Electromagnetic Z-Pinch:

Exploring the Nature of Electromagnetism in High-Energy Capacitor Discharges

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A Word to the Wise

WARNING -Voltages and currents present in many of the devices mentioned in this article, and the results they produce (flying objects) are potentially LETHAL!! Remain a healthy and living reader by exercising *extreme* caution and common sense when handling such devices.

This article is presented for informational and research purposes in order to provide other researchers with a diverse viewpoint to aid in their work. Experimentation with high voltage and high frequency electricity can be extremely dangerous. This article is to provide information for competent workers in the field. ITS and the author disclaims any responsibility for individuals experimenting with information provided herein. We fully support a responsible person's natural right to research and investigate for themselves.

The Capacitor Bank

I had become the proud owner of some not so ordinary capacitors. There were six of them weighing in at around 150 pounds each, three feet tall and a foot square, with three inch copper pipe terminals on top. Sure they looked ominous, but my associates and I had no idea what they were used for, or what their ratings were.

A capacitance meter showed them to be 2 microfarads each for a total of 12 altogether, hardly impressive. However, I located a staff technician at the laser research facility where I picked them up who could vaguely remember what they were used for. He said they were rated at seventy-five thousand volts each. He cautioned us about taking them to more than about sixty thousand because they had been worked pretty hard. They were from a test to produce an X-ray preionized laser called Lucy, named after its Lucite housing.

Initial Experiments with Flat Coils

We were aware that by winding a flat coil of insulated wire and discharging the whole contents of one of the capacitors through the coil with a piece of aluminum on top, the aluminum would be shot upward from the pulse. It's the same phenomenon that makes maglev trains lift above their aluminum tracks, that makes an aluminum ball float in mid-air with an alternating magnetic field below it, and basically the same as in all induction motors and in electromagnetic induction in general. The only difference is that in this case it is the first pulse that does the work and creates the observable results.

Our first experimental setup worked very well. It popped a piece of light aluminum four or five feet in the

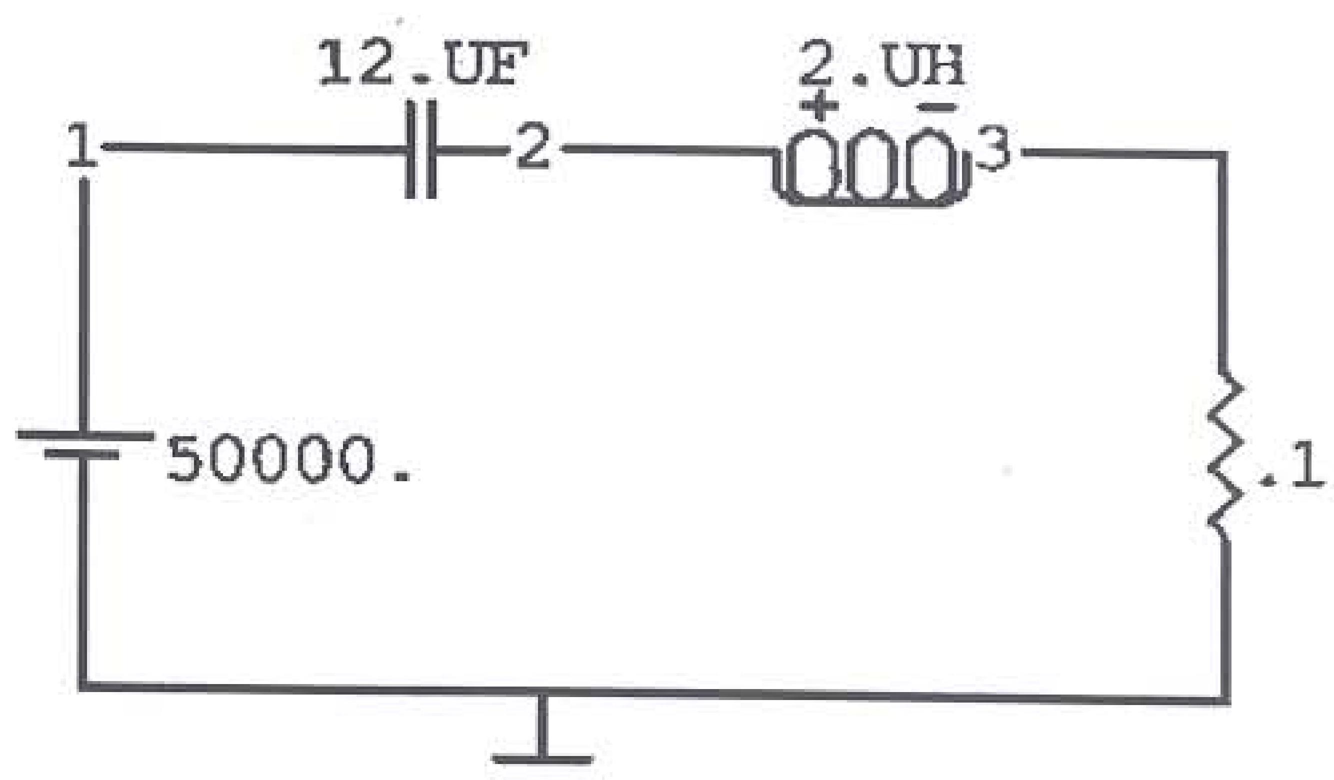

Figure 1. The Basic Representation of the Internal Dynamics. During the initial experiments, 2μF were used. During later experiments, the capaitance was increased to 12μF. Connections inside and outside of the capacitors have inductance and resistance.

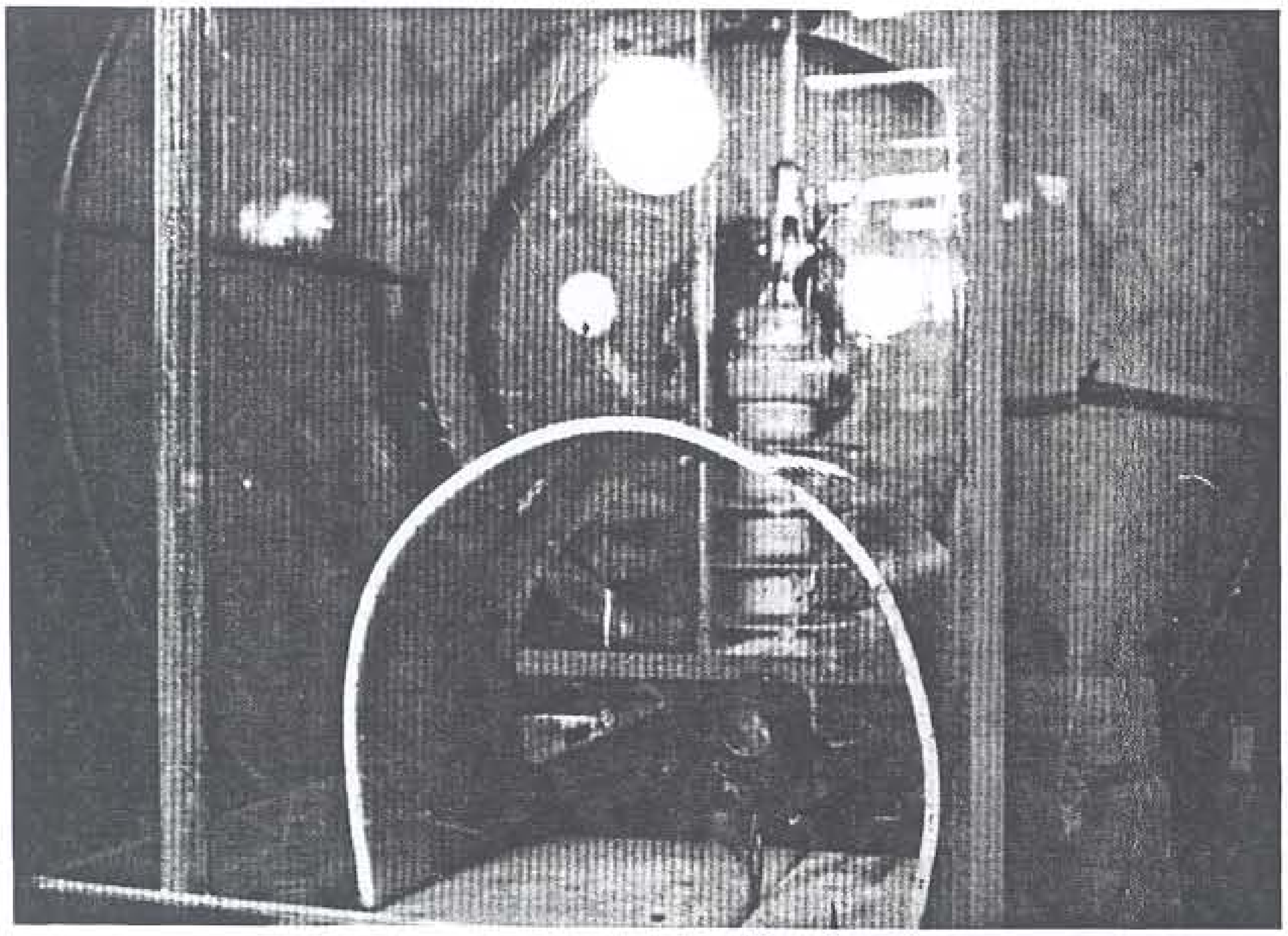

Figure 2. Later Experimental Setups. During the initial experiments, 2μF were used and the coil was placed under the objects. At this stage of the experiments, the capaitance was increased to 12μF, and the coil was wrapped around the target object. In this case, a coin is the target and is visible in the center of the coil. Note the shielding around this setup! Photo by Aubrey

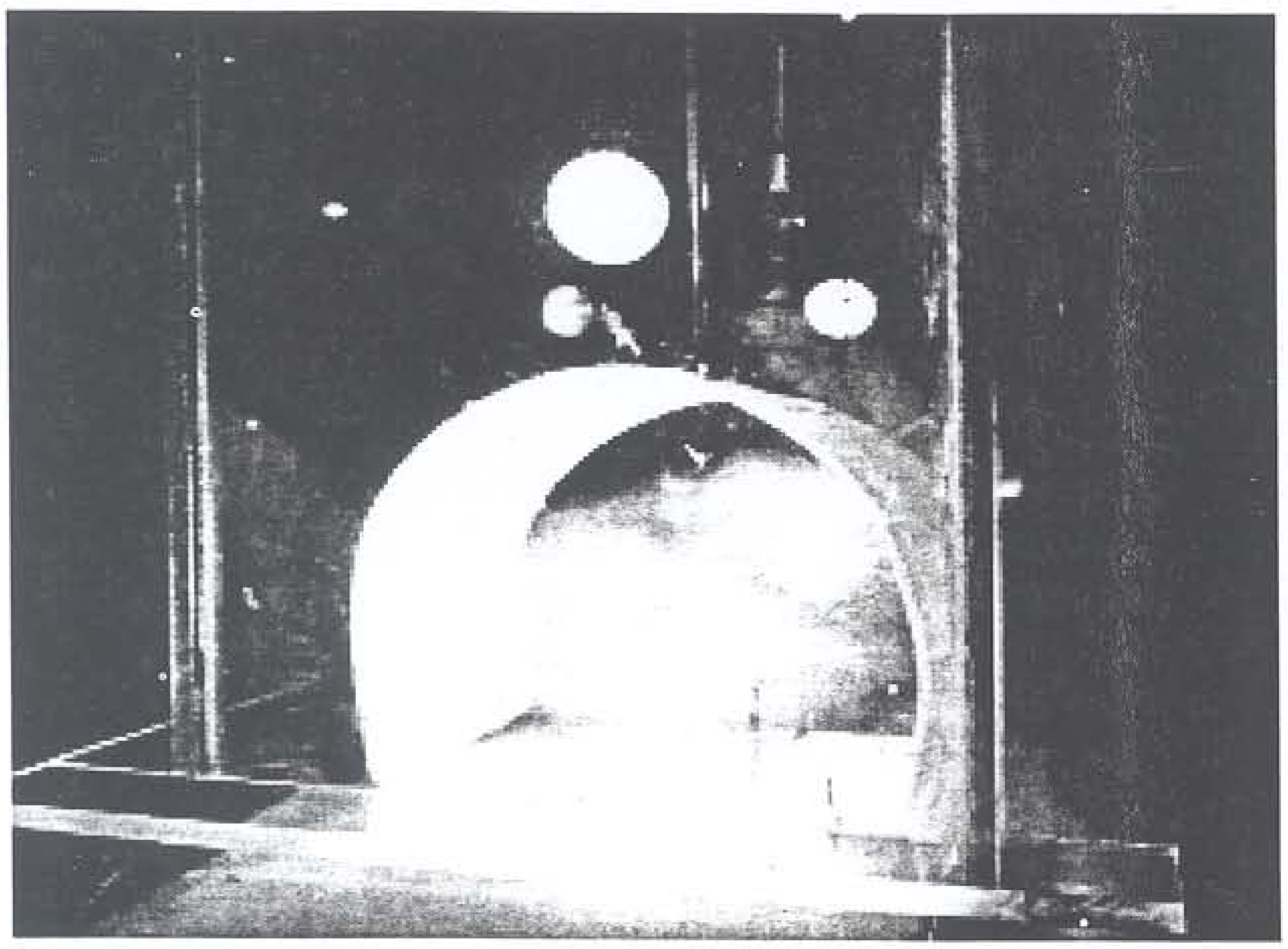

Figure 3. The Initial Current. At this stage, the capacitors are dumping their charge into the circuit. The tremendous amount of energy being released is apparent by the intense, violent discharge we see taking place. The light is so bright that it is painful to watch! Photo by Aubrey

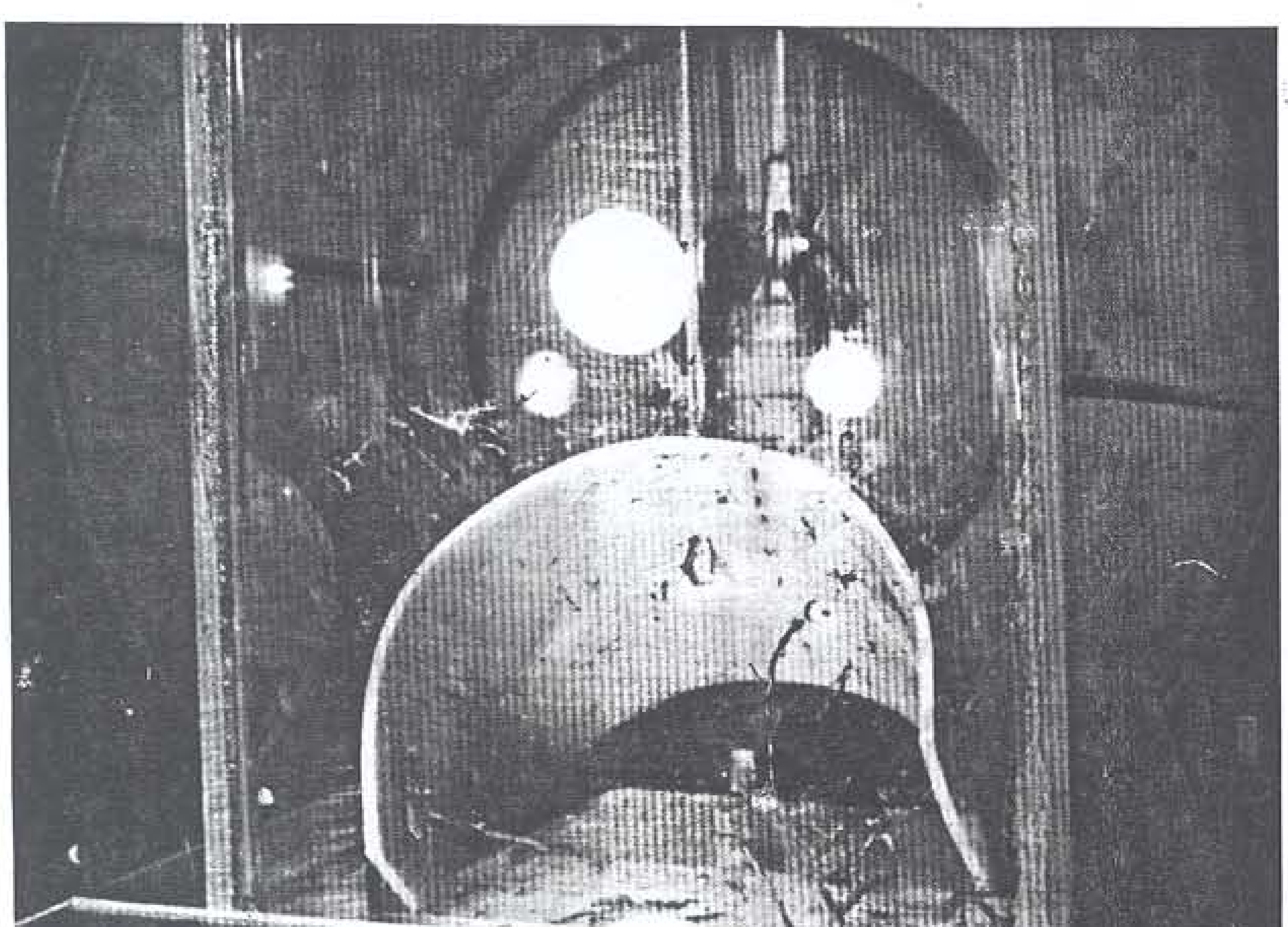

Figure 4. Disintegration. The coil is unable to handle both the amount of current and high voltage. In a grand finale' explosion with an explosive BANG, the circuit is broken on the first upswing of power; before the power has peaked. Photo by Aubrey

Figure 5. The Charging Station. The capacitors are charged from an X-ray machine transformer rated for 50,000 volts. Charging losses limited the capacitors to be charged to just over 40,000 volts. Charging took about one minute...discharges in microseconds!

air and caused it to look like it had been hit with a sledge-hammer. The common explanation is that when the current flows through the coil, a strong magnetic field begins to expand out from it through the aluminum. As the field moves through the aluminum it induces current in the aluminum itself. That current flowing in the aluminum has its own magnetic field that is opposite to the one that produced it. So the magnetic field in the aluminum and the magnetic field in the coil repel each other.

The effect is fast and furious. Coils of ten gage wire were devastated by the pulse. The insulation was often blown off the wire. Magnet wire (varnish coated wire) works well for this. Because the insulation layer is more thin, the windings are therefore closer together and the magnetic field more concentrated as a result.

We were quickly running out of pieces of aluminum that were suitable for rendering useless. Beer cans worked okay and by wrapping a coil of a couple turns around a beer can, the effect would cause it to squish in the middle, even to the point of causing a beer can to tear into two pieces. Eventually we had about all the squashed and mangled beer cans anyone needs.

Experiments with Different Metals

The next step was to try some copper, since it is the second best conductor. Aluminum only rates fourth (silver, copper, gold, aluminum, magnesium, tungsten, in that order). The better the target material conducts, the more electricity that is induced in it and the stronger the opposing magnetic field to repel against the initiating current in the coil. However, none of us really wanted our precious pieces of copper looking as if they had been hit with a sledge hammer.

So what could we find that is made of copper and expendable? Pennies. We went to flat coils again and launched pennies into the 16 foot ceiling. They came out shaped like a contact lens, not from hitting the ceiling but from being shot away from the coil by the edge. Quarters, dimes, and half-dollars are 91% copper so they worked almost as well. In 1982, the content of pennies was changed to a high concentration of zinc. Those particular pennies simply became distorted beyond recognition, while those made prior to 1982 retained their features with better contrast than before.

Increasing the Power

Now a lot of you know what happens when you build a Tesla coil. You optimize everything and get the healthiest discharge you can from it and that's terrific.

Figure 6. The Basic Tesla Coil. The author worked on this Tesla coil constructed by Dale Travois. Tesla coil construction and operation is an excellent way to begin learning about the intricacies of high voltage-high frequency electricity. Photo by Aubrey

Then you reach a point where you realize you've got to build one bigger and better. One capacitor was great. With all six capacitors connected together in parallel, we were really in business.

We charged these caps from an X-ray machine transformer rated for 50,000 volts. Charging took about two minutes. Because of losses at those electrical pressures, we were peaking at just over 40,000 v. A feedback wire through a 50 megohm resistor back to a voltmeter on the control panel about 15 feet away provided a stable kilovolt readout.

Increasing the *voltage* on a capacitor increases the *energy* in the cap by the square of that value.

$$E = \frac{1}{2}CV^2$$

where:

E is *Energy in Joules*
C is *Capacitance in Farads*
V is *Voltage in Volts*

So we were dealing with about 10,000 joules at 40,000 volts with the ability to go to over 33,000 joules at 75,000 volts.

The Incredible Shrinking Coins

Then the thought occurred, what would happen if we wrapped a coil around the rim of a coin? Maybe it would cause an effect the way it did to a beer can. And it did. It shrank the coin in a fairly symmetrical manner. The coin appeared to have retained its weight, but it was smaller in diameter and a bit thicker.

The coil by the way, explodes into little shreds, so it required a containment cylinder to reduce the danger. Prior to a method of containment, we often had coins flying across the room to be found much later. If they were at all off-center inside the coil, they were propelled out the end. When that happened, the coin was forced into a concave shape as it was when sitting on a pancake coil.

Determining the Engineering Parameters

By blasting a quarter for each different voltage between 10 and 40 KV, I was able to obtain a progression of quarters of different sizes, showing the size that each voltage would deliver. Also, by wrapping different numbers of turns (between one and eighteen turns), and discharging them all at the same voltage, I was able to find the optimum number of turns (about eight) for maximum effect on a quarter, applying specifically to #12 insulated wire. *In the photograph, the top row of quarters represents different numbers of turns, the lower row represents the same number of turns at different voltages.*

Has the density changed on the material? Although the coin, as it gets smaller in diameter does also get thicker and the weight stays the same, we don't readily have a way to measure the volume on such a small amount of material to find out if the density has changed. Maybe you do. Let me know.

After speaking to a gentleman from the Physics Department of the University of Washington about this, he did some checking and told me that this would be called a ***z-pinch***. If you lay the coin flat on a table, the x-y plane is represented by the table, and the z-axis runs vertically through the center of the coin.

We took some careful measurements, checking for internal resistances of the conductors, the "Q" of the circuit (how well it "rings" as the electricity oscillates back and forth) since we have something of a tank circuit in the capacitors and the coil around the coin. We measured the inductance of the coil, with and without a coin in it, and ran a computer analysis of it.

The computer provided graphs showing voltage, current, and energy vs time, and how fast the circuit would "ring down" to the point where all the forces were equalized, if not for the fact that the coil explodes,

Figure 8. Empirical Data. In order to determine the extent of primary and secondary forces, a number of quarters were shrunk. At first, the number of windings were varied to determine the optimum number of windings. Later, the voltage (hence the power) was varied. In the photograph, the top row of quarters represents different numbers of turns at 22KV, the lower row represents the same number of turns at different voltages.

disconnecting the circuit almost immediately. (Under the right conditions the copper inside vaporizes and flies through the varnish insulation before the insulation has a chance to heat up leaving a slit in its side but otherwise intact.)

The computer showed that the electrical flow induced in a quarter is 680,000 amps and that the pulse happens in a brief four millionths of a second. That's about the amount of time that it takes a 25 MHz 386 computer to process 100 ones or zeros. Until that point, we intended to obtain some high speed photographic equipment that could run 11,000 frames per second and get a slow motion view of the shrinking of a quarter. But it would show on only one or two frames if we were lucky, it's just too fast. It's also *loud,* requiring ear protection, and the flash from the discharge is *extremely* bright.

Current Applications

Although we discovered this phenomon through our own experimentation, it does in fact have some applications already in use. Swaging is one of those uses where a fitting is z-pinched onto a rubber hose for hydraulics or other use. It has been used in the de-icing of wings, details not available.

In a related application, Boeing for example, uses capacitor discharge through a coil to remove dents from the aluminum shell of aircraft. A company called Electro-Impact in Seattle, WA, found a niche in this area by developing coils that can withstand the tremendous currents and magnetic forces used in this process. John Hartman from Electro-Impact explains that two different capacitor banks are used.

The first pulse through the coil is one direction, and therefore one polarity, from a 500 volt capacitor bank at a relatively low capacitance. The magnetic field that develops in the coil, permeates the aluminum indentation, increases in its intensity slowly enough to not move the material. The second pulse from the second capacitor bank immediately follows the first through the coil, in the opposite direction and therefore opposite in polarity, thus pulling the first magnetic field back toward the coil, bringing the aluminum material with it and repairing the dent. That second pulse comes from a much higher charge of around 5000 volts.

Figure 9. Shrunken Coins...A Unique Collection. No, this is not a "subtle" message as to what the future could hold. Rather, this is the result of a lot of research to see how the different metals react to the magnetic pulse. As you can plainly see, both the front and reverse side of the coin images shrunk symmetrically. For those who are interested in pursuing like interests, U.S.C. 18, section 331 points out that there is no problem in doing such things to coinage!

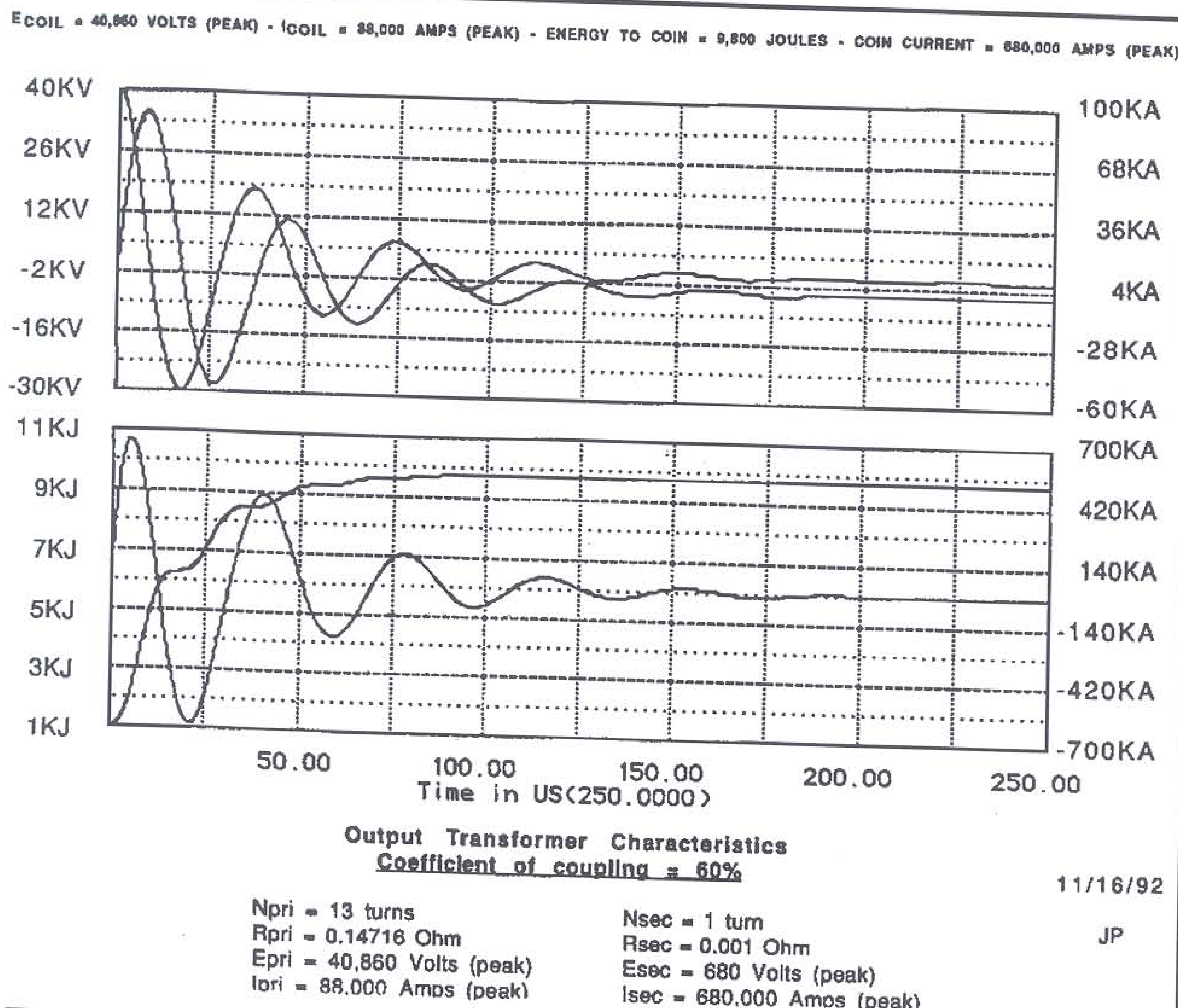

Figure 10. Computer Analysis of the Electromagnetic Z-Pinch Experiment

Back to the Basics

That use is, of course, possible only because aluminum is so conductive and due to the currents induced in it can therefore, temporarily, be made essentially magnetic for brief instants. So what about a nickel? Well, nickel is ninth on the list of good conductors so they don't shrink down as well, but they do so very uniformly. —GLH