Nov. 8, 1949 A. M. LA RUE 2,487,658

ELECTRICALLY HEATED ICE-REMOVING COVERING

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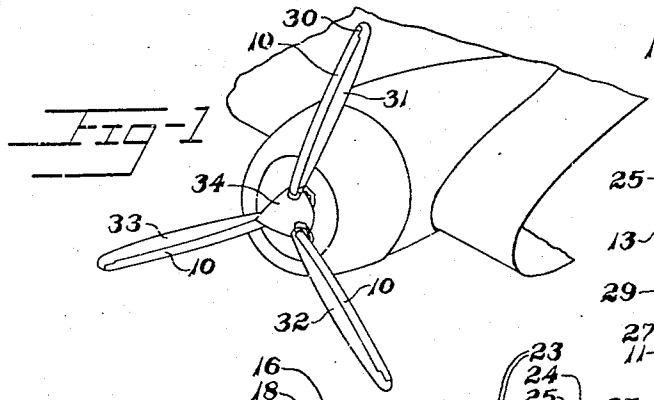

Fig-1

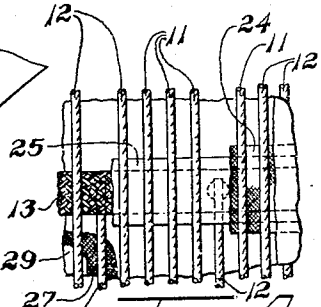

Fig-4

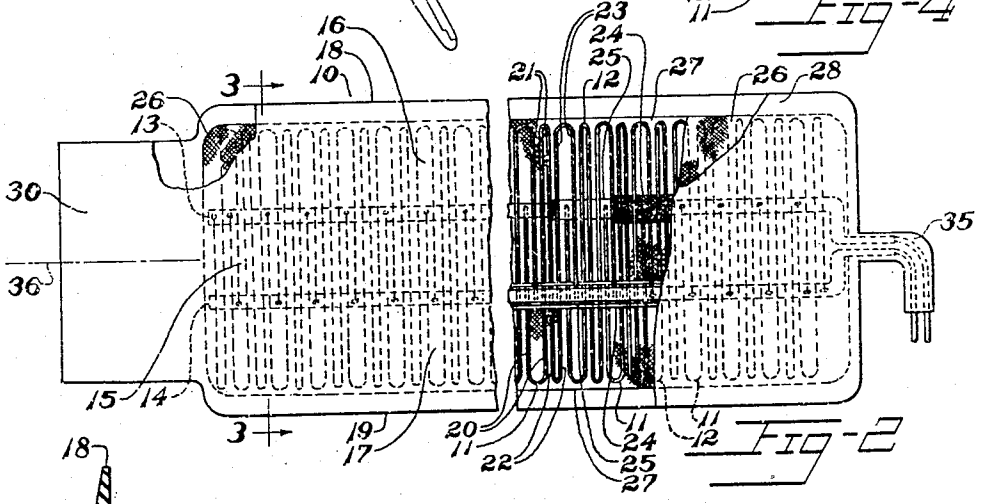

Fig-2

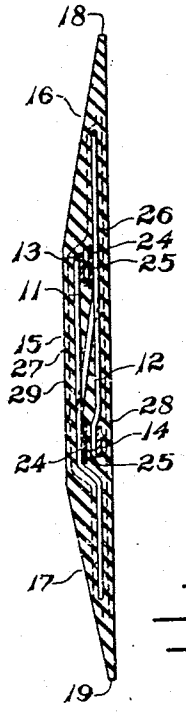

Fig-3

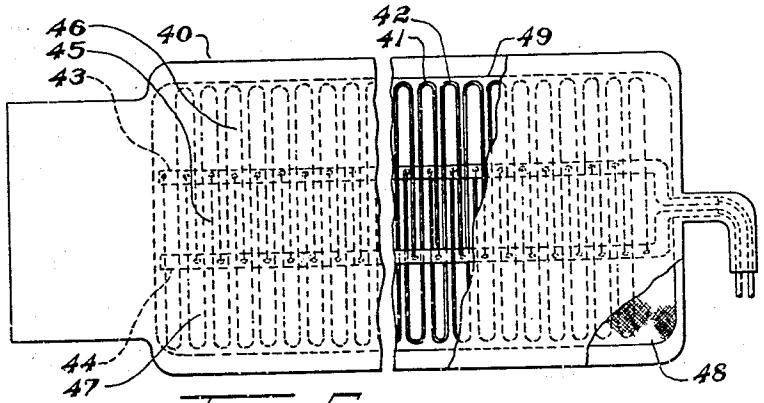

Fig-5

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ELECTRICALLY HEATED ICE-REMOVING COVERING

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15 Claims. (Cl. 244—134)

1

The invention relates to electrically heated coverings for surfaces exposed to ice-forming conditions, especially leading edge surfaces of airfoils such, for example, as propeller blades, wings, and control surfaces.

For preventing the accumulation of ice upon the leading edge of an airfoil, it has been found advantageous to provide greater heat at the immediate leading edge region than that to the rearward or side regions of the covering. Expedients proposed heretofore to obtain this result have not been entirely satisfactory in view of the problems sometimes unavoidably introduced in the way of providing conveniently for the necessary electrical connections and providing the desired flexibility and even stretching in proper places to make the covering conformable to the compound curvature of the airfoil surface.

Objects of the invention are to provide for flexibility and stretchability in proper places of the covering to facilitate conforming the covering to curved surfaces; to provide for the electrical connections of the covering in which covering greater heat is effected at the immediate leading edge region than that to the rearward regions thereof; and to provide for a close disposition of heating elements and uniformity of heating along the covering.

Other objects are to provide for flexure of the covering about its longitudinal neutral axis of bending without buckling of the conductors, heating elements and other parts thereof; to provide for greater flexibility and stretchability of spaced-apart marginal portions than that of a portion therebetween to facilitate conformance with the curved surface of the airfoil, especially at the root of a propeller blade; to provide for convenience of installation and for holding the installed covering in place throughout its extent; and to provide for thinness and durability of construction, convenience of manufacture and for effectiveness of operation.

These and other objects and advantages of the invention will be apparent from the following description.

In the drawings which form a part of this specification and in which like numerals are employed to designate like parts throughout the same,

Fig. 1 is a front perspective view from above of electrically heated coverings on a multi-blade aircraft propeller and constructed in accordance with and embodying the invention, parts being broken away,

Fig. 2 is a plan view from above of a covering as molded and before installation on the propeller blade, parts being broken away,

Fig. 3 is a sectional view taken along line 3—3 of Fig. 2,

2

Fig. 4 is a plan view from above on an enlarged scale showing a portion of the covering at a conductor thereof shown in Fig. 2, parts being broken away, and

Fig. 5 is a view like Fig. 2 but showing a modified construction of the covering.

In the illustrative embodiment of the invention shown in Figs. 1 to 4, inclusive, the covering has a body 10 of resilient rubber, natural or synthetic, or other rubber-like material having electrical insulating, heat-resisting and abrasion-resisting characteristics. Within the rubber body adjacent its outer surface there is provided a serpentine or looped arrangement of laterally disposed reaches of a plurality of flexible strip heating elements which may be resistance wires 11, 12 of the desired electrical resistance. For maximum flexure the wires may be of fine gauge and stranded form.

The rubber body 10 has embedded therein a pair of conductors 13, 14, which may be of flexible, braided wire in flat strip form capable of stretching and shortening without objectionable buckling. The conductors extend longitudinally of the covering in spaced-apart, substantially parallel relation one to another throughout the heating area of the covering. The conductors separate a leading edge or intermediate portion 15 between the conductors, that may be disposed along and across the leading edge center-line, from side portions 16, 17 rearwardly thereof which extend laterally beyond the conductors toward opposite marginal edges 18, 19 of the covering.

The invention makes possible conveniently effecting a mode of heat dissipation providing greater heating of one portion of the covering than that of another portion, which in the case of propeller blade coverings, for example, may be greater heating at the immediate leading region along the leading edge center-line of the blade than rearwardly thereof. Moreover, this result may be obtained with a determinate ratio between the portions of wattage dissipation per unit area.

The looped wire arrangement shown in Fig. 2 provides greater heating of the leading edge or central portion 15 than that of the side portions 16, 17. The wire 11 extends laterally in the direction across the conductors from the conductor 13 to which it has a first connection, across the portion 15 between the conductors and into the side portion 17 and returns to the conductor 14 thereby providing in the side portion a loop having spaced-apart reaches 20, 20. The wire 11 continues from a reach 20 of the loop across the central portion 15 into the other side portion 16 and returns to the conductor 13 providing in the portion 16 a second loop having spaced-apart reaches 21, 21. The wire 11 then continues in a

similar fashion back and forth across the portions 15, 16, 17 and terminates at the conductor 14 and has a second connection therewith in a manner providing additional loops having reaches 22, 22, 23, 23 in the side heating portions 16, 17. The reaches of the wire 11 are disposed preferably directly across the portions 15, 16, 17 from one side of the covering to the other and to the conductors. This looped construction provides in effect four heating elements in each side portion 16, 17 and five heating elements in the central portion 15, whereby the desired increased heating action at the central portion 15 is accomplished with lesser heating at the side portions 16, 17.

A second resistance wire 12 may be similarly disposed in the covering and in a manner so that end loops of adjacent wires 11, 12 have end portions of the wires disposed within one another of said end loops. Since the spaces between end reaches 20, 20 and 23, 23 of the wire 11 may be relatively wider than those between the intermediate reaches 21, 21 and 22, 22, this facilitates the first connection of the wire 12 to the conductor 13 at a position between the reaches 23, 23 and less advanced than the second connection of the adjacent preceding element 11, to permit close and substantially uniform spacing of the wires in the portion 15 for providing continuity of heating along the portion 15. Additional wires 11, 12 are disposed in like manner throughout the entire heating area of the covering.

Thus, there is provided a plurality of heating elements disposed in succession along the conductors, each element extending laterally of the conductors and deviously from one conductor to the other and having a first connection with a conductor and a second connection with the other conductor at a position advanced along the conductors with respect to the first connection, and the first connection of each of a plurality of the elements being at a position less advanced along the conductors than the second connection of the adjacent preceding element. This makes possible a variety of arrangements of the heating elements while facilitating close spacing of the elements and uniformity of heating along the covering.

The wires 11, 12 may pass over the conductor 13 and under the conductor 14 as shown especially in Figs. 2 and 3, the ends of the wires being secured as by soldering to the under side of the conductors 13, 14. A continuous insulating strip 24, 24 of square-woven, cotton or glass fabric material friction coated with suitable rubber insulating material is disposed between the wires and each conductor at the crossing positions where contact is not desired, as shown especially in Fig. 4. A continuous strip or layer 25, 25 of suitable rubber material may be disposed between each insulating strip 24, 24 and its associated conductor 13, 14 for further insulating the wires from the conductor and for filling the interstices of the conductor with rubber by flow of the latter under vulcanization thereby avoiding objectionable air bubbles or pockets in the covering.

The rubber body 10 has, preferably, sheet reinforcements 26, 27 of square-woven, bias-cut, cotton fabric material friction coated with suitable rubber material, as shown especially in Fig. 3, overlying and underlying the heating means assembly comprising resistance wires 11, 12 and conductors 13, 14 so that protective layers 28, 29

of the rubber body 10 overlie and underlie the reinforcements. The fabric reinforcements facilitate anchoring the wires and conductors in position during manufacture of the covering for resisting localized displacement of such heating means assembly, especially under flow of the rubber upon vulcanization. The reinforcements also permit some stretching of the side portions 16, 17 when the covering is applied to the leading edge surface.

At its tip end, the covering may be provided with an end holding portion 30 of all-rubber construction projecting longitudinally beyond the ends of the conductors for facilitating installation of the covering upon, for example, each blade 31, 32, 33 of an aircraft propeller 34. Although the holding portion 30 may be wholly removed by a subsequent trimming operation, it has been found advantageous to utilize the holding portion 30 for many propeller blade applications. The portion 30 promotes holding the tip end of the covering in position on the blade under rotating conditions despite the loosening effect of centrifugal forces, and in addition also protects the tip of the blade itself against erosion and wear due to hail, sleet, sand and other foreign material in the ambient air. The construction facilitates balancing the propeller blade after installation of the covering on the blade by trimming the portion 30 as required.

At the root end of the covering, end portions of the spaced-apart conductors 13, 14 may extend first to a central position of the covering and then side-by-side in insulated relation to one another within a flat, lead-in strip 35 of rubber material, whereby the conductors may be connected to a suitable source of electrical energy.

In producing the covering, the protective layer 29 and the fabric reinforcement 27 may be superimposed and adhered together by a suitable rubber cement while uniformly supported in a substantially flat condition. The conductors and heating wires are next adhesively anchored to the reinforcement in the disposition described hereinabove. One of the conductors, for example conductor 14, having the ends of the wires 11, 12 soldered thereto is adhesively mounted on the fabric with the wires extending across and beyond the side heating portion 17; the rubber strip 25 and the fabric insulating strip 24 are next cemented down overlying the conductor. Then the wires are looped back and forth across the portions 15, 16, 17 and overlying the conductor 14 and strips 24, 25 until the last loop is reached. The other insulating strip 24 and rubber strip 25 and other conductor 13 are successively adhered in position overlying the wires 11, 12 after which the last loop is completed and the other ends of the wires soldered to the conductor 13. The other reinforcement 26 and protective layer 28 are next cemented successively in place overlying the heating wire-conductor assembly, the covering thus being in assembled relation in condition for vulcanization.

The fabric and rubber parts of the covering are desirably integrally united as by vulcanization under heat and pressure and may be molded in flat form. For the molded condition, the side portions 16, 17 taper in section to thin marginal edges 18, 19, as shown especially in Fig. 3, for facilitating flexure and stretching of portions 16, 17 to conform with the curvature of the blade and for avoiding objectionable disturbance of the airflow across the blade.

The installation of the covering in the flat condition upon the propeller blade is accomplished by flexing the covering according to the longitudinal and lateral curvature of the leading edge and desirably adhering the covering thereto as by a rubber cement of the air-curing type, so that the central portion 15 is disposed about the leading edge center-line with the resilient protective layer 28 exposed directly to the ambient air. By virtue of the disposition of the flat, braided conductors 13, 14 along the sides of the central portion 15 and and the relatively greater thickness of the portion 15, the flexible covering has substantial resistance to localized lateral distortion yet permits flexure about its longitudinal neutral axis of flexure which, for the construction shown, coincides with the longitudinal center-line at 36 of the covering positionable along the center-line of the leading edge of the blade. This is advantageous to facilitate the desired uniformity of disposition of the central portion 15 about the leading edge and the smooth conformance without buckling of the side portions 16, 17 to the rearward areas of the blade, especially at the root of the latter where relatively abrupt changes in blade contour occur.

This construction avoids a condition wherein conductors might stiffen the side or marginal portions objectionably against flexure and cause buckling of the same including the heating wires, especially at the root of the blade. The tapered side or marginal portions 16, 17 of the covering 10 are relatively free to stretch and flex to the compound curvature of the blade surface and buckling of the heating wires imbedded in the portions 16, 17 is avoided.

A further advantage of the arrangement of the conductors 13, 14 at the sides of the central portion lies in the fact that inasmuch as these conductors may offer some resistance to the flow of electrical current and hence effect a heating action along the margins of the central portion 15 supplementing the heating effected by the resistance wires in this portion, the effective ice-removal at the leading edge is facilitated. The greater heating at the central portion 15 is advantageous in that it is in this portion where the ice tends to form in greater thickness thus requiring greater heat for removal, as compared to that at the side portions where the ice-deposit is thinner and hence less heat is required.

The chordwise extent of the heated area of the covering may vary from about 20% to 100% of the chord of the blade, and the central portion 15 providing increased concentration of heat in the leading edge region may extend back approximately 10% of the chord of the blade. Good results are obtainable with the covering 10 having a chord coverage of about 10% for the central heating portion 15 and an overall heated area chord coverage of about 25%. Although the covering may, if desired, extend the full length of the blade, it is preferable that the covering extend not less than the major portion of the length of the leading edge.

Since relatively greater erosion, abrasion and deterioration of the covering by the impact of foreign particles tends to occur at the radially outward region of the propeller, the heating wires or conductors or both in such region may, after extended use, become damaged or broken. The construction advantageously facilitates cutting off the damaged tip-heating portion of the covering without effecting the heating action of the remainder thereof and without removing the entire covering from the blade thereby increasing the service life and the safety of operation of the covering.

The modified construction 40 shown in Fig. 5 differs from that of the covering 10 in the respect of the number of loops of each resistance wire 41, 42 between its connections to spaced-apart conductors 43, 44 whereby a greater number of reaches of the wire are disposed in a central portion 45 than those in each side portion 46, 47 for providing greater heat at the portion 45 than that at the side portions. Each wire 41, 42 has a single loop having a pair of spaced-apart reaches in each side portion 46, 47 as shown in Fig. 5. The covering 40 also includes in the rubber material thereof suitable fabric reinforcements 48, 49 overlying and underlying the heating wire-conductor assembly.

Variations may be made without departing from the scope of the invention as it is defined in the following claims.

I claim:

1. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering for said surface having electrical heating means therein comprising a pair of spaced-apart conductors extending along the covering, the first of which conductors separates a region of said covering between said conductors from a region of said covering beyond said first conductor, and a resistance element connected to the other conductor and extending laterally thereof across said region between said conductors and into said region beyond said first conductor and returning to said first conductor and connected therewith in a manner providing a greater number of reaches of said element in one of said regions of the covering as compared to the number of reaches of the element in the other region of said covering.

2. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering for said surface having electrical heating means therein comprising a pair of spaced-apart conductors extending along the covering, the first of which conductors separates a region of said covering between said conductors from a region of said covering beyond said first conductor, and a resistance element connected to the other conductor and extending laterally thereof across said region between said conductors and into said region beyond said first conductor and disposed in at least one loop in the latter said region, said element returning to said first conductor and connected therewith in a manner providing a greater number of reaches of said element in one of said regions of the covering than those in the other region of said covering.

3. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering for said surface having electrical heating means therein comprising a pair of spaced-apart conductors extending along the covering and separating a region of said covering between said conductors from side regions of said covering beyond said conductors, and a resistance element connected to one of said conductors and extending laterally thereof across said region between said conductors and into one of said side regions and then back and forth in a looped disposition across all said regions of the covering with a loop in each of said side regions and terminating at the other

conductor and connected therewith in a manner providing a greater number of reaches of said element in said region between said conductors as compared to the number of reaches of the element in each of said side regions of the covering.

4. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering for said surface having electrical heating means therein comprising a pair of spaced-apart conductors extending along the covering and separating a region of said covering between said conductors from side regions of said covering beyond said conductors, and a plurality of resistance elements disposed along said conductors, each element extending laterally of said conductors across all said regions and in a looped disposition in said side regions, end loops of adjacent elements having end portions of the elements disposed and connected to said conductors within one another of said end loops.

5. An electrically heated covering for preventing the accumulation of ice on the leading edge of an airfoil, said covering comprising a body of resilient rubber-like material for said leading edge having in said body a pair of spaced-apart conductors extending along the covering, the first of which conductors separates a leading edge portion of said covering between said conductors from a portion of said covering rearwardly of said first conductor, said body having therein a resistance element connected to the other conductor of the pair and extending laterally thereof across said leading edge portion and into the rear portion of the covering and returning to said first conductor and connected therewith in a manner providing a greater number of reaches of said element in one of said portions of the covering as compared to the number of reaches of the element in the other portion of said covering.

6. An electrically heated covering for preventing the accumulation of ice on the leading edge of an airfoil, said covering comprising a body of resilient rubber-like material for said leading edge having in said body a pair of spaced-apart conductors extending along the covering and separating a leading edge portion of said covering between said conductors from portions of said covering rearwardly of said conductors, said body having therein a resistance element connected to one of said conductors and extending laterally thereof across said leading edge portion between said conductors and into one of the rear portions of the covering and then back and forth in a looped disposition across all said portions of the covering with a loop in each of said rear portions and terminating at the other conductor and connected therewith in a manner providing a greater number of reaches of said element in said leading edge portion than those in each of said rear portions of the covering.

7. An electrically heated shoe for a propeller blade comprising a covering of resilient rubber-like material for the leading edge center-line portion of the blade and portions thereof rearwardly of the center-line, said covering having therein a first conductor at one side of the center-line portion of the covering, a second conductor in spaced-apart relation to said first conductor at the other side of said center-line portion, said conductors separating said center-line portion from portions of said covering to the rear thereof, and a resistance element connected to said second conductor and extending laterally thereof across said center-line portion and into one of the rear portions of the covering and then back and forth in a looped disposition across all said portions of the covering with a loop in each of said rear portions and terminating at said first conductor and connected therewith in a manner providing a greater number of reaches of said element in said center-line portion as compared to the number of reaches of the element in said rear portions of the covering.

8. An electrically heated shoe for a propeller blade comprising a covering of resilient rubber-like material for the leading edge center-line portion of the blade and portions thereof rearwardly of the center-line, said covering having therein a first conductor at one side of the center-line portion of the covering, a second conductor in spaced-apart relation to said first conductor at the other side of said center-line portion, said conductors separating said center-line portion from portions of said covering to the rear thereof, and a resistance element connected to said second conductor and extending laterally thereof across said center-line portion and into one of the rear portions of the covering and then back and forth in a looped disposition across all said portions of the covering with a plurality of loops in each of said rear portions and returning to said first conductor and connected therewith in a manner providing a greater number of reaches of said element in said center-line portion than those in said rear portions of the covering.

9. An electrically heated shoe for a propeller blade comprising a covering of resilient rubber-like material for the leading edge center-line portion of the blade and portions thereof rearwardly of the center-line, said covering having therein a first conductor at one side of the center-line portion of the covering, a second conductor in spaced-apart relation to said first conductor at the other side of said center-line portion, said conductors separating said center-line portion from portions of the covering to the rear thereof, and a plurality of resistance elements in said covering disposed along said conductors, each element being connected to one of said conductors and extending laterally thereof across said center-line portion and into one of the rear portions of the covering and then back and forth in a looped disposition across all said portions with a loop in each of said rear portions and terminating at the other conductor and connected therewith in a manner providing a greater number of reaches of said element in said center-line portion as compared to the number of reaches of the element in each of said portions of the covering, said resistance element at its crossing positions with respect to said conductors being in overlying relation to one of said conductors and in underlying relation to the other conductor.

10. An electrically heated shoe for a propeller blade comprising a covering of resilient rubber-like material for the leading edge center-line portion of the blade and portions thereof rearwardly of the center-line, said covering having therein a pair of spaced-apart conductors at the sides of the leading edge center-line portion of the covering and separating said center-line portion from portions of the covering to the rear thereof, and a plurality of resistance elements in said covering disposed along said conductors, each element being connected to one of said conductors and extending laterally thereof across said center-line portion and into one of the rear portions of said covering and then back and forth

in a looped disposition across all said portions with at least one loop in each of said rear portions and terminating at the other conductor and connected therewith in a manner providing a greater number of reaches of the element in said center-line portion than those in said rear portions of the covering, end loops of adjacent elements having end portions of the elements disposed and connected to said conductors within one another of said end loops, and each of said resistance elements at its crossing positions with respect to said conductors being in overlying relation to one of said conductors and in underlying relation to the other conductor.

11. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering body of stretchable material for said surface having a pair of spaced-apart conductors anchored to said stretchable material and extending along the covering, and a plurality of flexible and non-stretchable electrical heating elements anchored to said stretchable material in succession along the conductors, each element extending laterally of said conductors and having a first connection with a conductor and a second connection with the other conductor at a position advanced along said conductors with respect to said first connection, and the first connection of each of a plurality of elements being at a position less advanced along said conductors than the second connection of the adjacent preceding element so that by virtue of such anchorage and disposition of the non-stretchable heating elements their heating effect is maintained substantially unchanged while accommodating flexing and stretching of the covering in conforming it to the surface.

12. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering body of stretchable material for said surface having a pair of spaced-apart conductors anchored to said stretchable material and extending along the covering, and a plurality of flexible and non-stretchable electrical heating elements anchored to said stretchable material in succession along the conductors, each element extending laterally of said conductors and deviously from one conductor to the other and having a beginning end connected to a conductor and a terminating end connected to the other conductor at a position advanced along said conductors with respect to said beginning end, and the beginning ends of elements being connected to a conductor at positions less advanced along said conductors than the terminating ends of the adjacent preceding elements so that by virtue of such anchorage and disposition of the devious non-stretchable heating elements their heating effect is maintained substantially unchanged while accommodating flexing and stretching of the covering in conforming it to the surface.

13. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering for said surface having a pair of spaced-apart conductors extending along the covering, the first of which conductors separates a region of said covering between said conductors from a region of said covering beyond said first conductor, and a plurality of electrical heating elements disposed in succession along the conductors, each element extending from a conductor into said region beyond the said first conductor and returning to the other conductor in a greater number of reaches in one of said regions than in the other region and along a devious path in one of said regions, each element having a first connection with a conductor and a second connection with the other conductor at a position advanced along said conductors with respect to said first connection, and the first connection of each of a plurality of elements being at a position less advanced along said conductors than the second connection of the adjacent preceding element.

14. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering for said surface having a pair of spaced-apart conductors extending along the covering and separating a region of said covering between said conductors from side regions of said covering beyond said conductors, and a plurality of electrical heating elements disposed in succession along the conductors, each element extending laterally of said conductors across all said regions and in a looped disposition in said side regions with a greater number of reaches in the region between the conductors than in each of said side regions, each element having a first connection with a conductor and a second connection with the other conductor at a position advanced along said conductors with respect to said first connection, and the first connection of each of a plurality of elements being at a position less advanced along said conductors than the second connection of the adjacent preceding element.

15. Apparatus for preventing the accumulation of ice upon a surface exposed to ice-forming conditions, said apparatus comprising a covering body of stretchable material for said surface having a pair of spaced-apart conductors anchored to said stretchable material and extending along the covering and separating a region of said covering between said conductors from side regions of said covering beyond said conductors, and a plurality of flexible and non-stretchable electrical heating elements anchored to said stretchable material in succession along the conductors, each element extending laterally across all said regions and in a looped disposition in said side regions with a greater number of reaches in the region between the conductors than in each of said side regions, each element having a first connection with a conductor and a second connection with the other conductor at a position advanced along said conductors with respect to said first connection, and the first connection of each of a plurality of elements being at a position less advanced along said conductors than the second connection of the adjacent preceding element so that by virtue of such anchorage and disposition of the non-stretchable heating elements their heating effect is maintained substantially unchanged while accommodating flexing and stretching of the covering in conforming it to the surface.

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