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LINEAR PINCH WORK IN BERKELEY

O. A. Anderson and W. R. Baker

July 1956

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LINEAR PINCH WORK IN BERKELEY

by

O. A. Anderson and W. R. Baker

University of California Radiation Laboratory
Berkeley, California

Experiments conducted with the linear pinch have disclosed more factors in the mechanics of this phenomenon. The addition of a magnetic field parallel to the pinch axis modifies the pinch characteristics and notably affects the instabilities. An effective diagnostic tool, the Z-field pick-up loop, has been introduced. Photographs of the breakup of the pinch with Z field indicate a corkscrew instability as predicted from Z-loop data. Insulator hang-up has been encountered with a system driven by a water-dielectric capacitor, and a simple solution for the problem has been found.

I. FAST PINCH

Our work with fast-pinch discharges started more than a year ago, but the results at that time were not very interesting because, (1) our stored energy was small, (2) we had not yet discovered the advantages of quartz, and (3) we weren't fully aware of the need for what we now call starting current.

It has been a difficult problem throughout the Sherwood Project to obtain a suitable source of high energy for a fast discharge. Existing commercial capacitors are not adequate, and improved versions, although easy to design, are apparently not easy to manufacture. While waiting what has seemed an incredibly long time for a few high-voltage low-inductance condensers to be commercially produced we have worked up a home-made substitute.

This capacitor, employing water as the dielectric material, can unfortunately only be described as makeshift, for its operation is far from reliable. However, the limited number of successful discharges

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it has produced have given interesting results, and we intend to pursue further the fast-pinch work with something less recalcitrant.

The water capacitor we used for our recent work is shown schematically in Fig. 1. The approximate numbers for the capacitor itself are: length, 30 ft; average diameter, 8 in.; electrode spacing, 3/8 in.; capacity, 0.5 μf; impedance as transmission line, 0.75 Ω; two-way propagation time, 0.6 μsec; breakdown voltage hoped for (based on small models), 300 kv; breakdown voltage obtained in practice, 150 kv.

The discharge tube, also schematically represented in Fig. 1, is quartz, 3 in. in diameter and 6 in. long. The anode of the tube connects to the outside return pipe of the capacitor, and the cathode connects to the inner electrode through a pressurized spark gap. The cathode is also shown connected to two cables. One is a signal cable and goes to a voltage divider, and the other is used to bring in low-level starting current in advance of the fast high-level discharge.

Starting current seems to be required by nature in a fast-pinch setup, and those planning similar work may be interested in some details. When a high-voltage condenser is switched to a cold pinch tube the gradient during breakdown is too high for efficient ionization of the gas. In a typical geometry, many high-speed electrons will strike the insulating wall. If the circuit inductance is very low, current will increase rapidly, but is likely to flow at the insulator and not in the gas. When we operated under these conditions we observed no pinch symptoms in the voltage or current signals. Because we knew pinches were not impossible, we made the natural move: we started with a slowly rising current to ionize and slightly pinch the gas, and then switched on the water condenser. This worked properly when the starting current was adjusted to reach at least 2×10^4 amperes (about right to start a weak pinch) by the time of the main discharge. The relatively high inductance of the starting current circuit diverts little current from the fast-pinch circuit.

Figure 2 shows the voltage, current, and neutron fast-scintillator wave forms obtained when the condenser was charged to 140 kv, just below the point of self-destruction, and the initial pressure was 100 μ of D_2. The traces start just after gas breakdown, and for the first 0.8 μsec the starting current is rising at about 0.3 kamp/shake while the voltage stays low. Then, the water capacitor is switched on and the main pinch takes place. The voltage on the tube jumps to 40 kv, almost 1/3 of the initial condenser voltage, and the current starts climbing at the rate of about 20 kamp/shake or 2×10^{12} amp/sec. This is six times the fastest rate obtained in our previously reported work with slow condensers, and incidentally, twice the best figure mentioned by Kurchatov.

The voltage gradient on the tube, due first to $L\dot{I}$ and later to $I\dot{L}$, stays around 3 kv/cm during the pinch time. The current dips to a

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minimum about 0.3 μsec from the start of the pinch, and this dip presumably corresponds to the minimum diameter of the current sheath. (The time to the dip was sensitive, of course, to gas pressure and condenser voltage, and could be increased to at least 0.6 μsec, which was beyond the natural current peak. No dip at all was observed in the absence of the starting current.) The neutron signal starts about the time of the current dip in Fig. 2. Between 10^5 and 10^6 neutrons were produced by the discharge.

The pinch-tube current and voltage signals become hard to follow after the current dip because of reflections caused by the geometry of the water condenser. These effects may as well be ignored, since in our future work the energy will be stored in lumped condensers rather than in transmission lines.

The slow-pinch work at Berkeley (see Princeton report, Baker and Anderson; and Gatlinburg report, Ise and Pyle) showed that neutrons may be produced in a low-energy pinch by plasma instability. These neutrons usually appeared at the third bounce, together with hash in the voltage and current signals; then neutron yield fell when the condenser voltage was raised above 40 or 50 kv. The pinch speed was too low to lead one to expect very high temperatures.

With the fast pinch, the evidence is quite different: (1) The neutrons appear on the first bounce, with no associated hash on the other signals. (2) Neutron yield still rises steeply with condenser voltage near 150 kv. (3) The high pinch speed implies a fourfold increase in deuteron energy over our best slow pinch at the first bounce. Although it is hard to say exactly what the effective energy is, it may be high enough to be interesting in the fast pinch. The neutron-production mechanism, in any case, merits careful investigation. Robert V. Pyle and John Ise, Jr. are planning to study the neutron energy distribution as soon as a reliable fast-pinch system is available.

II. STABILIZED PINCH EXPERIMENTS

Since December, Stirling Colgate has been promoting interest throughout a good part of the Sherwood Project in the stabilized pinch. We describe here some of the work we have done recently at Berkeley, mostly instigated by Colgate.

A typical experimental configuration is given in Fig. 3. The dc machine we borrowed to supply current to the stabilizing field coils permits an 8-kilogauss field, and the water-cooled coils are good for still more current. Most of the work has been done in the range of 500 to 5000 gauss. The 3-in. quartz tube shown in Fig. 3 is enclosed by the usual heavy-wall copper return conductor, which in this case also serves to bottle up the stabilizing flux. The pickup loop shown placed in the small space between the quartz and copper is known as the Z loop. We normally integrate the Z-loop wave form, getting a flux signal rather than rate of change of flux. Figures 4a and 4b show

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how the current and Z-loop flux signals, respectively, change with initial condenser voltage. These are interpreted with the aid of Fig. 5, which shows the Z-loop flux signal tending to flatten off at a definite value as the pinch radius is decreased. The amplitude at the flat tops in Traces 2 and 3 of Fig. 4b checks with the calculated value for the Z-field strength and dimensions involved. This amplitude can be exceeded, however, if the pinch configuration changes, as shown at the right in Fig. 5, so that the pinch current itself can produce a contribution to the Z field. The fourth and fifth traces in Fig. 4b show this instability effect. The value of current at which the instability appears seems to agree with theory (see Rosenbluth, LA-2030).

The photographs in Fig. 6 were taken looking in the end of a stabilized pinch tube arranged to be particularly unstable (high residual Z field external to the pinch). There is considerable background light, since no Kerr cell was used, and some of the original detail may be lost in reproduction, but close examination should reveal foreshortened corkscrews of opposite sense in the two pictures. The direction of Z field is reversed in the second photograph. In the absence of stabilizing field the gas (deuterium) would be too highly ionized to produce much light, but with the Z field the temperature is lower.

We have work in progress with a stabilized pinch of higher energy, and have had promising results with a system in which most of the insulator has been eliminated. The eventual hope is to build a toroidal stabilized pinch tube not requiring a toroidal insulator. We also have plans for a stabilized coaxial, double-ended rail discharge which can operate with or without high θ-direction velocities.

So much trouble has been encountered with pinch-tube insulators that for some time work has been going on in an effort to replace the glass tube with a metal one. At Colgate's suggestion we experimented with a scheme using the ion-pumping action of a PIG-type discharge to clear the region adjacent to the metal wall of neutral gas atoms. Once ionized in the central discharge region the gas is trapped in the Z field there, and it was felt that the pressure near the wall might be reduced enough to give the necessary insulation. The experiments were abandoned after many variations had been tried without success.

A second scheme has been tried recently that shows great promise. A metal pinch tube is placed in a Z field of the magnitude and direction used in the case of the normal stabilized-pinch system. A voltage is applied at one end that is separated from the metal tube with a short, cylindrical glass insulator of the same i.d. as the metal tube. The resulting current in the gas between the end electrode and metal tube is adjusted to force the plasma and trapped Z field toward the tube axis opposite the insulated section. If the current does not exceed a critical value (set by Z-field magnitude, primarily) a stable central column of plasma is established and the column formation propagates along the tube axis away from the insulated end at a constant velocity. With present equipment a typical condition is 15 in. in 5 μsec. Plans are being made to

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pursue this metal "rail" system further, and many novel uses have been suggested.

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FIGURE CAPTIONS

Fig. 1. Fast-pinch setup.

Fig. 2. Fast-pinch waveforms.

Fig. 3. Stabilized pinch setup.

Fig. 4. Stabilized pinch waveforms.

Fig. 5. Amplification of Fig. 4.

Fig. 6. Corkscrew instability.

Schematic cross-section of fast-pinch arrangement

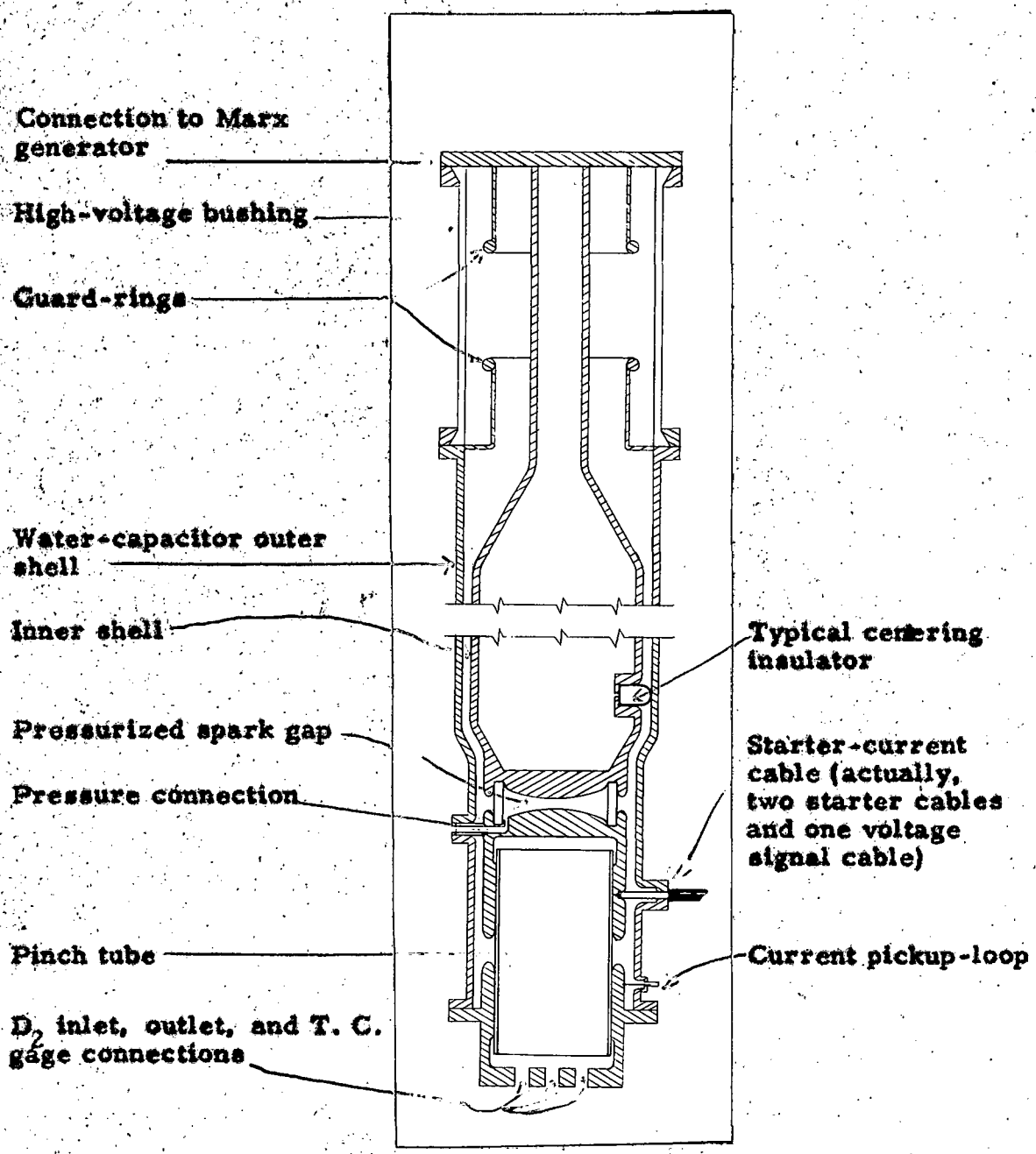

Fig. 1

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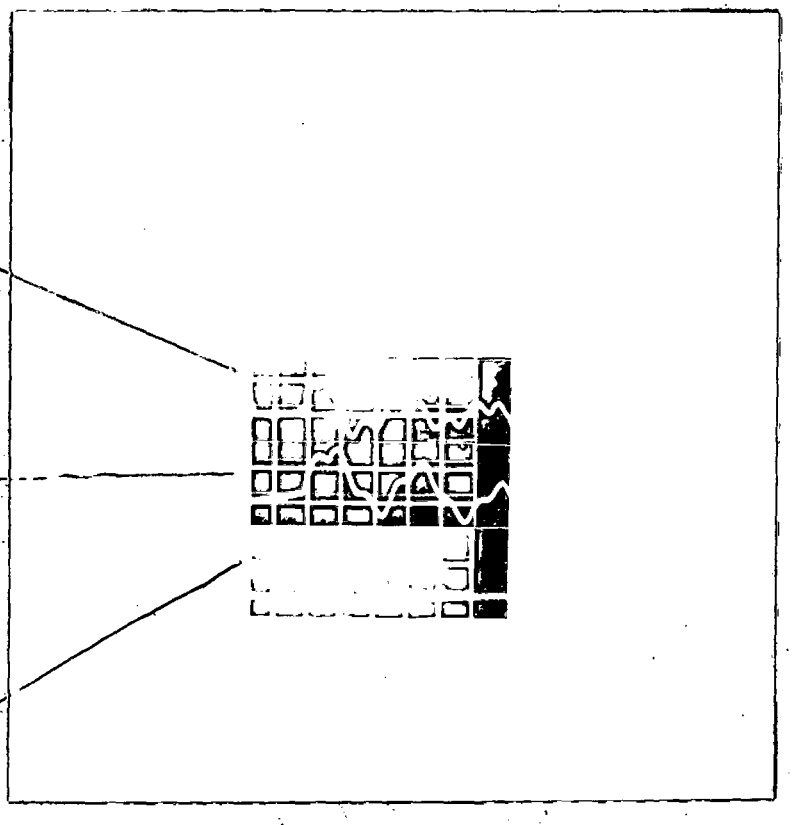
Fast-pinch waveforms



Sweep: 0.5 μsec per division
Initial D_2 pressure: 100 μ
Initial capacitor voltage: 140 kv

Fig. 2

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Stabilized pinch setup

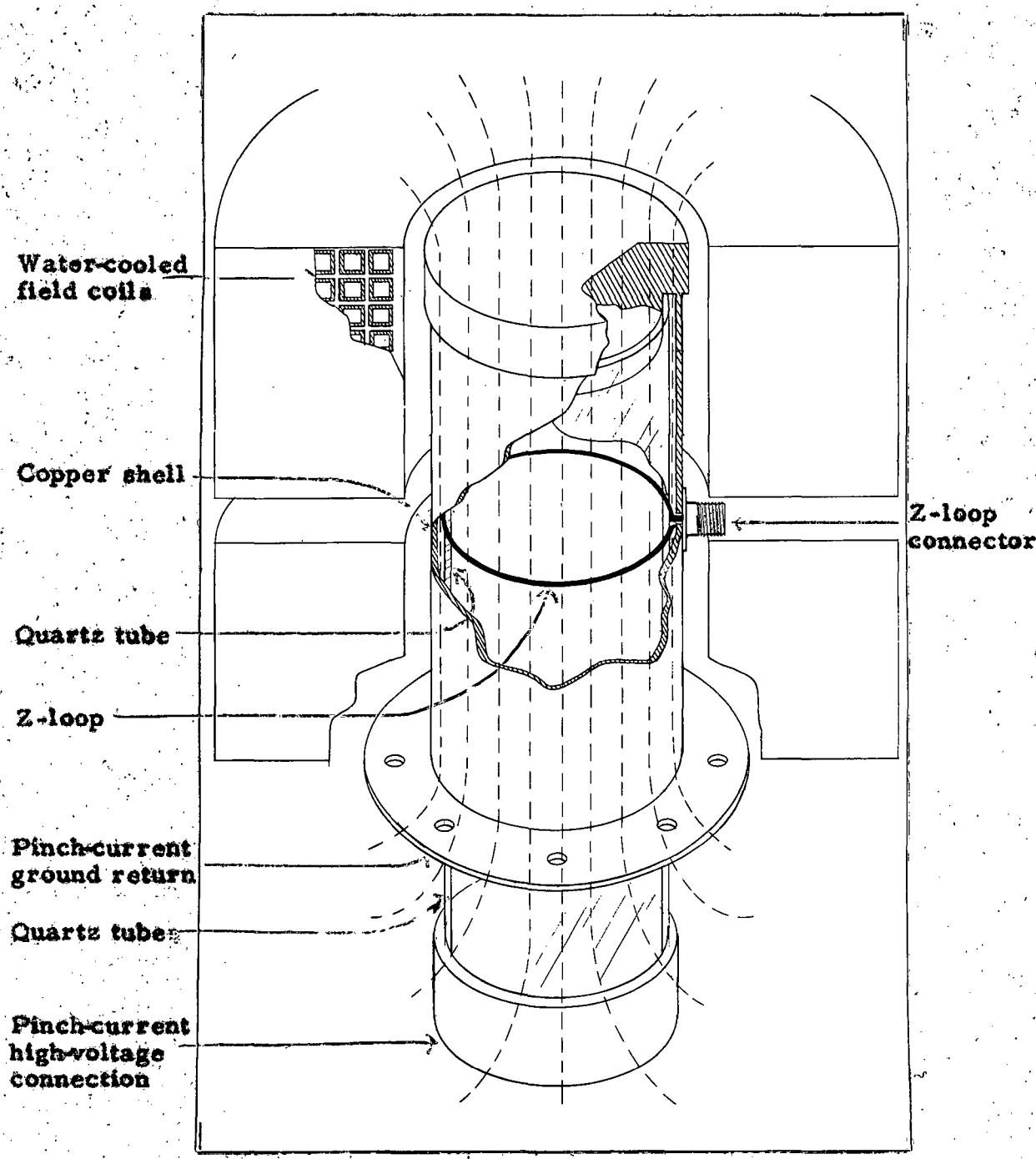

Fig. 3

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Fig. 4a
Pinch current
(10^5 amp per division)

Fig. 4b
Z-loop flux
(Integrated Z-loop signal)

Initial capacitor voltage:

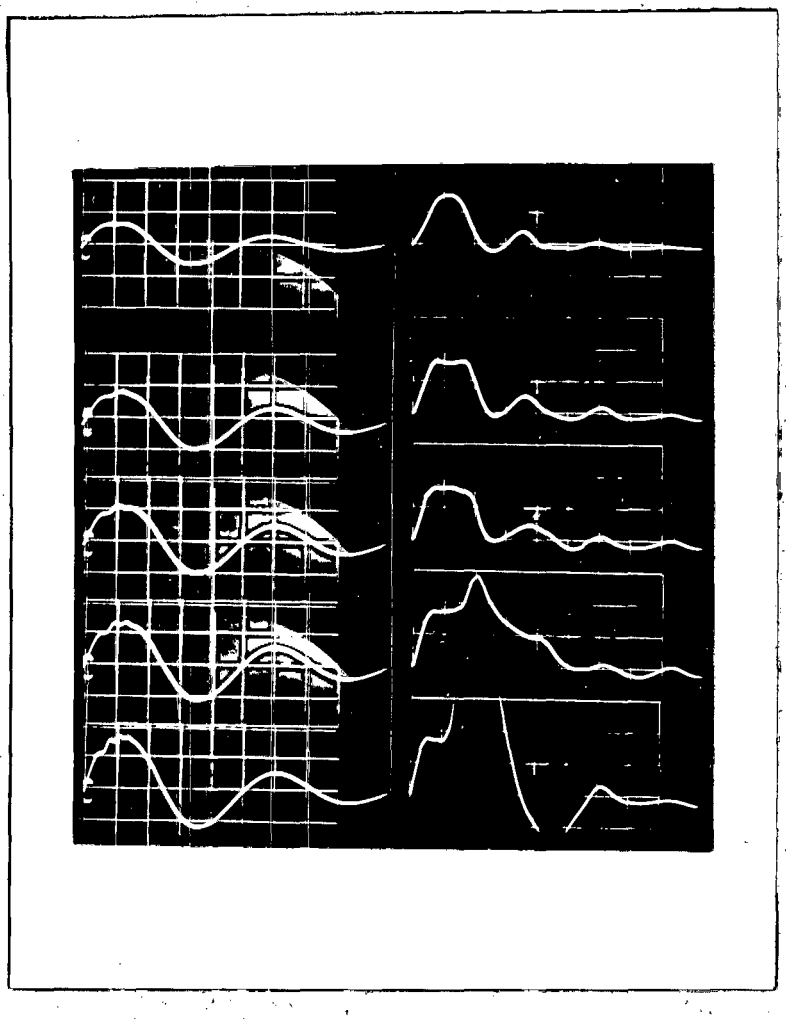
(1) 8kv

(2) 10 kv

(3) 12 kv

(4) 15 kv

(5) 20 kv



Sweeps: 2.0 μsec per division
Initial D_2 pressure: 500 μ
Initial Z-field: 1200 gauss
Pinch tube: 3" x 18" quartz
Capacitance in pinch circuit: 12.0 μf

Figs. 4a and 4b

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Schematic description of the situation in Fig. 4, traces #4 (15 kv)

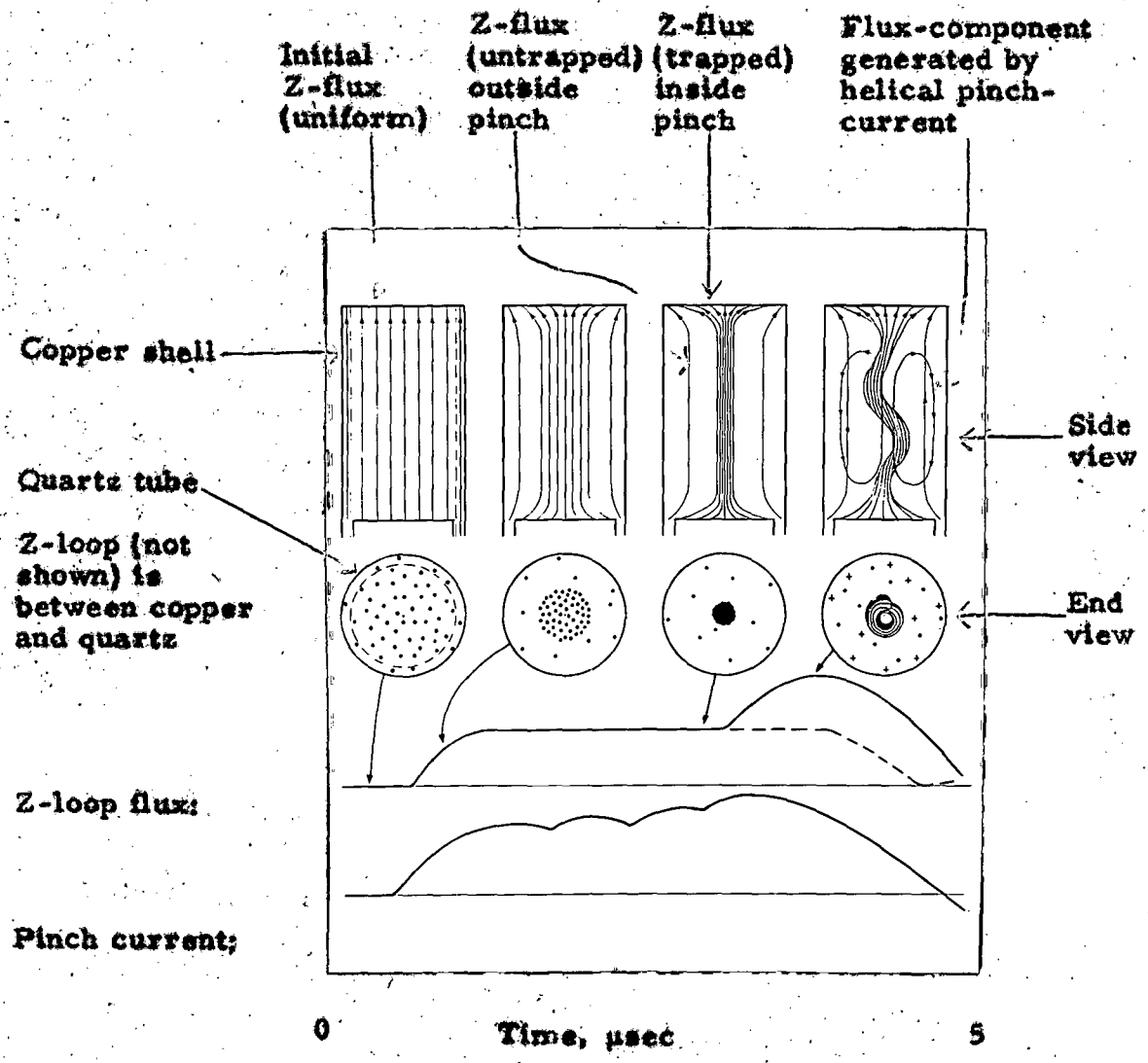

Fig. 5

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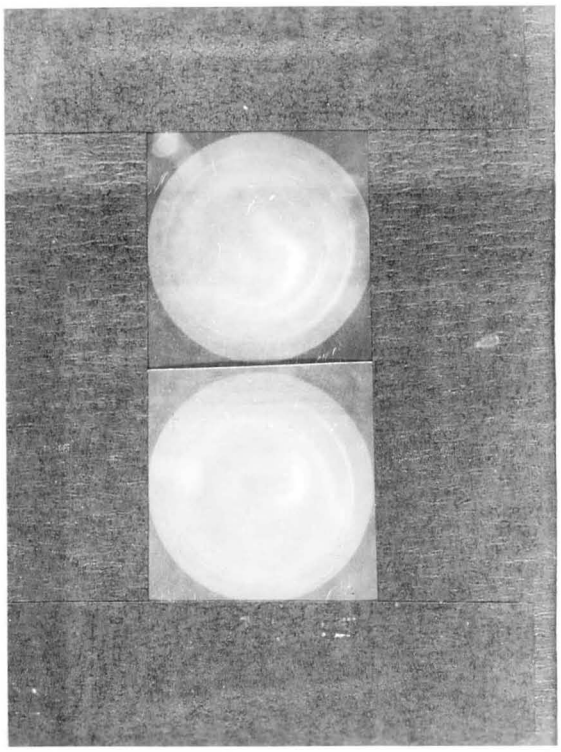
Corkscrew instability

Z-field up



Z-field down

Fig. 6

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