Variable Resistor Experiment Log

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Magnets:

Design and Construction:

An initial group of ten magnets was created using NTE Inc. Teflon-coated, eighteen gauge (18AWG) wire. The magnets were fashioned in a typical manner; for each magnet, between 134 and 150 turns of wire surround a 6.5-inch (6.5") long bolt with a half-inch (.5") diameter. Wing nuts were used while building to make possible wrapping the Teflon-coated wire over itself near the tip of the carriage bolt for another layer of coils.

Due to the high cost of NTE Inc. Teflon-coated, 18AWG wire rated for a maximum operating temperature of 200º Celsius, we opted for the far less expensive NTE Inc. wire rated for 90º Celsius, and the latter wire has so far been fully capable of handling the heat generated from current delivered by our power supplies.

One of the ten magnets with a wing nut attached. Each magnet was labeled with the number of turns on the upper and lower layer, as well as the type of wire used – two magnets were built using the 200º C-rated wire mentioned above. Though the wire is the same gauge as the 90º C-rated wire, the sheath tends to be slightly smaller so a few more turns were possible.

Another magnet with the wing nut removed. The wing nut lessens the effective concentrated magnetic field strength due to its shape; during testing of the first resistors, I found it necessary to remove the wing nut to produce a more efficient magnetic field with the .8amp 6V DC power supplies. When two or more magnets are wired in parallel, the three smaller .8amp supplies overheat in approximately 45 seconds and the magnets become somewhat hazardous to operate past this time.

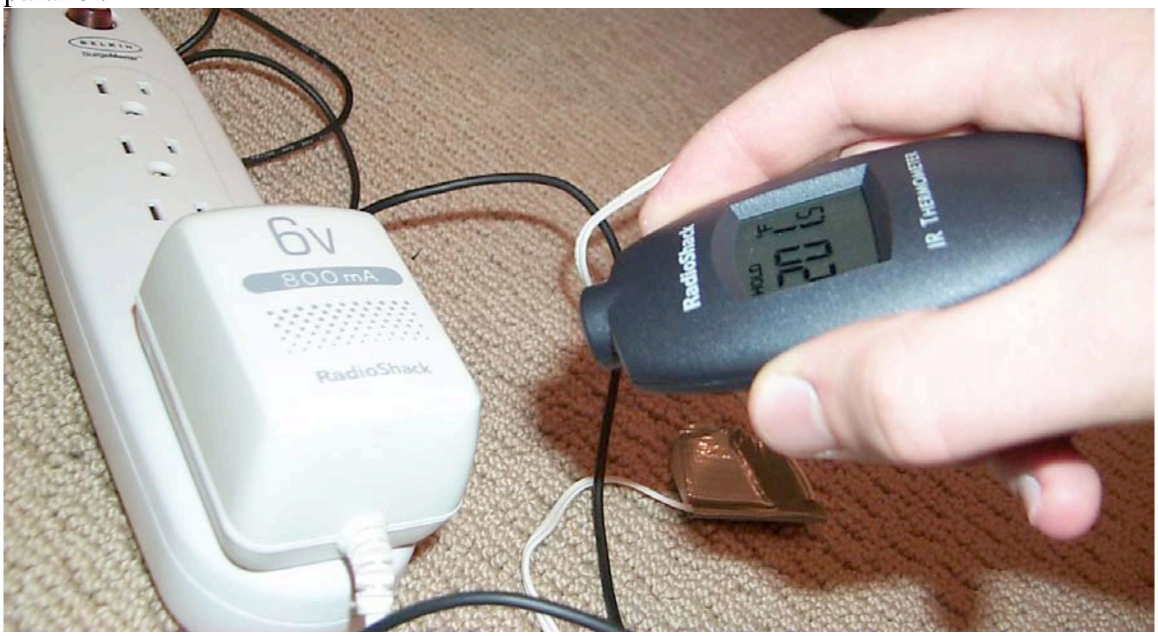
Other Notes:

It is probable that future experiments will necessitate a variety of differently sized magnets with differing strengths. For the variable resistor, however, the more simplified and uniform set of ten nearly identical magnets alleviates the need for an elongated design and testing phase.

Material acquisition was the most difficult part of constructing the magnets. It took several weeks to procure a reasonable form of wire with as thin a sheath as possible; actually building and assembling the magnets took only one afternoon.

Power Supplies:

Three Radioshack-brand, 800mA (.8amp), 6V DC (125V AC, 9W input) power supplies were purchased and tested with the electromagnets. A single magnet (one of the 145 turn magnets was used in the test) causes the power supply to reach over 190º Fahrenheit near the base of its exterior casing after two minutes of use, while two or three magnets wired in parallel cause the power supply to overheat in 30-45 seconds. A maximum of three magnets wired in parallel was tested in these experiments as the power supplies overheat too quickly to be useful when operating four or more magnets in parallel.



One of the .8amp power supplies after powering a magnet for approximately 2 minutes. The IR Thermometer reading was 201.5º Fahrenheit. The plastic casing on the power supply starts to melt and bottom of the case begins to fall in upon itself after remaining above 200º Fahrenheit for any significant amount of time.

With nominal resistance, the power supplies were measured to have a voltage of 7.69V, which stayed stable to the accuracy of the multimeter in use and, despite exerting excessive heat, showed no signs of voltage instability after two minutes powering a single magnet.

A 13.8-volt DC (12 volt listed, 13.8 actual), 3amp regulated power supply was purchased after the first experiments due to the unexpectedly short time of safe operation of the .8amp models.

Testing and Design Phase:

Overview:

We planned to use wax to build the actual case for the variable resistor. Plexiglass and types of formed glass were ruled out due to the difficulty of shaping and working with the materials in small sizes. Before cutting the wax, I performed a series of tests to decide the best shape for the variable resistor, where to place the magnets, and the best design for the container for ferrofluid. A major problem occurred in the planned experiments after the placement tests (explained below) that has, as of the 15th of November, 2002, paused work on the experiments. Though there are various academic institutions working on their development with promising results, and though they have been shown to be possible to create, there are currently no commercial sources of conductive ferrofluids. Please see possible remedies (also below) for further information about methods to continue the experiments without commercial sources of conductive ferrofluids; despite not having working conductive ferrofluids, I was still able to plan out several working designs and build the necessary equipment to craft a variable resistor when conductive fluids become available.

Magnet Placement and Structure Tests:

The test vial, filled with nonconductive ferrofluid and a water/alcohol mix. Two neodymium magnets were placed on opposing sides of the vial, pulling approximately half of the ferrofluid to either side. Clearly, electromagnets capable of exerting their magnetic field in a controlled and variable fashion are far better suited to the task of manipulating the contained liquid.

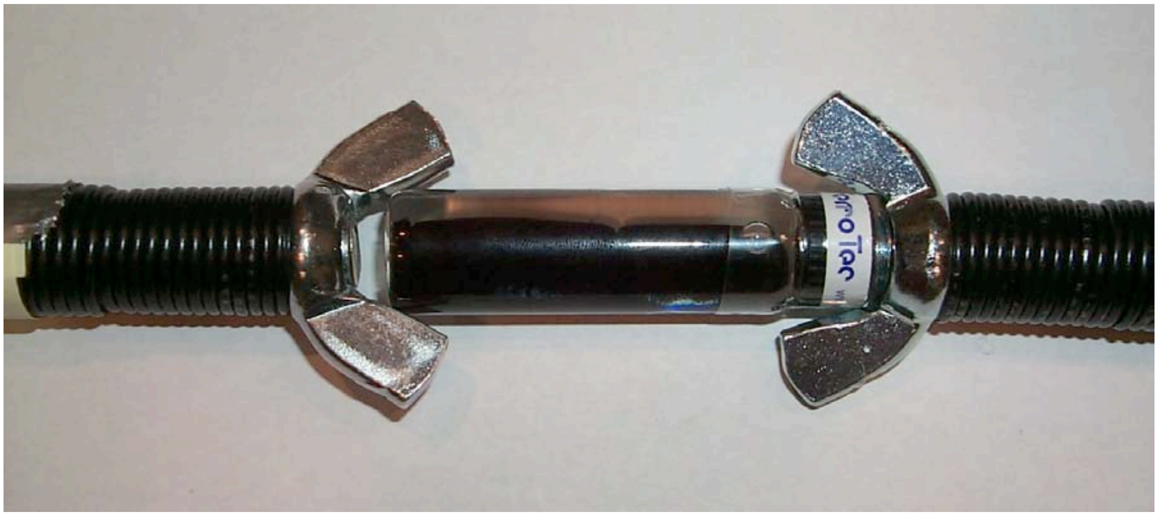
The first placement tests were based on the idea that limiting the throughput of current through a conductive ferrofluid medium can create a working variable resistor. We decided that the best method for reducing the current in a controllable manner is to place electromagnets on the outside of a contained mass of ferrofluid in a nonconductive liquid with two conductive leads attached to opposite ends of the container, entering the liquid to allow them to come into contact with the ferrofluid.

Based on the first tests with the permanent neodymium magnets, an attempt was made at accurate control by placing an electromagnet at each end of the test vial. No holes were cut for leads, nor did we concern ourselves with the specific type of ferrofluid in the vial for these tests. Rather, the purpose was to find a method to effectively and efficiently control the movement of the ferrofluid within an enclosed space.

The test vial with electromagnets, in the off state, placed at both ends. The ferrofluid in the vial remains at rest, and if this particular fluid had been a conductive one, and had leads already been installed in the vial, the fluid would have carried its maximum possible current. Two 140-turn magnets were used.

Due to the construction of the vial and the power supplies in use on the magnets (one .8amp connected to each due to the heat and timing issues of parallel wiring) we needed to place one of the magnets slightly farther away from the vial than the opposing magnet to achieve the same field strength.

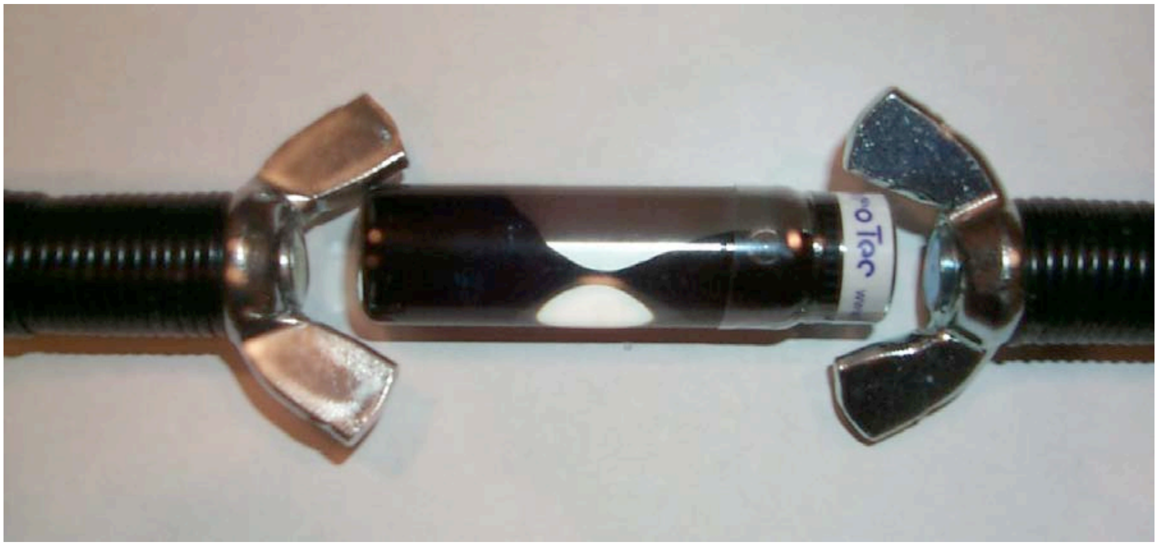
Taken immediately after electricity was applied to the magnets (the ferrofluid was in fact moving while the shot was being taken). The ferrofluid was pulled unevenly because of the vial's asymmetry. This was easily remedied by altering the effective field strength of the magnets.



Another shot of the deactivated magnets and resultant position of the ferrofluid. This picture was taken shortly after the magnets were turned off, and the divided ferrofluid has not yet fully reconnected near the center. The surfactant prevents immediate recombination, and must be taken into account when deciding the requirements and purpose of the resistor.

After moving the magnets farther away to reduce their maximum exerted fields, I re-applied electricity until I achieved relatively good results. The most promising results are indicated by a very thin, but still connected, strand-like formation of ferrofluid in the center of the vial.

The magnets exerting a very weak field on the ferrofluid. With an applied field and a center strand width such as this, the resistance of a conductive ferrofluid would be essentially ineffectual and purposeless; the resistor would act as a conductor.



Increased field strength led to a fairly thin center width. Despite the improvement, the effective diameter of the center point of ferrofluid in this photograph is still approximately 2 tenths of an inch (~.2")

The diameter of the center strand of ferrofluid in this picture is approximately 2 hundredths of an inch (~.02"). This width alone, with a moderately conductive ferrofluid, can create an effective variable resistor for currents usable in practical applications.

Shown on this page are the two most successful tests of the two-magnet experiments on structure and placement. Less successful tests included parallel wiring of two or more magnets – 4 magnets were positioned during one test, to try to affect center ferrofluid dispersion – using the .8amp power supplies, and removal of the wing nuts on the magnets, which proved to be less effective, as the ferrofluid tended to collect near the center of the opposite ends of the vial, which led to more of the fluid collecting in and around the center band of fluid, decreasing the maximum resistance.

Conclusions:

Using a 2.5-inch length, .5-inch diameter cylindrical container (whether made of wax or glass) containing a ferrofluid and carrier fluid (in the cases of these experiments water and alcohol) one can effectively control the diameter of the ferrofluid in the center of the vial using just two electromagnets placed on opposite sides of the vial. Given this, it is reasonable to investigate development of a variable resistor based on a conductive ferrofluid and the container and magnet orientation and structure developed in the course of these experiments.

Ferrotec, the supplier of the sample ferrofluids (EFH1 from their FerroSound division, and another fluid in the test vial), does not manufacture conductive ferrofluids. I contacted them via e-mail and telephone and spoke with a representative who explained that, while various research institutions do make or are developing methods to make conductive ferrofluids, no corporations currently sell or produce conductive fluids. With this information, I have developed several possible remedies to continue experimentation without a corporate supplier of ferrofluids.

Possible solutions:

It is possible, given necessary equipment and materials, to manufacture conductive ferrofluids for use in further experiments. There are obvious problems with this method, most of which involve the high cost of materials and devices needed to produce and effective mixture.

If it is deemed reasonable, we can contact research institutions working with ferrofluids – a group or two at Caltech, for instance – and ask to acquire some conductive fluids. This solution seems reasonable and has a very low investigation cost. Assuming an institution was willing, the fluids should be relatively cheap, as well.

It is also possible to re-develop to experiments to use the ferrofluids as a nonconductive substance limiting another conductive liquid (such as mercury or even ionized water) in varying amounts to produce a resistor. Problems with this include redesign of the container and magnet placement structures, and a necessity of at least 4 independent magnets for each resistor – it was found ineffectual to use just 2 in various tests of this idea.