May 8, 1945. C. T. SCULLY 2,375,497

CIRCUIT ARRANGEMENTS FOR RESISTANCE ELEMENTS HAVING A HIGH RESISTANCE-TEMPERATURE COEFFICIENT

Filed Aug. 25, 1943 2 Sheets-Sheet 1

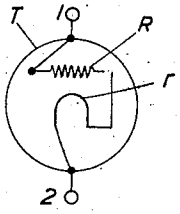


FIG. 1.

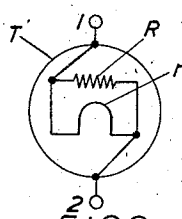


FIG. 2.

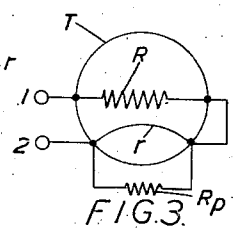


FIG. 3.

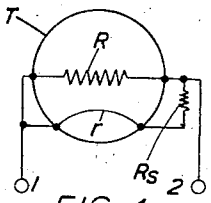


FIG. 4.

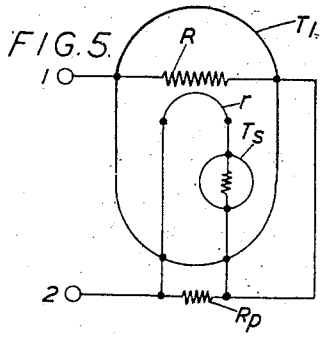


FIG. 5.

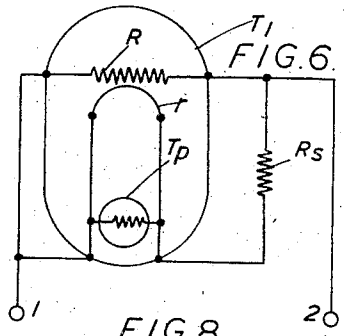


FIG. 6.

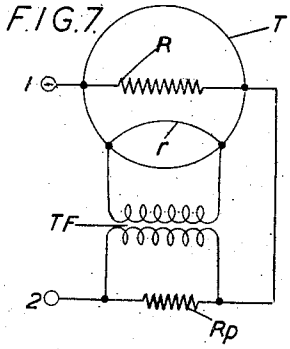


FIG. 7.

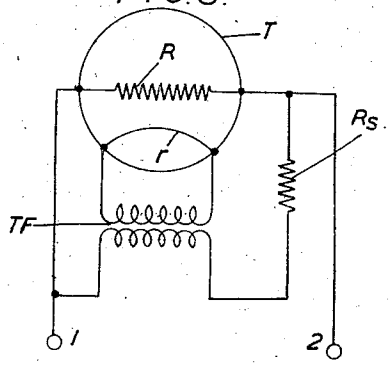


FIG. 8.

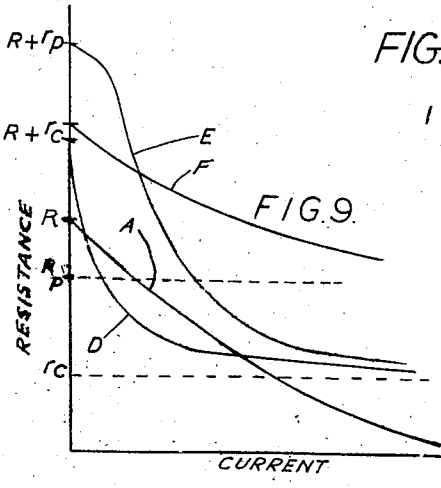


FIG. 9.

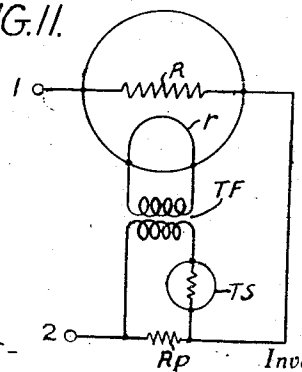


FIG. 11.

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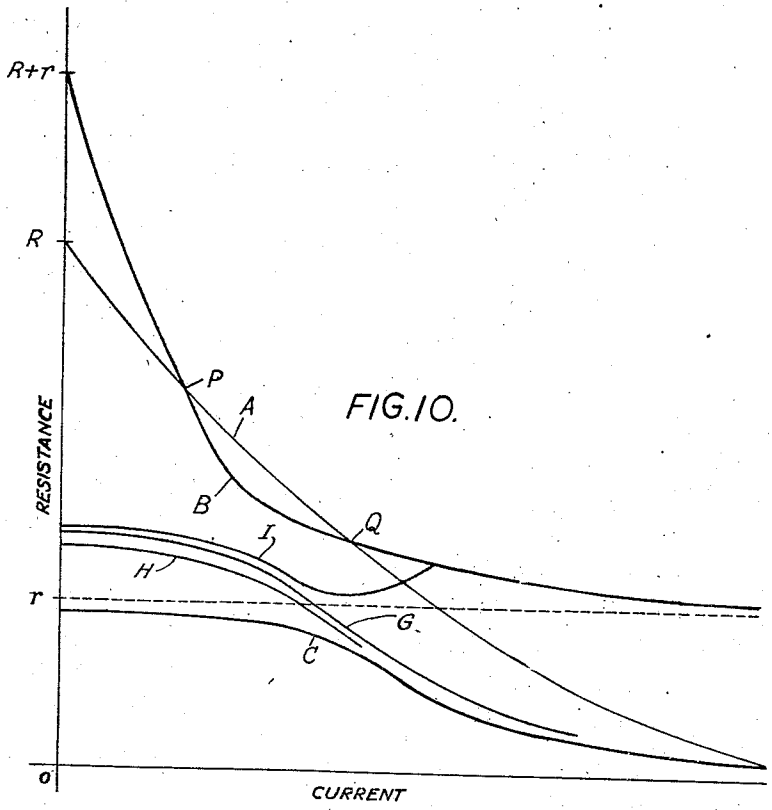


FIG. 10.

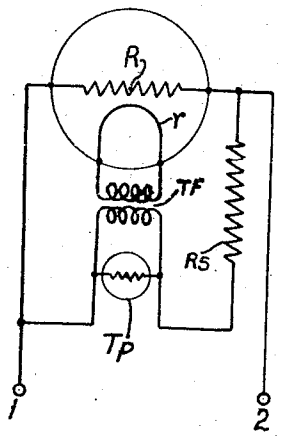


FIG. 12.

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CIRCUIT ARRANGEMENT FOR RESISTANCE ELEMENTS HAVING A HIGH RESISTANCE-TEMPERATURE COEFFICIENT

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Application August 25, 1943, Serial No. 500,001
In Great Britain May 29, 1942

4 Claims. (Cl. 219—20)

The present invention relates to circuit arrangements for modifying the resistance characteristics of thermally sensitive resistance devices such as those known as Thermistors.

Thermistors have been in use for some years and are characterised by a temperature coefficient of resistance which may be either positive or negative and which is moreover many times the corresponding coefficient for a pure metal such as copper. This property renders thermistors particularly suitable for a variety of special applications in electric circuits.

Various different materials are available for the resistance element of a thermistor, these various materials having different properties in other respects; as one example, a resistance material having a high negative temperature coefficient of resistance comprises a mixture of manganese oxide and nickel oxide, with or without the addition of certain other metallic oxides, the mixture being suitably heat treated.

Thermistors have been employed in two different forms: (*a*) known as a directly heated Thermistor and comprising a resistance element of the thermally sensitive resistance material provided with suitable lead-out conductors or terminals, and (*b*) known as an indirectly heated Thermistor comprising the element (*a*) provided in addition with a heating coil electrically insulated from the element. A directly heated thermistor is primarily intended to be controlled by the current which flows through it and which varies the temperature and also the resistance accordingly. Such a thermistor will also be affected by the temperature of its surroundings and may therefore be used for thermostatic control and like purposes with or without direct heating by the current flowing through it. An indirectly heated thermistor is chiefly designed to be heated by a controlling current which flows through the heating coil and which will usually, but not necessarily, be different from the current which flows through the resistance element, but this type of thermistor may also be subjected to either or both of the types of control applicable to a directly heated thermistor.

More detailed information on the properties of thermistors will be found in an article by C. L. Pearson in the Bell Laboratories' Record Dec. 1940, page 106.

The present invention is concerned with circuit arrangements by which the resistance characteristic of an indirectly heated thermistor may be modified.

According to the present invention, there is provided a two-terminal non-linear electric resistance network comprising an indirectly heated thermistor having its resistance element and heating coil connected in the network in such manner that the said resistance element is heated both directly and indirectly by the current supplied to the terminals of the network, or by a proportion thereof.

According to another aspect, the invention consists in a two-terminal non-linear electrical resistance network comprising an indirectly heated thermistor, in which the resistance-current characteristic of the network is controlled by associating the resistance element and heating coil of the thermistor in a circuit so that both the heating coil and the resistance element are traversed by the current which is supplied to the network terminals, or by a proportion thereof.

The invention will be described with reference to the accompanying drawings in which Figs. 1 to 8, 11 and 12 show schematic circuit diagrams of a number of different embodiments of the invention, and Figs. 9 and 10 show characteristic curves for a thermistor.

The curve which gives the relation between the resistance of a thermistor element and the power expended in heating it is much the same whether the element is heated by the current which passes through it or by the current which passes through the heating coil. If the heating coil and the element be connected in series, the same current passes through both of them, and the thermistor will be subjected to heating from both sources at the same time. If, therefore, the curve relating the resistance to the current be plotted for the two cases: (A) the resistance element alone, and (B) the element in series with the heating coil, different curves will be obtained and the shape of the (B) curve will depend on the relative values of the cold and hot resistances of the element and the resistance of the heater (assumed to be approximately constant).

In Fig. 10 curve A shows the relation between the current and the resistance for a typical thermistor having a negative temperature coefficient, the heating coil not being included in the circuit, and curve B shows the relation between the current and the sum of the resistances of the element and the heating coil when they are connected in series. If R is the cold resistance of the element and r that of the heating coil, then it is evident that for zero current the combined resistance will be $R + r$ and the curve B will start on the resistance axis r units above curve A. At some point P for a moderate current, the additional power contributed by the heating coil will

make the resistance of the element just r units less than before, so that the combined resistance is the same. The two curves A and B therefore cross at P; and the combined resistance will clearly be less than before for larger currents. The curve B is thus initially steeper than curve A.

For large currents the resistance of the element alone as given by curve A will become less than r; accordingly when the power from the heating coil is added, the resistance of the element alone will be still further reduced so that ultimately the curve B will become asymptotic to the resistance r which is indicated by the horizontal dotted line. The two curves must therefore cross again at some point Q as indicated. At the point Q the combined resistance is again just r units less than that of the thermistor alone.

The positions of the points P and Q will depend on the relation between the resistance of the element and the heating coil. If r is small compared with R the later portion of the curve B will principally be affected. If, however, r and R are of the same order, then the early portion will be considerably affected and the curve B will be much steeper than the A curve.

If the resistance element and the heating coil be connected in parallel instead of in series a different kind of characteristic shown at C in the figure will be obtained. If R is large compared with r, the resistance of the combination will be slightly less than r for small currents and will decrease at first slowly as the current is increased until the element resistance becomes comparable with r when the decrease will become increasingly rapid, and the curve of the combination will then be ultimately asymptotic to the curve for the element alone, when the element resistance becomes much less than r.

The curves may be further modified by connecting a constant resistance or another thermistor in series or in parallel with the heating coil, by which the proportion of the current flowing in the heating coil may be varied.

It will also be evident that a different series of curves will be obtained if the thermistor has a positive temperature coefficient.

Figures 1 to 8 show a number of examples of resistance networks according to the invention. In all these figures R denotes the resistance element of an indirectly heated thermistor T and r is the corresponding heating coil. In each of the arrangements terminals 1 and 2 are the terminals of the resistance network by which it will be connected into a circuit in order to produce a resistance-current characteristic having some desired form or features.

Figs. 1 and 2 show the simplest arrangements according to the invention, in which the elements R and r are connected in series or in parallel, respectively to the terminals 1 and 2. Thus if the thermistor has a negative temperature coefficient of resistance, Fig. 1 will produce the curve B and Fig. 2 the curve C of Figure 10. It will be noted from curve C that the parallel arrangement acts to delay the resistance change until the current has become moderately large.

As has already been mentioned, the resistance characteristic of the network may be modified by the use of additional resistances of the ordinary type. Thus in Fig. 3, which corresponds to Fig. 1, the heating coil r is shunted by a resistance R_p. This will have two effects:

1. It will reduce the resistance connected in series with R.

2. It will reduce the power available for indirectly heating the thermistor for the same current at the terminals 1 and 2.

Thus the curve B will be modified by making it generally lower, and also less steep over the earlier portion.

In Fig. 4, which corresponds to Fig. 2, a resistance R_s has been connected in series with the heating coil r. This will also have two effects:

1. It will increase the resistance connected in parallel to R.

2. It will reduce the power available for indirectly heating the thermistor and will increase that available for directly heating it for the same current at the terminals 1 and 2.

The effect in the curve C will be to make it generally higher, to make the sloping portion of the curve steeper and to make it occur earlier. See curve G (Fig. 10).

Figs. 5 and 6 show how still other variations in the characteristics may be obtained by the use of an auxiliary directly heated thermistor. Fig. 5 is derived from Fig. 3, and shows an indirectly heated thermistor T having a resistance element R and heating coil r, and mounted in the same envelope is a separate directly heated thermistor T_s which is connected in series with the heating coil r. It will be assumed that the thermistor T_s does not appreciably heat the resistance element R and that r does not appreciably heat T_s. It will be further assumed that T_s has a negative temperature coefficient of resistance.

Fig. 9 has been drawn to indicate the effect of including the thermistor T_s. In this figure, curve A is the characteristic curve for the thermistor T_1 alone, and is of the same type as the curve A in Figure 10.

Curve D is the curve like curve B which would have been obtained if the thermistor T_s had been short circuited. It starts on the resistance axis at a point r_c units above the point R, where r_c is the equivalent parallel resistance of the heating coil and the shunt resistance, and is equal to $r \cdot R_p/(r+R_p)$. If the thermistor T_s is now included, and if its resistance be initially high, there will be practically no indirect heating of the element R_1 for small currents and the corresponding characteristic curve E for the combination will start on the resistance axis R_p units above the curve A and will at first run practically parallel to A. However, when the resistance of the thermistor T_s begins to fall, the curve E will begin to turn downwards as indicated and will become almost as steep as the curve D. If the thermistor T_s be chosen so that for large currents its resistance is small compared with r, the characteristic curve E will be ultimately asymptotic to the resistance r_c, as before.

It will be seen that the effect of the thermistor T_s is to delay the steep fall of resistance of the combination, and this may be used to provide a critical current or voltage for operating relays or the like.

If the thermistor T_s has a positive temperature coefficient of resistance, and if its initial resistance be moderately low, that is, less than or not more than r, the indirect heating of the element for small currents will be only a little less than without T_s in circuit and its curve F (Fig. 9) will start at a point on the resistance axis just above the start of curve D. As the resistance of T_s increases the heating current is reduced and the effect will be to produce a curve

rather like A, but flatter and less steep, which will be asymptotic to the resistance R_p.

Fig. 6 corresponds to Fig. 4, and a directly heated thermistor T_p is connected in parallel with the heating coil r. Assuming, first, that T_p has a positive temperature coefficient, and that its cold resistance is small compared with r, the characteristic curve will be practically the same as that for Fig. 4 (similar to curve C) for large currents, but will be rather lower for small currents, since the thermistor T_p will practically short-circuit r. See curve H (Fig. 10). If the thermistor T_p has a negative temperature coefficient, and has a resistance which is initially large compared with r, the early part of the curve will be substantially the same as for Fig. 4, but the later part may tend to a rather higher resistance than for Fig. 4, and the resistance of the combination may increase with increasing current for large currents owing to the reduction of the heating current through r by the thermistor T_p. See curve I (Fig. 10).

In all the explanations so far, the resistance element R has been assumed to have a negative temperature coefficient of resistance; if it has a positive temperature coefficient, a different series of characteristics will be obtained, and the main features of these characteristics can be derived from considerations similar to those of the above discussion.

In the manufacture of some types of thermistors, while the resistance characteristics of R can be varied over an extensive range, practical considerations tend to restrict the possible choice of the value of the heating coil resistance r to relatively low values over a rather narrow range. In alternating current circuits, this limitation may be completely overcome by associating a transformer with the heating coil, whereby its resistance effective in the circuit may be made any desired value.

Two examples are shown in Figs. 7 and 8 corresponding respectively to Figs. 3 and 4. In each case the heating coil r is connected to the rest of the circuit through a transformer TF which may be given any desired ratio. The characteristics of the network measured at terminals 1 and 2 using alternating currents will be substantially as explained, and will not be restricted by the practical limitations of the heating coil r.

It will be evident that the transformer TF may be associated with the heating coil r, in Figs. 1, 2, 5 and 6, in the manner indicated in Figs. 7 and 8, and in any other like arrangements which may be adopted. Figs. 11 and 12 show circuit diagrams indicating the association of the transformers in connection with the examples shown in Figs. 5 and 6 respectively. Furthermore, an auto-transformer arrangement may clearly be used having only one winding, the resistance r being connected across one portion of the winding, and another portion being connected in the associated circuit in the well known way.

In Figs. 3 and 4, the auxiliary resistances have been shown outside the corresponding thermistor envelopes. If desired, they could clearly be mounted inside the envelopes to form self-contained units. The same considerations apply to Figs. 5 and 6; or alternatively in Figs. 5 and 6, if preferred, the directly heated thermistors could be separate elements, mounted outside the indirectly heated thermistors. In Figs. 7 and 8, likewise, the resistances could be put inside the corresponding envelopes, but this would probably be of little or no advantage since the transformers could hardly also be placed in the envelopes.

The various embodiments of the invention which have been described clearly do not exhaust all the possible arrangements, and have only been given as illustrations. It will be evident that any of the arrangements appropriately chosen may be used in any electrical circuit requiring a resistance device having some special resistance-current characteristic.

What is claimed is:

1. A non-linear electric resistance network having only two terminals comprising an indirectly heated thermistor provided with a resistance element and a heating coil in heat conductive relation thereto said resistance and heating coil being electrically connected between the network terminals, and means comprising a second directly heated thermistor circuitally connected with the heating coil between the two network terminals for controlling the heating coil current to modify the shape of the resistance-current characteristic curve of the network.

2. A two terminal network according to claim 1 wherein, the second thermistor has a negative temperature coefficient for initially delaying the occurrence of the steep portion of the resistance-current characteristic curve of the network.

3. A two terminal network according to claim 1, wherein, the heating coil and the second thermistor are in series connection.

4. A two terminal network according to claim 1, wherein, the circuit connections between the heating coil and the second thermistor include a transformer.

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