MHD GENERATOR

Learn the basic theory behind magnetohydrodynamic generators by building your own working model.

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THIS ARTICLE WILL SHOW YOU HOW TO BUILD A WORKING MODEL of an MHD (*M*agneto*H*ydro*D*ynamic) generator for under $30.00. You're probably thinking, "Great! What's that?"

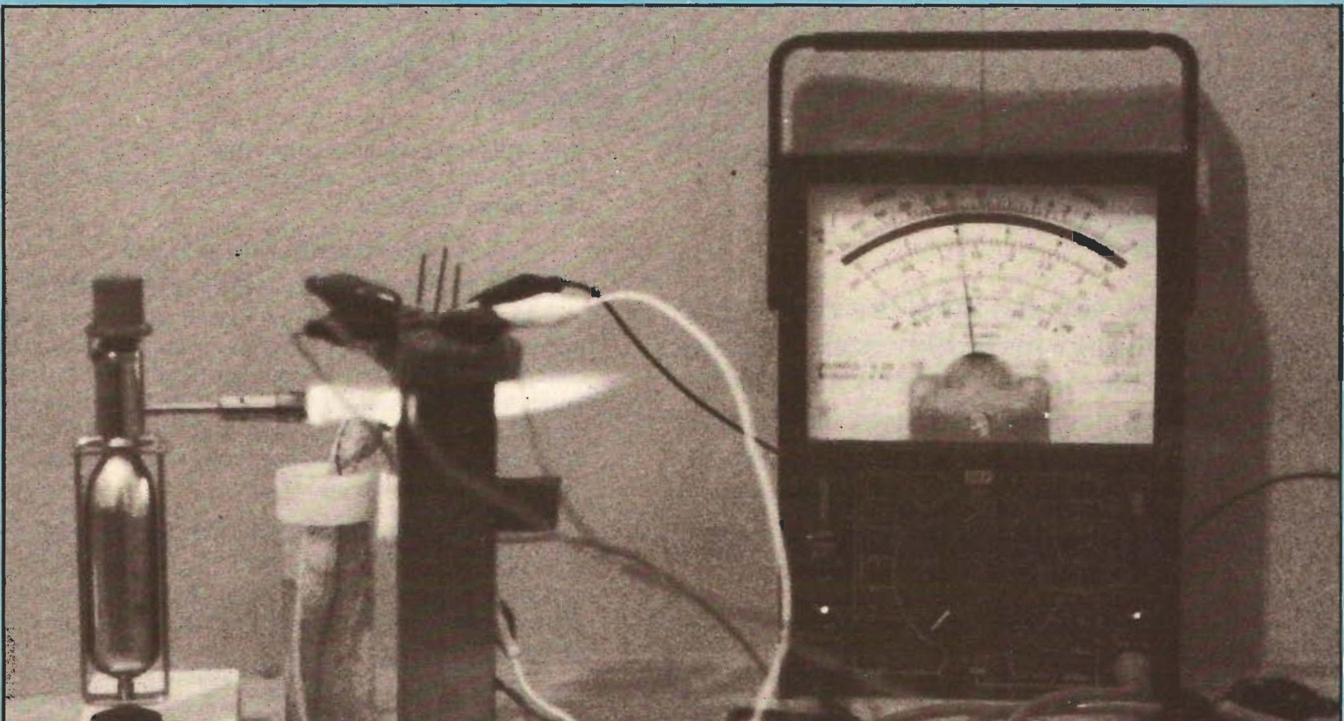
Before we can answer that question, we have to give a brief definition of what magnetohydrodynamics is: it's the study of the effects of magnetic fields on ionized gases or fluids. (It is often also called magnetogasdynamics or hydromagnetics.) An MHD generator uses an ionized gas and a magnetic field to generate an electric current. And it does it more efficiently than conventional power plants do. We don't expect to see commercial MHD power plants until the end of this century. But you can learn about MHD technology now as we discuss the basic theory and even build a working model of an MHD generator.

The power output of the model we will experiment with is on the order of one milliwatt. That certainly is not a lot of power, but it is enough to demonstrate some of the principles of MHD power generation—the same principles that will be used in full scale MHD power plants. We will give you some pointers on how to improve on the basic design. But we encourage you to have the simple model working properly before you try to make improvements.

It is beyond the scope of this article to deal with all of the mathematical formulas that can determine performance of MHD generators. But you will be working empirically with the factors that are involved. They include magnetic field strength, gas velocity, ion-seed concentration, and the Hall effect.

MHD basics

The basis of the magnetohydrodynamic generator is the same as conventional generators: A voltage is induced across a conductor that is moving in a magnetic field. Unlike conventional generators, however, the moving conductor in a MHD generator is not wire. Instead it is a high-velocity electrically-conductive gas (or fluid) stream. As shown in Fig. 1, the gas travels through a duct or *channel* in which a transverse magnetic field is present. An electric field is generated perpendicular to both the magnetic field and the direction of motion of the gas: $\boldsymbol{E} = \boldsymbol{u} \times \boldsymbol{B}$; where $\boldsymbol{E}$ is the electric field strength, $\boldsymbol{B}$ is the magnetic flux density, and $\boldsymbol{u}$ is the velocity of the gas. (Note that bold, italic letters indicate vector quantities.) If electrodes are placed in contact with the gas



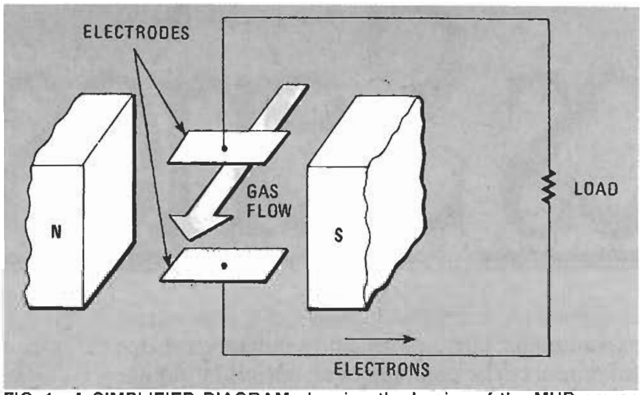


FIG. 1—A SIMPLIFIED DIAGRAM showing the basics of the MHD power generator is shown. As discussed in the text, the model that we'll build is different in several respects.

jet, energy can be extracted and delivered to an external load.

We see that some of the major factors that govern the voltage and current generated include the gas velocity and the magnetic field strength. Also important are the electrical conductivity of the gas, and the design and placement of the electrodes. Once you build the basic model and have it working properly, those are the factors that you should vary if you want to try to improve the performance.

Minimizing losses

The design of an efficient MHD generator is not a easy task. The study of electromagnetics, fluid mechanics, and heat transfer are involved. However, let's look at some of the ways to design a generator to keep losses to a minimum.

One of the most important loss factors is that of the Hall effect. When electrons move through the magnetic field, they are subject to a force, F (called a *Lorentz* force), that is perpendicular to both the direction of electron flow, u_e, and to the magnetic field: $F = eu_e \times B$, where e is the charge of an electron. As a result of that force, the electrons do not move in a straight path between the electrodes. Instead, they tend to flow to one end of the collecting electrode; thus, an electric field is generated. However, the electrode simply shorts the electric field, and so short-circuit currents flow in the electrodes and dissipate power. Those Hall-effect losses can be reduced by using a *segmented electrode*, as we will do in our model. That is, instead of using one pair of plate-like electrodes as shown in Fig. 1, we will use three smaller, independent sets of electrodes.

End loss is another factor that can reduce the effeciency of an MHD generator. End loss occurs because a shunt path between the electrodes is provided by the gas at the entrance and exit points of the generator channel. If the conductivity of the gas is high, the shunt currents at each end can introduce significant losses. End losses are reduced as the length of the channel increases with respect to its width. They can also be reduced by extending the magnetic field past the electrodes.

There are also *electrode losses* due to the fact that the gas at the electrodes is cooler than that of the rest of the chamber, and thus its conductivity is low. Those losses can be reduced in our model by keeping the flame as large and as hot as possible.

There are losses due to to skin friction (fluid dynamic loss). And there are also losses due to heat transfer (which can be reduced by increasing the ratio of channel volume to surface area). Because we are using permanent magnets in our model, we will not concern ourselves with losses due to producing the magnetic field. However, in a commercial MHD plant, those losses would be an important consideration.

How does a gas conduct?

The gases used in the MHD generator become conductive through a process known as *thermal ionization*. As the temperature of the gas is increased, the kinetic energy of the bound electrons increases until it reaches a point where the electrons are no longer bound to the atoms of gas. At that point, because of the free electrons, the gas becomes electrically conductive. That high-temperature, electrically conductive gas is called a *plasma*. In the plasma, along with the free electrons, there are also positive ions of gas (the atoms from where the electrons were originally bound). It is those free electrons and positive ions that are captured by the electrodes in the plasma, thus inducing the load voltage.

The temperature required to ionize a gas is usually extremely high, about 4500°C. We can reduce the ionization temperature by *seeding* the gas with an alkali metal that readily ionizes at much lower temperature. (An alkali metal is *univalent*—it has only one outer-shell electron, thus it ionizes at a relatively low temperature.) Potassium nitrate (which we'll use) and cesium nitrate are two alkali-metal salts that are commonly used for that purpose. We will use a small butane torch (with an output of about 1370°C) to achieve the temperature needed to ionize the seeded gas.

Why MHD?

New research is being conducted on the MHD generator for several reasons. First, the MHD generator promises to use fuel more efficiently than conventional generators do, especially when it is used as a *topping cycle* in a generating plant. In other words, MHD generators will not be stand-alone plants. Let's see how they'll be set up.

After the hot gas passes through MHD the channel, it is too cold to be sent to another MHD generator. However, that gas *is* hot enough to operate a conventional steam turbine, thus producing additional electricity. A commercial power plant using an MHD generator as a topping cycle is expected to be able to work with an efficiency of over 45%. Present-day coal-fired plants that use scrubbers obtain an effeciency of about 34%.

Another reason for renewed interest is that the MHD generator can use all conventional fuels, and it can use high-sulfur coal in an ecologically safe manner. (The particular fuel choice for an MHD power plant would depend on where the plant was located. For example, to make use of its large coal reserves, coal-fired generators would probably prevail in the United States.) Scrubbers, which remove sulfur from the smokestack emmisions of coal plants, are not needed for MHD generators because the sulfur combines chemically with the ion seed and can then then be separated and sold. In a coal plant, the sulfur is left in a useless limestone sludge.

There are some problems that have yet to be overcome. First the cost of MHD generating plants has to become economically competitive with other types of electric plants. And the reliability and life expectancy of MHD generators has to be increased. The major problem is that the electrodes deteriorate quickly because of the extremely high temperature of the gas in the generator. However, work has been done (at Avco Everett Research Laboratory) to suggest that water-cooled copper electrodes with stainless-steel and platinum cladding could have a lifetime of up to 8000 hours.

But, a question that remains unanswered is: How close is MHD power generation to being commercially viable? The goal of the National MHD Program (sponsored by the U.S. Department of Energy) is to have commercial MHD power stations in the early 1990's. Technologically, that is a fair timetable. But because of a lack of available funding, it is doubtful that commercial plants will appear that soon. However, the USSR is currently constructing their *U500*. That 500-megawatt, natural-gas-fired MHD generator is expected to be completed before the end of this decade.

Building the MHD generator

All of the materials that you'll need to build an MHD generator model are shown in Fig. 2. We'll begin construction with the *segmented-electrode* assemblies. First mold and cut a block of

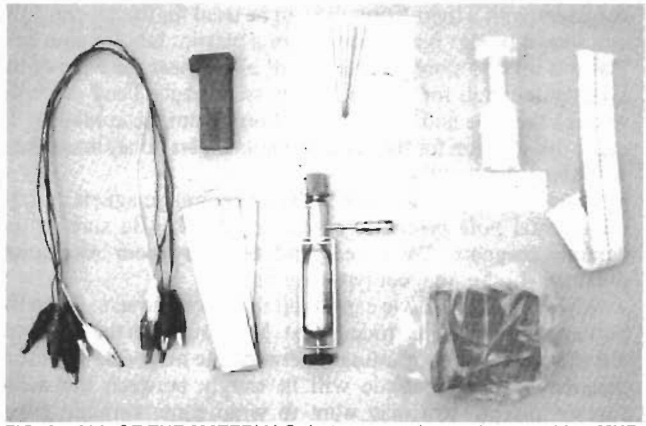


FIG. 2—ALL OF THE MATERIALS that you need to make a working MHD generator model are shown here.

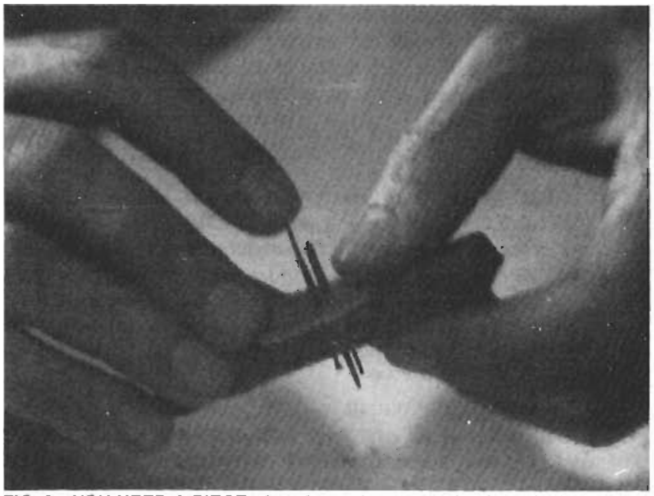
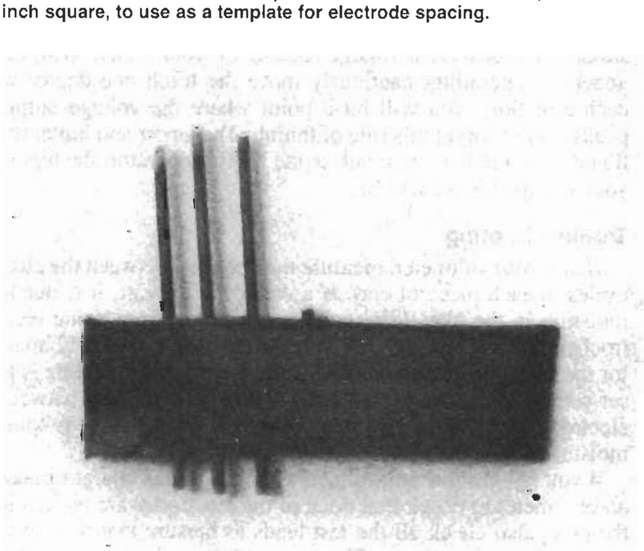


FIG. 3—YOU NEED A PIECE of perforated construction board, about one inch square, to use as a template for electrode spacing.



FG 4—THE BOTTOM SEGMENTED ELECTRODE is shown here before installation.

clay approximately 3/8 inch thick by 1 1/4 inches wide by 2 1/2 inches long. Then center a piece of perforated construction-board (about 1 inch square) on the clay block. That perforated board, whose holes are spaced on 1/10-inch centers, is used merely as a template for spacing and inserting the graphite electrodes. You'll want to make sure that the top and bottom electrode sets are spaced similarly. Although the actual spacing is not important, start by leaving 2/10 inch between each electrode segment.

Next gently insert the electrodes through the board and clay as shown in Fig 3. Use three electrodes to begin with. You want about 1/4-inch of the graphite to be sticking out on top (for connecting to clip leads), and about 1/2-inch into the channel. If an electrode is too long, simply pinch and snap it at the desired length.

To make the second (bottom) segmented electrode, form some clay into a rectangular shape, 3/16 × 3/8 × 2 inches. (The thickness of the clay should match the thickness of the center magnet that you'll be using.) Now insert three graphite electrodes. Use the perforated board to help set the spacing between electrodes the same as in the top electrode set. The bottom segemented electrode should be similar to that shown in Fig. 4.

When you have completed making the segmented-electrode assemblies, remove the perf-board template. Wrap the units loosely in aluminum foil and bake them in an oven at 375°F for an hour and a half, leaving the door of oven open approximately 2 inches. After baking, remove the assembly and allow to cool. Connect an alligator-clip lead to each of the electrodes. If you want, you can connect all of the top segments together and all of the bottom segments together, although in a commercial MHD generator, each set of electrodes is connected to its own load (or its own inverter to be converted to AC) as we show in Fig. 5. If an electrode breaks when you're connecting the test leads, use a straightened paper clip to push the electrode out of the clay, and replace it with a new one. You can also use that technique when the electrodes wear out from use.

The next unit to construct is the seeder, which is used to feed the alkali-metal salt solution into the flame. Almost any small

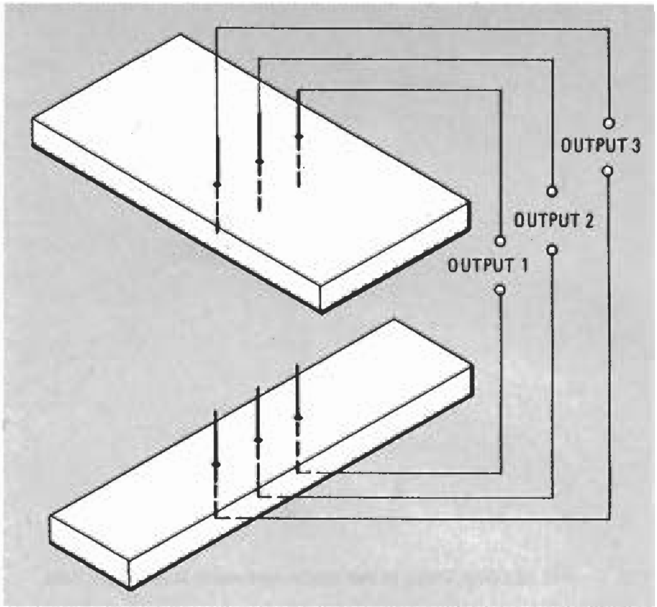


FIG. 5—THE "PINOUT" of the electrode assemblies. In a commercial MHD generator, each set of electrodes would feed its own inverter to be converted to AC.

PARTS LIST

½ pound modeling clay, oven baking
6 0.036-inch diameter carbon pencil leads
1 square inch perforated construction board
1 ounce potassium nitrate (KNO_3)
1 Alcohol-lamp wick
3 Ceramic magnets 3/16 × 3/4 × 1 inch
3 Steel (pole and support) pieces 0.095 × 1 × 3 inches
1 container with cover (about 1 × 3 inches) for alkali-salt solution
1 butane torch (Radio Shack 64-2164 or similar)
Miscellaneous—alligator-clip leads, ceramic paper
A kit of all parts is available from Images Co., South Richmond Hill Station, Jamaica, NY 11419. The price of the kit is $30 including the torch, $20 without the torch. Please add $2.50 to cover postage and handling.

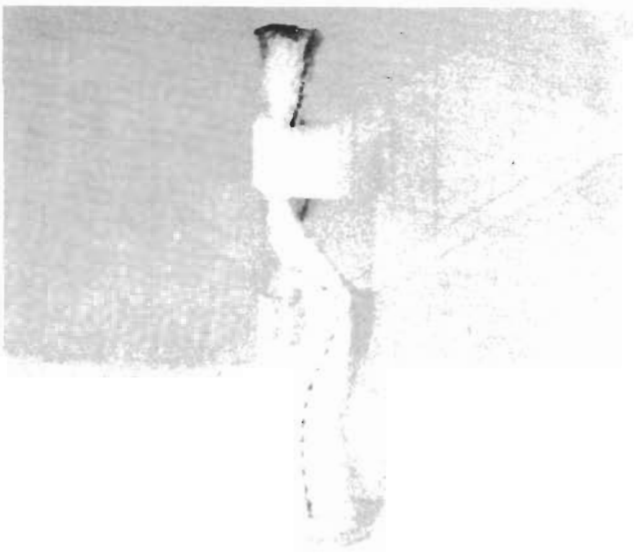


FIG. 6—THE SEEDER USED in our model was made from a coin tube.

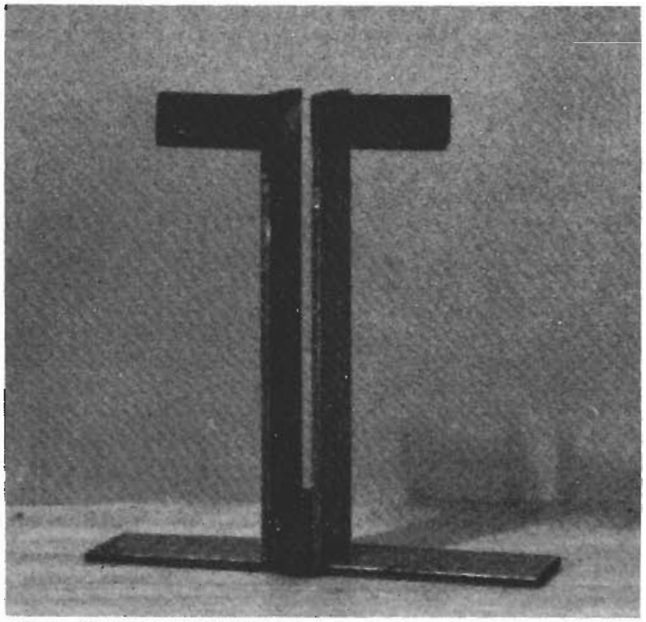


FIG. 7—ASSEMBLING THE POLE pieces and magnets to form the MHD chamber couldn't be easier.

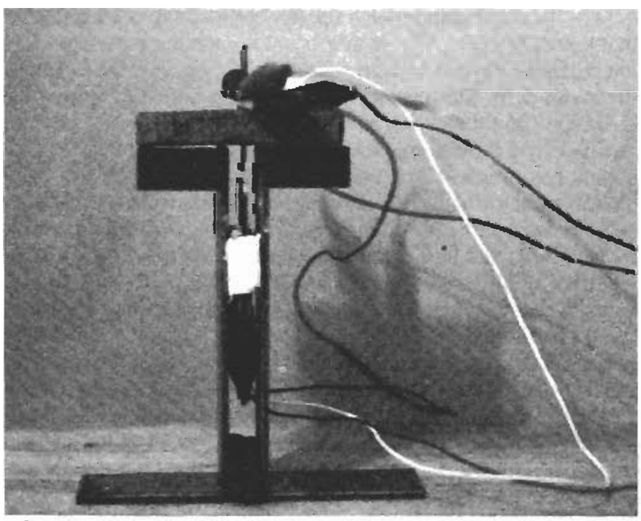


FIG. 8—THE ELECTRODE ASSEMBLIES should be placed between and on top of the support pieces as shown.

container with a tight-fitting lid can be used for the seeder. (The one shown in Fig. 6 was made from a plastic, tubular coin case that was used to store nickels.) Drill a hole near the edge of the lid large enough for the wick to pass through. Feed the wick through the hole and replace the lid back onto the container. To make the solution for the seeder, mix one part potassium nitrate with three parts water.

The next step is to arrange the three ceramic magnets and the three metal *pole pieces* as shown in Fig. 7. (Be sure to use ceramic magnets. We have found that very poor results are obtained if other magnet types are used.)

When that is done, we can install the electrode sets. Place the bottom segmented electrode in first. Make sure that the clip leads are attatched before inserting it between the magnets. To ensure that the bottom electrode will fit snugly between the metal support pieces, you may want to wrap some ceramic paper around it.

The top set of electrodes just has to be placed on top of the assembly. Make sure that that set is directly on top of the bottom set. Leave about ¼ inch between the tips of the top and bottom segmented electrodes. When you attach clip leads to each of the top electrode segments, your assembly should look like that shown in Fig. 8.

Operation

Caution: Before you even turn the unit on, keep in mind that the generator can get *very* hot, so be careful.

To operate the generator, fill the seeder unit with the alkali-salt solution. Make sure that the electrodes are between the two pole pieces and not touching either side. Place the seeder unit at the entrance of the channel with the wick facing into the channel. You want the wick to feed into the flame just ahead of the nozzle of the torch.

Connect one set of output leads to your voltmeter. Start on a scale that reads about one volt. Following the manufacturer's instructions, start the torch and position it so that the base of the flame is just touching the wick, with the main flame projecting straight into the channel. Allow 20 seconds for the unit to heat up, and try to obtain as large and as hot a flame as you can. You should then observe a voltage reading on your meter. With the generator operating, cautiously move the torch one degree in each direction. You will hit a point where the voltage-output peaks. Don't forget this rule of thumb: The larger and hotter the flame you're able to maintain in the MHD generator, the higher your voltage output will be.

Troubleshooting

Using your voltmeter, measure the potential between the electrodes in each piece of clay. If a voltage is present, it is due to moisture in the clay. (The voltage is coming from some electrochemical reaction.) Either bake the clay again or wait 12 hours for the moisture to evaporate. A simple check for moisture is to set your meter to read resistance. If you get a reading between electrode segments of anything other than infinity, there is some moisture left in the clay.

If you fail to show any voltage when the unit is operating, use an ohmmeter to check that none of the electrodes are broken in the clay; also check all the test leads to be sure that they're in good working condition. Check the seeder unit to be sure that part of the wick is touching the flame. Otherwise it cannot feed the salt solution to the generator. Also, double check the dimensions of unit against the parts list and the photos.

Now that you have your MHD generator working, why not experiment? For instance, try using more electrodes for better coupling to the gas, or changing the electrode spacing. A different torch with a hotter output could be used. You could also try using metals other than steel for the support pieces, or using larger magnets to obtain a stronger magnetic field. After you've experimented with changing all of the variables, why not let us know what you come up with! **R-E**