Title
THE FAULT DIVERTER-A PROTECTIVE DEVICE FOR HIGH-POWER ELECTRON TUBES

Author
Smith, Bob H.

Publication Date
1957-08-01

University of California

Ernest O. Lawrence Radiation Laboratory

Berkeley, California

DISCLAIMER

UCRL-3701 Rev

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

THE FAULT DIVERTER–A PROTECTIVE DEVICE FOR HIGH-POWER ELECTRON TUBES

Bob H. Smith

August, 1957

Printed for the U. S. Atomic Energy Commission

THE FAULT DIVERTER—A PROTECTIVE DEVICE FOR HIGH-POWER ELECTRON TUBES

Bob H. Smith

Radiation Laboratory
University of California
Berkeley, California

August, 1957

ABSTRACT

Fault diverters, or crowbars, have proven to be very effective protection against transient-induced power arcs within accelerator oscillator tubes. This device short circuits the oscillator-plate power supply in the event of an over-current, thus removing the power flow from the fault within a few microseconds. Ignitrons, thyratrons, and triggered spark gaps are used for this purpose. The power supply is protected from the short circuit either by a current-limiting device or a high-speed contactor which removes the system from the power lines within a few milliseconds. The paper describes the fault diverters, and associated circuitry, used on several of the accelerators in Berkeley and Livermore.

THE FAULT DIVERTER–A PROTECTIVE DEVICE FOR HIGH-POWER ELECTRON TUBES

Bob H. Smith

Radiation Laboratory
University of California
Berkeley, California

August, 1957

INTRODUCTION

Vacuum tubes used to excite the resonators of particle accelerators are subjected to severe high-voltage transient initiated by resonator sparks. These transients produce power arcs which may have magnitudes of hundreds of ampere and, if allowed to persist, are capable of destroying the oscillator tube.

The protective device that is employed on all of the UCRL accelerators is the fault directer (crowbar) first developed by M. V. Hoover.[1] This consists of an ignitron, thyratron, or spark gap that short-circuits the oscillator-anode supply voltage in the event of an over current, thus transferring the fault from the delicate oscillator tube to the rugged crowbar. The time interval between the initial fault and its diversion to the crowbar is sufficiently short (a few microseconds) to present appreciable energy transfer to the oscillator tube.

EQUIPMENT AND OPERATION

A typical power supply with ignitron crowbar is shown in Fig. 1. Three-phase 60-cycle power is fed through an ignitron contactor to the plate transformer and rectifier and hence through a filter to the load. In the event of a fault condition in the load, the ignitron crowbar is fired, short-circuiting the power supply and preventing further power flow into the load. A second signal from the fault-detector is sent to open the ignitron contactor before sufficient power flows into the power supply to do any damage. The time required to fire the crowbar after detection of a fault is between one and ten microseconds--the former a rather fast crowbar and the latter, rather slow. The time required to open the ignitron contactor is always less than eight milliseconds--the time to the next current zero in the power lines.

The basic components of an ignitron crowbar are shown in Fig. 2. The purpose of the 2-ohm resistor in the anode circuit is to provide sufficient anode potential on the crowbar to permit firing under short-circuit load conditions. The resistance value assumes that this crowbar is intended to fire at about 50 amperes, which provides 100 v at the anode. The 0.25-henry choke limits the power supply current after the crowbar has been

---

[1] M. V. Hoover, U.S. Patent 2, 615, 147, Oct. 21, 1952.

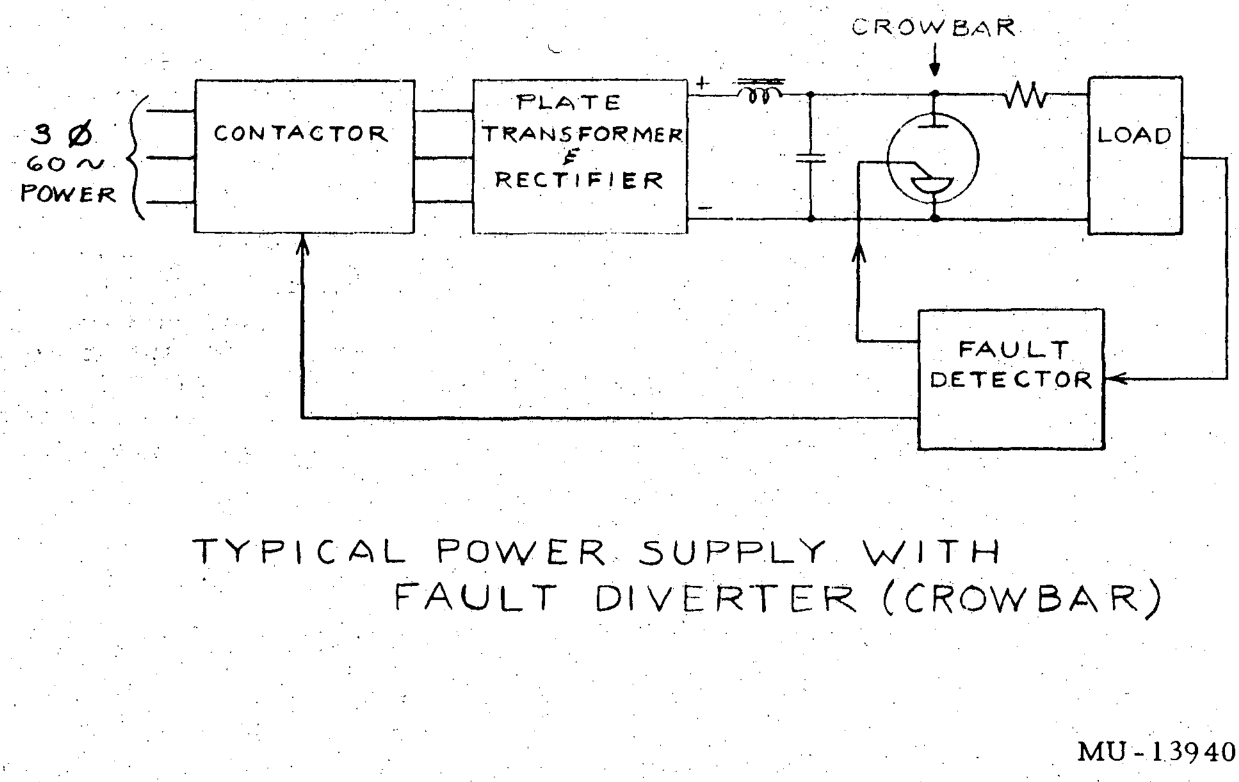
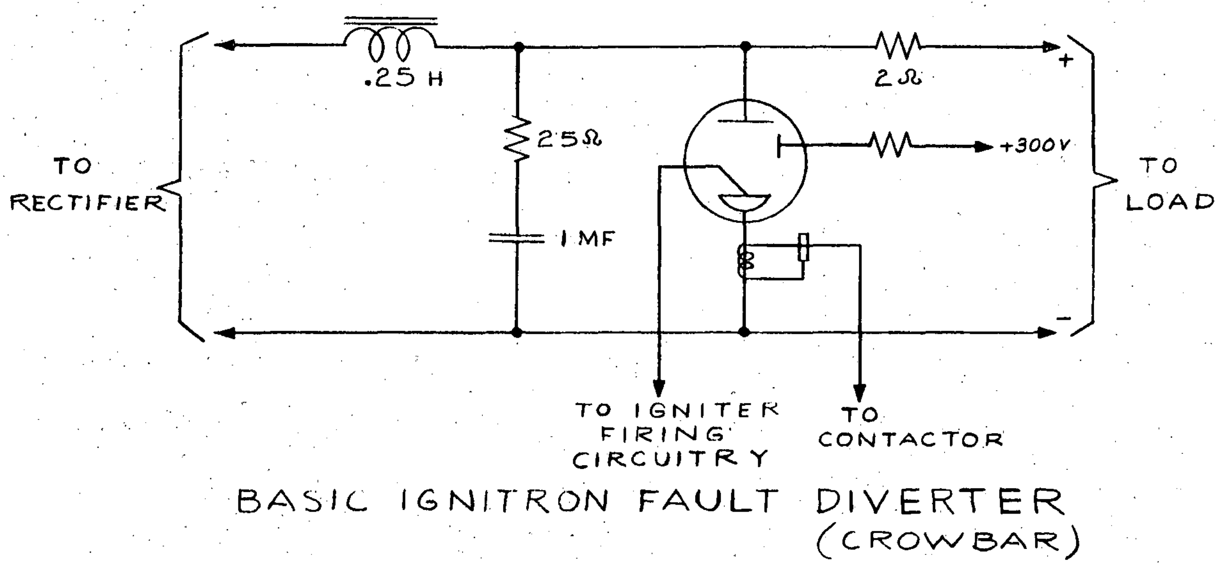


Fig. 1. Typical power supply with fault diverter (crowbar).



MU-13941

Fig. 2. Basic components of a fault diverter.

fired until the contactor can be opened. The holding anode may be used to prevent the arc from being extinguished in the event the positive buss should ring, as is often the case. Overlooking this condition is one of the most frequent errors in crowbar design. It is possible to omit the holding anode by locating the 1-mfd capacitor and 25-ohm resistor near the anode so as to minimize the inductance in this circuit. This capacitor and resistor also speed up the anode arc. The current transformer in the cathode of the crowbar opens the contactor in the event that the crowbar itself sparks over.

Figure 3 shows a typical fault detector. An overcurrent is detected by means of the magnetron--typically a G. E. type 2B23. The coil in the d. c. high-voltage line usually consists of about 5 turns and surrounds the magnetron. The coil is designed so that excessive current provides sufficient magnetic field to cut off the electron flow in the magnetron, permitting the grid of V-1 to rise to positive 300 v. This trips the Schmit trigger consisting of V-1 and the first half of V-2 which fires the thyratron, V-3, discharging the capacitor into the ignitor of the crowbar. The current trip adjustment typically provides about a five-to-one range of currents required to cut off the magnitron.

The relays are employed to provide a fail-safe feature. Each cathode in V-1 and V-2 must be emitting in order to close the interlock chain and keep the machine in operation. A pentagrid tube is used for the first half of the Schmit trigger which is normally not conducting. Because grid number one is maintained at zero bias, current flows through the number 2 screengrid but not through number 4, the current normally being cut-off by the control gird number 3. Relay number 4 insures that the filament of the thyratron is continuous, Re 5 insures that it has plate voltage, and Re 6 insures that there are no cathode-to-filament shorts. We have found that the use of 1500 v on the thyratron speeds up the firing of the crowbar.

The power supply for the 90-in. cyclotron at Livermore (Fig. 4) consists of an ignitron crowbar, surge network, 100% buck-or-boost induction regulator, and two three-phase full-wave rectifiers connected in series to produce 20 kv. Because one power transformer is connected delta-delta while the other is connected delta-wye, the ripple is 12-phase rather than 6-phase. The reason that we prefer two stacked 10-kv rectifiers is that we have found type-857 rectifiers to be somewhat marginal when operated at 20-kv.

The transformers connected between the 2400-v line and the ignitron pulse chassis are potential transformers used for phasing the ignitors. The chassis employs an electronic gate which interrupts the ignitor firing upon receiving a signal from the fault detector.

The surge network is a rather large unit and prevents the snap-out current (about 3 amp) of the ignitrons from producing a transient by means of the magnetizing inductance of the induction regulator. The snap-out current drops to zero within one μsec. Further transient protection is provided by the Westinghouse autovalves and the thyrite connected across the power-transformer secondaries. Control of transients is the key to satisfactory ignitron performance and should be carefully considered.

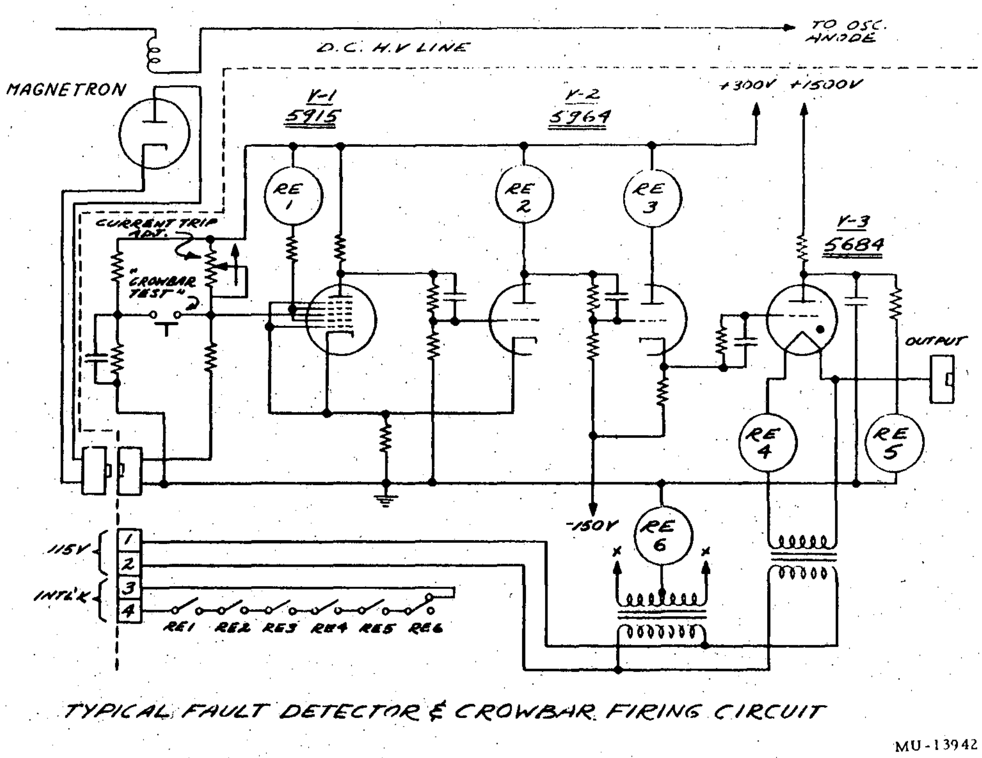
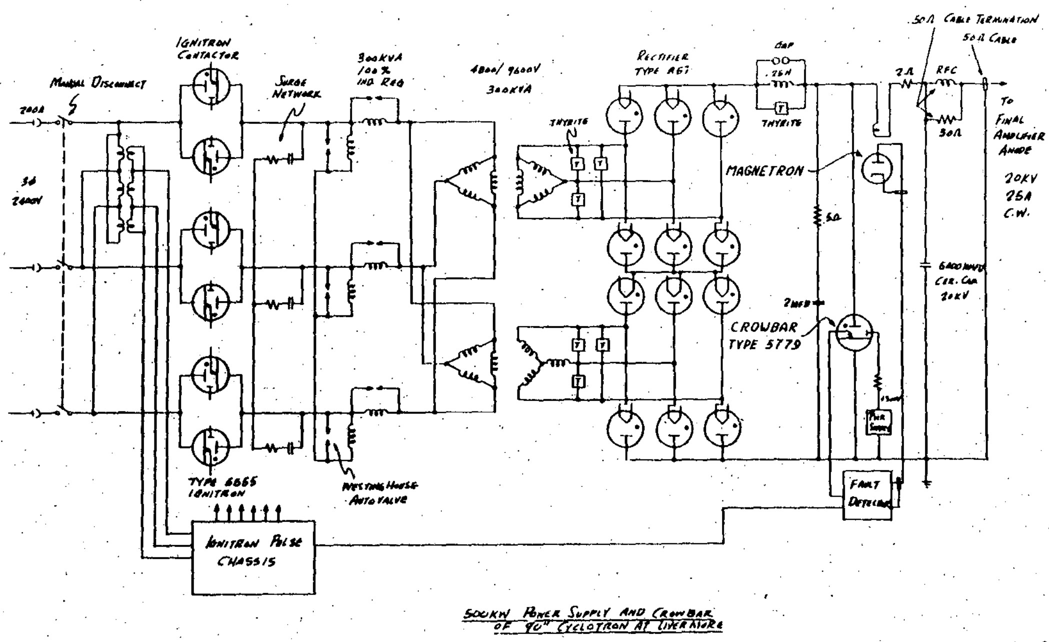


Fig. 3. Typical fault detector and crowbar firing circuit.



MU-13943

Fig. 4. 500-KW power supply and crowbar of 90-inch cyclotron at Livermore.

Figure 5 shows the surge-network cabinet, the induction regulator, and the two 300-kva plate transformers of the power supply of the 90-in. cyclotron.

The rectifier room of this machine is shown in Fig. 6. To the left is the ignitron contactor cabinet, rear center is the rectifier cabinet, and in the foreground is the filter and crowbar cabinet. The type GL 5779 is used as the crowbar. While this tube is only rated at 350 v in rectifier service, it operates at 20 kv in crowbar service without the slightest difficulty. In each crowbar operation the energy dissipated is only 83 w-sec. When the high-voltage buss is shortcircuited with a ground hook only a slight "click" is heard--about equal to the discharge of a 10 mfd. capacitor charged to 300 v --because most of the current is discharged through the crowbar.

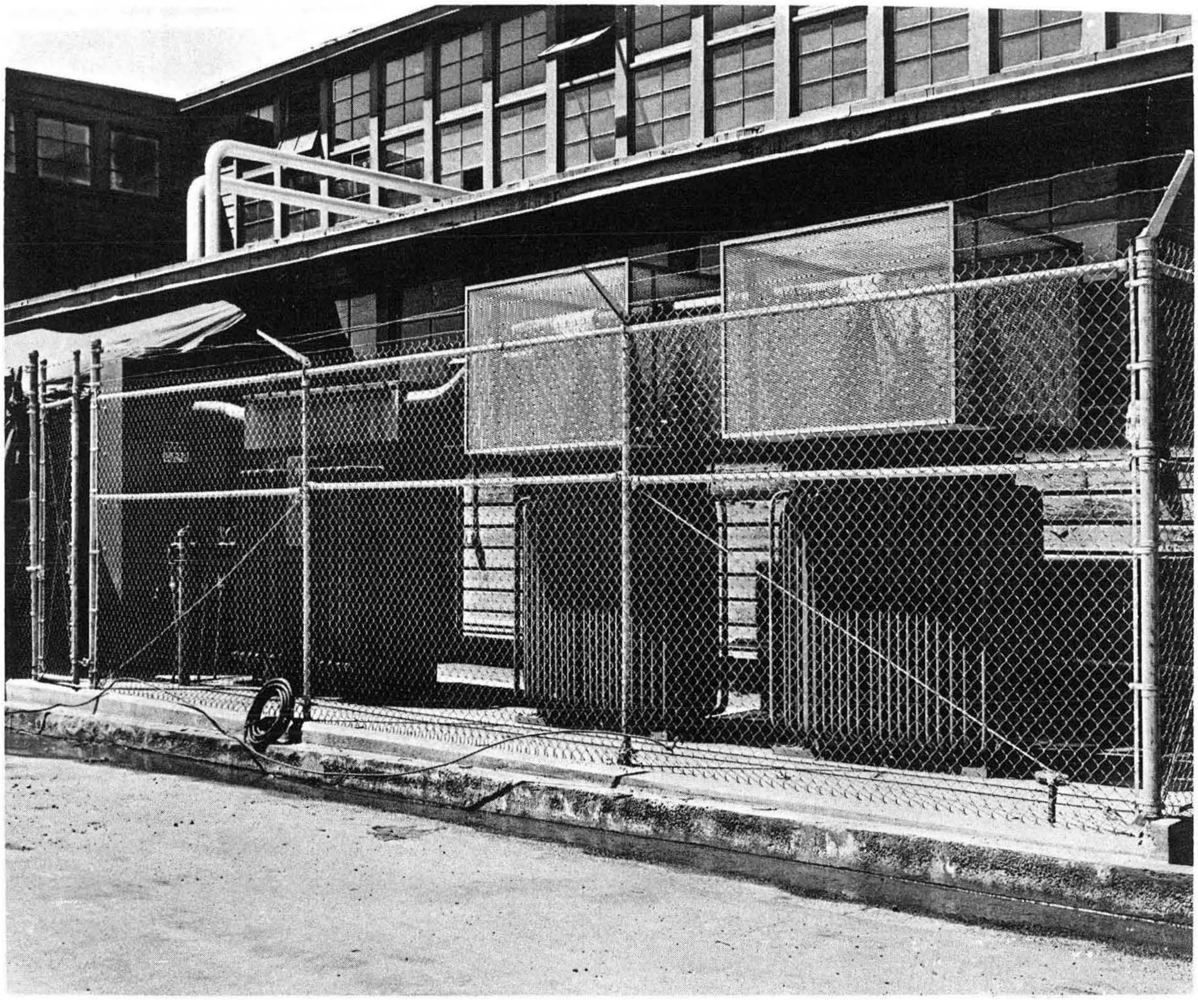
Figure 7 shows one phase of the ignitron contactor of the 90-in. cyclotron. A pair of type 5555 ignitrons are used in each line.

Figure 8 shows the 9-MW power supply of the A-48 linear accelerator at Livermore which is fed by a 110-kv to 13.8-kv line transformer (Fig. 9). A motor-generator set (Fig. 10) is used to isolate the power supply from the line. This accelerator sometimes operates under pulsed conditions near 18 MW with a duty factor of 50%, and the m-g set filters the pulse from the main power line.

This power supply does not use an ignitron contactor but uses an ignitron rectifier. The two plate transformers are shown in Figure 11. After a crowbar operation, the firing of the ignitors is stopped. Probably the choice of the large ignitrons as crowbars on this power supply was governed by the desirability of maintaining only one type of spare rather than by power considerations.

The power supply of the heavy-ion accelerator at Berkeley is shown in Fig. 12. It was chosen to illustrate a pulsed system. Figure 13 shows the power transformers and 562 rectifiers of the heavy ion machine. Type 562 tubes are used in an emission-limited arrangement to charge the pulse line (Fig. 14) to 40 kv. The pulse line is discharged into the oscillator by means of a triggered spark gap (Fig. 15). In the event of a fault a second gap serves as a crowbar to divert the remaining energy in the pulse line. Because the inductances in series with the spark gaps saturate at a relatively low current they are effectively removed during the main pulse of current. During the initial firing of the gap, however, they permit the cathode end of the gap to be depressed to about -100 kv by the trigger to insure the firing of the gap. Because the oscillator approximately matches the line, it receives only about half of the voltage to which the line was charged. The spark gaps probably will be replaced with ignitrons in the near future as ignitrons are regarded as being more reliable.

Figure 16 shows the crowbar installation of the Bevatron. In the foreground is the current-limiting choke, spark gap, and thyrite. Further back and to the right, the 5779 crowbar can be seen.



ZN-1767

Fig. 5. Plate transformers and induction regulator of the 90-inch cyclotron power supply.

Figure 5 shows the surge-network cabinet, the induction regulator, and the two 300-kva plate transformers of the power supply of the 90-in. cyclotron.

The rectifier room of this machine is shown in Fig. 6. To the left is the ignitron contactor cabinet, rear center is the rectifier cabinet, and in the foreground is the filter and crowbar cabinet. The type GL 5779 is used as the crowbar. While this tube is only rated at 350 v in rectifier service, it operates at 20 kv in crowbar service without the slightest difficulty. In each crowbar operation the energy dissipated is only 83 w-sec. When the high-voltage buss is shortcircuited with a ground hook only a slight "click" is heard--about equal to the discharge of a 10 mfd. capacitor charged to 300 v --because most of the current is discharged through the crowbar.

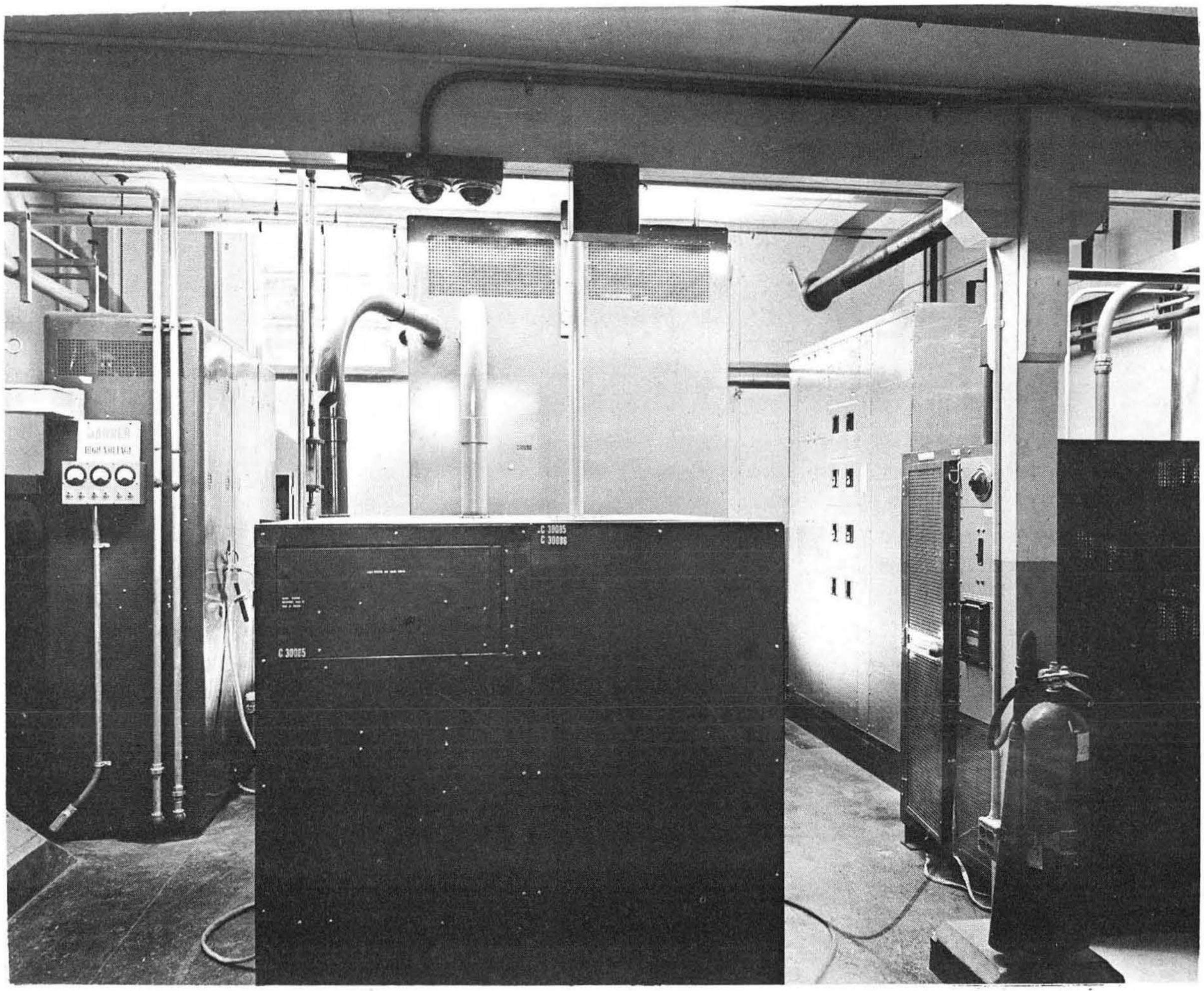
Figure 7 shows one phase of the ignitron contactor of the 90-in. cyclotron. A pair of type 5555 ignitrons are used in each line.

Figure 8 shows the 9-MW power supply of the A-48 linear accelerator at Livermore which is fed by a 110-kv to 13.8-kv line transformer (Fig. 9). A motor-generator set (Fig. 10) is used to isolate the power supply from the line. This accelerator sometimes operates under pulsed conditions near 18 MW with a duty factor of 50%, and the m-g set filters the pulse from the main power line.

This power supply does not use an ignitron contactor but uses an ignitron rectifier. The two plate transformers are shown in Figure 11. After a crowbar operation, the firing of the ignitors is stopped. Probably the choice of the large ignitrons as crowbars on this power supply was governed by the desirability of maintaining only one type of spare rather than by power considerations.

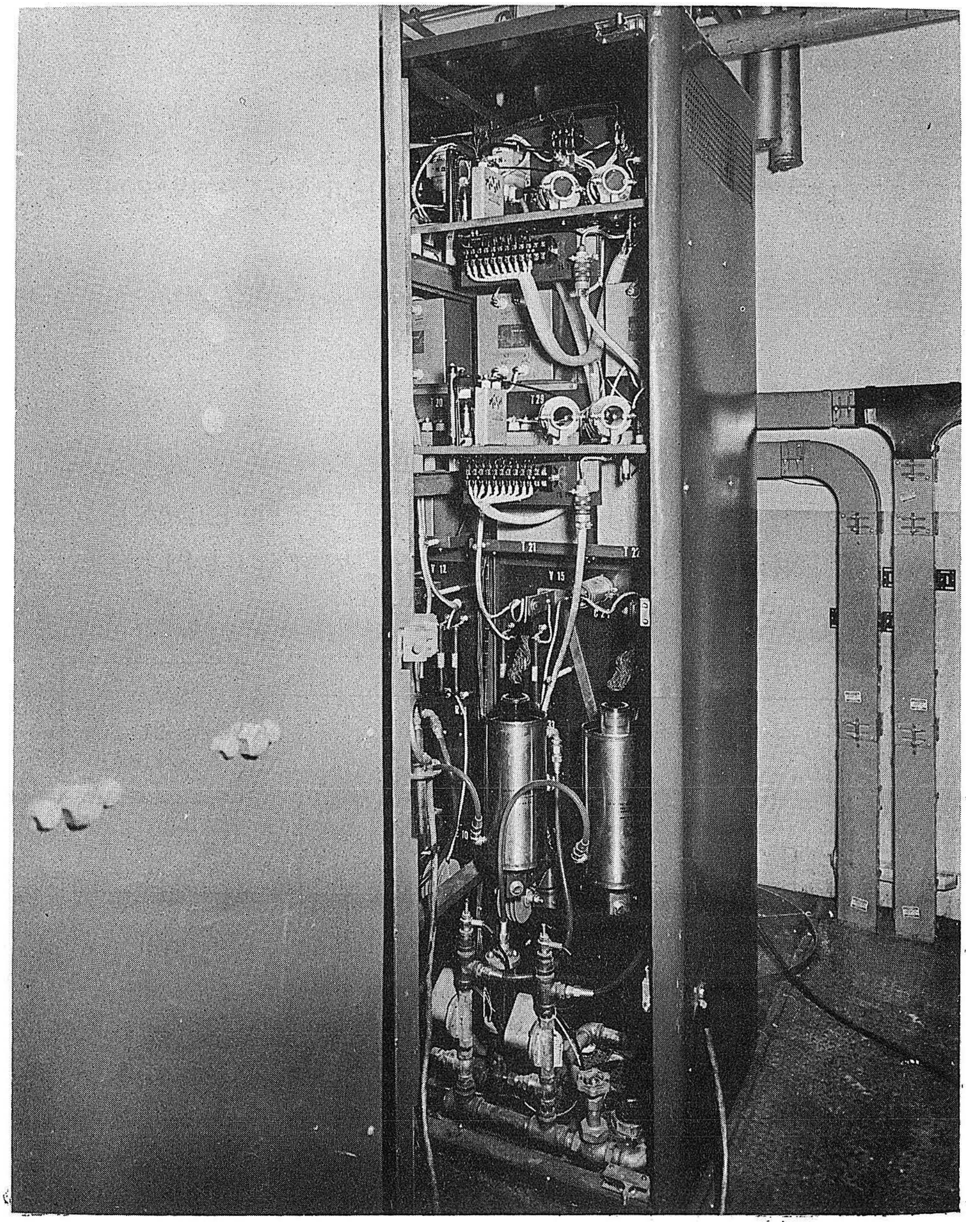
The power supply of the heavy-ion accelerator at Berkeley is shown in Fig. 12. It was chosen to illustrate a pulsed system. Figure 13 shows the power transformers and 562 rectifiers of the heavy ion machine. Type 562 tubes are used in an emission-limited arrangement to charge the pulse line (Fig. 14) to 40 kv. The pulse line is discharged into the oscillator by means of a triggered spark gap (Fig. 15). In the event of a fault a second gap serves as a crowbar to divert the remaining energy in the pulse line. Because the inductances in series with the spark gaps saturate at a relatively low current they are effectively removed during the main pulse of current. During the initial firing of the gap, however, they permit the cathode end of the gap to be depressed to about -100 kv by the trigger to insure the firing of the gap. Because the oscillator approximately matches the line, it receives only about half of the voltage to which the line was charged. The spark gaps probably will be replaced with ignitrons in the near future as ignitrons are regarded as being more reliable.

Figure 16 shows the crowbar installation of the Bevatron. In the foreground is the current-limiting choke, spark gap, and thyrite. Further back and to the right, the 5779 crowbar can be seen.



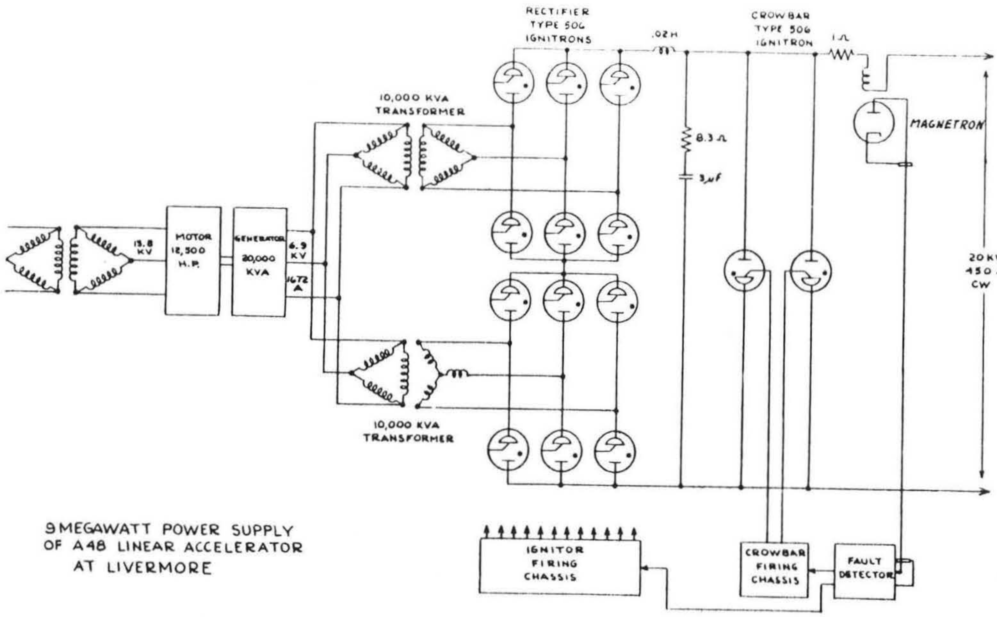
ZN-1766

Fig. 6. Ignition contactor-left rear, rectifier-rear center, and in the forground crowbar cubical of 90-inch cyclotron.



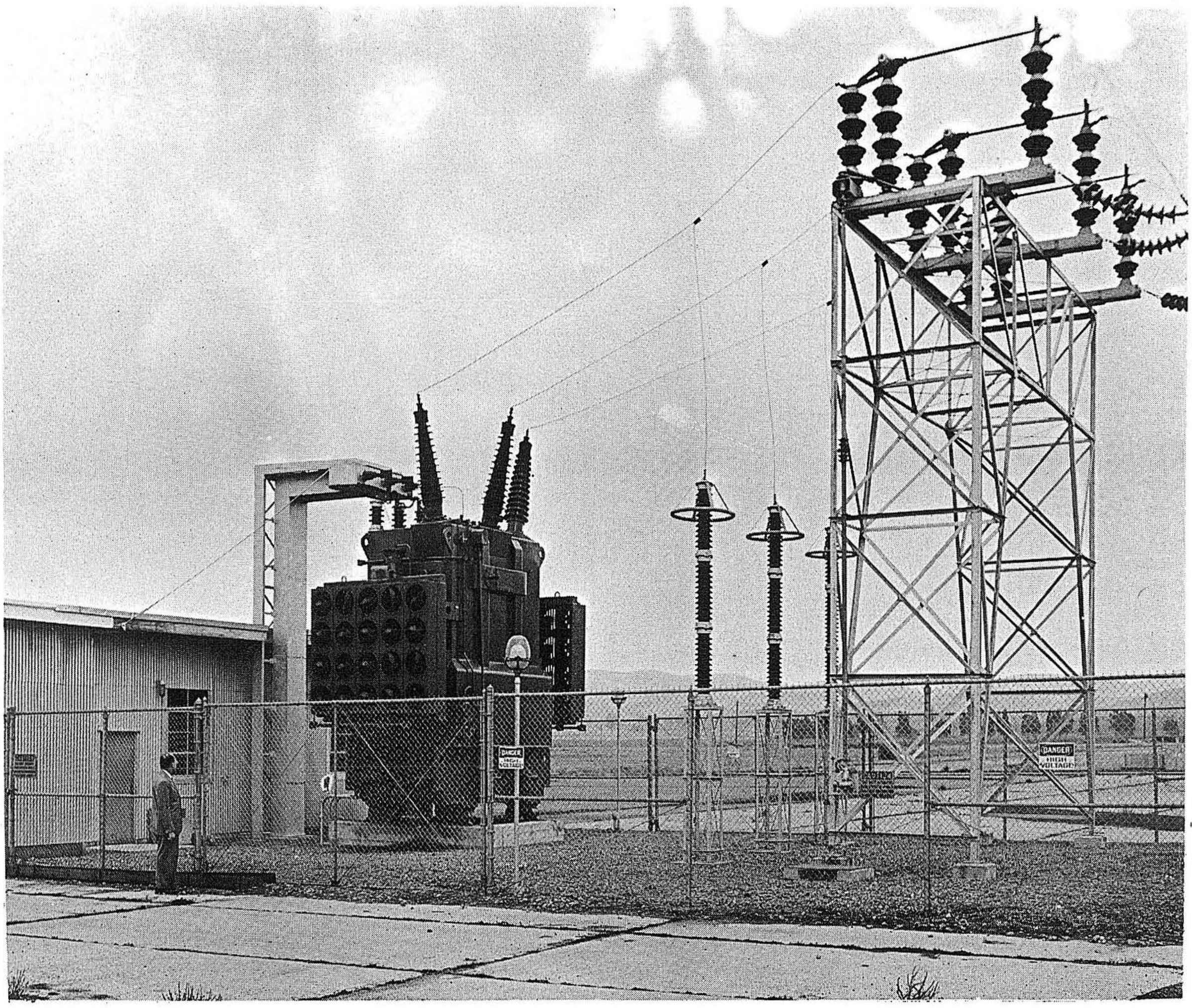
ZN-1765

Fig. 7. Construction details of one phase of ignition contactor of 90-inch cyclotron.



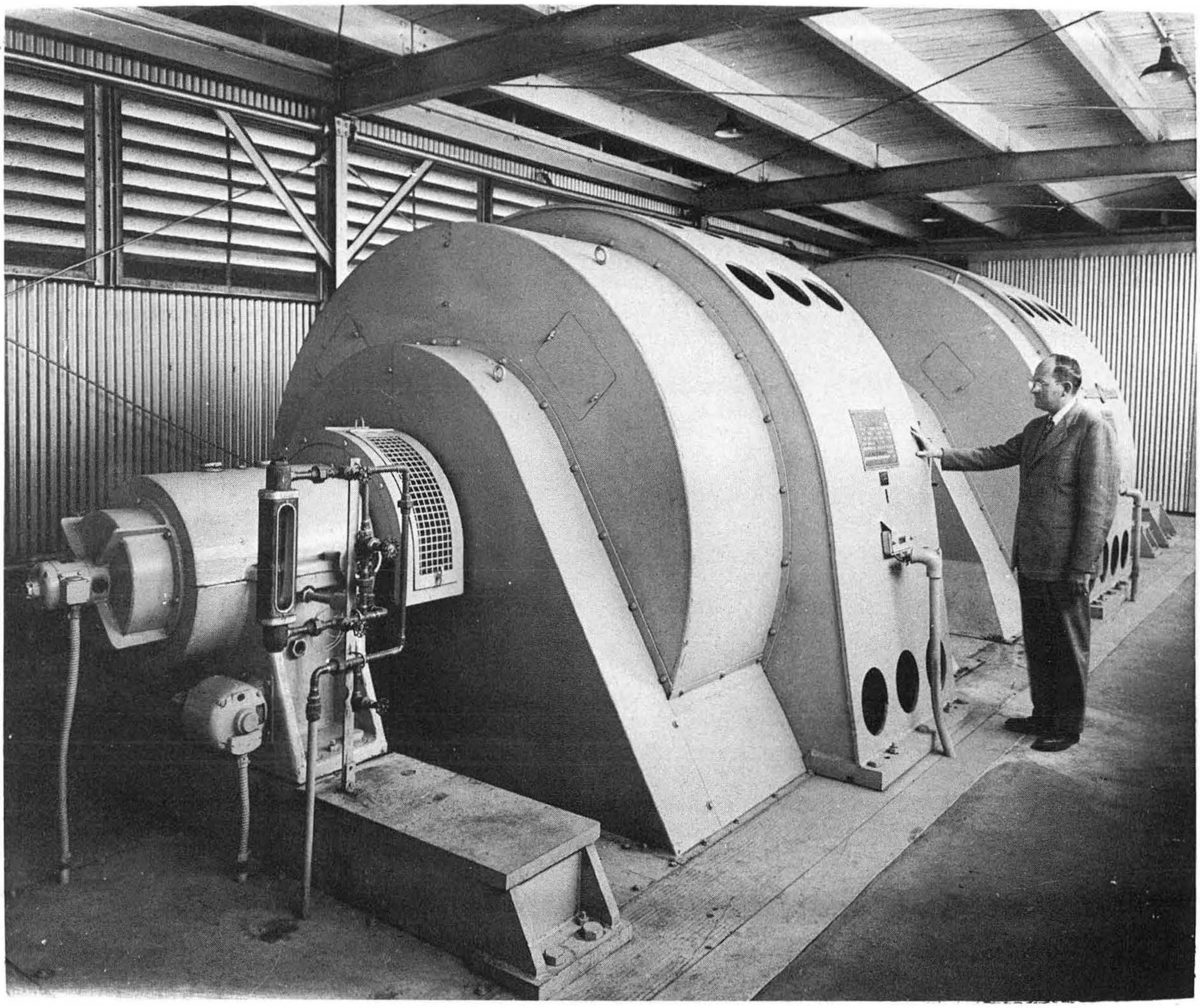
MU-13944

Fig. 8. 9-MW power supply of A-48 linear accelerator at Livermore.



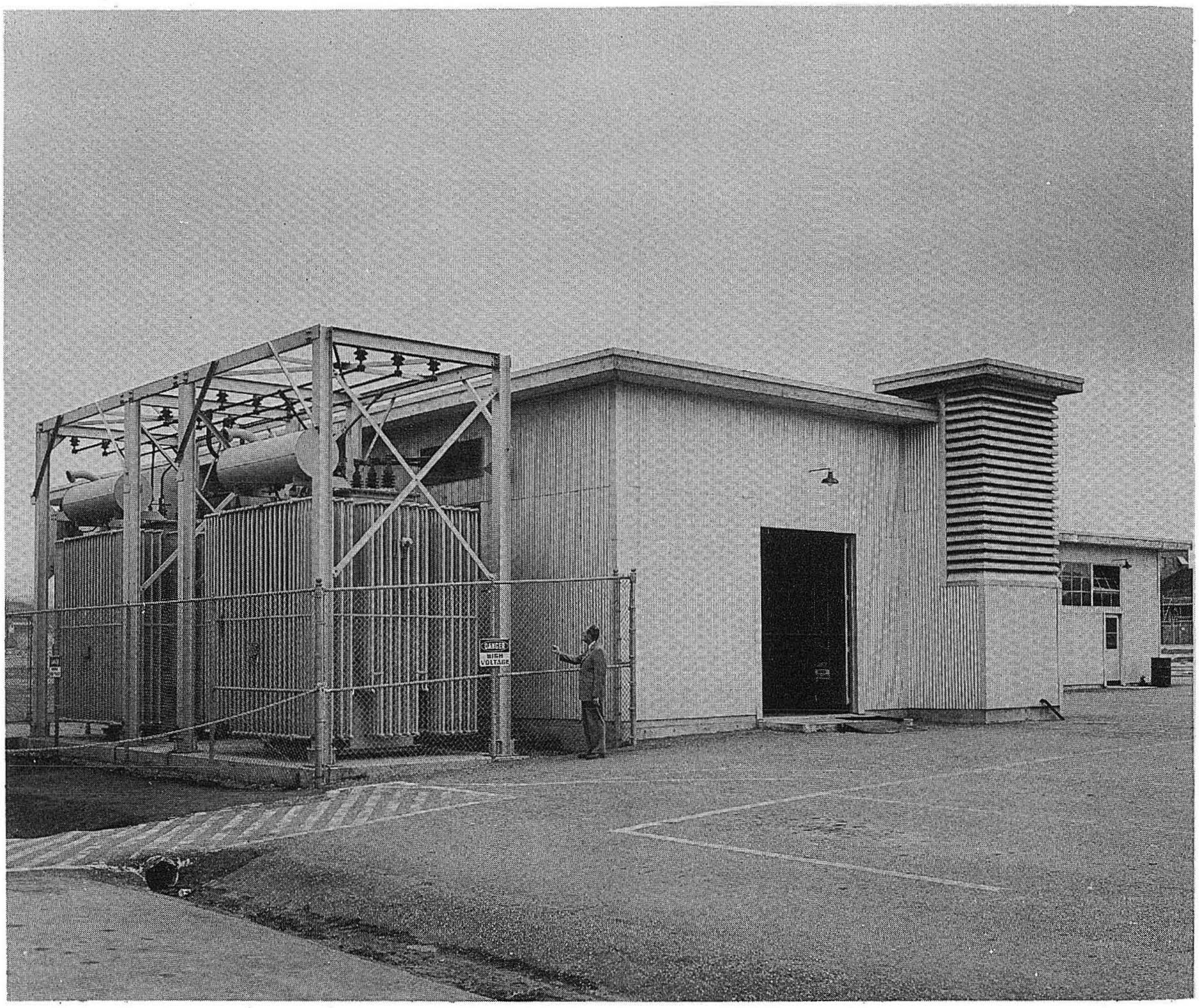
ZN-1762

Fig. 9. 110-KV to 13.8-KV transformer of A-48 linear accelerator.



ZN-1764

Fig. 10. Motor-generator set of A-48 linear accelerator.



ZN-1763

Fig. 11. Plate transformers of A-48 linear accelerator.

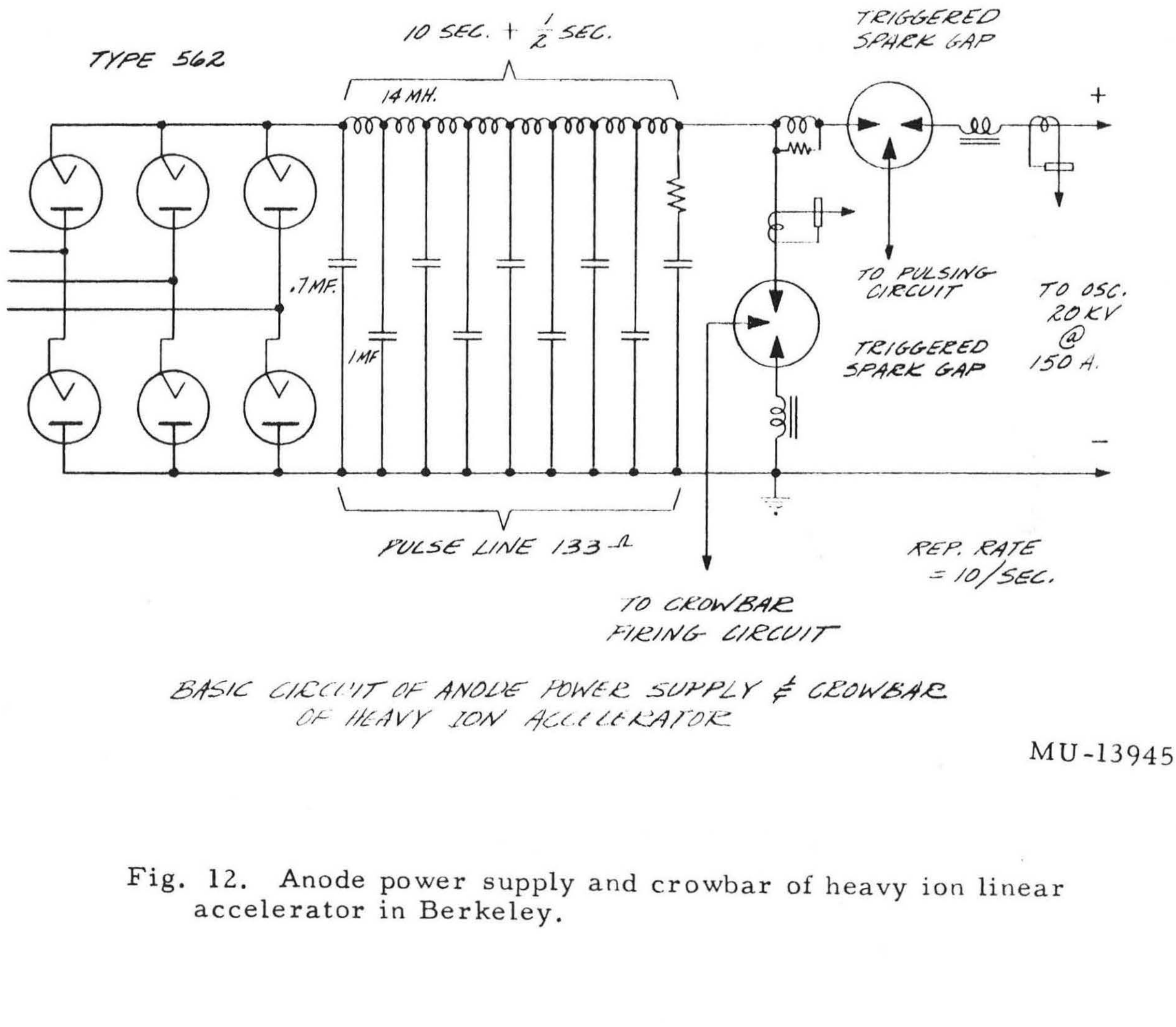
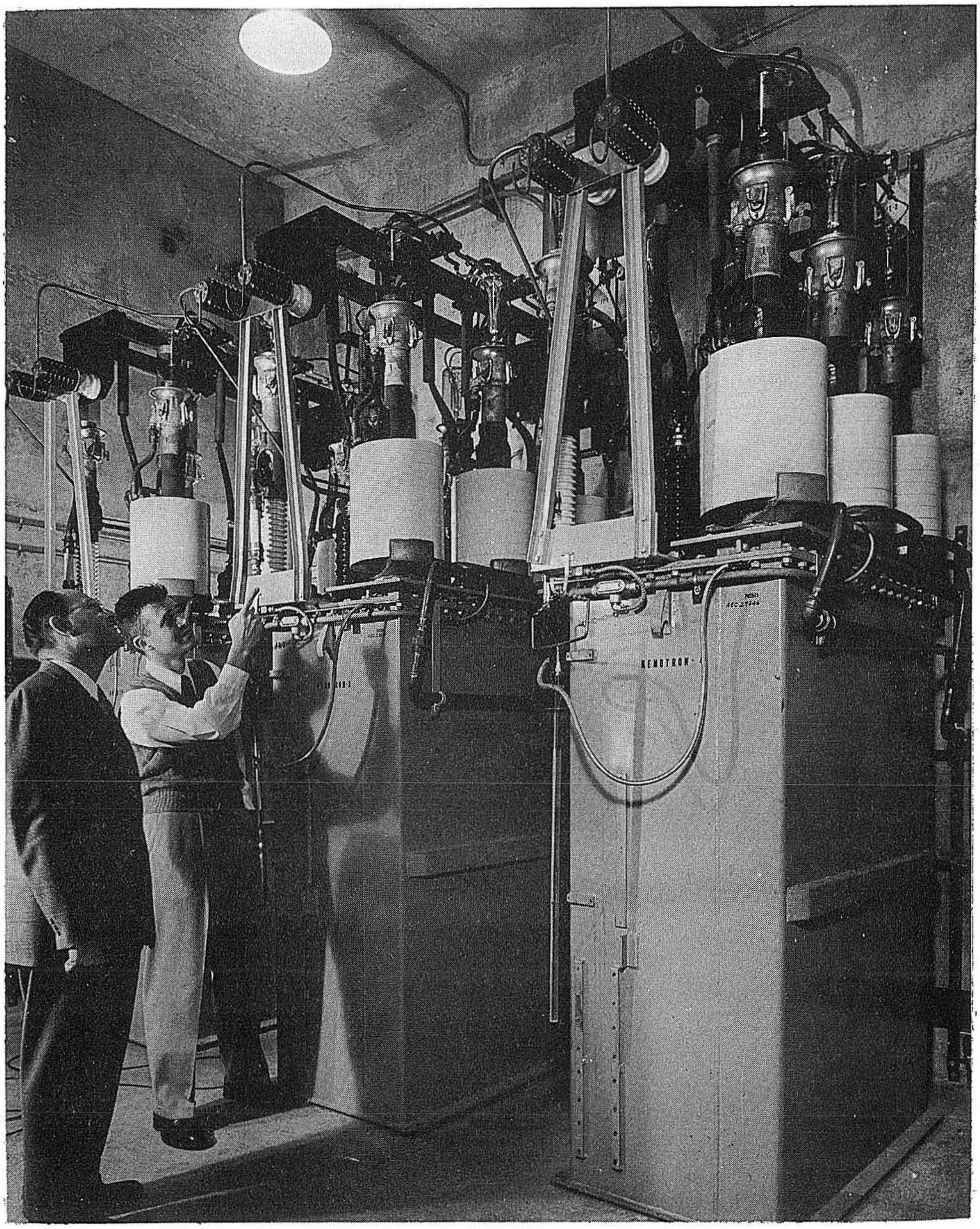
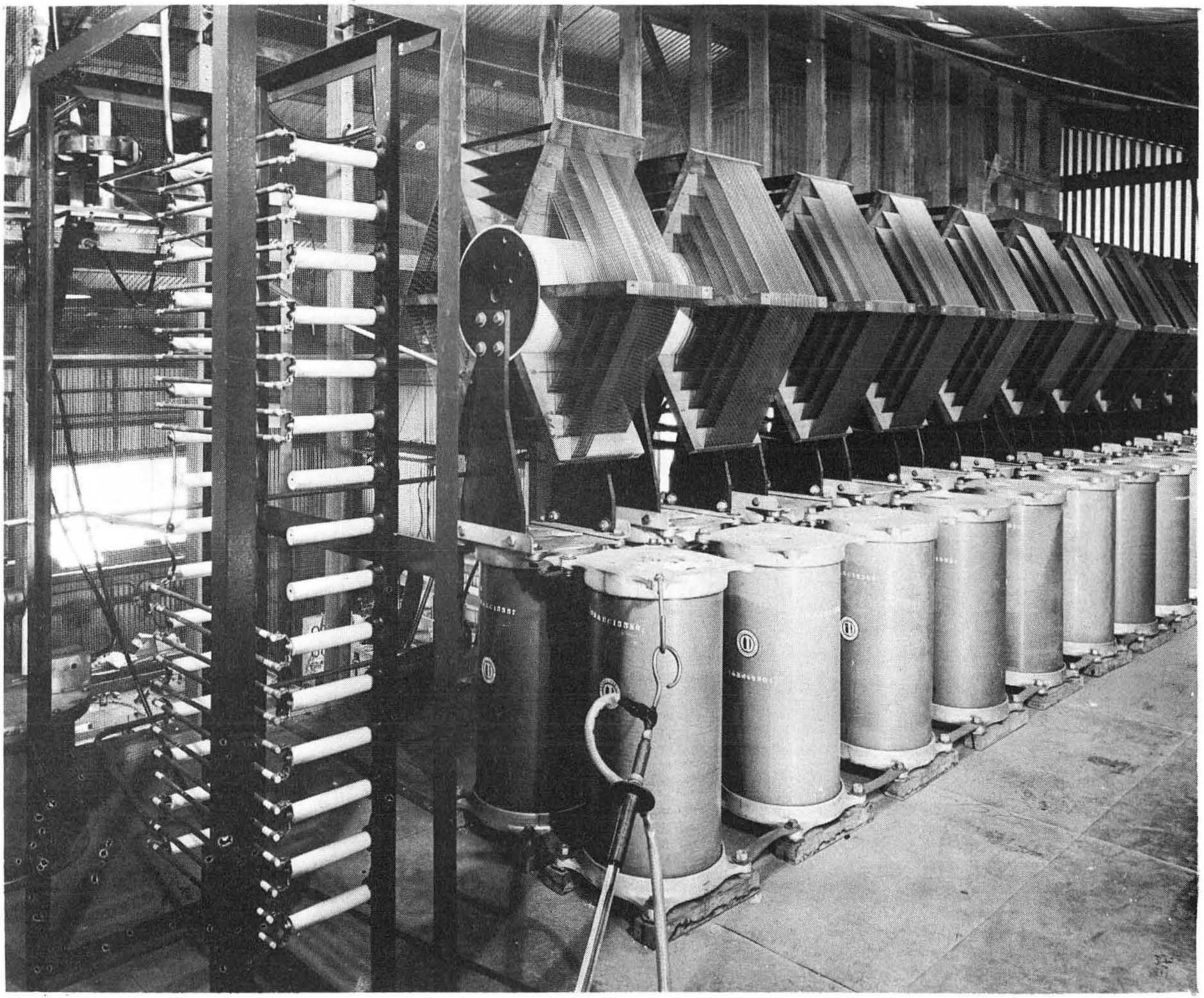


Fig. 12. Anode power supply and crowbar of heavy ion linear accelerator in Berkeley.



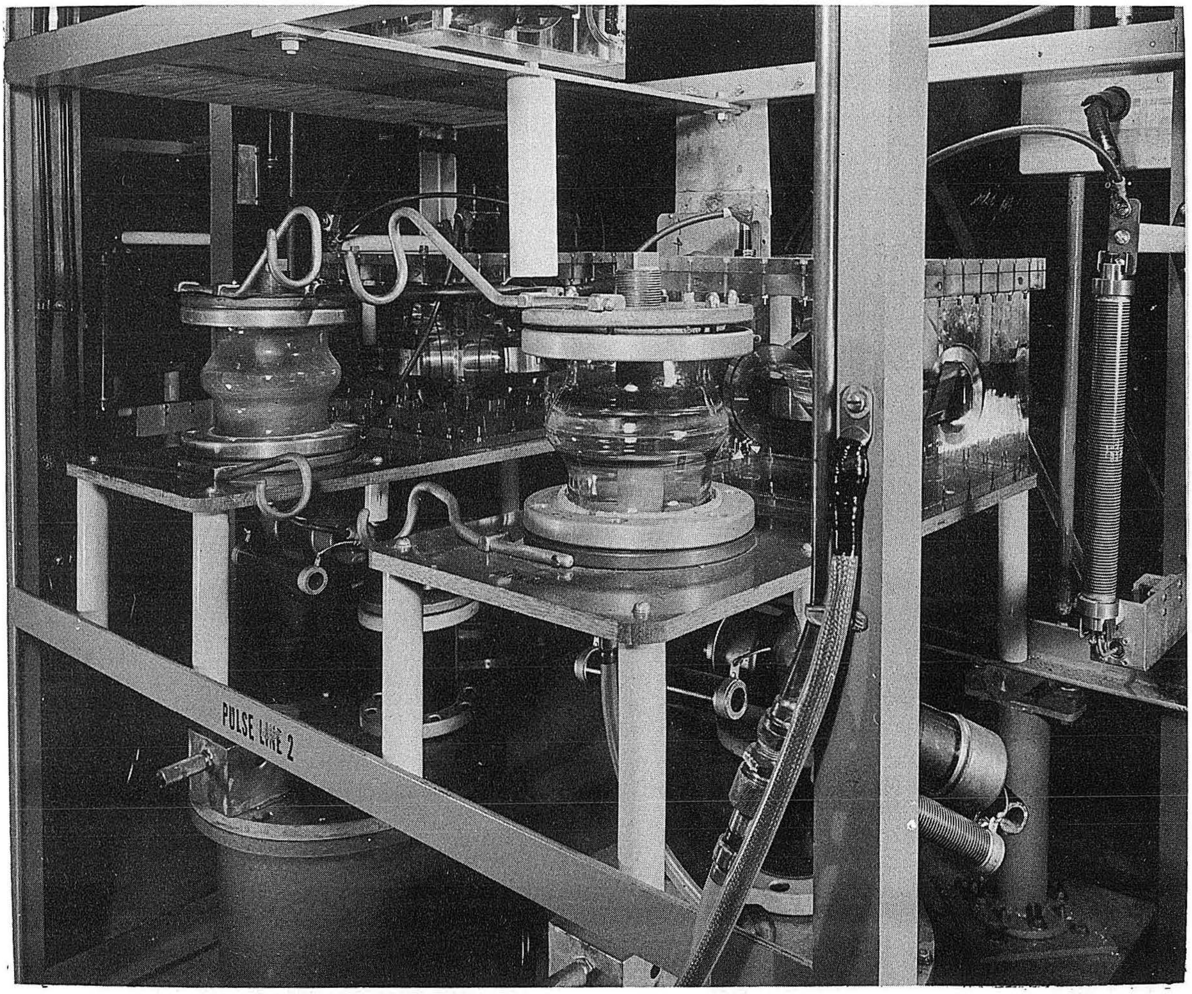
ZN-1760

Fig. 13. Plate transformer of heavy-ion linear accelerator.



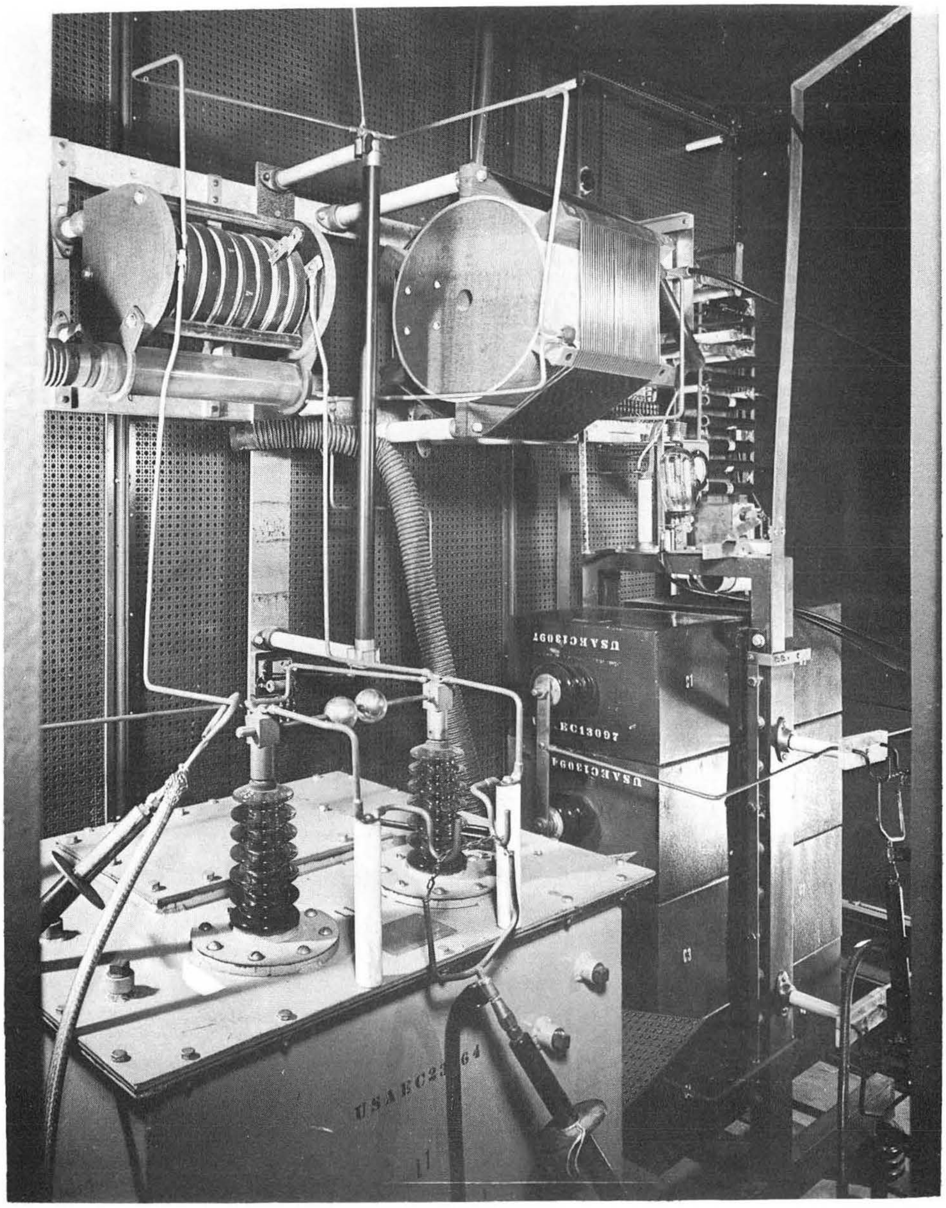
ZN-1758

Fig. 14. Pulse line used in the heavy-ion power supply.



ZN-1759

Fig. 15. Spark-gap type crowbar for the heavy-ion linear accelerator.



ZN-1761

Fig. 16. Bevatron crowbar and associated circuitry.