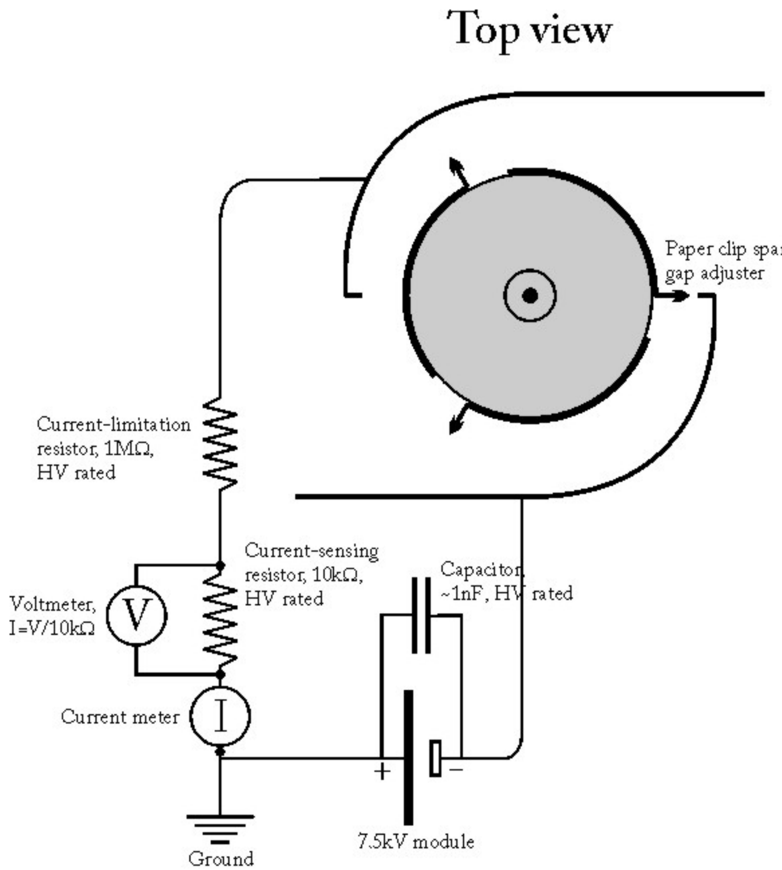
- **Make sure the HV side of your circuit has a well-defined grounding.**
- **Do not touch the wiring while the HV supply is turned on.**
- **To disengage the motor, turn the HV supply off. Before touching any of its parts, short the motor panels and all capacitors with a sufficiently well insulated wire.**
- **Mount the axle of the motor in a way that it is safe to touch it while the HV is on.**

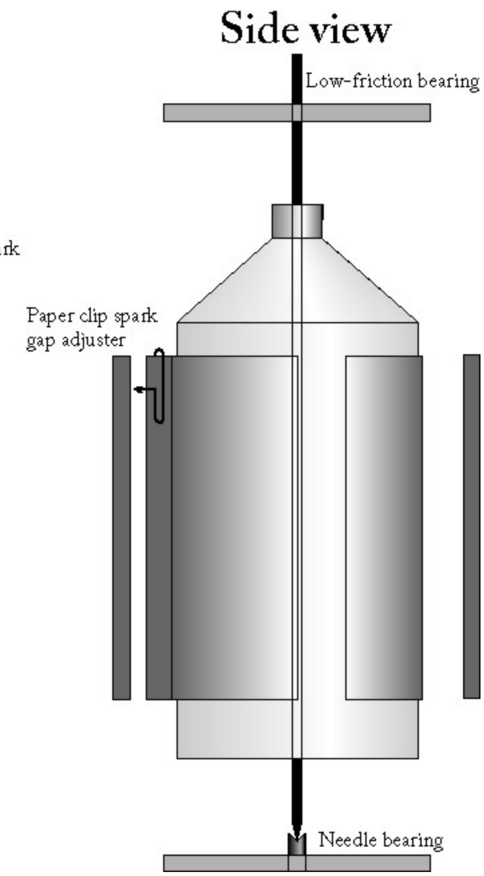
**I do not guarantee the safety of the described device or any of its parts. Building and operating it is at your own risk.**

## Movie of the device in operation:

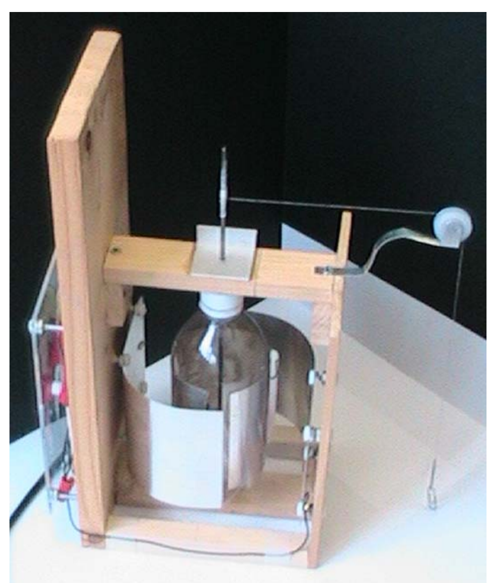
Download from http://www-personal.umich.edu/~graithel/emotor.avi
This is a 24MB file, so be patient. You'll need an avi-player installed.

# Building and operation instructions:



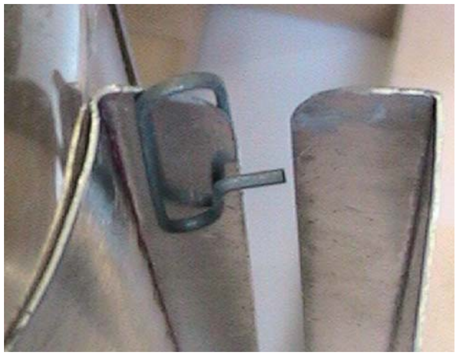




Model top view.



Model side view.

**Rotor:** Use a small soda bottle (b/c of weight) as rotor body. Form three identical aluminum sheet metal panels to approximately match the radius of curvature of the bottle. A sheet thickness between about 1/4mm and 1/2mm should be fine. You may do this by rolling the sheet metal over a solid cylindrical object that resembles the bottle. Near one of their edges, fold the panels up in a way that the panels have about 5mm wide lips away from the bottle. Slide paper clips over the lips and bend them to allow you to fine-tune the spark gaps.  Round off all corners to avoid unwanted discharge. Glue the panels on the bottle in a symmetric fashion (see sketch above and pictures below).



**Left:** One of the three panels mounted on the rotor bottle.

**Top:** Paper clip used to fine-adjust the spark gaps.

**Right:** One of the two stator panels.

**Stator:** Form two identical aluminum sheet metal panels as indicated in the above sketch. Near the inside edges, fold the stator panels inward in a way that the panels have about 5mm wide lips towards the bottle. Round off all corners to avoid unwanted discharge.

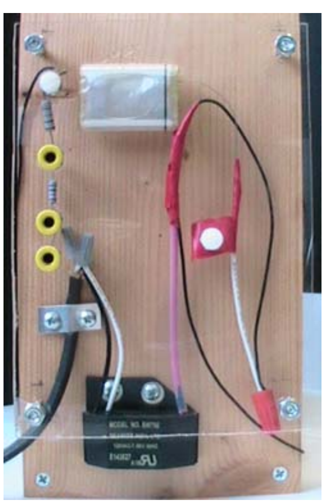
**Bearings: Low friction is essential to make this device work.** You may use a steel rod (like a welding rod), shape its end into a sharp tip, and push it through the bottle along its symmetry axis. The bottom bearing, which will carry the rotor's weight, should be some sort of needle bearing consisting of the tip and some receptacle with a conical indent (see picture). Setscrews with conical intents machined into their ends work well for that. The upper bearing only picks up small transverse forces. It is sufficient to just have the axle pass through a hole drilled in a piece of aluminum of about 1mm thickness (see picture).  While you are looking for a fairly tight fit, it is more important that you don't feel any friction when rotating the rotor with your fingers. Both bearings can be oiled as needed. Ball bearings don't work too well. [Note: If you do try ball bearings, make sure you find a type that **doesn’t stick when the load approaches zero**. Oiling ball bearings will typically make matters worse.]

**Left:** Top (friction) bearing.

**Right:** Bottom (needle) bearing. For clarity, the tipped axle has been lifted out of the conical surface that forms the lower part of the bearing.

**Structure:** I recommend using wood as main construction material, as it is a good enough insulator, cheap and easy to work with. If you use woodscrews, make sure they don’t come closer than about two inches to the HV-carrying parts. The structure mostly consists of a stable frame on which the upper and lower bearings and the stator panels can be mounted. I have used nylon screws to mount the stator panels. I recommend mounting the HV circuitry on the outside of the frame and covering it with plexiglass. This will result in a compact package with a nice view onto the HV parts. The plexiglass cover will allow you to explain the circuitry to spectators while keeping the HV mostly contained to where it belongs.

**Mechanical load:** I suggest you integrate a simple weight-lifting rig into your structure design. You may wind about one meter of fine yarn on the axle and feed the end of the string over the side of the device over a low-friction pulley. Rollers for patio doors work well; seek one out that has low friction and add some oil. You may also just feed the string over a ceramic or glass part with a glossy smooth surface. Attach a light weight to the end of the string. Expect that it can lift between 5 and 10 small paperclips when operated with 7.5kV.



**Circuit:** The HV circuit is shown in the sketch above. The main component is a negative-ion generator power supply. These come in varieties operated from low-voltage battery sources or from a standard 110V outlet. As the current produced by these supplies is tiny, the hazard level appears to be low if you don’t carry any medical electronics. The motor operates via sudden charge/discharge events of the panels on the rotor through sparks. The HV current to the motor is occurring in a sequence of sudden spikes that exceed the current rating of the HV supply. Therefore, the supply must be buffered with a **HV-rated** capacitor. Film or ceramics capacitors with a capacitance of order 1nF and a **voltage rating higher than the supply voltage**

work well. I have inserted a 1MΩ current-limiting resistor to reduce the risk of damage to the HV supply. Further, a 10kΩ sensing resistor is used to measure the current. Electrical connections can be soldered or be made using wire nuts. As a rule of thumb, keep a distance of one to two inches between wires and components that have a high-voltage potential difference. Also, in order to avoid unwanted charge loss, round off all edges of the HV-carrying parts, wire joints, etc.. Cover open wiring by plexiglass or another type of HV insulator. Make sure the HV circuit is grounded somewhere. Note that typical insulated household and hobby wire is not safe to touch at HV. If you use a 110V outlet as primary, exercise the usual caution when making the 110V connections and when operating the device.

**Here's a table of some of the parts:**

| Component | Part / Type | Vendors | Approx. Cost |
|---|---|---|---|
| HV supply | Seawise SW-750 low-current, -7.5kV supply. | http://www.allelectronics.com<br>http://www.goldmine-elec-products.com | $10.00 |
| Two cheap multimeters | generic | (many) | <$10.00 each |
| HV capacitor, ~1nF, 10kV | Ceramic or film | http://www.amazing1.com/capacitors.htm<br>http://www.goldmine-elec-products.com | <$5.00 |
| Resistors, 1MΩ and 10kΩ | Must be HV rated | (many) | <$5.00 |

**Measurements:** Use cheap multi-meters to measure I and V. Note that electrostatic damage of the meters beyond repair is not unlikely. Don't use expensive equipment for this. Always keep computers and electro-statically sensitive equipment far away.

- You can measure the current directly by inserting a current meter directly in the HV circuit **near its grounding point**.
- Alternatively, the voltage drop ΔV on the current sensing resistor, R=10kΩ, also reveals the current, I= ΔV/R.
- The current readings will fluctuate because of the choppy nature of the current. Make an estimate of the average current reading. Then, the electrical power $P_{el}$ = I * 7.5kV.
- If the motor is lifting a weight, determine the mechanical power, $P_m$=mg Δh/Δt. There, m is the mass of the lifted object, g=9.81m/$s^2$, Δh is the change in height of the lifted object, and Δt the elapsed time.
- Calculate the overall efficiency factor, η= $P_m$/ $P_{el}$.