

Nov. 7, 1939.

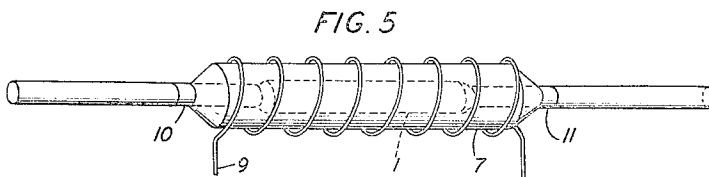
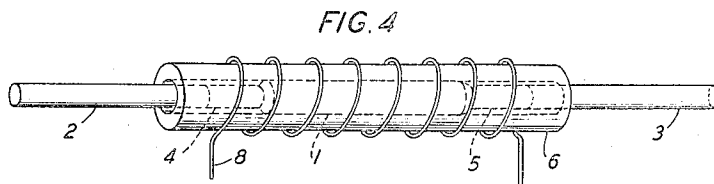
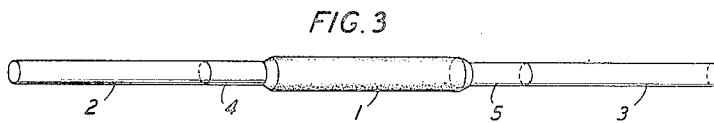
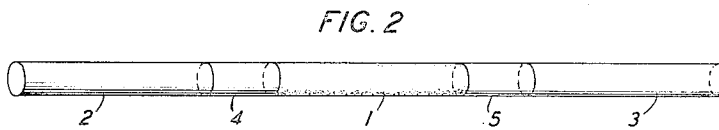
K. C. BLACK ET AL

2,178,548

RESISTOR

Filed Jan. 17, 1936

2 Sheets-Sheet 1



INVENTORS: K.C. BLACK
R.R. BLAIR
BY
C. V. McJannet
ATTORNEY

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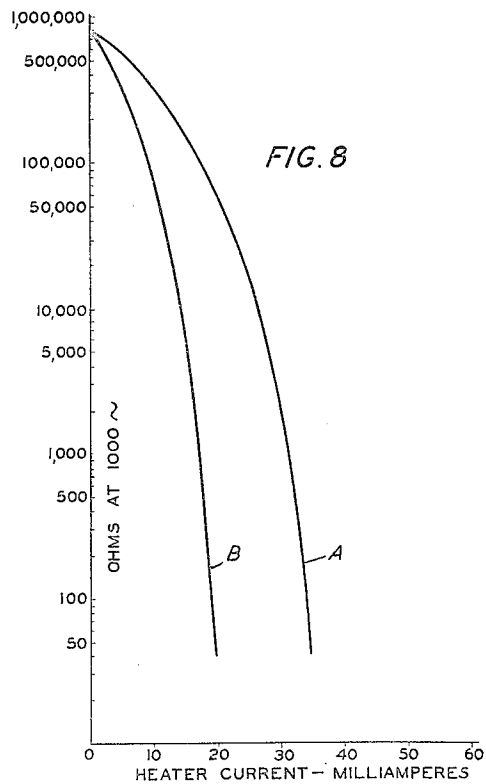
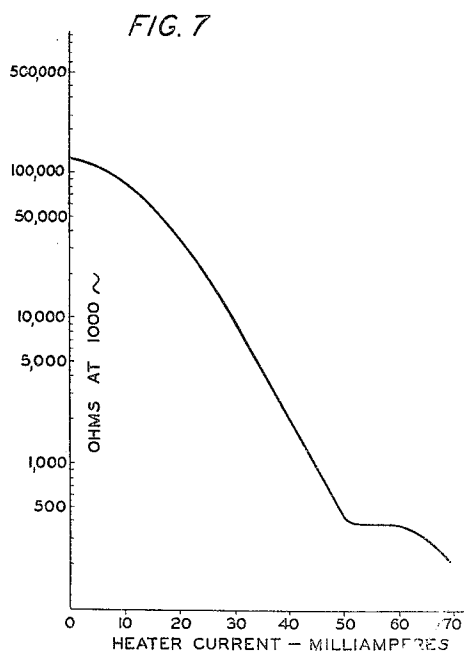
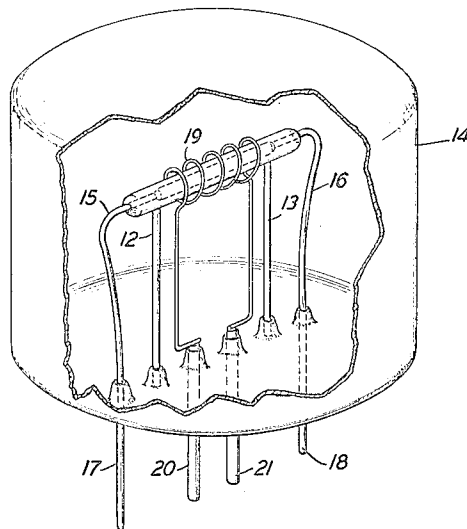
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RESISTOR

Filed Jan. 17, 1936

2 Sheets-Sheet 2

FIG. 6



INVENTORS: K.C. BLACK
R.R. BLAIR

BY
M. J. McNamee
ATTORNEY

UNITED STATES PATENT OFFICE

2,178,548

RESISTOR

Knox C. Black, Mountain Lakes, N. J., and Royer R. Blair, New York, N. Y., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 17, 1936, Serial No. 59,518

5 Claims. (Cl. 201-76)

This invention relates to current-carrying conductors and particularly to resistors of the variable-resistance type.

The objects of the invention are to increase the efficiency, to obtain greater sensitivity, to prolong the life, and to effect improvements in general in variable-resistance devices and in the methods of making them.

Numerous resistance devices have been proposed in the past in which the resistance element is of some substance having a temperature coefficient of resistance. And in some cases heating members have been provided in order that the temperature of the resistance element can be controlled to obtain the desired resistance values. We have discovered as a result of considerable experiment that a large increase in the useful life as well as improved efficiency can be realized in the use of resistors of this character by properly controlling the heating of the resistance element. Where the temperature of the element is controlled by heat applied thereto, as by means of a surrounding coil, we have found that the heat lost by conduction from the ends of the unit to the joining leads not only decreases the efficient performance of the resistor but also requires the application of larger quantities of heat to the element, thus rendering the element liable to failure because of excessive temperatures.

According to a feature of our invention, these difficulties are overcome by an improved resistor in which a resistance element having a suitable temperature coefficient of resistance, such as an element of silver sulphide, is jointed at both ends by circuit leads, welded or soldered thereto, and in which sections of some material having a low heat conductivity are inserted between the leads and the respective ends of the element. This prevents the loss of heat by conduction from the element to the lead wires, which are usually of some material of high electrical conductivity and consequently of high heat conductivity, such as copper. This arrangement permits the use of lower heating temperatures and thereby adds to the efficiency and to the life of the unit.

Another feature of the invention is a resistor of this kind in which the joints between the ends of the resistance element and the lead wires are held to minimum sizes, their thickness preferably not exceeding that of the element. This may be accomplished by welding the lead wires in abutting relation to the ends of the resistance element. The purpose is to reduce the loss of

heat from the element by conduction and by radiation.

A further and related feature is a resistor in which the heating coil is made sufficiently long to extend well beyond the ends of the resistance element. The effect of this is to secure a more uniform temperature throughout the length of the resistance element and to improve thereby the operating performance of the resistor.

Another feature of this invention is a resistor in which the resistance unit comprises an element, of some substance having a high temperature coefficient of resistance, and terminal conductors welded to the ends of the resistance element, in which a small glass tube having a heating winding wound about its exterior serves as a container for the resistance element and its lead wires, and in which the entire unit thus formed is mounted in a vacuum. By mounting a unit of this kind in a vacuum, we find that considerable improvement is secured in the efficiency and sensitiveness.

Another feature of the invention is a resistor of the kind above mentioned in which the resistance element and its lead wires are drawn into a capillary glass tube and the ends of the tube sealed to isolate the element from the surrounding space. In this way the capillary tube serves the double function of providing an insulating support for the heater winding and of isolating the resistance material from the outer space to prevent it from contaminating the vacuum. This is important when materials are used that have the property of disintegrating when placed in a vacuum.

Another feature is the process, described more in detail hereinafter, of making resistors of this character.

These and other features of the invention will be described more fully in detail in the following specification and will also be set forth in the appended claims. The invention is also illustrated in the accompanying drawings which constitute a part of the specification and in which:

Fig. 1 illustrates a resistance element;

Figs. 2 and 3 show a resistance element with its connecting lead wires;

Fig. 4 shows the resistance element enclosed within an insulating member, such as a glass tube, and a heating coil wound about the tube;

Fig. 5 shows the resistance element sealed within the insulating tube and a heating coil wound about the tube;

Fig. 6 illustrates the unit mounted within an evacuated vessel; and

Figs. 7 and 8 are curves showing the performance of the resistance elements.

It is often desirable in electrical systems to vary the resistance of a circuit automatically and with a high degree of precision. One way in which this can be done is by the insertion in the circuit of a resistor having a high temperature coefficient of resistance and by controlling the temperature of the resistor in accordance with the manner in which it is desired to vary the resistance of the circuit. While there are several materials which have high temperature coefficients of resistance, we have found that silver sulphide lends itself readily to the accomplishment of the purposes above mentioned. It has an extremely high negative temperature coefficient, which makes it possible to lower the resistance of a circuit from a high value to any desired low value by the application of the proper amount of heat to the resistance element. For many purposes in which resistors are used to control the resistance of electrical circuits it is desirable that the change of resistance shall be fairly uniform throughout the resistance range. In our investigation of silver sulphide as a resistance material we found that the resistance of units made with this material could be varied over a wide range by applying heat to the element by means of a current carrying heat coil wound about the element. These elements were constructed by taking a short strand of silver wire, soldering lead wires to the ends thereof, converting the silver wire to silver sulphide by introducing it into a heated vapor of sulphur; heat treating the sulphurized element thus formed to remove any excess of sulphur, placing the element within an insulating shield, such as a glass tube, and winding a heating coil about the exterior of the tube. By varying the intensity of the heating current flowing in the heating coil, we were able to vary the resistance of the element over wide ranges. A great deal of difficulty was encountered, however, in obtaining a uniform characteristic between the applied heater current and the resistance of the element. At certain values in the resistance range sharp discontinuities occurred. And to overcome these discontinuities it was necessary to apply higher heating currents, with the ultimate result that the resistance unit failed after a short time. Continued investigation led us to the discovery that the discontinuities in the resistance curve occurred whenever the resistance element was not heated to a uniform temperature throughout its length. Silver wires had formerly been used as connections to the resistance element. These wires are very good heat conductors, and hence lower the temperature at the ends of the resistance element quite appreciably. We were able to overcome much of this difficulty by inserting a section of some low heat-conducting material between the ends of the silver sulphide resistance element and the copper lead wires. The discontinuities were completely overcome by using a combination of the heat-insulating inserts just described and a heater winding considerably longer than the resistance element itself. Uniform temperature throughout the entire length of the resistance element is thus assured.

Referring now particularly to the drawings, there is illustrated in Fig. 1 a resistance element 1 in the form of a short cylinder the diameter of which is comparable with a thin wire. While these units may be made in different ways, one suitable method is to produce them from silver

wire by first subjecting the wire to an atmosphere of sulphur vapor and then heat treating it. The resistance unit 1 may have any suitable dimensions, but we have found that considerable gain is made in the efficiency of the resistor by preparing these units from silver wire of small diameters. For example, good results are obtained by utilizing silver wires of such sizes as No. 32 and No. 34 Brown & Sharpe gauge. The diameters of these gauges are approximately .008 and .006 inch, respectively. Having selected the diameter of the wire from which the silver sulphide resistor is prepared, the length of the resistance unit may be chosen to suit the requirements. In some cases the unit 1 may be as short as a quarter of an inch.

Figs. 2 and 3 illustrate the resistance unit 1 with the lead-in wires 2 and 3 joined thereto. The lead wires 2 and 3 may be of any good electrical conducting material such as copper. Since, however, copper is also a good conductor of heat, and since as above noted it is important to protect the element 1 from the loss of heat by conduction, heat insulating inserts 4 and 5 are included between the lead wires 2 and 3 and the resistance element 1. The inserts 4 and 5 may be of any suitable material such as copper and nickel alloy, the important requirement being that the material used shall offer high resistance to the conduction of heat without introducing too much electrical resistance in the circuit. Generally speaking, materials that are good electrical conductors are also good heat conductors, but by making the inserts 4 and 5 sufficiently short, the electrical resistance which they offer does not seriously affect the operation of the unit. The leads 2 and 3 and the insulating inserts 4 and 5 may be of the same diameter as the element 1, or they may vary somewhat in diameter. In Fig. 2 they are illustrated as having the same diameter as the resistance element, and in Figs. 3, 4 and 5 they are somewhat smaller in diameter than the resistance element. However, the manner in which these several elements are joined together is of considerable importance. We have found that good results are obtained by joining these elements by soldering or welding in abutting relation to each other as disclosed in the drawings. By making butt joints between the adjacent wires, the size of the joints is held to a minimum, and substantially no excess material is formed to provide a medium for the loss of heat. One way of constructing a unit as illustrated in Figs. 2 and 3 is to select the parts 1, 2, 3, 4 and 5, the part 1 being in the form of a silver wire, weld them together, introduce the assembled unit into a heated chamber of sulphur vapor to sulphurize the silver wire and reduce it to silver sulphide and then apply the heat treatment to remove any excess of sulphur. If necessary, the other parts of the assembly, such as the lead wires 2 and 3 and the insulating inserts 4 and 5, may be protected from the action of the sulphur vapor by a coating of any suitable material.

The next step in the construction of the resistor is to surround the resistance element 1 with a protective and insulating member so that an electrical heating coil can be wound about the unit for the purpose of controlling the temperature of the resistance element 1. This may be done by drawing the prepared assembly shown in Figs. 2 and 3 through the duct in a fine capillary glass tube 6. The length of the tube 6 may vary, but it should be chosen sufficiently long to well enclose the resistance element 1 as

seen in Fig. 4. Following this a coil 8 of heating wire having the proper resistance and a suitable number of turns is wound about the insulating tube 6. Coil 8 may be made of any suitable length with respect to the length of the resistance element 1. By making it somewhat greater in length than the element 1, a more uniform application of heat to the element is obtained. By controlling the application of heating current to the heating coil, the temperature of the element 1 and consequently the resistance of the unit may be varied at will.

In Fig. 5 of the drawings a modification of the resistance unit is disclosed. Here the glass tube 7 is sealed at both ends to completely isolate the resistance element 1 from the surrounding space. A coil 9 is then wound about the exterior of the glass tube 7. In this figure the heat insulating elements 10 and 11 are shown partly within and partly without the sealed tube 7, although they may be arranged in any desired relation with respect to said tube.

The efficiency of the resistor may be increased by mounting the assembly comprising the resistance element and heating coil in a vacuum. Such a device is shown in Fig. 6. The resistance unit and heating coil assembly is mounted on supports 12 and 13 within a glass envelope 14. The lead conductors 15 and 16 extending from the resistance element pass through the base of the glass tube 14 and appear in the external terminals 17 and 18. The heating coil 19 is connected to the terminal 20 and 21 appearing on the exterior of the tube. Because of the vacuum within the envelope 14, a more uniform and efficient performance is attained for the heating coil 19 which surrounds the insulating tube containing the resistance element. Sealing the resistance element within the tube prevents it from affecting the vacuum within the envelope 14. In the event that any excess sulphur remains following the heat treatment, or, should the silver sulphide element yield some of its sulphur under the influence of the heating coil, this sulphur might, when the unit is mounted in a vacuum tend to vaporize and interfere with the efficient operation of the device. This, however, is prevented as stated by sealing the entire resistance unit within the glass tube.

Figs. 7 and 8 show the performance, under different conditions, of resistors having silver sulphide resistance elements. The abscissae of these characteristic curves indicate the heater current in milliamperes, and the ordinates indicate the resistance of the element in ohms. The abscissae are measured in units of the usual uniform numerical series, but the ordinates, in order to include a wide range of resistance values, are expressed on a logarithmic scale. The curve in Fig. 6 shows the performance of a resistor in which no special precaution was taken to prevent the loss of heat by conduction. Accordingly, a sharp discontinuity takes place in the curve at a value of approximately 450 ohms. To overcome this discontinuity and produce the desired continued reduction of the resistance of the unit, it was necessary to increase considerably the intensity of the heater current. And, as has been stated hereinbefore, the usual effect of increasing the heater current is to shorten the life of the resistance unit. The units when overheated usually fail at or near the center of the heating coil. The reason for this is that a coil produces the greatest temperature at its central point, and, by increasing the current in the

coil sufficiently to overcome the discontinuities, the temperature at the center of the resistance unit is so increased as to cause failure to take place at that point. The curve A in Fig. 8 shows the performance of a unit constructed as illustrated in Fig. 4 but not mounted in a vacuum. It will be noted that the resistance of this unit falls along a substantially smooth line from a value close to a million ohms to a value as low as 40 ohms without discontinuity. Curve B of this figure shows the performance of a similar element when mounted within the vacuum as illustrated in Fig. 6. The advantages of this method of mounting the resistor are clearly apparent from a comparison of curves A and B. The curve B is much more uniform and proceeds downward to values without any apparent discontinuity. Furthermore, this wide range of resistance values is obtained with a much smaller heating current, thus greatly increasing the efficiency of the unit.

By utilizing the construction herein described it is possible to obtain a resistor having an extremely wide range of resistance values, having a performance characteristic which is substantially uniform throughout the entire resistance range, and one in which any desired resistance value may be obtained with a high degree of accuracy by controlling the temperature of the unit. Furthermore, the special feature of guarding the resistance element from the loss of heat by introducing heat insulated sections in the lead wires makes it possible to obtain a much more uniform distribution of the heat produced by the heating element and consequently a lower mean temperature for a given value of resistance. This in turn makes it possible to obtain any desired resistance value with the expenditure of a less amount of heating current, thus increasing the heating efficiency of the unit and also greatly extending the useful life of the resistance element.

While these resistance elements have been disclosed and described herein as made of cylindrical stock, such as ordinary wire, it is, of course, obvious that the invention is not so limited. The resistance elements may be made of stock of any desired or convenient shapes and sizes.

What is claimed is:

1. The process of making a resistor which comprises welding the ends of a length of silver wire respectively to one end of each of a pair of short inserts of wire of some low heat conducting material, welding the other ends of said inserts respectively to the ends of two circuit lead conductors, bringing the unit thus assembled into a heated sulphur vapor to convert the silver wire to silver sulphide, heat treating the unit, surrounding the silver sulphide element with an insulating covering, and winding a heating coil about said insulating covering.

2. The process of making a resistor which comprises welding terminal conductors to the ends of a length of fine silver wire, introducing said wire into a heated chamber of sulphur vapor to convert it to silver sulphide, drawing said wire and its terminal conductors into a capillary glass tube, placing a heating coil about the exterior of said tube, and mounting the unit thus formed in an evacuated envelope.

3. The combination in a resistor of an evacuated vessel, a small glass tube mounted within said vessel, a filamentary resistance element of a material having a high temperature coefficient

of resistance within said tube, terminal wires in alignment with said element and abutting the ends thereof and welded thereto with joints not exceeding in diameter that of said element, and a heating coil disposed about the exterior of said tube for controlling the temperature of said resistance element.

4. The combination in a resistor of an evacuated vessel, a capillary glass tube mounted within said vessel, a resistance element of filamentary proportions disposed within said tube and comprising a material having a high negative temperature coefficient of resistance, terminal wires welded in abutting relation to the ends of said resistance element and extending out of said tube, the ends of said tube being sealed to isolate the resistance element from the evacuated space within said vessel, and a heating coil wound

about the exterior of said tube and extending beyond both ends of the resistance element within said tube for the purpose of controlling the temperature of said resistance element.

5. A resistor of cylindrical shape and of uniform diameter throughout its length comprising a section of material having a negative temperature coefficient of resistance, a section of material having a low heat conductivity, and a section of material having high electrical conductivity and relatively high heat conductivity, said second-mentioned section being integrally jointed to both the other sections and serving as an insert between them to prevent the passage of heat from one to the other.

KNOX C. BLACK.
ROYER R. BLAIR.