REGULATED TUBE RECTIFIERS

1. GENERAL

1.01 This section describes J86207 rectifiers which are of the regulated tube type.

1.02 This section is reissued to add the booster type of control and to discuss the magnitude type of control when it is arranged for inverter operation. Minor changes have been made. Information on minimum operating temperatures and on reforming of condenser films has been revised.

1.03 These rectifiers are designed to convert commercial a-c power into regulated d-c power. In one case, the rectifier also operates as an inverter to convert d-c power to a-c during a power failure. The majority of rectifiers are designed for continuous floating of storage batteries and cannot be used with resistance loads.

1.04 Various regulating arrangements, as described below, are employed but all take advantage of the change in tube output or resistance caused by changes in the voltage applied to the grid of a tube. A, D, E, G, H, J, K, L, M, and N rectifiers have magnitude control and the N rectifier is also arranged for inverter operation. B and R rectifiers have series tube control. C and F rectifiers have phase shift control. P and S rectifiers have booster control.

1.05 The rectifier tubes are usually of the larger vapor-filled type while the control tubes are usually of the smaller radio type vacuum tubes.

2. OPERATION OF TUBES

2.01 The elements of 2 element tubes are known as anodes or plates and cathodes, sometimes called filaments. A cathode is a filament, however, only when it is self-heating and requires no separate heater. Besides the anode and cathode, a 3 element tube has a control element known as a grid. A screen grid element is sometimes added to increase the amplification of the tube.

2.02 With vacuum tubes, space current tends to flow between the anode and the cathode during the time the anode (due to the voltage impressed on the tube) is positive with respect to the cathode. In the 3 element tube, the magnitude of this current is controlled by a negative voltage, commonly known as the grid bias, applied to the grid. The grid has continuous control from zero grid voltage where the anode current is maximum to some negative value which causes the anode current to be reduced to zero. A grid battery, sometimes known as a "C" battery, combined with the voltage drop across a resistance is the usual supply for the negative grid voltage.

2.03 The vapor-filled Thyratron tubes used as the rectifying tubes in phase shift and

Fig. 1 - Output of Thyratron Tubes at Different Firing Points

magnitude control rectifiers are similar in construction to the 3 element radio type vacuum tubes but differ in the method of operation. Space current does not flow until the anode voltage reaches a certain critical positive value with respect to the cathode. The point at which space current starts to flow is known as the "firing point" and for mercury vapor tubes it is about 15 volts when the grid voltage is zero. The firing point changes with different grid voltages but the grid has no control from the firing point to the end of the cycle and the resistance of the tube is practically constant after the firing point. Control of the output of these tubes is obtained by changing the negative grid bias so that the firing point will occur at the desired place in the cycle. In other words, the length rather than the magnitude of each pulsation is controlled. The shaded portions on Fig. 1 show the active output time for a tube at different firing points. In practice, the control does not have to shift over the entire 180 degrees to give full control because of the effect of the counter emf of the battery and the reactance of the retardation coil shown as (L) on the schematics.

2.04 The rectifier tube of the 30 ampere, booster control rectifier is vapor filled, has a screw base and resembles a Tungar bulb. It is a 2 element tube and the output depends on the impressed a-c voltage which may be boosted above the line value and to a lesser extent on the voltage of the battery to which the rectifier is connected. The rectifier tube of the series tube control rectifier is a vacuum tube with a filament and two plates to make it full wave. The output is controlled by changing the resistance in the output lead.

3. OPERATION OF PHASE SHIFT CONTROL

3.01 With phase shift control, a-c voltage is supplied to the anode of a 3 element mercury vapor rectifier tube and a separate a-c voltage of the same frequency is supplied to the grid. The grid voltage, however, is out of phase with the anode voltage. This condition is shown on Fig. 2 which omits the negative loops of the anode voltage because in a rectifier tube no current flows when the anode is negative. For full wave rectification two rectifier tubes (V1 and V2) are required as shown on Fig. 4.

3.02 For any point in the positive loop of the anode voltage there is a critical grid bias voltage and whenever the grid voltage curve crosses the critical grid bias curve (shown

OPERATION OF PHASE SHIFT CONTROL (Continued)

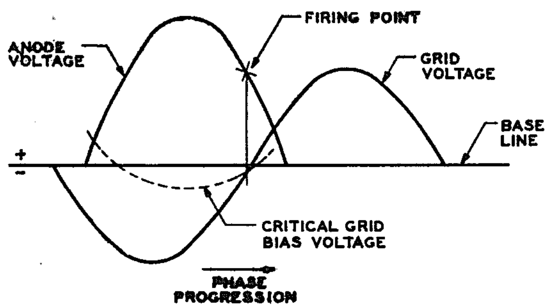

Fig. 2 - Voltage Relations - Phase Shift Control of Firing Point

dotted on Fig. 2) the tube will fire. Moving the grid voltage curve to the right gives a later firing point and a reduced output. Moving the grid voltage curve to the left gives an earlier firing point and an increased output. As shown on Fig. 2, the critical grid bias voltage curve extends above the base line to positive values but under normal conditions the grid voltage curve crosses the critical grid bias voltage curve below the base line while the grid bias is negative. Phase shift control is the control of the relative locations of the anode and grid voltage curves.

3.03 Fig. 3 shows a simple half wave rectifier where the phase relation of the anode and grid voltages is controlled manually by a rheostat in one leg of a phase shift bridge. The same a-c voltage is impressed on the primaries of the transformers (T1) and (T2) so that the voltage from (A) to (B) on the bridge and the anode voltage are in phase or nearly so. The grid voltage taken through transformer (T3) from the (C) and (D) corners of the bridge is out of phase by an amount depending largely on the relationship of the impedances in the four legs of the bridge. The amount of phase displacement is adjustable by changing the resistance of the (R) rheostat in the (B) to (D) leg of the bridge. If rheostat (R) were set for zero resistance, transformer (T3) would be directly across the (CB) winding of transformer (T2) and the grid and anode voltages would be practically in phase. Firing would occur near the start of the anode positive cycle and the output would be maximum. If rheostat (R) were of infinite resistance it could be considered as an open circuit and transformer (T3) would be across the (CA) winding in series with the (C1) condenser which would shift the grid voltage curve of Fig. 2 to the right until it was almost completely out of phase with the anode voltage. Firing would now occur, if at all, near the end of the anode positive cycle and the output would be minimum. Intermediate settings of the (R) rheostat result in intermediate shifts of the grid voltage curve. In general, increasing the resistance shifts the grid voltage curve to the right, gives a later firing point and decreases the output. Decreasing the resistance has the opposite effect.

3.04 Fig. 4 shows a full wave, phase shift control rectifier arranged for automatic regulation. The manual rheostat (R) of Fig. 3 is replaced by a vacuum tube (V3) whose resistance is raised and lowered by supplementary control equipment.

3.05 With automatic regulation the secondary winding of the transformer (T1) applies a-c current from the power source to the anode circuits of the rectifier tubes (V1) and (V2). The d-c output of these tubes is connected to the charging circuit for the battery being charged. The automatic control circuit is connected across the output of the rectifier by means of a potentiometer (R1). The voltage drop of the potentiometer is connected to the grid of tube (V4) through the slightly higher opposing voltage of the grid battery so that a small negative voltage bias (in the order -1 to -2 volts is applied to the grid.

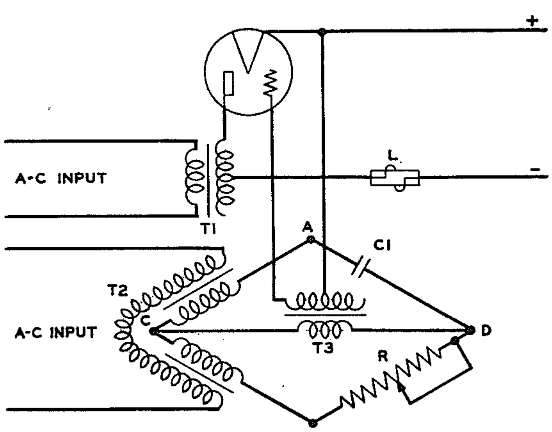

Fig. 3 - Phase Shift Control - Half Wave - Manual

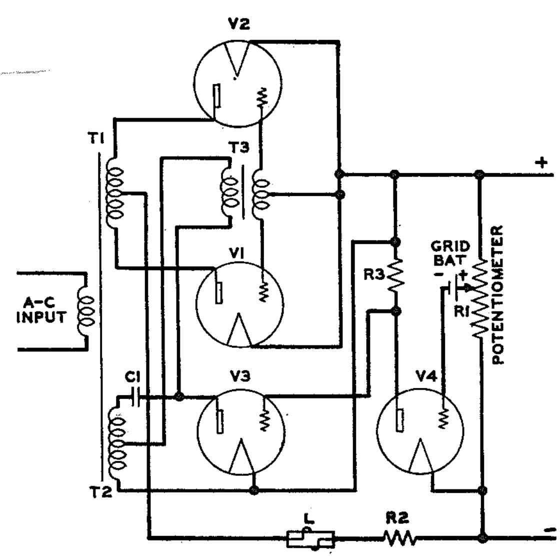

Fig. 4 - Phase Shift Control Full Wave - Automatic

3.06 When a load is applied to the battery being charged by the rectifier the voltage decreases slightly which in turn decreases the voltage drop across the potentiometer. This results in an increase in the negative bias applied to tube (V4) which decreases the anode current in this tube and the voltage drop over resistance (R3). This voltage drop provides the negative bias for tube (V3) and when this bias decreases it permits a greater current to flow in the plate circuit of (V3). This has the same effect as decreasing the anode to cathode resistance of tube (V3) which is the variable leg of the phase shifting bridge. This gives an earlier firing point and increased output. As the battery voltage varies with load changes the control tube (V4) amplifies the change and varies the bias on tube (V3) to change its anode to cathode resistance. This shifts the phase relation of the grid voltage applied to the rectifier tubes (V1) and (V2) with respect to the a-c voltage applied to the anode circuits of these tubes and thereby changes the firing points of these tubes. The above operation of the control circuit varies the output current from the rectifier in unison with load changes and causes the battery voltage to remain within the required limits.

3.07 Rectifiers may be arranged to transfer to regulated current when their capacity at regulated voltage is exceeded. This is usually accomplished automatically by a transfer relay, operated by a current relay in series with the output of the rectifier, which transfers the grid of the regulator tube (V4), see Fig. 4, from resistor (R1) to a series resistor (R2) in the negative output lead. The regulator tends to maintain a constant voltage drop over (R2) and thus a nearly constant current output. When the load decreases enough so that the regulated current raises the battery voltage somewhat above float value, a high voltage alarm relay releases the transfer relay and returns the circuit to regulated voltage operation. This arrangement (not shown in the sketch) provides for Equalizing and Boost charge voltages and permits the rectifier to be used in unattended offices as it can start automatically after a power failure. Where arrangements for transfer from regulated voltage to regulated current are not justified a ballast lamp is used in the output circuit to limit output currents.

4. OPERATION OF MAGNITUDE CONTROL

4.01 With magnitude control, see Fig. 5, the position of the firing point in the anode positive half cycle is controlled by changes in the grid bias voltage. Theoretically, the earliest firing point and maximum output would occur with a plus grid bias (note shape of critical grid bias curve) but under normal conditions the earliest firing point is at (A) which corresponds to zero grid bias. Latest firing point and minimum output that can be taken from the rectifier occur at (C) which is midpoint in the anode positive half cycle. Negative grid bias values greater (more negative) than (C) will not cut the critical grid bias curve and will not cause the tube to fire. By supplying the proper grid bias value between (A) and (C) any desired firing point between (A) and (C) can be selected. It is to be noted that the firing point if any always falls in the first half of the anode positive half cycle but this does not mean that the output is always between half and full output. The action of associated filter and control equipment makes any desired output from nearly zero to full rated output available.

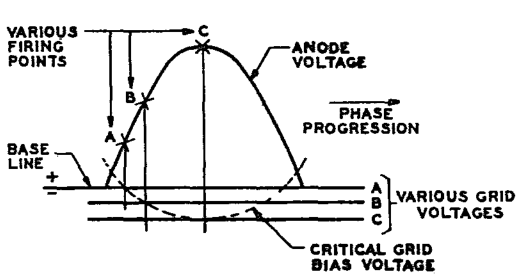

Fig. 5 - Voltage Relations - Magnitude Control of Firing Point

4.02 A half wave rectifier circuit is shown on Fig. 6. The voltage drop across the lower portion of the potentiometer (R1) normally exceeds the grid battery voltage sufficiently to give approximately -2 volts on the grid. As the d-c load increases the voltage decreases as does the drop across the potentiometer (R1). This decreases the grid negative bias giving earlier firing and increased output to compensate for the increased load and return the voltage to the desired value.

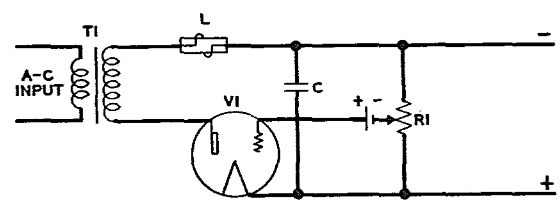

Fig. 6 - Magnitude Control - Half Wave

4.03 With a circuit of this type and with very light loads, the voltage is maintained by the condenser (C) sufficiently so that it is not necessary for the tube to fire every cycle. When the voltage falls due to the discharge of the condenser the tube begins to fire for several cycles to recharge the condenser. This irregular operation of the tube at light loads can be noticed as a flicker in the haze of the tube.

4.04 Fig. 7 shows a full wave magnitude control rectifier circuit. A second rectifier tube (V2) is added and current is supplied through one tube, during one half cycle of the a-c supply voltage and through the other tube during the other half of the cycle. The operation of the grid battery and potentiometer, (not shown), are the same as with the half-wave circuit. With the full-wave circuit, one tube may start firing earlier because of slightly different critical grid bias but due to the high impedance of the filter circuit the output current will be very small and no appreciable output current will flow until the output voltage is reduced suf-

OPERATION OF MAGNITUDE CONTROL (Continued)

ficiently to reduce the grid voltages sufficiently to fire the other tube. Then full-wave operation begins and normal control is exercised and one tube will carry slightly more load than the other, but the impedance of the filter coil tends to balance the load between the tubes.

4.05 If the a-c input voltage changes, the regulating circuit tends to compensate for the changes in the plate voltage applied to the tube but since the critical grid voltage of the tube also changes, the output voltage will increase with increases in plate voltage. This effect may be counteracted by connecting into the control circuit a small d-c voltage obtained from a copper oxide rectifier operated from a winding of the plate transformer. This rectifier, not shown on Fig. 7, may be in series with the potentiometer or in series with the grid battery. In either case, it can be adjusted so that variations in line voltage change the grid bias just enough to nullify their effect on the plate voltage and maintain constant output voltage.

4.06 The rectifier-inverter when operating as a rectifier is arranged for operation on regulated current after reaching its capacity at regulated voltage. This is accomplished by an overload relay which adds the voltage drop of a ballast lamp into the potentiometer circuit.

4.07 On nearly all magnitude controlled rectifiers, a filter is supplied, not only for noise suppression but also to assist in the control and to reduce the amount of output ripple which is fed back into the grid circuit. A battery load acts as a filter and makes unnecessary the extra filter equipment required with resistance loads. When desired, a ballast lamp may be used in the output leads to limit output currents to a safe value.

4.08 On rectifiers arranged for inverter operation, a power failure or the operation of the inverter test key (not shown on Fig. 7) will automatically open the a-c line connections, reverse the battery connections, disconnect the grid from the grid battery and potentiometer, and connect a battery driven frequency generator to the primary of the (T3) transformer. The a-c voltage from the (T3) secondary brings first one and then the other grid to firing point allowing the tubes to fire alternately. Condensers (C) between the plates of the two tubes extinguish one tube as the other reaches the firing point. The current in the (T1) secondary flows from the center point toward first one end and then the other setting up an a-c voltage in the (T1) primary to carry the a-c load. Power to heat the filaments during both rectifier and inverter operation is obtained from a transformer whose primary is in parallel with the primary of transformer (T1). If a tube must be replaced or the inverter is stopped for any reason during inverter operation the filaments must be heated from the battery during the starting period. A switch (not shown on Fig. 7) is provided for this purpose.

5. OPERATION OF SERIES TUBE CONTROL

5.01 The series tube control type rectifier is used primarily for supplying the plate voltage for amplifiers and oscillators. A schematic circuit for this type is shown on Fig. 8.

5.02 The two anodes of rectifier vacuum tube (V1) are connected so that one is positive during one half of the a-c supply cycle and the other during the other half which permits full wave operation. No grid is required because the magnitude of the output is controlled by changes in the resistance of the series tube (V2) in the output lead.

5.03 This tube (V2) has its cathode and anode connected in series with the positive output lead of the rectifier. The voltage drop over it is controlled by its grid voltage thus controlling the output voltage of the rectifier. In order to hold the output voltage of the rectifier constant, a regulating circuit is provided having a vacuum tube (V3) to amplify the small changes in the regulated output voltage to a value sufficiently large to control the grid of (V2). The resistances (R1), (R2), and (R3) form a potentiometer circuit across the output voltage to supply grid voltages. The voltage drop of a part of the potentiometer is

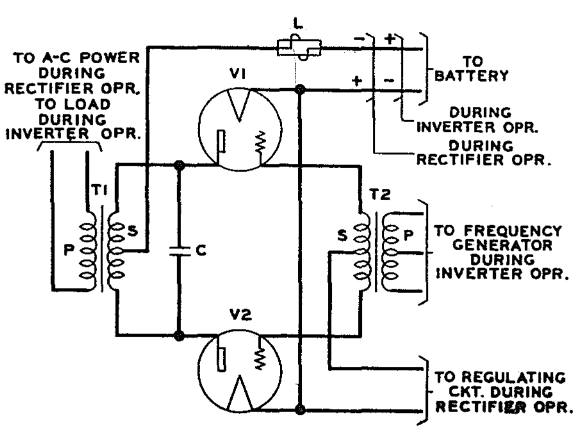

Fig. 7 - Magnitude Control - Full Wave - Arranged for Inverter Operation

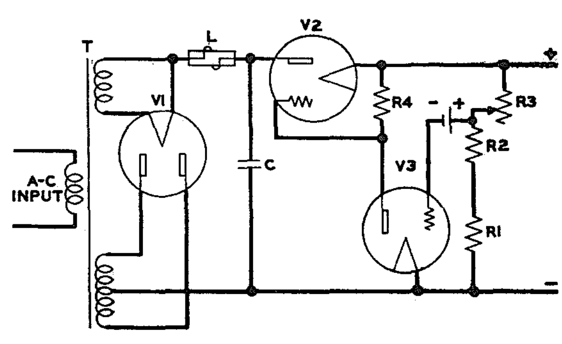

Fig. 8 - Series Tube Control - Full Wave with Grid Battery

connected to the grid of tube (V3) through the slightly higher opposing voltage of the grid battery so that a small negative voltage bias (in the order of -2 volts) is applied to the grid. When a load is applied to the output of the rectifier, its voltage decreases reducing the positive drop over the potentiometer to make the grid of (V3) more negative. A more negative voltage on the grid of (V3) decreases its plate current and the voltage drop over (R4). The voltage drop over (R4) when applied to the grid of (V2) drives it less negative which decreases its voltage drop (effective resistance) to increase the output voltage sufficiently to return it to the original value. In the same manner a reduction in load will be reflected through the regulating circuit in a direction to cause the output voltage to increase so that the effective voltage remains practically constant. The rheostat (R3) provides a means of changing the regulated voltage. Outputs greater than the capacity of series tube (V2) can be obtained by placing a second series tube in parallel with (V2).

5.04 If tube (V3) fails or there is excess voltage during starting a cold cathode protective tube not shown on Fig. 8 operates to drive the grid of tube (V2) negative and limit output.

5.05 An optional feature on this rectifier provides for transfer to a dry battery reserve.

5.06 The regulating circuit assists in filtering the output of the rectifier as the ripple is fed back to the grid of (V3) where it is amplified and applied to the output circuit by means of (V2) in a direction to reduce the ripple from the rectifier.

6. OPERATION OF BOOSTER CONTROL

6.01 With booster control the a-c line voltage is boosted by transformers and an auto-transformer to give the output necessary to maintain the desired battery voltage. The auto-transformer is motor driven and may be manually or automatically controlled.

6.02 Fig. 9 shows a full wave, booster control rectifier circuit with automatic regulation. Changes in battery voltage are reflected through potentiometer (R1) to the grid of vacuum tube (V3). The change in grid bias of tube (V3) increases or decreases the drop through resistance (D) and this drop is the grid bias voltage for tube (V4). Battery voltage changes, therefore, change the resistance of tube (V4) which with resistances (A2), (A1), and (B) form the four legs of a bridge. Unbalance in the resistance of the bridge caused by changes in tube (V4) allows current to flow across the diagonal of the bridge through relays (L) and (R) which are in series. These relays are polarized in opposite directions so that unbalance current caused by lowered battery voltage will cause the (R) or raise relay to operate while high battery voltage reflected through the (V3) and (V4) tubes will cause unbalance current in the direction to operate the (L) or lower relay.

6.03 Operation of the (R) relay feeds battery to the motor start circuit which connects

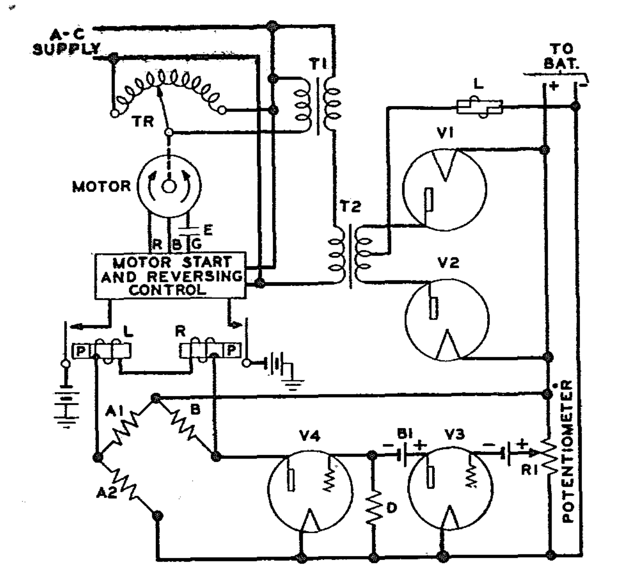

Fig. 9 - Booster Control

alternating-current to the motor. At the same time capacitor lead (G) is connected to the (B) lead which causes the capacitor start motor to start in the direction to move the brush of auto-transformer (TR) to the left as shown on Fig. 9 and raise the output voltage. Conversely, operation of (L) relay turns on the motor but starts it in the opposite direction by connecting the capacitor leg to (R) lead and operates brush of (TR) to reduce output. When on the same side of the panel as and facing the auto-transformer, clockwise rotation of the brush arm decreases voltage and counter-clockwise rotation increases voltage.

6.04 As indicated above the more of auto-transformer (TR) which is connected across the primary of transformer (T2) the more the line voltage is boosted, the higher transformer (T1) secondary voltage becomes and the more output is available from the tube.

6.05 Relays (L) and (R) release on about one-third to one-half of the bridge unbalance current necessary for their operation. This reduces the tendency of the control equipment to overcorrect or hunt.

6.06 A high-low ammeter relay (not shown on Fig. 9) prevents operation with output above or below the range for which the rectifier is designed. Limit switches (not shown on Fig. 9) are located at each end of the brush travel of the auto-transformer to stop the motor when the limits of the device are reached.

7. APPLICATION AND GENERAL CHARACTERISTICS

7.01 The series tube type is limited to the capacity of commercial radio tubes, and is not arranged for battery charging. The magnitude control type is simpler in operation and design than is the phase shift control type but does not lend itself as readily to multiple operation and to higher voltages. Booster control

APPLICATION AND GENERAL CHARACTERISTICS (Continued)

is used where the 3 element rectifier tubes of the desired capacity are not available or are uneconomical.

7.02 The voltage is regulated at the point in the circuit where the regulating lead is connected. For maximum battery life the point of regulation should be at the battery terminals. With this arrangement the fuse board voltage at no load will be the regulated value but under load the fuse board voltage will be slightly less than the regulated value because of the voltage drop in the leads between the battery and the fuse board. Where battery life is secondary to very close voltage regulation at the fuse board the regulating point may be the fuse board in which case under load the battery voltage will be higher than the regulated value by the amount of the voltage drop in the leads between the battery and the fuse board.

7.03 For satisfactory operation these rectifiers should be used only at the voltages or within the voltage ranges specified. It is very important that the line voltage tap nearest to the actual line voltage should be used and operation at d-c voltages other than those for which the circuit constants were selected is not recommended. Regulating rheostats are selected of such value that their position indicates the age of the grid battery and loss of such indication is one of the penalties of operation at other than specified voltages. The rectifiers are designed to protect themselves against damaging over loads due either to low battery voltage or excessive office loads.

7.04 These rectifiers operate most satisfactorily with ambient temperatures between 50 and 104 F. Where temperatures are high, special ventilation may be necessary and location of rectifiers near other heat producing equipment should be avoided. Operation considerably below 50 F may be satisfactory except that there may be a delay in starting. Limiting lower temperature, if any, will be stated in the circuit information.

7.05 It is necessary with all gaseous discharge tubes to permit the filament to reach its operating temperature before space current flows in order to prevent damage to the tube. This is cared for automatically.

7.06 With Thyratron or other vapor tubes, flicker is not an indication of trouble and the relative brightness is not a measure of tube efficiency or output. Tubes of this type usually require replacement because of poor emission, that is, low current output, even though the tube is still lighted.

7.07 With regulated rectifiers the output as indicated by ammeter readings is expected to change constantly because the output must follow the load in order to keep the voltage constant instead of remaining almost constant as on Tungar type battery chargers.

7.08 Where connection to power is necessary at regular intervals to maintain electrolytic condenser films it will be so stated in circuit information.

7.09 General instructions on gas filled rectifier tubes usually call for aging of new tubes by operation for a short time with the cap off to reduce the chance for flash over at rated maximum voltage for the tube. On these rectifiers, however, the voltage on the tube is usually low enough so that such precautions are unnecessary. If required, aging will be called for in the circuit information.

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