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M. A. LOGAN

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REGULATORY DEVICE

Filed Jan. 20, 1934

FIG. 1

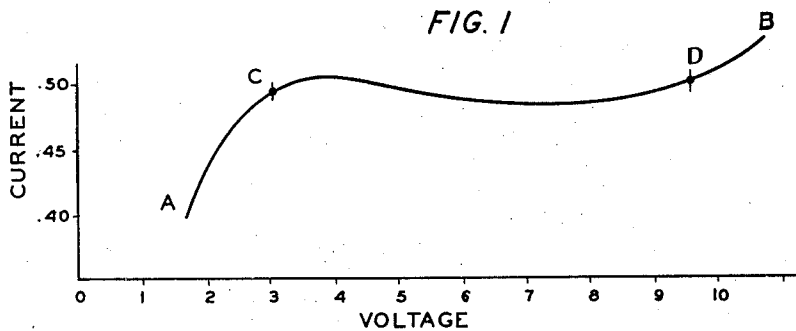


FIG. 2

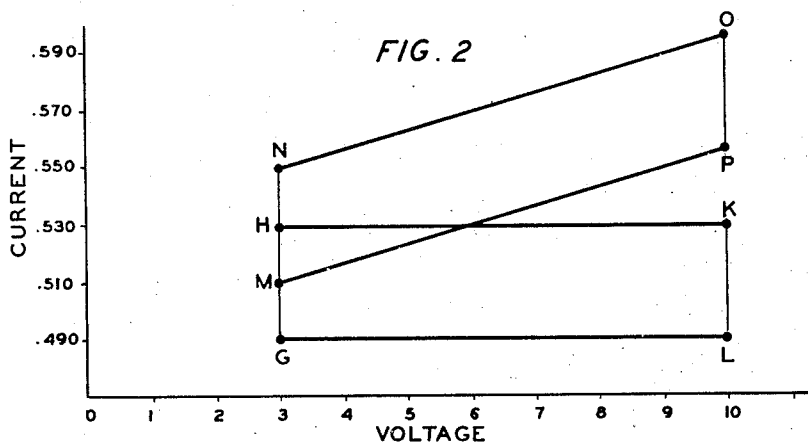


FIG. 3

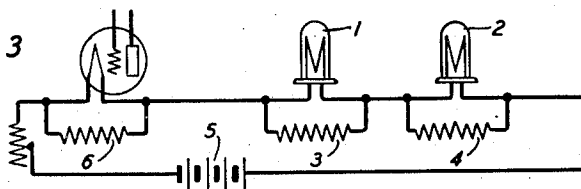
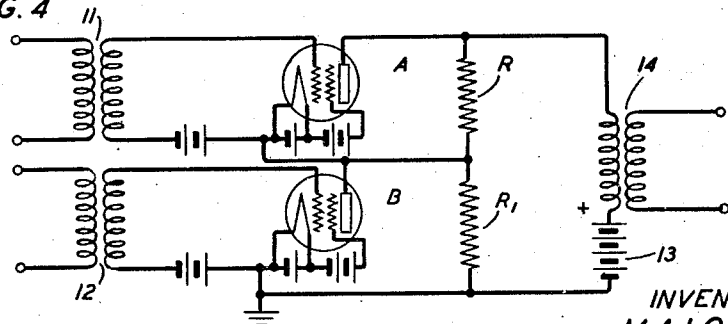


FIG. 4



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REGULATORY DEVICE

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5 Claims. (Cl. 171-229)

This invention relates to regulatory devices and more especially to devices which operate automatically or without constant attention and adjustment to control current flow.

5 The devices to which the invention is more particularly directed include those which, at least in a part of their operating range, will pass less current than would a linear device. Such devices include what are known as ballast lamps, which 10 may have in a portion of their operating ranges a negative resistance characteristic and screen grid space discharge devices which, in a portion of their operating range pass substantially constant plate current with increasing plate voltage.

15 It is well known in the art that certain of such devices, particularly a ballast lamp, will within given limits maintain a substantially constant current flow from a source of variable voltage. When attempt has been made to use more than 20 one such device in series, it has been found that one of them tends to operate at a potential outside its operating range. This results in circuit troubles due to the short life of the device when so used.

25 The present invention has as an object the utilization of devices such as described in series without the attendant difficulties heretofore experienced with such use.

30 Another object of the invention is the current regulation of a circuit having a variable voltage source.

These objects are attained in accordance with this invention by shunting each of a plurality of series-connected devices with a resistance, the 35 value of which depends upon the voltage variation and the difference between maximum and minimum current variation of the devices in use.

The invention will be better understood from the following description and attached drawing 40 forming a part thereof, in which:

Fig. 1 is a curve of the voltage current characteristic of a representative ballast lamp;

45 Fig. 2 is a graph showing the voltage current envelope of ballast lamps of one type and the envelope when a shunt resistance is used;

Fig. 3 is a circuit diagram illustrating one way in which the ballast lamps may be used according to this invention; and

50 Fig. 4 is a circuit diagram illustrating the application of the invention to screen grid space discharge devices having their anode circuits connected in series.

Referring now to Fig. 1, the curve A-B shows that as the voltage drop across a ballast lamp is 55 increased from a low value, the current through

the lamp increases at first rapidly, and then more slowly as the lower limit of the ballasting range is approached. This lower limit for the lamp in question is about 3 volts as indicated at C. 5 Soon after the voltage reaches this limit, the current reaches a maximum and as the voltage drop continues to increase, the current decreases until a minimum value is reached. Beyond this point, the current again increases slowly until 10 as the voltage passes beyond the ballasting range, at approximately 10 volts indicated at D, the current increases at a more rapid rate.

The operating range of the lamp is therefore between points C and D and for the particular case illustrated, these points are approximately 15 3 and 10 volts, respectively. In other words, with a voltage drop across the lamp of some value between 3 and 10 volts, the current through the lamp is substantially constant.

It will also be noted that for a portion of the 20 operating range the lamp has a negative resistance characteristic. For each lamp, therefore, there will be the same current flow at three different voltage drops across it. These three points, however, are not necessarily within the 25 operating range. As a consequence, when ballast lamps heretofore were used in series, one lamp would generally absorb nearly all the voltage, while the other lamp would absorb only a small voltage and both lamps would pass the same current. In many cases, the lamp with the greater voltage drop would be operating outside its operating range and as a consequence would have a relatively short life.

When it is necessary to control a voltage varia- 35 tion greater than the operating range of a single lamp, it is desirable that two or more such lamps be used in series. By using a shunt resistance with each lamp, the disadvantages previously mentioned are overcome. The best regulation occurs with the highest shunt resistance possible. 40 The maximum resistance which can be employed to prevent one lamp absorbing an excessive voltage drop is determined by dividing the maximum allowable voltage difference between lamps 45 by the difference between the specified maximum and minimum currents over their operating range. This may be seen from the following discussion.

In Fig. 2, the rectangle GHKL represents the envelope of a given type of ballast lamp having 50 an operating range between 3 and 10 volts. In this range, the maximum current is .530 ampere and the minimum current is .490 ampere. Point G is at 3 volts and .490 ampere; point H is at 3 volts and .530 ampere; point K is at 10 volts and 55

.530 ampere; and point L is at 10 volts and .490 ampere. The variations of all lamps of this type in their operating range are required by the manufacturer to fall within the rectangle just described.

The line GL connecting points (3 v. and .490 a.) and (10 v. and .490 a.) will be referred to as a minimum lamp, while the line HK connecting the points (3 v. and .530 a.) and (10 v. and .530 a.) will be referred to as that of a maximum lamp. While it is true that no such lamps exist, different lamps may be tangent to these lines at different points so that these lines are the envelopes of all lamps of the given type.

Fig. 3 illustrates a circuit in which two ballast lamps 1 and 2 are connected in series with the cathode of a space discharge device. Assume these ballast lamps to be of the type discussed in connection with Figs. 1 and 2 and assume that battery 5 has a nominal voltage of 24 volts with a variation of plus or minus 4 volts, that is a total variation of 8 volts. As one lamp may only absorb at most a variation of 7 volts, the other must absorb a variation of at least 1 volt in order that the 8 volt change will be absorbed. One lamp may, therefore, have a drop across it which must never exceed 10 volts, while the other may have a drop which will never be less than 4 volts when the battery has a voltage of 28 volts. The greatest allowable voltage difference is therefore $10-4=6$ volts.

It will be assumed that the voltage drop across lamp 1 is E_1 and that across lamp 2 is E_2 . Since either lamp may be in either socket, shunt resistances 3 and 4 must be equal. The current through the lamps may not be equal and to obtain the maximum value of resistance which will take care of any combination of lamps, assume that one lamp is a maximum lamp and that the other is a minimum lamp as defined above.

The current flow through the resistance shunting lamp 1 is E_1/R and that through the resistance shunting lamp 2 is E_2/R . The difference between these currents is

$$\frac{E_1}{R} - \frac{E_2}{R}$$

which must be equal to the difference in current passed by the two lamps in order that the total current flowing into the junction between lamp 1 and lamp 2 be exactly equal to the current flowing out of the junction. Therefore,

$$\frac{E_1}{R} - \frac{E_2}{R} = (I_{\max} - I_{\min})$$

where $I_{\max}$ and $I_{\min}$ are the limits of current for the particular lamps under consideration. This may be rearranged

$$\left(R = \frac{E_1 - E_2}{I_{\max} - I_{\min}} \text{ ohms} \right).$$

As seen above, $E_1 - E_2$ equals 6 volts and for the lamp being considered, the maximum difference in current is .040 ampere. Six volts divided by .040 ampere gives 150 ohms as the value of the shunting resistance for optimum regulation of this particular circuit. Of course, the vacuum tube filament may have to be shunted by a suitably valued resistance to by-pass the excess current obtained from the ballast lamps and resistance combination. The resistance determined above does not change under voltage and current variations and hence the current it will pass will vary linearly with the voltage. At 3 volts the current increase is .02 ampere and at 10 volts the

current increase is .067 ampere. The envelope of the lamp so shunted is shown by parallelogram MNOP of Fig. 2. The corners of the parallelogram corresponding to volts and currents are as follows:

M—3 volts .510 ampere
N—3 volts .550 ampere
O—10 volts .597 ampere
P—10 volts .557 ampere

The excess voltage which might exist across a lamp is therefore eliminated by the resistance and each lamp will be held within its operating range.

At maximum voltage, two maximum or two minimum lamps will each absorb the same voltage and will be at 7 volts ($8+2+3$) and with maximum lamps the maximum current will be

$$I_{\max} + \frac{7}{150} = .576 \text{ ampere}$$

At minimum voltage two maximum or two minimum lamps will each have the same voltage and will be at 3 volts and with minimum lamps the minimum current will be

$$I_{\min} + \frac{3}{150} = .510 \text{ ampere}$$

the current variation, therefore, is less than 6% from the average. In an actual circuit the current variation will be even less because as the current through the circuit increases, there will be an increase in voltage drop in the vacuum tube filaments and series resistances which will decrease the apparent fluctuation at the ballast lamp terminals.

An increase in the number of lamps will furnish less current variation because the value of the shunting resistance will be increased which will decrease the slope of the maximum and minimum combinations.

For circuits employing any number of lamps and having any voltage variation to absorb, providing of course that the total of the capacities of the lamps exceeds the total voltage variations, the following conclusions may readily be derived:

Let E = the total voltage variation

$V_{\max}$ and $V_{\min}$ = limits of voltage across lamps
 n = the number of lamps where n is an integer greater than 1

$I_{\max}$ = the upper limit of current of the lamps between 0 and $V_{\max}$.

$I_{\min}$ = the lower limit of current of lamps between $V_{\min}$ and $V_{\max}$.

R = the resistance to be shunted across each lamp

To determine the maximum shunting resistance

The voltage across each of $(n-1)$ maximum lamps after a minimum lamp has absorbed $(V_{\max} - V_{\min})$ volts will be

$$\left[\frac{E - (V_{\max} - V_{\min})}{n-1} + V_{\min} \right] \text{ volts}$$

and therefore the maximum voltage difference will be

$$V_{\text{diff}} = \left[V_{\max} - \left\{ \frac{E - (V_{\max} - V_{\min})}{n-1} + V_{\min} \right\} \right] \text{ volts} \\ = \frac{n(V_{\max} - V_{\min}) - E}{n-1} \text{ volts} \quad (1)$$

The proper shunting resistance will be Equation (1) divided by $(I_{\max} - I_{\min})$ or

$$R = \frac{n(V_{\max} - V_{\min}) - E}{(n-1)(I_{\max} - I_{\min})} \text{ ohms} \quad (2)$$

Equation 2 gives precisely the highest value of resistance which may be employed for any particular circuit arrangement. For example, if it is desired to control a 16 volt variation with four of the same type lamps employed in the example previously given, it is readily found that

$$R = \frac{4(10-3)-16}{(4-1)(.530-.490)} = \frac{12}{3 \times .04} = 100 \text{ ohms.}$$

To determine the regulation afforded by any circuit, it is necessary to determine the maximum and minimum currents. The maximum current occurs with maximum lamps when the voltage across the lamps is

$$V = \left(V_{\min.} + \frac{E}{n} \right) \text{ volts.} \quad (3)$$

The minimum current occurs with minimum lamps when the voltage across the lamps is

$$V = V_{\min.} \text{ volts.} \quad (1)$$

The maximum current will be

$$I'_{\max.} = \left[I_{\max.} + \frac{V_{\min.} + \frac{E}{n}}{R} \right] \text{ amperes.} \quad (5)$$

and the minimum current will be

$$I'_{\min.} = \left[I_{\min.} + \frac{V_{\min.}}{R} \right] \text{ amperes.} \quad (6)$$

The average current will be

$$I_{av.} = \frac{I'_{\max.} + I'_{\min.}}{2} \text{ amperes.} \quad (7)$$

and the maximum variation in per cent will be

$$100 \left[1 - \frac{I'_{\min.}}{I_{av.}} \right] \%$$

which on substitution gives

$$100 \left[\frac{I'_{\max.} - I'_{\min.}}{I'_{\max.} + I'_{\min.}} \right] \% = 100 \left[\frac{I_{\max.} - I_{\min.} + \frac{E}{nR}}{I_{\max.} + I_{\min.} + \frac{2nV_{\min.} + E}{nR}} \right] \% \quad (8)$$

For example, with the 16 volt variation and four lamps with the 100 ohm shunt as determined with the example following Equation (2), the maximum variation will be

$$100 \left[\frac{.530 - .490 + \frac{16}{4 \times 100}}{.530 + .490 + \frac{2 \times 4 \times 3 + 16}{4 \times 100}} \right] \% = 7.13 \%$$

An increase in the number of ballast lamps with a corresponding increase in shunting resistance will reduce this variation.

If a situation arises where quick heating of the vacuum tube filament is the predominant consideration, all other conditions being the same, some of the series resistance in the filament circuit may be replaced by ballast lamps which, when cold, have a relatively low resistance so that a higher than normal initial current will result which will tend to heat the filament of the vacuum tube quite rapidly. The ballast lamps then heat up and reduce the current to normal. It is desirable to eliminate as much resistance as possible and it is therefore necessary to employ the upper portion of the ballasting range. A value of shunt resistance lower than that computed by the use of Equation (2) is necessary in order to reduce the difference in voltage drop between maximum and minimum combinations in series so that the upper portion of the lamps will be employed. An increase in current variation is

experienced by the use of the lower value of shunting resistance but not as much as might be expected because only the upper portion of the ballasting range is used. In one case that arose in practice, it was found that with two of the same type lamps, used in the examples, each having a 67 ohm shunt, the vacuum tube became operative in the required time with a current variation of less than 8%.

The invention as described has used as an example ballast lamps for regulating filament current flow to a vacuum tube. As another example of using shunting resistances for properly distributing the load, reference is had to Fig. 4. Two screen grid tubes are represented at A and B respectively. The input to tube A is through input transformer 11 or equivalent arrangement while the input to tube B is through transformer 12 or equivalent. The anode or plate current source is indicated by battery 13 which may be any source of direct current.

The output of the tubes is represented as a single output transformer 14. Resistances R and R₁, the values of which may be calculated from the equations given in the preceding discussion, are of equal value and shunt the anode current path through the tubes A and B. The values of these resistances are high relative to the direct current anode-cathode resistances of tubes A and B. The anode path may be traced from the positive terminal of battery 13, primary winding of transformer 14, anode and cathode of tube A, anode and cathode of tube B to the negative terminal of battery 13.

It will readily be seen that with resistances shunted between the anode and cathode of the tubes as indicated, a circuit exists similar to that described in connection with the ballast

lamps and neither tube will be subject to an excessive voltage drop.

What is claimed is:

1. A variable voltage source of current, a work circuit requiring a substantially constant current flow, regulatory devices which have a predetermined operating range and which in part of said range pass less current than a linear device, connected in series between said source and said work circuit, and a resistance in shunt to each of said regulatory devices of a size to insure the operation thereof within their operating ranges.

2. A variable source of current, a work circuit requiring a substantially constant current flow, regulatory devices which have a predetermined operating range and which in part of said range pass less current than a linear device, connected in series between said source and said work circuit, and a resistance in shunt to each of said regulatory devices to insure operation thereof within their operating ranges, each such resistance being proportioned with respect to the regulating current and voltage range of the respective device and to the number of devices in series.

3. A circuit including a source of varying voltage and a plurality of ballast lamps in series for maintaining the current in the circuit substantially constant, the range of variation of voltage of the source exceeding the regulating range of any one of said lamps, and a resistance shunting each lamp, of a size to cause the total voltage

variations in the circuit to subdivide among the lamps such that the variations appearing across each lamp are within the limits of the regulating range of the lamp.

- 5 4. In a circuit having a source of variable voltage, means to hold the current flow substantially constant comprising a plurality of bal-
10 last lamps in series in the circuit, each shunted by a resistance proportioned with respect to the voltage difference over which the respective lamp
15 regulates, the current difference over which the lamp regulates, the number of lamps in series and the voltage variations of the source, for proportioning the voltage variations occurring across each lamp to values within its regulating range.

5. In a circuit having a source of varying voltage, a plurality of current carrying devices in series in said circuit having non-linear volt-ampere characteristics such that there is a tendency for unequal division of the voltage variations 5 among the devices and means to insure operation of each device within its normal range comprising a resistance shunted across each device of a size to cause the total voltage fluctuations to sub-
10 divide among the several devices such as to maintain the voltage variations occurring across each device within predetermined maximum and minimum limits.

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