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[redacted] UCRL-3711
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EXPERIMENTS WITH TWO NEW PINCH DEVICES

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Two new pinch ideas are described. One is a double concentric system whereby a cylinder of plasma is formed by pinch forces between two concentric metal cylinders. The other is a rotating disc of plasma in a transverse magnetic field much like a homopolar motor arrangement. Both devices seem stable at least for periods of several microseconds.

Since the last report no further work on the water-condenser-powered fast linear pinch system has been attempted. Operation at the level required to produce first-bounce neutrons was so plagued with equipment breakdowns that it hardly seemed worth the effort to continue just to prove that the neutron emission observed was or was not of thermonuclear origin.

An effort was made to replace the water capacitor with an assembly of the lowest-inductance commercial units available. We failed, however, to duplicate the $2x10^{12}$ amperes per second rate of current rise that was achieved with the water system. With the earlier low-level linear pinch work it had required neutron production levels around 10^8 per pulse and weeks of continuous operation to collect a sufficient number of recoil proton film tracks to establish the nonthermonuclear nature of that process. Hence, it seemed advisable at least to defer the project until better capacitors or ideas come along. To date we have mostly the latter.

Being compelled to work with available capacitors (the best was a 30-kv 1-microfarad unit that would release a peak 25,000 amperes in 2 microseconds), we looked for some sort of thermonuclear device that would make use of such a power supply. Also, a switch was developed that could connect 100 of these 1-μf units into a common load without

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adding appreciable inductance. The switch finally evolved was a pressurized spark gap. One hundred 50-ohm cables of minimum necessary length connect the 100 condensers each separately, to a common electrode inside a drum-shaped copper-clad steel chamber pressurized with approximately 80 pounds of nitrogen. At this pressure the clearances required for insulation are reduced enough to permit the low-inductance construction desired.

Early efforts to make use of this type of bank were with various forms of coaxial "rail" devices. This eventually led to a form of spinning plasma disc that we call the Homopolar Machine. Another development is a pinch device that, at least in a relative sense, appears much more stable than the simple linear pinch. It has been given the name Triaxial Pinch in line with an RCA term used to describe a three-conductor coaxial transmission line.

Figures 1A and 1B illustrate the Triaxial pinch arrangement. Figure 1A is a simplified schematic showing the essential elements, and 1B shows the detailed plan of the latest operating tube. This has a diameter of 4 inches and a length of 48 inches, and has successfully survived several hundred shots at 6×10^5 peak amperes.

The plasma as shown in Fig. 1A forms a cylindrical shape centered between two coaxial metal tubes. Current flows over both the outside and inside surfaces of this plasma body, and returns on the outer and inner metal walls. Magnetic forces from the current compress the plasma, and are approximately equal on both sides because of inductance balance. Current is free to transfer from either side to the other instantly if needed to maintain this balance.

Theoretical study by Lloyd Smith has indicated an instability in this system of the M = 0 or sausage mode. However, this mode for such a large cylinder should grow much more slowly than in the usual linear pinch, and at some sufficiently large size should not develop at all. Our present Triax indicates stability through at least the first current cycle, as shown in the following data.

Figure 2A shows various wave forms obtained so far. The voltage across the tube is similar to that obtained from a linear pinch except that it lasts for a much longer time and has several times as many waves. It is interpreted as primarily due to inductance variation arising from plasma-cylinder thickness changes. The initial slope indicates the first pinch, followed by a series of waves as the plasma bounces. If the power-supply voltage is altered these waves respond in frequency and amplitude as expected according to M theory. Calculation of inductance indicates that at no time does the plasma pinch to a thin film, and that it is on the order of 1 cm thick, which may help explain the observed stability.

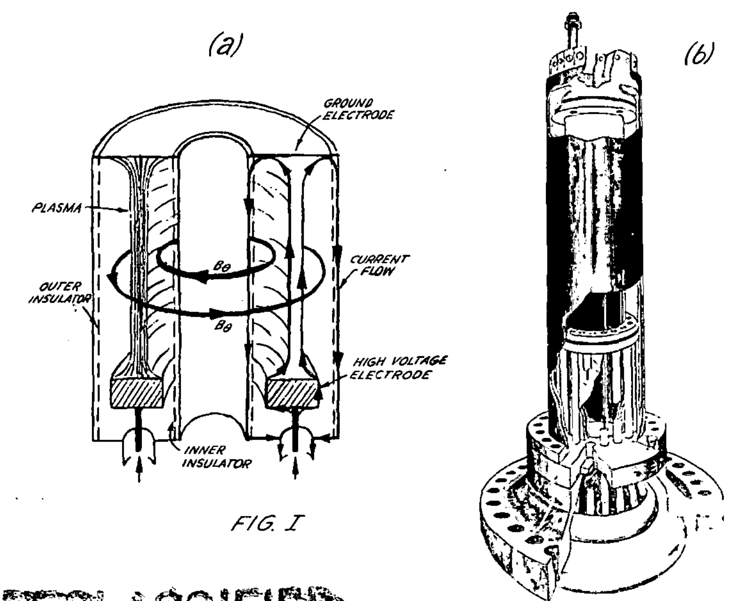
(a)
GROUND ELECTRODE
PLASMA
CURRENT FLOW
OUTER INSULATOR
B_θ
B_θ
HIGH VOLTAGE ELECTRODE
INNER INSULATOR
(b)

FIG. I

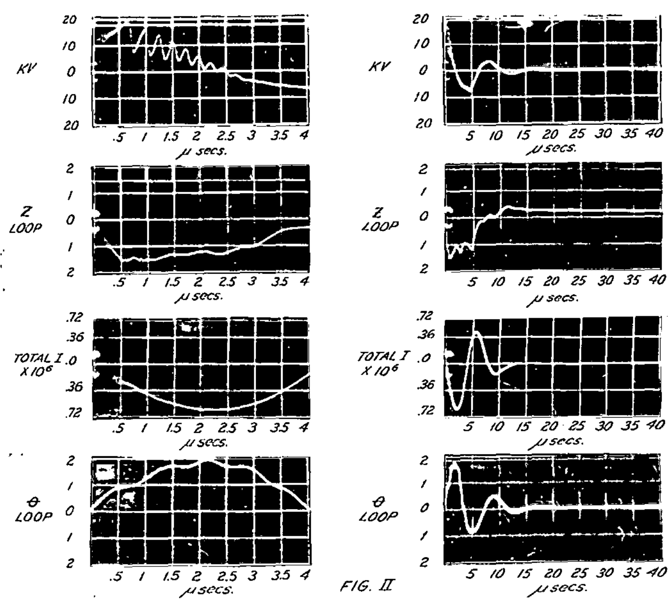

FIG. II

The current signal shows no fine detail simply because most of the over-all inductance of the system is in the power supply. To get Z-loop data (integrated) a field of approximately 500 gauss was applied. With this low value no appreciable effect on the other signals was noted. Lack of pronounced modulations of the signal corresponding to the voltage waves tends to substantiate that the plasma is thick and does not move far from the insulator.

The two current signals are different and show that an oscillation of the plasma-cylinder radius must occur. The total current as measured in the feed lines to the tube indicates a fairly smooth signal. The θ-loop signal, being a measure of the current to the outer Triax side, indicates that the relative currents to the inside and outside paths must be changing. Closer analysis indicates that the outer plasma surface must overshoot the equilibrium position on the first pinch. This is probably due to its greater momentum and the fact that initially more current goes to the outer system because of its lower impedance. If a θ-loop signal were available for the inside Triax current it should show this very well. The two θ signals should always add up to equal the total current.

Another point of interest is the very low resistance indicated by the tube voltage at the peak current: 6×10^5 amperes here produce approximately a kilovolt.

The Homopolar device is illustrated in Figures 3A and 3B. Here the Triaxial pinch idea is used to produce a 9-inch disc rather than a cylinder of plasma. The disc is made to form in the presence of a dc magnetic field as shown, and the pinch currents flowing across the plasma and through the superimposed field produce a motor force that tends to spin the plasma.

Originally this was set up just to see if it could be made stable for the duration of the 5-microsecond current pulse. The expectation was that as soon as the current went to zero the pinch forces would disappear and the plasma would blow up along the field lines to the insulators. Before this, however, it should be possible to put considerable energy into the rotational mode, and perhaps a modified form of the Homopolar idea could be devised that would convert rotational-system energy into thermalized form in the gas.

Figures 4A and 4B illustrate what actually happened. The first pictures are current pulse to the Homopolar and voltage across it without the dc magnetic field applied. The voltage is primarily resistive and relatively small. The next pictures show that when field is applied the voltage rises to 4 kv at the first current zero, drops to a minimum of about half this at the end of the reverse current wave, then rises again, etc. However, it always remains of the same polarity regardless of the current reversals. This can be explained only on the basis of

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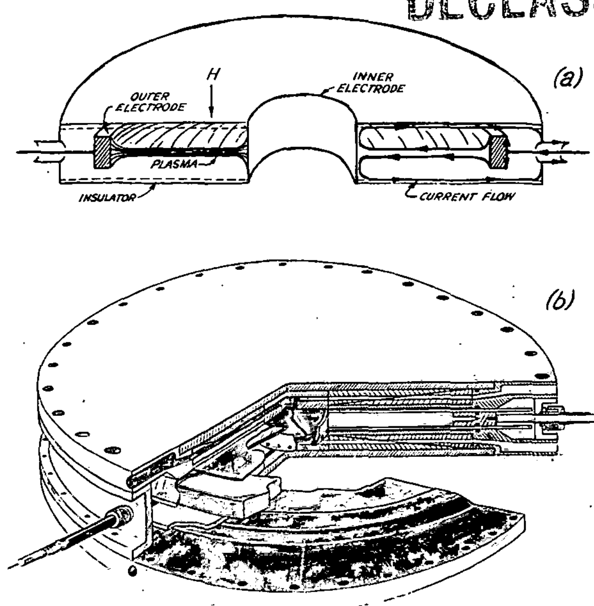

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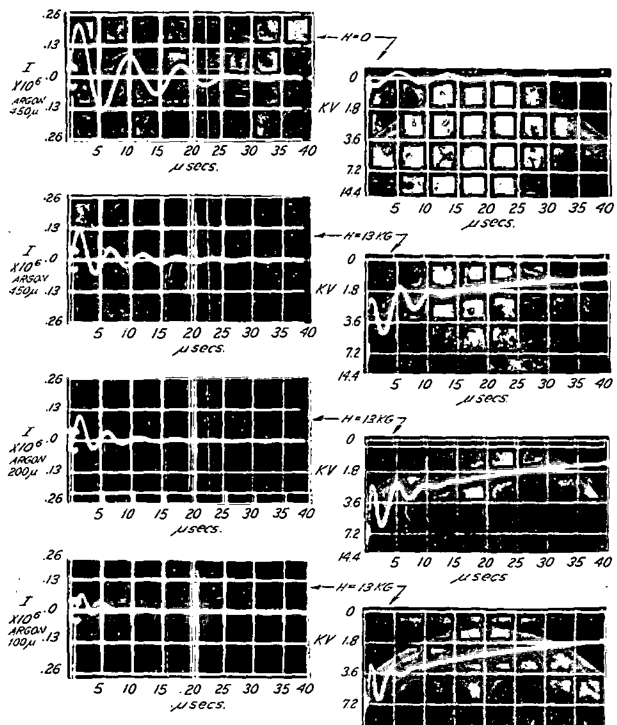

FIG. IV

rotational energy being fed into the plasma motor and a stable spin system existing far beyond the expected time. The nonreversing voltage is explained by the damped current wave train. Acceleration of the plasma during the first half cycle is greater than the deceleration during the reversal half. The last pictures show the effect of lowering the pressure to obtain an almost critically damped condition.

The most plausible mechanism for this unexpectedly long containment of the plasma is that azimuthal currents are set up because of centrifugal forces tending to drive plasma radially outward through the magnetic field. This current is always in one direction regardless of the main current reversal, and is evidently of sufficient magnitude to hold the plasma from the walls for considerable time. Indications of times to 200×10^{-6} sec have been noted on probes measuring the perturbation on the dc magnetic field. Some rotational energy must be converted to heat in the gas through I^2R losses in series with the azimuthal current.

Spectroscopic measurements have been made on this system that verify the rotation by Doppler shift. Lines examined have so far been predominantly from silicon and oxygen contaminants. Shifts reverse direction with field or current reversal and fall in the region of 10^6 to 10^7 cm/sec.

This work was done under the auspices of the U. S. Atomic Energy Commission.

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