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LOS ALAMOS SCIENTIFIC LABORATORY

OF THE UNIVERSITY OF CALIFORNIA ○ LOS ALAMOS NEW MEXICO

QUARTERLY STATUS REPORT OF THE LASL
CONTROLLED THERMONUCLEAR RESEARCH PROGRAM
FOR PERIOD ENDING FEBRUARY 20, 1962

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All LAMS reports are informal documents, usually prepared for a special purpose. This LAMS report has been prepared, as the title indicates, to present the status of the LASL program for controlled thermonuclear research. It has not been reviewed or verified for accuracy in the interest of prompt distribution. All LAMS reports express the views of the authors as of the time they were written and do not necessarily reflect the opinions of the Los Alamos Scientific Laboratory or the final opinion of the authors on the subject.

CAULKED PICKET FENCE EXPERIMENT

The work this quarter has been directed towards reproducing the long containment times for energetic deuterons observed in the Baked Picket Fence experiment. The first attempts showed no evidence for containment with the coils connected for simple picket fence operation.

During these experiments it was found that the gun provided a source of soft x-rays for as long as ~ 100 μsec; also, a current of > 30 amp flowed from the gun for ~ 100 μsec. The source of the high-energy deuterons ejected from the gun was located in space by a collimation experiment. It was found that the mechanism for deuteron acceleration is localized about the end of the center electrode. When the diameter of the outer electrode was increased from 4 in. to 10 in. (center electrode 2 in. diameter) the number of energetic deuterons produced by the gun was increased by a factor of about four.

Using this larger gun, containment of energetic deuterons was immediately observed. Typical containment times are about 10 msec. This result indicates that there is an apparent threshold for trapping which depends in some way on the number density of the injected plasma.

Preliminary observations on the contained deuterons show that (1) lifetimes are adversely affected by raising the base pressure in the system before the gun is fired, (2) lifetimes increase as the strength of the magnetic field is raised, (3) insertion of a probe into the confining volume decreases the lifetime, and (4) fast deuterons are trapped on the side of the picket fence magnetic field away from the gun.

MARK II BAKED PICKET FENCE

Experiments to locate the source of neutron production and to determine the dimensions of the plasma volume have continued. Preliminary exposures of a nuclear emulsion pinhole camera (0.001 in. Al window) indicate (1) that the number of neutrons produced in the volume is $< 10\%$ of the total neutron yield, and (2) the existence of a strong x-ray source in the confining volume. Further, a fast x-ray detector shows that this x-ray source may be asymmetric about the picket fence median plane, with the dominant long-duration x-ray source located on the exit cusp side. The outer radial dimension of the plasma at the ring cusp appears to be ~ 15 cm as determined by (1) the observed location of a ~ 2 cm thick sheath (placing the confined volume in a negative potential well of < 1 kv) and (2) the minimum radial position at which a probe does not change the lifetime of trapped particles.

The amplitude of the neutron tail and its characteristic decay time are found to be sensitive to the parameters of the picket fence confining field, the presence of probes within 15 cm of the field zero, and the neutral gas background pressure. A weakening of the entrance cusp relative to the ring and exit cusps allows operation up to 6 kgauss with an increase in the amplitude of the neutron tail and the extension of lifetime with magnetic field ($\tau_{1/e} \propto B^3$) up to at least 350 μsec at 6 kgauss (exit and ring cusp fields). The observed decrease in trapping amplitude with insertion of a small probe suggests the necessity of cooperative plasma effects (e.g., sheaths) in the trapping process. When additional amounts of neutral gas are pulsed into the system, the rate of loss of confined particles is initially measurable. But there is often recovery to give the long confinement times characteristic of good vacuum conditions. This latter result suggests "burnout" of the neutral gas.

Confinement times of up to 350 μsec for this apparatus appear to exceed theoretical predictions by a factor of about 10. This is due to the relatively large size of the nonadiabatic region for deuteron energies > 10 kev which are measured leaking out of the ring cusp. A preliminary model has been suggested in which the primary mechanism of ion confinement is due to the adiabatic trapping of electrons. These trapped electrons create a negative potential well which holds the ions. The ion loss rate is then brought into equilibrium with the nonadiabatic loss rate of the electrons.

COAXIAL GUN RESEARCH

A study of the characteristics of a coaxial gun when operated in the mode to accelerate deuterons to relatively high energies (> 5 kev) is under way. When the time delay, Δt, between the triggering of the electromagnetic gas valve and the application of the gun voltage, is between 100 μsec and 150 μsec the following phenomena have been found to occur: (1) asymmetric pinching of the discharge current between the electrodes, (2) high-voltage transients (up to seven times the applied voltage) at the gun input, (3) large electrostatic voltages measured downstream from the electrodes, (4) an axial current flowing off the ends of the electrodes, and (5) the detection of neutrons. When Δt is > 150 μsec the gun does not exhibit the above characteristics.

Changes in the geometry of the electrodes have been made. Optimum operation to date when evaluated in terms of total neutron yield and calorimetric measurements has been obtained with an inner electrode 6.2 cm diameter and 1.5 to 3.8 cm long and an outer electrode 10 cm diameter and length 37.5 cm. The lengths of electrodes are measured from the gas ports.

The operation of the gun under the conditions that $100 < \Delta t < 150$ μsec is not understood at this time. It appears, however, that the discharge near the gas ports becomes unstable and large voltages are induced which accelerate ions directly or electrons and ions (through a space charge potential) to high energies. The relatively long outer electrode appears to direct or focus the energetic particles down the axis.

PLASMA GUN RESEARCH FACILITY

Experiments on the interaction of a moving plasma with magnetic fields continue. Optical observations have to date not shown a sharp plasma-magnetic field interface. Quantitative measurements have been difficult to make since the plasma is apparently connected electrically to the gun electrodes.

In an attempt to disconnect the plasma leaving the gun from the high-voltage inner electrode, the end of this electrode has been grounded to the outer electrode by a set of radial fins. The output of the gun has been reduced by the addition of these fins to less than 10% of that under normal operating conditions.

RESONANT HELIX - COAXIAL GUN INJECTION EXPERIMENT

Investigation of the interaction of a resonant helix on the plasma produced by a coaxial gun has been continued. The results show that (1) the helix increases the diamagnetism of a plasma passing through it and (2) a mirror placed beyond the helix produces a longer diamagnetic signal upstream from the mirror, indicating some plasma reflection. Particle detectors also verify that some plasma is reflected from this mirror.

Experiments using two mirrors, one at each end of the helix, in an attempt to trap plasma between them, have not shown appreciable plasma containment.

INCOHERENT SCATTERING OF MICROWAVES FROM PLASMAS

Work in the past months has centered on creating plasmas in long cylindrical waveguides to be used for incoherent scattering with the greater collection efficiency possible in this geometry. P.I.G. discharges with currents of 10 mamp have been studied in long cylindrical waveguides with diameters as small as 3/8 in. An 8.6-mm radiometer is now being constructed as a detector for this experiment, and the discharge waveguide is being rebuilt to allow for much greater currents and energy dissipation.

CYCLOTRON RADIATION MASER

A theoretical study has been carried out on the dependence of negative absorption on the nature of the electron velocity distribution. The following results have been obtained for 90° propagation with respect to the magnetic field:

1) Negative absorption, $\langle\alpha\rangle$, depends upon the existence of a peak away from zero velocity.

2) The magnitude of $\langle\alpha\rangle$ depends upon the maximum positive slope of the distribution function.

3) Angular distribution of electrons is not very important provided a positive slope exists in the distribution function vs velocity perpendicular to magnetic field.

4) Transit time broadening due to motion along magnetic lines across the microwave system leads to reduced values for $\langle\alpha\rangle$.

5) Magnetic field inhomogeneities lead to a net reduction of $\langle\alpha\rangle$ for a given maser volume.

The condition for maser action has been derived in the form $1 = R \exp \langle\alpha\rangle L$, where R is the reflectivity of the walls surrounding electron gas, and L is the transverse dimension of the gas. To understand the effect of the microwave beam in an operating cyclotron maser upon the velocity distribution, a Boltzmann type of equation has been developed for an electron-proton gas, and is being studied.

Preliminary measurements have been carried out to determine the ability to detect this effect. The magnetic field in the solenoid has been found to be uniform to approximately 1 part in 10^3 over a cylindrical volume 6 in. long and 1 in. in diameter. An electron gun is under construction to permit evaluation of its emission characteristics.

SCYLLA I ZEEMAN EXPERIMENT

The Zeeman spectrometer has been applied to the measurement of the Scylla magnetic field after the following modifications of the optics:

1) Replacement of the fiber optics by a beam-splitting aluminum wedge.

2) Replacement of the Rochon prism analyzer by a Wallaston prism analyzer.

3) Installation of uv-sensitive photomultipliers and a uv order-selecting filter.

Using the CV-2270 A line, an attempt was made to observe the breakthrough of magnetic field to the axis of Scylla in the presence of a probe. The results so far are ambiguous because the effect, if present, is obscured by noise. A calculation of the expected Zeeman effect indicates that it should stand out above the noise, and the difficulty appears to be lack of resolution in the slit focusing by two achromatic lenses. Steps are being taken to remedy this situation.

APPLICATION OF THE HAIN-ROBERTS HYDROMAGNETIC CODE TO SCYLLA

The IBM-7090 computer runs corresponding to Scylla I parameters, which were previously discussed (LAMS-2651, p. 6), exhibited a greater degree of diffusion of the compressing magnetic field into the plasma than can be expected from theory at the electron temperatures involved. The difficulty was traced to the use of an additional term in the electrical resistivity to assure convergence of the numerical procedures. This term was reduced to small proportions and the diffusion made essentially negligible. Scylla IV parameters are now being fed into the code.

TRANSVERSE MAGNETIC FIELD INJECTION EXPERIMENT

In previous studies of the behavior of plasma injected from a coaxial gun into a transverse magnetic field, it was found that at sufficiently high B values the plasma is stopped. Under these conditions the plasma beam apparently splits, with each branch tending to follow the B-lines (cf. LAMS-2619, Fig. 4).

In order to test this phenomenon as a possible method of injection into a torus, mirror, or stellarator, an experiment was begun in which the gun injects into a mirror magnetic field (mirror ratio 1.3) at its mid-plane. The beam splitting is again seen. Experiments are under way to determine if injection of contained plasma results.

INJECTED SCYLLA III

Plans are being made to extend the experiments with gun plasma injection of Scylla III and to measure the energies of the deuterons trapped and compressed in the fast mirror field. It is proposed to apply a method in which plasma will be spilled out of the compression region through a quasi dc mirror on the far side from the gun. After spilling through the mirror, the plasma will pass through an axial field which decreases with distance gradually enough to be nearly adiabatic. This should transform the predominantly transverse energy of the ions after compression mostly into axial energy and deliver a large fraction of the plasma into a long drift space for measuring ion energy distributions. The drift space will be provided with an axial field of about 3 kgauss to contain the particles. Since the peak compression field is 70 kgauss, practically all of the energy should have been transformed into the axial direction if the spill field is nearly enough adiabatic. Since a detection scheme which requires sharp collimation of the emerging particles should be tested for bias in the sampling of the plasma, it was decided, initially, to detect and sort the spilled ions by a method requiring a minimum of collimation. A simple possibility is time-of-flight separation in a long drift tube with a relatively weak axial magnetic field, the deuterons being detected by production of neutrons in a heavy ice target or by secondary emission electrons.

COILS TO PRODUCE SPILL-FIELD FOR PLASMA ANALYSIS OF INJECTED SCYLLA III

Most of the system to produce the pulsed spill and drift fields has been constructed. The drift field will be run at approximately 3 kgauss and three coils have been made for that purpose. The flux conserver serves to smooth out the effects of the widely spaced turns of wire on the coil and allows the coils to be connected smoothly to each other and to the conical flux conserver of the spill field. Smooth connections between the coils are provided by short spiral flux conserving coupling units. These slip inside the ends of coils to be joined and reduce the inside diameter to 9 in.

The spill field (connecting the Scylla compression field to the drift field) consists of two sections, each one of which is provided with a conical spiral flux conserver. The low-field section provides a field which is graded from 12 kgauss at its small end to 3 kgauss at its wider end 52 in. farther along. Since the flux conserver is a linear cone, its area is parabolic with distance and the field should then vary inversely as the square of the distance from the apex. The high-field spill presents a more difficult problem because of the large forces to be expected from the 70-kgauss field at one end. A spiral flux conserver has been constructed and is being tested. It is made of copper because of its high conductivity, and is heavily supported with vacuum impregnated epoxy resin and fiberglass. A coil is under construction which will in some measure distribute the exciting current properly and it is hoped that this will reduce the forces caused by axial current flow in the flux conserver. The ratio of diameters at the two ends is such as to grade the design field of 12 kgauss up to 75 kgauss at the other end.

HEXAPOLE STABILIZATION OF FLUTE INSTABILITY IN SCYLLA III

Scylla III has been found to exhibit a rotational instability, with many of the characteristics of an $m = 2$ flute instability, under certain conditions of coil length and capacitor bank energy (cf. LAMS-2570, p. 31).

Such an instability should be stabilized by the application of a hexapole magnetic field convex toward the plasma, as shown in the actual experimental arrangement of Fig. 1. A six-pole magnetic field is produced by the six axial conductors which are equally spaced around the outside of the discharge tube and pass through the 18.7-cm compression coil. The wires are energized from a 50-kv, 12 or 25-kjoule capacitor bank to produce a magnetic field of 10 or 15 kgauss midway between the discharge tube axis and wall, with a rise time of 2 or 2.5 μsec.

In the absence of the hexapole magnetic field, streak photographs are essentially the same as observed previously. They are characterized by an elliptical distortion of the plasma column with a superimposed rotation, about an axis different from that of the discharge tube, which produces the asymmetrical structure about the axis of the discharge. With the hexapole magnetic field, the streak photographs show the following: (1) the frequency of the plasma distortion is reduced by approximately a factor of two, (2) the plasma distortion is symmetrical about the axis of the discharge tube and it is not clear as to whether the plasma has a superimposed rotation as before, (3) the onset of the instability occurs in general at later times than in the absence of the hexapole field, and (4) the instability does not grow in time as it does without the stabilization field.

ZEUS

The cable transmission system has been installed into 23 shelves of Zeus. The cables are being connected to the capacitors and headers.

Some of Zeus has been used intermittently to evaluate various coil designs. The coils will be used in a Scylla III diagnostic experiment.

SCYLLA IV BANK

The platform for the 50-kv bank was installed and the racks for the 50-kv capacitors were assembled on the platform. The 50-kv spark gap was evaluated in conjunction with the 50-kv, 2 μf capacitor. The total

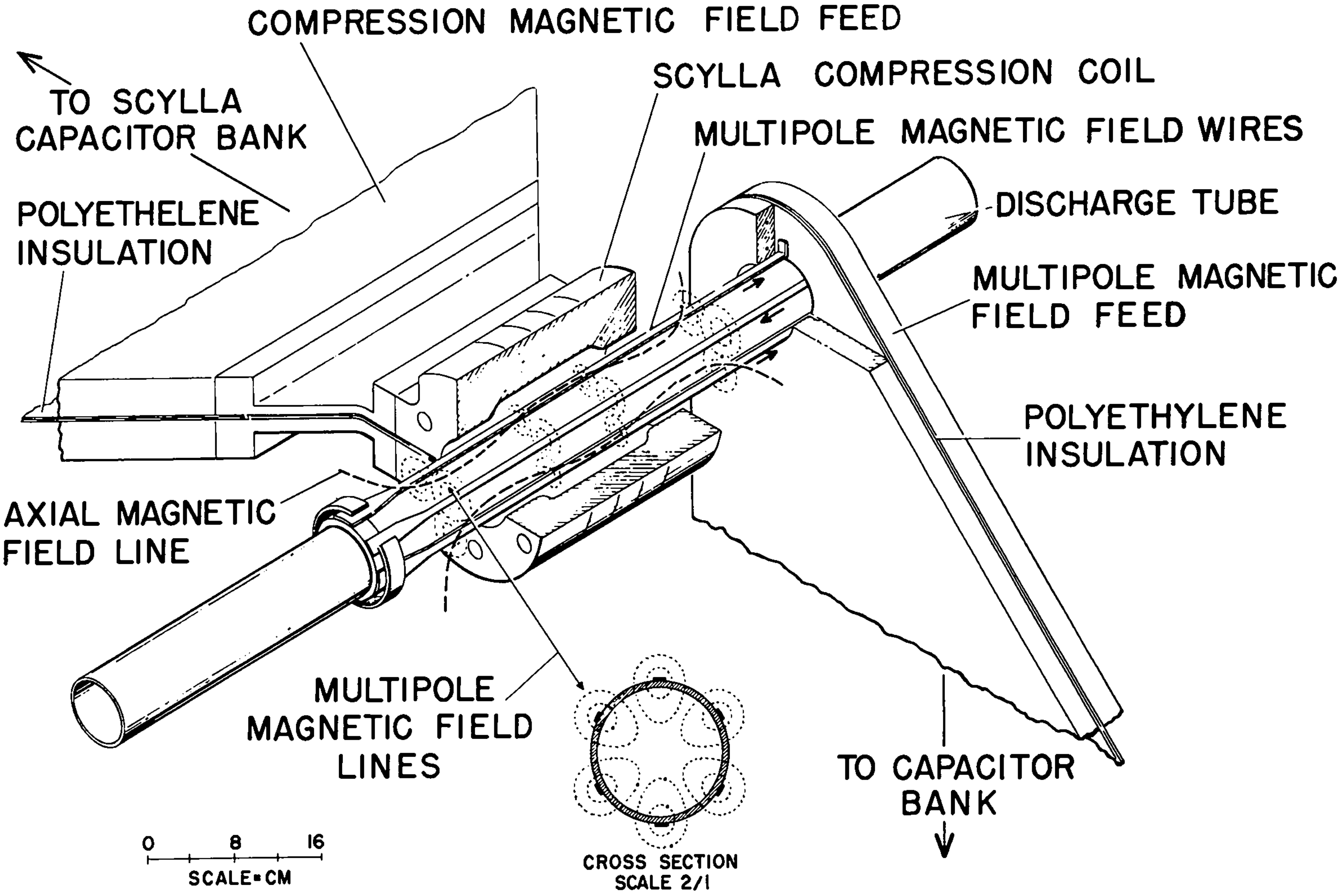

Fig. 1. Hexapole magnetic field of Scylla III

inductance of the spark gap and capacitor is 0.060 μh. This value is satisfactory for the Scylla IV system. Some minor modifications were made to the spark gap design and then the 216 spark gaps required for the Scylla IV 50-kv bank were ordered.

Five 2-μf, 50-kv capacitors from each of two companies were evaluated under Scylla IV operating conditions, but none was found to be suitable. The inductance of the capacitors was satisfactory, less than 0.02 μh in each case, but the life varied from 60 to about 2500 shots. The guaranteed life requirement for this bank is 5000 shots, and so both designs were rejected. Each company has submitted samples of a new design and these are being evaluated.

The charging and triggering circuits for the 50-kv bank have been designed and most of the components are on order. A prototype step-up coaxial pulse transformer for the firing system was designed and fabricated. This unit, shown in Fig. 2, was assembled using RG 14/U cable and has six outer braid sections connected in parallel as the primary and the continuous center section as the secondary. Thus, it provides excellent dc high-voltage isolation as well as ac voltage step-up. It performed as predicted with a voltage step-up of 6:1 and a rise time of 0.16 μsec.

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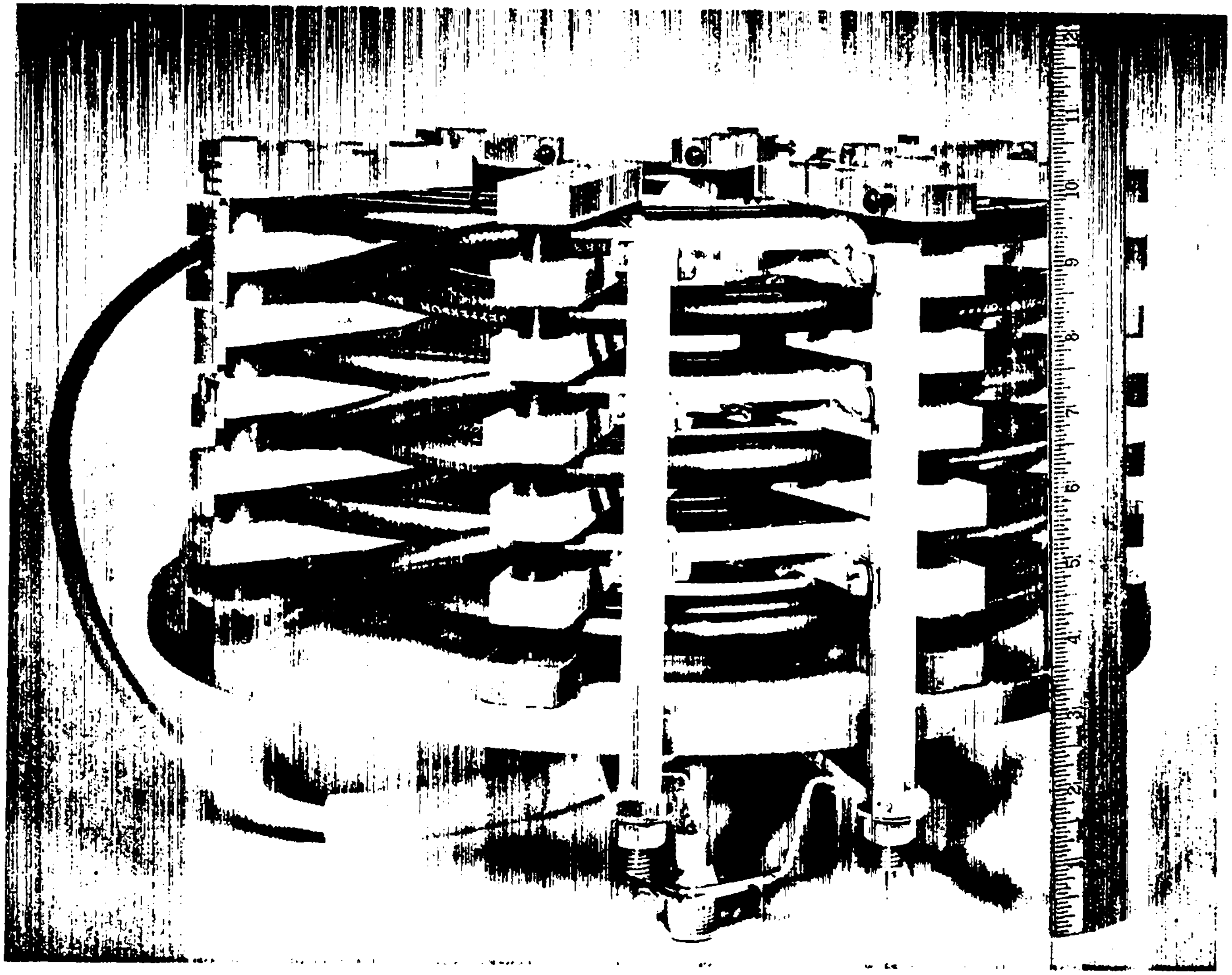

Fig. 2. Coaxial pulse transformer for firing system