

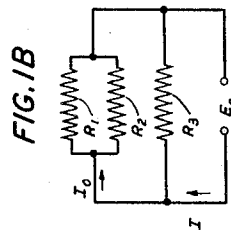
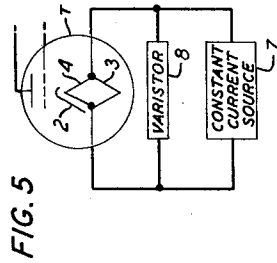
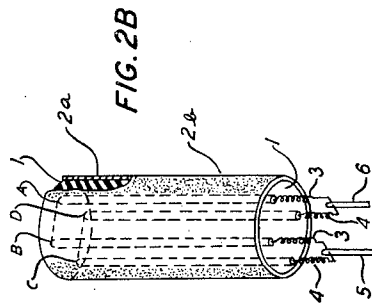
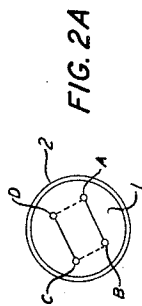
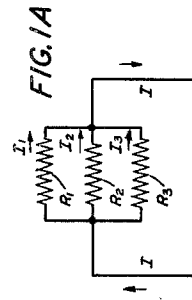
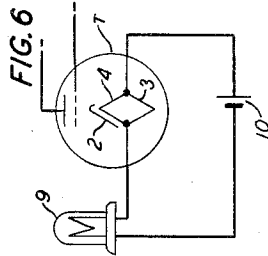
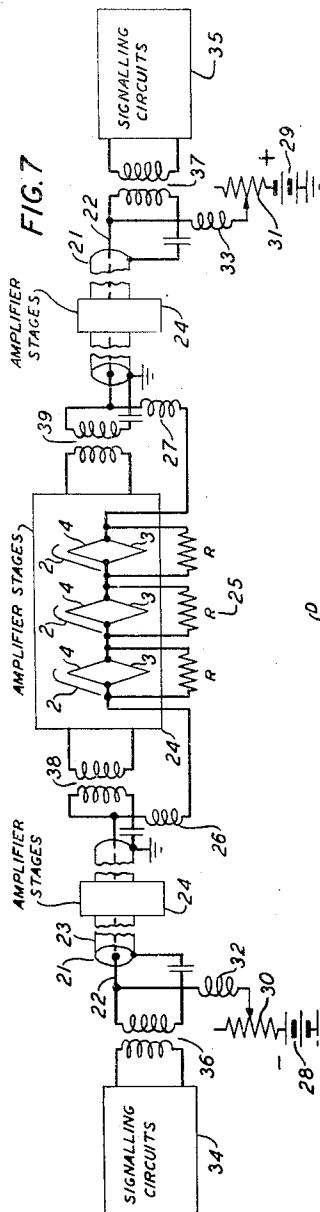
Nov. 22, 1949

E. A. VEAZIE
REPEATED TRANSMISSION SYSTEM, INCLUDING
MULTIFILAMENT AMPLIFIERS

2,488,948

Filed Nov. 28, 1947

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG.3

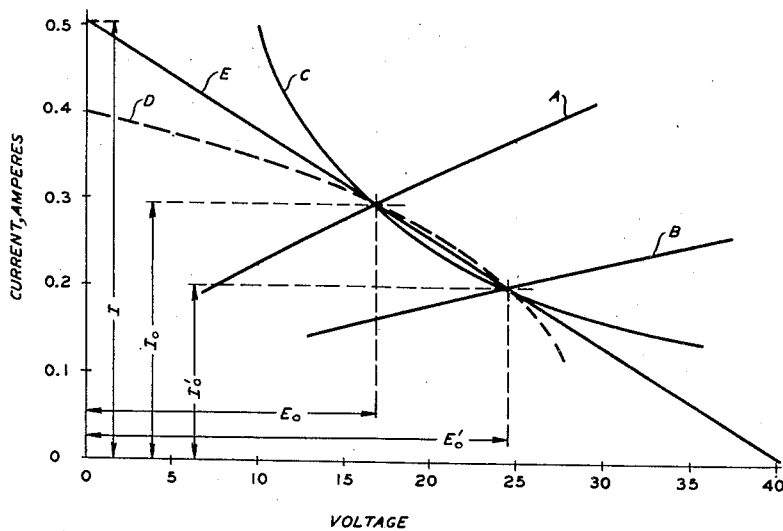
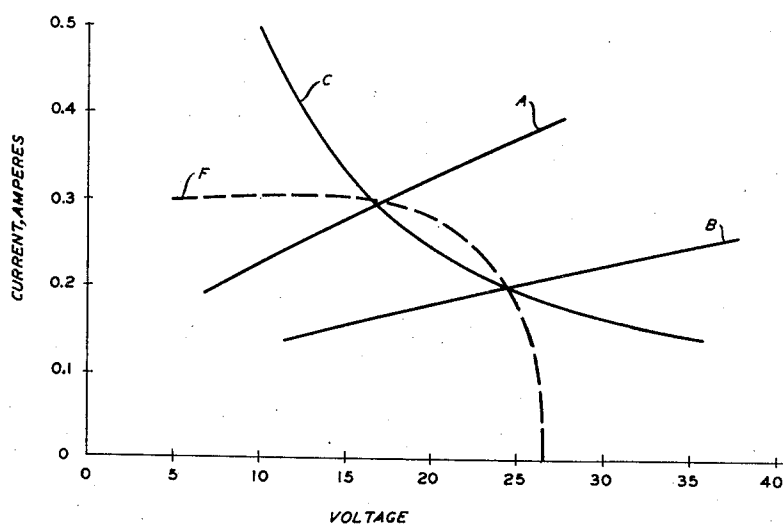


FIG. 4



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UNITED STATES PATENT OFFICE

2,488,948

REPEATERED TRANSMISSION SYSTEM, INCLUDING MULTIFILAMENT AMPLIFIERS

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14 Claims. (Cl. 179-170)

1

This relates in general to electrical transmission systems. More particularly, it relates to an improvement in repeaters in a repeatered submarine cable system.

In an electrical transmission system comprising ocean-bottom or buried repeatered cable sections, the repeaters are inaccessible for ordinary servicing, and replacement of damaged or inoperative repeater units is a costly and time consuming operation, causing interruption of normal transmission service for extended periods. One of the chief potential causes of repeater failure is rupture of vacuum tube cathode heating elements, several per cent of which are apt to be faulty because of inherent defects in the tungsten wire from which they are formed. Thus, in a transoceanic submarine cable system utilizing circuits comprising as many as 100 series-connected vacuum tubes for transmission in each direction, the possibility of open cathode heating elements presents a serious hazard to continuous service. Any means of introducing a large additional factor of safety into such a system appears to warrant serious consideration.

It is therefore the primary object of this invention to increase the operational life of the components, and to thereby decrease the necessary servicing and interruptions to service in an extended electrical transmission system comprising buried or submarine cable sections including repeaters.

A more specific object of the present invention is to provide a vacuum tube suitable for use in repeater amplifier stages which is designed to give a longer period of satisfactory uninterrupted service than those of the prior art.

In preferred form, the present invention relates to an extended submarine cable system including a plurality of repeaters wherein the amplifier tubes are energized by individual heater circuits connected together in series, and each comprising a pair of parallel-connected twin filaments in a single cathode sleeve shunted by an auxiliary resistor of critical design. The power dissipation is thereby maintained substantially constant in each of the individual cathode heating elements, irrespective of the rupture of one of the twin filaments thereof.

The principles of design of the aforesaid auxiliary resistor are set forth in detail, covering the requisites for elements having both linear and non-linear voltage-current characteristics.

In addition to an electrical transmission system of the foregoing type which inherently operates with substantially constant current because of its high over-all resistance, modified forms of the invention are described which are adaptable for use in conjunction with different types of systems, such as those in which constant volt-

2

age is supplied to the vacuum tube heater circuit terminals.

As used in the specification and claims hereinafter, the phrase "cathode heating element" will be understood to refer to a pair of heater filaments connected in parallel in a single cathode sleeve in accordance with the teachings of this invention.

The phrase "cathode heater circuit" or "heater circuit" will refer to the "cathode heating element" as defined in the foregoing paragraph in circuit relation with a critically valued auxiliary resistor, which may be connected thereto in series or in shunt in accordance with the teachings of the present invention.

The invention will be more clearly understood by a study of the detailed specification hereinafter, and the attached drawings in which:

Figs. 1A and 1B are diagrams illustrating the theory of the invention, as hereinafter described;

Figs. 2A and 2B show modifications in the arrangement within the cathode sleeve of a conventional vacuum tube in accordance with the present invention;

Figs. 3 and 4 are graphical representations of experimental data, which illustrate the theory of the present invention;

Fig. 5 shows a schematic arrangement of circuit elements in accordance with the present invention in a system having a substantially constant current supply;

Fig. 6 shows a modified arrangement of elements in accordance with the present invention in a system wherein the voltage supplied to the terminals of the cathode heater circuit is substantially constant; and

Fig. 7 shows a preferred form of the present invention comprising a repeatered submarine cable system in which the amplifier tubes are energized by constant-power cathode heating elements each of which is shunted by an auxiliary resistor of critical design.

For the purposes of illustration, the present invention will be considered primarily in relation to the repeater amplifier stages in an extended submarine cable system of the type described in Patent 2,020,297 to O. E. Buckley et al., November 12, 1935.

In accordance with the present invention, a vacuum tube cathode heating element comprising two similar filaments is mounted within a single cathode sleeve with the filaments connected in parallel either inside the tube or externally. I have discovered that if constant current is supplied to such a cathode heating element in combination with a suitably chosen external resistance, the power dissipated within the cathode sleeve will remain constant even though one of the filaments breaks and ceases to draw power. Thus, in a system such as the dis-

3

closed submarine cable system, it is possible by using a circuit arrangement devised in accordance with the present invention to operate a multiplicity of vacuum tube heater circuits in series, and to maintain the proper cathode temperatures in all of the tubes even though one or more of the individual heater filaments breaks, provided that at least one heater filament in each tube remains intact.

It is apparent that rupture of one unit in a system comprising three units in parallel must increase the resistance between the terminals of the heater circuit. Hence, if the current remains substantially fixed, the voltage and power in the circuit must both increase. The desired result of constant power dissipation by two of the units combined, including one which may or may not have infinite resistance, is achieved by providing for a variation of power in the third unit in exactly the same manner that the total power varies in the combined circuit.

For simplicity, let us consider three linear resistances R_1 , R_2 , and R_3 , connected in parallel, as shown in Fig. 1A of the drawings, R_1 and R_2 representing the equivalent resistances of the twin heater filaments, and R_3 representing the shunting resistor. It is desired to determine a value of R_3 such that the power W_1 dissipated in R_1 plus the power W_2 dissipated in R_2 will be the same for constant current I in the combined parallel circuit whether R_2 equals R_1 or R_2 is infinite. Denoting the various quantities by primes when R_2 is infinite, these requirements give:

$$W_1 + W_2 = W_1' = 2W_1 \quad (1)$$

For linear resistance this means that

$$E' = \sqrt{2}E \quad (2)$$

where E = the voltage drop across the parallel circuit comprising R_1 , R_2 , and R_3 when $R_1 = R_2$; and E' = the voltage drop across such parallel circuit when R_2 is infinite.

Hence

$$I_1' = \sqrt{2}I_1 \quad (3)$$

where I_1 = current through R_1 when $R_1 = R_2$; and I_1' = current through R_1 when R_2 is infinite.

$$I_3' = \sqrt{2}I_3 \quad (4)$$

where I_3 = current through R_3 when $R_1 = R_2$; and I_3' = current through R_3 when R_2 is infinite. Furthermore, since the voltage drop E is the same across R_1 and R_3

$$I_1R_1 = I_3R_3 \quad (5)$$

Since (by stipulation) I remains substantially constant both before and after the break in R_2 ,

$$I = 2I_1 + I_3 = I_1' + I_3' \quad (6)$$

Using Equations 3 through 6 the currents may readily be eliminated, as follows:

$$2I_1 + I_3 = \sqrt{2}I_1 + \sqrt{2}I_3 \quad (7)$$

$$\frac{2I_3R_3}{R_1} + I_3 = \frac{\sqrt{2}I_3R_3}{R_1} + \sqrt{2}I_3 \quad (8)$$

or, eliminating I_3 ,

$$2R_3 + R_1 = \sqrt{2}R_3 + \sqrt{2}R_1 \quad (9)$$

Then

$$\frac{R_3}{R_1} = \frac{\sqrt{2}-1}{2-\sqrt{2}} \quad (10)$$

or

$$\frac{R_3}{R_1} = \frac{1}{\sqrt{2}} \quad (11)$$

4

A simple numerical example can be used to further clarify the theory. Let $R_1 = R_2 = 10$ ohms. R_3 will then be 7.07 ohms in accordance with Equation 11. If $E = 10$ volts:

$$W_1 + W_2 = \frac{E^2}{R_1} + \frac{E^2}{R_2} = 20 \text{ watts}$$

$$I_1 + I_2 + I_3 = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} = 1.00 + 1.00 + 1.41 = 3.41 \text{ amperes} = I$$

If now R_2 breaks or is disconnected it has been shown by Equation 2 that E' should be 14.1 volts if W_1' is to be 20 watts. At E' equal to 14.1 volts:

$$I_1' = \frac{E'}{R_1} = 1.41 \text{ amperes}$$

$$I_3' = \frac{E'}{R_3} = 2.00 \text{ amperes}$$

and $I_1' + I_3' = 3.41$ amperes, the original value of I .

From the above computations, it is apparent that if the total current remains constant through the heater circuit including an auxiliary shunt having a resistance equal to

$$\frac{R_1}{\sqrt{2}}$$

the power dissipated by the cathode heating element remains constant irrespective of whether one or both of the twin filaments R_1 and R_2 are in operation.

Consider next the more general case in which R_1 and R_2 are non-linear resistance elements. Let I_0 represent the total current through this pair of resistors, and E_0 represent the voltage across them for one state in which the total power is at the desired level, as indicated in Fig. 1B of the drawing. Let I_0' and E_0' be the values of voltage and current for the same power for another condition of these resistances. The total current I through R_1 , R_2 and R_3 for the first condition will then be:

$$I = I_0 + \frac{E_0}{R_3} \quad (12)$$

If again I is held the same for the two conditions of the resistances we have also:

$$I = I_0' + \frac{E_0'}{R_3} \quad (13)$$

Combining:

$$I_0R_3 + E_0 = I_0'R_3 + E_0' \quad (14)$$

$$R_3 = \frac{E_0' - E_0}{I_0 - I_0'} \quad (15)$$

It might be noted that for $E_0I_0 = E_0'I_0'$ the numerator and denominator in this expression will always have the same design. R_3 will thus always be positive, a circuit condition which can readily be realized.

Utilizing Equation 15 a more specific expression for R_3 may be derived as follows:

If we let the value of the constant power be denoted by W ,

$$W = E_0I_0 \quad (16)$$

and

$$W = E_0'I_0' \quad (17)$$

Using Equations 15, 16 and 17 the voltages may be eliminated giving

$$R_3 = \frac{W}{I_0 - I_0'} \frac{I_0' - I_0}{I_0' - I_0'} \quad (18)$$

5

or

$$R_3 = \frac{W(I_0 - I_0')}{I_0' I_0} \quad (19)$$

or

$$R_3 = \frac{W}{I_0' I_0} \quad (20)$$

From Equations 16 and 20:

$$R_3 = \frac{E_0}{I_0'} \quad (21)$$

From Equations 17 and 20:

$$R_3 = \frac{E_0'}{I_0} \quad (22)$$

From Equations 21 and 22 we may write

$$R_3^2 = \frac{E_0'}{I_0} \cdot \frac{E_0}{I_0'} \quad (23)$$

or, rearranging

$$R_3^2 = \frac{E_0'}{I_0'} \cdot \frac{E_0}{I_0} \quad (24)$$

But

$$\frac{E_0'}{I_0'}$$

is simply the resistance of a single heater filament operated at the desired power level and

$$\frac{E_0}{I_0}$$

is the resistance of the parallel heater filaments operated at the same power level. Thus Equation 24 shows that R_3 should be the geometric mean of the resistances for the two conditions at which the power is to be the same. This holds even though the heater filaments do not have linear resistances.

It is thus apparent that the expression for the auxiliary resistance

$$R_3 = \frac{R_1}{\sqrt{2}}$$

which was derived hereinbefore for the conditions in which R_1 , R_2 and R_3 are linear, and $R_1 = R_2$, is merely a special case of the general expression derived above.

Several physical embodiments of the invention will now be described in which principles set forth in the foregoing paragraph are applied by connecting a critically valued auxiliary resistor in series or in shunt with a vacuum tube cathode heating element comprising twin filaments connected in parallel. A vacuum tube which may be structurally modified in accordance with Figs. 2A and 2B to permit operation of two conventional hairpin spiral filaments in parallel is disclosed, for example, in Patent 1,936,187 to A. H. Denzler, November 21, 1935.

Referring to Figs. 2A and 2B, an extruded cylindrical insulating element 1, having a cross-sectional dimension of the order of a small fraction of an inch, is designed to be supported in a central position in a tube of the type referred to in the foregoing paragraph. The insulating element 1 is surrounded by the cathode 2 which comprises a nickel sleeve 2a on which has been sprayed a cathode coating 2b comprising the usual electron emitting material. In addition, the insulating element 1 is provided with four internal bores of the order of one-hundredth of an inch in diameter, which are parallel with the

6

longitudinal axis thereof, and which are arranged symmetrically thereabout, so that a substantial spacing is provided between each bore and the bores adjacent thereto. Reading in a clockwise direction on the cross-sectional view of Fig. 2A, the bores are labeled A, B, C and D. The helically wound U-shaped filaments 3 and 4, are coated with a thin layer of ceramic, and are of such dimensions relative to the diameters of the bores A—D, that they may be readily inserted therein. Preferably, the filaments 3 and 4 are respectively arranged to occupy adjacent bores, although they may be cross-connected if properly insulated at the point of cross-over. The ends of the filaments 3 and 4 are brought out below the insulator 1 and connected in parallel to the terminals 5 and 6.

With such an arrangement of filaments 3 and 4 in a common cathode sleeve, the teachings of the present invention can be applied in each of the specific modifications described in detail herein-after by connecting the heating element terminals 5 and 6 to a suitable source of current and connecting the proper critically valued auxiliary resistor in series or in shunt therewith, as the case demands.

The several embodiments of the invention including a twin-element tube such as shown in Figs. 2A and 2B which will be described herein-after will be better understood by reference to the curves of Fig. 3. These curves representing the current in the heating element as the function of the applied voltage, are based on the operation of an experimental tube equipped with twin filaments, such as indicated in Fig. 2B, in which one end of each filament is brought out through a separate tap, whereby the two filaments are readily connected either in parallel or with a single filament in the circuit, and the other disconnected.

The purpose of the curves is to further clarify the theory discussed hereinbefore by a graphical representation of the manner in which the circuits of Figs. 1A and 1B function. Curve A, which shows the voltage-current relationship for the twin filaments connected in parallel, and curve B, which shows that for a single one of the filaments, are plotted in coordinate axes of which the Y axis represents current in amperes, and the X axis represents voltage in volts.

Drawn across the two characteristic curves is a hyperbola C showing the locus of all points for which the power EI equals some chosen constant value, in this case 5.0 watts. The intersections of the hyperbola C with the characteristic curves A and B give the operating points at which the cathode power is equal to 5.0 watts. If a line be drawn through these points extending through the vertical current axis, the point of intersection gives directly the total current I which must be supplied to the tube shunted by the resistor. The correct value for the shunting resistor R_3 in accordance with the present invention is given by the negative reciprocal of the slope of this line. The significance of a number of the other symbols used in the foregoing theoretical discussion such as I_0 and E_0 , which represent the current in the heater circuit and the voltage thereacross before the rupture of one of the twin elements, and I_0' and E_0' , which represent current and voltage values after such rupture, is also indicated.

One fact of interest is that the tungsten temperature has been found to be only moderately higher when only one of the twin heater fila-

ments is operating than when both are operating. As noted hereinbefore, inherent defects in the wire more often cause failure of heater filaments than "burn-out" because of excessive operational temperatures. Rupture of one filament of a pair thus does not seriously reduce the life of the other.

In accordance with a modified form of the present invention, such as shown in Fig. 5 of the drawings, considerable reduction in power wastage is effected by use of a suitable non-linear resistance in place of R_3 . This resistance is preferably designed to meet the requirement that the current through it increase by an amount equal to $I_0 - I_0'$ as the potential drop thereacross changes from E_0 to E_0' ; and in addition, that the current increase more rapidly than the applied voltage.

A preferred form of resistance element of a type which meets the foregoing requirements of design is described in an article entitled "Silicon carbide varistors" by R. O. Grisdale, Bell Laboratories Record, volume XIX, No. 2, October 1940.

Referring to Fig. 5, a space discharge device T of the type described, with reference to Figs. 2A and 2B hereinbefore, has a cathode heating element comprising twin heater filaments 3 and 4 connected in parallel within the sleeve of the electron-emitting cathode 2. The heating element comprising filaments 3 and 4 is connected in series with a substantially constant source of current 7, which may be construed as any electrical system having a resistance of such relative magnitude that rupture of one of the filaments 3 or 4 causes a substantially inappreciable change in the total current through the system.

Connected across the heating element terminals in parallel with the twin filaments 3 and 4 is a silicon carbide varistor 8 of the type described in the article by Grisdale, supra, and designed in accordance with the teachings of this invention to maintain the dissipation of power into the cathode 2 substantially constant, irrespective of the rupture of one of the filaments 3 or 4.

The potential saving in power which might be achieved using a circuit such as shown in Fig. 5 is shown by the broken line curve D of Fig. 3, which represents a possible current-voltage characteristic of the varistor 8. The curve D indicates a reduction of 50 per cent in the current wastage in the circuit of Fig. 4, over that required in a circuit, such as shown in Fig. 1, in which R_3 is linear.

It is also apparent from further analysis of the curves of Fig. 3 that the resistance R_3 , if connected in series with the cathode heating element, produces a combination which if operated at a relatively high total voltage, in this case about 41 volts; also results in constant power dissipation within the cathode, regardless of whether only one filament or both are functioning. Thus, tubes operated on a constant voltage supply basis, such as shown in Fig. 6 of the drawing, can also be made to function if one of a pair of twin filaments breaks. Here again a considerable saving in power may be obtained by use of a non-linear resistance for R_3 . In this case, however, the auxiliary resistance unit should increase in resistance with increase in voltage across its terminals.

The requirement of a non-linear resistance which increases with voltage increase is substantially met in a ballast lamp, such as is dis-

closed in an article entitled "The ballast resistor in practice" by H. A. Jones, General Electric Review, volume XXVIII, No. 5, May 1925. The design theory of such devices is discussed further by the same author in an article entitled "The theory and design of ballast resistors" in the September 1925 issue of the same periodical. A resistor of this type for use with a cathode heating element having the characteristics illustrated in Fig. 3 should pass a current of 0.300 ampere at some voltage in the flat section of its characteristic, and at a voltage 7.7 volts lower should pass a current of 0.205 ampere. From Table I of the latter paper it is seen that for the conditions specified a filament 0.00254 centimeter in diameter and one centimeter long would pass 0.304 ampere at 4.5 volts and 0.301 ampere at 7.0 volts. These current values are sufficiently close to the desired 0.300 ampere to be satisfactory. For such a filament two centimeters long the corresponding voltages would be 9.0 and 14.0 volts. This filament would be satisfactory provided that at 0.205 ampere the voltage across it lies in the range 1.3 to 6.3 volts, 7.7 volts below the ballasting range.

From the data included in the two papers it has been calculated that for a filament as above passing a current of 0.205 ampere the voltage would be 1.3 volts. Since from Fig. 3 the voltage across a single tube filament at this current is 24.5 volts, the supply voltage for use with this lamp filament and cathode heating element would be $24.5 + 1.3$ or 25.8 volts. This is made clearer in Fig. 4. By the same method it may be shown that $I_{360} = 0.204$ ampere and $E_{360} = 1.3$ volts.

Fig. 4 illustrates the way in which this ballast lamp would function. Curves A, B and C here are the same as in Fig. 3. Curve F shows the calculated ballast lamp current as a function of the supply voltage minus the ballast lamp voltage. It is apparent that for a supply voltage of approximately 26 volts the desired conditions are met. The saving in supply voltage in this case in comparison with that for use of a linear series resistor is thus of the order of 15 volts.

Referring to Fig. 6, an electron discharge device T, such as described hereinbefore with reference to Figs. 2A and 2B, has a cathode 2 energized by twin parallel-connected heater filaments 3 and 4, which are connected in series with a ballast lamp 9 of the type described, and a source of substantially constant potential, such as the storage battery 10. This circuit functions in the manner described hereinbefore to maintain the power dissipated within the cathode 2 substantially constant, irrespective of the rupture of one of the twin filaments 3 or 4.

The discussion hereinbefore leads readily to a generalization of the requirements for maintaining constant power. Basically, the regulation of the power source should be such that a change in the current load from I_0 to I_0' causes a change in the voltage across the cathode heating element from E_0 to E_0' . If the regulation is too good, as in the constant voltage case, it must be made poorer by use of a series resistor. If the regulation is poor, as in the constant current case, it must be improved by use of a shunt resistor. In any case, the resistance between the terminals of the cathode heating element looking back from that element should be adjusted to have the value

$$R = \frac{E_0' - E_0}{I_0 - I_0'}$$

Two further items of interest may be developed from a study of the curves of Fig. 3. The total power including loss in R_3 with both filaments functioning is $E_0 I$ and amounts, for example, in the actual case shown, to 8.45 watts. In this illustrative case the useful power actually supplied to the cathode was 5 watts, the indicated efficiency thus being about 59 per cent. It may also be noted in the case under consideration that the indicated voltage rise when one filament opens would be $E_0' - E_0$ or 7.8 volts, or about 47 per cent of the normal voltage across the heating element. If several tubes in series are being considered, the voltage rise brought about by a single open filament would not be excessive from a practical standpoint.

It will be apparent to those skilled in the art that the twin heater filaments referred to in the foregoing discussion might be of any conventional type. While some forms might afford less wastage of power than others, and therefore, be more desirable, any type can theoretically be used. Moreover, from the theory set forth hereinbefore it is apparent that three or more heater filaments of equal resistance might be used in parallel with any of the circuit arrangements of the present invention, the value of the resistor R_3 being correspondingly modified.

It will be further apparent from a study of the curves of Fig. 3 that by selecting a proper value of resistance for R_3 a predetermined change either upward or downward in power level can be made to result from failure of one of a pair of parallel heater filaments. As one limit E_0' may be made to approach E_0 by making R_3 small; or I_0' may be made equal to I_0 by making R_3 infinite.

The principles of the present invention as set forth hereinbefore, as embodied in the circuits shown in Figs. 1A, 1B, 5 and 6 of the drawings and described with reference thereto, and as also embodied in other circuits not shown herein which comprise elements having substantially equivalent functions to the elements in the circuits shown, are adapted for use in many different types of electrical systems and are not limited to use in the particular type of system which will now be described as an illustrative embodiment.

A preferred embodiment of the present invention which is shown in Fig. 7 of the drawings contemplates the use of a multiplicity of heater circuits designed in accordance with the principles hereinbefore set forth, which are connected in series to energize the cathodes in the repeater amplifier stages in an extended under-sea cable system for the transmission of speech and telegraph signals, such as disclosed in the patent to O. E. Buckley cited hereinbefore.

Referring in detail to Fig. 7, the submarine cable 21 comprises a plurality of sections, each having an inner conductor 22 and a grounded outer conductor 23, which are connected in series through a plurality of repeater stations comprising the amplifier stages 24 which may be assumed for the purposes of illustration to be substantially similar in circuit detail, with the exception of the heater circuits 25, to the disclosure of Fig. 2 of Patent 2,342,544 to O. B. Jacobs, February 22, 1944.

The heater circuits 25 may assume any of the forms described hereinbefore which are adapted to operate with a substantially constant supply of current, such as those in Fig. 1A, 1B and 5, and including an arrangement of heater elements such as described with reference to Figs. 2A and

2B. The heater filaments 3 and 4 which are included in the heater circuits 25 have substantially equal values and are connected in parallel within the sleeve of the cathode 2, in a manner described in detail hereinbefore. Moreover, the parallel combination of heater filaments 3 and 4 is shunted by the critically valued resistance element R . The voltage-current characteristic of the element R , in accordance with the theory set forth hereinbefore, should have a slope approximating the geometric mean of the resistance values of the heater filaments 3 and 4 in parallel operating at the desired power level and that of one of the filaments alone operating at the same power level. If the element R is non-linear, it may assume forms such as described in detail with reference to Fig. 5 hereinbefore.

At each group of amplifier stages 24, the heater circuits 25 are connected in series with respective sections of the inner cable conductor 22 through the high frequency choke coils 26 and 27. Energizing current of the order of 0.5 ampere for the heater circuits 25 is derived from the negative direct current source 28 at the western cable terminal and from the positive direct current source 29 at the eastern cable terminal. The source 28, which is of the order of 2000 volts, is connected to the inner conductor 22 through a circuit which includes the adjustable rheostat 30 and the high frequency choke coil 32; and likewise, the positive direct current source 29, also of the order of 2000 volts, to the inner cable conductor 22 through a circuit which includes the adjustable rheostat 31 and the high frequency choke coil 33.

Speech and/or telegraph signals are transmitted over the submarine cable system 21 in the usual manner, utilizing conventional signaling circuits 34 and 35 which are respectively located at the western and eastern cable terminals, and which are coupled to the central cable conductor 22 at said respective terminals through the transformer circuits 36 and 37. At each of the repeater stations input and output transformers 38 and 39 provide similar coupling for the transmission of speech and telegraph signals between the amplifier stages in the said repeater circuits and successive sections of the central cable conductor 22.

It is thus apparent that the possibility of interruptions to service and the necessity for costly repairs resulting from ruptured vacuum tube heating elements in a conventional submarine cable system comprising a large number of repeaters is reduced by a large factor in a system of the type disclosed in the foregoing paragraphs.

What is claimed is:

1. An electrical transmission system including repeaters, one of said repeaters including a space discharge device having a cathode, and a separate energizing circuit for said cathode, said circuit comprising a pair of cathode-heating filaments of substantially equal resistance connected in parallel, means for maintaining the total power dissipated in said filaments at a substantially constant value irrespective of the rupture of one of the filaments of said pair, said means comprising an auxiliary resistance element connected in shunt with said pair of filaments.

2. A system in accordance with claim 1 in which said auxiliary resistance element is of the same order of magnitude as the resistances of said pair of filaments.

3. A system in accordance with claim 2 in which said auxiliary resistance has a value which

11

approximates the geometric mean of the resistance of the filaments of said pair connected in parallel and the resistance of one of said filaments connected singly.

4. An electrical transmission system having repeater circuits comprising space discharge devices having separately energized cathodes, an energizing circuit for each of said space discharge devices, said energizing circuits connected in series to a source of power, certain of said energizing circuits comprising a pair of substantially equal cathode-heating resistances connected in parallel, and an auxiliary resistance connected in shunt with the resistance of said pair.

5. A system in accordance with claim 4 having substantially constant current, irrespective of the rupture of one of the cathode-heating resistances of said pair.

6. A system in accordance with claim 5 in which said auxiliary resistance is of the same order of magnitude as the cathode-heating resistance of said pair.

7. A system in accordance with claim 6 in which said auxiliary resistance has a value which approximates the geometric mean of the cathode-heating resistances of said pair connected in parallel and one of said cathode-heating resistances connected singly.

8. A system comprising in combination a substantially constant source of current, a space discharge device including a separately energized cathode, an energizing circuit for said cathode connected in circuit relation with said source, said energizing circuit comprising a pair of substantially equal cathode-heating resistances connected in parallel, and means comprising an auxiliary resistance connected in shunt with the cathode-heating resistances of said pair to maintain the power dissipated by said energizing circuit at a substantially constant value, irrespective of the rupture of one of the cathode-heating resistances of said pair.

9. A system in accordance with claim 8 in which said auxiliary resistance comprises a varistor having a voltage-current characteristic such that the current increase is greater than in direct proportion to the applied voltage.

10. A system comprising in combination a substantially constant source of voltage, a space discharge device including an indirectly heated cathode, a cathode energizing circuit for said cathode in circuit relation with said source, said energizing circuit comprising a pair of substantially equal heating resistances connected in parallel, and an auxiliary resistance connected in series with said energizing circuit, said auxiliary resistance having a value which approximates the geometric mean of the heating resistances of said pair connected in parallel and one of said heating resistances connected singly.

11. A system in accordance with claim 10 in which said auxiliary resistance comprises a device having a voltage current characteristic such that the current increase is less than in direct proportion to the applied voltage.

12

12. A system comprising in combination a source of power, a space discharge device including a cathode energizing circuit in circuit relation with said source, said energizing circuit comprising a pair of substantially equal heating resistances connected in parallel, and means connected in circuit relation with said energizing circuit to maintain the power dissipation in said energizing circuit substantially constant, said means comprising an auxiliary resistance having a value which approximates the geometric mean of the heating resistances of said pair connected in parallel and one of said heating resistances connected singly.

13. A submarine cable system comprising in combination a plurality of cable sections interconnected with repeaters, said repeaters comprising signal-repeating tubes having indirectly heated cathodes energized by individual heater circuits, all of said heater circuits connected in series with each other through said cable sections, a source connected to supply energizing current to said heater circuits over said cable sections, certain of said heater circuits comprising a cathode heating element which comprises a plurality of resistances connected in parallel in a single cathode sleeve, and an auxiliary resistance connected in parallel with said heating element, the said cable system having so great a resistance that the current supplied by said source remains substantially constant irrespective of the rupture of one of the resistances of said element, and said auxiliary resistance having such a value that the power dissipated in said heating element remains substantially constant irrespective of the rupture of one of the resistances of said element.

14. A system in accordance with claim 13 in which said heating element comprises a pair of substantially equal heating resistances connected in parallel, and said auxiliary resistance has a value which approximates the geometric mean of the heating resistances of said pair connected in parallel and one of said heating resistances connected singly.

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