PROTECTIVE CIRCUIT AGAINST CATHODE-TO-HEATER BREAKDOWN

FIG. 1.

FIG. 2.

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The invention herein described and claimed relates to electronic voltage regulators. More specifically, the present invention relates to an improvement in electronic voltage regulators whereby the tubes of the regulator circuit, particularly those lacking in size, are protected against failure due to voltage breakdown between cathode and heater.

As is well known, the conventional electronic voltage regulator usually comprises three tubes, one a cold-cathode gas-filled tube and the other two hot-cathode vacuum tubes. One of the hot-cathode tube functions as a variable resistance in series with the load current. This tube is sometimes called the series tube but will be referred to hereafter as the pass tube. The other hot-cathode tube, the control tube, functions to reverse the phase of, and to amplify, small changes in the D-C output voltage. The output of the control tube is applied to the grid of the pass tube to change the plate resistance of the pass tube in response to changes in the D-C output voltage, thereby maintaining the output voltage substantially constant. The cold-cathode gas-filled tube is held to hold the cathode of the control tube at a constant reference potential.

Within recent years, the voltage regulator has become a virtually indispensable feature of many electronic equipment. By means of the voltage regulator, oscillators are kept from straying over the spectrum, reference voltages are held constant within rigid limits, and grid biases are given a high degree of stability. Unfortunately, the conventional electronic voltage regulator is bulky, and in many instances requires more space than can be allotted to it. The use of miniature tubes would, of course, conserve space, but unless separate windings be provided on the heater transformer for supplying separately the heater of each tube, the miniature tubes will burn out very quickly, if not instantly, due to voltage breakdown between cathode and heater, the cathode-to-heater voltage ratings of miniature tubes being substantially lower than those of the octal type tubes.

The object, therefore, of the present invention is to provide an electronic voltage regulator having protective means for preventing the tubes of the regulator circuit, particularly miniature type tubes, from burning out as a result of voltage breakdown between cathode and heater, though the heaters be supplied from a common source.

A more specific object of the present invention is to provide a vest-pocket type electronic voltage regulator employing miniature type tubes whose heaters are supplied from a common source, said regulator to be capable of regulating a voltage of substantial magnitude across a substantial current load, as for example, to be capable of regulating a B+ voltage of several hundred volts across a current load of 50 milliamperes or more.

In accordance with the present invention, the above objects are attained by the provision of means, within the voltage regulator, for maintaining the potential of the heaters of both of the hot-cathode tubes at a value which is intermediate the potentials of the cathodes of the two tubes, thereby to insure that the cathode-to-heater voltages of the tubes do not exceed their respective voltage ratings, either during warm-up or during normal operation. More specifically, the heaters of the hot-cathode tubes are connected to a point on a voltage-divider network, the arrangement and voltage division being such that the potential of the heaters always falls between the potentials of the cathodes of the two hot-cathode tubes. During warm-up, the potential of the control-tube cathode is substantially higher than that of the pass-tube cathode, whereas the reverse is true under operating conditions, the potential of the pass-tube cathode during normal operation being substantially higher than that of the control-tube cathode. The arrangement provided by the present invention is nevertheless effective to place the heater potentials between the potentials of the two cathodes during both periods, i.e., during both the warm-up and normal-operation periods. During the warm-up period, the potential of the control-tube cathode rises toward the unregulated B+ voltage until the reference tube fires and thereafter is maintained at a voltage determined by the operating voltage of the reference tube. The potential of the pass-tube cathode during the warm-up period is, in accordance with the present invention, caused to follow the potential of the control-tube cathode and to be a fractional part thereof as determined by a voltage-divider network. The potential of the heaters, during the warm-up period, is caused to fall between the potentials of the two cathodes. Following the warm-up period, under operating conditions, the cathode of the pass tube rises to, and is held at, the regulated B+ potential, while the cathode of the control tube is held at the reference voltage determined by the reference tube. The difference between these potentials, i.e., the potential difference between the two cathodes during normal
operation is ordinarily quite large and substantially greater than the cathode-to-heater voltage rating of either tube. However, the potential difference between the two cathodes will ordinarily be less than twice the cathode-to-heater voltage rating. Hence, the present invention, by returning the heaters to a voltage located between, preferably about midway between, the potentials of the two cathodes, holds the cathode-to-heater potential of each tube within the voltage rating of the tube.

The invention will be most readily understood from a consideration of the following detailed description taken together with the accompanying drawing wherein:

Figure 1 is a schematic diagram of a vest-pocket type of electronic voltage regulator employing miniature tubes and embodying the circuit arrangement of the present invention, and

Figure 2 is a graphical illustration which will be helpful in explaining and understanding the invention.

Referring now to Figure 1 there is shown an electronic voltage regulator to which a positive B+ voltage is supplied from power supply 10. The regulator shown is largely conventional except for the employment of miniature type tubes and except for the modifications in circuitry introduced by the present invention and shown in heavy lines in the drawing. The regulator shown includes the cold-cathode gas-filled reference tube 12, the hot-cathode control tube 14, and the hot-cathode pass tube 15. Reference tube 12 may be a miniature type voltage regulator tube, type OB2; control tube 14 may be a miniature type pentode, type 6A6; and pass tube 15 may be a miniature type beam power amplifier, type 6AS5. If these tubes were used in a voltage regulator of conventional circuitry (the light lines in Figure 1), then the 6A6 control tube 14 would burn out within a few seconds after the power switch was thrown due to voltage breakdown between cathode and heater. Investigation and analysis of such breakdown indicates the following explanation: It requires about three seconds for the heaters of power supply 10 to heat up after the switch is thrown. During this time there is no D.C. current flowing in the regulator circuit. As soon as the rectifiers of the power supply 10 begin to conduct (at the end of about three seconds) the potentials of the plate and cathode of the 6A6 control tube 14 start to rise, the plate being connected to the unregulated B+ lead 18 by way of the resistor 19, and the cathode being connected thereto by way of resistor 20. The OB2 reference tube 12 remains in nonconductive state. The plate and cathode of tube 14 continue to rise, as the unregulated B+ voltage builds up until, by the end of about four and a half seconds, the cathode reaches +135 volts, the starting voltage of the OB2 reference tube 12. The OB2 tube then fires, and the control-tube cathode drops to +105 volts, the operating voltage of the OB2 tube. During this time, the heaters of the 6A6 control tube 14 and of the 6AS5 pass tube 15 are still at ground potential, due to the fact that the center-tap of the heater transformer 17 is connected directly to the cathode of the pass tube 15, and the pass tube does not begin to conduct until at least five seconds have elapsed. Consequently, at an instant approximately four and one-half seconds after the power switch is closed, the cathode of the 6A6 control tube 14 is at a potential of +135 volts while the heater of the tube 14 is still at ground potential. And, since the 6A6 tube has a cathode-to-heater voltage rating of only +90 volts, the tube burns out.

In an effort to correct the above situation, the center tap of the heater transformer 17 be connected directly to the cathode of the 6A6 control tube 14 instead of to the cathode of the 6AS5 pass tube 15, the 6A6 control tube would be safe, when the power switch was thrown, for the cathode and heater element would then be at substantially the same potential. The 6AS5 pass tube, however, would quickly burn out. The explanation in this case is that the heater of the 6AS5 pass tube 15 would, along with the cathode of the 6A6 control tube 14, rise in about four and a half seconds to the striking potential of the OB2 reference tube (12 (+135 volts) while the cathode of the 6AS5 pass tube 15 was still at ground potential. And, since the cathode-to-heater voltage rating of the 6AS5 tube is +90 volts, the tube would burn out. Even if the 6A6 tube were fortunate enough to survive the warm-up period, it would quickly burn out under operating conditions, during normal operation the pass-tube cathode is at the regulated B+ potential (+250 volts in the present example) whereas the heater is at the reference voltage (+105 volts).

To solve the problem hereinabove indicated, the present invention proposes to connect a voltage divider network between the cathode of the control tube 14 and the cathode of the pass tube 15, and to connect the common source of heater potential to a point on the voltage-divider network. In Figure 1, the voltage-divider network is shown to comprise resistors 31, 32 and 33, with their junction (point a) being connected to the center tap of the secondary winding of heater transformer 17. The employment of resistor 32, between point a and ground, is optional in this respect may be omitted, if desired. By properly choosing the values of resistors 31 and 33, the potential of the heaters (point 32 where used) is the potential of the heaters (point a in Figure 1) can be caused to lie between the potentials of the cathodes of the control and pass tubes, both during the warm-up period and during operating conditions. Typical (but not limiting) values for resistors 31, 32 and 33 are shown in Figure 1. It will be understood that if resistor 32 be omitted, the values of resistors 31 and 33 will be different than shown in the drawing. In a typical case, with resistor 32 omitted, resistors 31 and 33 are of equal value.

Consider now the operation of the voltage regulator when the particular voltage-divider network shown in Figure 1 is incorporated therein. As the unregulated B+ voltage supplied by the power supply 10 begins to build up (three seconds after the power switch is closed), the potential of the cathode of the 6A6 control tube 14 rises in corresponding manner, as a result of being connected to the voltage divider at point b, until, at the end of about four and a half seconds, the cathode reaches +135 volts, the firing potential of the OB2 reference tube 12. When the OB2 tube fires, the cathode of the 6A6 control tube 14 quickly drops to +105 volts, the operating voltage of the pass tube 15, and the pass tube begins to conduct as shown in Figure 2. As the control tube 14 rises toward 135 volts, the potential of the heaters (point a) rises in a corresponding and proportional manner, determined by the voltage-divider resistors 31 and 32 and the resistance which is in shunt with resistor 32, namely, the resist-
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The potential of the pass-tube cathode (point c) then rises rapidly to the regulated B+ value (+250 volts in the present illustration), but the potentials of the cathode of the control tube (point b) remains at the reference voltage (+108 volts).

The heaters (point a), as a result of the voltage-divider action of resistors 31, 32, and 33, then assume a potential between the potentials obtaining at the two cathodes (points b and c). All this is clearly illustrated in Figure 2 of the drawing.

As there shown, during the entire warm-up period i.e. both before and after the reference tube fires, the potential of the heaters is between the potentials of the two cathodes. Moreover, the cathode-to-heater potential of each tube is well within the tube's voltage rating of +90 volts. For example, just before the OB2 reference tube fires, the control-tube cathode is at +135 volts, the heaters are at +45 volts, and the pass-tube cathode is at +55 volts. After the reference tube fires, the control-tube cathode is at +108 volts, the heaters are at +37 volts, and the pass-tube cathode is at +50 volts. Following the warm-up period, the relative positions of the cathode potentials of the pass and control tubes are reversed, i.e. the pass-tube cathode rises to a potential substantially higher than that of the control-tube cathode. Nevertheless, as a result of the voltage-divider action of resistors 31, 32, and 33, the potential of the heaters changes in such direction and to such extent as to remain between the potential of the pass-tube cathode and that of the control-tube cathode. In the illustration shown, the potential of the heaters, following the reference tube failure and prior to the heater reset, is +175 volts, the potential of the pass-tube cathode is +250 volts, and the potential of the control-tube cathode is +108 volts. It will be seen that the cathode-to-heater potential of each tube is within the tube's voltage rating of +90 volts in operation as well as during the warm-up period.

A vest-pocket type electronic voltage regulator employing the miniature tubes and circuitry shown in Figure 1 has been successfully built and used. The completed chassis is but a trifle larger than a pack of cigarettes. It produces a +250 volt regulated output from a +300 volt supply, the voltage drop across the 6ASS pentode tube being about 50 volts at 50 milliamperes. It regulates a 50 millampere load at 250 volts very well, allowing variations of plus or minus one-tenth volt in operation.

The electronic voltage regulator shown in Figure 1 and discussed thus far can also be used as a very effective suppressor of hum voltage. Since the superposition of hum voltage upon a D-C voltage merely changes the amplitude of the output voltage at a regular rate, and since an electronic voltage regulator is designed to suppress changes in the amplitude of the output voltage, it will be seen that a voltage regulator can be used to supplement the action of the power-supply filter in suppressing hum. In order, however, to take full advantage of the hum-suppressing capabilities of the voltage regulator, any hum voltage present on the regulated B+ lead should be applied to the grid of the control tube with a minimum of attenuation. This is the further development of capacitor 26 shown in Figure 1 of the drawing. A portion of any D-C variations in the regulated B+ voltage is applied to the control-tube grid by means of the voltage divider consisting of resistors 23, 24, and 25, but a much smaller portion of any hum voltage depending on the regulated B+ lead is applied to the control-tube grid by means of the voltage divider comprising capacitor 29, resistor 27, the lower part of resistor 24, and resistor 25, thus making the voltage regulator very effective as a suppressor of hum.

In practice, it has been found that even though the unregulated B+ voltage from the power supply has a peak ripple of as much as 1.5 volts, which is unusually strong, the regulated B+ voltage will have a peak ripple of only 0.0. Having described our invention, we claim:

1. An electrical circuit employing at least two heater-type tubes, the heaters of which are supplied from a common source of heater supply voltage and the cathodes of which are operated at substantially different voltages, the difference in voltage between said cathode voltages being greater than the cathode-to-heater voltage ratings of said tubes; a voltage divider connecting said cathodes; and a connection from said common source of said heater supply voltage to an intermediate point on said voltage divider, thereby to maintain said heaters at a potential intermediate the potentials of said cathodes and thereby to prevent cathode-to-heater breakdown.

2. Apparatus as claimed in claim 1 characterized by the fact that said common source of heater supply voltage comprises a transformer having a center-tapped secondary to the ends of which said heaters are connected, and further characterized by the fact that said center tap is connected to said intermediate point on said voltage divider.

3. Apparatus as claimed in claim 2 further characterized by the fact that a resistor is connected from said intermediate point on said voltage divider to a point of fixed reference potential.

4. In a voltage regulator circuit having: a source of positive direct-current voltage, first and second tubes each having at least anode and cathode electrodes and each having a heater for its cathode, a common source of heater voltage, means connecting said common source of heater voltage to the heaters of both said tubes, a pair of output terminals, means connecting a high potential side of said source to the anode of said first tube, means connecting the cathode of said first tube to one of said output terminals, and impedance connecting at high potential side of said source to the anode of said second tube, a second impedance connecting a high potential side of said source to the cathode of said second tube, and a gas-filled voltage-regulator tube connected between the cathode of said second tube
and a low potential side of said source for maintaining the cathode of said second tube, in the period after said voltage-regulator tube fires, at a fixed potential substantially less positive than the potential of the cathode of said first tube, and in which the potential of said second-tube cathode, in the period prior to the firing of said voltage-regulator tube, attains a potential substantially more positive than the potential of said first-tube cathode, and in which the difference between the potentials of said cathodes in at least one of said periods exceeds the cathode-to-heater voltage ratings of said tubes; the improvement which comprises the provision of a voltage divider connected between the cathodes of said first and second tubes, and means connecting said common source of heater voltage to an intermediate point on said voltage divider to maintain said heaters at a potential intermediate the cathode potentials of said first and second tubes in the periods both before and after such voltage-regulator tube fires.

5. Apparatus as claimed in claim 4, characterized by the fact that said common source of heater supply voltage comprises a transformer having a center-tapped secondary to the ends of which said heaters are connected, and further characterized by the fact that said center tap is connected to said intermediate point on said voltage divider.

6. Apparatus as claimed in claim 5, further characterized by the fact that a resistor is connected from said intermediate point on said voltage divider to said low-potential side of said source of direct-current voltage.

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