Oct. 30, 1945. J. BURNHAM ET AL 2,387,829

ELECTRICAL APPARATUS

Filed Dec. 29, 1942

FIG. 1.

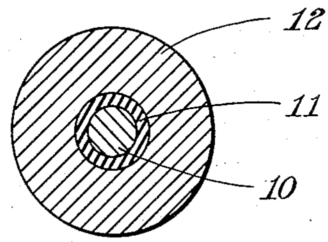
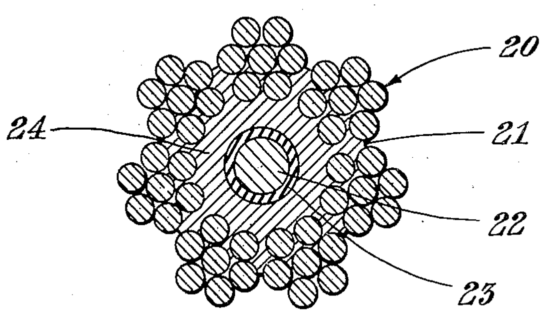


FIG. 2.



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ELECTRICAL APPARATUS

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The present invention relates to electrical apparatus and more particularly to electrical conductors comprising an insulated conducting core and a surrounding conducting sheath and to a method of manufacturing the same.

The invention is directed to a shielded electrical conductor, which conductor is also particularly suitable as an electrical heating element per se or in combination with other electrical apparatus such as radio antennas, in which latter use the conductor serves as a de-icing means, said shielded conductor being also particularly suitable as an electrical condenser capable of operating at high temperatures. While the invention will be described in connection with such uses, it should be well understood that the invention is not so limited but is equally applicable for other electrical purposes.

Electrical heating elements comprising a central resistance metal conductor, a surrounding heat-resistant insulating layer, and an enclosing metallic protective casing have been proposed. However, the prior elements have not been generally satisfactory for several reasons. More particularly, because of the inflexible character of the insulating layer and/or of the casing, such elements have been generally restricted to comparatively simple shapes and have been limited to uses under which the element is subjected to little or no deformation. For purposes requiring heating elements of substantially complex shape, the prior elements had to be formed into the desired shape simultaneously with their manufacture, which procedure considerably increased the cost thereof.

Moreover, because of the bulky character of the insulating layers heretofore used and the resulting poor heat-conducting path through the same and through the casing, it is necessary to operate the central conductor at substantially high temperatures in order to obtain sufficiently rapid heat transfer to the body to be heated; this results in a large temperature gradient through the insulation and subjects the insulation to maximum temperatures considerably higher than the average temperature thereof. Furthermore, since the central conductor must be operated at high temperatures, the useful life thereof and correspondingly of the heating element, is seriously impaired. A further and important disadvantage of such prior heating elements is that the comparatively great stiffness or rigidity thereof makes it difficult if not impossible to obtain an intimate contact, and correspondingly a good heat-conducting path, between the heating element and the body to be heated, thereby necessitating further increases in the operating temperature of the central heating conductor to produce a desired amount of heating in the body to be heated.

The prior heating elements consisting of a bare resistance wire are even more restricted in use. For example, because of the lack of any protecting shield whatever, such elements are easily short-circuited by contact with a piece of metal or by immersion in a solution and must be well spaced from the body to be heated. Furthermore, such elements are exposed to the surrounding atmosphere and hence are highly susceptible to oxidation.

In many uses radio antennas are subjected to atmospheric conditions which produce thereon accumulations of ice, particularly when mounted on an airplane. Previous attempts to prevent such accumulation of ice on the antenna or to remove the ice once formed, have consisted in a proper alignment of the antenna with respect to the direction of flight or in passing a large electric current through the antenna itself. However, the first method does not completely eliminate the possibility of ice formation and the second method requires inconveniently large currents and special apparatus to generate the same.

It is an object of the invention to provide a shielded conductor in which the central core is insulated from the shield and which is characterized by a high degree of flexibility, a high breakdown voltage, and a high rate of heat conduction away from the core.

Another object of the invention is to provide a flexible insulated electrical heating element characterized by a high heat transfer efficiency and low cost.

An additional object of the invention is to provide an improved radio antenna principally for aircraft use, although not limited thereto, having self-contained heating means to prevent icing thereof under even the most adverse weather conditions, and which requires only moderately small electric currents for proper operation.

Another object of the invention is to provide an electrical condenser characterized by a high specific capacitance and breakdown voltage and which is capable of continuous operation at high temperatures of the order of 100° C. or more.

A further object of the invention is to provide a novel method of manufacturing shielded electrical conductors having an overall diameter less than about .075″.

These and further objects of our invention will appear as the specification progresses.

The insulated electrical conductor in accordance with the invention comprises a central core of electrically-conducting material which is usually but not necessarily flexible, an electrically-insulating coating around the core and sufficiently thin to permit rapid heat transfer, and a sheath of durable material having high thermal conductivity positioned over the electrically-insulating coating and in such intimate contact therewith that substantially no air layer exists between the two. Such a conductor being substantially entirely de-aerated permits very rapid heat conduction throughout. As the sheath consists of an electrically conducting material, an electrostatic shield for the inner conductor, or an electrode for a condenser, is realized.

The invention will be further described with reference to the appended drawing forming part of the specification and in which:

Figure 1 is an enlarged cross-sectional view of an insulated conductor in accordance with the invention.

Fig. 2 is an enlarged cross-sectional view illustrating another embodiment of the invention.

Referring to Fig. 1, the insulated conductor there shown comprises a central conducting core 10 which is generally, but not necessarily, flexible. This may consist of any of the well-known metals or metal alloys capable of conducting an electric current. Metals and metal alloys of this character may have either high or low electrical conductivity, depending upon the purpose for which the resulting structure is to be used. A few of the many metals and metal alloys coming within the foregoing category are: Copper, aluminum, bronze silver, nickel, nickel-chromium, nickel-iron, etc.

Surrounding the core 10 and in intimate contact therewith is an electrically-insulating coating 11 permitting rapid heat transfer therethrough, and positioned thereover is a sheath of deformable metal 12. The electrically-insulating coating should be in intimate contact with the core 10 and as a general rule should be extremely thin. For optimum results it is advisable to select for the coating those insulating materials and to apply an amount thereof which is sufficient to provide the required electrical insulation without unduly reducing the heat transmission properties of the coating. Insulating materials meeting this requirement and the manner of applying them are well known and need not be described herein in detail. For purposes of illustration, however, a representative few of such materials are mentioned, such materials being fiber glass impregnated with heat-resistant electrically-insulating varnish, ceramics such as talc or china clay used alone and/or in admixture with one another and/or impregnated or coated with a resin or material of a resinous nature such as formvar, silicone, or any of those materials listed in Chemical and Engineering News, vol. 20, pages 536–538 (1942); natural fiber such as silk, cotton or hemp impregnated with insulating varnish, lacquer or the like; aluminum oxide electrolytically formed on the surface of an aluminum wire in the form of comparatively thick and thin films together or singly; insulating plastics or resinous materials (used singly or mixed) such as formvar, silicone, or any of those listed in Chemical and Engineering News, vol. 20, pages 536–538 (1942); any of which may contain plasticizers.

It is to be understood that the thickness of the electrically-insulating layer 11 will depend to a great extent upon the particular purpose for which the resulting structure is to be used and the material from which this structure is made. As a general rule, however, it may be stated that this layer should be extremely thin, approximating .020″ or less in thickness. For optimum results over a wide range of conditions and with a wide variety of materials the layer 11 should be between .002″ and about .005″ thick.

In general, coatings of the above thickness range lack sufficient strength at least under operating conditions to maintain intimate mechanical and thermal contact with the core 10. In accordance with the invention, the deformable metal sheath 12 is so formed about the coating 11 as to be in intimate contact with coating 11, so that it fixedly positions the coating 11 in intimate contact with the conductor 10 and maintains such contact under even the most severe flexing to which the conductor may be subjected in operation.

Furthermore, as previously mentioned, the core 10 after being coated with the electrically-insulating layer 11 is covered with a sheath of deformable metal in such manner as to produce a de-aerated conductor. Particular care should be taken in applying this sheath to obtain such intimate contact with the electrically-insulating layer throughout its entire surface so that substantially no air layer exists between the adjacent surfaces of these two layers; otherwise the thermal conductivity of the structure will be appreciably impaired due to incomplete de-aeration.

To meet the above requirement and in accordance with the preferred embodiment of the invention, the sheath is applied under compressional stress. More particularly, the sheath 12 consists of a material having a larger coefficient of expansion than the overall coefficient of expansion of the insulated core and is applied at a relatively high temperature whereby the resulting differential shrinkage on cooling causes the sheath to contract relative to the insulated core, causing the same to fit tightly around the outside of the insulation and thus aiding the process of de-aeration.

Numerous metals and metal alloys, as well as related thermally-conductive materials, may be used for the sheathing element 12. A few of the many materials within this category are lead, zinc, tin, alloys of lead, zinc and/or tin, copper, aluminum, silver, gold, etc. We have found that for optimum results over a wide range of conditions it is generally preferred to employ lead for this purpose.

The thickness of the sheathing 12 will likewise depend to a considerable extent upon the particular purpose for which the conductor is to be used and the materials from which it is made. Since this layer has, as a general rule, excellent thermal conductivity and also serves the function of protecting the more delicate insulating layer 11, it is possible to vary its thickness widely. As a general rule the sheath is made approximately .025″ thick, or less, although it is understood that this figure is not critical and may be exceeded considerably without departing from the scope of this invention. Customarily, particularly where the sheathing element is composed of lead, it will vary in thickness from about .010″ to about .020″.

For the manufacture of the insulated conductor of the invention and to obtain a de-aerated structure in which the core 10, the coating 11 and the sheath 12 are in intimate mechanical and thermal contact with each other, we have found the following procedure to be particularly effective:

The insulated wire passes through a chamber containing the coating metal under a very high unit pressure of the order of 20,000 to 45,000 pounds per square inch, which should be maintained constant to an accuracy of about 5% during the extrusion. The metal and wire together are extruded through a die and the high unit pressure with which the metal is pressed against the insulated wire substantially entirely prevents the formation of an air layer at the interface.

The metal in the chamber is maintained at a temperature sufficiently high so that, at the pressures used, the metal exhibits an adequate amount of plastic flow to permit reasonably rapid extrusion and the differential shrinkage on cooling causes the sheath to fit tightly about the insulated core further obviating the possibility of the formation of an air layer at the interface. When lead is to be extruded, this temperature is within about 30° C. of the melting point. In any case, the temperature should be accurately controlled to within about 3 to 5° C. of the desired temperature.

When the insulation layer 11 contains a substance that is to be heat-treated, such as a baking varnish, preliminary baking thereof is only partially completed so that the completion thereof takes place as the coated wire passes through the hot metal.

The thickness of the metal coating 12 is determined by the size of the extrusion die and by the speed or tension of the drawing of the wire. Preferably the speed or tension of the drawing is so regulated that the overall diameter of the coated wire is kept less than the diameter of the die. By this process is produced a metal-coated conductor whose outside diameter is less than .075''.

Other requirements which we have found to be necessary to produce a satisfactory coating on insulated wires or rods of small overall diameters above referred to are the following: The length of path of the coated wire through the hot metal must be kept comparatively short; i. e. in the neighborhood of ⅛'' or less, not only to prevent the insulation from becoming hot enough to be damaged during the extrusion, but also to prevent the motion of the hot metal under high pressure from stripping the wire or rod of its insulation. Moreover, to protect the insulation from excessive heating, the aperture in the tip of the hardened cone through the center of which the wire or rod enters the hot metal chamber, should be of such a diameter as to only loosely fit around the entering wire or rod and at the same time should be small enough so that the extrusion metal is not forced out through this hole during extrusion. Such precautions against heating of the insulation are not necessary in the commercial sheathing of cable, its size being sufficient protection.

It is furthermore necessary to provide accurate constant-tension drawing means for drawing the sheathed wire or rod out of the press to avoid excessive and irregularly applied tension leading to breaking of the conductor and to avoid variations in the thickness of the metal sheath produced. Withdrawal of the conductor at constant speed does not in general provide sufficiently precise tension control, and a device which maintains constant tension by means of appropriate changes in speed is required. Accurate tension control is not important in commercial sheathing of cable due to the strength of the cable and the greater thickness of the sheath.

The length of the metal coating which can be so applied is essentially limited only by the metal capacity of the extrusion apparatus, and lengths of more than 80 feet having an overall diameter of .040'' may be readily produced.

In a conductor fabricated according to the invention, any air layer under the sheath having been substantially eliminated by the methods herein described and the sheath being in very good contact with the insulated core, the resulting frictional forces are so great that it is extremely difficult, if not impossible, to move the sheath of a de-aerated conductor relative to the insulated core, even when the insulation used is relatively incompressible.

An example of a conductor of the type produced by the above process is as follows: An inner wire of diameter .010'', covered by a layer of insulating material .0035'' in thickness, over which is extruded a metal sheath .011'' in thickness, making a total outside diameter of .039'' for the complete conductor.

An important use of the conductor of the invention is for applications requiring a compact electrical condenser capable of operating at temperatures of the order of 100° C. or more. Because of the extreme thinness of the insulating coating and because of the intimate contact existing between the central core, the insulating coating and the surrounding sheath whereby air pockets are substantially eliminated, a high capacity value per unit length of conductor and a high breakdown voltage are realized. For example, in the case of a conductor having a central core consisting of a copper wire .010'' in diameter, an insulating layer consisting of a layer of fiber glass impregnated with insulating varnish and .0018'' thick and a surrounding sheath of lead, capacitance values of the order of 30 micromicrofarads per inch of conductor length and a breakdown potential of the order of 700 volts is realized even under operating conditions of 100° C. or more.

Other advantages characterizing a condenser made in accordance with the invention are the following: The condenser lends itself to close tolerance adjustment of its capacity value, such being effected by the simple expedient of adjusting its length. Moreover, the sheath effectively shields the condenser from external electrostatic fields. Furthermore, by using both ends of the central bore or electrode connected together as one terminal and the mid-point of the sheath as the other terminal of the condenser, a non-inductive condenser is obtained. Still another advantage is realized by the inherent flexibility of the conductor which permits the condenser to assume any desired overall shape.

Because of the unusually rapid heat transfer between the central conductor and the surrounding sheath, made possible by the extreme thinness of the insulating coating and by the intimate contact between the central conductor and the sheath, made possible by the de-aerated structure, the conductor of the invention is particularly suitable as an electrical heating element. Furthermore, because of the flexible and deformable character of the sheath which permits the element to be deformed without damage into the most advantageous shape with respect to the body to be heated and permits an intimate contiguous contact to be realized between the sheath and the surface of the body to be heated, a high thermal efficiency is obtained whereby the heat generated in the conductor is rapidly transferred to the body to be heated and with a minimum temperature gradient.

Because the sheath surrounding the insulated heating element is contiguous and of impervious, heat-conducting metal, it is possible to immerse the conductor in any liquid or solution which will not damage the outer sheath, without destroying the insulation or causing the heating element to be short-circuited. Furthermore, for the same reason the conductor can be attached with solder or other binding material to an object to be heated, providing excellent thermal contact without short-circuiting the heating element. Still further, because the outer sheath is of heat-conducting metal, good thermal contact is realized between the heater wire and the object to be heated even if only one side of the sheath is in contact therewith, as heat flowing out to any part of the sheath from the heater wire can be rapidly transferred around the sheath to the body to be heated. It is thus readily seen that the rapid transfer of heat as above pointed out, permits a very low operating temperature for the heater wire and a very short time lag between the generation of heat in the inner wire and its transfer to the desired point.

Since there is substantially no air layer between the insulating coating and the outer metal sheath of the de-aerated conductor, according to the invention, a capacitance per unit length of the conductor is realized which is not below an appropriate minimum value, according to the materials employed in the insulating coating and the thickness of this coating. For example, if the center wire or rod is .010'' in diameter, and if the insulation consists of fiber glass impregnated with a good baking varnish, the insulating layer being .0035'' in thickness, a conductor produced in accordance with the invention exhibits a minimum capacitance of at least of the order of 6 micromicrofarads per inch length.

In Fig. 2 of the drawing there is shown a radio antenna embodying a heating element according to the invention and in which the heating element serves as a de-icing means for the antenna or as a means for preventing the formation of ice on it under adverse weather conditions. The antenna shown comprises a multi-strand conductor 20 formed by a plurality of wires of copper, bronze, or similar metal of high electrical conductivity wrapped around and enclosing a heating element 21. The element 21 comprises a core 22 of resistance metal, for example, a nickel or nickel-chromium alloy wire, a coating 23 of heat-resistant electrically-insulating material such as fiber glass impregnated with insulating varnish, and a surrounding deformable metal sheath 24 of lead or a lead alloy. Sheath 24 is formed in the manner above described so as to provide intimate thermal contact with coating 23 and fixedly position and maintain the same in intimate contact with the core 22.

To insure good thermal contact and a short heat-conducting path between the sheath 24 and the multi-strand conductor 20, the conductor 20 is at least partially embedded in the sheath 24. This is shown in Fig. 2 from which it appears that because of its deformable character, the sheath 24 permeates not only the spaces between the strands of the conductors, but also the spaces between certain of the wires of the individual strands. Such contact between the multi-strand conductor and the sheath is effected by wrapping the multi-strand conductor about the sheathed conductor under tension. Preferably, to insure optimum thermal contact between the sheath and the strands 20, the so assembled structure is then drawn through a die whose diameter is less than that of a circle circumscribed about the cross-section of the multiple strands 20 and the sheathed conductor 21 when in parallel contact.

Because of the good heat-conducting properties inherent in an antenna constructed as herein described, it is perfectly feasible to use the complete cabled antenna, with a plurality of outer metal strands, as a heating element in the same way as above described for the metal-sheathed conductor. It is also perfectly feasible to use the complete cabled antenna as a condenser in the same way as above described for the metal-sheathed conductor. Since it is obvious that other uses for a conductor constructed like the antenna herein described may occur to one skilled in the art, the term "antenna" as uused herein is intended to apply to any conductor so constructed, regardless of the use to which said "antenna" may be put. The invention is intended to include use of a so-constructed "antenna" in any application in the same fashion as the de-aerated metal-sheathed conductor herein described.

It is seen from the above descriptions that the de-aerated conductor of this invention is very versatile and will fulfill a variety of purposes according to any particular design of the conductor. With a low-resistance metal as core, it is useful as a shielded conductor for electrical wiring or an electrical condenser with easily adjustable capacity. With a core of resistance metal the conductor provides a heating element which has a small total heat capacity and good heat conductivity, making for rapid heat transfer with a very short time lag. This heating element may be made flexible so as to conform minutely to the surface of a body to be heated or be cabled into a de-iceable radio antenna. Our novel method of manufacturing a small shielded conductor permits its fabrication in a manner which eliminates substantially all air from inside the metal sheath, which de-aeration is responsible for many desirable properties, including rapid heat transfer.

While we have described our invention in specific embodiments and by means of specific examples, we do not wish to be limited thereto for obvious modifications will occur to those skilled in the art without departing from the spirit and scope of the invention.

What we claim is:

1. A flexible antenna adapted to operate under conditions conducive to the formation of ice deposits thereon, comprising a central flexible core of electrical resistance metal, a heat-resistant electrically-insulating coating having a thickness not substantially greater than .020'' on said core and in intimate thermal contact therewith, a flexible deformable metal sheath surrounding said electrically-insulating coating and de-aerated so as to be intimate thermal contact therewith, and a plurality of flexible electrically-conducting wires surrounding said sheath and at least partially embedded therein.

2. The method of manufacturing a flexible antenna adapted to operate under conditions conducive to the formation of ice deposits thereon, comprising the steps of helically wrapping a plurality of flexible electrically-conducting wires

around a heating element comprising an electrical resistance metal core, an insulating layer thereon and a deformable metal sheath surrounding said layer, and drawing said wires and heating element through a die having a diameter less than that of a circle circumscribing the so-wrapped wires and heating element so as to at least partially embed said wires in said deformable metal sheath.

3. A flexible antenna adapted to operate under conditions conducive to the formation of ice deposits thereon, comprising a central flexible core of electrical resistance metal, a heat-resistant electrically-insulating coating having a thickness not substantially greater than .020″ on said core and in intimate thermal contact therewith, a lead sheath surrounding said electrically-insulating coating and de-aerated so as to be in intimate thermal contact therewith, and a plurality of flexible electrically-conducting wires surrounding said sheath and partially embedded therein.

4. A flexible antenna adapted to operate under conditions conducive to the formation of ice deposits thereon, comprising a central flexible core of electrical resistance metal, a heat-resistant electrically-insulating coating having a thickness not substantially greater than .020″ on said core and in intimate thermal contact therewith, a lead sheath between about .010″ and about .020″ thick surrounding said electrically-insulating coating and de-aerated so as to be in intimate thermal contact therewith, and a plurality of flexible electrically-conducting wires surrounding said sheath and partially embedded therein.

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