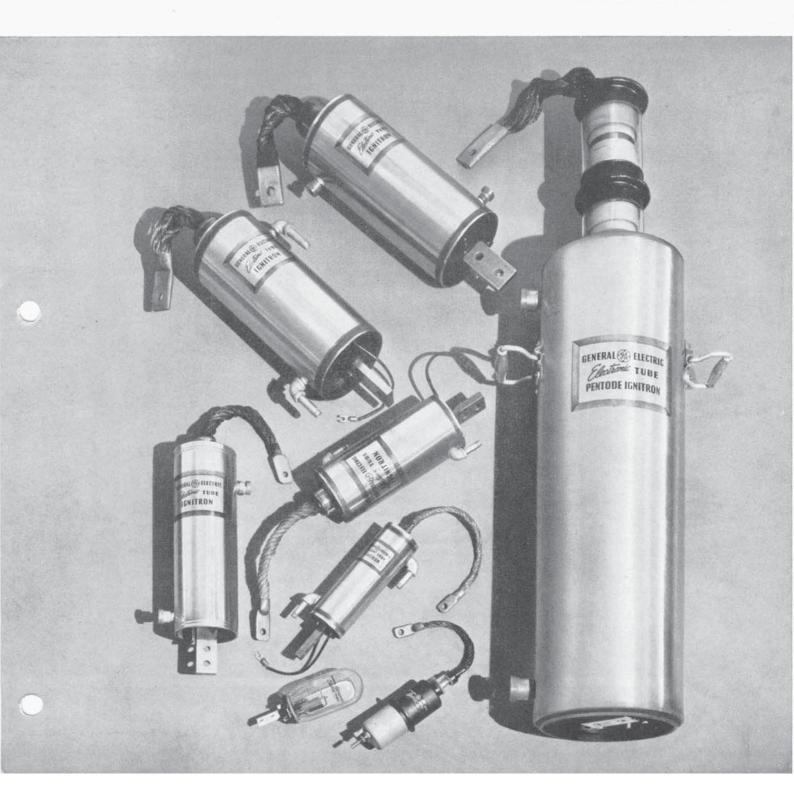# IGNITRONS

DESCRIPTION

Ignitrons are gas-discharge, pool-type cathode tubes in which the arc is started for each conducting cycle by means of a starting or ignition electrode. The tubes are of the half-wave type in which current is carried through the tube during only the positive part of the cycle. During the remainder or non-conducting part the residual ionization reaches very low values in comparison with the ionization present in the multi-anode type of pool tube where it is proportional to the load current carried. As a result of the so-called dark, negative half-cycle, the shielding required in half-wave tubes is greatly reduced from that in the multi-anode tube. Reduction of shielding in turn lowers the arc voltages so that tubes of this type may be efficiently applied in the lower voltage (125 to 250 volt) fields. Mercury-pool cathodes are capable of supplying emission currents of many thousands of amperes. By phase control of the point in the cycle at which the ignitor is fired, the output voltage or current may be reduced from the maximum to provide voltage or current control. The ignitron, therefore, possesses many of the control characteristics of the thyratron, and in addition has emission capacity for carrying very high currents. In general, the tubes are water-cooled, but in the smaller sizes may be air-cooled. Exceptions are the GL-415 ignitron for welder control use in which temperature control is provided by clamping the cathode portion of the tube in an air or water-cooled metal clamp, and the GL-427 ignitron which is a small glass tube designed specifically for ignitor demonstration purposes.

GENERAL CLASS OF OPERATION AND APPLICATION

There are three main fields of applications for which ignitrons are particularly suited—resistance welding, power rectification, and power conversion or transmission.

1. In welding control applications ignitron tubes are used to control the primary current supplied to resistance welding transformers. They are used in voltage supply circuits of 220, 440, 550, 1100, and 2300 volts rms. The control is the most exact that has been developed. The tubes operate as contactors and through suitable thyratrons and other electronic control, may be arranged to provide one, two, or a dozen cycles of current. Off periods may likewise be controlled with the same exactness in line welding operations. Given weld settings may be repeated indefinitely without change in the number of cycles. As a result, very great uniformity in the welds is obtained, and losses from poor welds are reduced almost to the vanishing point.

2. In the power rectification field ignitrons are available in sizes which permit d-c outputs of 40 to 1000 kilowatts to be obtained in single units depending on the operating voltage. Usual d-c voltage levels are 125, 250, 600, and 900 volts. Such rectifiers are used to provide d-c power for machine shops, elevators, mines, electrolytic reduction plants, arc welding, and similar types of service. Suitable voltage regulating equipment may be provided to give practically constant output voltage from zero to full load. Variable voltage output and control (similar to the Thy-mo-trol) will provide speed control for d-c motors.
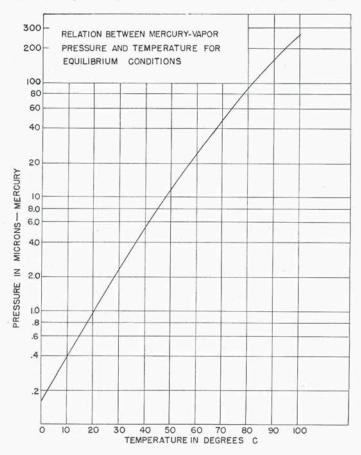
3. The third class of application is high-voltage d-c power transmission, or conversion of power at one frequency to power at another. In such applications the tubes are primarily for power conversion and are grouped to form units of 2000 to 20,000 kilowatt capacity. Higher capacity may, of course, be obtained by additional units. These electronic power converters provide a non-synchronous tie between two power systems and are able to transmit a constant amount of power independent of the usual variations in either the supply or receiving system frequencies and voltages.

PRINCIPLES AND FUNDAMENTALS OF OPERATION

The ignitor is a small rod of highly refractory material about the shape and size of the pointed end of an ordinary lead pencil. This point dips into a mercury pool and by passing a current of 10 to 30 amperes through the ignitor, a cathode spot is established at the junction between the ignitor and mercury pool. The mechanism is one in which the passage of current establishes sufficient voltage gradient at the mercury pool to draw electrons from the pool and start the cathode spot. Ionization from this initial spot spreads throughout the volume of the tube and if the main anode is positive, electrons begin to flow to it. Passage of the electrons in turn ionizes the gas and establishes the conditions for the low arc drop that is characteristic of gas-filled tubes. As the current increases above 20 amperes, the cathode spot divides and sub-divides until a sufficient number of spots exist to supply the anode current. These spots move rapidly and indiscriminately over the surface of the pool, tending in general to occupy a circle of given diameter for a given current, centered around the ignitor. The cathode spots in effect remain anchored around the ignitor, and the usual insulated pools used in the multi-anode tubes to prevent the arc from wandering onto the walls of the tube, are not required. At the end of conduction when the current begins to decrease, the number of spots decrease and finally at zero current die out altogether. Ionization rapidly decays at this point to values which permit

the application of the inverse voltage for which the tubes are designed without the occurrence of arc backs (that is, current conduction in the reverse direction with the anode acting as cathode). Mercury which is evaporated by the action of the cathode spot is condensed on the water-cooled walls of the tube. From this point it rolls back into the mercury pool to maintain the required ignitor im-

mersion. Approximately $\frac{3}{4}$ grams of mercury are evaporated for each 100 ampere-seconds a tube conducts current. The pressure (see Fig. 1) due to this mercury must be controlled and the water cooling serves in this function as well as to remove the arc losses. The arc drop is relatively low, approximately 12 to 18 volts, and the over-all efficiency even at low output voltages is, therefore, very high.

RELATION BETWEEN MERCURY-VAPOR PRESSURE AND TEMPERATURE FOR EQUILIBRIUM CONDITIONS

K-9033553

12-6-44

Fig. 1

DESIGN AND CONSTRUCTION

General Electric ignitrons have a number of design and construction features (see Fig. 19, page 11) which provide reliable operation and long trouble-free service. The tube jackets and water-cooling sections are constructed of stainless steel which minimizes corrosive effects as well as provides a vacuum-tight enclosing envelope. The insulating bushings which separate the anode from the main body of the tube, as well as the ignitor seals and leads, are constructed of fernico and a high-resistance borosilicate glass. Fernico is an iron-nickel-cobalt alloy which was developed in the General Electric Research Laboratories. It has the unique characteristic of having an inflection point in its temperature elongation characteristic at the same

temperature as that of certain hard glasses. The expansion of the fernico and the proper glass match very closely over the entire temperature range encountered in manufacture and use. Such seals are strain-free under usual operating conditions and form one of the strongest glass-to-metal combinations developed. The ignitor is one of the most essential parts in the tube and its manufacture requires very close control to insure uniformity of characteristics and life. Every operation in the manufacture of these ignitors is carefully controlled through inspection and testing. All of the welds in the General Electric ignitrons are made by means of ignitron controlled resistance welding machines. These welds are unusually strong and vacuum tight.

RATINGS

The ratings of ignitron tubes, in common with other electronic tubes, are defined in terms of the maximum instantaneous voltage and current conditions under which the tube may operate. Other factors are the water temperature which controls vapor pressure; and the capacity of the tube to dissipate losses, which is described in terms of the average anode current. One of the larger rectifier ignitrons, the FG-238-B for example, has an average anode current rating of 200 amperes and an arc drop of approximately 17 volts, so that the water cooling is required to dissipate approximately 3.5 kilowatts. The electrodes of ignitron tubes in common with other electronic tubes have much smaller mass than rotating machinery or other heavy electrical apparatus. The time required for welder tubes to reach equilibrium temperature is only a few seconds and is shorter than the time constant of most other electrical apparatus. The limiting factor encountered in this service is the high-current short-time peaks which rapidly increase the vapor pressure to values which may cause loss of control or arc back. The same factors govern rectifier tubes, but since the usual load is of a continuous nature with relatively low ratios between maximum and average currents, the time constant is of the order of minutes. The instantaneous capacity in either case is very high and meets the usual welder requirements, or those of rectifiers to clear fuses or breakers in case of short circuit. Minimum and maximum outlet water temperatures are other ratings. The graph in Fig. 1 shows the relation between mercury-vapor pressure and temperature for equilibrium conditions.

Roughly, mercury-vapor pressure doubles for each 10-degree increase in temperature, so that at higher temperatures the limiting pressures may be approached rapidly. The ignitor will fire even in a pool of frozen mercury. The lower limit is usually dictated by the point of freezing water and by a vapor pressure so low that there are insufficient ions to carry the required current. Arc constriction or starvation under these conditions is very unlikely to occur in the welder tubes which are of relatively open construction. Neither does it occur in the rectifier ignitrons, which are more completely shielded, within the temperature limits given as part of the technical data. In tubes with grids, such as the pentode ignitron, the effect becomes more pronounced and minimum temperatures are correspondingly higher.

Ignitor

The ignitor rating is described in terms of *maximum instantaneous potential and current required for ignition* as well as *maximum allowable forward and inverse voltages.* The ignitor, when not operating and cold, may have a resistance of 20 to 100 ohms. Under operating conditions, this resistance decreases to about 2 to 10 ohms. The ignitor behaves as though it were a constant resistance over any one cycle, but due to wave motion in the mercury pool,

resistance on successive cycles may vary widely. Ignition currents likewise vary widely from cycle to cycle, and normally require much less current than the values stated. Ignitors will not stand reverse current as this may cause a cathode spot on the ignitor itself and the resulting heat and burning tends to destroy the point. Some rectifying device such as a thyratron, or a dry-plate rectifier, must be connected in series with the ignitor.

Welder Ignitrons

The capacity of these tubes is described in terms of *maximum kva demand* for each type, for voltages from 220 to 600 rms and frequencies of 25 to 60 cycles. For higher voltages, tubes of the rectifier type are used and corresponding ratings applied. Each tube has a *maximum average anode current* rating which represents its heat dissipating ability and which may be read on an ordinary d-c ammeter. These two ratings, in conjunction with the supply voltage and the *maximum time of averaging the anode current* completely describe the necessary conditions for welder service. For example, assume a power demand of 500 kva and a supply voltage of 250 volts (rms).

The line current demand is:

$$I_{line} = \frac{500,000}{250} = 2000 \text{ amperes (rms)} \quad (1)$$

$$or = \sqrt{2} \times 2000 = 2800 \text{ amperes (max)} \quad (2)$$

Then, the demand average current per tube over any conducting cycle is:

$$I_{D.avg/tube} = \frac{I_{max}}{\pi} = \frac{2800}{3.14} = 891 \text{ amperes} \quad (3)$$

The demand kva is within the rating of the FG-271 and at this value of kva, the tube has an average anode current rating of 33 amperes, and at 250 volts a maximum time of averaging the anode current of 18 seconds as shown in the Technical Information. The maximum tube capacity, therefore, in ampere-seconds is:

Tube $I_{avg.} \times t_{max.\ avg.} = 33 \times 18 = 594$ ampere-seconds

The length of time the tube can conduct the demand current in any 18-second period must be within the tube ampere-second capacity. The permissible length of conduction, or weld, may, therefore, be represented by t in the expression:

$$I_{Demand\ avg./tube} \times t = 594 \text{ ampere-seconds}$$

$$t_{max} = \frac{594}{891} = .67 \text{ seconds} \quad (4)$$

or since we are usually interested in cycles, the corresponding number for a 60-cycle supply is,

$$n = t \times 60 = 40 \text{ cycles} \quad (4a)$$

A single weld using the 40 cycles is permissible or any number of welds using fewer cycles (2, 3, 4, etc.) may be made providing the total conduction does not exceed the maximum during any 18-second averaging time.

The duty in percent is the ratio of the on to total cycles in the averaging period.

$$\text{Duty} = \frac{\text{No. of conducting cycles}}{\text{No. of cycles in averaging time}} \times 100 \quad (5)$$

which for the above case is:

$$= \frac{n}{t_{\text{max. avg.}} \times 60} \times 100 = \frac{40}{18 \times 60} \times 100 \quad (5a)$$
$$= 3.7\%$$

The *maximum surge current* represents a measure of the circuit stiffness in case of fault conditions. It is the maximum current that the tube may be expected to carry under fault conditions without immediate damage. Repeated operations under such conditions may, of course, shorten the tube life.

Phased-back operation ratings are determined by the conditions at full advance (no phase retard). That is, phase-back operation produces a greater stress on the tubes. Therefore, the permissible current is reduced from full-on in proportion to the angle of retard.

Rectifier Ignitrons

Rectifier ignitron tube ratings also are given in terms of the usual circuit requirements. Most industrial rectifiers have current ratings of 100 per cent continuous, 125 per cent for two hours, and 200 per cent for one minute. The *maximum average anode current* is described in these terms. The *maximum instantaneous current* represents the maximum cycle-by-cycle duty for which the tube is designed to operate. Two levels of inverse voltage are given with different current ratings corresponding to output voltages of 300 and 600 volts d-c. The *surge current* represents the maximum forward current which the tube should carry under fault conditions. Its duration should not exceed the time given. These last two factors define the transformer and supply system impedance and the minimum operating speed of the circuit breakers. The value of the surge current is such that rectifiers having overall regulation of 6 to 7 per cent can be obtained with practicable designs of transformers. Higher regulation tends to reduce the duty on the tube by reducing the possible short-circuit current. In terms of d-c output, the current is simply the average current per tube times the number of tubes employed, provided the tubes are used in the usual circuits and that the peak anode current is not exceeded.

CLASSES OF TUBES

There are three classes of ignitron tubes especially designed for each type of service:

1. Welder Ignitrons

These tubes are of relatively open construction with little shielding and are designed specifically to carry the high currents encountered in resistance welding. They also may be used as rectifiers in certain welding equipment where the output voltage is usually less than 150 volts d-c. These tubes have the lowest arc drop voltage of any of the ignitrons.
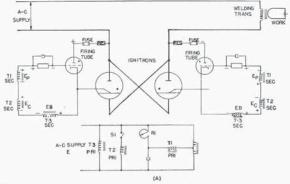
2. Rectifier Ignitrons

These tubes are more highly shielded to withstand the voltage and current conditions encountered each cycle during the commutation period at the end of conduction. The arc drop is approximately 2 volts higher than that of corresponding sizes of welder ignitrons. While used primarily for rectifier service, they are also applied in 2400-volt welding control applications where the higher voltage requires a more shielded tube.

3. Grid-Pool Tubes

This type of tube, such as the pentode ignitron, is primarily for high-voltage rectification or inversion in power or frequency-conversion work. Grids are added to the usual ignitron structure to provide additional control and deionization when the tube is used in inverter service. Its application requires considerable detailed coordination between the circuit and tubes, and it is recommended that applications for this type of tube be referred to the Electronics Department, Tube Division, Schenectady 5, N. Y.

APPLICATION CIRCUITS#

Ignitrons for resistance welding control are used in spot, pulsation, seam, and flash welding machines. Fig. 2 shows a typical circuit with two tubes in a back-to-back connection.

Fig. 2—Power Circuit for Synchronous Control of Welding Currents

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APPLICATION CIRCUITS (CONT'D)#

One older method (for illustration) of controlling the number of on and off cycles in line welding consisted of a moving tape or chain with insulated sections which supplied off-on bias to the grids of the thyratrons. The length of the conducting sections was such that at synchronous speed, the on-time corresponded to the number of cycles desired; say, 3, 5, etc. The non-conducting sections were of length to give off periods of say 4, 6, etc. It is present practice to use electronic control with thyratron tubes and capcitor-resistance combinations to give the proper time constant for controlling the on-off period. These electronic controls are comparatively complex and requests should be sent to the General Electric Company for a detailed description. Speed of control, cycle-by-cycle response, small space requirements, lack of noise, and flexibility of application all contribute to the success of welding ignitron control.

Ignitron contactors which operate in the same manner but which do not have the precise control of the number of cycles are also in wide use. In effect, the ignitron units simply replace ordinary contactors with the advantage of noise reduction and decreased maintenance. Fig. 3 shows the typical connections for this type of service.
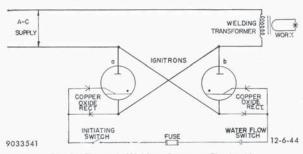

Fig. 3—Electronic Welding Contactor Circuit with
Manual Non-Synchronous Control

Such contactors are found in welding service where precise control is not required, and in applications where frequent opening and closing of the circuit is required such as in temperature-regulated furnaces. Phase control which permits a gradual change of the output voltage may be obtained by a modification of the control circuit and the addition of phase shifting networks and thyratrons. Another application for this type of equipment is the interruption of the power supply for radio transmitters. In case of arc over in the transmission line or coils, or flashing in the vacuum tubes, it is desirable to remove the plate power supply as rapidly as possible to prevent possible gassing or burning of the transmitting tube. These contactors, when placed in each line of the primary of the rectifier, may be controlled completely to interrupt the flow of power in one to two cycles, in case of a fault.

This compares with 6 to 8 cycles for most mechanical breakers. Regular circuit breakers are still required for overall fault protection.

Typical rectifier applications include the d-c supply for lighting and power loads in buildings, elevators, d-c motor supply in machine shops, printing presses, power for the electrolytic separation of hydrogen, oxygen, chlorates, aluminum and magnesium, plating and mining. Mining rectifiers, may be designed with very low head room (42 inches) so that the unit may be placed in the actual mine itself near the working source. As the mine is worked, the ignitron rectifier may be conveniently moved to provide full voltage at the location where the mining is centered. One particular advantage of rectifier equipment in mine service is that the rectifier does not have the problem of pull-out torque encountered in synchronous machines. Most mine
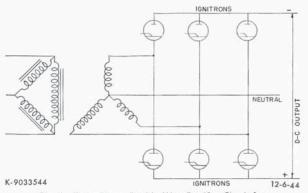

Fig. 4—Three-Phase, Double-Way Rectifier Circuit for
Three-Wire Service

load stations are at a considerable distance from the power source and as a result, reactance in the supply lines is usually high. This decreases the overload that can be carried without exceeding the torque limit. Three-wire rectifiers are possible (see Fig. 4) where 125/250 volt supplies are needed. Such units have also been used for d-c arc welding power supplies.
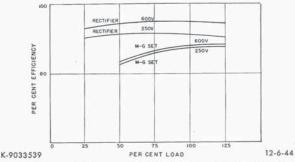

Fig. 5—Overall Efficiency of 300KW, 250-and 600-Volt Ignitron
Rectifier in Comparison with Motor-Generator Sets of Same Ratings

Circuits shown in ETT-108 are examples of possible tube applications and the description and illustration of them does not convey to
the purchaser of tubes any license under patent rights of General Electric Company.

Ignitron rectifiers have all the advantages of quiet operation, small space requirements, no special foundation requirements, ease of control, and low maintenance that are common to electronic tubes. The principal advantage from the user standpoint, however, is efficiency. Fig. 5 (see bottom of page 6) shows efficiency of the 300 kilowatt, 250 volt ignitron rectifier in comparison with other forms of conversion equipment.

In terms of losses for this size rectifier, there is a constant kilowatt difference of approximately 10 kilowatts in favor of the ignitron rectifier over the usual load range. Therefore, if the rectifier is operated continuously during the year, there is a net power saving of approximately 10 kw $\times$ 8760 hours $\times$ .01 = $876 at a power rate of one cent per kilowatt hour. Such savings are more than adequate to pay for the probable tube replacement cost.

SELECTION OF TUBES

Selection of ignitron tubes for welder service depends primarily on the kilovolt-ampere demand and the duty. The maximum kilovolt-ampere demand in terms of volts and amperes in the welding transformer primary can be obtained from the manufacturer. Where such data are not available, a clamp-on ammeter with a pointer stop or maximum swing indicator may be placed around one of the primary leads and the secondary of the welder shorted through well clamped copper bars or strips. The welder is then energized for periods long enough to allow equilibrium readings to be obtained on the meter. With synchronous ignitron control, 3 or more cycles will give accurate readings. With non-synchronous control, longer periods may be necessary to eliminate the probable starting transient. This constitutes the maximum current demand pro-

viding the maximum tap settings have been used. The tube selected should have sufficient capacity to conduct the maximum current demand within the tube rating. The permissible duty is then determined by the average current capacity of the tube and if this capacity is below that required, a larger size of tube must be selected. For example, suppose that a welder having a 1000-ampere rms current demand and a 20 per cent duty is required, and that the supply voltage is 500. Demand rms current for this voltage in terms of percentage duty has been plotted for convenience on curves included with the Technical Information. Reference will show that the FG-235-A tube has sufficient capacity and is the tube required. If the duty were less than 7 per cent two FG-271 tubes could be used.

Selection of the size and number of tubes for

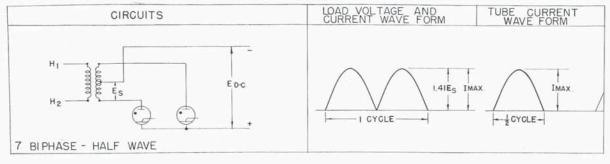| KILOWATT RATINGS AT				IGNITRONS		TRANSFORMER SECTION CONNECTIONS	PHASE OPERATION		PRINCIPLE RIPPLE COMPONENT IN OUTPUT VOLTAGE	
125V D-C	300V D-C	600V D-C	900V D-C	NO.	TYPE		INPUT	OUTPUT	FREQUENCY	MAGNITUDE
40	75	100	100	3	FG-259-B	Y, ZIG-ZAG	3	3	3X INPUT	0.25E D-C
50	100	150	150	6	FG-259-B	DOUBLE Y	3	6	6X INPUT	0.057E D-C
75	150	200	200	6	FG-259-B	DOUBLE Y	3	6	6X INPUT	0.057E D-C
100	200	300	300	6	FG-238-B	DOUBLE Y	3	6	6X INPUT	0.057E D-C
150	300	400	400	6	FG-233-B	DOUBLE Y	3	6	6X INPUT	0.057E D-C
—	—	500	500	6	FG-233-B	DOUBLE Y	3	6	6X INPUT	0.057E D-C
200	400	750	750	12	FG-238-B	QUADRUPLE Y	3	6 or 12	6 or 12X INPUT	0.057E D-C or 0.014E D-C
300	500	1000	1000	12	FG-238-B	QUADRUPLE Y	3	6 or 12	6 or 12X INPUT	0.057E D-C or 0.014E D-C

Fig. 6—Ratings of Standard Sizes of General Electric Sealed Ignitron Rectifiers for Industrial Service

rectifier service to supply a given d-c output is relatively simple. Assuming that the usual overload ratings apply, the average current per tube is the d-c load current divided by the number of phases

(see Useful Factors pages 9 and 10). Fig. 6 shows combinations for rectifiers of 40 to 1000 kilowatts at d-c outputs of 125 to 900 volts.
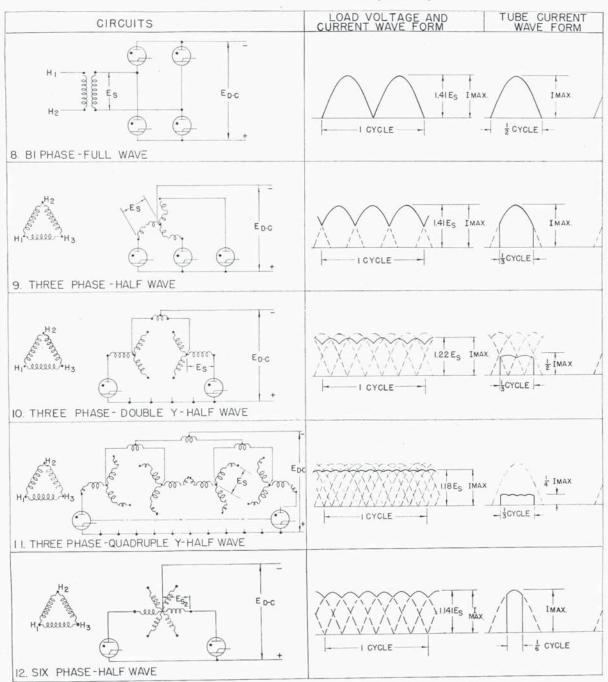
These values correspond to standard units which

CIRCUITS FOR RECTIFIER TUBES (Figs. 7 through 16)

CIRCUITS	LOAD VOLTAGE AND CURRENT WAVE FORM	TUBE CURRENT WAVE FORM

7 BIPHASE - HALF WAVE

the General Electric Company supplies as unit sub-stations. They require only electrical and water connections to function as a direct-current power substation. Various combinations of tubes may be us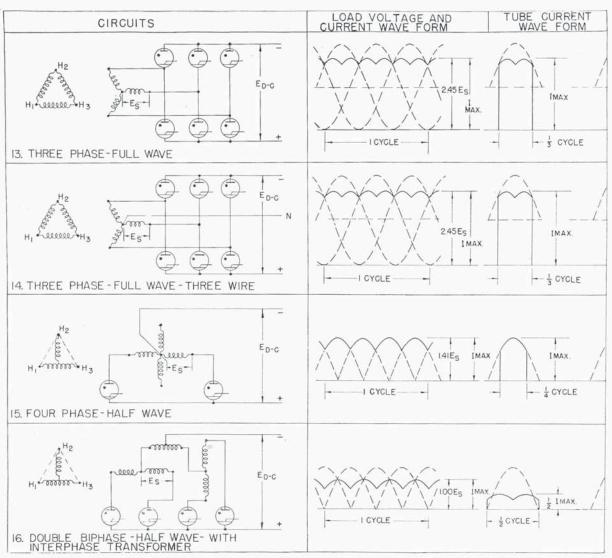ed such as shown in Figs. 7 through 16, but in general the 3-phase double-Y half-wave, and the 3 phase, half-wave circuits are widely used. These circuits give a 6-phase and 3-phase output ripple which is so low that it causes little effect on units using direct-current power.

CIRCUITS FOR RECTIFIER TUBES (CONT'D)

CIRCUITS	LOAD VOLTAGE AND CURRENT WAVE FORM	TUBE CURRENT WAVE FORM
8. BI PHASE - FULL WAVE	1.41 E_S I MAX. — I CYCLE	I MAX. — ½ CYCLE
9. THREE PHASE - HALF WAVE	1.41 E_S I MAX. — I CYCLE	I MAX. — ⅓ CYCLE
10. THREE PHASE - DOUBLE Y - HALF WAVE	1.22 E_S I MAX. — I CYCLE	½ I MAX. — ⅓ CYCLE
11. THREE PHASE - QUADRUPLE Y - HALF WAVE	1.18 E_S I MAX. — I CYCLE	¼ I MAX. — ⅓ CYCLE
12. SIX PHASE - HALF WAVE	1.141 E_S I MAX. — I CYCLE	I MAX. — ⅙ CYCLE

Notes for Figs. 7 through 16:

The theoretical wave forms are for a resistance load neglecting voltage reduction due to tube arc drop and current overlap at commutation.
E_s = Secondary voltage, RMS value.

CIRCUITS	LOAD VOLTAGE AND CURRENT WAVE FORM	TUBE CURRENT WAVE FORM
13. THREE PHASE-FULL WAVE	$2.45 E_S$ I MAX. — 1 CYCLE	I MAX. — $\frac{1}{3}$ CYCLE
14. THREE PHASE - FULL WAVE - THREE WIRE	$2.45 E_S$ I MAX. — 1 CYCLE	I MAX. — $\frac{1}{3}$ CYCLE
15. FOUR PHASE-HALF WAVE	$1.41 E_S$ I MAX. — 1 CYCLE	I MAX. — $\frac{1}{4}$ CYCLE
16. DOUBLE BIPHASE -HALF WAVE- WITH INTERPHASE TRANSFORMER	$1.00 E_S$ I MAX. — 1 CYCLE	$\frac{1}{2}$ I MAX. — $\frac{1}{2}$ CYCLE

USEFUL FACTORS

FIG. NO.	$\dfrac{\text{AVERAGE TUBE CURRENT}}{\text{LOAD CURRENT}}$	$E_{D\text{-}C}$ (AVERAGE OUTPUT VOLTAGE)	PEAK INVERSE VOLTAGE
7	.500	0.900 E_S 0.636 $E_{M\,D\text{-}C}$	2.282 E_S 3.141 $E_{D\text{-}C}$
8	.500	0.900 E_S 0.636 $E_{M\,D\text{-}C}$	1.414 E_S 1.570 $E_{D\text{-}C}$
9	.333	1.170 E_S 0.827 $E_{M\,D\text{-}C}$	2.450 E_S 2.090 $E_{D\text{-}C}$
10	.167	1.170 E_S 0.955 $E_{M\,D\text{-}C}$	2.450 E_S 2.090 $E_{D\text{-}C}$
11	.0833	1.170 E_S 0.955 $E_{M\,D\text{-}C}$	2.450 E_S 2.090 $E_{D\text{-}C}$
12	.167	1.350 E_S 0.955 $E_{M\,D\text{-}C}$	2.280 E_S 1.690 $E_{D\text{-}C}$

Note: $E_{M\,D\text{-}C} = $ Maximum of D-C voltage.

USEFUL FACTORS (CONT'D)

FIG. NO.	AVERAGE TUBE CURRENT / LOAD CURRENT	E D-C (AVERAGE OUTPUT VOLTAGE)	PEAK INVERSE VOLTAGE
13	.333	2.340 Es 0.955 E M D-C	2.450 Es 1.045 E D-C
14	.333	2.340 Es 0.955 E M D-C	2.450 Es 1.045 E D-C
15	.250	1.273 Es 0.900 E M D-C	2.280 Es 1.790 E D-C
16	.250	0.900 Es 0.900 E M D-C	2.280 Es 2.530 E D-C

DESIGN OF CIRCUITS

Mechanical

Tube supports should be of sufficient size to carry the tube weight and should be designed to provide sufficient electrical contact. Ignitrons are mechanically very strong and will withstand moderate shock. In general, however, excess vibration should be avoided. An adequate water supply of reasonably clean water should be available. Waters that are suitable for drinking are in general suitable for cooling tubes. In fact, such water is not contaminated in the passage through the ignitron water jacket and may be used for plant purposes. Water containing considerable acid or foreign matter which might clog the water jackets should be avoided. Stainless steel is immune to the effects of most corrosive waters, but is subject to attack by waters containing chlorides. If the chloride ion concentration exceeds 20 parts per million the water should be considered as suspicious and an analysis made to determine its corrosiveness. An excellent reference on the subject of water supplies is the United States Department of Interior, Geological Water Supply Paper 658. In general, local experience is one of the best guides as to the corrosiveness of water. Where highly corrosive waters are encountered, such as in mines, a heat exchanger may be employed of either the water-to-water or the water-to-air type. In such installations, corrosion may be minimized by the addition of 0.1 to 0.2 per cent by weight of sodium or potassium dichromate to the circulating water-cooling system. In general, tubes are connected in series when connected directly to water supplies, and in parallel when connected to heat exchanger units. The minimum water supply temperature must be such that the outlet temperature of the hottest rectifier does not exceed the values given under Technical Information for the voltage at which the unit is operated. The relation between water flow, temperature rise, and watts dissipated is as follows:

$$\text{Kilowatts} = 263.5 \times \text{gpm} \times \triangle\text{C}$$

Electrical

Electronic tubes of the ignitron type are power devices in exactly the same sense that transformers and rotating equipment are power devices and as a result adequate circuit breaker protection must be provided. In the case of the welder, the welding transformer acts in effect as a current limiting inductance. However, back-up or line protection in the form of fuses, contactors or breakers should be provided to remove the unit from the line in case there is a fault in the primary of the transformer.

In the case of rectifiers, similar switch gear must be provided for the primary and, in addition d-c breakers are usually required in the output. The d-c breaker is required when several units are connected in parallel to form a common bus bar. In this case, arc back in one tube will permit direct current to be fed through the tube and transformer from the remaining units. These breakers may also be adjusted to limit the permissible overloads as is the case with any conversion apparatus. The primary breaker must be capable of interrupting the maximum kilovolt-ampere of the supply system in case there is a short circuit directly across the primary terminals of the power transformer. Fig. 17 shows the schematic layout of a unit substation including circuit breaker equipment.

Special switch gear for these requirements have been developed by the General Electric Company and reference should be made through the nearest General Electric office or the General Electric Company, Schenectady, New York.
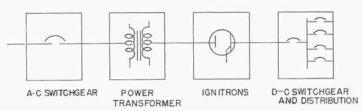

A-C SWITCHGEAR   POWER TRANSFORMER   IGNITRONS   D-C SWITCHGEAR AND DISTRIBUTION

Fig. 17—Line Diagram Showing Component Parts of Ignitron Rectifiers

FERNICO METAL ALLOY
AND PYREX TYPE
GLASS SEAL

WATER
CONNECTION

FLOW-DIRECTING
VANES

STAINLESS-STEEL
WATER JACKET

MAIN GRAPHITE ANODE

DEIONIZATION BAFFLE

SPLASH-HOOD BAFFLE

STARTING IGNITORS

AUXILIARY ANODE

WATER
CONNECTION

MERCURY POOL
CATHODE
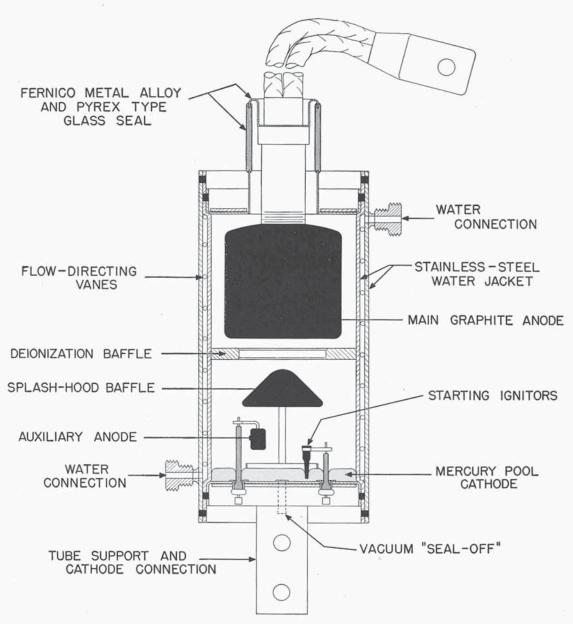
VACUUM "SEAL-OFF"

TUBE SUPPORT AND
CATHODE CONNECTION

Fig. 19—Cross-Sectional View of the Sealed Ignitron for Power-Rectifier Service

IGNITOR EXCITATION CIRCUITS

Ignition power is usually provided by (1) diverting a part of the load current through the ignitor or (2) by a separate-excitation system which is independent of load current.

The self or anode firing system (see Fig. 18) uses a thyratron to determine the instant of firing and to prevent reverse current from flowing through the ignitor.
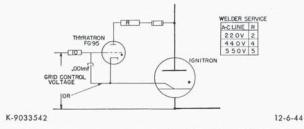

Fig. 18—Self or Anode Excitation in which a Part of the Load Current is Diverted through the Ignitor

A series resistor is used to reduce the duty on the thyratron by limiting the current which passes through the thyratron during the time between ignition and pickup of the main anode, or when misfiring occurs. The recommended value of this resistance depends upon the anode volage for which the set is designed to operate. It is usually 4 ohms for 600 volts and less, and approximately 50 ohms for 2300 volts. It is the simpler and more direct system and is used in the majority of welder applications. In rectifier work the loads, even on large capacity sets, frequently reach such low values that the available current is below the required ignition current. As a result, there tends to be some flickering of the output voltage which may be objectionable if lamps are a part of the connected load. Consequently, most rectifiers are equipped with a separate excitation system which fires the ignitor each cycle and is independent of the load. There is a small auxiliary anode near the cathode pool of each rectifier ignitron (see the cross sectional view, Fig. 19, page 11) which provides for cathode spot excitation current in case the main anode current falls below the stable value which is about 3 amperes.

Fig. 20A shows one form of separate-excitation system in which a capacitor is discharged through a phanotron during one part of the cycle and discharged through a thyratron into the ignitor at the instant it is desired to carry current. The ci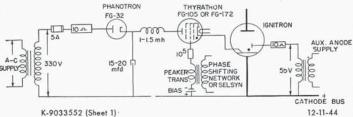rcuit is relatively simple and direct. Complete details showing the charging period, ignitor current wave shape, and output characteristics are shown in Fig. 20B.
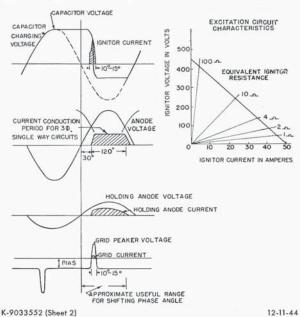

Fig. 20B—Voltage, Current and Phase Relationships for Three-Phase Single Rectifier Circuit

In another form of separate-excitation equipment magnetic circuits in conjunction with saturating reactors have been arranged to produce the required ignitor peak current. Fig. 21 shows the connections in this system. Special reactors are required both for the saturating reactor which determines the wave shape and for the saturable reactor which determines the phase position.
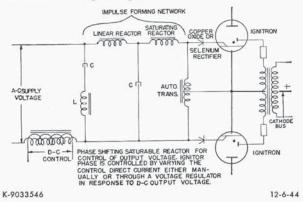

Fig. 21—Magnetic Separate Excitation Circuit for Firing Diametrically Opposite Tubes

Circuit constants for welder applications have been described previously and are essential to the ignitron tube in so far as the demands do not exceed the tube ratings. The ignitrons in the back-to-back connection operate simply as a switch.

Fig. 20A—Capacitor-Inductance Separate Excitation Circuit

RECTIFIER CONSIDERATIONS

In the case of the rectifier, various circuit relations in terms of d-c output, voltage and current wave shapes are given in Figs. 7 through 16. The constants give the theoretical output voltage at no-load conditions. Actually all rectifiers have a certain amount of regulation usually of the order of 6 to 7 per cent depending on the reactance in the power transformer and a-c supply system. Voltage regulation in the rectifier is due to the increase in tube drop with increasing current, the IR drop in the transformer and the voltage loss due to commutation. During the commutation period, current is transferred from one winding to another and for a short time both windings conduct giving an output voltage which is the average of the two phase voltages rather than the higher. This effect is shown in Fig. 22.
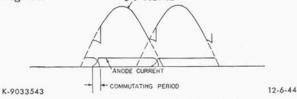

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Fig. 22—Wave Diagram Showing Voltage Loss Due to Commutation

The average voltage loss due to commutation is:

$$E_x = pfLI \text{ volts (d-c)} \quad (1)$$

where
p — Number of phases in each simple rectifier. Circuits shown in Figs. 7, 8, 9, 14 and 16 are simple single-way (current conducted in only one direction in transformer winding connected to tube) rectifiers having 2, 2, 3, 4, and 6 phases respectively.

Rectifiers formed of simple units such as Figs. 10 and 15 have "p" factors corresponding to the simple rectifier, i.e. p = 3 and p = 2.

f = Frequency in cycles per second.

L = Commutating inductance in henrys. It is determined from the transformer secondary reactance ($X_L = 2\pi fL$) of any two successively conducting phases in a simple rectifier, and is most easily determined by short circuiting the primary and determining the voltage to force rated secondary current through any two successively conducting phases. Then, the impedance,

$$Z = \frac{E}{I} \text{ ohms}$$

and if the resistance is known, X_L may be determined from

$$Z = \sqrt{R^2 + X_L^2}$$

I = Current at the start of commutation. This is equal (essentially) to the direct current in the case of simple rectifiers, or to the proportion carried if there are several simple rectifiers in the unit.

The theoretical average or d-c output voltage of a rectifier is:

$$E_{do} = P/\pi\sqrt{2} \ E_s \ (\sin \pi/P)$$

where
E_s = the rms value of the transformer secondary line to neutral voltage

For the normal delta double — Y circuit where P = 3;

$$E_{do} = 3/\pi\sqrt{2} \ E_s \ (\sin \pi/3)$$

$$= \frac{3\sqrt{3}}{\sqrt{2}\pi} E_s = 1.17E_s$$

If it is desired to find the secondary voltage required to supply a given output, the theoretical d-c voltage is first determined by adding the resistance, commutation and tube losses to the full load output voltage.

For example, assume a 300-kilowatt, 3-phase double-Y, 275-volt rectifier. Then,

D-c voltage at full load =	275 v
IR voltage loss in transformer Y at 545Amp =	4.5 v
Commutation voltage loss at 545Amp =	10.5 v
Tube arc drop =	15.8 v
Summation: E_{do} =	305.8 v

and   305.8 = 1.17 E
or E_s $= \dfrac{305.8}{1.17} = 261$ v (rms)

The regulation is due to the

IR loss in transformer =	4.5 v
Commutation loss =	10.5 v
Change in tube drop (0 to 545Amp) =	2.4 v
Total loss in voltage =	17.4 v

and the percentage regulation:

$$\text{Reg} = \frac{(\text{no load voltage} - \text{full load voltage})}{\text{full load voltage}} \times 100$$

$$= \frac{\text{loss in voltage}}{\text{full load voltage}} \times 100 = \frac{17.4}{275} = 6.25\%$$

Circuits other than those shown for rectifier or welder service may be desirable for a particular use. In general, the tube requirements for such circuits and service may be determined by writing to the Electronics Department, Tube Division, Schenectady 5, New York.

MAINTENANCE AND OPERATION

There is very little maintenance in the usual sense of the word that is required for ignitron tubes. The tube should be clean and accumulations of waste should not be allowed to collect around the anode insulation bushing. (Caution: All power should, of course, be removed prior to any cleaning operation.) In case water jackets become clogged with silt, they can, of course, be cleaned out with the usual cleaning solutions. Operational failures of ignitron tubes which are due to the tubes themselves are usually the result of air leakage, gas, or ignitor failure. Gas and air leakage most frequently result in arc back and thus is usually accompanied by severe flashing or showers of red-hot sparks in the anode seal. Such failures can be indicated in general from a visual inspection of the equipment while it is operating. Spare tubes may be checked for vacuum by means of a spark coil of the make and break type. Ignitor failure where the tip has been burned off results in misfire. This fault can be detected by connecting an ohmmeter between the ignitor lead and cathode terminal and slightly tipping the tube to lower the mercury level on the ignitor. The normal tube may be tipped approximately 20 degrees from vertical before the ignitor-mercury contact breaks. Ignitor wetting sometimes occurs in tubes which have carried excessive current. In this case, the cathode spots form on the side walls of the tube and vaporize metal into the mercury pool to cause wetting. This metal in turn is re-evaporated by the arc around the ignitor and since the arc starts each cycle at the ignitor, it tends to become coated with a layer of vaporized metal. This in turn is usually without an oxide for protection, and amalgamation with the mercury takes place. A simple check for this type of failure is again to connect the ignitor and cathode terminals to a resistance analyzer. As the tube is tipped slightly to withdraw the ignitor from the mercury, there should be a gradual increase in the ignitor resistance. If the ignitor is wet, the resistance will remain constant and then suddenly jump to a new and higher value. Operation at too-high water temperatures usually results in arc back in the case of the rectifier tubes, and extra conduction cycles in the case of the welder tube.

Ignitron tubes, in common with most other electronic devices, operate under the instantaneous conditions which occur cycle by cycle. In general, the ignitron tube forms the closing switch in the circuit whether it is a welder or rectifier. Most faults, therefore, appear when this switch is closed, and trouble in other parts of the equipment may frequently be considered as tube trouble. The simplest initial check is to replace the tube which seems in trouble with a spare tube. If additional work is required, a cathode-ray oscilloscope will be found almost invaluable. These units permit a visual observation of the voltage wave shapes across the tube and across component parts of the circuit. A knowledge of these wave shapes under normal conditions and a comparison under fault conditions usually gives a direct solution to the trouble. The General Electric Company is preparing a cathode-ray oscilloscope particularly suited for industrial electronic use. Information on this may be obtained by writing to the Electronics Department, Specialty Division, Syracuse, New York. In addition to a cathode-ray oscilloscope one of the small volt-ohm analyzers is useful in checking circuit constants.