Rectifier Considerations

Rectifier-type power supplies employing electron tubes are used as sources of plate, screen-grid (grid-No.2), and other dc operating voltages in all types of electronic equipment. They are also used extensively in electroplating, in motor-speed control, and in many other applications requiring economical and conveniently controllable dc power.

The glass envelopes of the rectifier tubes used in such supplies normally show some darkening after continued operation. In addition, mercury-vapor tubes exhibit a blue glow in normal operation. These symptoms are characteristic of such tubes, and should not be considered signs of tube deterioration or failure.

Mercury-Vapor Tubes

A mercury-vapor rectifier tube must be handled with special care to prevent dispersion of the liquid mercury from its normal position at the bottom of the bulb. Spattering of the mercury over other portions of the bulb or on the anode or filament must be avoided because it may lead to internal shorts or arcs when the tube is placed in operation. A mercury-vapor tube should always be transported, stored, and operated in a vertical position with the filament end down, and should never be jarred, shaken, or allowed to rest even momentarily in a horizontal position. The tube should never be rocked or allowed to snap into place in its socket or mounting, and should be protected against excessive equipment vibration.

If spattering occurs, the dispersed mercury must be completely reconcentrated before the tubes are placed in service by means of special preheating and conditioning treatments. In the preheating treatment, the mercury-vapor tube is operated at normal filament voltage, but without anode voltage, for 30 minutes to assure complete vaporization of the mercury content. When filament voltage is removed at the end of this preheating period, most of the vaporized mercury recondenses in a pellet or pool at the bottom of the bulb. The conditioning treatment is then applied to flash out any mercury which may have condensed on the bulb walls or in the vicinity of the anode and filament seals. In this treatment, the tube is operated at normal filament voltage and at about one-sixth normal anode voltage for 5 minutes. The anode voltage is then gradually increased over a period of about 30 minutes to the normal operating value. If an internal flashover occurs at any time during the conditioning treatment, the anode voltage should be reduced until the flashover ceases. It should then be held at this reduced value for a few minutes to assure complete vaporization of the mercury before the treatment is resumed.

Filament Heating Time

Voltage should not be applied to the plates or anodes of vacuum, mercury-vapor, or inert-gas rectifier tubes (except receiving types) until the filaments or cathodes of the tubes have reached normal operating temperature. For gas tubes, this delay is necessary to allow the formation of a plasma (region of electrons and positive ions) which protects the emitting surface against damage from high-velocity positive-ion bombardment. In the case of a mercury-vapor rectifier, the application of anode voltage must also be delayed until the condensed mercury has moved to its normal condensing zone at the bottom of the tube, as discussed above.

Minimum heating times for individual rectifier types are given in the *Tube Types* Section. In each case, the time specified is measured from the instant when the filament voltage reaches its normal operating value and, consequently, may have to be increased if the filament supply has poor regulation.

It should be noted that measurement of the filament voltage of a power-rectifier tube may involve serious personal-safety hazards because the filament is usually a high-voltage terminal of the rectifier circuit. When continuous measurements are *required, suitable voltmeters should be permanently incorporated in the equipment. These meters must be insulated to withstand the maximum peak inverse voltage applied to the tubes, and should be recessed in the equipment and protected by glass or plastic viewing panels to prevent any possibility of injury through accidental bodily contact. Portable instruments should not be used for the measurement of rectifier-filament voltages unless adequate personal-safety precautions are taken by the user.*

Because a mercury-vapor tube may be severely damaged if the temperature of its filament varies excessively, the filament should be operated from a constant-voltage transformer, or its supply circuit should include under- and over-voltage relays which will open the primary circuit of the rectifier anode supply if the line voltage varies excessively. Relays having small operating delays (less than 10 seconds) may be used in this application to minimize interruptions to operation by normal surges or transient variations in line voltage.

The required delay in application of anode voltage can be obtained conveniently by means of a time-delay relay connected in the primary circuit of the high-voltage transformer, as shown in Fig. 53. This relay should permit adjustment of the delay time to a value sufficient to assure protection for the tubes under the most adverse conditions that can be expected in service.

Mercury Temperature

The life and performance of a mercury-vapor rectifier are critically dependent on the temperature of the condensed mercury. Low ambient temperatures retard vaporization of the mercury, thus limiting the degree of ionization available at normal filament voltage and raising the anode-cathode potential at which the tube starts to conduct. High ambient temperatures, on the other hand, are conducive to rapid vaporization, but tend to produce over-ionization and thus reduce the peak inverse anode voltage that the tube can withstand without breakdown. Rectifiers using mercury-vapor tubes, therefore, should be equipped with means for measuring condensed-mercury temperatures, and for maintaining these temperatures within limits specified for the tubes employed. Condensed-mercury temperature may be measured with a thermocouple or thermometer attached to the tube by means of a small amount of putty in a region near the bottom of the bulb. The proper measurement zone for each of the mercury-vapor tubes included in this Manual is shown in the *Outlines* Section.

The method used to control condensed-mercury temperature depends on the ambient-temperature conditions under which the tubes operate. If the ambient temperatures are near the minimum values specified in the tube data, some form of heat-conserving enclosure should be provided for the tubes. In extreme cases, it may also be necessary to employ electrical heating, together with suitable means for limiting the maximum temperatures developed. If ambient temperatures are above the maximum values specified in the tube data, forced-air cooling should be employed. The air flow should start when the anode voltage is applied to the tube, and should be directed horizontally onto the bulb about ½ inch above the base at the filament end of the tube. The air flow may be removed simultaneously with the anode voltage. The rise of mercury-vapor temperature above ambient temperature is given as a function of heating time under no-load and/or full-load conditions for mercury-vapor rectifier types in the *Tube Types—Technical Data* Section.

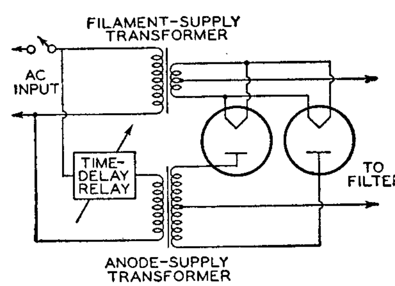

Fig. 53

Shielding

Rectifier tubes, particularly mercury-vapor types, should be isolated from transformers and other components which produce strong external magnetic or electrostatic fields. Such fields are generally detrimental to tube life, tend to produce breakdown effects in mercury vapor, and frequently make it difficult to obtain adequate filtering of rectifier output. When tubes cannot be completely isolated from such fields, they should be enclosed in shields of the type described in the *Power-Tube Installation* Section. Mercury-vapor rectifier tubes used to supply transmitters or other types of rf power equipment should also be protected from large rf voltages. Such voltages should be prevented from entering rectifier circuits by rf filters such as that shown in Fig. 54.

Mercury-vapor rectifier tubes occasionally produce multi-frequency oscillations or "hash" which may cause interference in the af stages of associated

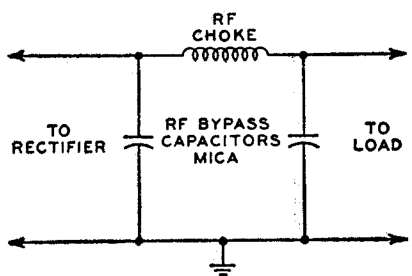

Fig. 54

equipment and in near-by radio receivers. These oscillations are caused by the development of a very steep wave front at the instant conduction begins in each rectifier unit, and may be propagated along internal circuit wiring and external power lines or radiated directly by the tubes. In a receiver, rectifier "hash" can usually be identified as a broadly tunable signal modulated at the rectifier "ripple" frequency. (The "ripple" frequency is equal to the power-line frequency times the number of half-wave rectifier units conducting independently.)

In some cases, this type of interference can be minimized by the use of very short leads to the rectifier anodes. It is usually necessary, however, to determine whether the interference is transmitted by radiation or by conduction, and to select the most effective method for its elimination by experiment. Radiation of such interference can usually be minimized by shields of the type used to protect rectifier tubes against external fields. The transfer of such interference to a power line can be minimized by the insertion of a low-pass inductance-capacitance filter in the input circuit of the rectifier, as shown in Fig. 55, or by the use of filament and high-voltage supply

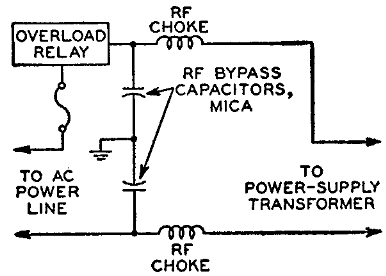

Fig. 55

transformers having electrostatic shields between primary and secondary windings. Low-pass filters of the type shown in Fig. 56 are also useful. The bypass capacitors used in such filters must have a voltage rating at least equal to the peak voltage developed across each half of the transformer secondary (approximately 1.4 times the rms voltage).

Rectifier tubes operated in circuits in which peak inverse voltages are 16000 volts or higher produce X-rays. Because

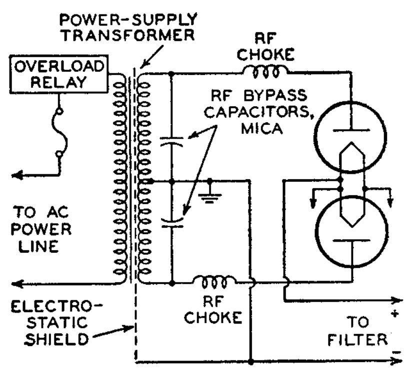

Fig. 56

these rays constitute a serious health hazard, tubes operated in such circuits should be equipped with shielding designed to absorb X-ray radiation.

RCA mercury-vapor and inert-gas rectifier tubes are equipped with internal cathode shields. These shields are connected to a filament or heater terminal designated as the "cathode-shield" or "anode-return" terminal. When two or more gas-rectifier tubes are operated from a common filament or heater supply, the cathode-shield or anode-return terminals of the tubes must be connected to the same side of the supply.

Tube Ratings

Rectifier-tube ratings usually include maximum permissible values for peak inverse anode voltage, peak anode current, average anode current, and fault anode current. Before these ratings are defined and their application to rectifier circuit design is discussed, it is desirable to define certain other terms frequently used in connection with rectifiers.

Forward voltage is voltage applied between the anode and cathode in the direction in which the tube is designed to pass current, *i.e.*, anode positive with respect to cathode. **Inverse voltage** is voltage applied between the anode and cathode in the direction opposite to that in which the tube is designed to pass current, *i.e.*, anode negative with respect to cathode.

Forward current is current flowing through a rectifier as a result of the application of a forward voltage. **Reverse current** is current flowing through a rectifier in the direction opposite to that of normal conduction. The flow of reverse current in a rectifier is an abnormal condition.

Peak inverse anode voltage is the highest instantaneous voltage applied between the anode and cathode during the fraction of any input cycle when the tube is normally not conducting. A maximum peak-inverse-voltage rating indicates the highest value this voltage may attain without danger of arc-back in the tube, electrolysis of glass, and reduced tube life.

Peak anode current is the highest instantaneous value reached by the forward current during the normal conduction interval. A maximum peak-anode-current rating indicates the highest current the tube can safely conduct during this interval. The peak current is determined by the duration of the conduction interval and, therefore, depends on the type of rectifier circuit in which the tube is employed.

Average anode current is the value obtained by integrating the instantaneous anode currents of a rectifier tube over a specified time and averaging the result. A maximum average-anode-current rating indicates the highest average current that should be permitted to flow through the tube in the direction of normal conduction. This current may be measured by means of a dc meter inserted in the anode circuit of the tube. When the rectifier load is constant, the average anode current may be read directly on the meter. When the rectifier load is varying, the meter readings should be averaged over the period specified in the tube data (usually 15 to 30 seconds).

Fault anode current is the highest current flowing through a rectifier tube in the forward direction under abnormal or fault conditions, *e.g.*, during a load short circuit or an arc-back in an associated tube. A maximum fault-current rating indicates the highest current that should be permitted to flow through the tube in the direction of normal conduction over a period not exceeding 0.1 second under fault conditions. Rectifier circuits should be designed to limit fault currents to values within the maximum ratings because even a single fault current of the maximum value will materially shorten or terminate the life of the tube.

Rectifier tubes of the same type can be connected in parallel to provide increased output current. When mercury-vapor or inert-gas types are operated in parallel, it is necessary to employ a resistor or a small inductance in the anode circuit of each tube to assure equal division of the total load current. Stabilizing resistors for high-voltage circuits should produce an average voltage drop of not less than 50 volts. Stabilizing inductors should have a value of approximately one-sixth henry each for a supply frequency of 50 to 60 cycles per second. Stabilizing inductors are generally preferable to resistors because they minimize power losses and help to limit the peak anode currents in the tubes. Center-tapped inductors (interphase reactors) can be used as stabilizing elements for pairs of parallel tubes. These inductors assure simultaneous starting as well as equal division of current. Vacuum rectifier tubes do not generally require the use of stabilizing devices when operated in parallel.

Corresponding filament terminals of mercury-vapor or inert-gas rectifiers operated in parallel must be connected together. Failure to observe this precaution will seriously unbalance the voltage drops in the paralleled tubes and may make it necessary to use undesirably high stabilizing impedances.

Circuits

The most suitable type of rectifier circuit for a particular application depends on the dc voltage and current requirements, the amount of rectifier "ripple" that can be tolerated in the output, and the type of ac power available.

The half-wave single-phase circuit shown in Fig. 57 delivers only one pulse of current for each cycle of the ac input

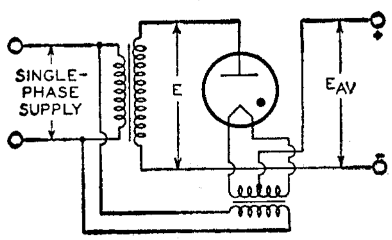

Fig. 57

voltage. Because its output contains a very high percentage of ripple, this type of circuit is used principally in low-voltage, high-current applications (*e.g.*, in power supplies for ac/dc receivers) and in low-current, high-voltage applications (*e.g.*, in ultor-voltage supplies for kinescopes and other types of cathode-ray tubes).

A full-wave single-phase circuit using two half-wave rectifier tubes is shown in Fig. 58, and a series single-phase circuit in Fig. 59. Although the bridge circuit requires four half-wave rectifier tubes and three filament transformers (or three independent filament windings), it can deliver twice as much output voltage as the two-tube circuit for the same anode-transformer voltage, and does not require a center-tapped high-voltage winding.

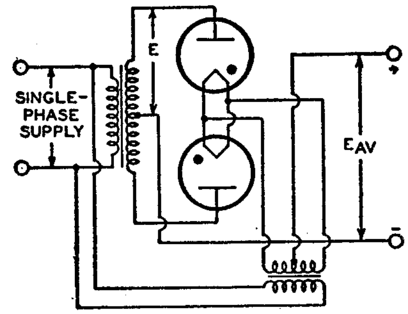

Fig. 58

Fig. 60 shows a half-wave three-phase circuit using three rectifier tubes. This circuit delivers three current pulses per cycle and its output, therefore,

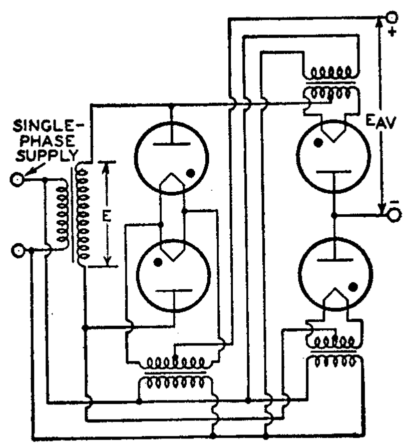

Fig. 59

contains a smaller percentage of ripple than that of a full-wave single-phase circuit.The parallel three-phase circuit employing six half-wave rectifier tubes

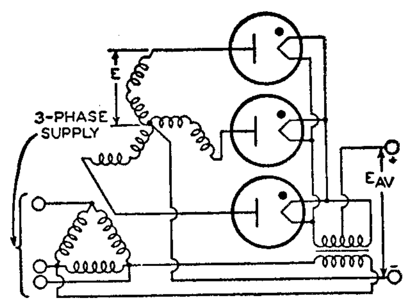

Fig. 60

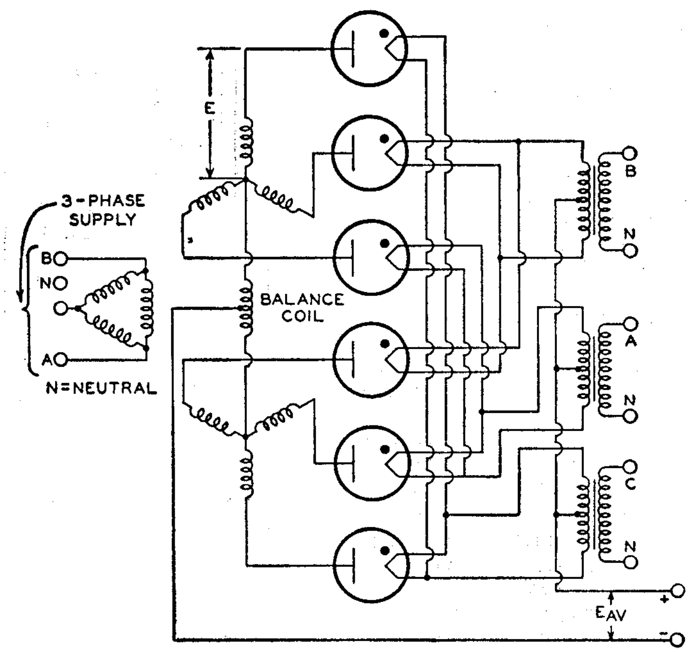

Fig. 61

shown in Fig. 61 delivers six current pulses per cycle. This circuit delivers twice as much output current as the circuit shown in Fig. 60 for the same average anode current per tube. The balance coil used in this circuit assures equal division of the load current and proper phasing in (or simultaneous starting of) the parallel branches.

In the series three-phase circuit shown in Fig. 62, two half-wave rectifier tubes are connected in series across each leg of the high-voltage transformer. This circuit delivers twice as much output voltage as the half-wave three-phase circuit shown in Fig. 60 for the same transformer voltage and peak inverse anode voltage per tube. Figs. 63 and 64 show

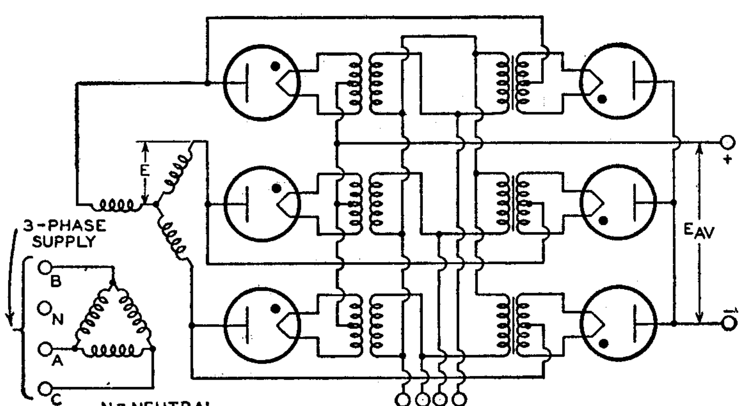

Fig. 62

half-wave four-phase and six-phase circuits, respectively.

Quadrature Operation

The filament current of a rectifier tube is composed of two components: the normal heating current supplied by the filament transformer, and the anode current, the greater part of which flows through the most negative portion of the filament. When the filament-supply voltage and anode voltage of a rectifier are in phase (the normal relationship when both voltages are obtained from the same ac supply line), the two components of the filament current reach peak value simultaneously during each conduction interval, and cause a localized increase in filament temperature which may seriously shorten the life of the tube.

In single-phase rectifier circuits, which have a conduction interval per tube of 180 degrees, the ratio of peak anode current to peak filament-supply current is relatively small and the effects of "in-phase" operation are usually negligible. In polyphase rectifier circuits having conduction intervals per tube of 120 degrees or less, however, the ratio of peak anode current to peak filament-supply current is relatively large, and

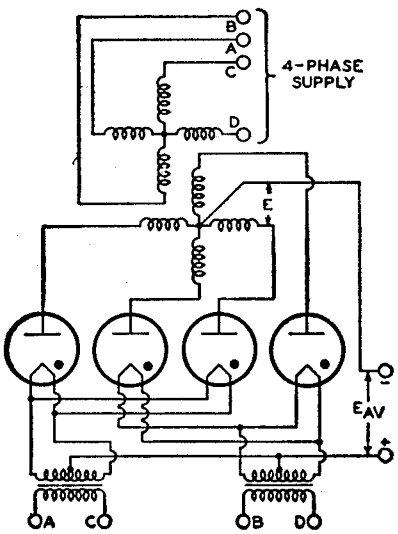

Fig. 63

the use of in-phase filament and anode voltages may result in extremely short tube life.

This difficulty can be minimized by the use of "Quadrature Operation." In this method of operation, the peak value of the total filament current is minimized

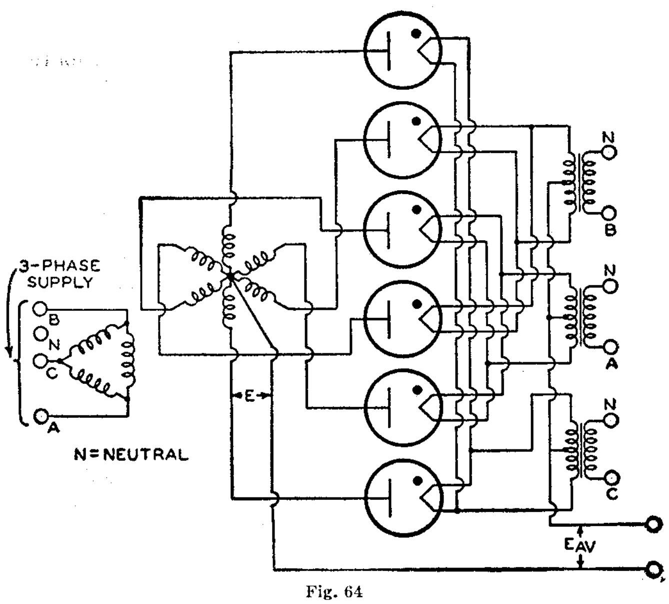

Fig. 64

by supplying the filament of each rectifier tube with voltage out of phase with its anode voltage. Although the ideal phase relationship between filament-supply voltage and anode voltage is 90 degrees (true "Quadrature"), substantial benefits are also realized at phase angles of 60 or 120 degrees, which are readily obtainable in three-phase and six-phase rectifier circuits.

Table IV gives the voltage, frequency, current, and power ratios for the basic rectifier circuits shown in Figs. 57 through 64. These ratios apply for sinusoidal ac input voltages. Current and power ratios given for inductive loads apply only when a filter choke is used between the output of the rectifier and any capacitor in the filter circuit. This table does not take into consideration voltage drops which occur in the power transformer, the rectifier tubes, or the filter components under load conditions. When a particular tube type has been selected for use in a specific rectifier circuit, the ratios given in Table IV can be used in conjunction with the tube data to determine the parameters and characteristics of the circuit.

Example of the Use of Table IV

Problem. Select the most suitable type of rectifier tube for use in a full-wave single-phase circuit which must de-

TABLE IV

RATIO	Fig. 57	Fig. 58	Fig. 59	Fig. 60	Fig. 61*	Fig. 62	Fig. 63	Fig. 64
Voltage Ratios								
E/E_{av}	2.22	1.11	1.11	0.854	0.854	0.427	0.785	0.74
E_{bmi}/E	1.41	2.83	1.41	2.45	2.45	2.45	2.83	2.83
E_{bmi}/E_{av}	3.14	3.14	1.57	2.09	2.09	1.05	2.22	2.09
E_m/E_{av}	3.14	1.57	1.57	1.21	1.05	1.05	1.11	1.05
E_r/E_{av}	1.11	0.472	0.472	0.177	0.04	0.04	0.094	0.04
Frequency Ratio								
f_r/f	1	2	2	3	6	6	4	6
Current Ratios								
I_b/I_{av}	1	0.5	0.5	0.33	0.167	0.33	0.25	0.167
Resistive Load								
I_p/I_{av}	1.57	0.785	0.785	0.587	0.294	0.587	0.503	0.408
I_{pm}/I_{av}	3.14	1.57	1.57	1.21	0.52	1.05	1.11	1.05
I_{pm}/I_b	3.14	3.14	3.14	3.63	3.14	3.14	4.5	6.3
Inductive Load■								
I_p/I_{av}	–	0.707	0.707	0.577	0.289	0.577	0.500	0.408
I_{pm}/I_{av}	–	1	1	1	0.5	1	1	1
Power Ratios								
Resistive Load								
P_{as}/P_{dc}	3.49	1.74	1.24	–	–	–	–	–
P_{ap}/P_{dc}	2.69	1.23	1.24	–	–	–	–	–
P_{al}/P_{dc}	2.69	1.23	1.24	–	–	–	–	–
Inductive Load■								
P_{as}/P_{dc}	–	1.57	1.11	1.71	1.48	1.05	1.57	1.81
P_{ap}/P_{dc}	–	1.11	1.11	1.21	1.05	1.05	1.11	1.29
P_{al}/P_{dc}	–	1.11	1.11	1.21	1.05	1.05	1.11	1.05

* Bleeder current of 2-per-cent full-load current will provide exciting current for balance coil and thus avoid poor regulation at light loading.

■ The use of a large filter-input choke is assumed.

E=transformer secondary voltage (rms)
E_{av}=average dc output voltage
E_{bmi}=peak inverse anode voltage
E_m=peak dc output voltage
E_r=major ripple voltage (rms)
I_{av}=average dc output current
I_b=average anode current
I_p=anode current (rms)
I_{pm}=peak anode current
f=supply frequency
f_r=major ripple frequency
P_{al}=line volt-amperes
P_{ap}=transformer primary volt-amperes
P_{as}=transformer secondary volt-amperes
P_{dc}=dc power ($E_{av} \times I_{av}$)

Note: *Conditions assumed include sine-wave supply, zero voltage drop in tubes, no losses in transformer and circuit, no back emf in the load circuit, and no phase-back.*